Impact of the ecological flow of some small hydropower plants on their energy production in Romania

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Abstract. In this paper, for 24 SHPPs with significant installed capacity, between 676 and 6430 kW, totalizing almost 76 MW, with installed flows between 1.3 and 80 m^3/s, the energy production is evaluated without and with an ecological flow representing 35 to 4.6 % from the mean flow in SHPP intake cross section. The energy loss is evaluated and there are presented some conclusions and assumptions regarding the way to impose an increased ecological flow without affecting too much the green energy produced in SHPPs.

1. Introduction

The inquiry regarding the ecological flow (EF) or environmental flow or minimum instream flow was concluded first time in the legislation in a serious manner in year 2000 in Water Framework Directive (WFD) [1]. Ecological flows are considered within the context of the WFD as "a hydrological regime consistent with the achievement of the environmental objectives of the WFD in natural surface water bodies" [2]. The Brisbane declaration (2007) "describes the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend upon these ecosystems" [3].

The importance of EF for live is no longer questionable. Many papers dedicated to this subject were published.

From the very beginning it is underlined the difficulty to establish common methods and rules for EF in different countries, for different rivers and landscapes, for different water users, even using the concept of Integrated Water Resources Management [4]. Other important issue is the correlation between the indicators used for describing the ecological status or rivers and the flow parameters [5]. It was demonstrated that for large Alpine catchments, at least, this correlation is poor.

Some papers are related to the adoption and the implementation of EF programs into national legislations [6], or to draw attention that it can be defined an EF science where one of the most important issues is to consider the natural regime concept and the non-stationarity in climate and other conditions [7].

Perhaps one of the most challenging aspects is represented by the modelling, calculation and evaluation of the appropriate EF for a certain river in different environmental conditions. Thus, it was proposed an improved water resources allocation model [8], a weighted multiple method considering hydrological alteration [9], a distribution flow method [10], a method based on water temperature and

critical water depth [11], and even there were compared different methods for a certain catchment [12].

Related also to the comprehensive evaluation of the ecological flow related to very large rivers it was applied a multi-objective assessment [13] and there were done researches related to the complex relationship between water supply services and human well-being in a broader sense [14].

Another very important issue related to EF is the accuracy of its measurement. From applying a physics- based distributed rainfall–runoff model [15] to measuring and evaluating EF from a river to a whole region [16] some papers were also dedicated to this subject.

A large area related to studies dedicated to EF cover the influence of EF to different processes in rivers, from which one of the most important is spawning. Thus, there were done studies covering: the analysis and restoration of the EF during spawning period of a certain species [17]; the EF assessment to improve spawning habitat for more species in Yangtze River [18], and the influence of the EF on different spawning patterns [19].

A broader study must consider other aspects than spawning, as bird diversity and shellfish fisheries [20], or, related to the whole river health assessment there are methods based on EF [21].

On the other hand, it is obvious that the release of an EF downstream a reservoir realized by a weir or a dam related to water resources management affect all the water uses: irrigation, water supply, fisheries, and hydropower. Regarding water use for agriculture it was build a model to calculate agricultural economic losses caused by a high level of the EF [22]. There are recommendations based on policies of agricultural ecological compensation which enable the agricultural water department to decrease losses and improve food safety.

Hydropower is one of the most affected sectors from the establishment of high levels of EF the more so as this was not imposed before that the hydropower development is achieved. Many studies are dedicated to study the performance of water reservoir systems with the implementation of EF even on different climate conditions [23], to demonstrate the necessity of a well-established EF in order to bring back migratory fish [24], or to correlate hydropower production and an appropriate level of EF for fish habitat suitability [25]. Other studies were dedicated to the evaluation of the ecological flow of a Hydropower Station's Dehydration River [26], or, in a broader way, to present the practices related to EF in rivers affected by storage and hydropower [27] and even to present the adaptive management of hydropower engineering projects for 15 years in China [28].

Related to hydropower reservoir operation under the constraint of a high level of the EF, some authors present a model for a multi-objective ecological operation optimization of a cascade of reservoirs considering different values for the EF [29].

The transposition in Romanian legislation of the WFD is Water Law no. 107/1996 with subsequent amendments and completions and establish in art. 21 the flow required for the protection of aquatic ecosystems, both in terms of quantity and its dynamics for the achievement of environmental objectives for bodies of surface water.

After the transposition of the WFD into the Romanian legislation becomes obvious the necessity of the reevaluation of the ecological flows for hydropower developments in general and particularly for the small hydropower plants (SHPPs). As large this ecological flow is, less is affected live into the river downstream the SHPP intake. Meanwhile, the ecological flow is proportionally reflected in an energy loss for the SHPP.

Regarding the ecological flow in Romania, there were three stages:

1. Before year 1990, when if the scheme was only for hydropower purposes, no ecological flow downstream or if the scheme was also for other uses of water, there is a flow in order to cover the necessity in water of that water uses.

2. Between 1990 and around 2000, downstream hydropower developments the ecological flow was 10% of the mean flow.

3. After year 2000, there are in force some regulations for the ecological flow:

- if the surface of the catchments area is inferior to 3000 km^2, depending on the minimum monthly average discharge with the insurance of 95%, Q95:

if Q95 > 0.2 m^3/s, then EF = Q95 + 0.1 [m^3/s],
if Q95 < 0.2 m^3/s, then EF = 1.25*Q95 + 0.05 [m^3/s].

In this paper, the EF refers at the flow required to be left in the riverbed after a hydrotechnical construction which obstructs the river flow: dam, weir, more precise SHPP intake. Thus, for some SHPPs with significant installed capacity, with a large variety of installed flows, the energy production is evaluated without and with an ecological flow, which varies a lot form one SHPP to another. The energy loss is evaluated and there are presented some conclusions and assumptions regarding the way to impose an increased ecological flow without affecting too much the green energy produced in SHPPs.

2. Data and method

For 24 SHPPs with significant installed capacity, the energy production is evaluated without and with an ecological flow representing 35.56 to 4.6 % from the mean flow in SHPP intake cross section. The following data were known for the SHPPs: gross head between 10 and 110 m, installed capacity between 676 and 6430 kW, totalizing almost 76 MW, installed flows between 1.3 and 80 m^3/s, ecological flows between 0.46 and 3.5 m^3/s, Table 1, [30].

The following notations were used:

H_g – gross head, Q_m – mean flow, Q_i – installed flow, Q_{ec} – ecological flow,

P_i – installed capacity.

Table 1. Data for the analysed 24 SHPPs

SHPP	Gross head [m]	Mean flow [m^3/s]	Installed capacity [kW]	Installed flow [m^3/s]	Ecological flow [m^3/s]
1	10	76.01	5603	80	3.50
2	10	76.01	5603	80	3.50
3	10	76.01	4902	80	3.50
4	10	76.01	5253	80	3.50
5	10.9	47.72	3665	50	2.23
6	10.91	29.71	2460	30	1.43
7	11.15	29.71	2583	30	1.43
8	11.25	29.71	2631	30	1.43
9	11.55	29.71	2458	30	1.43
10	11.85	47.72	4222	50	2.23
11	14.0	22.28	2680	25.0	2.74
12	15.0	22.28	2890	25.0	2.74
13	20.0	22.28	4050	25.0	2.74
14	20.0	22.28	4020	25.0	2.74
15	20.0	22.28	4010	25.0	2.74
16	31.0	22.28	6430	25.0	2.74
17	38.5	7.61	1900	6.5	1.47
18	57.00	1.72	706	1.7	0.58
19	72.00	1.29	676	1.3	0.46
20	72.50	2.46	1337	2.5	0.78
21	77.00	2.17	1198	2.2	0.70
22	78.00	2.46	1456	2.5	0.78
23	107.00	1.57	1292	1.6	0.54
24	110.0	5.16	3900	4.5	1.03

For these SHPPs, will be considered two alternatives:

A1 – no ecological flow, so the mean flow is used for producing electricity,

A2 – with ecological flow, so the available flow, Q_a, is the difference between the mean flow and the ecological flow, equation (1), and is used for producing electricity:

$$Q_a = Q_m - Q_{ec}, [\text{m}^3/\text{s}]. \quad (1)$$

For a better image, for the 24 SHPPs, the following graphical representations were used: gross head in Figure 1, mean and available flow in Figure 2, and installed capacity in Figure 3.
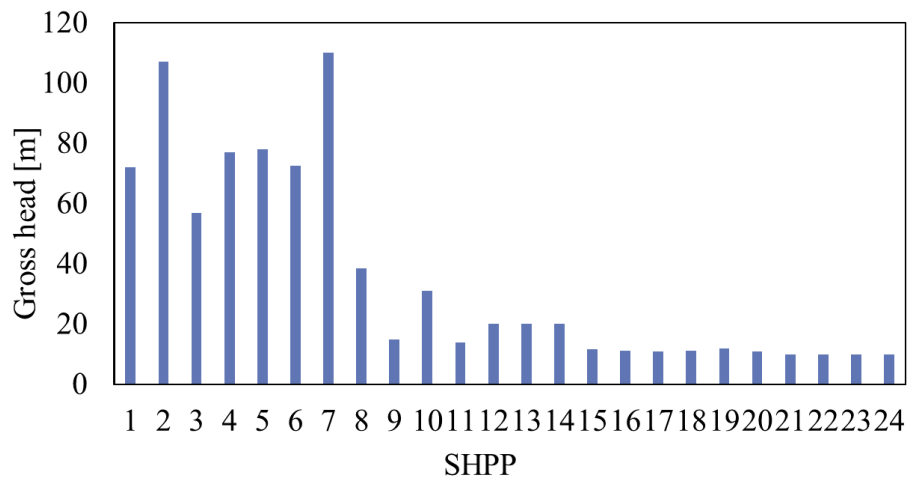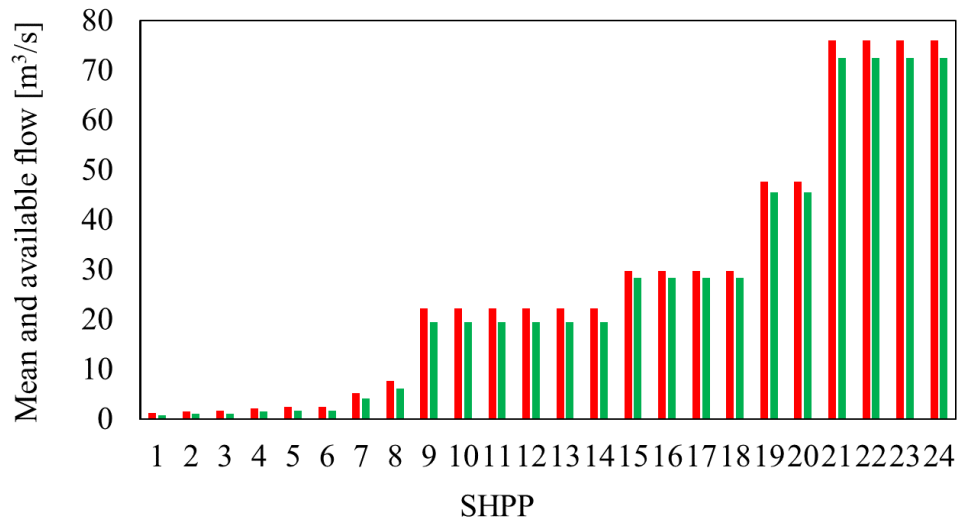

Figure 1. Gross head

Figure 2. Mean flow and available flow (minus ecological flow)
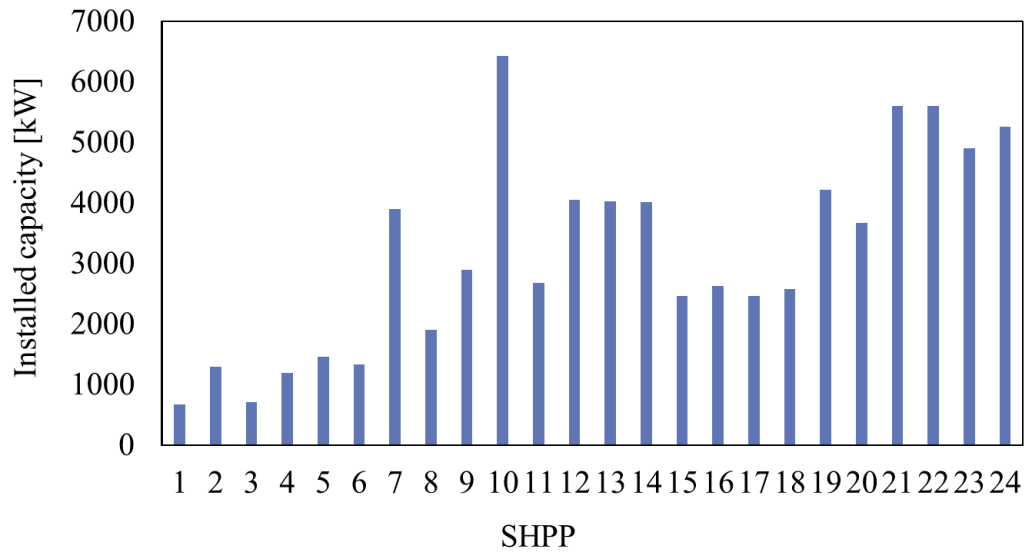
Figure 3. Installed capacity

3. Results and comments

For having an image on how much it represents the ecological flow from the mean, it was calculated the percentage represented by the ecological flow from the mean flow:

$$q_{ec} = \frac{Q_{ec}}{Q_m} \cdot 100, [\%]. \tag{2}$$

For the calculations of annual energy productions for the two alternatives, E_1 and E_2, there were done the following assumptions:

- the mean efficiencies of turbines are 0.88 to 0.91 for Francis type, and 0.89 to 0.9 for Kaplan type;
- the mean efficiencies of generators are 0.93 to 0.97;
- the coefficient of availability of hydropower units is 0.96, corresponding to a period of revisions / reparations of 15 days/year.

In Table 2 there are presented results for the percentage represented by the ecological flow from the mean flow, q_{ec}, for annual energy productions for the two alternatives, E_1 and E_2, the difference between energy productions and the ratio of this difference from the energy production without EF, named energy loss (which can be considered as rate in decreasing of the energy production due to ecological flow):
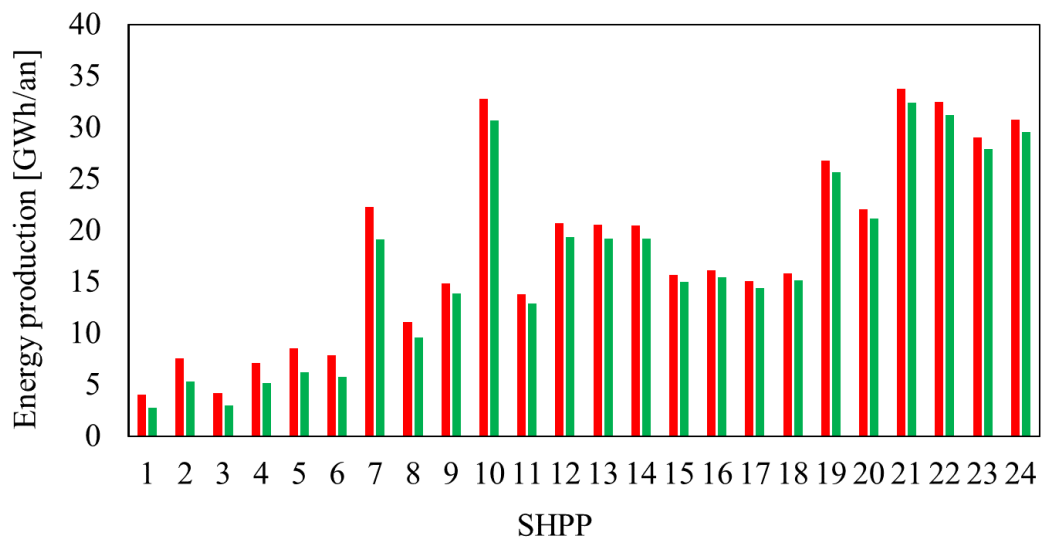
$$\Delta E = \frac{E_1 - E_2}{E_1} \cdot 100, [\%]. \tag{3}$$

From Table 2 it can be easily observed that the rate in decreasing of the energy production due to ecological flow evaluated with an ecological flow representing 35 to 4.6% from the mean flow in SHPP intake cross section varies between 30.9 and 3.89%.

In Figure 4 is represented the energy production without (red) and with (green) ecological flow. In Figure 5 is represented the energy loss to percentage of ecological flow from the mean flow. The dependence between those quantities was then very well approximated with a 4th degree polynomial equation.

Table 2. Calculations for the analysed 24 SHPPs

SHPP	q_{ec} [%]	E_1 [GWh/a]	E_2 [GWh/a]	$E_1 - E_2$ [GWh/a]	ΔE [%]
1	35.56	4.01	2.77	1.24	30.9
2	34.14	7.52	5.29	2.22	29.6
3	33.62	4.20	2.98	1.22	29.0
4	32.29	7.13	5.16	1.97	27.6
5	31.76	8.50	6.19	2.31	27.2
6	31.76	7.85	5.72	2.13	27.2
7	19.95	22.23	19.10	3.13	14.1
8	19.32	11.07	9.60	1.47	13.3
9	12.30	14.82	13.88	0.94	6.3
10	12.30	32.73	30.66	2.07	6.3
11	12.30	13.77	12.90	0.87	6.3
12	12.30	20.65	19.35	1.30	6.3
13	12.30	20.50	19.21	1.29	6.3
14	12.30	20.47	19.18	1.29	6.3
15	4.81	15.64	14.98	0.67	4.26
16	4.81	16.12	15.41	0.71	4.40
17	4.81	15.07	14.41	0.66	4.40
18	4.81	15.83	15.13	0.70	4.40
19	4.67	26.73	25.63	1.11	4.14
20	4.67	22.06	21.11	0.95	4.30
21	4.60	33.73	32.38	1.35	4.01
22	4.60	32.49	31.20	1.29	3.97
23	4.60	29.01	27.91	1.10	3.81
24	4.60	30.75	29.55	1.20	3.89

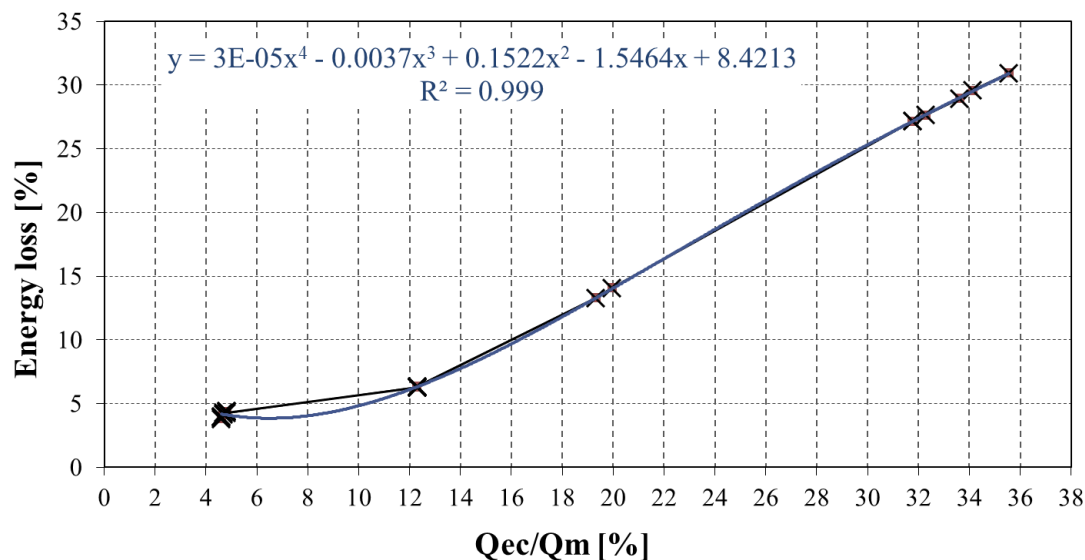**Figure 4.** Energy production without (red) and with (green) ecological flow

Figure 5. Energy loss to percentage of ecological flow from the mean flow

4. Conclusions

Ecological flows downstream the intakes of SHPPs are a must for living rivers and nature. The balance between water volumes for EF and for other water uses is not an easy task, especially when these other water uses are related to agriculture, meaning food.

Hydropower production in SHPPs is not essential for human live but it represents one of the renewable energy sources used for diminishing greenhouse gases emissions in conventional power plants.

In this paper it was demonstrated the loss of energy production for SHPPs because of the release of the ecological flow downstream weirs and dams used for SHPPs. Moreover, periodic changes in required ecological flows downstream SHPPs is not beneficial for their owners because, sometime, there are required structural changes of intake construction, and the increase of ecological flows determine a great energy loss and a subsequent loss of income.

A solution for diminishing the negative impacts related to an increased ecological flow to SHPPs owners could be to establish liabilities or compensations for the owners from some environmental funds.

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