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INTEGRATED HYDRAULIC, ENERGY AND ECONOMIC ASSESSMENT OF TWO DIVERSION SYSTEM ALTERNATIVES FOR THE SHP "MERĆEZ"

Abstract:

This paper presents an integrated hydraulic, energy and economic analysis of two diversion-system alternatives for the small hydropower plant "Merćez" on the Lukovska River. Two technical concepts are considered: Alternative I – water conveyance through a pressurized steel pipeline, and Alternative II – an open-channel diversion system with a forebay tank. The comparison is based on hydraulic losses, operating head, installed capacity, annual electricity production and investment requirements. The open-channel diversion option yields better energy metrics but demands higher investment. The economic analysis is restricted to comparative cost metrics.

Keywords: small hydropower plant; diversion system; hydraulic design; installed capacity; economic analysis

ИНТЕГРИСАНА ХИДРАУЛИЧКА, ЕНЕРГЕТСКА И ЕКОНОМСКА АНАЛИЗА ДВЕ ВАРИЈАНТЕ ДЕРИВАЦИОНОГ СИСТЕМА МХЕ „МЕРЋЕЗ"

Сажетак:

У раду је спроведена интегрисана хидрауличка, енергетска и економска анализа две варијанте деривационог система мале хидроелектране „Мерћез" на Луковској реци. Разматране су две техничке концепције: Варијанта I – транспорт воде челичним цевоводом под притиском и Варијанта II – отворени деривациони канал са водном комором. Поређење је засновано на показатељима хидрауличких губитака, радног пада, инсталисане снаге, годишње производње електричне енергије и инвестиционих улагања. Добијени резултати показују да варијанта са отвореним деривационим каналом има боље енергетске перформансе, али изискује већа инвестициона улагања. Економска интерпретација темељи се искључиво на компаративним показатељима трошкова.

Кључне ријечи: МХЕ; деривациони систем; хидрауличко димензионисање; инсталисана снага; економска анализа

1. INTRODUCTION

Small hydropower plants represent a mature renewable-energy technology with particular relevance in mountainous catchments, where relatively small discharges can be combined with favorable topographic conditions and available hydraulic head [1]. In run-of-river diversion schemes, the performance of the plant depends significantly on the configuration of the conveyance system, since the selected diversion concept affects hydraulic losses, usable head, installed capacity and annual energy production [2].

The selection of a diversion system is therefore a comparative engineering problem involving hydraulic, energy and investment-related criteria. Pressurized pipelines and open-channel diversion systems differ in flow regime, head-loss mechanisms, construction requirements and operational behavior. Their comparison requires a consistent methodological basis in which gross head, conveyance losses, operating head and energy output are evaluated using the same assessment structure [3]. The hydraulic structures forming the diversion system, such as intakes, channels, forebay tanks and small dams, should consequently be treated as parts of a single conveyance concept rather than as isolated elements [4].

In small hydropower planning, annual energy production is commonly estimated from the hydrological regime, installed discharge, operating head and overall efficiency [5]. However, when alternative conveyance concepts are compared, the reliability of the energy assessment depends on the consistency of the hydraulic model. This is particularly important for diversion-type plants, where the difference between gross head and usable head is governed by conveyance losses [6]. Open-channel systems require a clear distinction between channel slope and plant gross head [7], while pressurized systems require the evaluation of friction losses, local losses and possible transient effects [8].

This paper establishes and applies a structured comparative assessment model for two diversion-system alternatives of the small hydropower plant “Merćez” on the Lukovska River. Alternative I consists of a pressurized steel pipeline, while Alternative II consists of an open-channel diversion system with a forebay tank and short pressurized penstocks. The alternatives are compared through linked hydraulic, energy and investment-related indicators, including hydraulic losses, operating head, installed capacity, annual electricity production and cost indicators [9]. The economic component is limited to comparative cost indicators; a complete financial feasibility analysis, including electricity price assumptions, discount rate, payback period, internal rate of return and sensitivity analysis, is outside the scope of this paper [10].

2. COMPARATIVE ASSESSMENT MODEL

The two diversion-system alternatives are compared using an indicator-based assessment framework that links hydraulic performance, energy production and investment-related cost indicators. The framework is based on four calculation levels: definition of hydraulic boundary conditions and conveyance geometry, determination of hydraulic losses and operating head, estimation of installed capacity and annual electricity production, and comparison of investment-related indicators [3], [5], [9], [10].

The hydraulic performance of each alternative is evaluated using the head-retention coefficient:

$$k_H = \frac{H_{op}}{H_{br}} \tag{1}$$

where:

- k_H – the head-retention coefficient,
- H_{op} – the operating head (m),
- H_{br} – the gross head of the plant (m).

The relative hydraulic loss is expressed as:

$$k_L = \frac{\sum h_L}{H_{br}} \tag{2}$$

where:

- k_L– the relative head-loss coefficient and
- $\sum h_L$ – the total hydraulic loss along the relevant conveyance path (m).

Where separate turbine branches are considered, H_{op}, $\sum h_L$, $k_H$and $k_L$are evaluated for each flow path.

The investment intensity of the alternatives is assessed using the specific investment per installed capacity:

$$c_P = \frac{I}{P} \tag{3}$$

where:

- c_P – the specific investment per installed capacity (€/kW),
- I – total investment (€),
- P – installed capacity (kW).

In addition, the investment intensity per annual energy output is defined as:

$$c_E = \frac{I}{E_a} \tag{4}$$

where:

- c_E – the investment intensity per annual energy output (€/(MWh/year)), and
- E_a – the annual electricity production (MWh/year).

This indicator is used only for comparative purposes and does not represent the levelized cost of electricity. The adopted indicators allow the two hydraulically different alternatives to be compared on a common basis, by linking conveyance losses, usable head, energy output and investment intensity.

3. BASIC SITE CHARACTERISTICS AND HYDROLOGICAL CONDITIONS

The small hydropower plant "Merćez" is planned on the Lukovska River, in the municipality of Kuršumlija, southern Serbia. It is analyzed as a run-of-river diversion-type plant with two alternative conveyance layouts. Such schemes are typical for mountainous watercourses where available head can be utilized through diversion systems [1], [2].

The hydrological input data adopted for the intake profile are summarized through the characteristic discharges:

$$Q_{0.1\%} = 109.90\ \mathrm{m^3/s},$$
$$Q_{1\%} = 43.47\ \mathrm{m^3/s},$$
$$Q_{\mathrm{avg}} = 1.205\ \mathrm{m^3/s},$$
$$Q_{95\%} = 0.343\ \mathrm{m^3/s}.$$

The installed discharge was determined from the mean annual discharge increased by 5% [2], [5]:

$$Q_i = 1.05 \cdot 1.205 = 1.26\ \mathrm{m^3/s}.$$

This value is used as the common installed discharge for both diversion-system alternatives. The adopted hydraulic input parameters for the comparative model are given in Table 1.

Table 1. Main hydraulic input data adopted for the analyzed alternatives

Parameter	Alternative I	Alternative II
Installed discharge Q_i	$1.26\ \mathrm{m^3/s}$	$1.26\ \mathrm{m^3/s}$
Gross head H_{br}	40.00 m	42.00 m
Main conveyance length	3230 m	3328 m
Main conveyance element	Steel pipeline	Concrete open channel
Main diameter / channel width	$D = 1.10$ m	$B = 1.60$ m
Longitudinal channel slope	—	$i = 0.0003$
Roughness coefficient	$n = 0.011$	$n = 0.022$

The gross head is treated as an alternative-specific boundary condition, since the analyzed conveyance layouts differ in hydraulic configuration.

The parameters in Table 1 are used as input data for the hydraulic and energy comparison of the two alternatives.

The analyzed layout and longitudinal profile are shown schematically in Figure 1.

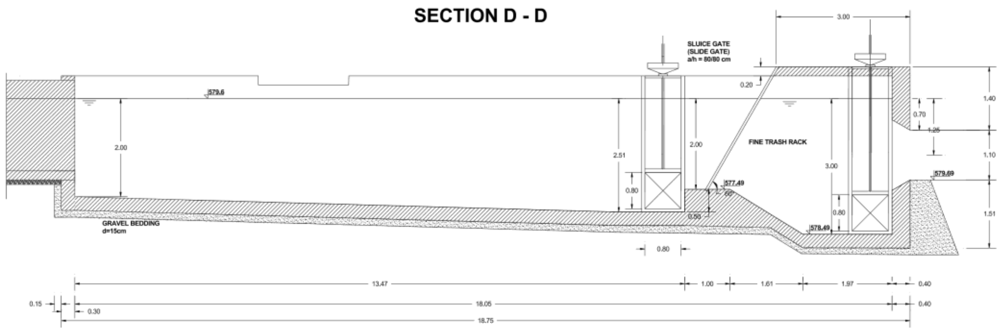

Figure 1. Longitudinal section D–D of the forebay/diversion structure

3.1. ANALYZED DIVERSION SYSTEM ALTERNATIVES

Two diversion-system alternatives were considered for the SHP "Merćez", representing two different conveyance concepts: a pressurized pipeline system and an open-channel diversion system with a forebay tank. Since the alternatives differ in hydraulic regime, alignment and conveyance structure, their comparison is performed through a unified set of hydraulic, energy and investment-related indicators, rather than through isolated design parameters [2], [3], [9].

Alternative I consists of a pressurized steel pipeline conveying water from the intake section toward the powerhouse. The adopted configuration is characterized by a long pressurized conveyance route and short turbine branches. The hydraulic performance of this alternative is evaluated through the calculated conveyance losses, resulting operating head and corresponding energy output [3], [8].

Alternative II consists of an open-channel diversion system conveying water toward a forebay tank, followed by short pressurized penstocks supplying the turbines. In this alternative, the open-channel conveyance loss is treated separately from the losses in the turbine branches. The longitudinal channel slope is included in the hydraulic balance as the conveyance energy gradient, while the gross head is treated as a separate boundary condition and must not be confused with the channel slope [7], [9].

The alternatives are evaluated using the same comparative sequence: definition of hydraulic boundary conditions, calculation of conveyance losses, determination of operating head, estimation of installed capacity and annual electricity production, and comparison of investment-related indicators. This structure enables a consistent assessment of the influence of diversion-system configuration on the overall performance of the plant.

4. HYDRAULIC DESIGN OF THE DIVERSION SYSTEM

The hydraulic calculation was carried out for the installed discharge $Q_i = 1.26\ \mathrm{m^3/s}$.

The gross head, conveyance losses and operating head were evaluated separately for each diversion alternative. The operating head was determined as:

$$H_{op} = H_{br} - \sum h_L \tag{5}$$

The notation follows the definitions given in Section 2. The calculation was performed separately for the two diversion alternatives and, where applicable, separately for each turbine branch.

The hydraulic calculation includes the conveyance losses that can be directly evaluated from the adopted geometric and hydraulic input data: friction losses in the main conveyance elements and losses in the short turbine branches. Local losses at intake structures, transitions, gates, trash racks and forebay–penstock connections were not modeled as separate detailed design components due to the limited availability of corresponding local-loss coefficients. Therefore, the hydraulic analysis is interpreted as a comparative hydraulic assessment based on documented conveyance and branch losses, rather than as a final detailed design calculation.

4.1. ALTERNATIVE I — PRESSURIZED PIPELINE

Alternative I was modeled as a pressurized steel pipeline system. The adopted parameters are:

where:

$$Q_i = 1.26\ \mathrm{m^3/s},$$
$$D = 1.10\ \mathrm{m},$$
$$L = 3230\ \mathrm{m},$$

$$n = 0.011.$$

The mean velocity in the main pipeline is:

$$v = \frac{Q_i}{A} = 1.326 \text{ m/s}.$$

The friction factor was determined using the Manning–Chezy relation and the Darcy–Weisbach formulation [3]:

$$\lambda = 0.0146$$

The linear head loss in the main pipeline is:

$$h_{f,p} = \lambda \frac{L}{D} \frac{v^2}{2g} \tag{6}$$

$$h_{f,p} = 0.0146 \cdot \frac{3230}{1.10} \cdot \frac{1.326^2}{2 \cdot 9.81} = 3.84 \text{ m}$$

The installed discharge is distributed between two turbine branches:

$$Q_1 = 0.42 \text{ m}^3/s,\ Q_2 = 0.84 \text{ m}^3/s.$$

For the first branch:

$$D_1 = 0.50 \text{ m},\ L_1 = 8 \text{ m}$$
$$h_{f,1} = 0.071\text{m}$$

For the second branch:

$$D_2 = 0.80 \text{ m},\ L_2 = 4 \text{ m}$$
$$h_{f,2} = 0.012 \text{ m}$$

Since the two turbine branches represent separate flow paths, the operating heads were calculated separately for each unit.

For turbine 1:

$$\sum h_{L,I,1} = h_{f,p} + h_{f,1} = 3.84 + 0.071 = 3.911 \text{ m}$$
$$H_{op,I,1} = 40.00 - 3.911 = 36.09 \text{ m}$$

For turbine 2:

$$\sum h_{L,I,2} = h_{f,p} + h_{f,2} = 3.84 + 0.012 = 3.852 \text{ m}$$
$$H_{op,I,2} = 40.00 - 3.852 = 36.15 \text{ m}$$

Thus, the operating head range for Alternative I is:

$$H_{op,I} = 36.09 - 36.15 \text{ m}$$

This value is used in the energy-performance calculation.

As an additional intake-control check, the adopted pipe submergence satisfies the anti-vortex condition ($h = 0.43 \text{ m} > h_{crit} = 0.41 \text{ m}$); therefore, vortex formation is not considered a limiting factor for the analyzed operating regime [8].

4.2. ALTERNATIVE II — OPEN-CHANNEL DIVERSION SYSTEM

Alternative II consists of an open-channel diversion section, a forebay tank and short pressurized turbine branches. The adopted parameters for the open-channel section are:

$$Q_i = 1.26 \text{ m}^3/\text{s},$$
$$L_{ch} = 3328 \text{ m},$$
$$i = 0.0003,$$
$$n = 0.022,$$
$$B = 1.60 \text{ m}.$$

The open-channel flow was evaluated using the Manning equation [7]:

$$Q = \frac{1}{n} A R^{2/3} i^{1/2} \tag{7}$$

For the adopted rectangular channel geometry, the calculated normal depth is approximately:

$$y = 1.54 \text{ m}.$$

The corresponding hydraulic parameters are:

$$A = 2.46 \text{ m}^2,$$
$$R = 0.526 \text{ m},$$
$$v = 0.51 \text{ m/s}.$$

The head loss along the open-channel diversion is:

$$h_{f,ch} = iL_{ch}$$

$$h_{f,ch} = 0.0003 \cdot 3328 = 0.998 \text{ m}.$$

This loss is included in the operating-head calculation for Alternative II.

The short turbine branches are treated separately. The adopted branch losses are:

$$h_{f,1} = 0.071 \text{ m}, h_{f,2} = 0.012 \text{ m}.$$

For turbine 1:

$$\sum h_{L,II,1} = h_{f,ch} + h_{f,1} = 0.998 + 0.071 = 1.069 \text{ m}$$

$$H_{op,II,1} = 42.00 - 1.069 = 40.93 \text{ m}$$

For turbine 2:

$$\sum h_{L,II,2} = h_{f,ch} + h_{f,2} = 0.998 + 0.012 = 1.010 \text{ m}$$

$$H_{op,II,2} = 42.00 - 1.010 = 40.99 \text{ m}$$

Thus, the operating head range for Alternative II is:

$$H_{op,II} = 40.93 - 40.99 \text{ m}$$

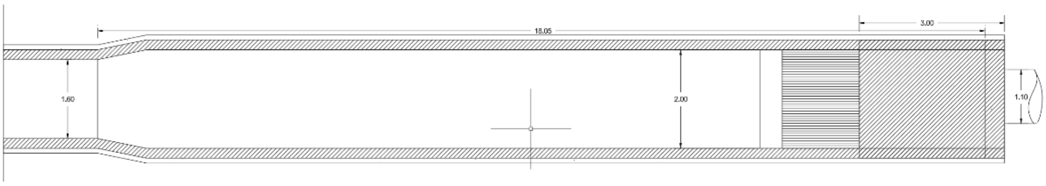

Figure 2. Longitudinal layout and characteristic dimensions of the diversion channel

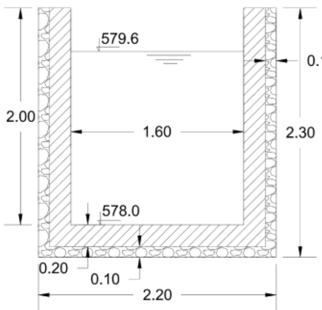

Figure 3. Characteristic cross-section of the diversion channel

4.3. COMPARATIVE HYDRAULIC INDICATORS

The hydraulic results are summarized in Table 2.

Table 2. Comparative hydraulic indicators of the analyzed alternatives

Indicator	Alternative I	Alternative II
Gross head H_{br}	40.00 m	42.00 m
Main conveyance loss	3.84 m	0.998 m
Branch loss, turbine 1	0.071 m	0.071 m
Branch loss, turbine 2	0.012 m	0.012 m
Total loss, turbine 1 path	3.911 m	1.069 m
Total loss, turbine 2 path	3.852 m	1.010 m
Operating head, turbine 1	36.09 m	40.93 m
Operating head, turbine 2	36.15 m	40.99 m
k_H, turbine 1	0.902	0.974
k_H, turbine 2	0.904	0.976
k_L, turbine 1	0.098	0.026
k_L, turbine 2	0.096	0.024 (8)

The results show that the two alternatives differ primarily in the share of gross head retained as operating head. Alternative I is governed by friction losses in the long pressurized pipeline, while Alternative II is governed by the open-channel conveyance loss and the short turbine-branch losses. These operating-head values are used as input data for the energy-performance assessment.

Local losses at intake structures, transitions, gates, trash racks and forebay–penstock connections were not modeled as separate detailed design components due to the limited availability of corresponding local-loss coefficients. Therefore, the hydraulic analysis is interpreted as a comparative hydraulic assessment based on documented conveyance and branch losses, rather than as a final detailed design calculation.

5. ENERGY DESIGN AND INSTALLED CAPACITY

The energy-performance calculation was carried out using the operating heads obtained from the hydraulic analysis. Since the two diversion alternatives have different hydraulic configurations, the installed capacity was calculated separately for each alternative and for each turbine branch. The installed discharge of the plant is:

$$Q_i = 1.26\ \text{m}^3/\text{s},$$

with the discharge distribution between the two generating units:

$$Q_{i1} = 0.42\ \text{m}^3/\text{s},\ Q_{i2} = 0.84\ \text{m}^3/\text{s}.$$

The installed capacity was calculated using the standard hydropower relation [9]:

$$P = 9.81 Q H_{op} \eta \tag{9}$$

where:

- Q – turbine discharge (m³/s),
- η – overall efficiency coefficient. In this study, the adopted efficiency is:

$$\eta = 0.90.$$

5.1. INSTALLED CAPACITY OF ALTERNATIVE I

For Alternative I, the operating heads obtained from the hydraulic calculation are:

$$H_{op,I,1} = 36.09\ \text{m},\ H_{op,I,2} = 36.15\ \text{m}.$$

The installed capacity of the first unit is:

$$P_{I,1} = 9.81 \cdot 0.42 \cdot 36.09 \cdot 0.90$$

$$P_{I,1} = 133.8\ \text{kW}$$

The installed capacity of the second unit is:

$$P_{I,2} = 9.81 \cdot 0.84 \cdot 36.15 \cdot 0.90$$

$$P_{I,2} = 268.0\ \text{kW}$$

Therefore, the total installed capacity of Alternative I is:

$$P_I = P_{I,1} + P_{I,2}$$

$$P_I = 133.8 + 268.0 = 401.8\ \text{kW}$$

or approximately:

$$P_I \approx 402\ \text{kW}.$$

5.2. INSTALLED CAPACITY OF ALTERNATIVE II

For Alternative II, the operating heads obtained from the hydraulic calculation are:

$$H_{op,II,1} = 40.93\ \text{m},\ H_{op,II,2} = 40.99\ \text{m}.$$

The installed capacity of the first unit is:

$$P_{II,1} = 9.81 \cdot 0.42 \cdot 40.93 \cdot 0.90$$

$$P_{II,1} = 151.8\ \text{kW}$$

The installed capacity of the second unit is:

$$P_{II,2} = 9.81 \cdot 0.84 \cdot 40.99 \cdot 0.90$$

$$P_{II,2} = 304.0\ \text{kW}$$

Therefore, the total installed capacity of Alternative II is:

$$P_{II} = P_{II,1} + P_{II,2}$$

$$P_{II} = 151.8 + 304.0 = 455.8\ \text{kW}$$

or approximately:

$$P_{II} \approx 456 \text{ kW}.$$

5.3. COMPARATIVE ANALYSIS AND INTERPRETATION

The installed-capacity results are summarized in Table 3.

Table 3. Installed capacity of the analyzed alternatives

Parameter	Alternative I	Alternative II
Installed discharge Q_i	$1.26 \text{ m}^3/\text{s}$	$1.26 \text{ m}^3/\text{s}$
Discharge, unit 1 Q_{i1}	$0.42 \text{ m}^3/\text{s}$	$0.42 \text{ m}^3/\text{s}$
Discharge, unit 2 Q_{i2}	$0.84 \text{ m}^3/\text{s}$	$0.84 \text{ m}^3/\text{s}$
Operating head, unit 1	36.09 m	40.93 m
Operating head, unit 2	36.15 m	40.99 m
Installed capacity, unit 1	133.8 kW	151.8 kW
Installed capacity, unit 2	268.0 kW	304.0 kW
Total installed capacity	401.8 kW	455.8 kW

The calculation shows that Alternative II provides a higher installed capacity than Alternative I. The difference results from the higher operating head retained in the open-channel diversion concept after the explicitly included open-channel conveyance loss. The installed-capacity increase is:

$$\frac{455.8 - 401.8}{401.8} \cdot 100 = 13.4\%$$

Thus, under the adopted hydraulic model, Alternative II provides approximately 13–14% higher installed capacity than Alternative I.

6. ESTIMATION OF ANNUAL ELECTRICAL ENERGY PRODUCTION

Annual electricity production was estimated using the flow duration curve method. The same representative flow-duration segments were used for both alternatives, while the operating heads were taken from the hydraulic calculation. For each segment, the energy contribution was calculated from the representative discharge, operating head, efficiency and segment duration [5], [9]:

$$E_i = 9.81\, Q_{m,i} H_{op,i} \eta t_i \tag{10}$$

where:

- E_i – the energy contribution of the i-th segment (kWh),
- $Q_{m,i}$ – the representative discharge of the segment (m^3/s),
- $H_{op,i}$ – the corresponding operating head (m),
- η – the overall efficiency coefficient, and
- t_i – the segment duration (h).

For segments with two active units, the energy contribution was calculated by summing the contributions of the individual turbine branches:

$$E_i = 9.81\, \eta\, t_i \sum_j Q_{ij}\, H_{op,ij} \tag{11}$$

where:

- j – the active turbine branch.

The operating heads used in the annual energy assessment are summarized in Table 4.

Table 4. Representative FDC segments used for annual energy production assessment

Segment	Representative discharge Q_m (m³/s)	Operating head, Alt. I (m)	Operating head, Alt. II (m)	Operating regime
1	1.26	36.09–36.15	40.93–40.99	Two units
2	1.15	36.09–36.15	40.94–40.99	Two units
3	0.86	36.09–36.16	40.95–40.99	Reduced load
4	0.50	36.09	40.96	One unit
5	0.21	36.14	40.98	One unit
Total annual production	—	≈ 0.91 GWh/year	≈ 1.03 GWh/year	Sum of FDC segments

Based on the operating heads and the same flow-duration segmentation, the annual electricity production is estimated as:

$$E_I \approx 0.91 \text{ GWh/year},$$

for Alternative I, and:

$$E_{II} \approx 1.03 \text{ GWh/year},$$

for Alternative II.

The results show that Alternative II still provides higher annual electricity production than Alternative I. However, the difference is lower than previously indicated, because the open-channel conveyance loss is now explicitly included in the operating-head calculation.

7. COMPARATIVE COST INDICATORS

The economic component of the study is limited to comparative investment-related indicators. The analysis does not include a complete financial feasibility assessment, since the available data are not sufficient for calculating net present value, internal rate of return, payback period or sensitivity scenarios. Therefore, the comparison is based on total investment, specific investment per installed capacity and investment intensity per annual energy output, using the indicators defined in Section 2 [5], [10]. The adopted investment values and the resulting cost indicators are summarized in Table 5.

Table 5. Comparative cost indicators of the analyzed alternatives

Parameter	Alternative I	Alternative II
Installed capacity P	402 kW	456 kW
Annual electricity production E_a	0.91 GWh/year	1.03 GWh/year
Total investment I	1,003,220 €	1,281,650 €
Specific investment c_P	2,496 €/kW	2,811 €/kW
Investment intensity c_E	1,102 €/(MWh/year)	1,244 €/(MWh/year)

The comparison shows that Alternative II provides higher installed capacity and higher annual electricity production, but it also requires a higher total investment. In addition, both investment-related indicators, c_P and c_E, are higher for Alternative II. Therefore, although Alternative II is more favorable from the hydraulic and energy perspective, the available cost indicators do not support a final conclusion on financial profitability.

Accordingly, the economic interpretation is limited to a comparative cost assessment. A complete economic evaluation would require additional financial data, including electricity purchase price, discount rate, financing structure, depreciation model, operation and maintenance assumptions, payback period, internal rate of return and sensitivity analysis.

8. DISCUSSION AND COMPARATIVE ANALYSIS OF ALTERNATIVES

The comparative assessment model enables the two diversion-system alternatives to be evaluated through a common set of hydraulic, energy and investment-related indicators (Table 6).

Table 6. Comparative overview of hydraulic, energy and cost indicators

Parameter	Alternative I	Alternative II
Conveyance concept	Pressurized pipeline	Open-channel diversion with forebay tank
Installed discharge Q_i	1.26 m³/s	1.26 m³/s
Gross head H_{br}	40.00 m	42.00 m
Operating head H_{op}	36.09–36.15 m	40.93–40.99 m
Installed capacity P	≈ 402 kW	≈ 456 kW
Annual electricity production E_a	≈ 0.91 GWh/year	≈ 1.03 GWh/year
Total investment I	1,003,220 €	1,281,650 €
Specific investment c_P	≈ 2,496 €/kW	≈ 2,811 €/kW
Investment intensity c_E	≈ 1,102 €/(MWh/year)	≈ 1,244 €/(MWh/year)

The results show that the main difference between the alternatives is not only the adopted gross head, but also the proportion of that head retained as operating head after conveyance losses.

Alternative I is governed by losses in the long pressurized pipeline, resulting in operating heads of approximately 36.09–36.15 m. Alternative II retains a higher operating head, approximately 40.93–40.99 m, even after the open-channel conveyance loss is explicitly included. This confirms that the hydraulic behavior of the conveyance system is a key factor in the comparative evaluation of diversion-type small hydropower schemes [3], [7], [9].

From the hydraulic and energy perspective, Alternative II performs better under the adopted comparative model. Its installed capacity is approximately 13–14% higher than that of Alternative I, while the annual electricity production is approximately 13% higher. This result is lower than the previously reported difference because the head loss along the open-channel diversion is now explicitly included in the operating-head calculation.

From the investment-related perspective, Alternative II requires a higher total investment and has higher values of both specific investment per installed capacity and investment intensity per annual energy output. Therefore, the preferred alternative depends on the adopted decision criterion. If the criterion is hydraulic and energy performance, Alternative II is more favorable. If the criterion is investment intensity, Alternative I has an advantage.

The results should therefore be interpreted as a comparative hydraulic-energy-cost assessment, not as a complete financial feasibility analysis. No final conclusion on profitability, payback period or financial feasibility is made in this paper. Such a conclusion would require additional financial data, including electricity purchase price, discount rate, financing structure, operation and maintenance assumptions, and sensitivity analysis [5], [10].

9. CONCLUSION

This paper established and applied an indicator-based comparative model for evaluating two diversion-system alternatives of the small hydropower plant "Merćez" on the Lukovska River. The model links hydraulic losses, operating head, installed capacity, annual electricity production and investment-related cost indicators in order to compare two hydraulically different conveyance concepts on a common basis.

The hydraulic calculation shows that Alternative I, based on a pressurized steel pipeline, has operating heads of approximately 36.09–36.15 m. Alternative II, based on an open-channel diversion system with a forebay tank and short pressurized penstocks, has operating heads of approximately 40.93–40.99 m after explicitly including the open-channel conveyance loss.

The resulting installed capacities are approximately 402 kW for Alternative I and 456 kW for Alternative II. The estimated annual electricity production is approximately 0.91 GWh/year and 1.03 GWh/year, respectively. Therefore, under the adopted comparative model, Alternative II remains more favorable from the hydraulic and energy perspective. However, the previously indicated advantage is reduced after including the open-channel head loss in the hydraulic balance.

From the investment-related perspective, Alternative II requires a higher total investment and has higher specific investment indicators. Therefore, the final selection of the preferable alternative cannot be based on energy production alone, but must consider both energy performance and investment intensity.

The economic component of the study is limited to comparative cost indicators. No final conclusion is made regarding profitability, payback period or financial feasibility. A complete economic assessment would require additional financial data, including electricity price assumptions, discount rate, financing structure, operation and maintenance assumptions, and sensitivity analysis.

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