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ASSESSMENT OF THE TECHNICAL JUSTIFICATION AND PROFITABILITY OF THE NEWLY BUILT SHPP–S IN MONTENEGRO

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Abstract: Basic approach to small hydro power plant (SHPP) design implies techno–economic analysis, which determines the SHPP installed parameter more precisely by using the following criteria: the annual electricity production, the annual revenue of the HPP, net present value (NPV), internal rate of return (IRR) and payback period (PB). The SHPP installed parameter represents the ratio of the design flow and the average perennial flow obtained from the flow duration curve at the location of the intended water intake. The main goal of the current research is to compare the 27 newly built SHPPs in Montenegro with the developed methodology, and provide an assessment of their technical justification and profitability. According to the conducted analyses, it can be concluded that 82% of them are designed properly and 18% have serious shortcomings.

Keywords: small hydro power plant, design flow, installed capacity, techno–economic parameters

INTRODUCTION

The construction of small hydropower plants in the Western Balkans in recent years has been followed by many controversies related to environmental, social, hydrological and hydro energetic issues. One of the main problems faced by hydropower engineers was the lack of reliable hydrological data. During 2010 and 2011, flows on 65 small watercourses were measured under the project named the Registry of Small Rivers and Potential Locations of SHPPs at Municipality Level for Central and Northern Montenegro, and relevant flow duration curves (FDCs) have been obtained [1]. This Registry was enhanced during 2018 and 2019 [2]. Location for SHPPs in Montenegro are characterized by relatively low average annual flows and high gross heads. The proper determination of the design flow also proved to be a challenge in terms of technical and economic justification. Due to all of the above mentioned, a methodology was developed for determining the SHPP installed parameter [3, 4]. The methodology takes into account technical (installed capacity, annual electricity production) and economic parameters (the annual revenue of the HPP, NPV, IRR and PB). The application of techno–economic parameters when determining design flow with different approaches can be found in the literature [5 ÷ 12]. The main goal of the current research is to compare the 27 newly built SHPPs in Montenegro with the developed methodology, and provide an assessment of their technical justification and profitability.

METHODOLOGY

This paper investigates 27 (twenty–seven) small watercourses on the territory of Montenegro where small hydropower plants of different capacities have already been built. The SHPP installed parameter is defined as the ratio of the design flow and averaged perennial flow according to the following equation,

$$K_i = \frac{Q_d}{Q_{av}}. \quad (1)$$

The annual gross income of the small power plant is calculated from the generated energy based on the FDCs and the incentive energy prices (Table 1).

Table 1. Electricity prices depending on the capacity of the power plant [13]

Hydro power plant capacity [MW]	Incentive price [c€/kWh]
$P_{SHPP} < 1$ MW	10.44
$1 \leq P_{SHPP} < 3$ MW	$10.44 - 0.7 \cdot P_{SHPP}$
$3 \leq P_{SHPP} < 5$ MW	$8.87 - 0.24 \cdot P_{SHPP}$
$5 \leq P_{SHPP} < 8$ MW	$8.35 - 0.18 \cdot P_{SHPP}$
$8 \leq P_{SHPP} \leq 10$ MW	6.8

The net present value (NPV) is defined as the value of the net cash flow during exploitation period of SHPP discounted back to its present value, and it is calculated according to the next equation [10,14].

$$NPV = \sum_{t=1}^{T} \frac{R(t) - C(t)}{(1+d)^t} \quad (2)$$

where are: *R* – annual net income of the SHPP, *C* – annual costs of the SHPP (in the first year this implies total investment costs of the project and in all next years the operation and maintenance costs), *d* – discount rate (*d* = 8% for Montenegro), *T* – the time of cash flow, equal to concession period of 30 years. The internal rate of return (IRR) is the discount rate that reduces the present value of the net project cash flow to zero in a discounted cash flow analysis and can be calculated from eq. (3), as the value of *d* corresponding to a NPV = 0 [10,14].

The payback period (PB) is the period it takes to recover the cost of an investment and it is obtained by dividing total investment costs with net annual income of SHPP.

RESULTS AND DISCUSSION

Based on hydrological data (flow duration curves and characteristic flow durations), calculations were made to select the optimal K_i on 27 watercourses on the territory of Montenegro. These results were compared with the designed values on these constructed plants and the results are shown in Table 2.

Table 2. Values of SHPP installed parameter (K_i – obtained by methodology, K_i^* – constructed)

	SHPP Name	K_i / K_i^*	NPV (kEUR)	IRR (%)	PB (year)	Annual electricity production (GWh)
1	Jezerštica	2.2	1431.92	15.69	6.56	3.04
		2.1	1402.08	15.63	6.59	3.00
2	Bistrica	1.0	8810.63	22.00	4.37	17.44
		1.2	8992.72	20.96	4.64	19.45
3	Orah	1.4	951.00	11.38	9.93	3.54
		1.4	951.00	11.38	9.93	3.54
4	Spaljevići	2.2	422.70	10.43	10.98	2.17
		1.7	303.96	9.89	11.71	1.96
5	Šekular	1.0	1146.78	11.17	10.21	4.42
		1.7	781.74	9.77	12.14	5.51
6	Jelovica 1	1.2	5149.83	22.11	4.33	8.82
		1.7	5217.91	19.93	4.92	10.36
7	Jelovica 2	1.1	–116.56	7.32	17.12	1.78
		1.4	–175.25	7.08	17.91	1.91
8	Vrelo	1.8	1630.62	16.64	6.10	3.22
		1.3	1336.12	15.82	6.48	2.83
9	Piševska	2.5	523.94	11.28	9.92	2.11
		3.0	557.97	11.33	9.88	2.21
10	Temnjačka	1.9	8484.88	25.97	3.57	15.36
		1.3	7461.46	27.57	3.32	12.53
11	Treskavička	1.9	4350.62	23.59	3.99	7.63
		1.1	3894.91	25.04	3.71	6.08
12	Babinopoljska	1.5	5041.42	23.43	4.03	8.60
		1.5	5041.42	23.43	4.03	8.60
13	Bistrica Majstorovina	1.0	7086.93	21.29	4.55	12.52
		1.6	6457.47	17.52	5.79	14.92
14	Bradavac	1.0	2710.11	22.57	4.19	4.07
		0.9	2580.22	22.25	4.26	3.92
15	Šeremet	1.7	2605.95	22.45	4.21	3.94
		1.7	2605.95	22.45	4.21	3.94
16	Ljevak	1.5	2290.21	18.31	5.43	4.04
		1.0	1653.47	16.86	6.00	3.22
17	Kutska 1	1.0	5044.77	23.62	4.00	7.95
		1.2	5300.22	23.06	4.12	8.65
18	Kutska 2	1.3	2083.14	17.71	5.66	3.81
		1.2	2016.71	17.63	5.69	3.71
19	Mojanska 1	1.1	2801.65	15.80	6.63	6.23
		1.5	3006.11	15.39	6.83	7.15
20	Mojanska 2	1.3	1690.36	14.29	7.44	2.35
		1.6	1417.61	12.84	8.52	4.35
21	Mojanska 3	1.5	670.34	11.86	9.33	2.35
		2.0	723.35	11.69	9.53	2.59
22	Bistrica Lipovska	1.3	2383.78	18.42	5.39	4.17
		1.3	2383.78	18.42	5.39	4.17
23	Paljevinska	1.0	–16.97	7.90	15.56	1.75
		1.3	–69.33	7.63	16.32	1.93
24	Pecka	2.1	563.35	10.07	11.60	3.17
		2.0	543.97	10.03	11.61	3.13
25	Vrbnica	1.3	10338.05	33.56	2.65	16.23
		2.1	10926.19	29.64	3.06	19.83
26	Štitska	2.2	730.09	11.73	9.49	2.59
		2.0	685.91	11.57	9.65	2.53
27	Mišnića	1.9	365.72	10.71	10.53	1.77
		1.0	124.27	9.12	12.80	1.38

Few typical results are shown in the next figures.

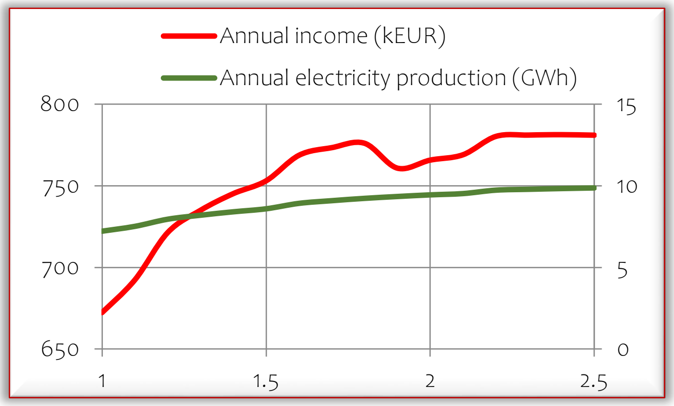

Figure 1. Annual electricity production and income– SHPP Babinopoljska

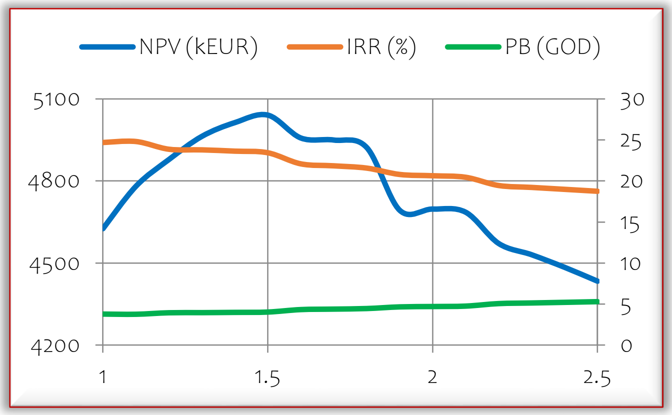

Figure 2. NPV, IRR and PB–SHPP Babinopoljska

The maximum value of annual production and income for SHPP Babinopoljska is obtained for K_i = 2.5 (Figure1). From Figure1 it can also be seen that the annual income is constantly increasing up to K_i = 1.8, after which due to the increase in installed capacity over 3 MW and the reduction of the incentive price it decreases to K_i = 1.9 after which it constantly increases until the end of the range. The maximum values for NPV (5041.42 kEUR) and IRR (24.8%) were obtained for K_i = 1.5 and K_i = 1.2. Designed values of K_i on constructed SHPP Babinopoljska is 1.5. For this value annual electricity production is 8.60 GWh, annual income is 753.12 kEUR, NPV is 5041.42 kEUR, IRR is 23.43% and PB is 4.03 years. Comparing the results obtained by applying the developed methodology with the designed parameters it gives the same parameter values. This designed solution seems to be well chosen if the economic aspect is to be observed.

For SHPP Vrelo the maximum value of annual production 3.58 GWh is obtained for K_i = 2.5, while the maximum value of annual income 350.51 kEUR is obtained for K_i = 1.9. The maximum values for NPV (1702.64 kEUR) and IRR

(16.64%) were obtained for K_i = 1.9 and K_i =1.8, (Figure4). Designed value of K_i on constructed SHPP Vrelo is 1.3. For this value, annual electricity production is 2.83 GWh, annual income is 295.52 kEUR, NPV is 1336.12 kEUR, IRR is 15.82% and PB is 6.48 years.

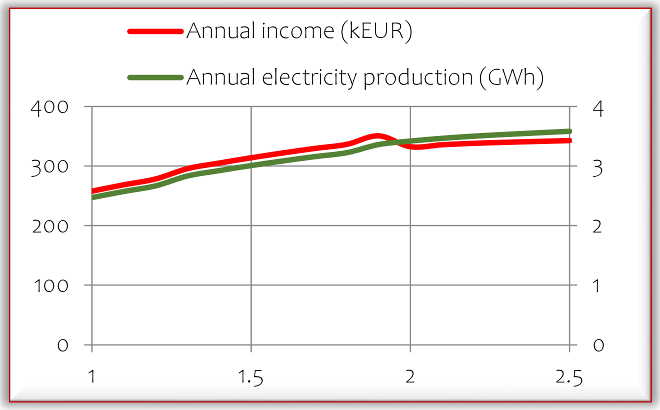

Figure 3. Annual electricity production and income– SHPP Vrelo

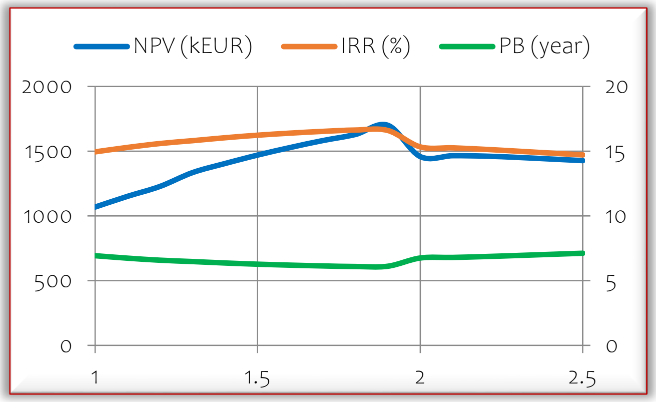

Figure 4. NPV, IRR and PB– SHPP Vrelo

For SHPP Jelovica 2, the maximum value of annual production 2.09 GWh is obtained for K_i = 2.5, while the maximum value of annual income 213.05 kEUR is obtained for K_i = 2.3. The maximum values for NPV (–116.56 kEUR) and IRR (7.32%) i.e. the corresponding PB (17.12 years) were obtained for K_i = 1.1. Designed value of K_i on constructed SHPP Jelovica 2 is 1.4. For this value, annual electricity production is 1.91 GWh, annual income is 199.27 kEUR, NPV is –175.25 kEUR, IRR is 7.08% and PB is 17.91.

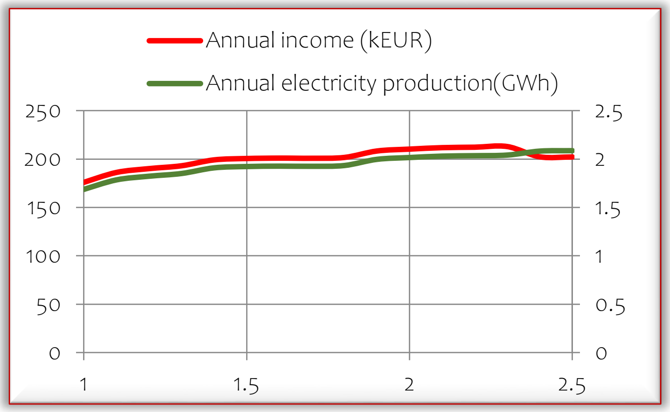

Figure 5. Annual electricity production and income– SHPP Jelovica 2

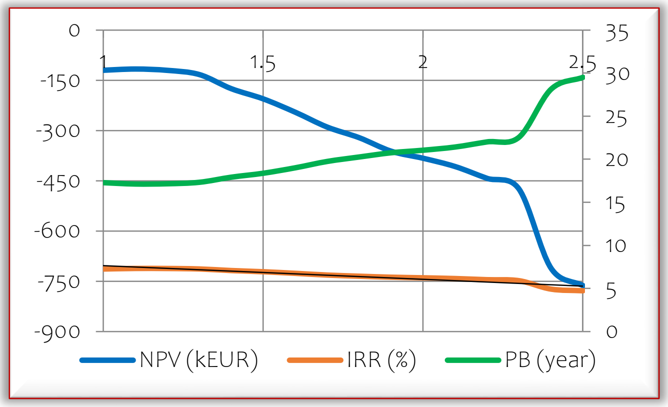

Figure 6. NPV, IRR and PB– SHPP Jelovica 2

Based on the obtained results, it can be noted that the NPV has a negative value for the entire K_i range, which indicates that this SHPP was not designed properly or was designed with wrong input data. Also, the maximum IRR value of 7.32% is lower than the adopted discount rate of 8%, which means that the project is not feasible. The normalized values of NPV and IRR are used for a precise comparison of the results obtained by the methodology and the constructed SHPP solution. Normalized values were obtained by dividing calculated values with optimal ones given with chosen K_i for every plant. With relative values, we are able to check results on the same level and compare different plants. Vertical lines mean constructed K_i and cross points with NPV or IRR lines give constructed NPVs or IRRs. Table 3 shows the criteria for evaluating the validity of the constructed solution.

Table 3. Criteria for evaluating the validity of the constructed solution

Criteria
Optimal solution – (0.85–1.0)
Good solution – (0.6–0.85)
Far from optimal solution – (0.3–0.6)
Bad solution – (0–0.3)

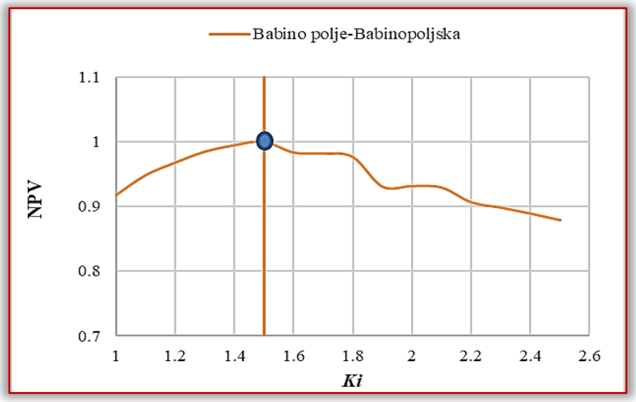

Figure7. Normalized values of NPV – SHPP Babinopoljska

For SHPP Babinopoljska (Figure7), the solution obtained by the methodology is the same as the constructed solution. Considering the above, the constructed SHPP installed parameter (NPV=1) is the optimal solution.

Figure8 shows normalized values of IRR for SHPP Vrelo. By comparing the constructed SHPP installed parameter and the SHPP installed parameter obtained by the methodology, it can be observed that slightly better results of all considered parameters are provided by the optimal solution. However, the constructed value of the SHPP installed parameter (IRR=0.95) is the optimal solution.

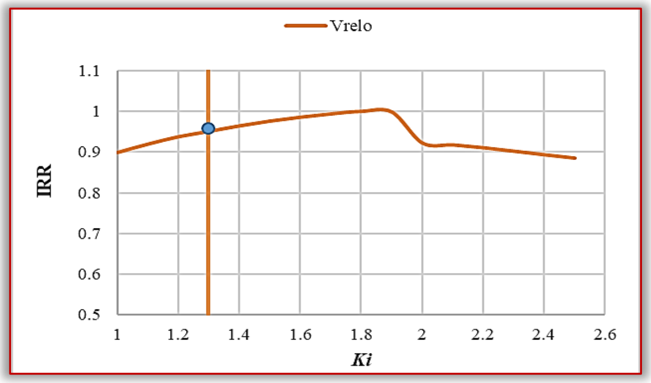

Figure 8. Normalized values of NPV – SHPP Vrelo

Bearing in mind that for SHPP Jelovica 2, NPV has a negative value and that the maximum IRR value is lower than the adopted discount rate, it can be concluded that this power plant was built as a bad solution.

CONCLUSION

The research subject in this paper is 27 small hydropower plants that were built in the period from 2014 to 2023 on the territory of Montenegro. Based on hydrological data (flow duration curves and characteristic flow durations), calculations were made to select the optimal SHHP installed parameter. By comparing the obtained with the constructed results, a conclusion can be drawn as to whether the designed solutions are optimal, good, far from optimal, or bad.

Table 4. Evaluation of the validity of the implemented solutions of SHPPs built in Montenegro

Optimal solution	20 SHPPs
Good solution	3 SHPPs
Far from optimal solution	1 SHPP
Bad solution	3 SHPPs

In all cases, it was found out that choosing the optimal K_i value depending on the annual income and annual electricity production leads to an increase in the annual income, but also to an increase in the price of the investment. From the research it is also concluded that the difference in the investment between the highest income and the maximum NPV and IRR is several times greater than the difference in income. It proves that in all cases NPV and IRR are more influential parameters for choosing the SHPP installed parameter compared to the annual income and annual electricity production. Finally, the developed methodology can serve as a guide for designers and investors of small hydropower plants.

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