Identification of the best location for an environmental friendly small hydropower plant

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Abstract. The promotion of renewable energy sources exploitation represents an important goal of the European Union and in this respect the Water Framework Directive was issued. The document requires periodic hydropower assessment of the water courses, using software tools if possible. In this paper a methodology to identify best location for a small hydro power plant is proposed. The methodology is based on two software VADIPRO-ASTE and SMART MINI-IDRO and takes into consideration environmental restrictions. The optimization process uses available monthly average flows in a river section, calculated by taking into consideration the ecological flow and the water consumption for non-electricity production purposes. The ecological flow was calculated by a method elaborated by the National Institute of Hydrology and Water Management, to respect the legislation OUG 78/2017 that supports aquatic ecosystems functionality.

1. Introduction

Due to the accelerated rate of depletion of the conventional energy sources, producing more clean energy with a low environmental impact is an important energy policy target for all Member States. The first step taken by the European Union was to create a legislative frame for the regulation of the production and trading of green energy from renewable sources on the single energy market. The RES Directives issued, respectively Directive 2001/77/EC repealed by the Directive 2009/28/CE and amended by Directive 2013/18/EC established for the year 2020, a target -20% from the total internal gross consumption of energy should be produced from renewable energy sources [1].

Every country implemented the Directives in the national legislation, taking into consideration the environmental objectives and especially the Water Framework Directive 2000/60/EC [2].

In Romania, the RES-e Directive 28/2009/EC on promotion of the use of energy from Renewable Energy Sources was transposed into the Electricity Law, while the Water Framework Directive 2000/60/EC was transposed into the Water Law.

Small hydropower plants (SHP), defined to have installed capacity less than 10 MW, belong to production units from renewable power source category, only if environmental restrictions are respected. The calculation of the hydropower potential of water courses to be used on studies regarding construction of new hydropower schemes, must consider the environmental issues restrictions, to be in line with the EU regulations.
In this paper, VAPIDRO-ASTE software, SMART MINI-IDRO software and a new theoretical method (EFC) elaborated to calculate the ecological flow downstream of the small hydropower plant, are all together used for identification of the best location to build a small power plant. The originality of the work consists in combining the three methods to obtain a methodology, ready to be used in prefeasibility studies.

2. Methodology
The methodology proposed in this paper is based on three methods, presented in the following.

2.1. VAPIDRO-ASTE
The VAPIDRO-ASTE tool uses a GIS interface and is a dedicated tool for the assessment of the hydropower potential. The software has been produced by RSE S.p.A in the frame of the SEE HYDROPOWER project, financed by the South East Europe Program and the Research Fund for the Italian Electrical System [3].

The main parameters determined by the software are: the average head of a river sector, the proposed installed power and the estimated annual electricity production. Also, an economic evaluation of the potential investment can be performed by the tool, presented as a cost–benefit analysis, which can be transposed on the GIS maps along with the results of the small hydro power plant (SHP) technical parameters. Next, for determining the best location for the water intake and for the hydropower plant, an optimization procedure is performed.

The problem with VADIPRO-ASTE software is that it takes into consideration the ecological flow, as a percentage of the average flow. This method is not in line anymore with the present legislation. The new OUG 78/2017 stipulates that the ecological flow must be calculated monthly in order to assure the continuity of the river, similar to natural conditions to preserve the ecosystem [4]. One aim of the present work is to propose a methodology that answers to the challenge.

2.2. SMART MINI-IDRO
The SMART MINI-IDRO tool uses hydrological data as inputs. Based on the flow duration curve of the daily mean flows in a river section, the software can be used for a preliminary evaluation of the environmental flow, to select the appropriate turbine type and to perform a synthetic economic analysis. The software can consider national financial supporting scheme for SHP investors by issuing green certificates, corresponding to the installed power and according to generated electricity. The preliminary calculation of the monthly ecological flow is performed as a percentage of the mean flow \(Q_{\text{mean}}\) at the analyzed gauging station or as a direct input of a value (the flow with 95% probability of occurrence \(Q_{0.95}\) from the flow duration curve) [5].

2.3. Ecological flow calculation theoretical method (EFC)
The proposed method to calculate the ecological flow was elaborated by the National Institute of Hydrology and Water Management, in order to fulfill the requirements related to water quality and quantity necessary for the protection of the aquatic ecosystem and to support the implementation of the Water Framework Directive 2000/60/EC provisions in Romania.

The ecological flow is be calculated based on the available monthly average flows at the gauging station, recorded during a long period, at least 30 years. The ecological flow of each month \(Q_{\text{ecol},i}\) \((i=\text{Jan., Feb.,…, Dec.})\) is a distinct value. From this 12 mean monthly values of the ecological flow it is calculated one mean multiannual value which can be converted as a percentage of the multiannual monthly average flow \(Q_{\text{mean}}\). This value must be higher than the minimum value, recorded during a long period for the corresponding month and lower than the maximum value recorded for the corresponding month. The results of the EFC method, respectively the ecological flow mean value \(Q_{\text{ecol}}\), expressed as percentage of the mean flow, can be used as input data in VAPIDRO-ASTE.

3. Case study. Numerical simulation and results
The case study refers to Bratia River, located in the central part of Romania within the Arges - Vedea River Basin and it is 57 km long. The Bratia River basin area is about 360 km², the mean slope of the river is 15 % and the mean altitude of the river basin is 806 m [6].
The river sector analyzed, for the development of a new SHP on the Bratia River, is located upstream of the Rausor Pod gauging station, up to the river springs. The VAPIDRO-ASTE software was run based on the mean flow for the section of calculus (Rausor Pod gauging station) and the ecological flow calculated with the EFC method was expressed as a percentage of the mean flow. The EFC method results are presented in Figure 1. The ecological flow \(Q_{\text{eco}}\), necessary to protect aquatic ecosystems of the river, varies monthly, in accordance to the natural variability of the flow regime [7].

In the studied case, the monthly ecological flow \(Q_{\text{eco}}\) varies in an interval situated between the minimum monthly average flow recorded in January \(Q_{\text{JAN}} = 0.55 \text{ cm/s}\) and the minimum monthly average flow recorded in June \(Q_{\text{JUN}} = 1.18 \text{ cm/s}\).

In order to respect the Water Framework Directive recommendations a “near natural” flow regime must be assured for all the rivers. For the mountain area rivers typology, the ecological flow must be 25% to 35% of the monthly average flow rate. The ecological flow was calculated for Bratia River, Rausor Pod gauging station, as 25% of the monthly average flow rate.

**Figure 1.** The ecological flow at the Rausor Pod gauging station located on the Bratia River.

Figure 2 presents the flow duration curve of the mean flows at the Rausor Pod gauging station, located on the Bratia River, designed by using the SMART MINI-IDRO flow duration curve frame.

**Figure 2.** The flow duration curve of the mean flows at the Rausor Pod gauging station.
The ecological flow calculated with the EFC method depending on a series of hydro-morphological factors is presented in Figure 3. It was implemented as one of inputs in VADIPRO-ASTE.

![Flow Duration Curve](image1)

**Figure 3.** The ecological flow calculated with the EFC method at Rausor Pod gauging station.

Summarizing, the technical and economic data used by VAPIDRO-ASTE as inputs are the following:
- Digital Elevation Model (DEM with a 30 m grid cell);
- the mean flow for the 1959-2017 period at the Rausor Pod gauging station \(Q_{\text{mean}} = 2.28\) cm/s;
- the ecological flow at the Rausor Pod gauging station \(Q_{\text{eco}} = 0.6\) cm/s;
- the hydropower plant’s lifetime – 30 years.

![Mean heads distribution](image2)

**Figure 4.** The mean heads distribution

![Variation of installed power](image3)

**Figure 5.** The variation of the installed power
The VAPIDRO-ASTE results presented on GIS maps, based on the DEM and the hydrological data ($Q_{\text{mean}}$ and $Q_{\text{eco}}$) are the mean heads distribution (Figure 4) and the variation of the installed power (Figure 5) along the Bratia River.

**Figure 6.** The VAPIDRO-ASTE manual optimization procedure performed on the Bratia River

**Figure 7.** The best location of the water-intake and the SHP facility on the Bratia River.
Based on the results generated by VAPIDRO-ASTE tool for the head distribution and the installed power variation along the Bratia River, the appropriate turbine was selected according to the turbine selection diagram from the SMART Mini-Idro tool. The results of the integrated analysis performed with the VAPIDRO-ASTE and SMART MINI-IDRO tools indicated that the appropriate turbine type for the studied case is the Pelton turbine type.

The installed power resulted for the simulated SHP is 989 kW; the mean annual electricity generated is 4570 MWh/year and corresponds to an operation time of 4618 of equivalent hours/year. The optimal distance resulted from the water intake to the SHP facility location is 2000 meters. Results are presented in Figures 6 and 7.

4. Conclusions
The paper presents a methodology, based on VAPIDRO-ASTE software, SMART MINI-IDRO software and EFC method for calculation of the ecological flow. The methodology was developed to identify the best location for building a new small hydropower plant. A case study, Bratia River from Romania, is presented and results are encouraging. The methodology is detailed enough to be used in prefeasibility studies regarding the development of new SHP’s, with respect to restrictions imposed by the Water Framework Directive regarding good status/ecological potential preservation and no impact on fish fauna migration conditions by maintaining the river continuity.

Acknowledgments
The authors are grateful to the National Institute of Hydrology and Water Management, for providing the hydrological and GIS data necessary for the tools application in the presented paper and to the RSE S.p.A for VAPIDRO-ASTE tool, produced in the frame of the SEE HYDROPOWER project financed by the SEE Program and the Research Fund for the Italian Electrical System.

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