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ENVIRONMENTAL, SOCIAL AND OTHER NON-PROFIT IMPACTS OF MOUNTAIN STREAMS USAGE AS RENEWABLE ENERGY RESOURCES

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ABSTRACT

The main subject of this manuscript is mountain streams used by construction of small hydro power plants. The motivation for this research stemmed from a number of conflicting opinions about the justification of the construction of small hydropower plants and their facilities. This research encompasses different methods for the analysis of the justification of the construction of a small hydropower plant, starting from tradition in correlation with water mills, through a techno-economic approach to a complex multi-criteria research model. All methods are represented by objective formulas.

World experiences are also presented, through the level of potential utilization, compared to the degree of development. The possible positive and negative impacts of the construction of such facilities for the exploitation of the potential of small watercourses were analyzed. After the conducted research, and with respect to the principle of minimum energy, which has become the paradigm of modern civilization, it can be concluded that using the potential of small watercourses by building small hydropower plants belongs to the domain of using renewable energy sources and that it is a function of sustainable development.

Decision makers are recommended to exclusively apply a multi-criteria methodology, which can holistically include all technical, economic, environmental, social and other non-profitable but important impacts.

Key words: *streams, renewable energy, resources, environmental impacts, social impact*

INTRODUCTION

Analysis of coal reserves and coal quality show decreasing function [1] and that is why the transition to renewable energy sources is imperative and the paradigm of the new age. The potential of small streams and small hydropower plants (SHPP) is one of the possible resources and means of using renewable energy sources (RES). The recent negative practices in some countries that SHPP couldn't be constructed due to public hearing; although the design fulfilled every legal step, are a motive for the research carried out in this paper. The goal is to examine the issues of conflicting interests on a holistic way, to quantify and rank certain negative environmental impacts and seek synergistic sustainable solutions with less negative environmental, social and other non-profit impacts.

The obtaining of a permit for the construction of SHPPs, in accordance with the law, necessarily follows the preparation and adoption of the Environmental and Social Impact Assessment Study. The study is reviewed by the competent authorities, but since the public hearing becomes one of the most important steps in a decision making process, the study has to be accepted by the interested local community and the wider public. Rejecting a study, and consequently rejecting a project at a public hearing, regardless of whether the investment is private or social, results in the devaluation of previously invested funds in the project. At the same time, if the Study is accepted and if the project is approved and implemented, the question arises whether the prescribed biological minimum and environmental and social protection measures, such as monitoring and sanctions for offenses, will be respected in practice.

The implementation of renewable energy sources is an imperative of the modern age and obligations under the Kyoto Protocol, the Paris Agreement and other binding international agreements signed so far [2]. Although RES are far more favorable for the environment, it happens more and more often that environmental movements in public debates shoot down hydropower projects, including SHPP projects. That is why this manuscript represents a tradition, techno economy and multi-criteria holistic assessment of relevant aspects of synergic incorporation of SHPPs.

In order to manage resources efficiently, so that they can be used by future generations, and in order to avoid any abuse, it is necessary to include all relevant stakeholders in the decision-making process at the very beginning of the optimal construction concept. Also, it is important to have access to adequate methodologies. The goal of this paper is to analyze all potential impacts, all conditions and constraints, and then to align the criteria by degree of importance as positive or negative, in order to help in compromise decisions. Comprehensive and long term consideration of the problem is required, and that is why the methodology starts from the traditional approach. In this paper, after tradition and techno economy approach, for the selection of an optimal SHPP concept, whether it will be a multipurpose, accumulative, flow or derivative type of plants, it proposes a methodology with multicriteria approach with respect to all conflicting interests and the search for synergistic compromise solutions. Examples of different practices in the field of hydropower in EU are given too. Main positive and negative environmental and social impacts are analyzed. The multicriteria methodology is offered as a support for decision makers, with the goal to reach the optimal holistic solution for optimal streams exploitation.

METHODOLOGY

Although the carbon dioxide level is very high and SHPP are RES, in some countries, SHPP can't be constructed due to negative public hearing. Recently, in some cases, consideration of environmental protection has appeared as absolute conservation of everything in the stage "as it is". That idea is to remain small rivers intact. A series of random events is possible to happen on public hearing. This introduces entropy in decision making process of big strategic projects. On the same time, elimination of some profitable strategic energy structure by giving such a big importance to public hearing in local community is under risk sometimes, although this construction can present big benefit for wider social community. Science try to develop a different multicriteria holistic approaches in order to prevent mistakes in strategic decisions, such as the construction of hydro technical structures, HPPs or SHPPs are. The methodology in this manuscript encompasses holistic approach which respects tradition and develops multicriteria analyze of all relevant input variables, i.e. influencing factors for decision-making.

Methodology based on tradition

Carter d'Kinsey said that in order to reach the original principles in the contemporary construction and building creativity of different countries, there were several paths [3]. The main ones, which lead to the goal the fastest, rely on the tradition and nature of the given area, on concepts and phenomena proven throughout history, as well as on the cultural monuments already built. One of the cultural monuments is certainly the water mill, as a forerunner of SHPP.

Starting from the traditional principles of construction and the selection of the location of the existing, old mills, optimal solutions for the construction of SHPP are arrived at [4]. The researches on the locations of old water mills have confirmed that the locations of old water mills are most often the optimal disposal solution for small, mini, or micro hydropower plants. With relatively small additional investments, it is possible to reconstruct and revitalize the mill building, install equipment for a small hydroelectric power plant, implement "feed in" tariffs, or be part of the program of co-financed CDM (clean development mechanism) projects, with green certificates, reap benefits on the CER market (certified emission reduction), and yet preserve the quality of the environment and have a positive social impact on the local community.

The reconstruction of old mills into small hydroelectric plants, while retaining the authentic architectural and cultural values of the buildings, is one of the possible ways of efficient use of renewable hydro energy, in the function of sustainable development.

If the region of Serbia is analyzed as a case study, it can be said that throughout history, from the time of the Nemanjic dynasty until today, significant constructions that use renewable energy sources have been recorded. Regardless of the history and literary works related to the mills, it is evident that they were built in the locations where the flows are relatively stable, where the watercourse rarely dries up and where, definitely, there is technically usable potential, so notes from history can still be purposeful used today. The hydro potential at the site of an old water mill is not large, but it is significant through the mathematics of a series of small numbers and in the context of preventing global warming and the difference related to the impact on the environment, when renewable, instead of non-renewable energy sources are used.

In a long-term analysis, Serbia does not have enough energy resources to meet the needs of its own consumption in the future and that in this case it would have the right to ignore the potential of small watercourses.

Techno economy approach

Profitability can be examined by the cost-benefit method of economic analysis. Comparison and evaluation of all advantages and shortcomings of different models of small hydro power plant, as a business operation, is to be performed. Also, costs and benefits are analyzed. This method is important for making right decisions and project corrections, but this method doesn’t include environmental and social impact factor.

Techno economy approach relly on calculation of correlation between all benefits (measured by money income) and real construction cost of all necessary feacilities. When calculating the profitability coefficient, as basic techno-economic indicator of profitability, following formula (1) is to be applied:

$$r = \frac{B}{C} \quad (1)$$

with following values:

- r_i – profitability coefficient for small hydro power plant
- B_i – financially quantified benefits (gains) of small hydro power plant
- C_i – costs (investment, maintenance and operational costs) of small hydro power plant

Multicriteria approach

Small-scale hydropower is a promising area and at the same time has its theoretically proven justification [5]. Sometimes one comes across various abuses of the water resources of small streams, as a common good, on blocked fishing paths, on situations with non-observance of the specified guaranteed ecological flow, which unfairly casts a shadow on the entire area of small hydropower and forces scientists and engineers to look for more adequate methodological approaches to testing and proving the justification for the construction of such facilities. When a wider area is chosen for the construction of the SHPP, the methodology offered in the following text enables the selection of an optimal synergistic solution, which holistically respecting all relevant decision-makers at the very beginning of the process, would reconcile conflicting interests in the function of environmental protection, positive social impacts, as well as other components of sustainable development.

New methodologies must inevitably have a holistic approach. To solve a series of problems, a synergistic solution can be sought by forming a multi-criteria system with n relevant input variables that should holistically include, but not be limited to:

- Technical
- Economic
- Financial
- Energy
- Environmental
- Cultural and historical
- Political
- Regulatory influencing factors

For each individual situation in practice, the relevant input variables are specifically formed, ie. influencing factors for decision-making. In the light of today's sharpened conflicting interests, for the solution of the optimal concept of the SHPP construction, for the selection of, whether it will be a multi-purpose, accumulation, flow or derivation plant, a methodology is proposed that respects all opposing actors and seeks compromise synergistic solutions, using multi-criteria optimization, supplemented with Delphi method and survey method.

In order to understand all possible developing strategies for construction of small hydro power plant, not only from the angle of technical, economic and financial parameters, but also from the angle of environmental, social and other impacts, a multi-criteria analysis can be applied. *n* alternative solutions for electricity supply from small hydro power plant a_i are analyzed:

a_1 – Supply from small hydro power plant technical solution 1
a_2 – Supply from small hydro power plant technical solution 2
a_3 – Supply from small hydro power plant technical solution 3
...
a_n – Supply from small hydro power plant technical solution n

Alternative supply solutions can be scaled by one of multicriteria method: Analytic Hierarchy Process (AHP) [6], ELECTRE [7], PROMETHEE [8], VIKOR [9], Simple Additive Weighting (SAW) [10] and their variations. It is considered that for the decision maker following criterion functions f_j are crucial:

f_1 - investment (€),
f_2 - maintenance and other costs (€/day),
f_3 - price of 1 kWh in the energy market (€c/kWh)
f_4 - environmental impact (objective note, scaled from 1 to 5, gained by Delphi method)
f_5 - social impact (objective note, for instance scaled from 1 to 5, gained by Delphi method or survey method)
...
f_j - other impacts not numerically quantified.

$i = 1, 2, 3, ..., n$
$j = 1, 2, 3, ..., m$

The matrix with criteria values k_{ij} for each variant can be constructed as presented in Table 1.

Table 1: Matrix of alternatives a_i and relevant criteria f_j

	f_1	f_2	f_3	...	f_j
a_1	k_{11}	k_{12}	k_{13}	...	k_{1m}
a_2	k_{21}	k_{22}	k_{23}	...	k_{2m}
a_3	k_{31}	k_{32}	k_{33}	...	k_{3m}
...	...	...	...	...	...
a_n	k_{n1}	k_{n2}	k_{n3}	...	k_{nm}

Investment (€) represents the criteria f_1 for each variant. Criteria f_2 means maintenance and other costs (€) on daily bases. Criteria f_3 represents the price of 1 kWh in the energy market. For instance criteria f_4 or f_5 can be calculated as objective notes (scaled from 1 to 5), obtained by Delphi method or questioner method.

Every community strives to minimize investment, maintenance and other costs (criteria f_1 and f_2). At the same time, the goal is to maximize the selling price of electricity on energy market (criteria f_3) and positive impact on the environment (criteria f_4) and social impact (criteria f_5). In this case the function of criteria f_1 and f_2 are to be minimized, and the function of criteria f_3, f_4 and f_5 are to be maximized, as per equations:

$$\lim (f_1, f_2) \rightarrow \min \qquad (2)$$

$$\lim (f_3, f_4, f_5) \rightarrow \max \qquad (3)$$

In order to test results stability and conclusions, an analysis of sensitivity of the result changes to input variables change has to be made by criteria weight. Matrix of different combinations of criteria weight f_j is to be done. The results of the multi-criteria ranking by any method can have a graphic and/or table representation.

Delphi method

Experts from the field were interviewed, all of them in long-term business contact with the small hydro power plants, among which were: main investor, chief manager, marketing manager, main supply manager, main engineer for construction, main engineer for the design of small hydro power plant, environmental expert, social expert, economy expert, low expert, energy expert, etc. Experts have been asked a set of the most important questions, for which it is considered, after the experts' response, to be able to reach conclusions on the best solution [11].

Answers of individual experts, their probability and statistical analysis of expert team survey results using the Delphi method can be presented graphically for each of the selected questions. The expert team is to be composed of renowned experts in the field, which ensured objectivity and competence. The experts answered the same questions in four rounds. Arithmetic mid, variant and standard deviation are statistical indicators can be calculated for each question.

Based on answers obtained in the first round of the Delphi method, average forecasts are calculated that represent the mid value of individual forecasts, as well as variations of forecasts around the mid value, which represent a corresponding degree of forecast precision. The second round of the Delphi method, sent to the experts, contained a calculated average forecast, a corresponding degree of forecast precision and extreme forecasts with their explanations. Experts were asked to review their original forecasts, make possible corrections, and deliver an opinion on extreme forecasts along with appropriate argumentation.

The final forecast was obtained as the mid value of the forecasts from the last round of the Delphi method. In the next phase of the Delphi method, testing of time dimension of achieved and set target functions was carried out, as well as the level of compliance of the experts' responses with respect to all issues and realization period of targeted events with high probability.

RESULTS AND DISCUSSION

EU experiences

The utilization of water potential is on average around 65% in Europe [12], while for example in Africa it is 1,2% [13]. Some European countries have a very high level of hydropower utilization:

- Norway – 100%
- France and Italy - 87%
- Spain and Switzerland – 86%
- Sweden – 65%

In many underdeveloped countries, the percentage of technically and economically utilized hydro potential is relatively low. As a renewable form of energy, the most environmentally acceptable and cheapest form of energy, hydro potential certainly represents a natural source, i.e. good of public interest and significant economic potential in the development strategy of each country. It also plays an important role in the country's electricity balances, in the present and the future, which is characterized by a large lack of electricity in relation to the increase in the number of inhabitants and the increase in consumption on the one hand and the imperative to switch to RES on the other. Over 4,000 small hydroelectric power plants operate in Austria. The short-term plan is to build several hundred more MHE. Austria's national goal is to produce 100% of energy from RES by 2030 [14]. More than 70,000 SHPPs operate in Germany [15]. In Norway, for example, it produces more than 6000 GWh/year at small hydroelectric plants [16].

Positive and negative results in practice

By building a large number of SHPPs, the problem of increasing consumption and demand for energy cannot be solved entirely, but water can be used for multiple purposes and much more efficiently. Water flows in any case, it is a cheap and renewable resource, always available. After passing through the turbine, that resource is available to other users with unchanged quality. In addition, the implementation of SHPP reduces proportionally the use of non-renewable, environmentally much less clean type of resources, such as e.g. fossil fuel.

Various protective measures are being used to speed up the use of hydro potential at small hydro power plants in both developed and underdeveloped countries. Their positive impacts are numerous: SHPPs use water, which is a renewable natural resource, they have almost no negative impact on the environment, and there are feasible protection measures for eventualities, they have a favorable impact on the development of the domestic electrical and mechanical industry, the entire water management and small economies of underdeveloped regions, participate in the electrification of terrain and areas far from roads and main traffic routes, contribute to savings in the construction of the general distribution network, regulate and establish the biological minimum of mountain streams, help in the regulation of sediment transport of torrential watercourses.

Given the numerous advantages, many countries are introducing various forms of incentive norms, as well as hybrid models [17]. For example, the Norwegian government, which has almost 100% utilized hydro potential, provides non-refundable financial assistance for the construction of small hydropower plants, providing up to 80% of the total construction costs. Such large subsidies have their own strategic and economic justification, because they primarily refer to small hydropower plants, which are usually built outside the distribution network, as an independent energy facility, intended to supply and meet the energy needs of a small number of remote consumers.

If the natural conditions are analyzed, it can be concluded that in many countries there are prerequisites for the construction of small hydropower plants, but there is still not enough attention and necessary activities directed to this area. Today, bearing in mind the number of small hydroelectric power plants that have already been built and the need to consider the mass construction of such facilities, the construction possibilities are still increasing. In the field of construction of small hydropower plants, the following activities can be carried out:

- reconstruction and revitalization of existing small hydropower plants,
- automation of small hydropower plants that are in operation,
- adaptation of existing mills into small hydropower plants,
- additional installation of new aggregates with an installed power of up to 10 MW, within the existing dams and hydroelectric power stations, with the aim of fully utilizing the existing hydro potential and
- construction of new small hydroelectric power plants as independent facilities, at previously unused locations

With the goal of converting the existing hydro potential into used at small hydro power plants as soon as possible, standardization of projects and equipment for small hydro power plants should be done. The execution of typical construction works and facilities is the first step, which precedes the necessary standardization of electro-mechanical equipment, which enables faster and easier installation of the automatic system of control and management of small hydropower plants, without a crew. At the same time, this standardization represents the right move that makes the production of equipment for small hydropower plants financially attractive and profitable for the entire industrial production of a country. Another possibility lies in the research of all abandoned buildings and mills where the production of electricity could be ensured, in a short period of time and with relatively low investments and minimal construction work, which could be very necessary and important for the local consumers. It is necessary to analyze all possibilities of construction and reconstruction of small hydropower plants in order to solve the issue of supplying various small consumers, who are sometimes far from the power grid.

CONCLUSION

Today, when the principle of minimum energy is becoming a paradigm of civilization, using the potential of small watercourses by building small hydropower plants belongs to the domain of using renewable energy sources and is a function of sustainable development. The topic of this manuscript was research into the use of the hydro potential of small watercourses as synergistic solutions, analyzed multi-criteria, through tradition, time and space and in function of today's many conflicting interests. Current examples of world experiences are also given. Just as watermills once had a great sociological and cultural importance and role in the social life of the village, so today MHE, designed and built as a result of a multi-criteria holistic approach, can become a center of events and a feature of the development of the local community. Science can solve any engineering, environmental and social problem. Related to that, synergy with the monitoring function is needed in practice, as well as with the education and adequate information.

Small hydropower plants with the most modern standardized solutions for construction and equipment are very quick and easy to construct, operate and maintain. With standard electromechanical equipment and typical construction works, small hydropower plants require minimal technical and organizational conditions for management, have reduced construction and maintenance costs, and therefore a quick return on invested capital. Today, small hydropower plants play a significant role in the strategy of increasing the production of electricity from RES [18], in the context of reducing global warming and the humanitarian policy "Energy for all".

The construction of small hydropower plants relies on the natural wealth in the streams of mountainous regions. Positive legal regulations and stimulating forms of financing play a major role in accelerating development and giving due importance to small hydropower plants. The production of electromechanical and hydromechanical equipment at the local level could have the same effect. The existence of as many as possible of adequate solutions of small hydropower plants can alleviate the energy crisis, help stabilization and economic development, and most importantly, practically do not endanger the environment, and contribute to the general development of both local communities and the entire society.

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LITERATURE

[1] Ivković, Z., Tošić, D., & Dramlić, D. (2022). Analysis of coal reserves with the potential for underground exploitation in the Republic of Serbia. Archives for Technical Sciences, (26-1), 43-48.

[2] Mahabadi, D. (2023). Enhancing fairness in the Paris Agreement: lessons from the Montreal and Kyoto protocols and the path ahead. International Journal of Environment and Sustainable Development, 22(3), 329-348.

[3] Schneider, M., Golan, G., Yang, S., & Kinsey, D. (2015). US public diplomacy since 9/11: The challenges of integration. International public relations and public diplomacy, 15-36.

[4] Punys, P., Kvaraciejus, A., Dumbrauskas, A., Šilinis, L., & Popa, B. (2019). An assessment of micro-hydropower potential at historic watermill, weir, and non-powered dam sites in selected EU countries. Renewable energy, 133, 1108-1123.

[5] Stević, S., Milošević, H., Stević, I., & Hadrovic, S. (2014). Sustainable management of water resources in Prokletije region. Industrija, 42(1), 47-61.

[6] Ali, S., Stewart, R. A., Sahin, O., & Vieira, A. S. (2023). Integrated GIS-AHP-based approach for off-[]river pumped hydro energy storage site selection. Applied Energy, 337, 120914.

[7] Stević, I. (2017). Strategic orientation to solar energy production and long term financial benefits. Archives for Technical Sciences, (17), 1-12.

[8] Urošević, B. G., & Marinović, B. (2021). Ranking construction of small hydro power plants using multi-criteria decision analysis. Renewable Energy, 172, 1174-1183.

[9] Pan, Y., & Hashemizadeh, A. (2023). Circular economy-based assessment framework for enhancing sustainability in renewable energy development with life cycle considerations. Environmental Impact Assessment Review, 103, 107289.

[10] Taherdoost, H. (2023). Analysis of simple additive weighting method (SAW) as a multiattribute decision-making technique: A step-by-step guide. Journal of Management Science & Engineering Research, 6(1), 21-24.

[11] Yang, X., Xu, Z., & Xu, J. (2023). Large-scale group Delphi method with heterogeneous decision information and dynamic weights. Expert Systems with Applications, 213, 118782.c

[12] Wagner, B., Hauer, C., & Habersack, H. (2019). Current hydropower developments in Europe. Current Opinion in Environmental Sustainability, 37, 41-49.

[13] Bogaart, P. (2023). The potential for sustainable hydropower. Nature Water, 1(1), 22-23.

[14] Gaugl, R., Sommer, M., Kettner, C., Bachhiesl, U., Klatzer, T., Gruber, L., ... & Wogrin, S. (2023). Integrated Power and Economic Analysis of Austria's Renewable Electricity Transformation. Energies, 16(5), 2229.

[15] Couto, T. B., & Olden, J. D. (2018). Global proliferation of small hydropower plants–science and policy. Frontiers in Ecology and the Environment, 16(2), 91-100.

[16] Engen, S., Hausner, V. H., Fauchald, P., Ruud, A., & Broderstad, E. G. (2023). Small hydropower, large obstacle? Exploring land use conflict, Indigenous opposition and acceptance in the Norwegian Arctic. Energy Research & Social Science, 95, 102888.

[17] Kakoulaki, G., Sanchez, R. G., Amillo, A. G., Szabó, S., De Felice, M., Farinosi, F., ... & Jaeger-Waldau, A. (2023). Benefits of pairing floating solar photovoltaics with hydropower reservoirs in Europe. Renewable and Sustainable Energy Reviews, 171, 112989.

[18] Gebara, C. H., & Laurent, A. (2023). National SDG-7 performance assessment to support achieving sustainable energy for all within planetary limits. Renewable and Sustainable Energy Reviews, 173, 112934.