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The index of regional sustainable integration for hydropower plants

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Abstract

This paper presents the results of a P&D research developed by the Universidade Federal de Pernambuco (UFPE) for the Compahia Energética de Minas Gerais – CEMIG, entitled "Developing a tool to monitor and evaluate the economic, social and environmental sustainability of municipalities in the areas of influence around dams". In Brazil, the construction of large dams for hydropower plants generates transformations that cause conflicts of interest at national, regional, local and sector levels. In the areas of direct influence around power projects there are negative social and environmental impacts, particularly where populations have been displaced. Nonetheless, benefits are also brought to the region in which the energy is produced, and the power sector is interested in maximizing such benefits, while minimizing the negative impacts on the implementation area, particularly in the Amazon region. Thus, the critical challenge is how to measure such changes in an effective manner. Many multilateral institutions have undertaken efforts to produce tools to this end. This paper presents the Index of Sustainable Regional Integration (ISRI), a tool for monitoring and evaluating the regional integration of hydropower plants, based on a system of indicators covering the four main dimensions of sustainable development: environmental quality, socio-cultural quality, economic development and quality of public management.
Keywords: system of indicators, sustainable development, power sector, hydroelectric power plants, sustainable regional integration.

1 Introduction

The Brazilian electricity sector is considered central to the country's social and economic development, since it exerts a decisive influence over most productive chains, thus generating wealth, employment and income. Historically, the sector has faced the constant need to expand in order to meet energy demands, either from the growing Brazilian population or by the expanding commercial and industrial sectors. However, the implementation process of hydroelectric projects entails wide-ranging environmental, socio-cultural and economic impacts. Moreover, institutional conflicts are caused and, eventually, the dynamics of regions where projects are installed become affected.

It is largely considered that while the region of deployment absorbs the negative impacts of a hydroelectric power plant, the energy benefits are intended for other regions of the country. Such differing perspectives make hydropower one of the greatest paradoxes of environmental economics. It is necessary, therefore, to build tools for monitoring and evaluating the regions of influence around these plants in order to minimize the negative impacts and maximize the positive, thus leading to more harmonious, integrated regional development.

The P&D research, the results of which are presented herein, aimed to develop a tool for monitoring and evaluating the sustainability of municipal development in areas of influence around hydropower plants. The tool, named the Index of Sustainable Regional Integration (ISRI), contains a set of indicators that covers the four dimensions of local development: quality of life; economic development; quality of public management and environmental quality.

Fieldwork involved 40 municipalities in the areas of direct influence (ADI) around six hydroelectric plants, located in the State of Minas Gerais, south-eastern Brazil, namely: Emborcação, Irapé, Nova Ponte, Queimado, Rosal and Volta Grande. Besides consolidating the matrix of indicators, the fieldwork enabled the construction of a database that corresponded to the initial evaluation of the monitoring and evaluation process. The main criteria for selecting each indicator were: its adequacy in relation to measuring the relevant aspects of sustainable local development, its feasibility, availability and reliability, in order to produce a more accurate evaluation.

The ISRI has shown to be an important tool for evaluating the performance of the power plants and the effectiveness of public policies and programmes, enabling an on-going monitoring process of the actions of both power sector and public administration, in the areas of influence surrounding hydroelectric power plants.

2 Methodology

The first step of the methodology adopted in the research consisted of a conceptual consolidation of the term "sustainable regional integration", based on the technical and scientific literature. This was followed by the building of a preliminary matrix of indicators, consisting of dimensions, themes, aspects and indicators, which represent all that is involved in the integration of a specific hydropower plant in its region, here considered as the set of municipalities within its area of direct influence (ADI). The indicators were organized into four dimensions, all derived from the conceptual discussion: (i) quality of life; (ii) economic development; (iii) quality of public management; and (iv) environmental quality.

Secondly, a survey of data was developed, associating values to the indicators, and thus composed the baseline of the monitoring and evaluation process of the regional integration of the selected enterprises. Data collection involved secondary data, obtained from electronic sites or from hard databases of official institutions; and primary data, mostly obtained from the 40 municipalities within the areas of direct influence (ADI) of the six hydroelectric plants assessed.

Subsequently, these data were treated and consolidated in an electronic database, developed with the purpose of supporting the processing of the index of sustainable regional integration (ISRI). The indicators also underwent a process of standardisation and parameterization, enabling their values to be expressed in units of comparable measures, using percentages, per capita and density functions. The indicators were standardised on a scale of 0 to 1.

It should be noted that the methodology produced an initial assessment of the current situation of each studied power plant in relation to the baseline conditions that lead to regional integration. Based on these conditions, the ISRI evaluates the effectiveness of policies, programmes and actions that have been especially implemented to mitigate, control and compensate for the negative impacts, and to maximize the positive impacts of hydropower plants. It also allows for a comparison of the different power plant performances in terms of regional integration.

To validate the results of the research, a triangulation of methods was employed, i.e., more than one method of research was used, aiming at results with a high level of reliability. Generally, in this case, there is a central method, which is the remaining secondary method [1]. In this research, the main method was the Delphi technique. Additionally, the following methods were used to validate the indicators: factor analysis; correlation between variables; ISRI analysis versus the reality of the municipalities.

Throughout the research, the matrix of indicators was continuously modified, with the inclusion and exclusion of indicators, depending on the availability and reliability of data, as well as on the result of the validation testing. Finally, a series of recommendations for increasing the level of regional integration of hydropower plants was drawn up.

3 Sustainable development

The complexity of the environmental issue increases the importance and need for management from within all sectors to discover integrated, sustainable solutions to achieve a balance between man-made and natural spaces. This process reveals a set of difficulties within a vicious circle: planning systems that do not follow the dynamism of cities; the complexity of environmental issues and their role in the development context; the discontinuance of policies, plans, programmes and projects, reducing or nullifying positive impacts expected from investments in infrastructure and operating human settlements; and low public participation in the management process [2].

Debate regarding the impacts arising from hydropower projects is part of this discussion on sustainable development, since they cause national, regional and local conflicts. The power sector, acknowledging this reality, has created the means to mitigate or neutralize negative effects on the environment surrounding the works, and to extend the designed benefits beyond electricity production [3].

Within this context, the issue of "regional insertion", a term first coined in the *I Plano Diretor para Conservação e Recuperação Ambiental nas Obras e Serviços do Setor Elétrico* (I Master Plan for the Conservation and Environmental Restoration in the Works and Services of the Power Sector) [4] involves creating and maintaining alternatives for development opportunities on a regional level.

To deal with the challenge of evaluating the integration of a hydroelectric power plant with the development of its region, the use of indicators has proven to be a good measure, provided they are comprehensive enough to cover the main dimensions of sustainable development, such as the quality of life and socio-cultural aspects; economic development; the quality of public management and environmental quality. Together, such indicators are able to reveal the most relevant aspects of sustainable local development and integration, and are an important tool for monitoring the effects of actions implemented by the utilities, ensuring efficient allocation of resources and their effective management.

4 System of indicators

Initial incentives for constructing indicator systems date back to the 1920s and 1930s [5], when the first social indicators were used as evaluation and decision-making instruments for development planning [6]. However, it was only in the mid-60s that social indicators were developed from within a scientific body to monitor and evaluate social changes and the implications and results of social policies, both in developed and developing countries. According to Magalhães Junior [7], indicators are tools that help decision-makers, simplify reality and adapt information to language and local interests. Cutter *et al.* [8] suggest that a system of indicators provides measures to establish priorities and assess the progress of actions. In general, the main functions of indicators, according to Tunstall [9] are: (i) to evaluate the status quo; (ii) to compare places and situations; (iii) to assess trends; and (iv) to anticipate conditions.

In highly complex realities, such as municipalities in the area of influence around dams, monitoring and evaluation constitute a huge challenge. With the difficulties and risks involved in observing the behaviour of all the variables that affect economic, social and environmental sustainability within this universe, indicators need only be employed for a few selected variables, regarded as being capable of producing relevant information for managing these realities. These should be chosen through objective, feasible, controllable criteria, without overlooking the complexity of development and that the use of indicators stems from the principle that an indicator, or indicators, simplifies complex often abstract, phenomena, in quantifiable measures.

5 The matrix of indicators

As an intermediate step towards constructing the index of sustainable regional integration, an array of indicators was assembled, including dimensions, themes and aspects of reality that represent how the integration of a specific hydroelectric power plant occurs within its area, here considered as the set of municipalities in its area of direct influence (ADI). Throughout the various stages of research, this matrix has been modified, with the addition, removal and alteration of indicators from each dimension, depending on a number of factors, which are: difficulty to obtain information; lack of information or inconsistency in obtained information; and the periodicity of updating information.

Later, during validation of the ISRI by methods set out in item 6, other indicators were altered for the following reasons: a) removed for not providing relevant comparative information regarding municipalities; b) with the employed standardisation parameters, quantification of the indicators for the municipalities displayed very low scores, not contributing to the comparison of ISRIs; c) names were changed to provide a better match with the measured object or to make it clearer; d) removed for not demonstrating a correlation with the dimension; e) removed for being a dichotomous variable; and e) removed due to the existence of another indicator representing a similar aspect or theme. It is essential to note that, when an indicator was removed for any of the above reasons, researchers would always discuss its importance in measuring the aspect and theme into which it was inserted, and wherever possible, would seek to replace it with another that measured the desired information, even if indirectly.

5.1 Parameterization and standardisation of indicators

Once the distinct nature of the variables and their units of measure prevent a direct and comparative evaluation, it is necessary to transform these measures into dimensionless values within a range. Seeking to correct and harmonize such differences, the normalization procedures therefore bring all the indicators and their results to a single dimensionless scale with previously established values for minimum and maximum references. This procedure therefore allows comparisons to be made and to consolidate the indicators in the indexes, eliminating problems and distortions related to differences in the units of analysis. According to Bollmann and Marques [11], the obvious advantage in using this method is the flexibility involved in choosing indicators that best represent the variations monitored, thereby overcoming the difficulty of relating variables or variables of different scales and natures.

The current literature suggests several normalization methods, including linear normalization, using the maximum amplitude for calculating normalized values as a reference [12]. By means of an equation, the observed value is converted into a proportion of the distance between the established minimum and maximum values, proportional transformation occurring in the original data, normalizing them between 0 (zero) and 1 (one). When the indicator demonstrates a descending pattern, i.e., the lower (or closer to 0) it is, the better the situation, then it is necessary to reverse it. When the domain of the source range is fixed, as in most indicators in percentages, the minimum and maximum references are equal to the respective absolute values, minimum and maximum indicator range, that is, 0% and 100%.

In the system of indicators used for evaluating the index of sustainable regional integration, parameters were initially suggested, for 35 indicators. Later, however, it was discovered that the suggested minimum and maximum values for some indicators were oversized, leading to a distortion of the results. As a form of correction, a new criterion was applied to parameterize these indicators, where the adopted criteria were consistent with the theoretical-methodological assumptions that guided the research, and that allowed comparison between the municipalities of different regions of the country and hydropower plants, and were as follows: (i) the existence of established goals in plans and programmes by national government or international organizations; (ii) the minimum and maximum values amongst the Brazilian municipalities of up to 150,000 inhabitants, and which also receive financial compensation for the use of water resources (resulting in a universe of 670 municipalities in 2014); (iii) the national average observed for the period; and (iv) expert opinions and information obtained from specific associations and organizations.

5.2 Consolidated matrix of indicators

The consolidated matrix comprises 79 indicators distributed in the following dimensions: quality of life (34); economic development (18); quality of public management (17); and environmental quality (10). Table 1 presents a summary of these figures.

The following are examples of some of the indicators: i) dimension: quality of life; theme: income; aspect: income level; indicator: average household income per capita ($/inhabitant); ii) dimension: economic development; theme: economy size; aspect: volume of production; indicator: value of the nominal GDP per capita ($)/inhabitant); iii) dimension: quality of public management; theme: finance efficiency; indicator of the country’s annual investment per capita ($/capita); iv) dimension: environmental quality; theme: soil and water; water quality index of the reservoir (WQI).

6 Validation and reliability of the index

6.1 Validation methods

For validation of the ISRI, three methods were adopted (Fig. 1). The Delphi method adopts a central position in the triangulation procedure to validate the index. Its basic characteristics are: anonymity and no physical contact between the participants; interaction between the obtained answers; consensus and unattained consensus (controlled feedback); and statistical results of the respondent panel.

Table 1: Summary of the matrix.

DIMENSION	THEME	QUANTITATIVE	
		ASPECT	INDICATOR
Quality of life (34)	Income	4	4
	Habitable living conditions	5	9
	Health	3	3
	Justice	1	4
	Public safety	2	5
	Preservation of cultural heritage	1	1
	Education	3	8
Economic development (18)	Economy size	2	2
	Economy development	2	2
	Economy modernization	6	14
Quality of public management (7)	Finance efficiency	3	4
	Governance	2	4
	Management modernization	4	9
Environmental quality (10)	Flora and fauna	2	5
	Water and soil	2	4
	Environmental education	1	1

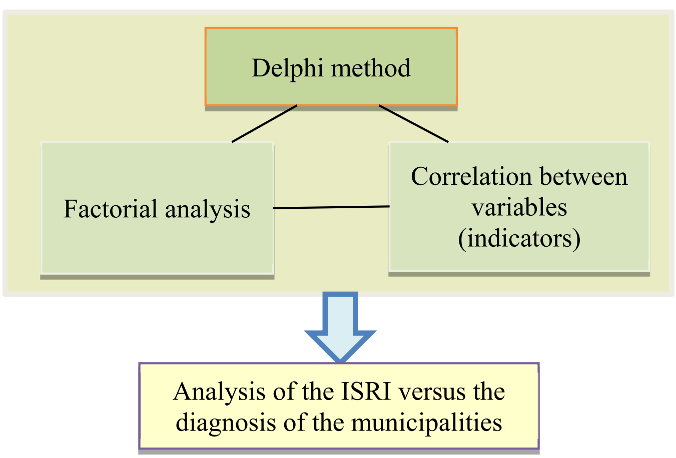

Figure 1: Validation methods.

Much of the success in implementing the Delphi method depends on the selection of participants, the preparation of questionnaires and analysis of the answers. Heterogeneity is an extremely important factor for enriching the results of the method used, since it aggregates different views on a subject. Therefore, three broad professional categories were chosen in order to select participating experts: Federal and State institutions (the power sector: environmental and development areas - 20); universities (20); and municipal public managers (40 municipalities in the ADIs of the analysed hydropower plants), totalling 80 participants. According to existing literature, this figure ensures good results for the method. A questionnaire with the list of indicators was used, involving multiple choice questions and open answers, allowing respondents to suggest new indicators.

The factor analysis method (FA) was employed based on the need to summarize the large amount of information generated by the matrix of indicators. Data reduction allows the use of a smaller number of concepts in relation to individual indicators. To construct the ISRI, the confirmatory factor analysis (CAF) was applied to test the representativeness of the variables chosen in relation to the concepts selected for the index [13, 14].

After using the FA, the final version of the indicator matrix, presented in item 5, was consolidated. It was then possible to confirm the four dimensions: quality of life, economic development (ED), quality of public management and environmental quality that make up the ISRI as an arithmetic mean. Another important issue was whether the dimensions of the ISRI were positively correlated, thus fulfilling one of the basic assumptions for creating an index: the existence of correlation between the variables.

Finally, it is possible to state that results suggest that the construction of the ISRI meets the requirements of FA, despite the quantitative limitation of the sample, below the minimum recommended by the literature. The indicators were also analysed in terms of significantly high correlations between individual variables. When high correlations were encountered, signifying that variables were homogenous, one of the indicators was removed. Lastly, the results for each municipality were compared with the socio-economic and environmental evaluations of the municipalities as performed in step 2 of the research, which also enabled us to confirm the validity of the ISRI. These results are presented in section 7.

6.2 Reliability analysis

The internal consistency (reliability) of the composite indicators was evaluated using the Chronbach's alpha reliability analysis. The Cronbach's alpha coefficient (α) is a statistical tool to estimate the reliability of a questionnaire applied in a poll or reliability of the results obtained from questionnaires [15]. The proposal to use this tool originated because of its ability to estimate the degree of reliability of responses arising from the applied questionnaire.

The measure of reliability of Cronbach's alpha should vary between 0 and 1, in which an α valued up to 0.70 is regarded as a basic standard of reliability. However, in several scenarios for research in social sciences, an α of 0.60 is considered acceptable, provided that the results obtained with this tool are interpreted carefully and consider the context of measurement.

In the present survey, information was collected from 40 municipalities in areas of influence around hydropower plants (UPs), the data of which made up the ISRI. In all evaluated items, the value of Cronbach's alpha and of the standardised α were 0.603 and 0.674, respectively. The values obtained were higher than the accepted standard, without having to remove any indicator. Thus, the scales used in the indicators that make up the IRSA were valid, and we may state that the ISRI is a reliable instrument for measuring regional integration.

7 Results

In order to qualify the results obtained for each index, a scale of analysis was formed with five classifications: very low, low, intermediate, high and very high. These classifications together with ratings are: Very Low (0 ≤ 0.30); Low (> 0.30 e ≤ 0.50); Intermediate (> 0.50 e ≤ 0.70); High (> 0.70 e ≤ 0.90); and Very High (> 0.90 e ≤ 1).

According to the results, the ISRIs of the hydropower plants ranged from 0.41 (Irapé HP) to 0.47 (Volta Grande HP), while the others fell between these two values. These results indicate a low degree of regional integration of the hydropower plants studied, all below 0.5 in the ISRI (fig. 2).

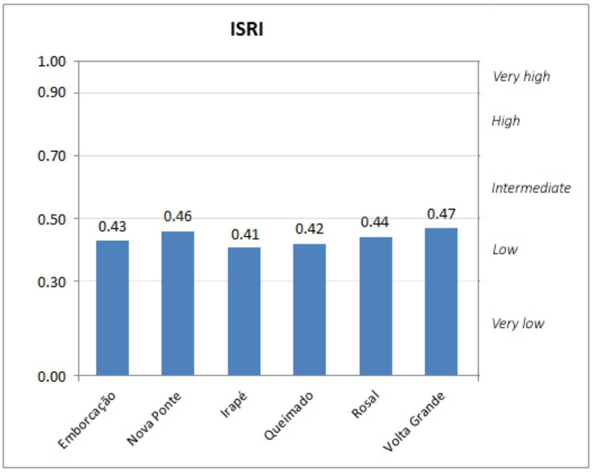

Figure 2: ISRI of the hydropower plants.

When the results of the dimensions are analysed (table 2), we observe that the quality of life dimension obtained the best results in the municipalities of every installation. The second best result was the quality of public management. The environmental quality and economic development dimensions obtained the poorest results in all hydropower plants, and effectively contributed to the low degree of regional integration of all hydropower plants studied.

Table 2: Dimensions of the ISRI for each HP.

Dimension (D) / Hydropower plant	Queimado	Nova Ponte	Irapé	Emborcação	Volta Grande	Rosal
Quality of life	0.64	0.67	0.58	0.68	0.69	0.78
Economic development	0.33	0.32	0.27	0.32	0.35	0.27
Quality of public management	0.52	0.54	0.47	0.44	0.53	0.48
Environmental quality	0.20	0.32	0.32	0.29	0.33	0.22

Quality of life was the only dimension in which all scores featured above 0.5, presenting intermediate values. Among the themes that make up the dimension, those which most excelled in all hydropower plants were health, habitable living conditions, income and public safety.

The most prominent themes of the quality of public management were management modernisation and governance. The theme finance efficiency presented the lowest results for this dimension, with the exception of Rosal and Volta Grande hydropower plants.

The economic development dimension obtained low scores for all hydropower plants, with rates ranging from 0.27 to 0.35. The theme that most contributed to the poor result was economic development.

The dimension of environmental quality presented the poorest results for the five hydropower plants, with the exception of Irapé. In all plants, themes with the lowest scores in the dimension were flora and fauna and environmental education, for which the latter obtained scores close to zero in five of the six hydropower plants. These results may be explained due to the stage of the plants. As these hydroelectric power plants have been operating for a long time, some environmental programmes have been concluded, and their results do not appear in the indicators.

Lastly, based on primary and secondary data collection from the beginning of the research, it may be stated that representations of the municipalities captured by the ISRIs are compatible with the diagnosis of the municipalities in the directly affected areas by the reservoirs of hydroelectric power plants. This proves that the index, a tool for monitoring and evaluating sustainable regional integration, is correctly measuring what needs to be appraised.

8 Final comments

Based on the research results, the ISRI has proved to be a strong instrument for strategic planning of the electricity sector, supporting the decision-making process, ensuring the efficiency of resource allocation and the effectiveness of management of hydroelectric power plants. Since the system of indicators in which the ISRI is rooted has a national basis, it may be applied across the country, thus allowing comparisons between hydropower plants in different states and regions.

The results have indicated that the studied cases demonstrate a low degree of regional integration, with significant differences between municipalities in the areas of direct influence of each power plant, particularly in relation to aspects associated to the quality of life, the dynamism of local economies, the current development levels of public management and for environmental conservation education programs.

The research has also revealed that strategic planning must go beyond mitigation and compensation of social demands, mostly practical or facile, indicating expansion of regional integration and the long-term sustainable development of these regions. Some guidelines must be strengthened, such as: improving the quality of life, diversifying local production bases, expanding economic competitiveness, developing public management and improving conservation and environmental education. Seeking to define an instance responsible for regional planning is a valuable alternative for the utilities in implementing these guidelines, freeing them from the pressures of fragmented, specific demands by municipalities and society, and enabling the construction of instruments involving the main actors of the region.

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