Evaluation of Cumulative and Synergistic Impacts in the Hydropower River Basin Inventory Studies

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Abstract:

The first stage of the studies cycle for hydropower development is the river basin inventory, when various alternatives for the division of the river basin water head are formulated, analyzed and compared. These studies aim to select the best alternative, considering the energetic, economical and socioenvironmental aspects. This paper presents a brief resume of the hydroelectric inventory studies framework and points out the methodology developed by CEPEL to incorporate the socioenvironmental analysis together with the other dimensions, under a multi-objective focus, describing the environmental indices composition method. It emphasizes the procedures for the evaluation of the cumulative impacts of the group of hydropower projects in the different stages of the studies, as well as the correspondent indicators.

Keywords:
Cumulative and synergistic impacts; hydropower environmental planning; socioenvironmental assessment.

1) INTRODUCTION

In the last decade, consistent efforts have been made to adopt a more strategic approach for addressing environmental issues from the very first stages of the Brazilian electricity sector's planning process. There is a growing awareness that, at the level of a specific project, essential decisions are difficult to reconsider because of the narrow margin available for comparing alternatives.

The first stage of the cycle of studies for hydropower development is the river basin inventory, when various alternatives for the division of the river basin water head are formulated, analyzed and compared. The Hydroelectric Inventory of Hydrographic Basins Manual, dated from 1997, established the procedures for carrying out these studies in Brazil. The methodology considers a multi-objective approach, and the basic criterion for the alternative selection is “maximizing economic-energy efficiency together with minimizing environmental impacts”.

Recently, a revision of these procedures and methodologies has been undertaken (MME/CEPEL, 2007). One of the changes is the improvement of the methodology for cumulative impacts incorporation. Another one is the integration of the positive socioenvironmental impacts as an additional criterion for the best alternative selection. These innovations were tested and the inventory studies, that are being undertaken to develop the hydro potential in the Amazon region, are following the procedures described in this new version of the Manual.

This paper initially describes the main characteristics of the Brazilian electric power sector and its hydropower planning process, and also presents a brief resume of the hydroelectric inventory studies framework. It points out the socioenvironmental studies methodology, describing the negative and positive impact indexes composition method and highlighting the improvements in the cumulative impacts assessment mentioned. Some examples extracted from the application of the methodology on a study case (Tocantins River Basin Hydroelectric Inventory Study) are presented to illustrate the descriptions.

2) ELECTRIC POWER SECTOR IN BRAZIL

The Brazilian power system is predominantly hydropower-based with a nationwide interconnection between hydrographic basins. The total estimated hydro generation potential is around 246 GW and 27.7% of this amount is already in operation. From the remaining potential, 30% is still even without inventory studies, and 78.6% of this amount is located in the Amazon Basin. That gives an idea about the importance of considering social and environmental aspects since the very early stages of the Brazilian power sector planning process.

River basin inventory studies are considered strategic since they constitute the first stage of a hydropower project planning cycle of. As it can be observed in the figure 1, the Inventory studies take place in the beginning of the decision-making process of the energy expansion planning and serve as a reference for elaborating the Long Term and the Decennial national expansion plans.

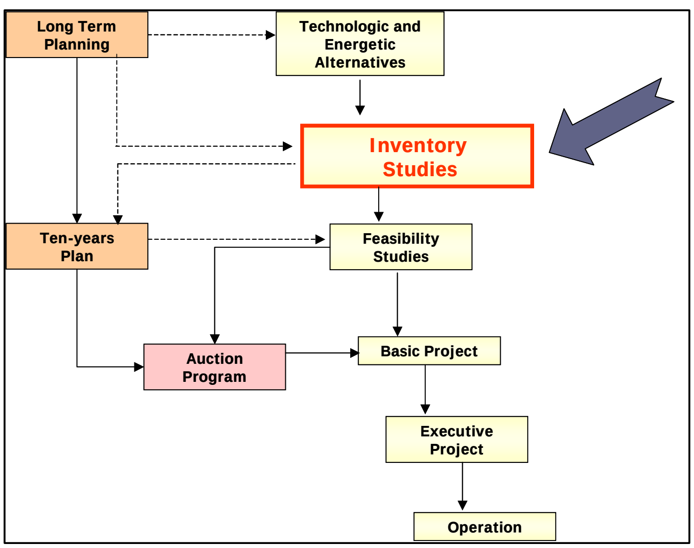

Figura 1- Brazilian power sector planning process x hydropower planning cycle

Inventory studies also constitute the stage where is initiated the interaction between each project and the planning of the hydrographic basin as a whole. At this time, the resources are not still committed with the implantation of the future hydropower plants in the river basin, providing more flexibility to the analysis of various alternatives.

These studies are characterized by the concepts and analysis of various alternatives for the river basin partition, formed of a set of projects, and that are compared with one another. Therefore, this is the ideal moment to study all the alternatives of the river basin head division and select the one that presents the best relationship between energy benefits, social-environmental impacts and implementation costs, including estimated mitigation and environmental compensation costs.

3) HYDROELECTRIC INVENTORY STUDIES

From the socioenvironmental point of view, the inventory studies are distinct from that of a specific project, giving support to the formulation, analysis and comparison of several partition alternatives. These studies consider:

a) the regional scale, in order to analyse the overall impact processes of the river basin head division alternatives on the study region, providing an adequate framework to analyse their cumulative and synergistic impacts and also the restrictions and opportunities related to the water resources uses;

b) the local scale, to analyse the impact processes of each project.

These studies in turn generate recommendations for the feasibility studies of each project. As well as highlighting the socioenvironmental questions for each project that should be subjected to further studies, they also cover aspects that require inter-institutional articulation, and questions related to environmental management and to the water resources uses at the river basin, that might have specific influences on each project.

All the procedures to enable these analysis and the selection of the best alternative are described in the "Hydroelectric Inventory of Hydrographic Basins Manual" (MME, CEPEL, 2007), that establishes a methodology for the Inventory Studies based on a multi-objective approach, developed by CEPEL, as well as the Computational System – SINV – that gives support and integrates the inventory energetic and environmental studies.

The basic criterion for the selection of the best river basin partition is "*maximizing economic-energy efficiency together with minimizing socioenvironmental negative impacts*". The benefits or positive socioenvironmental impacts due to the implementation of the hydropower plants (e.g.multi-purpose projects: energy generation and irrigation, flood control, navigation or recreation) are considered as an additional criterion for the best alternative selection. An energetic cost-benefit index and two environmental indices (one for the negative and another one for the positive impacts) are attributed to each head division alternative, with the aim of comparing and selecting the best one.

The inventory studies are developed in two phases:

- Preliminary Studies - the objective is to select from a large set of head divisions alternatives, the most competitive ones. The socioenvironmental analysis starts with its focus on each project, in order to avoid the most important impacts and to subsidize project conception and alternatives formulation, considering an estimation of cumulative and synergistic impacts. The positive impacts are not considered in the alternatives selection.
- Final Studies - the selected alternatives are submitted to a more detailed analysis in order to choose the one which represents the best compromise between

economic-energetic efficiency and socioenvironmental impacts. At this stage, the focus of the environmental analysis is on the group of projects that compose each alternative and its cumulative and synergistic effects. The positive impacts are incorporated in the alternative selection.

The socioenvironmental studies adopte an analytical framework where the socioenvironmental 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 socioenvironmental 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 head division 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. The map presented in Figure 2, shows the subarea division defined at the study case (Tocantins River Basin), considering the SC Aquatic Ecosystems.

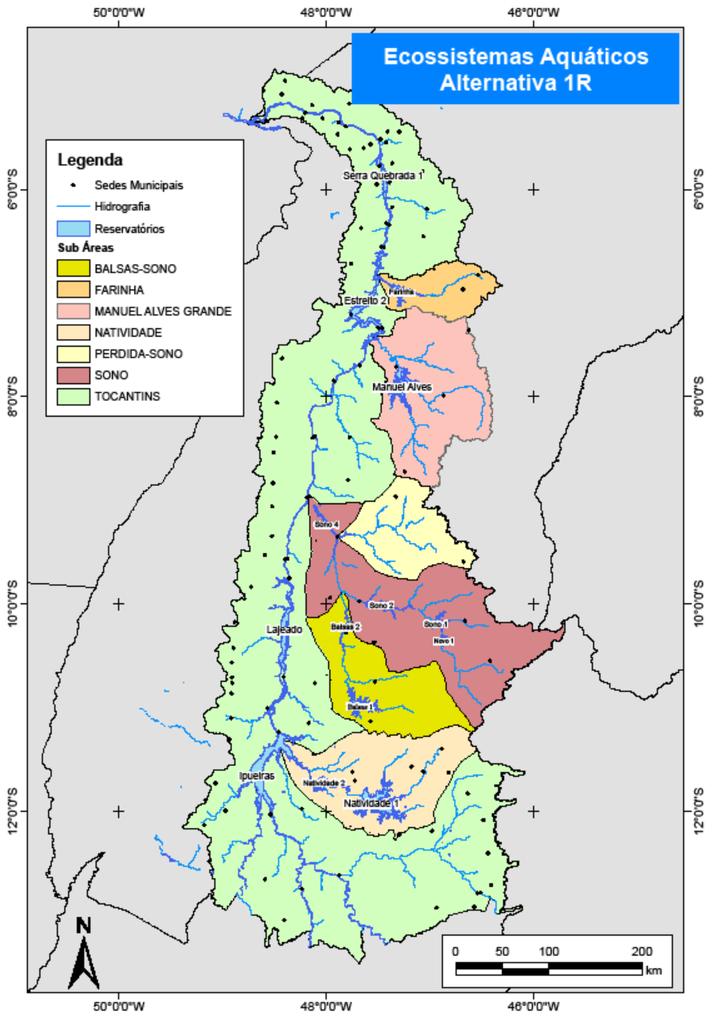

Figura 2- Aquatic Ecosystem subareas defined on the study case (Tocantins River Basin)

3.1) Preliminary Studies – Negative Socioenvironmental Index

At this phase 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 complete assessment of an alternative set of projects is shown in table 1, using the results obtained for a given alternative analyzed in the study case, for the SC - Ecosystem Aquatic.

Table 1- Negative Socioenvironmental Impact Index of one alternative on a SC - IAC Preliminary Studies

Sub-areas	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	
Weights	**0,089**	**0,26**	**0,187**	**0,096**	**0,13**	**0,1**	**0,138**	
Projects								
A						0,45		
B						0,13		
C		0,40				0,20		
E		0,30						
F								
G							0,05	
H			0,05					
I			0,10					
J			0,12					
K	0,15		0,15					
N				0,20				
O		0,45						
P					0,15			
Q_2		0,22						
$I^c_{SA}(j)$	0,15	0,82	0,36	0,20	0,15	0,617	**0,05**	IAC
$I^c_{SA}(j)\,P(j)$	0,013	0,213	0,067	0,019	0,020	0,062	0,007	0,401

At this stage, it is possible to have a large number of alternatives being assessed. So, a simplified procedure[3] is proposed to calculate the resulting cumulative index in each subarea $I_{SA}(i,j)$, that simulates the cumulativity of the impacts, considering the socioenvironmental negative indices assigned to each project in each subarea, using the following iteration:

$$I^C_{SA}(i,j) = I^C_{SA}(j,i-1) + \left[1 - I^C_{SA}(j,i-1) * I_{SA(j,i)}\right] \qquad i = 1,n$$

Where:

n	number of projects of an alternative with interference in the subarea **j**
$I_{SA}(j,i)$	negative impact value in the subarea **j** when there is only the o i-th project of the alternative;
$I^c_{SA}(j,i)$	negative cumulative impact in the subarea **j** considering the interference of the projects 1, 2, ..., i of the alternative;

being $I^C_{SA}(j,0) = 0$ the initial value of the cumulative impact in the subarea j.

After all iterations and considering all the alternative projects installed, the cumulative impact in the subarea **j** is:

$$I^c_{SA}(j) = I^c_{SA}(j,n)$$

[3] Source: EPE/CNEC/Arcadis Tetraplan, 2007, adapted by CEPEL/MME, 2007.

The alternative impact index for each Synthesis Component (IAC) is obtained by the weighted sum of the cumulative indices of each subarea, using weights that represent the relative importance of each subarea.

$$IAC = \sum_{j} I_{SA}^{c}(j)\, P(j),$$

where:
P(j) - weighting factor of each subarea j

The negative socioenvironmental impact index of each alternative (IAn) is obtained by the sum of the Synthesis Components indices (IAC) weighted by their relative importance for the socioenvironmental system.

$$IAn = \sum IAC_i x Pci,$$

where:
Pci - weighting factor of each Synthesis Component

3.2) Final Studies – Socioenvironmental Indices

The studies at this phase follow the same structure that in the Preliminary Studies. As some alternatives were discarded, the remaining ones can be studied more carefully. The negative socioenvironmental impacts analysis focuses on the set of projects which affects each subarea, instead of each project, incorporating an analysis of the cumulative and synergistic effects and not only a simulation.

Another important difference is the assessment of the positive impacts related to some elected elements, aiming its consideration in the final multiobjective analysis for alternative selection. In this case, the analysis is also done for the set of projects, already including the cumulative impacts.

3.2.1 – Negative Socioenvironmental Index

For the alternatives selected to be assessed in the Final Studies, the calculation of the negative socioenvironmental impact index of each alternative (IAn) is done using the same procedure previously described (item 3.1).

The main difference in relation to the procedures adopted in the preliminary studies is the calculation of the IAC (negative socioenvironmental impacts on each SC for each alternative). 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. Table 2 presents the results of the impact analysis of one alternative of the study case for a given component .

Table 2- Negative Socioenvironmental Impact Index of one alternative on a SC IAC - Final Studies

Projects	Sub-areas							
	I	II	III	IV	V	VI	VII	
A						X		
B						X		
C		X				X		
E		X						
G							X	
H			X					
I			X					
J			X					
K			X					
N				X				
O		X						
P					X			
Q_2		X						
I_{SAj}	0	0,85	0,7	0,2	0,1	0,65	0,4	**IAC**
I_{Saj} x P_j	0	0,221	0,131	0,019	0,013	0,065	0,055	**0,504**

Some examples of cumulative and/or synergistic impacts considered more relevant for the assessment of hydro power projects are presented in the Table 3.

Table 3 - Example of negative cumulative and synergistic impacts

Component	Impact
Aquatic Ecosystems	▪ Changes in the hydrological regime ▪ Changes in the sediment flow ▪ Changes in the quality of water ▪ Interruption in the migratory routes ▪ Interference in strategic biodiversity environment
Terrestrial Ecosystems	▪ Lost, fragmentation or isolation of habitats ▪ Interference or pressure over protected sites ▪ Lost of vegetal coverage ▪ Pressure over endangered species
Ways of Life	▪ Pressure over the ways of life due to people attracted to the area of the project ▪ Affected people (urban and rural) ▪ Changes in the way of life of people depending of the river environmental services ▪ Epidemiological changes ▪ Loss of archeological, historic and cultural patrimony ▪ Increase of conflicts

Territorial Organization	▪ Interference in the territorial organization of local people ▪ Interference in the flow of people, goods and services ▪ Loss of municipalities' territory
Economics	▪ Loss of areas with economic productivity ▪ Loss of resources (mining, fishery, touristy, agricultural, among others)
Indigenous People	▪ Pressure over sociocultural relationships ▪ Pressure over ecological conditions of indigenous area.

Source: CEPEL, 2003 ; EPE/CNEC/Arcadis Tetraplan, 2007.

The application of the methodology in the case study (Inventory of the River Basin Tocantins) has considered for the analysis of the Synthesis Component Aquatic Ecosystems (AE), the following impact indicators:

- Changes in hydrological regime – in terms of the percentage of the extension of the water course that will be flooded.
- Interference in important biodiversity sites – percentage of area of marginal lagoons and special environments lost.

The alternative presented as an example in the map shown in figure 2, and also in the tables 1 and 2, has 4 projects affecting the subarea #2 (Subarea Tocantins), causing the following cumulatives interferences:

- 32% main course will be flooded;
- loss of 28,8% of the marginal lagoons;
- loss of 69 % of special environments

As another example, this alternative has other 4 projects affecting subarea #3 (subarea Sono), resulting in the following interferences:

- 46% main course will be flooded;
- loss of 12 % of the marginal lagoons;
- loss of 46 % of special environments

Comparing the impact index for these 2 subareas presented in the previous tables 1 and 2, it is possible to observe the difference between the evaluation at the preliminary and at the final studies. The results are summarized in table 4, as well as the value of the IAC index.

Table 4 – Case study - Differences in the impact analysis for subareas #2 e # 3

Component Aquatic Ecosystems (AE)	Preliminary studies	Final studies
Subarea #2 - Cumulative Index	0,82	0,85
Subarea #4 - Cumulative Index	0,36	0,70
IAC Index for AE	0,213	0,221

It can be noted that, in the case of the subarea #2, the result of the preliminary studies simulation is very close to the one obtained with the analysis of the cumulativity in the final studies. For the subarea #3 there is a relevant difference between the two results. However, the difference between the indices IAC at each study phase it is not so significant.

3.2.2- Positive Socioenvironmental Index

Four elements were identified to represent the positive socioenvironmental impacts:

- Road Infrastructure Improvements;
- Local Government Revenues Increase;
- Local Labor Market Dinamization;
- Opportunity for the multiple uses of water

These aspects were selected because they are mentioned more often in the Brazilian hydropower environmental studies and there is less uncertainty about their positive effects for the local development.

The subareas defined for the Economical Bases component should be used for the evaluation of the following aspects: Local Government Revenues Increase, Local Labor Market Dinamization and Opportunity for the multiple uses of water. The Territorial Organization Component subareas are used for the evaluation of the "Road Infrastructure Improvements" aspect. The subareas relative weights should be necessarily reviewed.

The assignment of positive impact grades is also done in a zero (no positive impact) to one (full satisfaction of the analyzed benefit) scale. The calculation of an alternative positive socioenvironmental impact index (IAp) follows the same procedures defined for the negative impact index of the Final Studies.

3.3 - Multiobjective Analysis for the Final Alternative Choice

For the alternative comparison and selection, considering the objectives "maximizing of economic-energy efficiency together with minimizing environmental impacts", as a first step for the multiobjective analysis, a preference index, ***I***, should be obtained by the weighted sum of the energetic cost/benefit index and the negative socioenvironmental impact index, dividing the energetic cost/benefit index (ICB) by an unitary reference cost (CUR):

$$I = p_{cb} \times \frac{ICB}{CUR} + p_{an} \times IAn$$

where:

$$p_{cb} + p_{an} = 1 \qquad p_{cb} \geq 0 \qquad p_{an} \geq 0$$

pcb – weight that reflects the relative importance of the objective "maximizing of economic- energy efficiency ";
pan – weight that reflects the relative importance of the objective "minimizing negative environmental impacts ";

ICB – energetic cost/benefit index (US$/MWh);
CUR – reference unitary cost (US$/MWh) ;
IAn – negative socioenvironmental impact index.

For the final choice of the head division alternative, it is proposed an additional analysis incorporating to the above rank the positive socioenvironmental impacts for the study area represented by the IAp index. As closer of one is this index, the best is the alternative. For the energetic cost/benefit and the negative impact indexes, the best situation has a reverse direction (it is better when is close to zero). So, for the integration of IAp and the preference index ***I***, it is necessary to use the IAp complement in the scale, i.e., (1-IAp). The modified preference index ***I´*** is calculated by:

$$I' = \left(1 - p_{ap}\right) . \, I \; + \; p_{ap} \, .(1 - IAp)$$

where:
pap – weight that reflects the relative importance of the positive socioenvironmental impacts

4) FINAL CONSIDERATIONS

The inclusion of the cumulative impacts in the environmental impact assessment studies is one of the main demands of the Environmental Agencies in Brazil nowadays, indicating that these impacts must be considered since the beginning of the planning process.

In the Brazilian electric power sector, efforts had been made, since the edition of the Hydroelectric Inventory Manual in 1997, in order to incorporate the cumulative impacts analysis in the best alternative selection. In a recent revision of this Manual (MME/CEPEL, 2007), the methodology for cumulative impacts incorporation has been improved, providing in a first moment a simulation that can give agility and flexibility required for the analysis at the preliminary studies phase, and a better prediction for these impacts at the final studies. The results of the inventory studies, being undertaken recently, show that the knowledge of cumulative impacts subsidize the definition of more adequate ways to mitigate and to compensate these impacts, which in most of the cases require integrated solutions.

Aiming to give support to the choice of the best head division alternative decision process, this Manual revision also included the assessment of the positive impacts. In this case, the analysis also consider the cumulativity and synergy, but is restricted to the more frequent and less uncertain socioeconomic impacts, with respect to the favorable transformations brought to the region by hydropower. The studies also point out the institutional articulations that are needed to potentiate the benefits to the region.

All the procedures here presented are implemented in a computerized decision support system (SINV) developed at CEPEL, integrating the economic-energetic and environmental analysis and giving the multiobjective analysis more agility.

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