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METHODS OF ANALYSIS AND ASSESSMENT OF THE ECONOMIC EFFICIENCY OF MICRO HYDROPOWERS

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Abstract

As one of the renewable energy sources, micro hydropower is emerging as a resource to meet local electricity demand. At the same time, it is of great importance to propose methodologies aimed at increasing the economic advantage of the hydropower system. This article presents the methods of economic feasibility assessment for micro HPP and economic analysis of feasibility of micro HPP installation. Marhamat micro HPP as a practical case, considering the production of electricity, the profitability of the micro HPP project was checked and the feasibility of the installation was analyzed.

Keywords: Micro HPP, waterpower, economic efficiency, SWOT analysis, FAST analysis.

1. Introduction

Hydroelectric power is one of the most effective sources of renewable energy, and more than 16% of the world's electricity is generated by large and small power plants [1].

Hydroelectric power plants can be classified according to the functions of various parameters [2], [3]:

According to water pressure: low (less than 10 m), medium (from 10 to 50 m), and high (more than 50 m). According to installed capacity: pico (P < 5 kW, micro (5 ≤ P < 100 kW), small (100 ≤ P < 1 MW), medium (1 ≤ P < 10 MW), large (10 According to the type of turbines: they are divided into active and reactive groups.

Micro-hydroelectric power plants play an important role in supplying the Republic of Uzbekistan with electricity. Small hydropower is the most economical and environmentally friendly way to generate electricity compared to other traditional electricity sources. Micro-HPPs (micro-hydroelectric stations) allow to preservation of the environment and natural landscape not only during the operation phase but also during the construction process [4].

In addition, microhydropower plants are useful for the following reasons:

-Micro hydropower saves fossil fuels and uses environmentally friendly hydropower to generate electricity [5].

-Micro hydroelectric power plants provide electricity to areas that are not connected to or do not have a central power grid [6].

-Compared to large hydroelectric dams, microhydropower plants generally have a much smaller environmental impact [7].

- After installation, the micro hydropower plant is a stable and reliable source of electricity if there is a constant water supply [8].

-Through the production of local electricity, small enterprises will have an independent electricity supply, which will reduce interruptions in the electricity supply [9].

In general, microhydropower plants play an important role in stability, energy security and its economic development. But when it comes to economic efficiency indicators of micro hydroelectric power plants, there is a question of selecting turbine, generator, and other parts for newly built micro-hydroelectric power plants in our Republic and calculating their economic efficiency. To solve this problem, economic analysis methods for newly built micro hydroelectric power plants are given below as an example of a Marhamat micro hydroelectric power plant.

2. Materials and Methods

The purpose of calculating and analyzing the economic efficiency of a micro hydropower plant is to

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design and create technologies that meet modern requirements in the field of resource efficiency and resource saving.

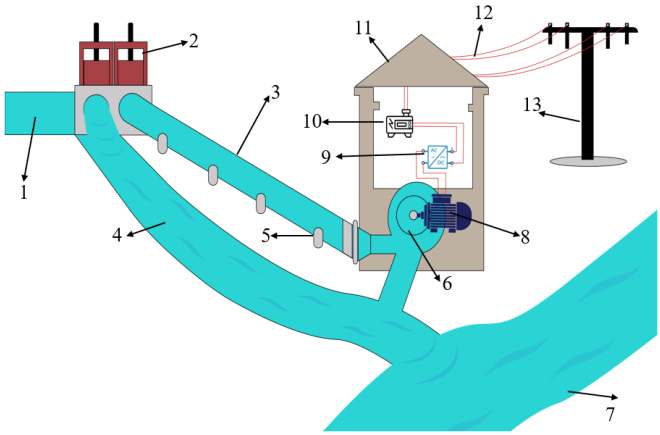


Figure 1. Marhamat micro HPP complete energy complex parts.

1-Water inlet pipe, 2- Gate, 3- Diversion pipe, 4- Discharge channel, 5- Consolidator, 6- Turbine, 7- Main channel (Southern Fergana channel), 8- Generator, 9- AC-DC converter, 10-inverter, 11- micro hydropower plant, 12- power grid, 13- pole for power grid.

The facility in question (Figure 1) is the Marhamat micro hydroelectric power station with a capacity of 50 kW. Micro HPP is a complete energy complex consisting of the main part and auxiliary parts (Fig. 1). Several methods were used in the economic analysis of Marhamat micro hydroelectric power plant. These analyzes are presented below.

FAST - (Functional Analysis Systems Technique)

Method of functional analysis of technical systems.

FAST analysis was developed by C. Bytheway (USA) in 1965, and this analysis is one of the most effective methods for analyzing and classifying functions. The purpose of FAST analysis is to express the problem in a functional form and understand the essence of objects in a functional form [10].

SWOT analysis is a strategic planning method, which consists in determining the factors of the organization's internal and external environment and dividing them into four categories:

S (strengths)

W (weaknesses)

O (opportunities)

T (threats)

Strong (S) and weak (W) sides mean the factors of the internal environment of the analyzed object, that is, what the object itself can influence. Opportunities (O) and threats (T) are environmental factors, that is, those that can affect the object from the outside and are not controlled by the object.

Economic analysis is the process of assessing the feasibility of a project by comparing its benefits and costs. An investment in a Marhamat micro hydropower project involves various types of costs and revenues spread over the life of the project. Costs are divided into two types, including capital and variable costs. Capital expenditure costs include construction work, transmission line, cost of electromechanical parts, etc. Variable costs include equipment repair and replacement as well as maintenance costs. The income of the project is adjusted only for the sale of electricity.

Table 1.
Calculation of the cost budget of the Marhamat micro HPP.

Types of expenses		**Share of total costs (in percent)**
Labor fund	(The share of labor costs in total costs should not exceed 20%)	16.2
Social contribution, 12% from the wage fund (the enterprise budget organization is not considered)		1.9
Equipment, inverter and equipment purchase costs		76.9
Costs related to certification and standardization documents, conducting clinical trials and developing a technical and economic basis		0.7
Other expenses		4.3
Total costs:		**100**

Capital expenditure can be divided into two main components.

1.Construction works of Marhamat micro hydropower plant, equipment, inverter and equipment purchase costs.

2. The construction work consists of the following parts: diversion pipe and water gate, water outlet channel, and micro hydroelectric power station building. The water pressure in Rohat MFY of Marhamat District is estimated to be 3.5 m [4].

The cost equations of the construction work are related to the water pressure -H, and the production power - P of the micro hydropower project and can be expressed as follows [12].

The cost of obtaining one kW of electricity through the diversion channel (in US dollars)

$$C_1 = 186.216 \cdot P^{-0.2368} \cdot H^{-0.0597} \quad (1)$$

The cost of building a building for a micro hydropower station per kW (USD)

$$C_2 = 1389.16 \cdot P^{-0.2351} \cdot H^{-0.0585} \quad (2)$$

The cost of general construction works is expressed for one kW of electricity: C_Q

$$C_Q = C_1 + C_2 \quad \text{(USD)} \tag{3}$$

Includes generator, turbine, inverter and control systems for micro hydropower project. These costs differ from construction costs because they do not have a significant impact on the characteristics of the area where the micro hydropower plant is located. The price of each part is calculated by the following equations [14].

For the turbine.

Kaplan.

$$C_K = 39398 \cdot P^{-0.58338} \cdot H^{-0.113901} \tag{4}$$

C_K −Kaplan turbine cost per kW of electricity (USD)

Frances.

$$C_F = 30462 \cdot P^{-0.50135} \cdot H^{-0.127243} \tag{5}$$

C_F −Cost of a Francis turbine per kW of electricity (USD)

Cross-flow.

$$C_{O'} = 10486 \cdot P^{-0.3644725} \cdot H^{-0.1281735} \tag{6}$$

C_K −Cross-flow price per kW of electricity (USD)

A Pelton turbine is twice as expensive as a cross-flow turbine per kW of electricity [13]. A Kaplan turbine has been selected for Marhamat micro hydroelectric power plant and the next calculations will be made for this turbine.

Generator price.

$$C_G = 1179.86 \cdot P^{-0.1855} \cdot H^{-0.2083} \tag{7}$$

C_G − Generator price per kW of electricity (USD)

The cost of the control system.

$$C_{BT} = 612.87 \cdot P^{-0.1892} \cdot H^{-0.2118} \tag{8}$$

C_{BT} − Cost of control system per kW of electricity (USD)

Inverter price.

$$C_I = 281 \cdot P^{-0.1803} \cdot H^{-0.2075} \tag{9}$$

C_I −One kilowatt of electricity transformer or inverter cost (USD)

Economic research and evaluation is one of the main factors of industrial projects. The main common methods of economic evaluation include: Net present value (NPV) method, benefit-cost ratio method, payback (Paybeck) method, return on investment (ROI) method and internal rate of return (IRR) method [15]. The NPV method was used to analyze the investment profitability of the micro hydropower project. This method is characterized by taking into account the time value of money and allows investors to compare projects. NPV can be determined as the difference between benefits and costs at a fixed periodic interest rate. In the case of micro hydropower projects, the duration of the project is assumed to be between 20-30 years.

3. Results

FAST analysis for Marhamat micro hydroelectric power plant was carried out in the following steps:

Stage 1.The object of FAST analysis is Marhamat micro hydroelectric power station.

Stage 2.The main task of the micro hydroelectric power plant is to provide the residents of the district with cheap and environmentally friendly electricity in the South Fergana canal flowing through the Marhamat district.

Table 2

Learning ob'classification of functions performed by micro hydropower plants.

Part name	Num of parts	Function execution	Level of function	
			Main	Ad/
Hydro turbine	1	Provides conversion of water energy into mechanical energy.	X	
Generator	1	Converting mechanical energy into electrical energy'provides	X	
Control unit	1	Automatic control of micro hydroelectric power plant and supply of electric energy produced by micro hydroelectric power plant to the grid'preparation of daily electricity production report.		X
Inverter	1	Convert DC current to AC current used to change.		X

Stage 3. In determining the importance of the functions performed by the ect, the prioritization method proposed by V.A.Blumberg and V.F.Glushchenko was used to evaluate the importance of the functions. This method is based on calculating and determining the importance of each function.

Table 3.

Function matrix

	Function 1	Function 2	Function 3	Function 4
Function 1 (Hydro Turbine)	=	>	>	>
Function 2 (Generator)	<	=	>	=
Function (Control Unit)	<	<	=	=
Function 4 (Inverter)	<	=	=	=

Here. "<" is less important; "=" are the same functions in importance; ">" is more important.

Table 5

Relative cost of functions.

Tools and equipment	Number of parts	Share of parts
Hydro turbine	1	0.31
Generator	1	0.28
Control unit	1	0.09
Inverter	1	0.01
Equipment and tools total:		0.77
Total :		$\sum 1$

Through the functional cost diagram (Figure 2), we can see the relationship between the importance and cost of each of the Micro HPP components.

Second stage by transforming the matrix into a matrix of quantitative relations of functions

Table 4

Relative importance of functions.

	Function 1	Function 2	Function 3	Function 4	Total importance	
Function 1	1	1.5	1.5	1.5	5.5	0.343
Function 2	0.5	1	1.5	1	4	0.25
Function 3	0.5	0.5	1	1	3	0.187
Function 4	0.5	1	1	1	3.5	0.218
					$\sum 16$	$\sum 1$

"<" at 0.5; “>” at 1.5; and is 1 for "=".

Step 4.O'cost analysis of the functions performed by the object under study.

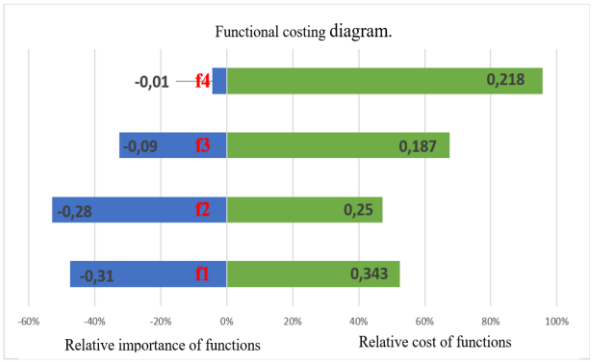


Figure 2. Functional costing diagram.

The results of the SWOT analysis are presented in the form of a table. Marhamat micro hydroelectric power plant will be the research object.

In order to calculate the capital costs of Marhamat micro hydroelectric power station, the construction work of micro hydroelectric power station was compared with the purchase costs of equipment, inverter and equipment and the funds spent on construction works and analog option. Below are economic calculation books for foreign analog option.

$$C_{AU} = C_K + C_G + C_{BT+}C_I \quad (10)$$

$$C_{AU} = 3486.3 + 439.8 + 224.2 + 107 = 4257.4$$

C_{AU} – cost of equipment per kW of electricity (USD)

Other indirect costs are added as a percentage of construction costs and are calculated at 13% of the cost of construction works and equipment [18].

Table 6

SWOT analysis for Marhamat micro hydropower plant.

Strengths:	Weaknesses:
1. Marhamat micro HPP is 3.2 times cheaper than its foreign analog. 2. Micro hydroelectric power plants have a long service life. 3. Smooth operation. 4.Production of environmentally friendly electricity based on water energy. 5. Provides power supply to local schools, clinics and small businesses. The absence of noise during the operation of micro hydroelectric power plants. 6. A small construction is enough to install and move a micro-hydroelectric power plant to another location.	1. Micro-hydroelectric power plants should have an auxiliary power plant to meet the energy needs of the population during periods of water shortage. 2. The fact that significant investments are required for the construction of micro-hydroelectric power plants with a capacity of 50 kW. 3.The complexity of the block diagram of the control panel. 4. That micro-hydroelectric power plants require constant maintenance. 5. Reproduction of aquatic vegetation caused by the construction of micro-hydroelectric power plants.

Features:	Risks:
1. Micro HPP can operate at low water pressure (3.5 m) and when the water speed is 3-5 m/s. 2.Use of micro HPP for non-electrified areas. 3.Implementation of an automated control system in micro HPP. 4.Lowering the cost of electricity through micro HPP.	1.The water level is lowered in accordance with the season. 2.The constant presence of household waste in the water. 3.The loss of fish and the decline of some species. 4.The fact that a large number of legal documents are required for the beginning of the construction of micro HPP
Analytical Conclusion	
Marhamat micro HPP analysis shows that micro HPP is environmentally friendly, efficient and allows energy production using local resources. This system can greatly benefit a small area as a sustainable energy source. Despite the initial investment and high maintenance costs, the problem can be solved with grants. The growing demand for green energy in the future will open up new opportunities for micro HPP. However, there are also threats such as competition with other renewable energy sources and natural disasters. Taking all factors into account, micro-hydroelectric power plants play an important role in meeting long-term energy needs and make a significant contribution to sustainable development.	

The total cost of the micro hydropower project for 1 kW of electricityM is obtained as follows:

$$C_U = 1.13 \cdot (C_{AU} + C_Q) \qquad (11)$$

$$C_U = 5469.7(\text{USD})$$

Variable costs.

Annual operation and maintenance costs are determined as a percentage of investment costs per kW. For large hydroelectric power plants, they are usually 2% to 2.5% on average, for micro hydroelectric power plants, this range is from 1% to 6% [18].

Table 7.

Economic comparison table of the cost of producing 1 kW of electricity with a foreign analogue of Micro-HPP built in Markhamat district.

Name of the economic object	Construction works (USD)	Equipment purchase costs (USD)					Variable costs
	$C_d + C_b$	C_K	C_G	C_{BT}	C_I	C_U	3%
Foreign analog micro HHP	583	3486.3	439.8	224.2	107	5469.7	3%
Marthamat micro HHP	108	510	466.8	155	113	1280	3%

The price analysis of micro HPPs operating at low water flow pressure in foreign companies is as follows: the average price of installation of a 1 kW Micro-HPP produced by US companies is 6300 US dollars, and the same price of micro HPPs in France and Germany 8 000 USD. Companies from Italy, the Czech Republic, Slovakia and Poland are engaged in the production of micro-hydroelectric power plants.

As can be seen from Figure 3, in general, each For the construction of a 1 kW micro hydroelectric power station, the foreign analogue micro hydroelectric power station cost 5469.7 US dollars, and the domestic Marhamat micro hydroelectric power station cost 1280 US dollars.

Payback period for the Micro HPP project.

NPV reduction is used as an indicator to classify different projects. Projects with a non-positive NPV are rejected because the discount benefits over the life of the project cannot cover the initial costs of the project. When comparing a group of projects, the project with the largest positive NPV is considered the best. This discount rate depends on the inflation rate. Its value is usually between 5% and 12% [15,16].

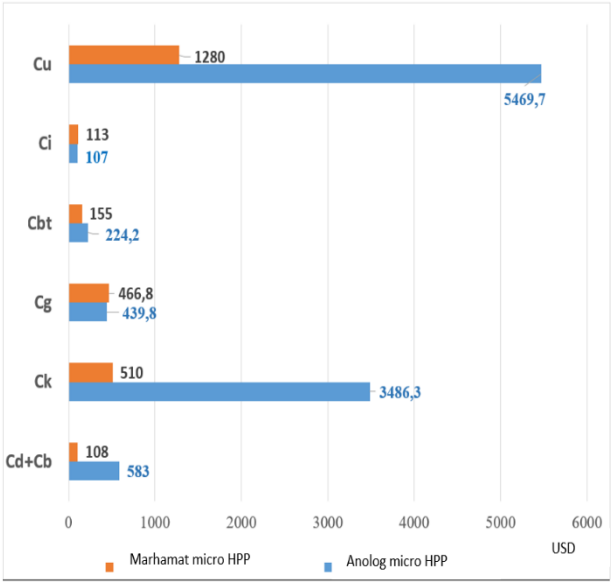


Figure 3. Economic comparison of the cost of producing 1 kW of electricity for micro hydroelectric power plants with domestic and foreign analogues.

In Uzbekistan, private producers of electricity (also for Micro HPP) are billed in the amount of 1000 soums per 1 kW/h. In practice, it works from about 4500 to 6500 hours per year for Micro HPP [17]. Based on this, the annual income from the sale of electricity can be calculated. Variable costs are Cv-2,500,000 soums [18] per year. Today's high capacity of Micro HPP in Markhamat district is 50 kW/h, 1200 kW/h in one day, and 324 000 kW/h in one year (for 9 months).

Table 8.

Production capacity and price of Micro HPP in Marhamat district.

Micro HPP power	kW/ hour	kW/ day	kW/ month	kW/ year
High	50	1200	36,000	324,000
Average	25	750	18,000	162,000
Low	10	240	7200	64,800
Micro HPP income	hour/ sum (1000)	day/ sum (1000)	month/ sum (1000)	year/ sum (1000)
High	50	1,200	36,000	324,000
average	25	600	18,000	162,000
Low	10	240	7,200	64,800

Marhamat Micro HPP will be billed at 3 production capacity from now on. These are in high (50 kW), medium (25 kW), low (10 kW) production capacities.

By calculating the payback period of Micro HPP without taking into account the discount rate U_{sum}- capital investment is 1,000,000,000 sums, D - annual income, C_v-annual variable cost is calculated .

High annual income price

$$D_y = D - C_v = 321\,500\,000\ sum \quad (12)$$

Average annual income price:

$$D_{o'} = \mathrm{D} - C_v = 159\,500\,000\ sum \quad (13)$$

Low annual income price:

$$D_p = \mathrm{D} - C_v = 62\,300\,000\ sum \quad (14)$$

Micro HPP payback period:

$$T_{qy} = \frac{U_{sum}}{D_y} = 3.13\ year \quad (15)$$

T_{qy} —high income for the price;

$$T_{qo'} = \frac{U_{sum}}{D_{o'}} = 6.26\ year \quad (16)$$

$T_{qo'}$ —average income for the price;

$$T_{qp} = \frac{U_{sum}}{D_p} = 16\ year \quad (17)$$

T_{qp} —low income for the price.

We calculate the net present value assuming that the discount rate of the project is 8.6 % (r =0.086) [19] and the service life is 20 years as of 2024, taking into account the inflation rate.

Net Present Value (NPV)characterized by:

$$NPV = \sum_{k=1}^{n} \frac{D_n}{(1+r)^k} - U_{sum} \quad (18)$$

u_{sum}- start at time t=0, internal investment cost,

α — operating expenses for years.

The net present value (NPV) of the project discount rate is given by equation (12).

$$\sum_{k=1}^{n=20} \frac{D_n}{(1+r)^k} = \sum_{k=1}^{n=20} \frac{D_y}{(1+r)^k} = 5\,920\,810\,313\ (\mathrm{sum}) \quad (19)$$

$$\sum_{k=1}^{n=20} \frac{D_n}{(1+r)^k} = \sum_{k=1}^{n=20} \frac{D_{o'}}{(1+r)^k} = 2\,983\,425\,414\ (sum) \quad (20)$$

$$\sum_{k=1}^{n=20} \frac{D_n}{(1+r)^k} = \sum_{k=1}^{n=20} \frac{D_p}{(1+r)^k} = 1\,193\,370\,166\ (sum) \quad (21$$

$$NPV_y = 4\,920\,810\,313\ (\mathrm{sum}) \quad (22)$$

$$NPV_{o'} = 1\,983\,425\,414\ (\mathrm{sum}) \quad (23)$$

$$NPV_p = 193\,370\,166\ (\mathrm{sum}) \quad (24)$$

Calculated NPV≥ 0, If the project is useful if NPV<0 project is economically unprofitable. In our case, NPV>it meansthe project is usefulis considered

At the next stage, micro-hydroelectric power plantproject. We calculate the profitability of investments. Profitability indicators of return on investment in the project (relative) describes.

$$RI_y = \frac{\sum_{k=1}^{n=20} \frac{D_y}{(1+r)^k}}{U_{sum}} = 5.9 \quad (25)$$

$$RI_{o'} = \frac{\sum_{k=1}^{n=20} \frac{D_{o'}}{(1+r)^k}}{U_{sum}} = 2.9 \quad (27)$$

$$RI_p = \frac{\sum_{k=1}^{n=20} \frac{D_p}{(1+r)^k}}{U_{sum}} = 1.1 \quad (28)$$

$RI_p, RI_{o'}, , RI_p$ it is big for all three cases $RI > 1$ and investing in the project is considered profitable. If $RI <$ 1 investment is considered useless.

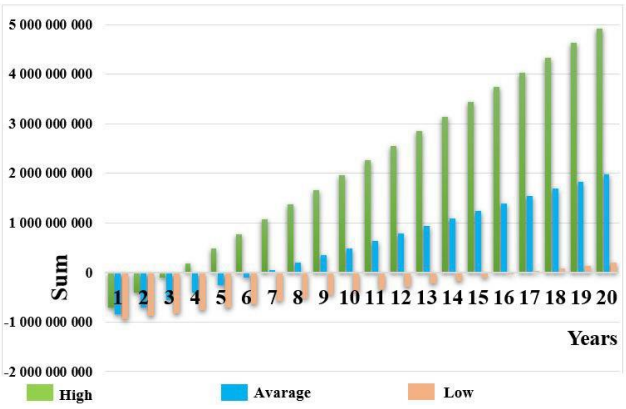


Figure 4. Thank you for years on the basis of NPV for the micro hydropower project amount spent on of payback period.

Figure 4 shows that the NPV range is 3-4 years for the high-income price, 6-7 years for the average,

and 16-17 years for the low.'ida changes to the value of the profit state.

5. Conclusions

The current capacity of the Micro HPP built in Marhamat District is 50 kW and if we assume that the capital cost of construction for 1 kW/h is 5469.7 US dollars, its total cost will be 273 490 US dollars. This is 3.2 times more than the amount allocated for the Marhamat Micro HPP project. Therefore, the Marhamat micro-hydroelectric power plant project is 3.2 times cheaper than its analogues, and it can be widely used in the streams and canals of our Republic.

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