Techno economic, environmentally and socially optimal energy efficient SHPP construction

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ABSTRACT

Water resources engineering is facing with the complex problem when the construction of hydro power plants and its techno economic evaluations is charged with environmental and social problems. This paper is dealing with the selection of optimal small hydro power plants construction in the catchment area of Babinopoljska river, in Prokletije region in Montenegro. Total available potential, technically available and technically usable potential on the fifteen small hydro power plants profile and for catchments area in total was calculated, as well as average and installed discharge, net head, installed power and energy production for each constructed power plant. Cost benefit analyses for fifteen possible small hydro power plants is conducted, together with belonging environmental and social parameters. Delphi method was applied for the results quantification of Environmental and Social impact assessment study of the project. Optimal energy efficient construction solution was developed by mathematical multi criteria operational research method. Numerical introduction of environmental and social parameters in to techno economic analyses is novelty of this research. The result is the solution of three small hydro power plants, which belong to the concept of sustainable development of the region.

Keywords
Optimal construction, region, techno economic analyses, environment, social community, energy efficiency.

1. INTRODUCTION

The construction of small hydro power plants contributes to energy development of the country, and rural areas economy at the same time. In the course of developing an optimal small hydro system and designing an optimal concept of hydro potential exploitation of the river, the first question is what are the maximum techno-economic possible effects of water resources exploitation and what is the optimal and sustainable water resources management decision for the profiles analyzed? Which parameters does it depend on? The problem in water resources management and planning was solved with different methodological approach in previous practice (Just & Netanyahu, 1998), (Babel, Gupta & Nayak, 2005), (Opricovic & Tzeng, 2007).

Consensus is popular as a democratic form of decision making, although it takes time and uses resources before a decision is made (Opricovic, 2009). Multi-attributive optimization is considered as the process of determining the best feasible solution, according to established criteria which represent different effects (Opricovic & Tzeng, 2007).

The multi-attributive decision making process (Mladenović-Ranisavljevic et al., 2012) consists of generating alternatives, establishing criteria, evaluation of alternatives, assessment of criteria weights, and application of adequate ranking method (Vincke, 1992). The technical alternatives are evaluated according to different economical, technical and non technical criteria, depending on the objectives of the problem (Hossein J. S., 2012). The evaluation of the technical alternatives should be performed according to each criterion from the set of defined criteria.

A comparative analysis of the methods for multi-attributive decision making process is presented in several publications (Escobar & Moreno-Jimenez, 2002), (Triantaphyllou, 2000), (Obradović et al., 2012). This paper is presenting the methodology for selectin optimal concept of small hydro development, by using artificial intelligence, adapted to Prokletije region case study.

Mathematical methods of operational research are used for quantification of environmental, social, political and cultural parameters and its incorporation in the concept of sustainable small hydro development optimization (Stevovic et al., 2010), (Stevovic et al., 2011). System of small hydro power plants optimization for Prokletije streams catchments area is case study where the developed methodology is tested and proved.

There are four streams, with few tributaries, presenting the Prokletije streams catchments area in the area under the same name - Prokletije Mountains in Montenegro. The head is imposing (between 32m and 225m) and the discharge (Milosevic et al., 2013) is not too variable and not too small (between $0.3m^3/s$ and $3m^3/s$). Fifteen possible small hydro power plants have been designed, grouped in two main strategic concepts (above the hills and along the road) and eight possible technical alternatives.

The context of global warming decreasing defines the energy efficiency as an important goal in the decision making (Mihajlović et al., 2010) and designing process. Energy efficiency increasing is possible to be achieved in the consumption area, energy transport system and in the plants as producers. This problem is not sufficiently analyzed in the field of concept definition of hydro power exploitation of the river (Barelli et al., 2013).

In previous practice, Technical and economical criteria (Harley, Shogreen, & White, 2002) were considered as input variables in mathematical models as the only relevant in the calculation optimization process.

Environmental impact assessment is analyzed in the separated studies (Perace, Perace & Palmer, 2002), after technical solutions are developed. Consequently, the proposed optimal techno-economical solution did not get the agreement for construction, because the Environmental and Social impact assessment study had not been successful at a public hearing (Radosavljević S. & Radosavljević M., 2011).

In previous practice, a lot of money was spent for the design of the dam and hydro power plants, with maximum achieved energy efficiency of the specific profiles, but it happened that this efficiency, calculated in theory, could never been realized.

The reason was that the environmental and other parameters, difficult for mathematical calculation, but important for the final decision, were not incorporated properly in optimization decision making process (Shim at al., 2002). Decision making is a process which starts with an idea and ends with the actual implementation of the decision (Opricovic & Tzeng, 2004).

Environmental, social, political, cultural impacts and their parameters were never quantified and included in the decision making process, simultaneously and equally with technical and economical parameters, in selection of optimal small hydro concept development. Engineers usually calculate the energy production, while economists calculate the investment and cost of the construction, but they write about the environment only in a descriptive way.

2. RESEARCH METHODOLOGY

The possible hydro potential of the river profiles could be increased, by incorporating all technical and non technical parameters, but simultaneously and at the early beginning in the decision making process.

The maximum energy efficient profile, which is usually impossible to be built, is eliminated and the compromise solution is achieved to the concept of sustainable and optimal small hydro development, which is realistic one. Therefore, small hydro concept development and maximum possible energy efficiency of the profiles, defined and increased in this way, is always environmentally friendly solution, ready for realization, with harmoniously solved conflict of interest of different users of the water.

The methodological approach for achieving the maximum possible realistic energy efficiency of the hydro profiles, in the process of environmentally friendly optimal concept selection of small hydro development, is defined through the next steps:

- design of alternative technical solutions of small hydro development
- technical criteria definition
- economical criteria definition

- financial limits definition
- environmental impact assessment study
- social impact assessment study
- definition of other relevant impacts
- quantification of environmental, social and other relevant impacts
- operation research method application
- selection of optimal small hydro power plants concept

It is possible to apply different algorithm and various kinds of software supports, such as experts' choice, Promethee, ELECTRE method, multi-criteria based interactive ranging, while it is even possible to make use of simplex method, with adequate simplifications made by the expert.

ELECTRE method was applied as possible multi-attributive operational research model. Delphi method is used for quantification of environmental and social impacts, which are results of Environmental and Social impact assessment study of the project. All necessary calculations and technical, economical, environmental and social analyses have been done for each of fifteen small hydropower plants separately and for eight possible systems of hydro potential exploitation of the river.

2.1 ELECTRE method

ELECTRE method is a multi-attributive assignment method (Rogers, Bruen & Maystre, 2000). It allows the assignment of alternatives to some predefined order criteria (Arondel & Giradin, 2000). ELECTRE II is applied in this paper and it is a variant of ELECTRE family that produces a ranking of alternatives rather than indicates the most preferred ones (Srinivasa Raju, Duckstein & Arondel, 2000). It allows outranking of alternatives that are preferred with respect to most of the criteria, and that are not drastically outperformed with respect to any other criteria (Raju & Duckstein, 2004). ELECTRE method is applied using developed software (Mousseau, Slowinski & Zielniewicz, 1999).

Data given in the Table 2 were used in the following steps: normalizing the decision matrix, weighting the normalized decision matrix, determining the concordance and discordance sets, construction of the concordance and discordance matrices, determining the concordance and discordance dominance matrices, determining the aggregate dominance matrix and elimination of the less favourable alternatives.

If the value of element e_{ks} of aggregate dominance matrix is 1, then this means that alternative a_k is preferred to alternative a_s by using both the concordance and discordance criteria. On the other hand, this does not mean that some other alternative is not preferred to a_k. Therefore, a_k would not be dominated only if:

- $e_{ks} = 1$ for at least one $s;\ s = 1, 2,\ldots,m;\ s \neq k$ (1)

- $e_{ks} = 0$ for every $i;\ i = 1, 2,\ldots,m;\ i \neq k;\ i \neq s$ (2)

The multi-criteria based decision-taking is one of the modalities for selecting a technical optimum, which offers possibilities for simultaneous incorporation of all the technical and environmental, social and other linguistically defined criteria.

It requires exact numerical quantifiers for each defined quality criterion and for input variables, while the respective weight coefficients represent the objective assessment of the expert who performs designing of the decision-taking support system.

If within the expert community the question is posed of a possible subjective approach of the expert, i.e. of the expert's defining the weight parameters and numerical quantifiers, the answer lies in the theoretical bases and the essence of the Delphi method (Stevovic, 2008).

2.2 Quantification method for environmental and social aspects

Environmental and social problems and decisions, in the context of technical alternative optimum selection, are often complex and multifaceted and involve many different stakeholders with different priorities or objectives (Eun-Sung and Kil Seong, 2009). Selection of the optimum small hydro technical solution in designing is a very complex problem, particularly if the standard task of defining the most convenient technical-economic solution is broadened by the request to preserve environment (Gupta, Kewalramani & Ralegaonkar, 2003) quality in the function of sustainable development. The optimum technical solution for all civil structures should have the maximum possible technical performances and economic-financial characteristics on one hand and it should fit in a harmonious manner into the natural and social-political environment on the other hand. Delphi method (Stevovic, S., 2008) enables quantification and numerical presentation of all relevant input variables, which in addition to techno-economic variables include the ones that represent historical and political factors and environmental impacts. The input variables defined in this way can be applied in the latest models and methodologies for defining the optimum technical solution of small hydro development. Delphi method consists of next important phases:

- Definition of the problem that requires assessment
- Forming a team of experts (10-15 members) and specialists in the subject field
- Determination of the stop-criterion for evaluation
- In the first round of questionnaires the forecast and arguments are required from all the experts
- Evaluation will be obtained from a growing array
- The median and upper and lower quartile calculation
- In the second round of questionnaires, all previously received values are sent to experts and they are required to examine and possibly correct their forecasts

- In the final round of questionnaires (3-4 sets) the expert are asked to give their final answer.

3. RESULT AND DISCUSSION

The Prokletije River flows below Bogicevica Mountain at an altitude of 2207masl and it is tributary of the Lim River. The length of the Babinopoljska River is 17km, its catchments area is 88.40 km^2, and the total head is 900 m. There is a local macadam road along and parallel to the Babinopoljska River, which connects the upper basin and the forest area of Bogicevica Mountain (Shim et al., 2002).

3.1 Available hydro potential in the region

In order to define the total technically usable potential, the available energy potential is reduced by requirements of the priority water users (environmental minimum and other requirements), acceptable technical solutions, common characteristics of the equipment, the dimensions of the equipment, intakes and derivations, possible or the most common regime work (base and variable production) and losses. Thus defined energy potential is the closest, in terms of value and structure, to the possible production of energy from water potential on the particular profile.

In order to transfer from the category of water potential to the category of technically available potential, it is necessary to take into account possible technical solutions and to define the available potential of the profile, the actual degree of utilization of equipment, without specifying the volume of possible work, but assuming full use of water.

Category of Technically usable potential, in addition to the above, takes into account the specific technical solutions with the actual dimensions of structures and equipment and the availability of water, after water is delivered to the priority user of water and space. Particular values for each profile considered, are shown in the Table 1. All three categories of potential and their sum are related to the catchments area as a whole.

Table 1. *Categories of the potential for SHPPs profiles and for catchments area in total*

SHPPs profile	$Q_{aver}(m^3/s)$	$H_{net}(m)$	W_a	W_{ta}	W_{tu}
Bogicevica	0,392	132,5	5,3	4,6	2,0
Babino Polje	1,012	173,5	16,8	14,5	6,7
Jara	1,922	207,5	37,2	32,2	18,3
Meteh 1	2,380	115,0	26,4	22,9	12,6
Meteh 2	3,000	26,0	8,2	7,1	3,6
Total			93,9	81,3	43,2

Source: Authors' calculations (Stevovic at al., 2009)

W_a is total available potential on the SHPPs profile, W_{ta} is technically available, while W_{tu} is technically usable potential in GWh/year. The total available potential of the subject sections is 93.9 GWh, while technically available potential is 81.3 GWh. If this is compared with the potential which flows from catchments area (122.9 GWh), there is a significant difference (decrease) of about 25% in the level of available resources. This difference is explained by the potential from the upper parts of the river that is not covered by technical solutions, and by potential of sub-catchments area not considered hereby

Taking into account the specific technical solutions with actual environmental and social constraints, the technically usable potential in this case is equal to possible energy production. The total amount of this potential is 43.2 GWh. The difference between available and useful technical potential is almost 50%. It comes from the head losses in the derivations, overflow waters, guaranteed environmental flows that must be provided downstream of the SHPP and technical minimum of aggregates.

Calculations of possible energy production, according to the actual technical parameters and requirements with respect to environmental constraints, indicate possibility of taking advantage of 43.2 GWh or approximately 45% of available energy potential.

Further economic analyses showed that, from actual point of view and foreseeable level of energy prices, equipment and civil work, it is economically feasible to use 40GWh.

3.2 Possible alternative solutions

Prefeasibility study for 15 possible SHPP is done. There are 8 possible alternatives, i.e. systems composed by different SHPP profiles in Babinopoljska catchment area.

Alternative A contains 3 SHPP, with dams and accumulations on the profiles Meteh, Babino Polje and Bogicevica.

Alternative B has SHPP Meteh with dam and accumulation, SHPP Jara, SHPP Babino Polje and SHPP Bogicevica.

Alternative C is using the potential by construction of SHPP Meteh, Jara, Babino Polje and Bogicevica, all without any accumulation.

Alternative D implies construction of SHPP on the profiles Meteh, Jara max, Babino Polje max and Bogićevica max.

Alternative E is a system of SHPP on the profiles Meteh 1, Meteh 2, Jara max, Babino Polje max and Bogicevica max.

Alternative F is presented with SHPP Meteh p, Jara max p, Babino Polje max p and Bogićevica max p.

Alternative G has SHPP Meteh 1 p, Meteh 2 p, Jara max p, Babino Polje max p and Bogicevica max p. Alternative H is a system of SHPP Meteh 1 p, Jara and Babino Polje max, for hydro potential exploitation of the Babinopoljska river and catchment area, see Table 2.

Table 2. *The main technical parameters of 15 particular small hydro power plants*

HPP	Q_{aver}	Q_{inst}	H_{net}	P_{inst}	E_{year}
	m^3/s	m^3/s	m	MW	GWh
Meteh	2,38	4,76	144,5	5,88	15,873
Meteh p	2,38	4,76	144	5,86	15,640
Meteh 1	2,38	4,76	115	4,68	12,634
Meteh 1 p	2,38	4,76	115,5	4,76	12,634
Meteh 2	3,00	6,00	26	1,28	3,642
Meteh 2 p	3,00	6,00	26	1,28	3,642
Jara	1,36 0,562	3,85	198,5	6,53	17,575
Jara max	1,36 0,562	3,85	207,5	6,82	18,279
Jara max p	1,36 0,562	3,85	208	6,84	18,313
Babino Polje	0,749 0,263	2,03	141	2,36	5,509
Babino Polje max	0,749 0,263	2,03	173,5	2,92	6,655
Babino Polje max p	0,749 0,263	2,03	175,5	2,96	6,712
Bogicevica	0,392	0,80	96	0,61	1,461
Bogicevica max	0,392	0,80	128	0,83	1,918
Bogicevica max p	0,392	0,80	132	0,86	1,968

Source: Authors' calculations (Stevovic at al., 2009)

Alternatives A and B are analysed in the Study of Lim and upper tributaries energy use, but these alternatives are here rejected, due to water management reason and new environmental quality request (Russell & Campbell, 1996). The project adopted the criterion that any flooding of agricultural and other areas in the catchments area is unacceptable. In the Prokletije region there are small private holdings, which represent the only fertile land, where the local population is engaged in agriculture.

In addition, Prokletije catchment area is characterized by streams with extremely high erosion and many dragged sediments, which could rapidly decrease useful volume of any reservoir. There is no water management justification for the construction of the dam and reservoir (Srinivasa Raju, Duckstein and Arondel, 2000) in the present case.

Alternatives C, D, E, F, G and H are considered for further elaboration on final selection of the hydro potential optimal use of the Babinopoljska

River. Necessary technical solutions, drawings, calculations and techno - economic analysis are prepared and calculated for all of these alternatives and for all 15 particular SHPPs that are included. The main results are presented in the Table 2.

The index p means that the derivation is along the road. The index max means that exploitation of possible head is the maximal one. If there is no the index, the derivation is along the top of the hill.

3.3 Criteria for sustainable decision making process

The issue of selecting optimal solutions for hydro potential exploitation of the river is not only technical and economical question. Therefore, the optimal solution selection had to be processed after standard techno - economic analysis also by implementing a contemporary mathematical model of artificial intelligence, for creating the optimal variant leads over multi-criteria evaluation.

For decision makers who need to evaluate a number of considered techno – economically analysed alternatives, relevant criteria could be: the economic cost €c/kWh (25 years, discount rate 8%), total investment (million €), impacts on the environment and social impact.

The following table 3 shows the matrix with specific values of the criteria of all alternatives for hydro potential exploitation of the Babinopoljska catchments area.

Value of economic cost and total investment as criteria were obtained from the techno-economic analysis, while other criteria are calculated by the Delphi method and normalized in the range from 0 to 1. Social impact criteria is going to be maximized, while the economic cost criteria, the total investment and the impact on the environment are to be minimized.

Table 3. *Matrix with specific criteria values for all alternatives*

Criteria / Alternative	Economic cost €c/kWh	Total Investment Mill €	Environm. impact	Social impact
C	6,04	18,913	0,2	0,95
D	6,04	20,053	0,2	0,95
E	6,23	20,623	0,2	0,95
F	5,98	19,735	0,15	0,80
G	6,19	20,526	0,15	0,80
H	5,20	14,620	0,16	0,90
Limes criteria	min	min	min	max

Source: Authors' calculations (Stevovic at al., 2009)

3.4 Multi-attributive selection of optimal SHPP concept

Multi-criteria ranking of the alternatives for hydro potential exploitation of the Babinopoljska River is done by ELECTRE method for four different combination of importance, i.e. Weight criteria.

If all the criteria are considered with the same importance, the weight of all the criteria is 1, then the Electra algorithm will provide the result that alternative C is better than D and E, D is better than E, E is dominated over none alternative, F is better than C, D, E and G, G is better than E, and H is better than C, D, E, F and G. The final conclusion is that alternative H is the best alternative from technical, economical, social and environmental point of view.

If the first two criteria have a weight of 1, and the other two are tentatively speaking not important, then this mathematical experiment provides the following results: alternative C is better than D and G, D is better than E and G, E does not outrank any alternative, F is better than C, D, E and G, G is better than E, H is better than C, D, E, F and G. In this combination of the criteria weight, alternative A is still the best action.

For the weight 2 of the first two criteria and the weight 1.5 of environmental and social criteria, alternative H is the best solution.

If weight of the first economic cost criteria is 2 ,total investment criteria is 1.5, and environmental and social impact of the alternatives criteria is 1, the alternative H outranks all activities.

4. CONCLUSION

The main goal of this paper was to present the methodology for applying artificial intelligence method in selecting environmentally friendly optimal concept of small hydro development. The conclusion is that small hydro concept, defined and selected by this methodology achieves the maximum possible realistic energy efficiency of the hydro profiles and it provides sustainable water resources management of the region.

The adopted optimal compromise solution was the system composed of three small hydro power plants: SHPP Babino Polje max, SHPP Jara and SHPP Meteh 1 p. The net head is 173.5m, 198.5m and 115.5m, the installed capacity is 2.03m^3/s, 3.85 m^3/s and 4.76 m^3/s, the installed power is 2.92 MW, 6.53 MW and 4.76 MW, total annual production is 6.655 GWh/year, 17.575 GWh/year and 12.634 GWh/year, respectively. Total investment is approximately $15x10^6$€.

Multi-criteria analysis performed by algorithm of Electre method, for different weight of adopted criteria, shows that the optimal alternative for hydro potential exploitation of the Babinopoljska catchments area is the alternative H with SHPP Babino Polje max, SHPP Jara and SHPP Meteh 1

p. This system of SHPPs presents the best solution from technical, economical, social and environmental point of view.

The algorithm of Electre operational research method applied as presented in this paper, provides engineers and designers of SHPP with the mathematical model for selecting optimal concept of hydro potential exploitation of the rivers. It enables decision makers to faster recognize the optimal environmentally friendly solution and prevent possible waste of time and money.

The analyses of sensitivity of the results on changing weight of the different criteria, shows the stability of the ELECTRE method. Alternative H is the best compromise solution, i.e. optimal solution for hydro potential exploitation of the Babinopoljska River, for all different weights of the defined criteria.

The energy efficiency is increased by application of the methodology presented in this paper, because it is closer to the realistic value of the technically usable potential.

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