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Sustainable model of hydro power development—Drina river case study

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ABSTRACT

The imperative of sustainability demands that every decision-making process in building and designing a hydro power system, analyzes the environmental, political, historical, cultural and other social impacts, besides the normal technical and economical concerns. Presently, most design processes incorporate impacts as non-technical criteria, through environmental and social impact assessment studies. These latter studies are mainly descriptive texts, conducted after all the technical optimizations of the design were completed and not always included within the optimization calculation. The main goal of this paper is to present the possibility for incorporating all the non-technical criteria as fuzzy mathematical functions in the optimization and decision-making process, right from the very first planning step, simultaneously and equally with other relevant, numerically presented, technical criteria. The idea was developed and tested on a practical example: the hydropower utilization of the Drina River between Foca and Gorazde, two towns in Bosnia and Herzegovina, a region with extreme environmental, political, historical, cultural and other social conflict. In spite of the restrictive environment, this part of the river has very high hydro potential, which is a renewable resource. Consideration of both the technical and non-technical criteria in the fuzzy optimized model, as presented in the paper, leads to novel project solutions. The final design consisting of three almost uniform dams plants: Sadba 362, Ustikolina 373 and Paunci 384, was proven to be sustainable for development as well as very similar to experts' reasoning. The chosen optimal solution for hydro power development is a cascade consisting of three hydro power plants, instead of a single high dam, which might affect the environment and strongly disturb local communities.

Contents

1. Introduction

Hydropower is predicted to take greater part of electricity generated from renewable energy [1] in the function of sustainability [2,3]. Different authors have been considering the conflicts between the need to use renewable hydro resources, to build

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hydro power plants and the need to preserve the environment [2,4-6]. The engineers and other experts have been involved in many attempts to develop different mathematical models for optimal hydro power development [7].

The main goal of this paper was to establish a fuzzy model for the evaluation and selection of optimal hydropower facility on a given river reach. Fuzzy logic seems to offer a way to improve the existing operating practices [8]. The fuzzy model will be developed through the Drina river case study. The task is to include not only the usual techno-economic performance indicators such as investment quotient, benefit/cost (B/C) ratio, peak hydro power plant (HPP) capacity, etc., but also those which characterize environmental and impacts on local communities. Impacts on local communities address the historical, political, cultural and other social issues [9,10]. Construction of dams and hydropower plants contribute to increasing employment at the local level and raise the standards of society at local and global levels. In this particular case, the construction of one larger dam causes an uneven distribution of the benefits and negative impacts to local communities. Benefits of employment then belong to the municipality where is location of the dam, but the problems of flooding and resettlement remain in the reservoir zone. The construction of smaller dams allows more uniform distribution of benefits, less negative impacts and divisibility of facilities at the local level. Environmental impact and impact on local communities will be incorporated and presented in this paper as fuzzy input variables and membership function.

Derangement of environment and local communities in general, caused by construction of dams and occupation of space during construction and utilization of hydro power generation facilities, cannot be quantified and covered by techno economic analyses only [11]. Water management and hydro power development is a demanding decision-making environment where optimal planning presupposes a synthesis of heterogeneous information and different input variables [12-15]. When designing power generation facilities, it is practicable to calculate the cost of expropriation, relocation of roads, churches, cemeteries, households, public facilities, but that price is never an adequate compensation for the environmental loss incurred and disturbances in the local community. Such changes or losses are more naturally expressed and described in linguistic terms, the quantitative values are needed as well [16-18]. The fuzzy systems theory represents a logical, i.e. suitable framework for modeling these variables [19-23].

The fuzzy model has been established and presented in this paper. It is tested on the basis of possible technical solutions on the Drina River section between the towns of Foca and Gorazde in Bosnia and Herzegovina, on the borderline between several national entities. This locality is particularly interesting in terms of impact of environmental and local community factors on selection of an optimal technical solution [9,24], since the towns of Foca and Gorazde are located on the opposite sides of the borderline dividing different national entities. This borderline is the outcome of the civil war (1991–1995) in Bosnia and Herzegovina, and represents the border between the Republic of Srpska and the Muslim-Croatian Federation.

The existing methods for the evaluation and selection of an optimal hydropower system are mainly based on standard techno economic analyses [25,26]. These methods can hardly address the issues such as quantification of environmental and impact on local community [27,28]. The reservoir's influence on modification of micro-climate, detachment of diluvia cover resulting from oscillations of the reservoir water level, impact on natural resources (e.g. the Pancic spruce), possible flooding of mosques or old orthodox cemeteries, relocation of inhabitants, agricultural land loss, new entities border, etc. are not included in calculation of optimal technical solution in the present practice [29-32]. The main contribution of this paper is a proposal for decision makers and the offered model for incorporation of environmental and local community parameters into the very first designing step.

The multi-criteria selection models [10,33] take one step ahead in the optimization model research, comparing with classical techno economic analyses. They require numerical quantifiers for each of the input variables, whereas the corresponding weight coefficients represent an expert appraisal [34].

Two steps ahead are taken by a model applying the fuzzy logic [35,36]. A fuzzy evaluation model enables a linguistic description of specified impacts and their presence in the designing and decision-making process [37]. Numerical evaluation of each of the possible hydropower solution variants is obtained subsequently as the output by an appropriate defuzzification procedure [38-40].

2. Possible concept of hydro power plants solutions

The subject locality is situated in the Drina River valley, between the towns of Foca, 18°47′ East longitude and 43°30′ North latitude and Gorazde, 18°59′ East longitude and 43°40′ North latitude. In this particular river reach, it is possible to construct seven hydropower plants: HPP Gorazde 383, HPP Gorazde 375, HPP Gorazde 362, HPP Gorazde 352, HPP Sadba 362, HPP Ustikolina 373 and HPP Paunci 384. The above numbers denote the backwater level in the corresponding reservoir (e.g. 375 m for the Gorazde 375 option). Given the geographic constraints, it is not possible to construct all seven hydropower plants simultaneously. Instead one of the following six alternative combinations is possible:

A—HPP Gorazde 375: a single concrete dam at the Gorazde II profile, with a hydropower plant near to the dam (i.e. located immediately downstream of the dam) and the normal backwater level of 375.00 m.

Table 1
Techno-economic parameters of hydropower plants in the section Foca–Gorazde, wherein Q_i is installed discharge, H is head, N_i is installed capacity, E_{year} is total annual output, E_{peak} is the annual produced energy during increased consumer consumption, B/C is benefit/cost ratio with Investment quotient and Specific investments in the last two rows.

	Gorazde 383	Gorazde 375	Gorazde 362	Gorazde 352	Sadba 362	Ustikolina 373	Paunci 384	Drina I	Drina II	Drina III	Kozluk
Q_i (m^3/s)	500	500	450	450	450	450	450	800	800	800	800
H (m)	35.8	27.8	15.0	5.0	9.5	10.0	10.6	13.3	13.3	13.3	13.3
N_i (MW)	166.5	130.8	61.5	20.7	43.2	43.2	43.2	93.4	93.4	93.4	93.4
E_{year} (GW h/y)	501.7	407.2	223.8	73.2	140.4	147.4	156.3	396.5	396.5	396.5	396.5
E_{peak} (GW h/y)	308.3	251.1	126.3	41.3	79.2	83.2	88.2	213.66	213.66	213.66	213.66
Investments (mil. $)	302.76	246.31	105.20	78.98	79.54	77.83	85.53	237.85	274.83	292.25	216.20
B/C	1.57	1.53	1.73	0.74	1.44	1.50	1.45	1.59	1.40	1.36	1.73
Inv. quotient ($/kW h)	0.603	0.605	0.470	1.084	0.566	0.528	0.547	0.545	0.600	0.693	0.737
Spec. inv. ($/kW)	1818	1881	1711	3842	1841	1801	1980	2546	2942	3129	2315