USE OF THE CROSS-FLOW TURBINE. CASE STUDY ON THE IMPLEMENTATION OF A CROSS-FLOW TURBINE

UTILIZAREA TURBINEI TRANSVERSALE DE TIP CROSS-FLOW. STUDIU DE CAZ PRIVIND IMPLEMENTAREA UNEI TURBINE CROSS-FLOW

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Abstract: The paper analyzes the possibility of using a Cross-Flow hydraulic turbine (Banki–Michell type) in a micro-hydropower plant located on the Dâmbovița River, in the Conțești area. The study starts from the current context of the energy transition and the need for the development of renewable energy sources, highlighting the role of micro-hydropower plants in exploiting local hydraulic resources and increasing the energy security of rural communities. Based on the hydrological data of the area and the engineering calculations made, the electrical power and annual electricity production were estimated. The sizing of the turbine, penstock, and generator confirms the technical feasibility of implementing a micro-hydropower plant of this type. The techno-economic analysis indicates an estimated investment of approximately €130,000, a payback period of about 6.8 years, and a positive NPV, which demonstrates the economic viability of the project. In addition, the environmental impact is low, and energy production is achieved without direct CO_2 emissions.

Keywords: Cross-Flow turbines, Renewable Energy, Micro-hydropower plants, Discharge

Rezumat: Lucrarea analizează posibilitatea utilizării unei turbine hidraulice transversale de tip Cross-Flow (Banki–Michell) într-o microhidrocentrală amplasată pe râul Dâmbovița, în zona Conțești. Studiul pornește de la contextul actual al tranziției energetice și al necesității dezvoltării surselor regenerabile

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de energie, evidențiind rolul microhidrocentralelor în valorificarea resurselor hidraulice locale și în creșterea securității energetice a comunităților rurale. Pe baza datelor hidrologice ale zonei și a calculelor inginerești realizate, s-au estimat puterea electrică și producție anuală de energie electrică. Dimensionarea turbinei, a conductei forțate și a generatorului confirmă fezabilitatea tehnică a implementării unei microhidrocentrale de acest tip. Analiza tehnico-economică indică o investiție estimată de aproximativ 130.000 €, o perioadă de recuperare de circa 6,8 ani, un NPV pozitiv, ceea ce demonstrează viabilitatea economică a proiectului. În plus, impactul asupra mediului este redus, iar producția de energie se realizează fără emisii directe de CO_2.

Cuvinte cheie: Turbina Cross-Flow, Energie regenerabilă, Microhidrocentrale, Debit

1. Introduction

The continuous growth of global electricity consumption, correlated with increasing pressures to reduce greenhouse gas emissions and limit environmental impact, has led to a strategic shift towards renewable energy sources. In the context of the energy transition and European climate neutrality objectives, decentralized energy systems are gaining increasing importance, offering flexible, efficient solutions tailored to local needs. Among these, hydraulic energy holds a distinct place due to the stability, predictability, and Long service life of installations.

Unlike intermittent renewable sources such as solar or wind energy, hydraulic energy is characterized by a high degree of continuity and control over production, being considered one of the most reliable forms of electricity generation. Especially in the case of micro-hydropower plants, the advantages are numerous: relatively low investments, low operating costs, limited environmental impact, and easy integration into rural or isolated areas [1-3]. These systems contribute to the sustainable development of local communities by reducing dependence on centralized networks and increasing energy security.

Micro-hydropower plants represent an efficient solution for harnessing the energy potential of rivers with low falls and variable flow rates [4], where the implementation of large-scale hydro-energy facilities is not technically or economically justified. In this context, the selection of the turbine type becomes a key factor in achieving optimal energy performance.

Among the various types of turbines used in small-scale power applications, the cross-flow turbine, also known as the Michell–Banki turbine (Figure 1), stands out due to its simple construction, mechanical robustness, and ability to operate efficiently across a wide range of hydraulic conditions [5-8].

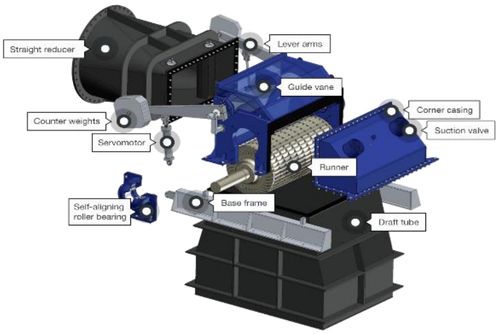

Figure 1. Cross-Flow turbine (Banki-Michell) [5]

The Cross-Flow turbine belongs to the category of impulse turbines, with energy conversion predominantly from the kinetic energy of the water jet, which passes through the runner twice, increasing the energy extraction rate. The particularity of the double impact on the blades ensures efficient use of the hydraulic resource and increased stability in varying flow rates.

A major advantage of Cross-Flow turbines is their ability to maintain relatively high efficiency under partial load conditions, which is crucial in micro-hydro applications where the flow regime is strongly influenced by seasonality. Additionally, their good tolerance to impurities (sand, leaves, fine sediments) and low maintenance costs make them suitable for areas where operating conditions are less controllable.

Recent optimization studies indicate that improvements in runner geometry, nozzle design and flow regulation can increase the hydraulic efficiency of Cross-Flow turbines by 5–10% compared to conventional configurations [9], [10].

This paper aims to analyze the performance of the Cross-Flow turbine from a theoretical, numerical, and practical perspective by conducting a case study on the implementation of a micro-hydropower plant with a Cross-Flow turbine on the Dâmbovița River, in the Conțești area, including technical sizing, analysis of hydraulic losses, and techno-economic evaluation of the investment.

Recent studies have demonstrated that Computational Fluid Dynamics (CFD) has become one of the most effective tools for optimizing the nozzle geometry, blade profile and internal flow field of Cross-Flow turbines, enabling significant improvements in hydraulic efficiency while reducing experimental development costs [11], [12].

The originality of this paper lies in the development of an integrated assessment framework for the implementation of a Cross-Flow turbine to exploit the small-scale hydropower potential of the Dâmbovița River in the Conțești area, a site that has not previously been investigated in the scientific literature. Unlike previous studies, which primarily focus on geometric optimization, CFD simulations, or experimental performance analysis of Cross-Flow turbines, this paper adopts a comprehensive approach that integrates site-specific hydrological characterization, preliminary hydraulic and turbine design, hydraulic loss assessment, and a techno-economic evaluation based on CAPEX, OPEX, NPV, IRR, and LCOE indicators. The results demonstrate the technical feasibility and economic viability of a micro-hydropower plant with an installed capacity of approximately 32 kW under the local hydraulic conditions. Furthermore, the proposed methodology can serve as a practical framework for assessing the feasibility of similar low-head hydropower sites, thereby supporting the sustainable development of decentralized renewable energy systems and contributing to the diversification of the energy mix.

Nomenclature

Table 1. **Nomenclature**

Symbol	Description	Unit
A	Cross-sectional area of the penstock	m²
B	Runner width	m
C_a	Annual costs, O&M, updated	€
CF_t	Annual net cash flow	€/year
c_v	Nozzle velocity coefficient	–
D_p	Penstock diameter	m
D	Runner diameter	m
E	Annual electrical energy production	kWh/year
E_a	Energy production over a lifespan	MWh
F	Darcy–Weisbach friction factor	–
F_t	Discount factor	–
g	Gravitational acceleration (9.81)	m/s²

Symbol	Description	Unit
H_b	Gross head	m
H_n	Net head	m
h_f	Friction head loss	m
Δh	Total hydraulic head losses	m
I_0	Initial investment (CAPEX)	€
i	Transmission (gearbox) ratio	–
k	Cross-Flow turbine filling coefficient	–
L	Penstock length	m
LCOE	Levelized Cost of Energy	€/MWh
n	Project lifespan	Years
n_{gen}	Generator rotational speed	Rpm
n_{turb}	Turbine rotational speed	Rpm
NPV	Net Present Value	€
PB	Simple Payback Period	Years
P	Electrical output power	kW
P_h	Hydraulic power	kW
P_{jet}	Water jet power	kW
P_m	Mechanical power at turbine shaft	kW
Q	Water discharge (flow rate)	m^3/s
r	Discount rate	%
t	Annual operating time	h/year
u	Runner peripheral velocity	m/s
v	Water velocity in the penstock	m/s
v_j	Water jet velocity	m/s
ρ	Water density	kg/m^3
η	Overall efficiency	–
η_G	Generator efficiency	–
η_h	Hydraulic efficiency	–
η_T	Turbine efficiency	–
IRR	Internal Rate of Return	%
CAPEX	Capital expenditure	€
OPEX	Operational expenditure	€/year
SCADA	Supervisory Control and Data Acquisition	–
PLC	Programmable Logic Controller	–
MHP	Micro-Hydropower Plant	–

2. Case study on the possibility of implementing a Cross-Flow turbine

For the implementation of a Cross-Flow turbine, the Dâmbovița River was selected as the study site, with the proposed location situated near Conțești.

Hydrological characteristics

- In Conțești, the Dâmbovița River has an average annual discharge of ~ 11.1 ÷ 11.4 m³/s, which is much higher than in the section through the city of Bucharest, where the flows are significantly reduced and affected by sewage systems/landscape modifications.
- The minimum daily discharge during drier periods can be around 2.0 ÷ 3.0 m³/s, but it varies seasonally (decreasing during summer/drought and increasing during snowmelt or heavy rainfall) [13].

Compared with the downstream reaches of the river (towards Bucharest), the Conțești area upstream of the capital has a higher and more stable water flow – an advantage for electricity generation. Relatively high and stable flow conditions.

Due to the fact that the river here is not yet heavily channeled and captured for urban needs, the natural flow and discharge are still significant.

More favorable topography than the Bucharest Plain

In this approximate area (before entering the wide floodplain downstream), the river's slope is generally steeper than in the plains sections, which can generate useful falls for small to medium head turbines like the Cross-Flow turbine.

The available hydrological data for the Dâmbovița River in the Conțești area indicate a significantly higher average annual flow rate compared to the urban sector downstream, providing favorable conditions for hydro-energy utilization [14]. The less regulated nature of the river course and the local topography allow for obtaining suitable useful heads for small and medium head turbines [14], [15].

Calculation of the Calculation of the electrical power output in the micro-hydropower plant located in the Conțești area.

The theoretical hydraulic power is:

$$P_h = \rho \cdot g \cdot Q \cdot H_b = 9.81 \cdot Q \cdot H_b \quad (1)$$

The net head H_n:

$$H_n = H_b \cdot \eta_h \tag{2}$$

The mechanical power P_m at the turbine shaft is:

$$P_m = P_h \cdot \eta_T \tag{3}$$

The electrical power at the generator terminals P is:

$$P = P_m \cdot \eta_G = 9.81 \cdot Q \cdot H_n \cdot \eta \tag{4}$$

And overall efficiency η:

$$\eta = \eta_T \cdot \eta_G \cdot \eta_h \tag{5}$$

where:

- η_T - turbine efficiency 80% [16], [17]
- η_h - the hydraulic efficiency 92% [18]
- η_G - generator efficiency 92% [19]
- η - overall efficiency (turbine + generator + hydraulic losses) 70% [20]

The assumed overall efficiency of 70% corresponds to typical values reported for low-head micro-hydropower plants equipped with Cross-Flow turbines, considering hydraulic losses, turbine efficiency and generator efficiency [16-20].

Representative design data for the Conțești (preliminary estimate)

For a realistic project, not all of the river's flow is used, but only a portion (the rest is the ecological flow).

Available discharge for capture: $Q = 1.5 \div 3.0\ m^3/s$
Possible gross head on a short section (50–200 m): $H_b = 2 \div 4$ m

Illustrative calculation:

Conservative scenario: $Q = 1.5\ m^3/s$; $H_b = 2$ m
The available electrical power is:

$$P \approx 9.81 \cdot 1.5 \cdot 2 \cdot 0.7 \approx 20.6 \text{ kW} \tag{6}$$

This operating condition is suitable for a low-head micro-hydropower plant, local consumption (farm, irrigation, buildings).

Average (realistic) scenario: $Q = 2.0$ m³/s; $H_b = 3$ m
The available electrical power is:

$$P \approx 9.81 \cdot 2.0 \cdot 3 \cdot 0.7 \approx 41.2 \text{ kW} \quad (7)$$

This operating scenario is suitable for:
- supplying a small village;
- partial grid injection.

Optimistic scenario (only where topography allows): $Q = 3.0$ m³/s; $H_b = 4$ m
The available electrical power is:

$$P \approx 9.81 \cdot 3.0 \cdot 4 \cdot 0.7 \approx 82 \text{ kW} \quad (8)$$

This operating scenario requires:
- Well-designed threshold / diversion
- More complex approval process

Determination of the net head

$$H_n = H_b - \Delta_h \quad (9)$$

Head losses occur in:
- Water intake
- Canal / penstock
- Bends, valves, turbine inlet

In practice, for micro-hydropower plants, acceptable losses are considered to be around 10–20% of the gross head.

If $H_b = 3$ m, then we have:
- Estimated losses Δ_h: 0.5 ÷ 0.7 m
- Realistic $H_n \approx 2.3 \div 2.5$ m

Calculation of penstock diameter and losses

Design data
- Discharge: $Q = 2$ m³/s
- Pipe length (typical): $L = 50$ m
- Material: steel / HDPE (High-Density Polyethylene)
- Optimal water velocity: 2.5 – 3.5 m/s

Penstock diameter

The calculation formula for determining the penstock diameter:

$$Q = v \cdot A = v \cdot \frac{\pi D_p^2}{4} \tag{10}$$

If we consider *v* = 3 m/s, we get:

$$D_p = \sqrt{\frac{4 \cdot Q}{\pi \cdot v}} \qquad D_p = \sqrt{\frac{4 \cdot 2}{3.14 \cdot 3}} \approx 0.92 \text{ m} \tag{11}$$

The recommended penstock diameter is D_p = 900–1000 mm.
Head losses (Darcy–Weisbach) h_f are:

$$h_f = f \cdot \frac{L}{D_p} \cdot \frac{v^2}{2g} \tag{12}$$

where:

• *f* is the Darcy friction factor (also known as the hydraulic friction coefficient) and is
approximately 0.02 (for smooth pipes)
• *L* is the penstock length, considered to be 50 m
• D_p is the penstock diameter, taken as 0.9 m
• *v* is the velocity in the penstock, considered to be 3 m/s

$$h_f \approx (0.02 \cdot 50 \cdot 9) / (0.9 \cdot 19.62) \approx 0.50 \text{ m} \tag{13}$$

Local losses (bends, valve, inlet): ~ 0.10 ÷ 0.20 m
Total penstock losses: $\Delta h \approx 0.60 \div 0.70$ (m)
Final net head: $H_n = 3 - 0.65 \approx 2.35$ (m)

<u>Electrical power considering hydraulic losses</u>:

$$P = 9.81 \cdot Q \cdot H_n \cdot \eta \longrightarrow P = 9.81 \cdot 2 \cdot 2.35 \cdot 0.70 \approx 32.2 \text{ kW} \tag{14}$$

The estimated electrical power output of approximately 30–35 kW represents the realistic engineering performance of the proposed micro-hydropower plant, as it incorporates hydraulic losses together with turbine, and generator efficiencies. This value is therefore more representative of the actual operating conditions than the theoretical hydraulic power.

Calculation of losses in the nozzle and in the turbine runner

Hydraulic losses in the nozzle

The hydraulic power P_h is:

$$P_h = 1000 \cdot 9.81 \cdot 2 \cdot 2.35 = 46.1 \text{ kW} \quad (15)$$

The formula for calculating the jet power is:

$$P_{jet} = c_v^2 \cdot P_h \quad (16)$$

Considering the nozzle velocity (loss) coefficient $c_v \approx 0.97$, then according to formula (16), the kinetic energy of the jet is: $P_{jet} = 43.7$ kW; and the losses in the nozzle ($P_h - P_{jet}$) are: 2.4 kW, which is approximately 5.2% of the total energy.

The mechanical power at the turbine shaft is:

$$P_m = 0.8 \cdot 46.1 = 36.9 \text{ kW} \quad (17)$$

$$P = P_h \cdot \eta_h \cdot \eta_T \cdot \eta_G \longrightarrow P = 46.1 \cdot 0.8 \cdot 0.95 \cdot 0.92 = 46.1 \cdot 0.7 \approx 32.2 \text{ kW} \quad (18)$$

The adopted efficiencies ($\eta_T = 80\%$, $\eta_h = 95\%$, $\eta_G = 92\%$) are consistent with the performance ranges reported for modern Cross-Flow turbines and medium-power induction generators operating under nominal conditions [16–19].

In Table 2 and Figure 2, the variation of electrical power depending on the turbine discharge for the Cross-Flow turbine in the Conţeşti area is presented.

Table 2. **Variation of electrical power as a function of discharge**

No.	Discharge Q (m^3/s)	Electrical power P (kW)	Efficiency η (%)
1	0,5	8,1	53
2	0,75	12.1	63
3	1,0	16,1	67
4	1,25	20,2	69
5	1,50	24,2	70
6	1,75	28,3	70
7	2,00	32,2	70
8	2,25	36,3	69
9	2,50	40,4	67

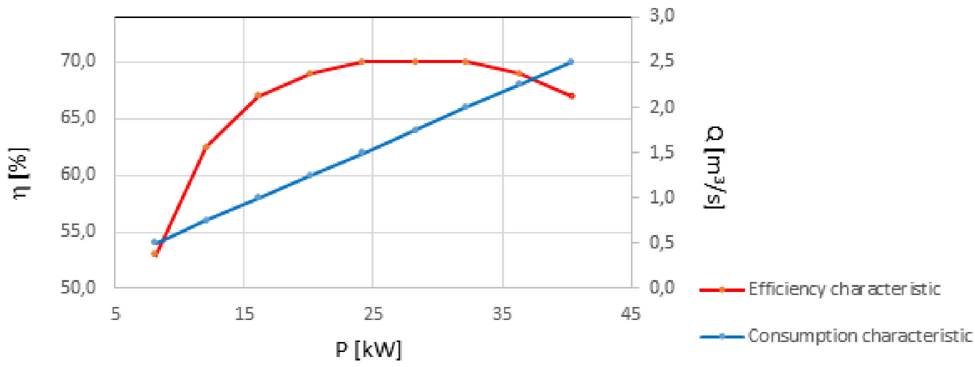

Figure 2. Power versus discharge characteristic and power versus efficiency characteristic

From the power versus discharge characteristic shown in Figure 3, the following can be observed:

- At the nominal flow rate of 2 m^3/s → ~32 kW;
- The optimal operating range of the turbine is between 1 m^3/s and 2 m^3/s;
- Below 1 m^3/s, the installation becomes economically inefficient, and the efficiency drops significantly;
- Above 2 m^3/s, the turbine efficiency begins to decrease.

Based on the data in Table 2, Figure 2 as well as the data in the specialized literature [7], the design discharge was chosen to be 2 m^3/s.

Annual electrical energy production calculation for the average scenario

If we assume an average operating time of: t = 6,000 h/year, accounting for seasonal variations [10], the estimated annual energy production is:

$$E = P \cdot t \approx 32 \cdot 6{,}000 \approx 192{,}000 \text{ kWh/year} \tag{19}$$

The installed capacity of 32 kW and the corresponding annual energy production of 192 MWh/year can be used for:

- supplying 20–25 rural households
- supplying a farm / pumping station / agricultural facility
- possible grid injection (if grid connection is available)

Cross-Flow turbine design

Design data

- useful power: 32 kW
- overall efficiency: $\eta \approx 70\%$
- jet velocity (from specific energy) v_j:

$$v_j = 2 \cdot g \cdot H = 2 \cdot 9.81 \cdot 2.35 \approx 6.8 \text{ (m/s)} \quad (20)$$

Runner diameter

For Cross-Flow turbines, the peripheral velocity u is:

$$u \approx 0.45 \cdot v_j \longrightarrow u \approx 0.45 \cdot 6.8 \approx 3.1 \text{ (m/s)} \quad (21)$$

The peripheral velocity u is also given by:

$$u = \frac{\pi \cdot n_{turb} \cdot D}{60} \quad (22)$$

We choose a turbine rotational speed: n_{turb} = 150 rpm (robust runner, low noise)

$$D = \frac{60 \cdot u}{\pi \cdot n_{turb}} \longrightarrow D = \frac{60 \cdot 3{,}1}{3.14 \cdot 150} = 0.40 \text{ m} \quad (23)$$

The recommended runner diameter is approximately 0.40 m.

Runner width (B) as a function of discharge

We start from the empirical discharge equation for Cross-Flow turbines:

$$Q = k \cdot B \cdot D \cdot v_j \quad (24)$$

where k is the filling coefficient, approximately 0.9

$$B = \frac{Q}{k \cdot D \cdot v_j} \longrightarrow B = \frac{2}{0.9 \cdot 0.4 \cdot 6.8} = 0{,}82 \text{ (m)} \quad (25)$$

Runner width: B = 800–850 mm ≈ 0.82 m

Blade geometry: number of blades: 26–32; jet inlet angle: 16°–18°; materials: stainless steel / protected carbon steel / HDPE

The calculation methods used for estimating hydraulic power, penstock sizing, and Cross-Flow turbine design comply with micro-hydropower design guidelines and specialized literature [21], [22].

Electrical generator

Three-phase asynchronous generator: robust, low cost, minimal maintenance

- Rated power: 30–35 kW, 400 V
- Frequency: 50 Hz
- Rated speed (n_{gen}): 1,500 rpm (4 poles)

A speed-increasing gearbox is required**.** Gear ratio:

$$i = n_{gen}/n_{turb} = 1{,}500/150 \tag{26}$$

Gear ratio: 1:10 (belt transmission or gearbox).

Main components of the proposed Cross-Flow micro-hydropower plant

Hydraulic structures

- Water intake – intake system equipped with a trash rack for retaining debris and solid materials
- Headrace channel – conduit or channel transporting water to the plant, equipped with drops to reduce energy losses
- Flow regulation and water level control structures – structures ensuring the required head for turbine operation
- Forebay (pressure chamber) – flow stabilization chamber before entering the turbine

Turbine and generator

- Cross-Flow turbine, with runner diameter adapted to available flow and head
- Synchronous or asynchronous generator coupled to the turbine
- Speed controller / inverter for maintaining operating parameters and grid adaptation

Auxiliary systems

- Transformer for voltage adaptation to the electrical grid
- Soft starter or capacitor bank (for off-grid or island operation)
- Electrical panel for control and distribution
- Overvoltage protection
- Frequency and voltage relay
- Grounding system for equipment and personnel protection
- Monitoring and control system (SCADA) for centralized supervision and operation

Table 3 presents the main parameters of the Cross-Flow turbine resulting from the design process.

Under the specific site conditions of the Dâmbovița River – Conțești sector, characterized by low head, variable flow, and the presence of sediments, the use of a Cross-Flow turbine represents the optimal solution from both technical and economic perspectives.

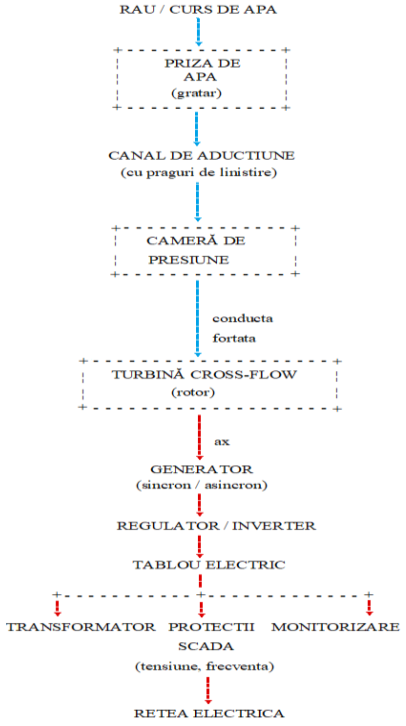

Figure 3. Schematically illustrates the main components of the proposed Cross-Flow micro-hydropower plant

Table 3. **Cross-Flow turbine (Banki–Michell)**

Parameter	Value
Nominal discharge	2.0 m³/s
Net head	2.35 m
Hydraulic power	46.1 kW
Turbine efficiency	80 %
Overall efficiency	70 %
Mechanical power	36.9 kW

Parameter	Value
Runner speed	150 rpm
Runner diameter	0.3–0.5 m
Runner width	0.7–0.9 m
Number of blades	26–32
Blade material	Stainless steel/HDPE
Service life	> 40 years

3. Technical and techno-economic analysis regarding the implementation of a Cross-Flow turbine in hybrid micro-systems for electric power generation

E CAPEX / OPEX cost estimation for a ~ 32 kW micro-hydropower plant equipped with a Cross-Flow turbine.

CAPEX – investment costs [23]

Table 4 presents the costs for hydromechanical and electrical equipment.

Table 4. **Hydromechanical and electrical equipment costs**

Component	Estimated cost (€)
Cross-Flow turbine	22,000
Generator + transmission	8,000
Intake valve + flap gate	5,000
Intake trash rack + cleaning system	6,000
Automation (PLC, local SCADA)	5,000
Electrical panel + protections	4,000
Equipment subtotal	50,000 €

Table 5 presents the costs for hydraulic (civil) structures.

Table 5. **Hydrotechnical construction costs**

Component	Cost (€)
Water intake + grid	18,000
Canal / intake pipe	15,000

Component	Cost (€)
Turbine house	12,000
Discharge canal	10,000
Land development	5,000
Subtotal Construction	60,000 €

Table 6 presents the costs for design activities, permits, and commissioning.

Table 6. **Design, permitting, and commissioning costs**

Element	Cost (€)
Feasibility study + permits	8,000
Technical project	5,000
Installation + commissioning (PIF)	7,000
Subtotal	20,000 €

Total CAPEX: I_0 = 130,000 € (±10%), resulting in a specific cost of 4,062 €/kW

Specific cost: (typical for micro-hydropower plants < 50 kW) ~ 5,900 €/kW, according to the specialized literature [24], [25], [26].

OPEX – annual operation and maintenance costs (O&M) [27]

In Table 7, the annual operating costs of the micro hydropower plant are presented.

Table 7. **Annual Operating Costs of the Microhydropower Plant**

Component	€/year
Operation and Maintenance	1,500
Partial Personnel	1,000
Parts, Consumables	800
Insurance, Taxes	700
Total OPEX	4,000 €/year

Economic Analysis (NPV, IRR, Payback)

Basic Economic Data

- Installed Power: 32 kW
- Annual Production: E_o = 192 MWh/year

- Energy Price: 120 €/MWh (without green certificates)
- Gross Annual Revenue: 192 × 120 = 23,040 €/year
- Net Annual Revenue (Net Cash Flow): CFt = 23,040 − 4,000 = = 19,040 €/year

Economic Indicators

Payback Period (Simple Payback) is: PB = 130,000 / 19,040 ≈ ≈ 6.8 years, acceptable for:

- Hydrotechnical infrastructure (> 40 years lifespan)
- Local/regenerative interest project

NPV (Net Present Value)

Calculation Assumptions:

- Project lifespan: n = 40 years
- Discount rate: r = 5%

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} - I_0 = \sum_{t=1}^{n} F_t \cdot CF_t - I_0 = \sum_{t=1}^{40} \frac{19040}{(1.05)^t} - 130000 \quad (27)$$

Discount Factor

$$F_t = \frac{1-(1+r)^{-n}}{r} = \frac{1-(1,05)^{-40}}{0.05} = 17.16 \quad (28)$$

NPV = 19040·17.16 − 130000 ≈ 196126 € ⟶ pozitive NPV (29)

IRR (Internal Rate of Return)

IRR is the rate at which NPV = 0.

IRR Calculation:

$$130000 = 19040 \frac{1-(1+IRR)^{-40}}{IRR} \quad (30)$$

Result: IRR ≈ 14.3 %.

Table 8. **Summary of Economic Results**

Indicator	Value
Annual Production	192,000 kWh
Annual Revenue	23,040 €
Net cash-flow	19,040 €
Payback	6.8 years
NPV (5%)	~196,000 €
IRR	~14.3%

Interpretation of the Technical-Economic Data from Table 8:

- The project is economically viable
- IRR is nearly three times the discount rate (5%)
- The margin between the IRR of 14.3% and the capital cost of 5% is +9.3% → low financial risk project.
- Sensitivity to interest rates is favorable (NPV increases significantly at low rates)
- Long service life → generates significant value after year 7
- Relatively moderate risk (hydropower has stable costs)

LCOE (Levelized Cost of Energy) – the levelized cost of energy

LCOE Calculation Formula [23]:

$$LCOE = \frac{I_o + C_a}{E_a} \tag{31}$$

where:

C_a represents the annual costs, O&M, updated: $C_a = C_o \cdot F_t = 4000 \cdot 17.16 = 68640$ €

I_o is the initial investment: 130.000 €

E_a is the updated energy: $E_a = E_o \cdot F_t = 192 \cdot 17.16 = 3294.7$ MWh

Substituting in formula (31): LCOE = $\frac{198640}{3294,7} = 60.3$ €/MWh = 0.06 €/kWh

Given that:

- Energy selling price: 120 €/MWh
- Levelized cost (LCOE): ~ 60 €/MWh

It results that the project has a very solid margin (price is about double the levelized cost).

The implementation project for a Cross-Flow turbine is justified by:

- Renewable energy
- Utilization of existing infrastructure
- Very low OPEX costs
- Long service life

Estimating costs and payback periods is based on typical values for this type of installation, according to European studies and renewable energy financing guides [28], [29].

Risk Assessment and Critical Factors for Implementing a Cross-Flow Turbine

- Seasonal flow variability
- Grate clogging
- Obtaining water management approvals
- Environmental regulations
- Stability of local grids

Environmental Impact Assessment

- Reduced impact compared to large power plants
- No need for a massive dam
- Allows for fish passage integration
- Zero direct CO_2 emissions

Sensitivity Analysis of the Main Economic Parameters

Since the economic performance of small hydropower projects is influenced by uncertainties related to the electricity market, hydrological conditions and investment costs, a quantitative sensitivity analysis was carried out. The objective was to evaluate the influence of the most important parameters on the Net Present Value (NPV), Internal Rate of Return (IRR) and Simple Payback Period (PB).

The reference case corresponds to the values previously adopted in this study:

- Installed power: 32.2 kW;
- Annual energy production: 192 MWh/year;
- Electricity selling price: 120 €/MWh;
- Initial investment (CAPEX): 130,000 €;
- Annual OPEX: 4,000 €/year;
- Project lifetime: 40 years;

Three parameters were varied independently while keeping all the other variables constant:

- electricity selling price (±20%);
- investment cost (±20%);
- available discharge (±20%), assuming that the annual energy production varies proportionally with the discharge.

The economic indicators were recalculated using Equations (27)–(31).

Sensitivity to electricity selling price

The electricity price directly affects the annual cash flow and therefore has a significant influence on the project's profitability.

Table 9. **Sensitivity of economic indicators to electricity price**

Electricity price (€/MWh)	Annual cash flow (€)	NPV (€)	IRR (%)	Payback (years)
96 (-20%)	14,432	117,700	10.9	9.0
120 (Base case)	19,040	196,100	14.3	6.8
144 (+20%)	23,648	275,200	17.6	5.5

The results indicate that a ±20% variation in electricity price changes the NPV by approximately ±40%, while the IRR varies between 10.9% and 17.6%. Even under the pessimistic scenario, the project remains economically feasible since the IRR remains above the adopted discount rate of 5%.

Sensitivity to investment cost (CAPEX)

Construction costs represent one of the largest uncertainties during the implementation phase.

Table 10. **Sensitivity of economic indicators to investment cost**

CAPEX (€)	NPV (€)	IRR (%)	Payback (years)
104,000 (-20%)	222,100	17.5	5.5
130,000 (Base case)	196,100	14.3	6.8
156,000 (+20%)	170,100	12.1	8.2

The increase in investment cost mainly affects the payback period and the IRR. Nevertheless, even with a 20% increase in CAPEX, the project maintains a positive NPV and an IRR well above the discount rate.

Sensitivity to available discharge

The available discharge determines the annual energy production and therefore the annual revenues.

For simplicity, the annual electricity generation was assumed to vary proportionally with the discharge.

Table 11. **Sensitivity of economic indicators to available discharge**

Discharge (m^3/s)	**Annual production (MWh/year)**	**NPV (€)**	**IRR (%)**	**Payback (years)**
1.6 (-20%)	154	117,700	10.9	9.0
2.0 (Base case)	192	196,100	14.3	6.8
2.4 (+20%)	230	275,200	17.6	5.5

The available discharge has an influence similar to that of electricity price because both parameters directly determine the annual income. Hydrological variability therefore represents one of the most important sources of economic uncertainty for small hydropower plants.

Comparative sensitivity analysis

Figure X illustrates the relative influence of the three parameters on the economic performance of the project. Among the analyzed variables, the electricity selling price and the available discharge produce the highest variation of NPV and IRR because they directly affect annual revenues. Conversely, CAPEX mainly influences the investment recovery period and has a moderate impact on long-term profitability.

Overall, the proposed micro-hydropower plant demonstrates good economic robustness. In all analyzed scenarios the NPV remains positive, while the IRR remains higher than the adopted discount rate of 5%, indicating that the investment remains economically attractive even under moderately unfavorable market or hydrological conditions.

4. Conclusions

This paper analyzed the potential of harnessing small-scale hydroelectric power through the use of a Cross-Flow turbine in a microhydropower plant located on the Dâmbovița River, in the Conțești area. The theoretical, hydrological, and techno-economic analysis conducted highlights that this solution represents an efficient option for generating electricity from renewable sources in areas with low water falls and variable flows.

Based on the available hydrological data and engineering calculations, it was estimated that for a nominal flow of approximately 2 m^3/s and a net head of about 2.35 m, an electrical power of approximately 30–35 kW can be generated. The annual electricity production is estimated at about 192

MWh/year, which allows for the supply of local consumers or partial injection of energy into the electricity grid.

The sizing of the main components of the proposed Cross-Flow micro-hydropower plant of the installation, namely the Cross-Flow turbine, hydraulic pipes, and electrical generator, confirms the technical feasibility of implementing such a microhydropower plant. The design characteristics of the Cross-Flow turbine, such as mechanical simplicity, efficient operation across a wide range of flow rates, and low maintenance costs, make it suitable for small-scale hydroelectric applications.

The results of the economic analysis indicate an estimated investment of approximately 130,000 €, with a payback period of about 6.8 years. The calculated economic indicators (positive NPV and an IRR of approximately 14.3%) confirm the project's economic viability. Additionally, the levelized cost of electricity (LCOE) of about 60 €/MWh demonstrates the competitiveness of this technology compared to the market price of electricity.

From an Environmental Impact Assessment perspective, the analyzed microhydropower plant presents significant advantages, having a minimal impact on the aquatic ecosystem and contributing to the generation of electricity without direct CO_2 emissions.

In conclusion, the use of Cross-Flow turbines in microhydropower plants placed on rivers with low heads represents a sustainable technical and economic solution for harnessing local hydroelectric resources and for the development of energy systems based on renewable sources.

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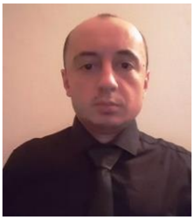
Authors' biographies



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