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Decision Support System for Hydro Power Plants in Amazon Considering the Cost of Externalities

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ABSTRACT

Feasibility studies on hydro power plants (HPPs) should adequately measure the values of the social, economic and environmental impacts (i.e., its externalities) of HPPs. In this case, the final cost of an energy generation project is lower than the actual value because the impacts are not appropriately assessed. Thus, the objective of this paper is to estimate the total cost of generated energy using a methodology capable of accounting for the cost of the externalities of hydroelectric plants. This study assesses the externality resulting from loss of fishing activity, an economic activity practised by a large part of a population affected by hydroelectric dam construction. To assess this externality, the opportunity cost method and a time series analysis are used to forecast future values. It is demonstrated that when considering only the externality resulting from the loss of fishing activity, the expected cost of energy production could increase significantly. This result indicates the need to calculate all the externalities caused by the implementation of a hydroelectric power plant (HPP) and to incorporate these actual values into the energy production cost, so the enterprise is sustainable and feasible. Our results also facilitate a realistic comparison with other sources of energy generation.

Keywords: Fishing Activity, Opportunity Cost, Forecast, Amazon
JEL Classifications: Q2, Q4

1. INTRODUCTION

Feasibility studies on hydro power plants (HPPs) should adequately measure the values of the social, economic and environmental impacts (i.e., its externalities) of HPPs. Such studies generally only estimate a quantity that is probably undervalued. Thus, the final cost of an energy generation/production project is lower than the actual value because the impacts are not appropriately or adequately assessed. This failing is easily demonstrated by numerous and large problems, conflicts and lawsuits involving social, environmental and economic issues caused by HPP implementation (Sousa and Reid, 2010). An externality can be understood as an external economic cost, or an impact (positive or negative), with an unintended effect that is paid for or absorbed by someone other than the entrepreneur or individuals, i.e., society, who directly or indirectly uses the product of an enterprise. The externality arises as a result of environmental, social and economic aspects that are not foreseen in the project design. Internalizing externalities means predicting and considering these costs in the initial phase of the project in an economic viability study (Sundqvist, 2004; Tolmasquim et al., 2001).

The value of externalities does not depend only on the amount of energy generated/produced, neither the production costs, nor the energy tariff, it depends on the characteristics and peculiarities of each locality, taking into account their uniqueness. That is, each enterprise and location is unique. Externalities include the loss of economic activities or assets of the affected population (e.g., agriculture, livestock husbandry, fisheries, irrigation sources), the loss of biodiversity (i.e., fauna and flora), the loss of landscapes and natural areas (when environmental protection measures are lacking), the appearance of diseases and epidemics, the loss of mineral resources and social problems, such as un employment/under employment, prostitution, crime, displacement, intense migration and other unplanned population movement (increasing the number of informal settlements, such as slums), and worsening urban infrastructure (Berchin et al., 2015; Morimoto, 2013 and Von Sperling, 2012).

Brazil's energy planners prefer hydroelectric power over alternatives such as wind or solar energy because it is considered the cheapest and most reliable option, although with increasing dependence on more expensive thermal energy as a reserve in times of insufficient rainfall (Prado et al., 2016). Dam's decision making essentially considers only monetary costs incurred by proponents, ignoring costs such as loss of biodiversity and impacts on local human populations (Fearnside, 2015). Biodiversity and ecosystem services cannot be treated as inexhaustible or free "goods." Their true value to society and the cost of their loss and degradation must be adequately measured to raise awareness through preventive actions or calculate the costs of conservation projects (Costanza et al., 1997; Costanza et al., 2014 and TEEB, 2010). All these externalities, either at least the most significant or sensitive of them, should be included in the environmental impact assessment of HPPs in properly performed economic feasibility studies that consider specific projects and their environmental, social and operational effects (Ritter et al., 2017).

In 1991, the European Community created a method to estimate the externalities of several electricity-generation options termed Externalities of Energy. The aim of this endeavour was to translate the externalities into monetary values and to discuss how these costs (or values) could be used as the basis of environmental policies to promote clean energy (Alves and Uturbey, 2010). In Brazil, the coordinating committee for environmental activities in the electric sector (COMASE) created the environmental costs working group in mid-1991, which together with the manual published by da Motta (1997) and a publication by ELETROBRÁS (2000) on methods to assess externalities to be practised by the Brazilian electric sector allowed the internalization of degradation costs in planning by the electric sector (Tolmasquim et al., 2001).

In the literature, there are several studies on the assessment of externalities caused by HPP implementation. Reis (2001) quantified the impacts associated with the generation of electric energy in hydroelectric plants in the states of Goiás and Minas Gerais (Brazil). Hynes and Hanley (2006) measured losses to canoeing activities in Irish rivers. Gunawardena (2010) calculated environmental losses related to river diversion, water sports losses and other externalities in Sri Lanka. Sousa and Reid (2010) evaluated externalities such as annual losses to fishing in the Belo Monte region (Brazil). Alves and Uturbey (2010) demonstrated the importance of including environmental degradation costs in the long-term planning of the Brazilian electricity sector. Ponce et al. (2011) determined the losses to the landscape due to floods by hydroelectric plants in Chile. Streimikiene and Alisauskaite-Seskiene (2014) measured the external costs of hydroelectric plants in Lithuania. Lessa et al. (2015) calculated the quantity of greenhouse gases emitted by hydroelectric plants. Berchin et al. (2015) listed and investigated the mitigation capacity of the negative effects of Belo Monte HPP, in the state of Pará, Amazon, Brazil.

The main objective of this study is to present a methodology to incorporate the values of externalities in HPP feasibility studies in a manner that calculates costs as realistically as possible while considering specific economic, social and environmental aspects of each region. This paper focuses on assessing fishing losses. Chosen among the numerous externalities, fishing is an economic activity practised by a large part of the population affected by HPP construction. Therefore, fishing has substantial social importance and within terms of not only its economic values but also its symbolic and cultural values.

2. METHODOLOGY

The measurement of externalities is extremely important to determine the viability of an enterprise. The feasibility study of any energy source should include revenues, operating costs, depreciation, maintenance and insurance, taxes and charges, investments (i.e., civil works, machinery, equipment and installation) and in particular the costs of externalities. These costs should be distributed over a time horizon compatible with the useful life of the project while applying a rate of predetermined attractiveness according to the market. The decision support system (Figure 1) presents a hub of energy sources. In the study, an HPP was chosen for externalities analysis.

The described methodology determines the cost of externalities, so they can be included in a reasoned and adequate manner in a study of the economic and financial viability of a project to verify actual viability by determining the true cost of the energy generated by an HPP. To calculate the cost of externalities, which may be environmental, social, economic or some other externality, it is first necessary to identify them. Then, each one can be measured using the appropriate calculation method. If the true viability of an HPP is to be analysed, the cost of generated energy must include the costs of the externalities. In this study, only the externality loss of fishing activity was estimated (Figure 2). This externality was chosen because of the substantial social and economic impact of this externality on the life of the riverside inhabitants of the region (a significant portion of the local population) and the cultural value of fishing for these individuals.

To measure the value of the loss of fishing activity, we used the opportunity cost method. This method determines the economic cost of the opportunity to maintain the natural resource, that is, the income sacrificed by users to maintain the resource at its current level. In this case, one must understand current as the moment of implementation or on set of operation of the HPP. Opportunity cost has been used for land use analysis in conservation planning (Sinden, 2004; Adams et al., 2010). The proposed methodology does not directly value the environmental resource but rather the opportunity cost to maintain it. The calculation is determined by

Figure 1: Decision support system for the assessment of hydro power plant externalities

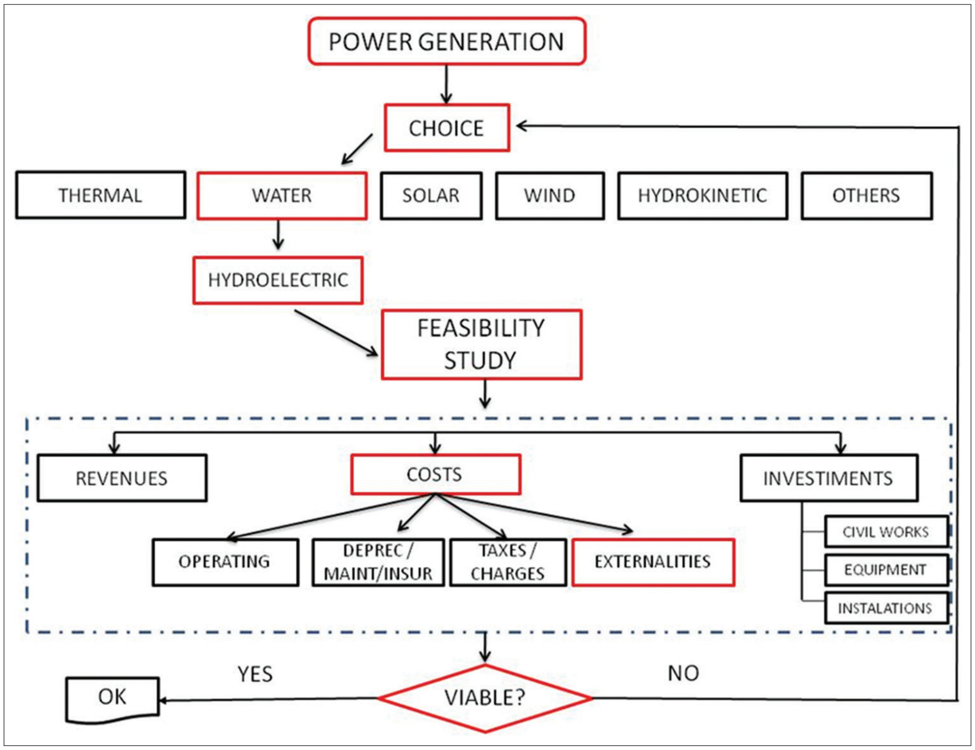
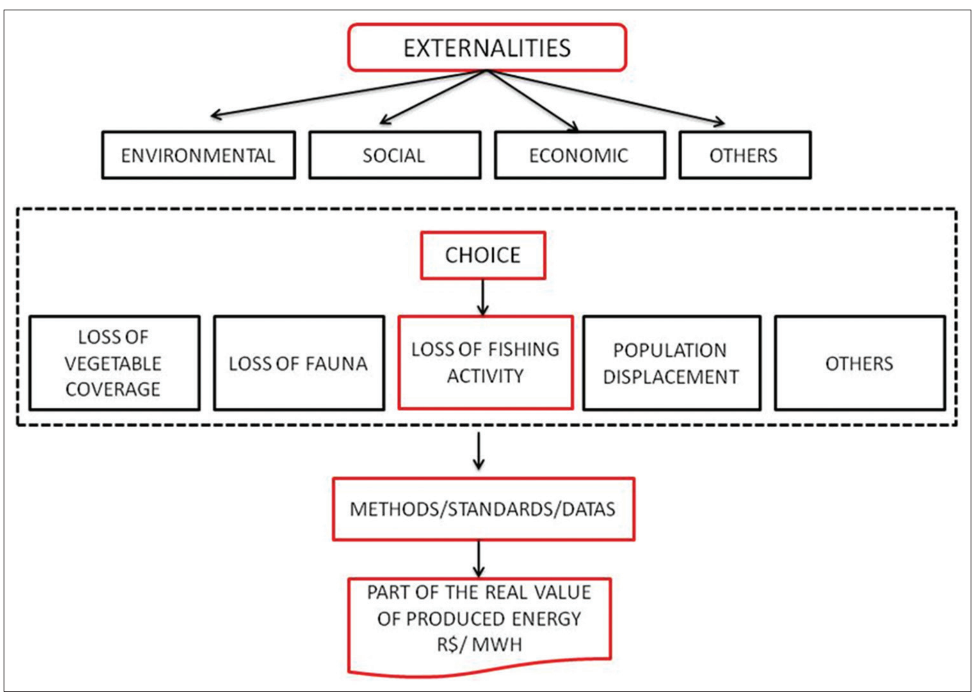


Figure 2: Externality assessment schematic with emphasis on fishing activity



the economic context of the activity that suffers income loss, which in this study is fishing (Figure 2). Thus, the first step is to calculate the average monthly revenue of a fisherman $\overline{R}$ (Equation 1).

$$\overline{R} = \left(\overline{Pr} \times \overline{P}\right) \times 25 \quad (1)$$

Where $\overline{Pr}$ is the monthly productivity of fishing (kg/fisherman/day) and $\overline{P}$ is the average monthly sales price of fish in the HPP region ($), considering 25 days of effective labor per month. Next, the average monthly total fishing costs ($\overline{Ct}$) are determined for a fisherman (Equation 2).

$$\overline{Ct} = \sum \overline{Cg} + \overline{Ca} + \overline{Cc} + \overline{Ce} + \ldots \quad (2)$$

Where $\overline{Cg}$ is the average monthly cost of ice ($), $\overline{Ca}$ is the average monthly cost of food ($), $\overline{Cc}$ is the average monthly cost of fuel ($)

and $\overline{Ce}$ is average monthly cost of a boat ($). Using the values of revenues and costs, the average monthly net income of a fisherman (Rm) is determined by Equation 3.

$$Rm = \overline{R} - \overline{Ct} \quad (3)$$

Where $\overline{R}$ is the average monthly revenue of a fisherman ($/month) and $\overline{Ct}$ is the average monthly total fishing cost for a fisherman ($/month). Then, the loss of the monthly income of a fisherman (P) in the region of the HPP is determined by Equation 4.

$$P = \left(\sum \overline{Rd} - \sum \overline{Ra}\right) / T \quad (4)$$

$\sum \overline{Rd}$ is the sum of the average monthly net income of a fisherman in the period after the HPP begins operation ($/month). $\sum \overline{Ra}$ is the sum of the average monthly net income of a fisherman in the initial period of HPP operation ($/month) and is thenumber of months since the start of HPP operation (months). T is considered equal to 25 months, since it is the period for which data from $\overline{Rd}$ are available. The externality rate of the monthly loss of fishing activity (E) is calculated by Equation 5.

$$E = P \times Q_p \quad (5)$$

Where P is the monthly loss of a fisherman ($) and Q_p is the number of fishermen affected by the HPP. The increase in the cost of power generation with the inclusion of the externality (ΔC_E) is determined by Equation 6.

$$\Delta C_E = E/E_G \quad (6)$$

Where E is the externality of the loss of fishing activity ($) and E_G is the energy generated annually (MWh). However, to quantitatively characterize the variables: Productivity, prices and monthly average total costs obtained in the period and predicted for a time T were used time series. Time series are a set of observations obtained by measuring a single variable regularly over a period of time to identify non-random patterns in the temporal series of a variable of interest, and the observation of this past behaviour, allowing making predictions about the future.

To make these predictions, we used IBM SPSS 25, statistical data analysis software that estimates the model best fit to the time series and makes predictions with the least error. The method chosen was the exponential smoothing method and the model used was the Winter Additive Model (WAM). This model is used in time series with linear trend and seasonal effect independent of the series level (Khaliq et al., 2015; Veiga et al., 2014). In WAM the amplitude of the seasonal variation is constant over time, that is, the difference between the highest and the lowest value remains relatively constant over time. The predictions are calculated by Equation 7.

$$\hat{x}_{t+k} = L_t + kT_t + S_{t-s+k} \quad (7)$$

Where L_t is the level component; T_t the trend component; S_t the seasonality component; s the seasonal period; h the forecast horizon; and k = 1, 2,…, h, given by equations 8, 9 and 10, respectively.

$$L_t = \alpha(x_t - S_{t-s}) + (1-\alpha)(L_{t-1} + T_{t-1}) \quad (8)$$

$$T_t = \beta(L_t - L_{t-1}) + (1-\beta)T_{t-1} \quad (9)$$

$$S_t = \gamma(x_t - L_t) + (1-\gamma)S_{t-s} \quad (10)$$

α with values in the interval ($0<\alpha<1$), is the smoothing constant of the level component (L_t); β ($0<\beta<1$) is the smoothing constant of the trend component (T_t); and γ ($0<\gamma<1$) is the smoothing constant of the seasonal component (S_t).

3. STUDY AREA

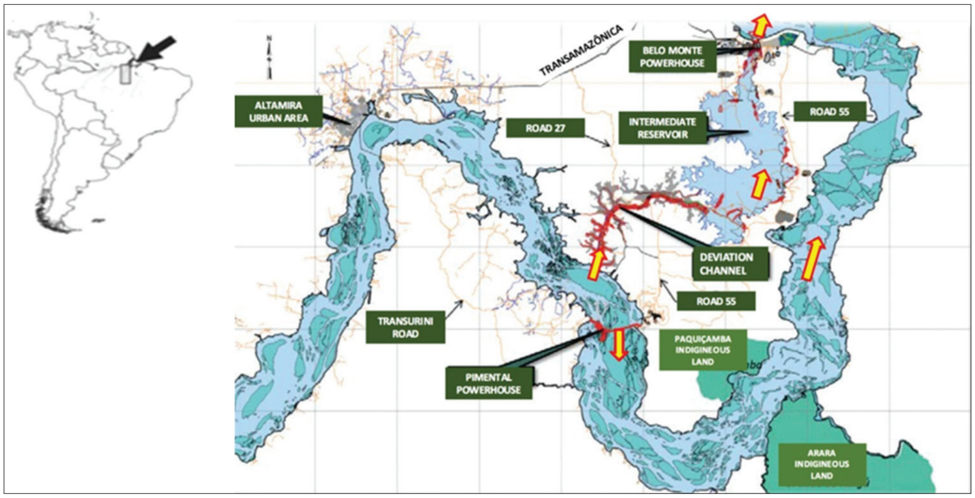
Belo Monte hydroelectric power plant, located in the Xingu River Basin, Amazon, Brazil, was built in an area known as Volta Grande do Rio Xingu (Figure 3).

The Xingu River is one of the main tributaries on the right bank of the Amazon, and it has 1600 km of extension, with its watershed comprising a total area of approximately 531,000 km^2. The project involves three sites: Belo Monte, located at the intersection of the Xingu River and the Transamazônica Highway; Pimental, which lies between Vitória do Xingu and Altamira; and Bela Vista, in the region between Belo Monte and Pimental. The main spillway and complementary water supply/powerhouse are located at the Pimental site. The Bela Vista site is a complementary spillway to the main spillway. The average quantity of energy produced by the Belo Monte hydroelectric power plant is 4.57 thousand MWH. The plant started partial generation in April 2016. Full generation is scheduled for 2019.

We measured the externality loss of fishing activity in Belo Monte because of the substantial social and economic impact of this externality on the life of the riverside inhabitants of the region (a significant portion of the local population) and the cultural value of fishing for these individuals. According to the atlas of Belo Monte impacts on fishing (ISA, 2015), the impacts on fishing are the result of explosions, river bed dredging, grounding of beaches and streams, elimination of species feeding sites and nurseries, suppression of areas and the interdiction of navigation on certain stretches of the river, among other causes.

Traditional fishermen affected by the hydroelectric plant were excluded as affected population in the administrative procedure for environmental licensing of Belo Monte HPP, although thousands of fishermen live and use the areas most directly affected by the hydroelectric dam. Despite predicting impacts to the ichthyofauna, the EIA did not relate them clearly and in detail to the damages to the fishing activity. The changes in the way of life of the traditional fishermen, natives or inhabitants of the city were enunciated, but not studied, that is, the consequences of the physical and biotic alterations of the river and its environment on the fishing activity were not evaluated for not considering even the existence of this social group.

Figure 3: Location and configuration of the Belo Monte hydroelectric complex



Source: Veronese and Großkinsky, 2017 modified

According to the ISA (2015), artisanal and riparian fishermen alerted IBAMA and the concessionaire company from the beginning of construction of the work on the occurrence of negative impacts that needed to be mitigated and compensated, but no effective compensation measure for the communities was adopted. The entrepreneur is limited to collecting fishing landing data at the largest ports in the region, so that subsistence fishing, which is not landed in these ports, and fish for sale landed in smaller ports, even if located within the reduced flow and therefore, in the directly affected area, are not monitored.

According to Isaac (2008), the loss of local fishing activity occurs due to the decrease and disappearance of some groups of endemic species mainly in the region of the Xingu Reservoir and Volta Grande (Figure 3). There are 450 fish species that occur in this watershed, where at least 44 (approximately 10%) are considered endemic, one third of which are under risk of extinction. According to the same source, with changes in hydrological regimes, other due to lack of habitat, as is the case with most migratory *Characiformes* (such as Matrinxã, Tambaqui and Jaraqui), with an increase in opportunistic predators (such as Tucunaré and Pescada) to the detriment of herbivorous or detritivorous migrators (such as Pacu and Curimatã).

4. DATA

Data were obtained from the 12th consolidated report on the progress of the Basic environmental plan and assistance of conditioners of Norte Energia (NORTE ENERGIA, 2017). The main objective of this plan is to obtain information to mitigate and compensate for the impacts anticipated in the ambit of the Belo Monte environmental impact study related to fishing activities in a sustainable way. This report includes the sustainable fishing incentive project that began in April 2012, with data available through April 2017 for nine locations: São Félix do Xingu, Maribel, Altamira, Belo Monte, Vitória do Xingu, Vila Nova, Senador José Porfirio, Porto de Moz and Gurupá. In these locations, the fish landings were monitored daily Monday to Saturday through interviews. The information collected in these interviews (for each fishing trip) included the catch type (i.e., subsistence, commercial or ornamental), the vessel type (i.e., boat or canoe), vessel propulsion type (i.e., outboard ortail motor), the number of fishermen, the fishing days, equipment, the catch quantity and locality.

A total of 3244 fishermen were interviewed. This number represents a significant sample since the number of fishermen with general fisheries register (RGP) is 6193 in the area of influence of the HPP. As well as, the associates in the Fisher Colonies total 12,450 fishermen (NORTE ENERGIA, 2017). Of the total fishermen interviewed, 57.6% are city dwellers (live in the cities monitored by the project) and 27.9% are fishermen living in rural riverside villages. The others had no interest in declaring the place of residence, or are pre-registered fishermen, with incomplete information. It should be pointed out that 92.7% are exclusively engaged in catching fish, 2.5% are exclusively engaged in fishing for ornamental fish, and 4.8% catch ornamental and consumer fish, dealing with both activities, according to the needs and demands. This study only considered commercial fishing, for which data were collected of sufficient number, regularity and reliability for a robust numerical treatment. We excluded subsistence and ornamental fishing due to the small catch quantities and because the data identified for these two segments were insufficient for our purposes.

5. RESULTS AND DISCUSSION

5.1. Revenue

The average monthly income per fisherman, per locality, was determined by Equation 1. Therefore, it was necessary to obtain data on average monthly fishing productivity and average monthly fish market prices. Figure 4 shows the values of average monthly fishing productivity (kg/fisher/day) over the period, being red (up to the vertical line) observed data from the NORTE ENERGIA (2017) and, in light blue, the adjusted curve (WAM model) and, in dark blue, the forecast for a futher 12 months made using the WAM model using SPSS. It should be noted that the beginning of the generation of the Belo Monte HPP was in April 2016, and that from this date onwards there is a downward trend in productivity with seasonal variation, and, the forecast is from May 2017.

Figure 5 shows the rates of the average monthly fish market prices (R$) over the survey period projected for an additional 12 months using the WAM. It is observed that prices increase over time according to the behaviour of the product market. Since the prices for different periods were priced, they were adjusted using the broad consumer price index (IPCA) of the Brazilian Institute of Geography and Statistics. IPCA is the official inflation index in Brazil and it is published monthly (IPCA, 2017). The result for the average monthly income per fisherman is shown in Figure 6. In the figure, one can observe a sharp decrease in the income value from the beginning of HPP operation in April 2016, since after this date a decrease in productivity is presumed caused by externalities from the HPP.

5.2. Cost

Figure 7 shows the average monthly total costs (e.g., ice, fuel, food, boat) by locality and fishing trip according to the report (NORTE ENERGIA, 2017) and forecast by WAM. In this case, after the start of HPP operation, there is an increase in the total cost in relation to the initial years in addition to seasonal variation.

The rates shown in Figure 7 were readjusted by the IPCA and transformed into the form R$/fisherman and considering that according to the report (NORTE ENERGIA, 2017), a fishing trip lasts 2.24 days and has 2 fishermen. Thus, as shown in Figure 8, the result of the readjusted average monthly total cost per fisher no longer exhibits a trend of significant increase in value over time. However, the seasonal behaviour of the fishing activity continues to be observed.

5.3. Monthly Average Net Income of Fishermen

The result for the average monthly net income of a fisherman (R$) according to Equation 3 is shown in Figure 9. We can observed its decrease in value, from April 2016 (beginning of the HPP generation), respecting the seasonality, caused by the decrease in the value of the average monthly productivity and by the appearance of externalities.

5.4. Loss of Fishing Activity Externality

The monthly income loss for a fisherman (Equation 4) was estimated to be R$ 184.07/month, or R$ 2208.84/year, it is equivalent to US$ 674.74/year (1U$ = R$ 3.2736). Table 1 shows the results of the externality calculation of the loss of fishing activity (Equation 5) for 1 fisherman, for the 3,244 fishermen who participated in the research in the nine localities. However, according to NORTE ENERGIA (2017) there are 6,143 fishermen who own general fishing register and 12,450 members in the fishing colony in these localities, therefore, it was decided to make the calculation also for these fishermen.

5.5. Increase in the Cost of Power Generation with the Inclusion of the Externality

According to the Belo Monte Feasibility Study (ELETRONORTE, 2002), the energy produced by the HPP has a generation cost

Figure 4: Observed monthly average productivity in the period April 2012-2017 and forecast monthly average productivity for the period May 2017-April 2018

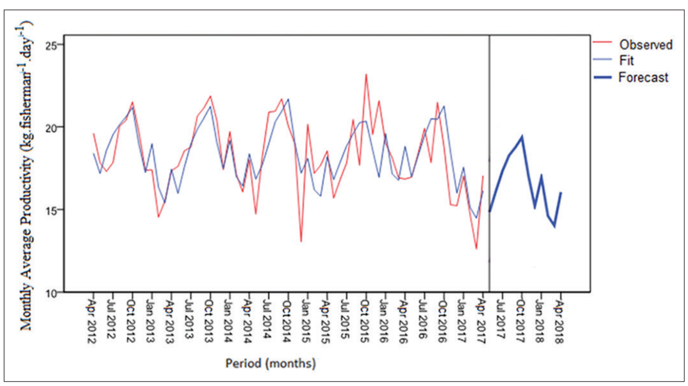


Figure 5: Observed monthly average price in the period April 2012-2017 and forecast monthly average prices for the period May 2017-April 2018

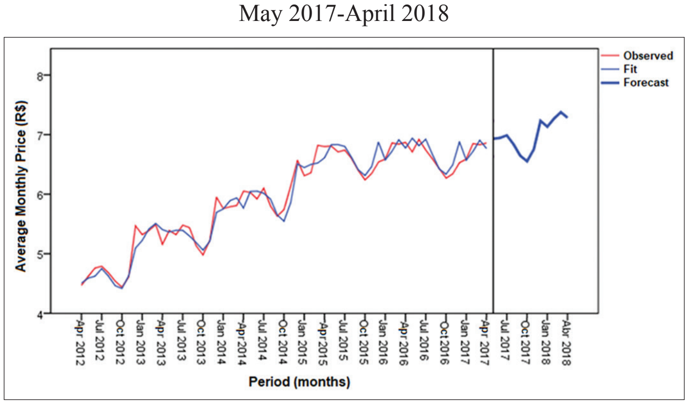


Figure 6: Observed monthly average revenue for the period April 2012-2017 and forecast monthly average income for the period May 2017-April 2018

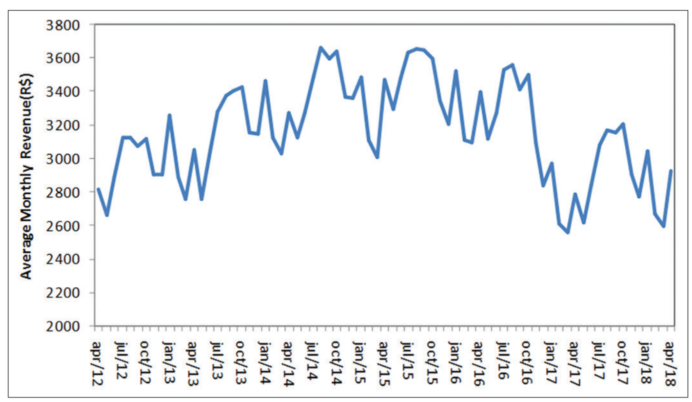


Figure 7: Observed monthly average total cost per trip in the period April 2012-2017 and forecast monthly average total cost per trip for the period of May 2017-April 2018

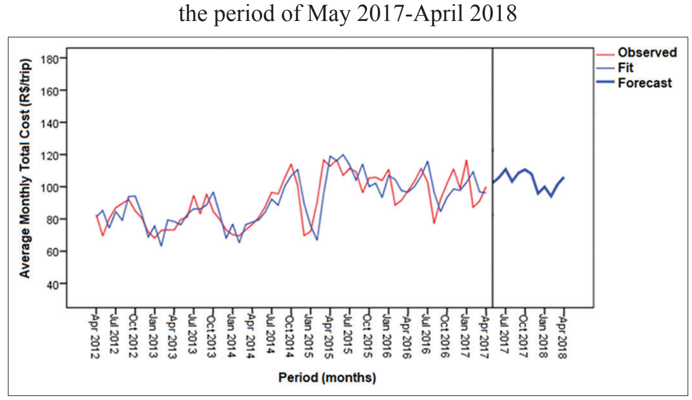


Figure 8: Observed monthly average total cost in the period April 2012-2017 and forecast monthly average total cost for the period May 2017-April 2018

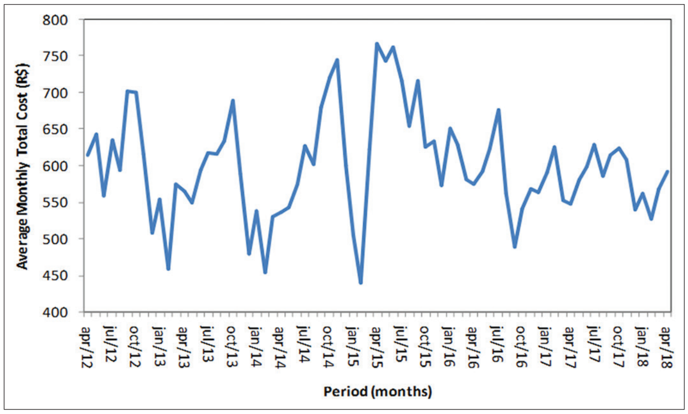


Figure 9: Average monthly net income of a fisherman affected by the hydro power plant influence

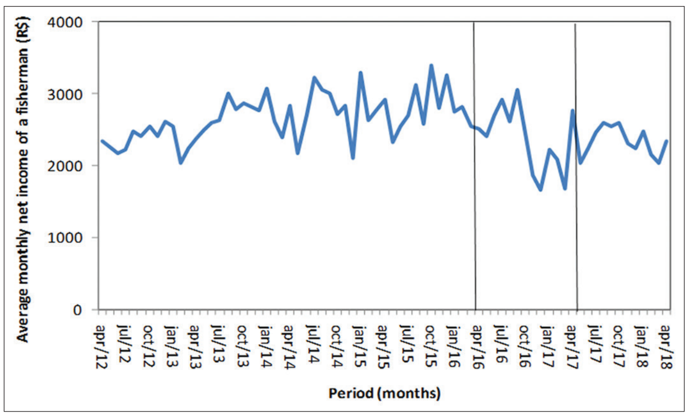


Table 1: Monthly and annual loss for fishermen

Number of fishermen	Monthly loss (R$)	Annual loss (R$)	Annual loss (US$)
1	184.07	2,208.84	674.74
3244	597,123.08	7,165,476.96	2,188,856.56
6193	1,139,945.51	13,679,346.12	4,178,664.82
12,450	2,291,671.50	27,500,058.00	8,400,513.00

of US$ 12.4/MWh, equivalent to R$ 40.59/MWh. The single externality determined using the opportunity cost method in this study was R$ 27.5 million/year (U$ 8.40 million/year). Considering that the average energy assured production of the HPP is 4.57 thousand MW, the total amount of electricity generated in a year under full operation will is approximately 39.5 million MWh, which represents a total production cost of US$ 489.8 million/year (US$ 12.4/MWh × 39,500,000 MWh). If the cost of the estimated externality (US$ 8.4 million/year) is included, then the total cost of energy increases by US$ 0.21/MWh (Equation 6), i.e., by 1.7% of the estimated energy cost adopted in the feasibility study, which represents US$ 12.61/MWh.

Adopting data from Leitão (2005), which lacks a strict methodological basis, Sousa and Reid (2010) estimated the annual losses of fishing in the Belo Monte region at U$ 1.86 million/year (R$ 6.08 million/year) for traditional fishing. In another study, Guatam et al. (2014) estimated annual losses of fishing in the Belo Monte region at US$ 3.19 million/year (R$ 10.47 million/year) for traditional fishing. The feasibility study report (ELETRONORTE, 2002) estimated that US$9.61 million (R$ 31.46 million), adjusted for 2017, would be required for the conservation of all fauna (i.e., fish, birds, reptiles and mammals) and US$ 215.46 million (R$ 705.34 million) for all the externalities generated by the enterprise.

The useful life of a hydroelectric plant is approximately 50 years. However, considering a period of only 15 years for the influence of this externality (since after that period the aquatic environment of the location could be altered or the affected fishermen could change to agricultural employment or migrate to the cities), the value of only this externality for these 15 years is US$ 127.5 million. This amount is equivalent to 59% of the value allocated for all the externalities of the venture by the feasibility study (US$ 215.46 million). The calculation of this externality reveals that it is an economic aspect that must be considered when an HPP is proposed. In addition, this externality represents a worrisome social factor since a river side population that suffers the loss of its income tends to migrate to the city, leaving home to search for employment elsewhere, generating other externalities previously unforeseen in technical, economic and environmental studies.

6. CONCLUSION

In this study, the value of the externality loss of fishing activity in the Belo Monte HPP (US$ 8.40 million/year) was determined using the opportunity cost method. This value is much higher than those available in the literature and to the amount of compensation negotiated by an entrepreneur for not only for this externality but also the fauna in the area. The measurement of the loss in commercial fishing revealed that the cost of energy would increase by 1.7%, from U$ 12.40/MWh to U$ 12.61/MWh. Therefore, if the values of other, reasonably estimated externalities are incorporated into the total cost of hydroelectric power generation, this cost would likely not be as competitive as it appears to be. Loss in fishing activity in the region was not caused solely by the construction of the HPP. There are other aspects that are being added, for example, the changes of fishing technology that can directly influence the reduction of the amount of fish. In addition, Brazil experienced a period of recession with gross domestic product shrinkage, which, because it was an exogenous factor, was not considered at work. The importance of assessing the externalities of all energy generation ventures (hydro, solar, wind, biomass, etc.) is to verify their economic viability associated with lower environmental and social impacts is highlighted.

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