Improving the Selection of Cascade Alternatives

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ABSTRACT. Hydroelectric inventory studies are a tool to decision support applied to sets of hydroeletrical projects, designing, analyzing and comparing different cascades with the goal of selecting the one that presents the best balance between the construction and operational costs, energy benefits and environmental impacts.

The comparison is made through a multi-objective analysis that considers the cost-effective energy and negative and positive environmental impacts, as recommended in the Manual for Hydropower Inventory Studies of River Basins - 2007 edition.

In calculating the Cost-benefit Index, used to perform the comparison of the cascades, values are homogenized by complementing the power generation associated with cascades with lower gain of firm energy to the greatest value among all. This supplement is valued using a unit cost of reference. This standardization allows us to identify the most attractive alternative under the strict point of view of the economic and energy efficiency.

However, the calculation of the Negative environmental impacts Index does not consider the impacts of the complementary amount of energy, that is assumed to be generated outside de basin, every time that the chosen cascade is not the one with highest firm energy generation.

This article discusses the development of a methodology that aims to incorporate to the multi-objective comparison of cascades, an index that represents the negative environmental impacts related to the complementary electric energy generation outside the river basin, using the same, or using other sources of electric generation.

1. Introduction

The large hydroelectric potential of Brazilian river basins (≅ 250.000 MW) is being progressively exploited since the beginning of the last century, and today, with 30% of the potential already exploited, this type of electricity generation represents 86% of the Brazilian electric power matrix, with more than 120 hydro plants with capacity greater than 30 MW in operation. The hydroelectric expansion planning in Brazil is done through a series of studies that considers different time horizons and successive approximations. The Hydropower Inventory Studies is one of the earliest stages of this process. It comes after river basin Recognition Studies and is requested by Long Term Planning studies as shown in Figure 1.

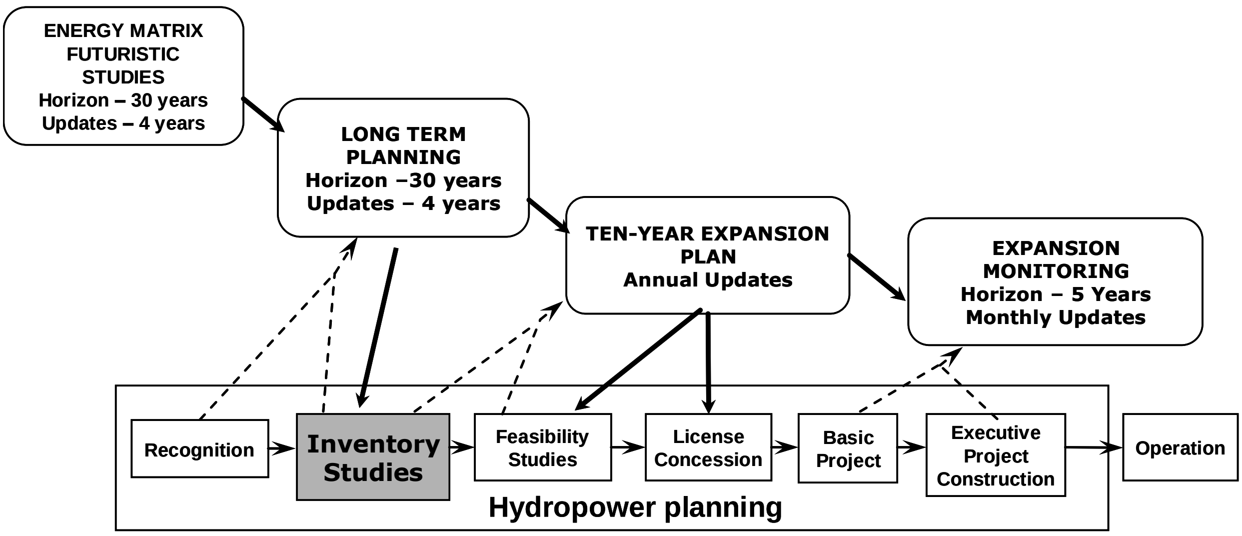

Figure 1. Brazilian National Power System Expansion Planning and Hydropower Planning.

The position of the river basin inventory studies in the beginning of the decision-making process of the power system expansion planning gives to these studies a strategic character, as, at this time, the resources are still not committed with the implantation of the future hydropower plants that will compose the river basin head division, or cascade. Therefore, that is the moment that all the alternatives for the river basin cascade should be surveyed and studied to select the one that presents the best efficiency in energetic and socio-environmental terms.

2. The Inventory Studies

The Inventory Studies are developed according to the Hydroelectric River Basin Inventory's Manual (BRASIL, 2007a), which criteria and methodologies were recently revised with special focus on socio-environmental and multiple use of water issues.

The Hydropower River Basin Inventory goal is to analyze all the river basin cascade schemes and select the best one according to a basic criterion stated as "the maximization of the economical-energetic efficiency with the minimization of the negative socio-environmental impacts, taking into account the positive impacts from the implementation of the hydropower plants in the basin".

The Inventory Studies are divided in two phases: Preliminary Studies and Final Studies. The objective of the Preliminary Studies is to reduce the number of river basin cascade schemes which will be considered in the Final Studies, when the schemes will be studied with more details and the best one will be selected. The hydropower plants of the scheme selected on the Final Studies are added to the country inventoried set of hydropower plants and pass to the next stage of the Hydroelectric Expansion Planning Studies. The studies in a Hydropower River Basin Inventory can be grouped as: Engineering studies, Energetic studies, Socio-environmental studies and Multiple Use of Water studies.

The socio-environmental studies adopt an analytical framework where the socio-environmental system is represented by six components, named Synthesis Components (Aquatic Ecosystems, Terrestrial Ecosystems, Ways of Life, Territorial Organization, Economical Basis and Indigenous Population).

The Synthesis Components (SC) guide the elaboration of all the phases of the socio-environmental studies: diagnostic, identification and impacts assessment. They also establish an adequate framework for the analysis of the impact process for each project and of the cumulative and synergetic effects in the study area for each cascade alternative. For the analysis of positive impact some elements of this component are previously selected. At the end of the diagnostic, each component analysis should be spatially represented and the study area divided in units of analysis (subareas) that are defined considering the occurrence of processes, fragilities or peculiarities that determine the relationship between each subarea and the component dynamic all over the study area. Weights should be assigned to each subarea representing its relevance to this dynamics.

At the preliminary studies the impact assessment starts with the analysis of the impact of each project in the subareas defined for each Synthesis Component (SC), assigning impact grades in a numerical scale from zero (no impact) to one (component full deterioration), in each subarea affected. The alternative impact index for each Synthesis Component (ISC) is obtained by the weighted sum of the cumulative indices of each subarea, using weights that represent the relative importance of each subarea.

At the final studies the negative socio-environmental impacts on each SC for each alternative is calculated in a different way. It starts by assigning the subarea cumulative impact grade according to the analysis of the cumulative impacts of the project set that affects the same subarea. At this phase the impact analysis is oriented by the indicators related to the most relevant impacts identified, considering all the projects. Also at this point it is calculated a positive socio-environmental impact index for each cascade.

After obtaining the Cost-benefit Index (CBI), and negative and positive socio-environmental impacts Indexes (NSI, PSI), it is performed a multi-objective analysis, in order to selected the alternative that meets the criteria established, as said before: “the maximization of the economical-energetic efficiency with the minimization of the negative socio-environmental impacts, taking into account the positive impacts from the implementation of the hydropower plants in the basin”.

In calculating the CBI, used to perform the comparison of the cascades, values are homogenized by complementing the power generation associated with cascades with lower gain of firm energy to the greatest value among all. This supplement is valued using a unit cost of reference. This standardization allows us to identify the most attractive alternative under the strict point of view of the economic and energy efficiency.

So in this paper it is proposed a method to calculate the Negative Socio-environmental Impact Index of the Complementary Amount of Energy (NSICE) that is assumed to be generated outside the river basin, every time that the chosen cascade is not the one with highest firm energy generation. This index is a complementation to the negative socio-environmental index.

3. Steps of the Method

Well as the consideration of additional power is made in the Cost-Benefit Index, it was considered that the NSICE should incorporate external environmental impacts to the representative basin from various electric generation sources, associated with the Long Term Generation Electricity Expansion Plan. The method was developed considering the following steps:

1. Selection of the environmental impacts of electricity generation sources considering long-term planning;
2. Developing indicators for selected impacts;
3. Aggregation of indicators into a single index (NSEI);
4. Calculating the environmental index of complementation of alternative energy division falls (NSICE);
5. Incorporation of NSICE in multi-objective analysis of the Inventory Studies.

The electric sources considered were: hydroelectric , thermoelectric natural gas, thermoelectric coal, biomass fuel from sugar cane, thermonuclear and wind, as these sources in 2006 were about 98 % of the Brazilian electric energy matrix and the same scenario is expected for 2030 as considered at the National Energy Plan 2030 (PNE 2030, BRASIL , 2007b).

3.1 Selection of the Socio-environmental Impacts

The first step of the methodology consists in raising the most significant socio-environmental impacts of power generation, considering all stages of their life cycle. It is recommended that this survey is based on references acknowledged. A key publication in this analysis is the National Energy Plan 2030. This survey resulted in a fairly extensive list (CEPEL, 2012), needing the application of filters to the initial listing. The method proposes the application of four filters, using different exclusion criteria, as described below:

- First filtering - keeping only the most relevant impacts considered in the references consulted for the preparation of the initial listing.
- Second filtering - drop the impacts associated with "risk", [i.e.] the effects of accidents and non-routine operation. Thus they regarded only the negative socio-environmental impacts

related to the routine operation of the facility in operating condition within the standards required by the law and using the best technology available.

- Third filtering (qualitative selection of environmental impacts) - consider the impacts based on the attributes “duration”, “spatial extent” and “reversibility”; discarding those classified as “temporary” and “reversible” or those classified as “local” and “reversible”.
- Fourth filtering (final selection of the main environmental impacts) - select the impacts according to their "significance" defined as a function of the magnitude and importance of the socio-environmental impacts (CEPEL, 2011).

As a result we had 17 socio-environmental impacts (SOURCE IMPACTS), showed below, that could be grouped on 10 kinds of socio-environmental impacts (CATEGORY-IMPACTS).

Hydro	**Gas**	**Nuclear**	**Coal**	**Biomass**	**Wind**
Land use	Land use	Land use	Land use	Air Quality	Land use
Ways of life	Air quality	Water quality	Water quality		Noise
Ethno ecological conditions	Global Warming	Land Contamination	Air quality		
		Risk	Global Warming		

3.2 Selection of the Indicators

Each source-impact must be reported in a record description, including: the actions that cause it, description of the impact, receptors and potential effects. These records are the basis for defining the most appropriate indicator to measure the impact effects. In order to obtain degrees of impact between zero and one (0-1) should also be defined the maximum permissible values for each indicator, meaning that the degree of zero corresponds to no impact and degree of impact equal to 1 corresponds to the Maximum Allowable impact.

3.3 Calculating the NSEI

The NSEI, or Negative socio-environmental índex of the Expansion represents the socio-environmental impact associated to the expansion planned within a time horizon. Each source impact receives an impact degree (at 0-1 interval), that are combined in a index using a weighted sum. The weights are associated to the category-impacts, which have been analyzed and compared using the Saaty Method of Hierarchical analysis (Saaty, 1980). The equation is:

$$ID*_{k,j} = ID_{k,j} \cdot W_j \quad (1)$$

ID* = Modified Impact Degree
ID = Impact Degree
W = Category-Impacts Weight

To calculate the preliminary NSEI it is necessary to obtain the participation of the sources in the matrix of electric power generation planned. This information is available on the National Energy Plan 2030 (BRASIL, 2007). In possession of the modified impact degrees (ID *) and the participation percentage of each source (S) in the mix of the expansion of electricity generation, using equation (2) one arrives at the value of an index that represents the negative socio-environmental impact of the expansion planned in a preliminary version (NSEIprel).

$$NSEIprel = \sum_j \sum_k ID*_{k,j} \cdot S_k \quad (2)$$

The NSEI is obtained by dividing the NSEIprel by the maximum NSEI, considering all ID of all source-impacts equal to 1.

3.4 Obtaining the NSICE

The NSICE (negative socio-environmental index of the complementary energy) is the product of NSEI and the energy complementation of the alternative cascade, divided by the greater amount of firm energy produced by a cascade in the river basin being inventoried, as shown at equation 3.

$$NSICE_a = \frac{(\Delta FE^* - \Delta FE_a)\ x\ NSEI}{\Delta FE^*} \qquad (3)$$

ΔFE^*: Firm Energy of the cascade with greater firm energy among the alternatives in an inventory study; and
ΔFEa: Firm energy of alternative “a”.

3.5 Incorporation of NSICE in multi-objective analysis of the Inventory Studies

At the Inventory studies, the choice of alternative cascades is usually performed in two stages. In the first stage (Preliminary Studies) all possible alternatives are analyzed and identified those most attractive, whose studies will be further developed and detailed in the subsequent stage (Final Studies). The purpose of this step is to eliminate non- competitive alternatives, so that the work of detailing the alternatives is not overloaded. For the choice of alternatives that will go to the next stage, it is performed a multi-objective analysis comparing the Cost-Benefit Index (CBI) and Negative Socio-environmental Impact (NSI), where the dominant alternatives (Pareto optimal) will be detailed.

At the Final Studies the best alternative cascade is chosen, considering a multi-objective analysis by linear combination of the CBI and NSI in a single index (Index of Preference, IP) , and subsequently the linear combination of IP and Positive Socio-environmental Impact (PSI) index, resulting in modified Preference index (IP*), calculated for each cascade alternative . The alternative that obtains the lowest value for IP* is selected as the best alternative cascade. For more detail, see in BRASIL (2007a) and Costa et al (2011).

To incorporate the NSICE in the multi-objective analysis of the Inventory Final Studies it is proposed that an index of Modified Negative Socio-environmental Impact (NSI*), to substitute the NSI at the analysis. Three approaches were analyzed to calculate the NSI*:

1. Sum the NSICE to the NSI at each cascade alternative, so that the socio-environmental impact would have the same importance at the NSI*, whether occurring inside or outside the river basin under study.
2. Linear combination of NSICE and NSI, using a weighted sum;
3. Linear combination of NSI and NSEI, where weights are fixed and proportional to the firm energies produced inside and outside the river basin under study, respectively.

4.0 Results and Conclusions

The consideration of the negative environmental impact of non-utilization of hydropower potential economically attractive in Inventory Studies explicit to decision-makers and society at large, that this non-exploitation, in a country where the demand for electricity still is growing, does not mean lack of environmental impact, since the amount of energy regarding this potential has to be produced by another source and/or other river basin.

In order to enhance the results obtained, we suggest sets of actions such as: review of topics such as the definition of the criteria for maximum permissible impact; renewed discussion of the life cycle of electric power generation by biomass cane of sugar; range extension of specialists involved in the discussions. Likewise, reviewss on the National Energy Plan demand reviewing the steps of the method to calculate the NSEI. This work can be seen as a first step towards structuring procedures for consideration of the negative environmental impact related to the non-use of economically attractive hydropower potential of river basins in Brazil.

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