Energy Policy 36 (2008) 2320–2329

ENERGY POLICY

www.elsevier.com/locate/enpol

A probabilistic approach to evaluate the exploitation of the geographic situation of hydroelectric plants

Leonardo A.F.P. Sant'Anna[a], Annibal Parracho Sant'Anna[b,*]

[a]EPE, Brazil

[b]Escola de Engenharia – UFF, Rua Passo da Patria, 156 bl. D sl. 309 Niteroi, RJ 24210-240, Brazil

Received 13 March 2007; accepted 14 January 2008

Available online 4 March 2008

Abstract

A procedure to evaluate efficiency in the exploitation of the geographic situation of hydroelectric plants is developed here. It is based on the probabilistic composition of criteria. A comparison of 80 plants is carried out, with volume of water flow at the location and transmission rates paid measuring the potential of the geographic situation and installed power and assured energy measuring the employment of such potential. An analysis based on a new index of quality of approximation and a new measure of importance derived from Shapley value is used to select the criteria that enter a second stage of the efficiency evaluation.

Keywords: Electric energy; Probability; Rough sets

1. Introduction

The main goal of this study is to build a methodology for evaluating the efficiency of hydroelectric plants (HEPs) in energy generation. The main tool employed is the probabilistic composition of evaluations according to multiple criteria. The measures of preference according to each criterion are calculated in terms of probability of reaching an excellence frontier, as proposed by Sant'Anna and Sant'Anna (2001).

Four attributes are considered. The suitability of the geographic situation is evaluated by two independent criteria measuring the importance, respectively, of the water resources exploited and of the proximity to the markets supplied. On the other hand, the capacity of production of the plant is accessed by measuring two indicators, installed power and assured energy.

The comparison based on variables representing the physical production structure provides an orientation to the expansion of the electric energy generation system, either by expanding active HEP or by building new HEP. It also enables the evaluation of the effect on the economic viability of the enterprises of the form of measuring variables such as transmission tariff and assured energy.

The situation attributes are measured in an inverted form. The availability of water resources is measured by the inverted inflow, that is, in terms of time per volume of water. The proximity of the market is measured in terms of transmission tariff, that is, by the ratio of total cost charged for the transmission of energy from the plant to the consumer market to power transmitted. Thus, as desirable in an efficiency analysis, efficiency increases as the values of the variables measuring inputs decrease. The opposite occurs with the production attributes. The higher the values of installed power or assured energy, the higher the output generated and the efficiency in the exploitation of the available resources.

A second stage is based on the application of rough sets theory (RST), of Pawlak (1982, 1991), to investigate the importance of each variable. To measure such importance, a probabilistic variant to the index of quality of approximation of Pawlak is employed. This measure is based on the computation of probabilities of concordance between classifications according to different sets of attributes.

*Corresponding author. Tel.: +55 21 26295436; fax: +55 21 26295435.
E-mail addresses: leonardo.santanna@epe.gov.br (L.A.F.P. Sant'Anna), tppaps@vm.uff.br (A.P. Sant'Anna).

0301-4215/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2008.01.023

Thus, instead of disregarding the cases of indiscernibility according to the decision variable, this new measure considers all alternatives of indiscernibility or dominance. Following Greco et al. (1998, 2001), the evaluation of the importance of each attribute and of the interaction between attributes employs the computation of a variant to Shapley values (Shapley, 1953).

In the following section, the probabilistic approach is discussed. Section 3 presents the data of 80 HEPs operating in the Brazilian territory and preliminary results of their probabilistic comparison. In Section 4 the new indices of the quality of approximation are presented. In Section 5 they are applied to the selection of criteria to compare the HEP. Final comments are presented in Section 6.

2. Probabilistic evaluation

To compare production units in terms of productivity, currently the most employed approach is that of data envelopment analysis (DEA). DEA, proposed by Charnes et al. (1978) on the basis of the concept of efficiency of Farrell (1957), compares the production units in terms of efficiency in extracting the maximum output aggregate from the minimum input aggregate, measuring the efficiency by the distance to the frontier of best performances. In Sant'Anna and Sant'Anna (2001), an approach with this same characteristic is developed, replacing absolute distances by probabilities of reaching the frontier. Taking into account the possibility of measurement errors, this approach treats the observed amounts of inputs and outputs as estimates for location parameters of random distributions. Then, assuming the classical hypothesis of independent disturbances, each vector of observations of a variable is transformed into a vector of probabilities of reaching the frontier. The calculus of the probability of reaching the frontier involves measuring distances between all the production units, not only distances of each one to the frontier, what makes the new procedure robust against the influence of heavy-tailed random disturbances.

The choice of the form of the disturbances distribution, of the upper or the lower frontier of reference and of the algorithm of combination of evaluations according to different criteria will affect the final evaluation scores and must take into account the kind of variables measured and the goals aimed by the analyst. For instance, if assuring viability is more important than maximizing profit, it is advisable to compose probabilities of not reaching the lower frontier, instead of probabilities of reaching the upper frontier, as would be the case if the DEA approach was strictly followed.

Centering attention in the lower boundaries leads to endow the disturbances in the present model with a Pareto distribution. The form of this distribution, bounded from below and invariant under truncation from below, is well suited to modeling variables concentrated near a lower frontier with some possible exceptions concentrated far away. In the computation of criteria to be minimized, the observed values are more probably close to their lower bounds and more susceptible to positive disturbances.

The properties of the Pareto distribution has an advantage of the transformation into probabilities of reaching the frontier, which consists of increasing the distances between the evaluations of the production units with observed values closer to the frontier of interest and reducing the distances between those at the other end. This property is valid in general because, except for the units near the frontier, the calculation of the probability of reaching this frontier involves a product with many small factors. This is an advantage, since observations closer to the frontier of interest are generally measured more carefully and consequently are more reliable.

After evaluating the preferences according to each separate criterion, we must translate such sets of separate evaluations into global scores. Measuring the preferences in terms of the probability of choice naturally induces forms of composing preferences. One such form consists of considering the probabilities of choice according to each criterion as conditional probabilities. The global preference measures are then computed by adding the products of each such conditional probability by a probability of choice of the respective criterion. In such an approach, the determination of the weights may become a difficult matter, whether or not, as in Yager (1988), the weights are associated with the observed ranks.

A different approach is taken here, deriving the global measure from the joint probability. Assuming independent disturbances, this joint probability is obtained simply by multiplying the probabilities of choice according to the different criteria. To keep the scale unchanged, the geometric mean substitutes for the product in the final scores. No weights are needed for such computation, which, furthermore, brings the advantage of penalizing the options with contradictory preference evaluations according to different criteria. A posterior analysis of the influence of each criterion in the final result may suggest differentiated weights to be used in future evaluations within the same context.

Formally, the final score for the ith unit under evaluation is given by $\Pi_j\,(1-p_{ij})^{1/n}$, where n is the number of criteria, the index j runs along the n criteria and, for every i and j, p_{ij} denotes the probability that such ith unit reaches the lower frontier of the set of observed preference values according to the jth criterion. If, as in the present application, the evaluation according to the jth criterion is based on observed values $(x_{1j}, \ldots, x_{mj})$ of some attribute along m units under evaluation, the above referred hypotheses of independence and Pareto distributions lead to determine p_{ij} by another product, $\Pi_i\; P[X_{ij} \leqslant X_{kj}]$. This is the product of the probabilities that random variables with a Pareto distribution centered on x_{ij} assume values smaller or equal to the values taken by other Pareto distributions centered on x_{kj}, for k varying along the $m-1$ indices of the other units under evaluation.