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SUSTAINABLE TRANSBOUNDARY HYDROPOWER SYSTEM ON DRINA RIVER AS SYNERGY OF WATER -FOOD-ENERGY-CLIMATE NEXUS

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Abstract: The Drina River has always been a source of drinking water and irrigation for food production, with all its tributaries and branching catchment area across the territories of Bosnia and Herzegovina, Montenegro and Serbia. It has connected peoples and cultures for centuries with its bridges. At the same time, with its great head, the Drina has always represented a significant hydropower potential. Throughout history, numerous watermills have been built on it. Currently, there are several constructed hydro-technical facilities on the Drina and in its catchment area. Among them, the most important are dams, with roads over them, associated hydroelectric power plants and belonging structures for flood control, water intakes for drinking water or irrigation. Due to multiple possible, almost always conflicting purposes, as well as several states, entities and other stakeholders, the management of Drina River water resources from the angle of the water-food-energy and climate nexus is an extremely complex problem. In addition to the impact on hydropower, agriculture, forestry, transport, irrigation and drainage, tourism and socio-cultural events, the construction of such strategic structures has also an impact on the climate of the Western Balkans. The issue of optimization within the nexus of the water-food-energy-climate requires holistic research to find synergistic solutions. These solutions are certainly a compromise. But inevitably, they must meet the criteria of sustainable development and the requirements of reducing global warming, according to the set conditions of the adopted European Green Plan for the Western Balkans. This paper proposes a methodology for finding optimal/compromise hydropower solutions, which synergistically include all parameters of influence. Holistic research of sustainable hydropower systems on the Drina River, from the angle of the water-food-energy-climate nexus, is presented. Particularly detailed analyses of the course of the river between the towns of Foča and Goražde, as well as the downstream part between Zvornik and mouth, known as the Lower Drina. In these sections, the most pronounced conflict is whether water will be used for drinking and/or food production and/or energy production and what impact possible solutions have on the climate of the region.

Keywords: the Drina, water, food, energy, climate, Foča-Goražde, Lower Drina.

1. INTRODUCTION

The water-food-energy-climate nexus is one of the most important scientific and engineering challenges in the world, facing the Drina River transboundary hydropower system, which has to provide an integrated framework for sustainable development and climate neutrality within the European green plan in the Western Balkan.

Water, food and energy are essential for human well-being, poverty reduction and sustainable development. Projections suggest the demand for increase due to demographic changes, economic development and international trade, amongst others. Climate change puts additional stress on water availability and quality and causes extreme events, like floods, or droughts, that have severe socioeconomic and environmental consequences. Actions to mitigate and adapt to climate change and variability can have strong implications for the surface and groundwater system and its users [1]. Changes in energy usage and types of energy production affect water usage and impact agricultural production.

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Addressing the strong nexus between water, food, energy and climate is essential to achieve the objectives of the European green plan in the Western Balkans, which aims at making the economy of the Balkan countries sustainable by turning climate and environmental challenges into opportunities across all policy areas. The European green plan in the Western Balkan proposes actions to boost efficient use of resources by moving to a clean and circular economy, achieve climate neutrality, revert biodiversity loss, cut pollution and provide a fair, healthy and environmentally-friendly food system. Water is a key element in all these actions [2]. A water-food-energy-climate nexus will help address these complex and interlinked challenges by exploiting available synergies across all policy areas of the Balkan countries, maximising coherence and promoting positive trade-offs between different policies.

The resulting conflicts in the allocation of water and between the water, food and energy sectors cause additional concerns for the sustainable management of surface and groundwater bodies, especially the transboundary ones, like Drina River, with dense population in its region. People live in the Drina River valley, scattered throughout the villages and concentrated in the towns. The major settlements near the Drina River are:

– in Bosnia and Herzegovina: Foča, Goražde, Višegrad, Srebrenica, Bratunac, Zvornik, and Janja.

– in Serbia: Bajina Bašta, Ljubovija, Mali Zvornik, Banja Koviljača, Loznica, Lozničko Polje, and Badovinci.

The Drina is crossed by several bridges: in Višegrad, Skelani, Bratunac and Zvornik (in Bosnia and Herzegovina), and Loznica and Badovinci in Serbia. The newest bridge is the one in Badovinci, lokally known as the “Pavlovića ćuprija”.

Since the Drina River catchment area belongs to three countries, it is clear that strengthening regional cooperation has to be imperative. The Drina constitutes a large part of the boundary that separates Bosnia and Herzegovina to the west from Serbia to the east. Drina River originates from the confluence of the rivers Tara and Piva (from Bosnia and Herzegovina, and Montenegro) and follows a northerly course for 215 miles to its confluence with the Sava. The Sava flows into the Danube and the Danube into the Black Sea. The total length of the Tara River is 144 km, of which 104 km are in Montenegro, while the final 40 km are in Bosnia and Herzegovina along which form the border between the two countries in several places. After that, the Drina flows through Bosnia and Herzegovina northward for 346 km, of which 206 km is along the border of Bosnia and Herzegovina and Serbia [3].

The Drina River upper course generally flows through canyons and gorges, and is convenient for power production, while its lower course is generally wider and convenient for agriculture and food production. In between, there are a lot of stakeholders, investors, interested parties and a lot of possible utilization of these water resources. Two large man-made lakes, at Višegrad, Bajina Basta and Zvornik, currently supply the power for hydroelectric stations. There is considerable hydro potential on the Drina and all its tributaries.

This paper is a contribution to the targeted optimal hydropower selection within the synergy with the water-food-energy-climate nexus. All developed solutions are based on the natural potential of the river resource. The main technical characteristic of the Drina River resource is presented in Table 1 below.

A lot of designs for Drina River water development were developed in this and the past century but many of them were not implemented due to a lack of holistic appreciation of the water-food-energy-climate nexus. Three dams and power plants have been constructed on the main Drina River course: HPP Višegrad, HPP Bajina Basta and HPP Zvornik. Their main characteristics are presented in Table 2.

Table 1. Technical characteristic of the Drina River and tributaries

Drina River		
1	Total length	346 km
2	Discharge at the Ćehotina mouth	125 m^3/s
3	Discharge on the confluence of the Drina with the Sava	370 m^3/s
4	Catchment area	20 320 km^2
5	The Drina starts at	Šćepan Polje
6	Šćepan Polje altitude	432 m.a.s.l.
7	Confluence with the Sava River	Crna Bara and the Bosanska Raca
8	Crna Bara and the Bosanska Rača altitude	75 m.a.s.l.
9	Total head	357 m
10	Tributary Lim	113 m^3/s (28.6% of total Drina water mass)
11	Tara	77 m^3/s (19.5% of total Drina water mass)

Drina River		
12	Piva	73 m^3/s (18.7% of total Drina water mass)
13	Ćehotina	22 m^3/s (5.6% of total Drina water mass)
14	Drinjača	21 m^3/s (5.3% of total Drina water mass)
15	Prača	21 m^3/s (5.3% of total Drina water mass)
16	Sutjeska	13 m^3/s
17	Jadar	10 m^3/s
18	Rzav	8 m^3/s
19	Present estimated power production (total basin)	6 x 103 GWh/year

Table 2. Technical performances of the constructed power plants on the main Drina River course

Existing hydropower structures		
HPP Visegrad		
1	Commissioning date	26 November 1989
2	Total installed power	315 MW
3	Useful volume of the reservoir	101 x 106 m^3
4	Average annual power production	1010 GWh
HPP Bajina Basta		
1	Commissioning date	22 November 1966
2	Total installed power	365 MW
3	Useful volume of the reservoir	340 x 106 m3
4	Average annual power production	1500 GWh
HPP Zvornik		
1	Commissioning date	26 July 1955
2	Total installed power	92 MW
3	Useful volume of the reservoir	89 x 106 m3
4	Average annual power production	500 GWh

The selection of an optimal concept of the construction of sustainable hydropower system in synergy with nexus the water-food-energy-climate can be accomplished only by applying contemporary mathematical models of artificial intelligence. Fuzzy logic, neural networks and expert systems, incorporating multi-criteria analysis provide the ideal framework for selecting optimal solutions of the river hydro potential utilization concept, with the incorporation of all relevant input variables like technical, economic, environmental, social, and political and others. The methodology presented in this paper is applied to two real case studies, presented in the following chapters: the hydro potential exploitation of the Drina River, within the section Foča-Goražde and Lower Drina between Zvornik and the confluence with the Sava River.

2. METHODOLOGY

To achieve the complex requirement of the nexus water-food-energy climate, a contemporary methodology of artificial intelligence optimization models is developed within this research. Fuzzy logic, fuzzy neural networks and expert systems are applied to fulfil the conditions of sustainable development and reduce global warming. Multicriteria operation research is also applied. The chosen methodology enabled the researchers to introduce the values of the environment, climate and other issues quantified into the optimization models when problem-solving of the water-food-energy-climate nexus appeared.

Contemporary methods applicable in designing sustainable Drina River development are presented in this chapter. All of them allowed us to analyse hydropower solutions as complex nexus of the water-food-energy-climate.

The research within this chapter is showing the methodology, which is enabling the quantification and incorporation of all relevant decision criteria into a mathematical model to select the correct technical solution of an optimum construction degree. The environmental impact parameters, impact on the underground water body, and impact on climate can be quantified as the expert evaluation by the Delphi method. All these impacts can be represented by the fuzzy input variable, together with technical, economic and other input variables, within the conceptual design phase, when decision making is on the agenda.

Theoretical basics of fuzzy logic, neural networks and expert systems are given, as well as real case studies, selection of optimal technical solution of the hydropower utilization at the Drina River within the section Foča-Goražde and Drina between Zvornik and the confluence, where the applying methodology of the modern technical solution of artificial intelligence is tested and confirmed.

The Drina River is a watercourse with significant hydro potential and it is not irrelevant in which way the construction sustainability of the facilities for the production of valuable, renewable and pure energy is researched and proved. The necessary investments in designing such huge strategic facilities are not irrelevant. The methodologies in selecting optimum synergy solutions as the support of the decision-makers are of the same importance.

The previously applied evaluation methods of optimum hydropower utilization concept and construction of dams and hydropower plants were generally based on models of standard technical-economic and financial analysis. Parameters such as the negative influence of dam constructions on climate and other users and creation of water accumulations on the underground water bodies, natural and social-political environment cannot be easily incorporated into such methods.

Multicriteria decision-making became an imperative a long time ago [4]. Exact numeric quantifiers for each of the input variables from the water-food-energy-climate nexus are requesting, while the corresponding weighted coefficients are representing the objective rating by the expert, who will have to design the expert system. The fuzzy expert system is enabling a linguistic characterization of all mentioned impacts and their presence within the decision system. A numeric evaluation (rating) of each possible technical solution the output is acquired at by a corresponding dephasification process.

Each part of the Drina River has its specific characteristics, users and requirements. AHP linear programming, as well as Electra, Promethee and the program package VICOR [5] for multi-criteria compromise ranking are applied due to methodological improvement and comparison of the results.

2.1. Opportunities of fuzzy technologies

The word „fuzzy" has appeared for the first time within the world of science and technology in the report „Fuzzy sets", published in 1965 in the prestigious international journal 'IT sciences', by professor Lotfi Zadeh from Berkley University. Fuzzy and neural technologies experienced a boom in Japan and, thanks to its emphasized feasibility and new approach in solving problems within the engineering praxis, they spread among mathematicians, philosophers, scientists, managers and engineers. Fuzzy and neural technologies enable us to make our computers 'more intelligent' and make them our virtual partners.

Due to the fuzzy approach, non-precise qualifications and especially descriptive linguistic qualifications (for example partial environmental impact, low/high disturbance, low/high influence ...) can be represented by synthetic quantifiers and processed by computers. The new fuzzy technology is a new computer technology bringing mankind and computer together.

The next stage in fuzzy technology development is the setting of these technologies with neural networks. This setting is adding another characteristic of intelligent systems to fuzzy systems meaning the ability of adoption to variable environmental conditions. The fuzzy sets [6] are introduced with the basic aim to initiate and mould an indetermination within the linguistic in a mathematically formalized way and thus defined settings can be considered as a generalisation of the classical set theory.

The fuzzy systems are adapting to the applied situations correspondingly. This was already emphasized by Lotfi Zadeh when defining the fuzzy sets, with a special remark that each domain can be fuzzed and that the previous conventional (crisp) set theory approach can be corresponding generalized. In such a way, out of neural networks, genetic algorithms, stability theories, shape recognition and mathematical programming, you can obtain fuzzy neural networks, fuzzy genetic algorithms, fuzzy stability theories, fuzzy shape recognition and fuzzy mathematical programming and determining. The advantage of such fuzzification is within a higher level of generalization and expression with a higher ability to model real case problems with a specific methodology in analysing tolerances within inaccuracies.

When qualitative descriptions of phenomena are used together with learning through practice, it is possible to obtain a system that can learn and qualitatively describe its knowledge. The qualitative component of such systems can be realized through a fuzzy approach. The learning component can be realized through neural networks. When such systems are developed in the form of computer programs, then we can talk about fuzzy neural technologies or fuzzy-neural computing.

The fuzzy technologies can have a widespread application area. This is why fuzzy technology is not just a technology but also a certain approach to problems and a way of observing and studying phenomena. Fuzzy is a new prospect [7]. During the last ten years, fuzzy systems have become a substantial replacement of conventional technologies in a great number of scientific applications and engineering systems, especially within the domain of systems management and shape recognition.

The fuzzy technology has found its appliance within IT technologies in the form of approximative comprehension, where it is used as a backup in determining and within expert systems, which will be theoretically further processed in realistic examples from engineering practice. One of the most important characteristics of fuzzy logic is its ability to express the degree of indetermination in human apprehension and subjectivity. The most often situations fuzzy logic is demanded are the cases and situations when an expert system is designed, with the belonging functions having to describe the validity of particular characteristics in a corresponding way. The fuzzy logic has found its application within the management theory, shape recognition, quantitative analysis, expert diagnosis systems, planning and prediction, IT systems etc.

2.2. Expert systems for the water-food-energy-climate nexus

In its nature, the fuzzy logic is very appropriate for shape recognition methods and expert determinations, simply because the terms of classes, clusters and classifications are most often of a subjective nature, defined by non-numeric attributes. The fuzzy logic can be introduced into the shape recognition process and expert determination in two ways. The first way is phasification of the space within which the characteristic vector is defined, and the second is concerning the phasification of a classifier. The accentuation is on the general character of the classification method based on fuzzy logic, as well as the method called fuzzy min-max classifier with neural network [8].a

Due to the utilization of new technologies, systems are developed which are adaptable to the environment and accessible to humanity. The learning process using neural networks is derived from changing parameters within the computer program, which is epresenting this network, thus demonstrating that exiting the program satisfies certain criteria. After setting the neural networks with the fuzzy systems, the learned knowledge can be expressed qualitatively.

Training of the computer systems is possible due to the utilization of fuzzy and neural technologies and the knowledge of the experts can be described and represented within the computer. The expert system is a program with expert behaviour for a certain problem domain. The expert system has mainly two basic functions [9]. In our cases, the first function is the so-called problem-solving function, i.e. ability to use knowledge from a certain domain. Within this function, the expert system is expected to be able to function within indetermination conditions or lack of information. The second important function is the possibility of interacting with the user, meaning an explanation of intensions before and after the problem-solving process. The basic structure of the expert system is involving three blocks: knowledge basis, inferential machines and user interface.

The knowledge basis is implying the specific knowledge of the given application domain, including facts regarding rules and relations, which exist within this application domain. IF-THEN rules are the most popular formalism. It is a form of fuzzy rules, which represent this knowledge. The inferential machine, i.e. the determination algorithm has the task to apply the knowledge basis and answer the user’s questions. The user interface means the communication between the user and the knowledge basis, i.e. the inferential machine.

The ability of the expert system to handle inaccuracies is of great importance. Before introducing the fuzzy system, the most used possibility to master indeterminations was based on the probability theory. However, the fact is that the experts mostly do not cogitate in terms of probability, their knowledge can be expressed most often using descriptions such as ‘low impact’, ‘expressive impact’, ‘much’, ‘always’ etc. In such a way, the fuzzy expert system offering fuzzy comprehension and linguistic expressions for describing objects and relations becomes a usable and good alternative. As the main goal of this report is the design of a determination expert system, which based on objective (numeric, quantitative) or some more linguistic (qualitative) parameters will decide on the solvency of a potential hydropower plant at the given location, this is a determination expert system rather than classical expert system.

2.3. Delphi method

As an expert rating method, the Delphi method belongs to the group of exploratory methods [10] and uses the advantage of an expert group comprehension. The method is named after the old Greek temple. It is based on the statistical processing of collected opinions given by experts in certain domains. The utilization of expert knowledge is methodologically organized to evaluate and quantify certain impacts. The method is suitable for defining criteria, parameters and quantities used in determinations related to selecting designs. It has numerous modifications depending on studied issues, however, when briefly reviewed, the conclusion is that the application process involves the following phases:

- Definition of requested rated issues;
- Creation of an expert team (10-15 members), specialists on the defined problem;
- Determination of the rating horizon;
- Within the first questionary series, each expert is requested to give a forecast and arguments;
- The obtained evaluations are arranged into an increasing sequence and the median and the lower and upper quartile are determined;
- Within the second questionary series, the experts receive information on all obtained values and they are requested to revise and possibly correct their forecasts, having in mind the obtained information;
- Within the last questionary series (3-4 series) the experts are requested to give their final rates.

The median is a medium rate, i.e. such a rate value for which the number of experts whose rate is higher than this value is equal to the number of experts whose rate is lower than this value. This is the medium value of a sequence of objective rates. The quartile is the range of limits, which describes the rate variation about the medium value. It practically represents the precise rate measure. The lower quartile is the rate for which the number of experts whose rates are lower than this value amounts to ¼ of the total number of experts. The upper quartile is the rate for which the number of experts whose rates are higher than this value amounts to ¼ of the total number of experts.

2.4. AHP linear programming

The very nature of this problem and its variables implied that integer linear programming should be an appropriate method for finding an optimal solution. Linear programming has been used very often in civil engineering for solving organizational and economic problems but, despite its great possibilities, it has not yet been widely used in engineering practice and it has not yet been used in solving such a complex problem as hydro development optimization. The standard form, as a usual form to describe a linear programming problem [11], consists of the following two parts:

Objective function in the form of linear function to be maximized or minimized:

$$\min/\max Z = c_1x_1 + c_2x_2 + \ldots + c_nx_n \quad (1)$$

Problem constraints in the form of linear equality or inequality:

$$a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \leq,=,\geq b_i \quad (2)$$

$$x_j \geq 0;\ i = 1, \ldots, m;\ j = 1, \ldots, n \quad (3)$$

The final values of the non-negative variables x_j, found by some of the linear programming algorithms are an optimal solution to the problem (1) that meets all given requirements defined by the problem constraints (2). Variables $X_{1\text{-}7}$ in this problem present the number of given types of facilities in combination that will meet all the given constraints. Therefore, to avoid having the same facility in the same combination twice, this problem can be solved only in integer binary mode, in which variables can only have values 0 or 1 [12].

The first and the basic constraint is that the sum of the heads in any given combination must not exceed the biggest possible head, to eliminate all impossible combinations from further consideration:

$$\Sigma\Delta h_iX_i \leq Head_{max} \quad (4)$$

The second constraint considers the main purpose of the dam(s), which is the annual energy production. Therefore, it is requested that the sum of annual energy production for any given combination of the dam(s) has to be greater than the adopted minimum energy production:

$$\Sigma E_iX_i \geq E_{min} \quad (5)$$

The third constraint is defined in a way that would ensure that the average environmental influence grade of any given combination is higher than the adopted minimal value:

$$(\Sigma ENV_iX_i) / \Sigma X_i \geq ENV_{min} \quad (6)$$

This constraint can also be represented as:

$$\Sigma(ENV_i - ENV_{min})X_i \geq 0 \quad (7)$$

The fourth and fifth constraints are defined in the same way as the third, but they consider average values of the socio-political factor and the cost-benefit ratio:

$$\Sigma(CQ_i - CQ_{min})X_i \geq 0 \quad (8)$$

$$\Sigma(B/C_i - B/C_{min})X_i \geq 0 \qquad (9)$$

In accordance with which criterion is chosen to be the most important, the left side of its inequality becomes the objective function, while the other inequalities are problem constraints. This, of course, cannot be applied to the first constraint because its purpose is to eliminate the impossible solutions from further consideration. The determination of minimal acceptable value of numerical quantifiers describing environmental and socio-political acceptability, as well as the choice of criterion to be taken as the objective function, is based on the knowledge and objective estimation of an expert in this field.

2.5. Multicriteria optimization

The mathematical model uses the VICOR multicriteria compromise ranking program package. The decision is mathematically presented first detecting and elaborating the possible solutions. This part of the research could be very extensive. The reason for this is that every possible solution should be developed at the relevant and uniform technical level. Practically, it would be necessary to prepare as many designs for the hydro potential utilization of the river course as required and as existing. Then, upon consultations with the Client (Clients) and stakeholders, the essential criteria for decision (objective) are highlighted. Hence, multi-criteria optimization develops in several stages of phases such as:

– Designing alternative solutions of the system,

– Defining of the criteria and criteria functions for evaluation of the water-food-energy-climate nexus alternatives (economic, technical, social, ecological, climate, etc.)

– Evaluation of all the alternatives per each criterion individually. Evaluation can be made applying quantitative indicators of the water-food-energy-climate nexus (which are the results of economic analyses, engineering calculations, desk research or different measurements) or using the quantitative indicators, which can be the result of expert opinion.

– Multi-criteria ranking of the alternatives

– Adopting the final (multi-criteria optimal) solution.

Multi-criteria optimization of the hydroelectric power system can be made using the method of multi-criteria compromise ranking (2). Ranking alternative solutions can be made using the program packages such as VIKOR, Electra, or Promethee [13]. All of them offer the possibility to introduce multiple criteria in the decision-making process, such as different users' benefits, flood defence issues, environmental impact, impact on groundwater bodies, social impacts, constraints and climate impact.

3. WATER-FOOD-ENERGY-CLIMATE NEXUS FOR THE FOČA-GORAŽDE SECTION

The locality subject to this analysis is in the Drina River basin between the towns of Foča and Goražde. During the 1970s, the construction of a dam in this river section was suggested, which would have had the greatest energy-economic effects, but also very adverse environmental impacts. For a long time, the adopted solution could not be implemented as it did not reflect the complex optimum selection issue nor respect the minimum requirements of the water-food-energy-climate nexus.

Cvilin Polje was the unique agricultural area of this part of the Drina River. It was the only possibility for food production for local inhabitants. There were two technical solutions proposed at that time:

– first HPP Goražde and the dam with retention level 383,00 m.a.s.l. and after that

– HPP Goražde and the dam with lower retention level 375.00 m.a.s.l.

Both variants, within their hydropower solutions, included concrete dams with relatively large reservoirs behind them. These reservoirs endangered/flooded agricultural land on both riversides. The especially endangered area was Cvilin Polje. The flooding of Cvilin Polje left the local population without the possibility of growing and producing food. Even if a protective embankment to keep the Cvilin Polje unflooded had been constructed, these reservoirs would have had a negative impact on the disturbance of groundwater body levels.

Raising the groundwater level in Cvilin Polje would increase the humidity of the terrain. It would lead to the rotting of the roots of cultivated crops. Both solutions, HPP Goražde with the dam of 383.00 m.a.s.l. retention level and HPP Goražde with the dam of 375.00 m.a.s.l. retention level had maximum energy effects. Dams with large reservoirs and heads had higher power production than other solutions. However, the requirement of the water-food-energy-climate nexus indicated the necessity to lower the retention level. All water-food-energy-climate nexus indications led the research towards the solutions in the riverbed as a compromise between the targeted power production, the need for water and food, and climate neutrality.

Modern techniques of artificial intelligence, which enable the incorporation into optimisation models of valorised, quantified and functionally expressed factors from the water-food-energy-climate nexus, offer the possibility to revise an optimum solution and search for a new one, which will neither endanger the environment, agricultural lands, underground water bodies, nor climate change. Conceptual designs are made for profiles where the creation of six schemes of alternative technical solutions in hydropower utilization of the river is possible, representing the combination of seven different schematic elements.

The following HPP technical systems at the Drina River between the towns of Foča and Goražde are represented as varieties from A to F:

– A – HPP Goražde 375: one concrete dam at the Goražde II profile, with a dam-toe hydropower plant with retention level of 375.00 m.a.s.l.

– B – HPP Goražde 383: one concrete dam at the Goražde II profile, with a dam-toe power unit and resevoir at the normal retention level of 383.00 m.a.s.l.

– C – HPP Goražde 352, HPP Sadba 362, HPP Ustikolina 373, HPP Paunci 384: four concrete spillway dams, cascade series, reservoirs with acompanying retention levels, respectively.

– D – HPP Goražde 375, HPP Paunci 384: consisting of two hydropower facilities at profile Goražde II and Paunci, with respective retention levels of 375.00 m.a.s.l. and 384.00 m.a.s.l.

– E – HPP Goražde 362, HPP Ustikolina 373, HPP Paunci 384: this alternative has a cascade of three concrete dams with the following run-of-river hydropower plants: Goražde II, Ustikolina and Paunci, with accumulations at levels 362.00 m.a.s.l., 373.00 m.a.s.l. and 384.00 m.a.s.l., respectively.

– F – HPP Sadba 362, HPP Ustikolina 373, HPP Paunci 384: this possible technical solution is a cascade of three uniform hydropower facilities within the Drina River bed at the following profiles: Sadba, Ustikolina and Paunci with levels at 362.00 m.a.s.l. 373.00 m.a.s.l. and 384.00 m.a.s.l., respectively, with 11,00 m cadence each. All possible alternatives, with accmpanying water retention levels, are shown in Figure 1 as the longitudinal cross-section of the Drina River between the towns of Foča and Goražde.

The basic techno-economical characteristics of the hydropower plants at the Drina River section between the towns Foča and Goražde are shown in Table 3.

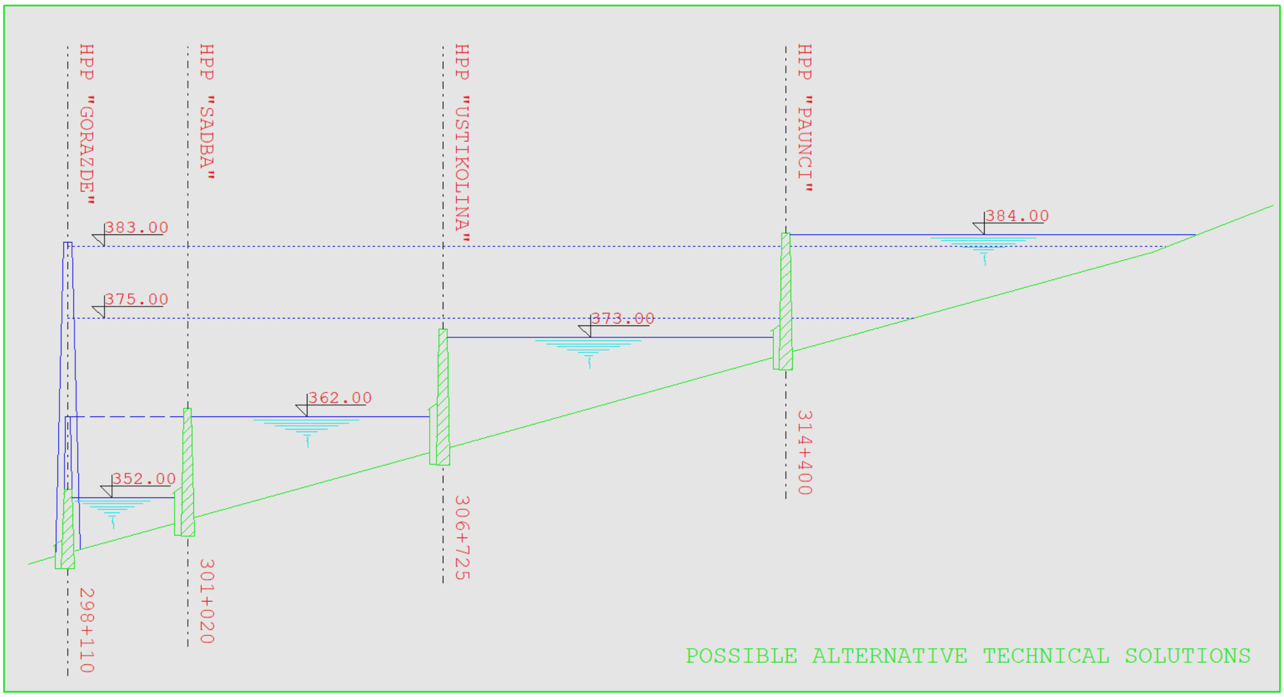

Figure 1. Possible hydropower alternatives for water-food-energy-climate nexus optimization

Table 3. Techno-economical indicators of possible hydropower plants at Drina River within the Foča-Goražde section

	Gor. 383	Gor. 375	Gor. 362	Gor. 352	Sadba 362	Ustik. 373	Paunci 384
Q (m^3/s)	500	500	450	450	450	450	450
H (m)	35.8	27.8	15.0	5.0	9.5	10.0	10.6
N_i *(MW)*	166.5	130.8	61.5	20.7	43.2	43.2	43.2
E_{year} *(GWh/year)*	501.7	407.2	223.8	73.2	140.4	147.4	156.3
E_{peak} *(GWh/year)*	308.3	251.1	126.3	41.3	79.2	83.2	88.2
Investments (mill. $)	302.7	246.3	105.2	79.5	79.5	77.8	85.5
B/C	1.57	1.53	1.73	0.74	1.44	1.5	1.45
Inv. quant. ($/kWh)	0.603	0.605	0.47	1.084	0.566	0.528	0.547
Spec. inv. ($/kW	1.818	1.881	1.711	3.842	1.841	1.801	1.98

3.1. Results of the fuzzy expert system for the water-food-energy-climate nexus

The expert system is a program with incorporated expert knowledge intended to be trained on an example of 11 different hydropower facilities, seven on the Drina River between Foča and Goražde and four between Zvornik and the confluence, balanced and verified on a real case study from the water-food-energy-climate nexus research. This is a selection of an optimum construction concept of hydropower facilities at Drina River within a defined section, with 6 alternatives of different possible constructed dams and hydropower plants with higher and lower retention levels. Each alternative has its specific print on the water-food-energy-climate nexus.

The suggested expert system can interact with the user. The basic knowledge built into this expert system, relating to the evaluation of the hydropower facilities, is not only included in the interferent machine and fuzzy rules basis but into the very structure of phasificators and dephasificators, selection of input and output variables and selection of corresponding belonging functions.

Five input variables x_i, $i=1,...,5$ are impact factors of solutions within the suggested expert system. The idea was to involve three techno-economic parameters: facility pick production expressed in *GWh/year* with standardized value identified as x_1, quotient B/C expressed as non-dimensioned quantity and identified with standardized value x_2, standardized investment quotient of others water users in $ identified as x_3. The fourth input variable x_4 is representing the environmental impact of the selected technical solution and this variable is calculated based on objective rates, i.e. synthetic quantifier – the median of the Delphi method [14]. The last, fifth variable x_5 is nominated as the climate impact factor with the basic idea to indicate and include issues appearing when the hydropower facilities are constructed within areas stretching over different territories.

The input quantities are the result of conceptual designs made with 6 various technical solutions of hydropower facilities [15]. In order not to favour any of the mentioned variables, each of them being normalized within the range [0,1] according to the maximum and minimum values of single considered technical solution parameters. Table 4 is created to define explicitly the normalisation process results.

Normalization factor values of different input variables are the results of the real data from the optimization of the hydropower exploitation of the Drina River between Foča and Goražde, made by the author of this research. This design was the Conceptual design titled 'Hydropower utilization of the Drina River in the Foča – Goražde stretch', made with the engineering team from Energoprojekt – Hidroinženjering Company, in Belgrade, 2002. [15].

Table 4. Normalisation factor values of different input variables

Input value	Maximum value	Minimum value	Normalized variable
V=Facility pick production (GkWh/year)	41.3	308.3	$x_1 = \frac{V-41.3}{308.3-41.3}$
B/C quotient	0.74	1.73	$x_2 = \frac{B/C-0.74}{1.73-0.74}$
IK=Investment quotient ($)	0.47	1.084	$x_3 = \frac{IK-0.47}{1.084-0.47}$
UE – Environmental impact (objective rate)	1	5	$x_4 = \frac{UE-1}{5-1}$

Input value	Maximum value	Minimum value	Normalized variable
PI – Climate impact factor (objective rate)	1	5	$x_5 = \frac{PI-1}{5-1}$

Linguistic variables with corresponding affiliation functions are associated with each input variable. It was decided to define two linguistic variables for each input variable (changeable) x_i, i=1,...,5, where the affiliation function parameters are selected in such a way to reflect the expert expression estimation of the observed characteristics.

The selected input variables are representatives having the strongest impact on the optimum construction concept selection and being the most important factors for the decision-maker. It is clear that, if merely the techno-economic indicators or energy production are favoured, the optimum solution would be represented only by one, highest dam and dam-to HPP with maximum power performances.

However, as the indicators on the water-food-energy-climate nexus the following were investigated: the environmental quality is involved in the input variables, as well as the investment quotient of other water users and climate impact factors; the arguments are extended, and the concept composed of a series of low cascade dams and small accumulations has become topical. The solution of the expert system will show us the optimal number of construction facilities and allowed flooding levels.

The expert system solution is searched in any case within the range of one hydropower plant and a high-arch dam with accompanying accumulation and four spillway dams within the river bed with smaller reservoirs, and thereby lower flooding and smaller energy-economic effects. The technical solution with one large hydropower facility would have high financial and economic results in terms of power production. At the same time, these solutions cause maximum environmental, flooding, climate and other disturbances to users. For that reason, five input variables are selected, within which the technical, energy, other users' economy, climate and environmental performances have been considered equally and using the same weight factor. Two linguistic variables are defined for the pick production input variable – medium and high pick production. For the linguistic variable, the affiliation function of the medium pick production is as follows:

$$\mu_1^1(x) = \exp\left(-0.5\frac{x^2}{0.4^2}\right) \tag{10}$$

whereby the affiliation function is associated with the linguistic variable 'high pick production':

$$\mu_1^2(x) = \exp\left(-0.5\frac{(x-1)^2}{0.4^2}\right) \tag{11}$$

These two affiliation functions representing the facility pick production are defined, and the belonging functions associated with linguistic variables of medium and high pick production of hydropower plants are quantified.

The input variable *B/C* is defined by the following two linguistic variables: profitable and non-profitable facility. The belonging function of the profitable relation *B/C* is as follows:

$$\mu_2^1(x) = 1 - e^{-x/0.26} \tag{12}$$

while the belonging function of the non-profitable relation *B/C* is as follows:

$$\mu_2^2(x) = \frac{1}{\left(1+\left|\frac{x+0.23}{0.43}\right|\right)^{8.2}} \tag{13}$$

The formation of these belonging functions associated with linguistic variables of the profitable and non-profitable technical solution, according to the relationship B/C, is also calculated.

The third input variable is related to other users' economies, as investment quotient ($). The following wo variables are associated with it: low cost and expensive technical solutions with corresponding functions $\mu_3^1(x)$ i $\mu_3^2(x)$ respectively, with:

$$\mu_3^1(x) = -0.34x^3 - 0.38x^2 - 0.28x + 1 \tag{14}$$

$$\mu_3^2(x) = e^{-0.5\left(\frac{x-1}{0.25}\right)^2} \tag{15}$$

The formation of these belonging functions associated with linguistic variables: low cost and expensive technical solutions according to the investment quotient criterion of other users is performed and expressed in $.

The fourth input variable is representing the climate impact factor related to locality and takes up a larger space of the considered technical solutions. Regarding the delicacy of the inter-ethnic relations within the considered locality, the climate impact factor is of high importance. Its impact on the selection and realisation of the design cannot be neglected.

Regarding this variable, it has been decided to define two belonging functions marked as an unacceptable and acceptable solution, while the belonging function formation has been selected within the domain of the Gaus' functions [16], with corresponding parameters:

$$\mu_4^1(x) = e^{-0.5\left(\frac{x}{0.4}\right)^2} \tag{16}$$

$$\mu_4^2(x) = e^{-0.5\left(\frac{x-1}{0.4}\right)^2} \tag{17}$$

The formation of these belonging functions is shown in Figure 2 (left).

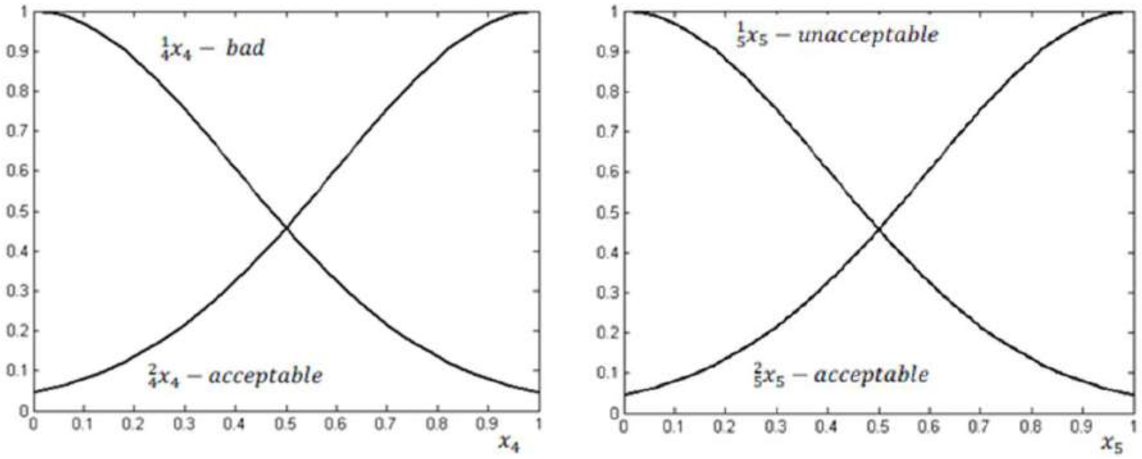

Figure 2. Accompanying function associated with the fourth input variables: climate impact factors (left) and the accompanying functions of the fifth input variable: environmental impact (right)

The last input variable within the formed expert system is changeable, marked as the environmental impact. Similar to the climate impact factor, it is characterized by two accompanying functions with the following analytical values:

$$\mu_5^1(x) = e^{-0.5\left(\frac{x}{0.4}\right)^2} \tag{18}$$

$$\mu_5^2(x) = e^{-0.5\left(\frac{x-1}{0.4}\right)^2} \tag{19}$$

The formation of these functions is shown in Figure 2 (right). The variable marked as *the solvency* of the technical solution is representing the exit from the fuzzy expert system. This is again the fuzzy variable characterized by 10 belonging functions type *singleton*. The positions of these *singletons* are determined according to the given delicacy of the whole determination system, but at the same time with the fuzzy rules structure. The position of the *singletons* within the exiting changeable *solvency* is shown in Figure 3.

The *singletons* are marked with sa s_i, i=1,...,10, where the positions of these singletons are {0.05, 0.07, 0.1, 0.15, 0.3, 0.6, 0.7, 0.75, 0.9, 0.95}. In this case, the dephasification was made by the centroid method [17].

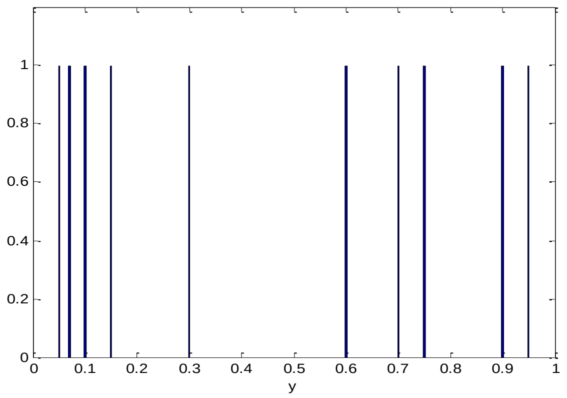

Figure 3. The belonging function of the output variables: solvency of technical solutions

3.2. Fuzzy rules of the expert system for the water-food-energy-climate nexus

The fuzzy rules are defined and shown in Table 5. It is proved that the optimum number of fuzzy rules is 10 for the specific water-food-energy-climate nexus expert system, having in mind that there are 5 different input variables. All rules are associated with the same weights, except the variable representing peak production, as it is not necessarily supposed that a hydropower facility is simultaneously producing a large quantity of peak energy. In this specific case, ten fuzzy rules are sufficient to reflect the real-world practice function within the expert system.

Table 5. The water-food-energy-climate nexus fuzzy rules and their weight coefficients

Rule number	Rule content	Weight
1	If (pick production is medium) then (solvency is s5)	0.8
2	If (pick production is high) then (solvency is s7)	0.8
3	If (B/C is not profitable) then (solvency is s1)	1.0
4	If (hist.-polit. factor is bad) then (solvency is s4)	1.0
5	If (hist.-polit. factor is good) then (solvency is s8)	1.0
6	If (environmental impact is bad) then (solvency is s2)	1.0
7	If (environmental impact is good) then (solvency is s6)	1.0
8	If (B/C is profitable) then (solvency is s9)	1.0
9	If (USD/kWh is super) then (solvency is s10)	1.0
10	If (USD/kWh is expensive) then (solvency is s3)	1.0

3.3. Expert system synergy solution for hydro development at the Foča-Goražde section

In defining the rules, which are representing the functional relation between single input variables and solvencies, total solvencies are obtained for technical solutions from the set of training the expert system as a result of the fuzzy expert system in selecting the optimum concept for constructing hydropower facilities, as shown in Figure 3. Total solvencies shown in Table 6 are calculated for alternatives A, B, C, D, E and F, which represent sets of possible technical solutions of hydropower facilities at the Drina River, between the towns of Foča and Goražde.

Table 6. Total solvencies of alternative solutions of Drina hydro potential exploitation

Possible alternatives	Total solvency
Alternative A	0,532
Alternative B	0,514
Alternative C	0,707
Alternative D	0,533
Alternative E	0,714
Alternative F	0,724

After comparing the calculated solvencies, the conclusion was made that logic and authentic results are gained and the most acceptable optimum synergy solution in constructing hydropower facilities at the Drina River is the alternative F, i.e. a system consisting of three uniform hydropower plants: HPP Sadba, with normal reservoir retention level of 362 m.a.s.l., HPP Ustikolina, with normal reservoir retention level of 373 m.a.s.l. and HPP Paunci, with normal retention level of 384 m.a.s.l. These have the highest solvency amounting to 0.724. These cascades in the riverbed represent the water-food-energy-climate nexus synergy solution for the Foča-Goražde part of the river.

This construction concept within the area between Foča and Goražde, with three approximately same facilities, has 30% lower costs of hydro-mechanical, machine and electricity equipment, because of the same type of equipment and mutual spare parts. The facilities consist of low concrete dams with spillways being at the same time bottom outlets. Such solutions have a minimum environmental impact and they perfectly fit into the environment as single complexes within the territory divided between different entities. HPP Paunci is located in one entity and hydropower plants Sadba and Ustikolina in the other.

The construction concept of the hydropower facility within the Drina River section between the towns Fočca and Goražde with second-rated solvency is the alternative E with a solvency of 0.714. This solution consists of the following hydropower facilities: HPP Goražde, with normal reservoir retention level of 362 m.a.s.l., HPP Ustikolina, with retention level of 373 m.a.s.l. and HPP Paunci, with retention level of 384 m.a.s.l. The third concept, i.e. the alternative solution to the spatial issues and construction of hydropower facilities at the Drina River within the considered section Foča-Goražde is the alternative C, with the solvency of 0.707 consisting of the following construction of hydropower facilities: HPP Goražde, with retention level of 352 m.a.s.l., HPP Sadba, with retention level of 362 m.a.s.l., HPP Ustikolina, with retention level of 373 m.a.s.l. and HPP Paunci, with retention level of 384 m.a.s.l.

After this optimization, additional studies were conducted, which considered the detailed position and retention level of HPP Goražde. Considering all detailed analyses of the particular location, the final retention water level of 357.00 m.a.s.l was adopted for the dam and HPP Goražde.

3.4. Recommendations for the water-food-energy-climate nexus

The determination of the optimal hydropower utilization concept of the Drina River within the section between Foča and Goražde with an extremely pronounced conflict of all existing interests and users is a real case study from the practice, ideal for balancing the mathematic model and suggested methodology for the complex water-food-energy-climate nexus synergy solution solving. The logic of calculated results and reality conclusions related to the selection of the optimal construction concept of hydropower facilities at the Drina River between Foča and Goražde shows the following:

– the expert system based on the example of 11 (eleven) different hydropower facilities with different technical and economic, historical and political, and environmental parameters was correctly 'exercised',

– the selection of 5 (five) relevant input variables is representative and valid enough for the determination of an optimum water-food-energy-climate nexus alternative,

– the defined 10 (ten) interactive rules reflect the real functional dependence of input variables and solvencies,

– weight coefficients accurately reflect the importance and impact on the solvency of input variables of the accompanying functions.

The conclusion is that the expert knowledge was reliably transferred to the computer. The computer is now programmed to select the optimum utilization concept of renewable water resources, respecting the water-food-energy-climate nexus. The computer is also programmed to select the optimum construction of hydropower facilities in other watercourses and related to similar water-food-energy-climate nexus problems.

The defined goal has been achieved. The conclusion is that, on the one hand, by using this methodology, maximum possible techno-economic effects are produced and, on the other hand, the adopted technical solution uses the optimum of all resources, which is proportionally fitted in and is does not disturb the natural and social-political environment. The adopted solution does not affect the climate, the groundwaters are not disturbed, Cvilin Polje will remain the agricultural area, flood control has been established and other water users are not affected. The methodology mentioned in this paper is recommended for further analysis and applications.

4. THE WATER-FOOD-ENERGY-CLIMATE NEXUS FOR LOWER DRINA

The hydro potential development of the Lower Drina is analysed within the context of the water-food-energy-climate nexus. The goal is to meet the criteria of sustainable development and the requirements of reducing global warming, according to the set conditions of the adopted European Green Plan for the Western Balkans. A selection of optimum parameters and conceptual definition of hydropower facilities from Zvornik to the confluence of the Drina with the Sava River is incorporated in the function of the integral water management solution. Multipurpose resource utilization, such as power production, flood control, navigation, agricultural and food production improvement, stabilization of underground water level, gravel exploitation, environmental protection, climate neutrality, development of tourism and sports are all in conflict with interests and criteria to achieve the goal. The synergy solution of the water-food-energy-climate nexus for the Lower Drina is presented in this chapter.

The Drina River is an aquifer boundary with substantial, yet insufficient utilized hydro potential. It is a resource whose distribution and the possibility of multipurpose utilization has been for decades the subject of research by designers, scientists and investors worldwide. Necessary financial resources for the design and construction of dams as large strategic key facilities are huge and the question of methodology [18] in selecting optimum technical solutions and distribution of resources between users with conflicting interests within the scope of an integrated water management solution is an issue worth noticing. It is a subject of many modern scientific analyses.

The Drina River is characterized by extremely high and favourable hydropower potential mostly due to its high-water level and large cadence. Out of the 14.2 billion KWh/year of total usable power potential of the Drina River, about 4 billion KWh/year have only been utilized so far, due to the construction of hydropower plants at upper and medium Drina River parts. The Lower Drina has a usable power potential of 1.6 billion KWh/year. It has not been utilized so far, mostly due to less favourable topographical characteristics of the river basin, as the Drina River flows at its lower section through the low lands of Mačva (the right riverbank – Serbia) and Semberija (the left riverbank – Bosnia and Herzegovina).

Having in mind the most recent global experience with facilities constructed on rivers with large flows and low cadences, after a series of designs opting the utilization potential of Lower Drina River flow, an analysis has been made on the hydropower utilization of the Drina River within the section from Zvornik to the river delta [19], in accordance with other present and future potential users of the resource within the scope of the regional water management basis.

4.1. Criteria and limitations of the goal function

Criteria and limitations of the goal function, the water affluence, utilization of the Drina River hydropower potential and other existing natural resources were the goal function long ago, which prompts the scientific research and create a series of studies on complex solutions of conflicted interests of the users of the resources. The issue of optimization within the nexus of the water-food-energy-climate requires holistic research to arrive at synergistic solutions. These solutions are certainly a compromise but it is inevitable that they meet the criteria of sustainable development and the requirements of reducing global warming, according to the set conditions of the adopted European Green Plan for the Western Balkans.

The utilization of the available Lower Drina power potential has been subject to different basic design studies, which have been engaged in utilization of the available water potential of the complete Drina River flow and subject to the Study on hydropower utilization of the Drina River at the section from Zvornik to the river delta [19]. This design has enabled definite adoption of the optimum power utilization scheme, as well as the number, type and main parameters of the hydropower plants at the Drina River section from Zvornik to the river delta. This solution has been confirmed by creating the water management basis of Lower Drina.

The hydropower and hydro-technical system facilities of holistic and sustainable water resources management of Lower Drina are capital investments. Their construction is a goal function representing an important step in strategy-making and, within this scope, it is necessary to reach compromise and fulfil the following criteria and limitations:

– Maximize power production

– Improve irrigation and drainage regime of agricultural land

– Increase flood protection level

– Stabilize groundwater level in Mačva and Semberija

– Improve navigation possibilities

– Gravel exploitation within the lower riverbed excavation zone, under the law and other users of the resources

– Develop tourism and sports

– Environmental quality protection

– Climate neutrality

The last two criteria, i.e. limitations are often taken literally. Due to its incorrect understanding, a great number of qualitative, import and strategic water management and hydropower solutions have not been approved for realization. The maximization of construction benefits and the tendency of certain environmental associations to preserve the untouched nature are extremely conflicted interests, whose solving requires a thorough, holistic approach. The social community is changing inevitably. The consumers' demand on energy and the complete social community demands of water, food and other resources are growing exponentially. At the same time, there is a need for an increased level of protection against flood waves. Flood disturb the environment substantially and sometimes the lives of residents, agriculture, traffic and other users are threatened.

The stabilization of groundwater levels in Mačva and Semberija has to be obtained within the areas of agricultural land, as well as below settlements to avert the threat to agricultural products, cellars and foundations of residential buildings. The maximization criteria on flood protection point out the necessity of constructing dams and reservoirs on the Drina River. We have witnessed flooding that occurred within the Drina River basin. These environmental damages could have been avoided or reduced substantially if the upper and medium Drina River flow dams and accumulations had been constructed following already existing designs. Therefore, the compromise of goal functions within optimum utilization of water resources, together with meeting the above-quoted criteria for the nexus of water-food-energy-climate, can be achieved by constructing dams and reservoirs sized following the modern methodological and sustainable approach presented in the second chapter of this research.

4.2. Sustainability of the integral water management solution

The hydro potential is the most important energy resource and it must gain priority at any rate within the scope of energy resources management and within the context of renewability and non-renewability. Hydropower is clean renewable energy. Constructed dams and artificial reservoirs make possible to build intakes for water supply or irrigation for food production. The reservoirs can be used for fishing, aquaculture and fish farming, sailing, kayaking and tourism. At the same time, flood control is possible only by water management if dams and accumulations exist. Bottom outlets, spillways, and power outlets can be opened when the information system warns about a flood. In this case, pre-discharge of the reservoir could be done and an empty reservoir would be able to accept or mitigate the flood peak. Depending on the reservoir volume, the flood peak can be retained in the reservoir, or mitigated, i.e. reduced. Such measures can protect downstream towns and agricultural lands. On the other hand, besides a certain number of positive effects, the construction of dams and accumulations disturbs the environment in a certain way.

The concept of sustainable development in this specific case represent the harmonization of all direct and follow-up activities in solving the Lower Drina exploitation as a natural resource of international importance. Such a defined integral approach of water-food-energy-climate nexus facilitates development, which will cause minimum negative environmental impacts through increased efficiency within the production and consumption process, as well as within the utilization of all Lower Drina natural resources.

Although the environmental protection still does not represent a factor in setting limits for development in the Balkans, it has a crucial influence on the requirement that the future, designed development has to be sustainable, i.e. permanent for next generations, which means that optimization could be in the context of circular economy [20]. Being aware of the importance and necessity of environmental preservation, the stability of the technical solution within the environmental impact area must be a minimum equivalent to the static, hydraulic and geotechnical stability of the facility.

The transition period has brought new relations in concessional financing models, in preparing the design documentation, construction and exploitation of hydro-technical and hydropower facilities and systems. In the following chapters, a modern holistic and sustainable solution in the utilization of water resources is shown within a realistic water flow section from Zvornik to the Drina River confluence with the Sava River. It is conceived in such a way to fit absolutely into the complete solution of regional water management and water-food-energy-climate nexus.

4.3. Lower Drina alternatives

The Lower Drina potential can be used by constructing hydropower plants at derivation channels or in the main river flow, named the ‘river alternative’. The first concept (hydropower plants at derivation channels) has been developed on a study level. It has not been elaborated in detail, because it has been always less profitable compared with the concept of ‘river variety’. At the same time this alternative has always been technically more difficult to achieve, less sustainable and out the holistic development concept for water-food-energy-climate nexus.

4.3.1. Channel alternative

The concept of channels has been created to bring out the power facilities from the zone of flood wave influence. The disadvantages of this concept, compared with the river variety, are less installed power, lower production and uneven distribution of the effects and benefits among Bosnia and Herzegovina and Serbia. The previously developed idea consisted of two widely divergent channels: one through Serbia, in Mačva with HPP Lešnica and HPP Šabac, and the other through Bosnia and Herzegovina, Republic of Srpska, Semberija with HPP Bijeljina. The channels and hydropower plants evaded the reach of the flooding wave. The concept of a channel was developed through three sub-alternatives. Each of them implied channels subparallel with the main Drina River course.

4.3.2. River flow alternative

The solution with hydropower plants on the main river course consists of a sequence of four hydropower plants with equal modulation and unified equipment. These are run-of-river hydropower plants with a concrete spillway dam section and segment gates, and a retention building, held by side embankments. The downstream reservoir retention level tails at the lower outflow from the powerhouse, belonging to the upstream dam. To prevent the rising of groundwater levels in Mačva and Semberija, channels have been designed parallel to the embankment immediately behind them, which would function as drainages within the retention area and as irrigations within the lower flow area. They are built mostly by excavations. Such a system will stabilize the underground water body. Its task is to maintain the underground water level on an agricultural optimum level. The second goal is to maintain the underground water below the settlements on an allowable level according to the regulations.

The concept with four standard cascades (dams with hydropower plants) developed on a conceptual design level serves to develop the profitability and financial ability of such facilities by a single user – the electricity through concessions or otherwise. Although the profitability ratios were calculated only with the benefits of power production, they were still positive. The benefits from constructing such facilities would be used also by the water management, as the side embankments, barrages and the activity mode were determined in such a way that hundred-year floodwater could be transmitted through the main water flow between the embankments. Thereby the coastal area would be protected for free from a flooding probabilistic period of 1%. During processing the hydropower utilization of the Drina River between Zvornik and the Drina River mouth, beside the water management basis and previously developed conceptual designs, main and design projects for regulation of the Drina River, some of the Drina embankments and the bypass road around Loznica were used and corresponding research activities performed and analysed. This produced far greater benefit and the cost-benefit ratio increased when research was reached by incorporating the approach of water-food-energy-climate nexus.

4.4. Adopted alternative for Lower Drina

The adopted river alternative consists of four concrete gravity dams: Kozluk, Drina I, Drina II and Drina III. Each of them has accumulations, held inside embankments. A dam-toe hydropower plant as a non-spillway facility section is situated within the dam body, on the right side of the river flow. Each hydropower plant has four cross flow turbines. A switchyard is located on the right riverbank. The dam spillway section with segment barrages is simultaneously used as a bottom outlet. Starting downstream from Zvornik the adopted facilities are as follows:

– HPP Kozluk, NRL = 135.00 m.a.s.l., stationary km 64+150

– HPP Drina I, NRL = 121.00 m.a.s.l., stationary km 46+800

– HPP Drina II, NRL = 107.00 m.a.s.l., stationary km 31+140

– HPP Drina III, NRL = 93.00 m.a.s.l., stationary km 10+960

The basic concept of the so-called ‘river alternative’ with dams and hydropower plants within the main Drina River course is based on the idea of maximum utilization of the Drina River potential and cadence from Zvornik to the Drina River mouth. Therefore, it will admit the flooding wave upstream of the river basin; partially at the main facilities and partially by its inundation retention capacities. Such a solution will not disturb the groundwater level within the usual activity mode, i.e. it will avoid adverse and legally unacceptable environmental impacts.

Phased construction of dams and accumulations at the Drina River upstream of Zvornik is incorporated within such a concept. HPPs Kozluk, Drina I, Drina II and Drina III will simultaneously protect the riverbank area from hundred-year floods. Thanks to these hydropower cascades, the flooding within the riparian area of Mačva and Semberija would be less than in non-constructed conditions. It will be until upstream accumulations are constructed, which would retain and/or transform flooding wave’s peak larger than hundred-year flood wave’s peak. After all accumulations at the Drina River have been constructed according to previously implemented projects, the present and in such way designed hydropower cascades with side embankments Kozluk, Drina I, Drina II and Drina III (Table 7) fit into the future global concept of sustainable solution of the water-food-energy-climate nexus for the Drina River basin and riparian area.

Table 7. The main characteristics of the possible HPPs in the Lower Drina River section

Facility	Station	NRL	H_{br}	Q_{inst}	N_{inst}	E_{year}	$Q_{spillway.}$ with NRL
	km	m.a.s.l.	m	m^3/s	MW	GWH	m^3/s
HPP Kozluk	60+200	135	13.3	800	93.4	396.5	8000
HPP Drina I	43+600	121	13.3	800	93.4	396.5	4075
HPP Drina II	28+200	107	13.3	800	93.4	396.5	4075
HPP Drina III	8+800	93	13.3	800	93.4	396.5	4075

HPP Kozluk and the dam are completely the same as the facilities Drina I, Drina II and Drina III. The only difference is that HPP Kozluk has eight spillway sections sized to admit thousand-year flood waves of 8000 m^3/s. The probability of the occurrence of such flood is once in thousand years. The Kozluk accumulation retention does not flood the lower water of HPP Zvornik, and the lower water of HPP Drina III is not flooded by the Sava River levels. Sava River levels for certain discharges are taken from enveloped consumption curve at the Drina mouth into the Sava River, basically defined by the Drina River flow correlations and the Sava River level.

The cascades are uniform and partially created by excavations (Figure 4). The river bed is excavated within an approximate width of 160 m, with different sections resulting in different quantities of gravel excavation material. The layouts of the facilities are the following: there is a concrete dam within the river bed, consisting of the spillway section for floodwater evacuation and the non-spillway section with the powerhouse with horizontal flow pipe units. The spillway sections are set low with simultaneous bottom outlet function. All facilities are of the same size: the width is 20 m and height 8.6 m to NRL (normal retention level). The detailed sizes of all the structures are given in Table 8. These data are corresponding to Figures 4, 5 and 6.

The HPP Kozluk dam has eight spillway sections (Figure 5). The dams of Drina I, Drina II and Drina III have four spillway sections each (Figure 6). Every section is equipped with a segment steel shutter. The spillway at the HPP Kozluk dam has two valves for the evacuation of surface alluvium or possible ice evacuation. The spillway parts of the dams of HPPs Drina I, Drina II and Drina III are each equipped with one valve for the evacuation of the surface alluvium, or possibly, ice evacuation valve. These valves are located at spillway sections close to the hydropower plant.

Table 8. Basic elevation on hydropower plants layout

	DRINA I	DRINA II	DRINA III	HPP KOZLUK
Dam crest level	122.50	108.50	94.50	136.50
Turbine axes level	99.35	85.35	71.35	113.35
Mounting space level	115.50	101.50	87.50	129.50
Entrance building brink level	94.50	80.50	66.50	106.50
Siphon bottom level	95.05	81.05	67.05	109.05
Drainage channel bottom level	99.35	85.35	71.35	113.35
Stilling basin bottom level	96.70	83.60	69.60	111.60
Downstream plateau level	115.50	101.50	87.50	129.50

Since the hydropower plants are at the right Drina Riverbank and since the switchyard is installed on the same riverbank, the facilities are accessible from the embankment and inundation. A bridge is planned above the spillway sections for service vehicles and the cranes rather than public traffic.

4.5. Balancing of the underground water body

Underground water body equilibrium is very important in the Lower Drina section of the river. The accumulations are formed between the left and right-side embankments. Normal retention level causes the increase of the elevation of the groundwater level at the forehead of the accumulation, near the upstream part of the dam. A certain depression of natural underground water levels appears at the tail of the accumulation, due to river bed excavations.

To bring groundwater bodies into natural equilibrium or to desired levels convenient for agriculture, the channels are constructed parallel with the embankment. These channels are mostly drainage channels. The function of the drainage comes to the fore at the part of the river where the groundwater level is increased. Those channels are used for irrigation where the depression section is caused by excavation. There is a decrease in the natural underground water levels. The main task of the constructed channel would be the stabilization of groundwater levels in Mačva and Semberija, as well as improvement of the agricultural, i.e. food production.

The facility Drina I is a non-standard facility as there are auxiliary spillways at its side embankments with two spillway sections, each one of the same sizes and with the same equipment as at the main facilities. They have been used for evacuation of one part of the floodwater for less than one hundred years, which would otherwise flood more intensely. If one part of the flood wave was discharged into the inundations uncontrolledly, the side embankments would be destroyed, causing disastrous flooding of Mačva and Semberija.

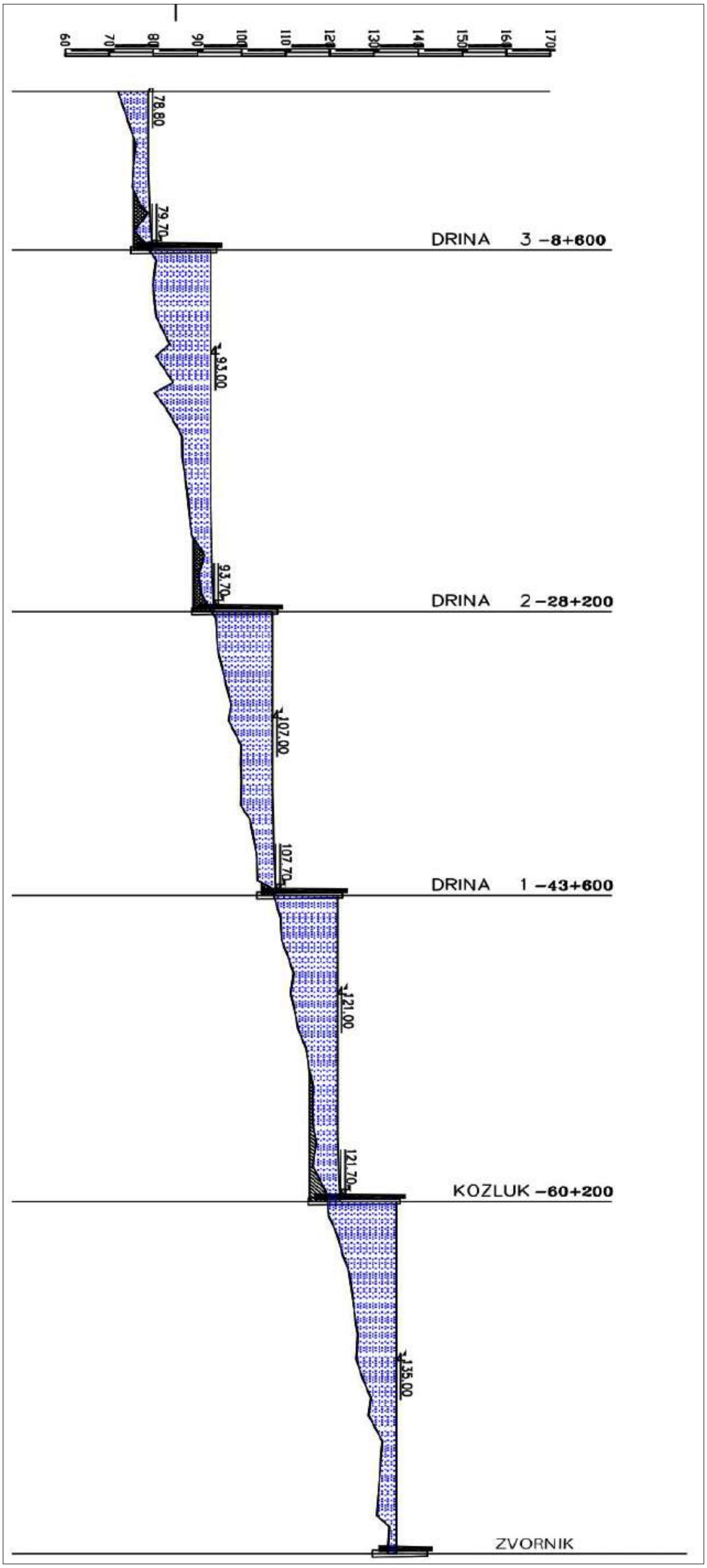

Figure 4. Longitudinal cross-section of the Lower Drina River with four cascade dams and apparent powerhouses

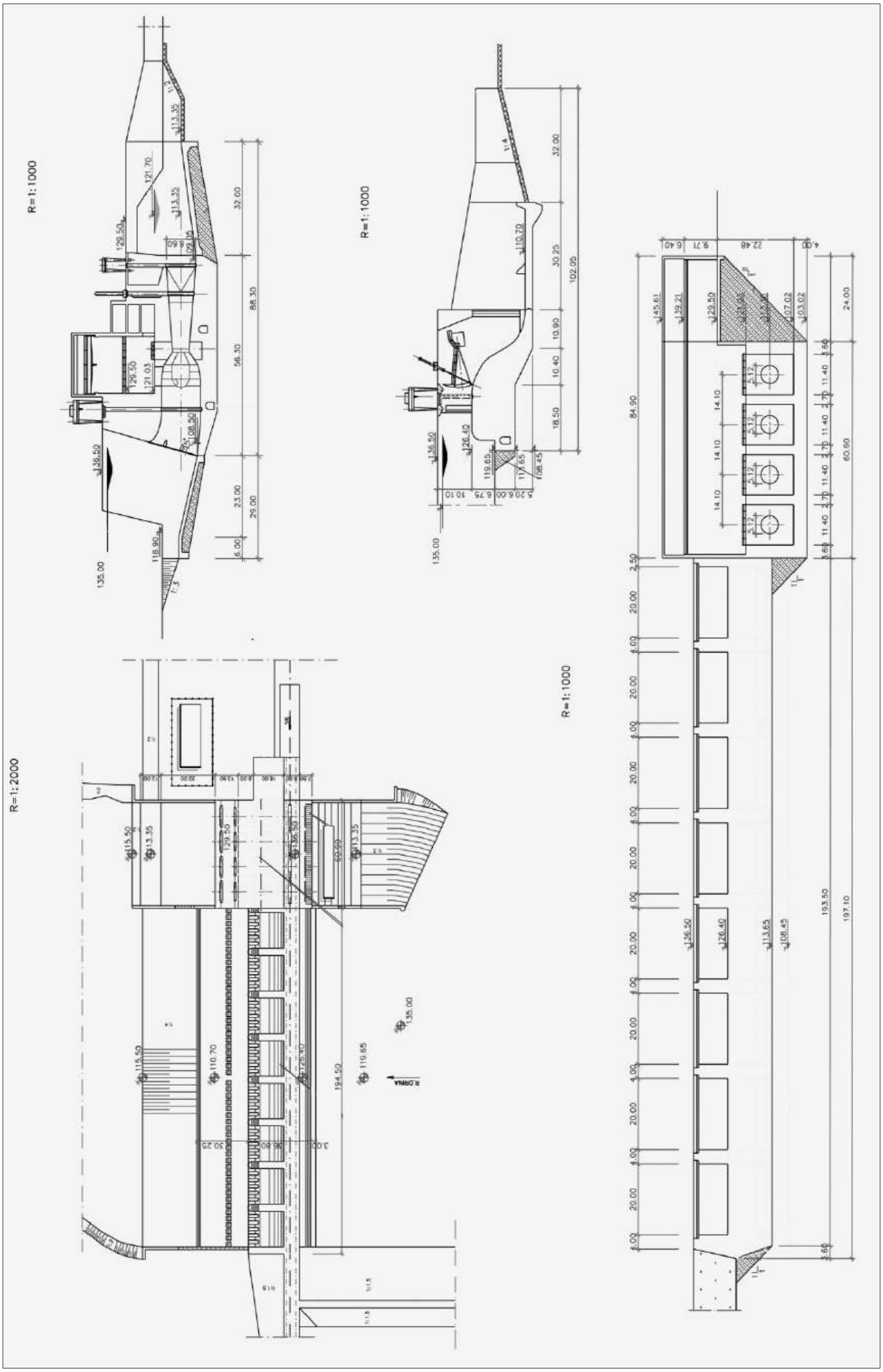

Figure 5. The layout of the dam and HPP Kozluk with cross-sections through the powerhouse, spillway and the concrete dan

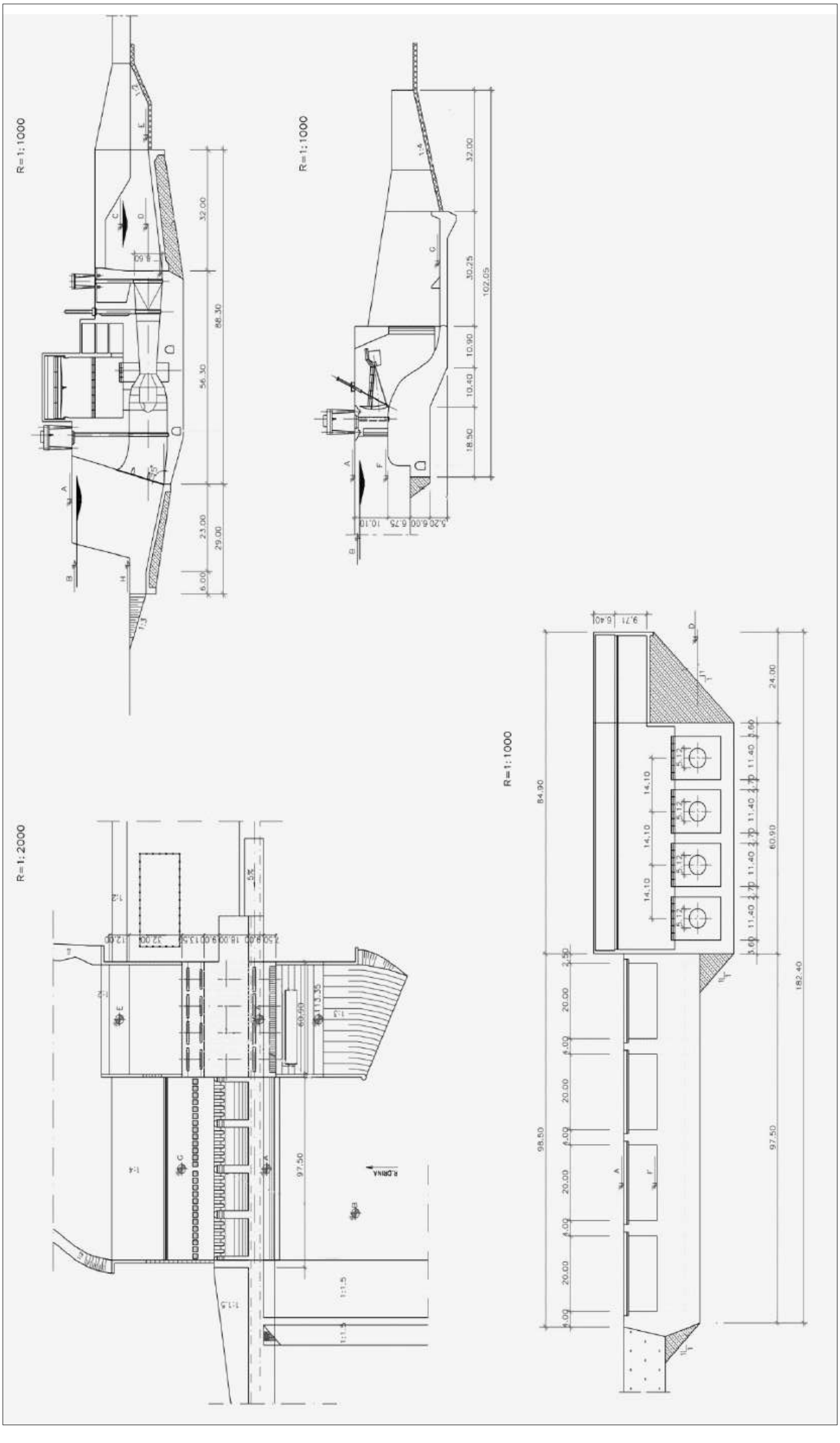

Figure 6. The layout of the uniform dams and HPP Drina I, Drina II and Drina III with cross-sections through the powerhouse, spillway and the concrete dan

If the social community wants to be protected against the probability of less than one-hundred-year floodwater, reservoirs could be constructed to control flooding (one of several purposes) within the upper or medium Drina River flow and/or the side embankments at Kozluk, Drina I, Drina II and Drina III could be elevated and/or within the valleys of Mačva and Semberija cassettes could be constructed for controlled admission of larger than one-hundred-year floods. Previous experiences and analyses have shown that river flow water can be optimally managed with the best effects in flood protection if at the upper river flow front reservoirs and/or reservoirs at the medium river flow are constructed while the valleys are still unpopulated.

Certain embankments already constructed exist within some sections for hundred-years flood protection of Mačva and Semberija. However, they are considerably damaged. Serious reconstruction jobs are needed and planned. Main designs already exist for embankments within certain sections. Within this solution, the embankment around Loznica is built into the body of the Drina I side embankment.

The embankments near Crna Bara, Badovinci and Balatun could not be used as they are too far from the requested side embankment track, but they might be used within probable cassetting. The locations of the side accumulation embankment from hydropower solution mostly concur with the last phases of the main embankments, designed for coastal protection against hundred-year floods.

4.6. Hydrogeology and coastal area protection

According to the determined concept and defined criteria that the planned hydropower facilities, dams and belonging reservoirs within the Lower Drina River flow shall not influence the change of the coastal groundwater regime, but vice versa, to stabilize the groundwater level related to oscillations within the natural regime, it is necessary to take protective actions to facilitate the water spillage evacuation from the reservoir, reduce the pressure at the hinterland and stabilize the groundwater level. As the accumulations are created and held within the side embankments, the conclusion is that within the reservoir area near the upstream dam side normal retention level causes the groundwater level to rise, and within the reservoir tail, a depression of underground natural water level is created due to riverbed excavations. Due to this, the construction of embankments is necessary and parallel with embankments of channels, which mostly have a drainage function, and within the section of groundwater level depression due to excavations an irrigation function.

The simulation of these systems activities was made by applying the following mathematical model: a three-dimensional model for verification of natural conditions and response of the aquifer to full reservoir and drainage system activity conditions and by using the method of finite elements, the channel geometry and unit flow, as well as the groundwater level position directly in the hinterland have been determined.

With this research model, the aquifer hydraulic scheme has been adopted on a free level, which lies on impervious grounds with a medium filtration ratio $K = 2 \times 10^{-3}$ m/s. The limiting conditions have been determined with H = const (Drina) for the natural condition and H = const (retention level) for full accumulation conditions. In the riparian area, at the distance from about 3 km from the river, the condition of maintaining the natural groundwater level is given (H = const).

The three-dimensional models for full accumulation and drainage system activity conditions for the facility Drina III shows that the aquifer natural conditions are preserved at a certain distance from the river and that the imperfect drainage channel parallel to the embankment successfully maintains the hinterland water level at the minimum allowed depth.

Downstream the dam, within the affected zone of excavated riverbed, the groundwater level is 5-9 m lower than the terrain level. As the natural regime is substantially aggravated in this way, intervention is necessary to eliminate the drainage effect of the excavated river bed as much as possible. In addition, an extension of the drainage channel is suggested downstream the partition profile, through the terrain with low groundwater level having the function of an irrigation facility. The length of irrigation channels is 1.5-2.5 km.

Using the method of finite elements, several mathematical profiles of each streamline have been created, with detailed schemes of the river bed, inundation area, accumulation, embankment and drainage channel. A simulation has been made of an imperfect river bed 70-80 m wide, of a low impermeable area with an average width of 200 m and basic embankment width of 70 m. The requested width of the drainage channel is 3 m.

The supply units into the drainage channels (q), total channel supplies (Q) and groundwater levels at the direct hinterland have been calculated using a mathematical model. At the ends of the calculation profiles, natural aquifer conditions have been maintained. The results are shown in Table 9.

At the profiles Drina I and Drina II, the average depth of the drainage channels (3.5 and 4 m) is sufficient to allow coastal protection along the whole track. Along with the accumulation of Drina III, the average channel depth is 4.5 m, with 5 m or more at the downstream section. Considering the difficulties in creating deep channels, it was suggested that the depth should be also 4.5 m at this section at a length of 7 km and that a system of self-outlet wells should be constructed to achieve a full protective effect.

Table 9. Results of mathematical models (according to finite element method)

Profile		DRINA I	DRINA II	DRINA III
Retention level (m.a.s.l.)		121.0	107.0	93.0
Drainage channel	Channel water level	114.8	100.6	88.0
	Channel depth	3.5	4.0	4.5
	Channel bottom level	113.5	99.0	86.5
q (l/s/m)		0.500	0.849	0.825
Left channel	Length (m)	3 500	11 200	16 000
	Q_L (l/s)	1.748	9.509	13.198
Right channel	Length (m)	15 000	11 200	16 000
	Q_D (l/s)	7.492	9.509	13.198
$Q = Q_L + Q_D$ (l/s)		9.240	19.018	26.396
Terrain level – Maximum by-pass level		117.0/115.28	103.0/101.55	91.0/89.16

4.7. Embankments for protection of Mačva and Semberija

The embankment type has been adopted based on existing experiences in constructing embankments along the Drina River, which means that primarily the availability of clay materials has been taken into consideration. The cross-section geometry is complying with exploitation conditions, as the embankments are exposed to constant retention impacts of HPP Drina I, Drina II and Drina III. The embankment trails are new, except for the right embankment section of Drina I at the length of 500 m, where the existing embankment is higher, together with the bypass around Loznica town. The accumulations of Kozluk, Drina I, Drina II and Drina III are created within the scope of the left and right embankments of the reservoir. The embankment lengths are:

- at Kozluk on the left side 8.5 km,
- at Drina I, the left embankment has a length of 4.4 km, the right embankment has a length of 11.6 km,
- at Drina II left embankment has a length of 10.4 km, the right embankment has a length of 9.8 km and
- the Drina III left embankment has a length of 11.5 km and the right embankment has a length of 13.0 km.

The embankment crest level is defined on the complete section between Zvornik and mouth of the Drina River into Sava River, as a higher value according to the following criteria:

- NRL + 1.5 m, where NRL is normal retention level and
- MRL + 0.5 m, where MRL is a maximum retention level.

The embankment construction is of great importance due to its multipurpose character. These embankments hold the reservoirs for energy production protect Mačva and Semberija from flooding and allow better agricultural conditions.

4.8. Hydropower production

The installed power (93.4 MW) and possible production on each of four hydropower plants are equal (HPP Kozluk, HPP Drina I, HPP Drina II and HPP Drina III). The possible production was calculated using a 40-year sequence of medium daily flows and using the curve of lasting medium daily flows. A daily adjustment is made at the reservoir, with a delevelling up to 1 m. The biological minimum of 75 m^3/s is constantly discharged to maintain the flow downstream HPP Drina III. All four dams are set in a disposition in such a way that the retention level of downstream reservoir is at the same time tailing, i.e. outlet level from the upstream powerhouse. The gross head of each HPP is 13.3 m.

The installed flow of 800m^3/s complies with the installed flow of all upstream hydropower plants [14] and with HPP Zvornik, whose increase from 640 m^3/s to 800 m^3/s is being considered and processed. All four hydropower plants in a sequence (HPP Kozluk, HPP Drina I, HPP II and HPP III) operate under the operating mode of HPP Zvornik. All power plants in the section of Lower Drina equally depend on the adjustment at the upstream power plants and reservoirs.

The energy production is calculated using medium daily flows from HPP Zvornik with maximization of the peak daily power production. The total annual production of each of the four hydropower plants is 396.49 GWH, whereby 213.66 GWH is peak power. In accordance with the diagram form of the network charge duration, the peak power has less than 20-hour duration. The minimum duration of peak activity is 2 hours. The basic energy is produced with medium daily flows, which are:

- higher than the installed flows
- equal with the installed flows, or
- equal to the biological minimum, as well as those
- lasting longer than 20 hours.

The basic hydropower power is the power at which it is possible to produce constant energy with a thermopower plant utilization coefficient of 0.7. The difference above the installed and in the above manner calculated basic strength is recognized as the guaranteed peak power, under the condition that the peak power is guaranteed with a daily duration not less than two hours, within 90% hydrological researched cases and not longer than 20 hours. In such a method calculated basic power is 34.84 MW and the peak power is 58.56 MW. Guaranteed productions during the year within periods of higher and lower seasons and higher and lower rates have also been calculated.

4.9. Results of techno-economical analysis

The results of financial and economic analysis of the hydropower exploitation of the Lower Drina, as well as the comparative review of basic indexes, are shown in Table 10.

Table 10. Main financial and economical parameters

	Investments (mill $)	Spec. investments ($/KW)	Invest. quotient ($/KWh)
HPP Kozluk	299.75	3315.98	0.83
HPP Drina I	113.42	1384.86	0.33
HPP Drina II	125.12	1527.72	0.37
HPP Drina III	126.67	1546.64	0.40

This chapter presents the optimum utilization concept of the Lower Drina River at the section between the dam and the HPP Zvornik and the Drina mouth into the Sava River with an extremely expressed conflict of all existing interests of the resource users making a water-food-energy-climate nexus realistic. A real example from the practice of an interstate multipurpose solution of the hydro potential distribution, concerning the users and within the scope of an integrated water management solution is analysed. The goal function has been achieved by a defined compromise solution of a water-food-energy-climate nexus. Maximum possible techno-economic effects of the hydropower plants construction have been achieved. On the other hand, the adopted hydropower technical solution allows using the optimum of all resources. It proportionally blends without disturbing either the natural or social and political environment. The shown holistic and sustainable hydropower technical solution has been recommended for further analysis and elaboration. The simultaneous conclusion is that the construction of the flow dams and hydropower plants, before and along the whole Drina River, as key and strategic facilities, is of the same great importance for all users from the aspect of water-food-energy-climate nexus, and especially for such a region as the Lower Drina, which also has the potential for food production.

The results obtained have arisen only from calculating the costs and benefits of power production. Since the embankment construction and drainage channels construction have obvious positive effects on agriculture, food production and flood control, it is clear that the proposed solutions will have only higher coefficients of rentability, by including all benefits of the water-food-energy-climate nexus.

5. DISCUSSION

Hydropower plants and reservoirs, besides energy production, enable a set of different benefits within the nexus water-food-energy-climate. The point is to define the optimal retention level of the accumulation, in order not to affect other users. In most cases, according to case studies presented in this paper, the optimal solutions for water-food-energy-climate nexus are the cascades in the river bed.

The beneficiaries of the hydropower potential of the Drina catchment area shall also participate in the financing activities including the Republic of Serbia, Republic of Montenegro, Republic of Srpska and Federation of Bosnia and Herzegovina [21] (Table 11). The percentage of participation in financing shall be according to the appertaining part of the potential in the catchment area, according to the possible portion of power generation respectively:

Table 11. Percentage in participating in Drina River hydro potential

	User	Number of power plants in the catchment area	Financing (%)
1	Republic of Serbia	11 -(2)	33%
2	Montenegro	14 - (1)	37%
3	Republic of Srpska	8 - (3)	27%
4	Federation of BiH	3	3%

The participation in financing would be similar for the construction of all plants totalling 3120 MW, and the total investments were estimated to be approximately 3.5 billion dollars. Possible specific power generation on Drina River and its tributaries amounts to 0.74 kWh/year/m^2 from the catchment area which is three times more than in the other catchment areas in Balkans' countries [22]. To date design documentation has shown that reservoirs with approximately 5 billion m^3 live capacity can be constructed, and the structures constructed by now comprise 2 billion m^3 [23]. The annual power production of all reservoirs could reach about 6 billion kWh, not taking into account the development of other water resources (water supply, irrigation, flood control, etc.) [24]. The total annual power potential of the entire Drina catchment area is 15.6 billion kWh with a total capacity of about 5300 MW. Up to now constructed and operational facilities generate 6.4 billion kWh/annually with about 2000 MW [25]. These figures show that 63% of the total Drina capacity remains free for future construction.

This research was conducted to find optimal and synergy solutions for the remaining parts of the Drina River. The goal was to offer artificial intelligence methodologies for selecting the compromise water-food-energy-climate nexus. Fuzzy expert system, AHP linear programming, Delphi method, Electra, Prometee and multi-criteria compromise ranking (VIKOR) were applied. All of them helped the researcher incorporate the requirement of sustainable development and climate neutrality into water management optimization problems. The diversity of possible water usage makes the complexity of the Drina River water-food-energy-climate nexus.

Figure 7 shows the longitudinal profile of the Drina River with its main tributaries and constructed and designed hydropower facilities, according to today's level of knowledge and opinion of decision-makers, scientists and engineers. Regardless of which method was used in this research, most of them indicate that the solutions for water-food-energy-climate nexus should be sought as cascades in the riverbed.

6. CONCLUSION

The hydropower potential of the Drina River and its tributaries is significant. The Drina is the river that connects the people, entities and countries. Having a set of conflict interests and different stakeholders and different decision-makers, the strategic hydro-technical structures on the Drina River have to be optimized with serious consideration, applying contemporary methodologies, which allows us to incorporate all criteria from the nexus of water-food-energy-climate. The goal is to fulfil all the requirements from the adopted European Green Plan for the Western Balkans and to meet the criteria of sustainable development and the requirements of reducing global warming.

Water is an essential matter in the world. There is no life without water. There is no food without water. On the other hand, uncontrolled waters can endanger man and his goods. Drina River is very known for its floods. However, the fact is that the watercourses having the imposing head like Drina River is natural significant potential for the production of clean renewable energy. All human activities within the Drina River valley, i.e., constructing channels, embankments, dams and hydropower plants, can affect the climate at the same time. This paper offers a solution to finding the synergy within the complexity of that multidisciplinary optimization problem.

The previously shown longitudinal section of the Drina River in Figure 7 shows a set of previous and new solutions, thus making a complete solution for hydropower utilization of the Drina River, with all tributaries, from source to the mouth, with maximum respect for nexus of water-food-energy-climate.

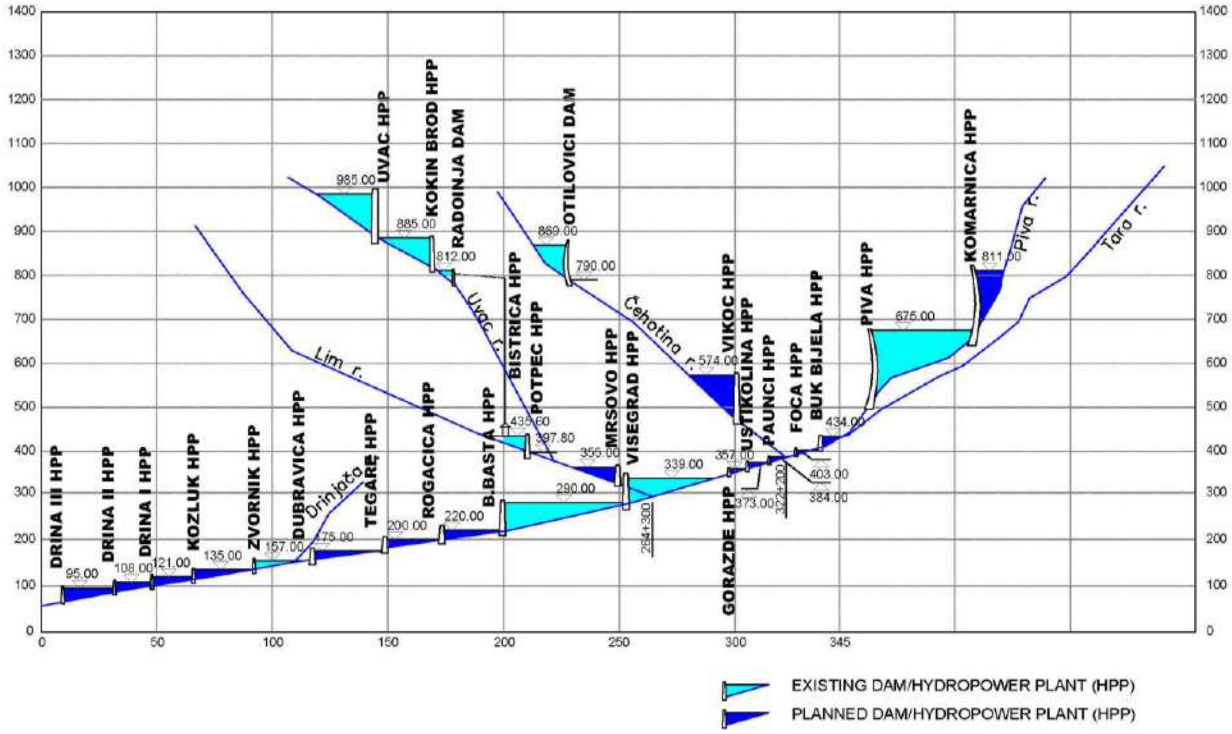

Figure 7. Drina river longitudinal cross-section with existing and planned power plants in its catchment area

This paper presents contemporary artificial intelligence methodologies. Complex methods are applied and a sustainable transboundary hydropower system on Drina River as a synergy of water -food-energy-climate nexus is investigated. Drina River nexus of water-food-energy-climate case studies, between Foča and Goražde and downstream of HPP Zvornik, along the river to the mouth to Sava River, are analysed. It is proven that the cascades in the riverbed are the optimal solutions. Further research can analyse the remaining parts of the river and tributaries in detail.

It is a general trend that people are increasingly building their households in river valleys, as well as the roads. It is especially present in the valley of the Drina River. Bearing in mind that the Drina River valley is becoming more and more populated, it is clear that there is a great risk that the technically usable hydropower potential will be further devalued. For the technically usable potential to become economically usable, it is necessary to find investors for the designed dams and hydropower plants and build these important strategic facilities on the Drina River as soon as possible. Frontal reservoirs in the upper part of the river can be with larger volumes. They would play a significant role in stopping the flood wave because floods occur in the upstream parts of rivers. The Cascades would be built downstream. Joint design and construction of such hydropower facilities would strengthen regional cooperation in the field of renewable energy sources to meet the conditions of the European Green Plan in the Western Balkan.

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ОДРЖИВИ ПРЕКОГРАНИЧНИ ХИДРОЕНЕРГЕТСКИ СИСТЕМ НА РЕЦИ ДРИНИ КАО СИНЕРГИЈА НЕКСУСА ВОДА–ХРАНА–ЕНЕРГИЈА–КЛИМА

Сажетак: Река Дрина са свим својим притокама и разгранатим сливом преко територија Босне и Херцеговине, Црне Горе и Србије, одувек је била извор воде за пиће и наводњавање за производњу хране. Својим мостовима вековима је спајала народе и културе. Истовремено, са великим падом Дрина је увек представљала значајан хидроенергетски потенцијал. Кроз историју, на њој су грађене бројне воденице. Тренутно на Дрини и у њеном сливу постоји низ изграђених хидротехничких објеката. Међу њима су најважније бране, са саобраћајницама преко њих, припадајућим хидроелектранама и пратећим органима за контролу од поплава, водозахватима за воду за пиће или наводњавање. Због више могућих, скоро увек супротстављених намена, као и више држава, ентитета и других заинтересованих страна, управљање водним ресурсима реке Дрине из угла нексуса вода–храна–енергија и клима екстремно је комплексан проблем. Поред утицаја на хидроенергетику, пољопривреду, шумарство, саобраћај, наводњавање и одводњавање, туризам и социокултурна збивања, изградња оваквих стратешких објеката има свој одраз и на климу региона Западног Балкана. Питање оптимизација у оквиру нексуса вода–храна–енергија и клима захтева холистичка истраживања са циљем проналажења синергијских решења. Та решења су свакако компромисна. Али неизоставно, она морају испуњавати критеријуме одрживог развоја и захтеве смањења глобалних загревања, према постављеним условима усвојеног Европског зеленог плана за Западни Балкан. У овом раду је предложена методологија за изналажење оптималних / компромисних хидроенергетских решења, која синергијски обухватају све параметре од утицаја. Представљена су холистичка истраживања одрживих хидроенергетских система на реци Дрини, из угла нексуса вода–храна–енергија–клима. Посебно детаљно су урађене анализе потеза реке између градова Фоча и Горажда, као и низводног дела од Зворника до ушћа, познатог као Доња Дрина. На тим деоницама је највише изражен конфликт да ли ће се вода користити за пиће и/или за производњу хране и/или за производњу енергије и какав утицај могућа решења имају на климу региона.

Кључне речи: Дрина, вода, храна, енергија, клима, Фоча–Горажде, Доња Дрина.

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