HSR (LONDON),
HOUGHTON STREET REVIEW JOURNAL
ISSN: 2058-5519|Impact factor-15.9
http://houghtonstreetreview.com/index.php/hsr

ASSESSMENT OF THE ECONOMIC AND ENVIRONMENTAL EFFECTIVENESS OF HYDROPOWER DEVICE

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Abstract. The article examines the economic and environmental impact of a hydropower device. The economic efficiency of the hydropower device was assessed using the net present value (NPV) method. The results showed a net present value of 68.96 million soums, a static payback period of 1.56 years, and a dynamic payback period of 2.78 years.

Keywords: hydropower device, net discounted profit method, net present value, static payback period, dynamic payback period, ton of equivalent fuel, carbon dioxide.

Ensuring global energy security, mitigating environmental challenges, and improving the reliability and continuity of electricity supply for autonomous consumers located far from centralized power grids have become issues of paramount importance. As a sustainable solution to these pressing challenges, the utilization of renewable energy sources, particularly hydropower, has emerged as one of the leading approaches worldwide. Extensive research is being conducted globally on the design, modeling, development, and performance optimization of hydropower devices adapted to low-head water flows in order to provide autonomous consumers with a reliable and uninterrupted electricity supply.

In Uzbekistan, extensive measures are being implemented to reduce the use of fossil fuel-based energy systems, minimize their adverse environmental impacts, and mitigate global warming. These measures focus on meeting the growing energy demand through the utilization of renewable energy sources and energy-efficient technologies, taking into account the country's geographical characteristics. Particular emphasis is placed on establishing autonomous and sustainable energy supply systems for regions located far from centralized power grids. In particular, Presidential Decree No. PD-63 of the Republic of Uzbekistan, “On Measures to Improve Public Administration in the Field of Energy Efficiency and to Develop the Market for Energy Service Companies,” signed on March 27, 2025, sets a target of generating 2.60 billion kWh of electricity in 2026 through the installation of hydropower facilities and other energy-efficient technologies. The present research contributes to the implementation of the objectives outlined in this decree, as well as in other relevant regulatory and legal documents governing the development of the energy sector [1].

For local electricity consumers located in remote areas far from the centralized power supply system, an installed capacity ranging from 1 kW to 10 kW is generally sufficient to meet their energy demand. Conventional power systems are unable to economically satisfy the needs of such consumers. The primary challenge lies not in the amount of electricity generated, but in its transmission and delivery to remote locations. Extending power transmission lines over hundreds of kilometers to supply electricity to small settlements consisting of 20–30 households or to farms situated in desert regions is neither technically nor economically feasible, as such investments may not be recovered even over a period of 50 years. In contrast, small settlements and farms are typically dispersed across wide geographical areas, making the deployment of small-scale renewable energy systems a more technically viable and economically efficient solution for ensuring a reliable electricity supply.

In regions where the potential for utilizing renewable energy sources such as solar and wind energy is limited, the use of hydropower devices capable of efficiently harnessing the energy of flowing water offers a highly effective alternative. Such systems provide a reliable and sustainable

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ISSN: 2058-5519|Impact factor-15.9
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source of electricity, particularly for remote areas with access to low-head or small-scale water resources.

The developed hydropower device was implemented at a farm operated by "Bukhoro Chorvo Omad" LLC in the Bukhara region of Uzbekistan. The farm is located approximately 9.5–10 km from the nearest centralized electricity distribution network. At present, its electricity demand is met using a gasoline-powered generator. However, the increasing cost and limited availability of fuel, together with the environmental pollution caused by the operation of gasoline generators, significantly restrict the practical and sustainable use of such power supply systems. These challenges highlight the need for alternative energy solutions based on renewable energy resources, such as small-scale hydropower devices.

The economic performance of the proposed hydropower device implemented in the farm's electricity supply system was evaluated.

The developed hydropower device has a rated capacity of 3,000 W (3 kW) and is designed to operate efficiently under variable and low-head water flow conditions. The electrical energy generated by the hydropower device is first converted into direct current (DC) using rectifier circuits. The rectified DC power is then converted into alternating current (AC) by an inverter and supplied to the electrical loads.

To assess the practical applicability of the proposed system, the developed 3,000 W hydropower device was used to supply electricity to a 2.2 kW electrical load at the farm. The results demonstrate the feasibility of employing the proposed hydropower device as a reliable and sustainable power source for remote agricultural consumers.

In determining the economic efficiency of the hydropower device, the costs associated with the manufacturing, installation, and commissioning of the 3,000 W capacity system are calculated using the following expression [2].

$$C=C_m+C_{cm}+C_{tr}+C_{gcs}+C_i+C_{is}+C_{oc} \quad (1)$$

where: C_m– costs of materials used for the hydropower device, million UZS; C_{cm}– costs associated with the manufacturing of the hydropower device, million UZS; C_{tr}– transportation costs, million UZS; C_{gcs}– costs of the generator and control system used in the hydropower device, million UZS; C_i– installation costs of the hydropower device, million UZS; C_{cc}– commissioning costs, million UZS; C_{oc}– other associated costs, million UZS.

The total cost required for the manufacturing, installation, and commissioning of the 3,000 W hydropower device designed for efficient operation under low-head water flow conditions is determined using the above expression (1).

The total investment required for the manufacturing of the proposed hydropower device, including the cost of construction materials, amounted to 20 million UZS. The total cost of developing the control system and manufacturing the generator used in the hydropower device was 3 million UZS. The expenses associated with transportation services and labor costs amounted to 1 million UZS. Other expenses, including assembly, installation, and commissioning costs, were estimated at 1 million UZS. Thus, the total cost required for the development and installation of one 3,000 W hydropower device was 25 million UZS (the stated cost corresponds to the price level of 2026).

The annual operating costs of the hydropower device are determined using the following expression:

$$U_{hpd}=U_{dc}+U_{rc}+U_{ws} \quad (2)$$

where: U_{dc}– annual depreciation costs, million UZS/year; U_{rc}– annual maintenance and repair costs, million UZS/year; U_{ws}– annual wages of service personnel, million UZS/year.

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The hydropower device is serviced approximately twice a year**.** These maintenance activities are carried out by specialists from the enterprise that developed and manufactured the hydropower device. The annual wage costs for the personnel providing maintenance services are determined using the following expression:

$$U_{ws}=2\cdot n\cdot \Pi \quad (3)$$

where: Π– semi-annual salary, million UZS; n– number of maintenance personnel.

The depreciation costs of the hydropower device are calculated using the following expression:

$$U_{dc}=0{,}029\cdot K_{hpd} \quad (4)$$

where: K_{hdp}– the value of the hydropower device, million UZS;

The maintenance and repair costs of the hydropower device are determined using the following equation:

$$U_{rc}=0{,}03\cdot K_{hpd} \quad (5)$$

The average cost of electricity generated by the hydropower device is determined using the following expression:

$$C_{1kWh}=(U_{dc}+U_{rc}+U_{ws})/W_{year} \quad (6)$$

Currently, in determining the optimal option for the application of hydropower devices, various methods such as variant-based, extremal, or combined calculation approaches, as well as the method of generalized differences in reduced costs, can be applied. Worldwide, the Net Present Value (NPV) methodology is currently used for evaluating the efficiency of power plant projects. According to this methodology, the project costs and future benefits are discounted to their present value at the time of project implementation.

The method of calculating the Net Present Value (NPV) is defined as the difference between the present value of all future benefits generated during the project lifetime and the present value of all future costs associated with the project. The essence of this method is that the annual net profit generated in each period is discounted back to the initial stage of project implementation. As a result, the cumulative value is expressed as the net discounted income or present value of the project. It is determined using the following expression [2]:

$$NPV=\sum_{t=1}^{n}\frac{P_t-A_t}{(1+E)^t}-I_0 \quad (7)$$

where: P_t – total annual profit, million UZS/year; A_t – annual costs, million UZS/year; E – discount rate (for constant conditions, the value of the fixed discount rate is assumed to be 15%); I_0 – initial investment, million UZS; t – project lifetime, hours.

Levelized Cost of Electricity (LCOE) Method. Globally, the Levelized Cost of Electricity (LCOE) generated in the energy sector is widely used as a specific indicator for evaluating the economic efficiency of power generation projects. LCOE is utilized by investors as a key decision-making tool, as well as by government authorities of various countries (such as the Netherlands, Germany, and others) for the development of renewable energy sources and energy systems, and by international agencies for forecasting purposes [3,4]. Although the concept of the levelized cost of energy emerged in the 1980s, research into its potential applications and capabilities is still ongoing. In many countries, this indicator is widely applied for the assessment and implementation of investment projects in the energy sector [5,6].

The expression for the Levelized Cost of Electricity (LCOE, UZS/kWh) of the generated electricity was developed by the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) [3,7]:

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$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + OM_t + F_t}{(1+DR)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+DR)^t}} \quad (8)$$

where: I_t– annual investment costs, UZS; OM_t– annual operation, maintenance, and service costs, UZS; F_t– annual fuel costs, UZS; E_t– amount of electricity generated per year, kWh; DR– discount rate; n– economically justified payback period of the power plant, years.

Internal Rate of Return (IRR) Method. The Internal Rate of Return (IRR) method represents the rate of return at which the discounted value of project benefits is equal to the discounted value of project costs. In other words, the IRR is the discount rate at which the discounted value of the net profit generated by the project equals the discounted value of the investment, or when the Net Present Value (NPV) becomes equal to zero. The value of the internal rate of return is determined using the following expression:

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$$NPV = \sum_{t=1}^{n} \frac{P_t - A_t}{(1+E)^t} - I_0 = 0 \quad (9)$$

If an investment project requires sequential financing of financial resources over several years, the following expression is used to determine the value of the Internal Rate of Return (IRR)**:**

$$\sum_{t=1}^{n} \frac{P_t - A_t}{(1+E)^t} = \sum_{t=1}^{n} \frac{I_t}{(1+E)^t} \quad (10)$$

Profitability Index (PI) Method. The Profitability Index (PI) is defined as the ratio of the total discounted profit to the total discounted capital investment. In other words, this indicator shows how many times the obtained result exceeds the initial investment amount. This relationship is determined using the following expression:

$$PI = \sum_{t=1}^{n} \frac{P_t - A_t}{(1+E)^t} / I_0 \quad (11)$$

The investment profitability index allows investors (or companies) to evaluate the increase in value generated per one unit of invested capital.

If investment expenditures are carried out over an extended period at different stages, the expression for determining the Profitability Index (PI) is given as follows:

$$PI = \sum_{t=1}^{n} \frac{P_t - A_t}{(1+E)^t} / \sum_{t=1}^{n} \frac{I_t}{(1+E)^t} \quad (12)$$

The capital cost payback period is defined as the number of years required for the profit generated by a project to fully recover the invested capital costs. Static and dynamic payback periods are distinguished from each other. The static payback period represents the time required to recover the initial capital investment allocated by the investor and is calculated using the following equation:

$$T_{st} = \frac{I_0}{P_t - A_t} \quad (13)$$

The dynamic payback period is defined as the period required for the investor to fully recover the invested costs and obtain the required level of profit, taking into account the time value of money. The value of this indicator is calculated using the following equation [8]:

$$T_d = \sum_{t=1}^{n} \frac{P_t - A_t}{(1+E_n)^t} \geq I_0 \quad (14)$$

Thus, the investment payback period calculation method characterizes the time required for the complete recovery of the invested funds based on their real (present) value. In this regard, it is considered more advantageous compared with the conventional payback period method.

The economic efficiency indicators for the implementation of the hydropower device at the farm site are presented in Table 1.

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ISSN: 2058-5519|Impact factor-15.9
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Table 1.
Economic efficiency indicators of the hydropower device implementation.

№	Economic efficiency indicators	
1.	Net Present Value (NPV), million UZS	68,96
2.	The Internal Rate of Return (IRR), %	67
3.	Profitability Index (PI)	4,4
4.	Levelized Cost of Electricity (LCOE), UZS/kWh	85
5.	The static payback period, year	1,56
6.	The dynamic payback period, year	2,78

The methodology for calculating greenhouse gas emissions released into the environment due to the application of the hydropower device is considered:

In settlements located in desert and mountainous regions far from centralized electricity supply systems, gasoline is mainly used as an energy source. The supply of organic fuels to these remote areas creates significant challenges due to the continuous increase in fuel costs, as well as transportation expenses. As a result, energy supply problems arise in off-grid agricultural enterprises engaged in horticulture and livestock farming, as well as in remote residential areas. Furthermore, the transportation of fuel over long distances is technically challenging. For example, during spring and autumn precipitation periods, such settlements and farms may become isolated from external access routes. Gasoline generators also require qualified maintenance and regular servicing, which represents a difficult issue to address under the conditions of hard-to-reach settlements. The operation of such power generation units leads to environmental pollution through the emission of carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NO_x), and significant amounts of unburned hydrocarbon compounds.

The analytical expression for determining the amount of carbon dioxide (CO_2) emissions released into the environment when small-scale electricity consumers located far from centralized power supply systems use gasoline generators is determined as follows [9]:

$$E=M\cdot K_1\cdot TNZ\cdot K_2\cdot 44/12 \quad (15)$$

where: E− annual CO_2 emissions by mass units, tons/year; M− annual fuel consumption, tons/year; K_1− carbon oxidation coefficient of the fuel (represents the fraction of carbon that is oxidized during combustion); TNZ− net calorific value, J/ton; K_2− carbon emission coefficient; 44/12− conversion coefficient of carbon into carbon dioxide (CO_2) (the molecular weight of CO_2 is 44 g/mol).

Table 2 presents the internationally standardized values of the conversion coefficients for natural organic fuels into carbon dioxide (CO_2).

Table 2.
Internationally standardized values of conversion coefficients for natural fuels into carbon dioxide (CO_2).

Fuel types	TNZ, TJ/thousand tons	K_1, -	K_2, t.C/TJ
Gasoline	44.21	0.995	19.13
Natural gas	34.78	0.995	15.04
Diesel	43.02	0.995	19.98

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Table 3 presents the values of carbon dioxide (CO_2) emissions released into the atmosphere by gasoline generators of different power capacities [10].

Table 3.

Carbon dioxide (CO_2) emissions from gasoline generators of different power capacities.

Rated power of gasoline generators, W	Gasoline generator efficiency, %	Fuel consumption		Amount of carbon dioxide (CO_2) released into the atmosphere	
		L /day	L/k W·h	kg /day	kg/kW· h
2000	0.52	2 .560	0.42	7. 670	1.22
3000	0.35	3 .060	0.49	9. 180	1.46
4000	0.26	3 .570	0.57	10 .700	1.70
5000	0.21	4 .070	0.65	12 .210	1.94

A 3 kW gasoline generator currently used at the farm belonging to “Bukhoro Chorvo Omad” LLC, located in the desert area of Bukhara district, consumes approximately 9,550 liters of gasoline per year to generate about 19,500 kWh of electricity annually. It was determined that the generation of this amount of electricity results in the release of approximately 28.5 tons of carbon dioxide (CO_2) into the environment annually.

The developed hydropower device plays a significant role in providing a reliable and uninterrupted energy supply to residents of settlements located far from centralized power supply networks, small-scale farms engaged in horticulture and livestock production, as well as people whose activities are associated with seasonal work or expeditionary operations.

Conclusions:

1. Based on the analysis of the technical and economic indicators of the system, it was determined that the practical application of the developed 3,000 W hydropower device enables the generation of approximately 19,500 kWh of electricity annually.
2. It was established that the implementation of the developed 3,000 W hydropower device allows saving approximately 14.53 tons of standard fuel equivalent per year and prevents the release of more than 28.5 tons of carbon dioxide (CO_2) into the atmosphere annually.
3. The economic efficiency of the 3 kW hydropower device was evaluated using the Net Present Value (NPV) method. The results showed that the net present value (NPV) amounted to 68.96 million UZS, while the static payback period was determined to be 1.56 years and the dynamic payback period was 2.78 years.

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