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Mapping Sites for Retrofitting non-Powered Dams in Romania as Renewable Power Sources

Georgiana Dunca[1], Diana Maria Bucur[1], Tor Haakon Bakken[2], Atle Harby[2], Elena Pummer[3], Marcel Istrate[4], Costel Boariu[4], Costica Roman [4]
[1]University POLITEHNICA of Bucharest, Bucharest, Romania
[2] SINTEF Energy Research, Trondheim, Norway
[3]Norwegian University of Science and Technology, NTNU, Trondheim, Norway
[4]Technical University "Gheorghe Asachi" of Iasi, Romania
georgiana.dunca@upb.ro, diana.bucur@upb.ro (corresponding author), tor.h.bakken@ntnu.no, atle.harby@sintef.no, elena.pummer@ntnu.no, mistrate@ee.tuiasi.ro, costelboariu@gmail.com, corpad03@yahoo.com

Abstract **In the context of growing need for energy and the shift to low-carbon energy sources, innovating solutions in the renewable energy sector are encouraged. Currently, hydropower is the largest source of renewable energy in the world and is expected to play a major role in future power systems. Many dams in Romania are not equipped for hydropower generation, and they can represent a potential for new power production in the existing river system, most likely not adding new major environmental impacts to the already regulated systems. This paper presents a methodology to identify and analyze for retrofitting dams having hydropower potential applied on Romanian territory. The data base applied consists of dams and small sills, having any type of use.**

Keywords**: hydropower potential, retrofitting, small dams, sills**

I. INTRODUCTION

At the end of the 20th Century, climate change policies triggered the development of renewable power generation solutions, mainly wind and solar. As energy demand is continuously increasing, renewable and sustainable power sources are becoming more important. Europe's governments (EU-28, Norway and Iceland) have all set targets to reduce greenhouse gas emissions by at least 40% by 2030 and to significantly increase the use of renewable energy sources. To achieve these goals and to build an affordable, secure, and sustainable power system, many European countries have launched numerous regulations to sustain de-carbonization of the power sector [1, 2, 3].

Hydropower is especially valuable to power systems due to its flexibility, storage and ability to complement other more intermittent forms of renewable power sources such as wind and solar [4, 5], and providing valuable ancillary services [5]. With its controllability, flexibility and storage capability, hydropower is playing a major role in the transformation of the European power system. In 2017, about 2.3 GW of hydropower capacity was added across the wider European region, including non-EU countries. This brings the total European hydropower capacity to 278 GW [6].

Usually, building new hydropower schemes leads to alterations of river flows which may affect the environment. Therefore, extending the use of already built hydraulic structures, like dams and reservoirs, can represent an economically feasible and competitive method to increase the amount of energy production, without significant, negative social and environment impacts [7, 8, 9].

A large number of the world's dams and reservoirs are built for purposes other than electrical power production, like: flood control, drought mitigation, water supply, irrigation, navigation, aquaculture or recreation. In the ICOLD World Register of Dams (2022) there are 58713 registered dams all around the world, out of which 39110 dams have defined functions that can be divided in two main categories [10]:

- single-purpose dams (Fig. 1) – 28791, representing 49% of the total number of dams.
- multipurpose dams (Fig. 2) – 10319, representing 17,6% of the total number of dams.

It can be observed that only 12.7% of all world's dams are built for electrical power production (Figs. 1 and 2).

Romania ranks among the countries with the greatest achievements in the field of dams in the world. Among the 104 membership countries of ICOLD [10], Romania ranks 20th in "large dams" and the 10th in Europe. The total number of big dams in Romania is 241, which are dams with a height of 15 m or greater from lowest foundation to crest or dams between 5 m and 15 m impounding more than $3 \cdot 10^6$ m^3 of water. The dams on Romanian territory have also various purposes, as presented for the world's scale.

Non-powered dams retrofit projects must be economically and environmentally competitive with other power sources, as the low-cost renewables (e.g., wind and solar).

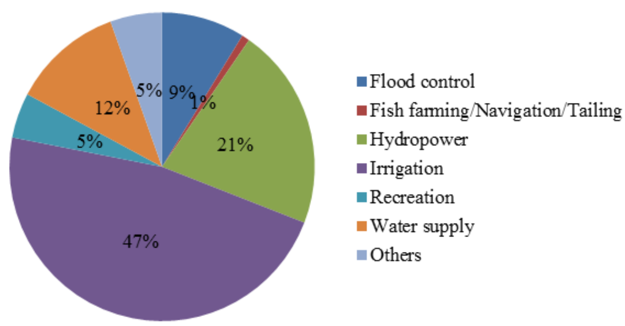

Fig. 1. Purpose distribution for single - purpose world's dams [10].

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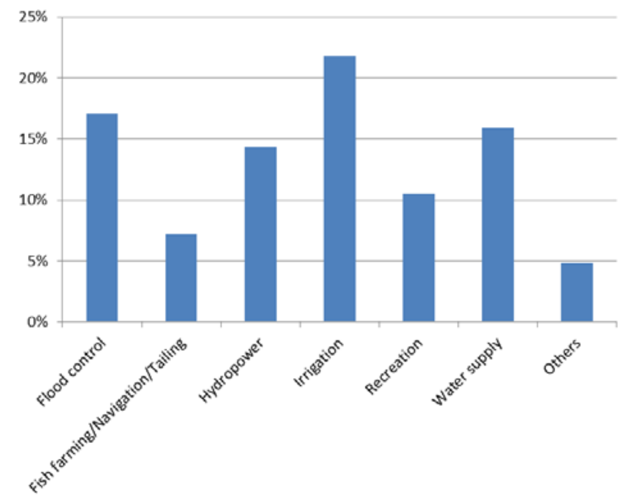

Fig. 2. Purpose distribution for multi-purpose world's dams [10].

Constraints such as environmental conditions, current use, and existing infrastructure can vary significantly across different sites. This results in high variation of the costs due to mitigation actions and benefits that could be derived from retrofitting an existing dam [11, 12]. As such, there is a need for high quality data and analyses to identify and prioritize competitive projects among the thousands of unique non-powered dams.

This paper presents a methodology with the aim to create a database with dams and small sills, with non-power use and to identify the dams having hydropower potential within the Romanian territory. The proposed methodology is in accordance with the EU recommendations related to the development of small hydropower plants and the sustainable use of renewable sources [13]. The sorting methodology is divided in two steps. First, the sites with hydropower use and the non-permanent water resources are excluded.

The aim of this first selection is to retain about 100 sites. Secondly the locations that meet certain conditions in terms of dam height and mean annual flow are kept and additional qualitative criteria are considered. The aim of this second selection is to obtain a list of about 10 sites for more detailed investigation of the real potential for retrofitting.

II. Rivers And Lakes In Romania

Romania's hydrographical network contains four bodies of water: streams or rivers, lakes, groundwater and marine waters [14]. Those that are of interest for generating electricity are the streams, rivers and lakes. The number of lakes in Romania is around 3,500, with a total area of approximately 2620 m^2, representing 1.1% of the total surface of the country. There are over 1270 artificial lakes (i.e. almost 40% of the total number of lakes), spreading over an area of 1150 km^2, which represents 1/3 of the total surface of the lakes located in Romania. The artificial lakes have a storage volume of water of 5.4 billion m^3/year, and their mainly used is power generation.

III. Sites Data Available For The Analysis

The information used for the retrofitting analysis consists of data collected from National Administration "Romanian Waters" (ANAR), data collected on-site and data from the ICOLD database [10].

According to the data collected from ANAR, 242 sites on Romanian territory were reported as dams and small sills, having any type of use. As the data from ANAR did not cover the entire Romania territory, information collected on site from 7 small dams was added. In addition, another 16 dams with heights greater than 20 m from the ICOLD database [10] were selected and analyzed. A total of 265 sites resulted.

The distribution of the collected data over the country, classified on the 11th local water administrations, and specifying, for each, the total sites and the non-powered sites, is presented in Fig. 3.

The basic information collected consists of the following 17 characteristics:

1. name of dam and reservoir / use
2. type of water accumulation
3. geographic position
4. construction year
5. hydrographic basin
6. watercourse
7. usage
8. dam height
9. dam type
10. importance class/category of importance
11. actual dam state
12. construction material of the dam
13. total volume/volume at normal water level
14. normal water level
15. hydro technical equipment
16. fish ladder and state of fish ladder
17. mean annual discharge

From the 265 sites, 53 are known to be associated with power generation (hydropower plants), representing 20% from the total sites (Fig. 4). The remaining 212 sites have non-power purposes, with heights varying from 0.5 m to 60 m (Fig. 5).

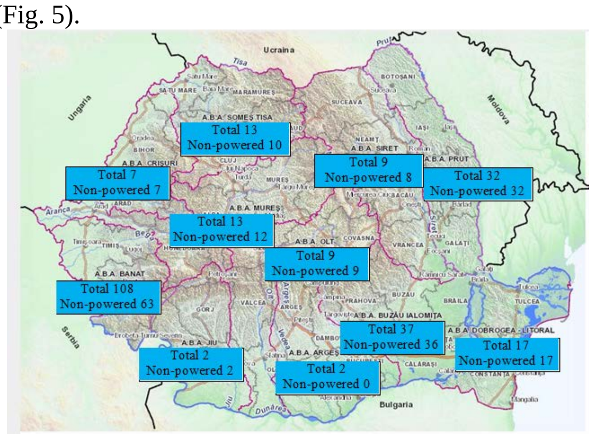

Fig. 3. Distribution of total and non-powered dams over the Romania territory.

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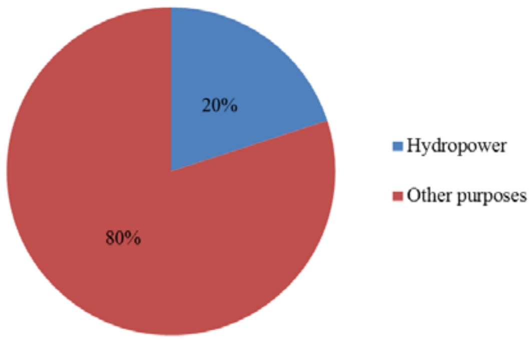

Fig. 4. Distribution of analyzed powered and non-powered dams in Romania.

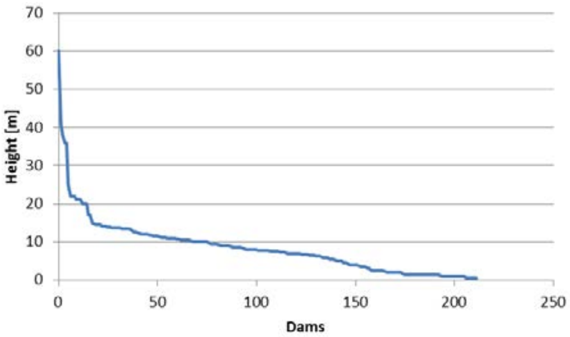

Fig. 5. Height distribution of analyzed non-powered sites in Romania.

The analysis was carried out for the 212 sites with specific non-power purpose. The information regarding these locations was completed and corrected by means of site visits and new data requested from ANAR.

IV. First Selection: Criteria and Results

In the present study, the following types of retrofitting were considered:

- ✓ existing reservoirs without hydropower
- ✓ existing dams/barriers in rivers without reservoir without hydropower
- ✓ abandoned/unfinished hydropower sites where the dam was built

In order to sort the collected data, one quantity was introduced, representing a gross indication of the sites' hydraulic potential: H×Q, the product between dam height (H) and mean annual flow (Q).

The hierarchy of the 212 analyzed dams was obtained following the steps:

1. exclude the non-permanent water resources: from 212 non-powered sites, 13 sites are non-permanent reservoirs. Further, 199 sites remained to be analyzed.

2. select the dams with heights equal or over 4 m: After sorting the 199 sites 140 sites remained.

3. create a hierarchy using the following information:

- ✓ H×Q, the product between dam height and mean annual flow;
- ✓ H, the height of the dam.

V. Classification Of The Remaining Dams, According To Specific Criteria

In the second part of the study there was decided to further investigate those locations that meet both the following criteria:

- ✓ dam height, $H \geq 4$ m
- ✓ mean annual flow, $Q \geq 1$ m^3/s

These limits were established based on the following reasons. Firstly, the height of the dam is the difference between the crown and the base of the foundation, while the difference between the upstream and downstream water levels can be much lower. Secondly, the National Plan for the Development of Hydrographic Basins in Romania [15] sets the limit of 150 kW/km minimum economic potential that can be managed. Without having enough information, if a site on a river with a valley slope of 1.5% has a flow rate of at least 1 m^3/s, the condition of the above mentioned plan is fulfilled.

Furthermore, the following quantitative and qualitative criteria were added, including in this way aspects, such as: existing use of the dams and reservoirs, the hydrological resources available, environmental and social restrictions, technical limitations, and potential judicial and legislative barriers:

A. H×Q, the product between dam height and mean annual flow;

B. the technical status of the dam/reservoir – define as: bad, medium, good, unknown;

C. the current use of dam/reservoir - would potential future hydropower production comprimise the existing use Are there water management issues with drinking water supply, irrigation, flood control or other use of the river? – define as: yes, no, partially, unknown

D. the grid connection or access to site – define as: yes, no, partially, unknown

E. the existence of local power consumers nearby – define as: yes, no, partially, unknown

F. the environmental situation– define as: yes, no, partially, unknown

G. the legal or regulatory challenges – define as: yes, no, partially, unknown.

From the list of 140 selected locations, only the sites that met the conditions for dam height and flow rate were selected. The result was a list of 30 locations. The geographical position of the 30 sites is presented in Fig. 6. Further, the criteria established for the selection of top 10 sites were considered to evaluate all 30 locations.

For each selection criterion, we established a rank of their importance on a scale from 1 to 3 based on expert knowledge: 1 is very important and 3 is less important. Several ranks were awarded to each criteria and an average was computed. The results were as follows:

A. $Q \times H$ – importance rank 1.

B. the technical status of the dam/reservoir – importance rank 2.

C. the current use of dam/reservoir – importance rank 1.33.

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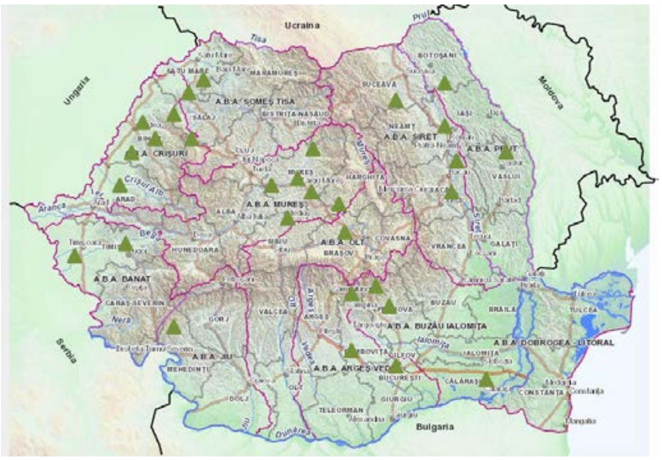

Fig. 6. Geographical position of the 30 dams.

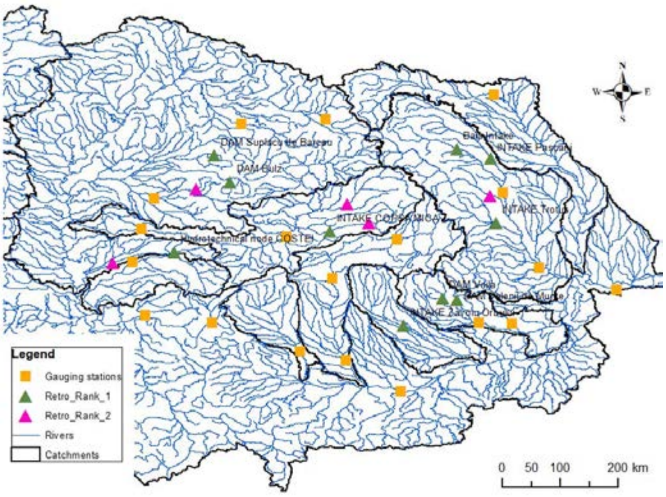

Fig. 7. Location of the 10 dams that have a significant potential for retrofitting, ranked 1 (green triangles) and of the 5 dams considered with a second priority, ranked 2 (magenta tringles). The orange squares are location where discharge data is available for hydrological assessments.

D. the grid connection or access to the site – importance rank 3.

E. the existence of local power consumers nearby – importance rank 3.

F. the environmental situation – importance rank 1.67.

G. the legal or regulatory challenges – importance rank 1.

The final ranking of the 30 sites was established considering, firstly the value of the criterion, $H{\times}Q$, and then the evaluation of the additional criteria, prioritizing those criteria based on their importance rank.

Three classes of sites were obtained:

1. 10 sites that will be considered for retrofitting, class 1
2. 5 sites considered with potential for retrofitting, class 2
3. 15 sites considered to be not accessible for retrofitting, class 3.

Fig. 7 presents the location on the map of the 10 dams that have a significant potential, class 1 (green triangles) and the location of the 5 sites considered to have a potential for retrofitting, class 2.

VI. Conclusions

This paper presents the first steps of a comprehensive national study on the hydropower potential of non-powered dams, weirs and sills in the existing water network in Romania.

The main purpose of the study is to develop a methodology for the analysis and evaluation of retro-fitting existing non-powered dams with hydropower production, in order to increase power generation from renewable resources.

So far, based on data provided by National Administration “Romanian Waters” and ICOLD database, selection criteria was formulated and a classification procedure was established. At this moment, a list of 10 non-powered dams and sills that have a significant potential, and another additional 5 sites considered to have a potential for retrofitting was established, located on the entire Romanian territory. Further, hydrological data and environmental impact analyses, hydropower potential evaluation, equipping solutions, and preliminary evaluation of the costs and power generation will be carried out. Based on the results obtained, one site will be selected for which a pilot project will be developed.

Acknowledgment

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