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ASSESSMENT OF THE EFFICIENT UTILIZATION OF GARLAND TURBINE-BASED MICRO-HYDROPOWER PLANTS UNDER CLIMATE CHANGE CONDITIONS AND THEIR IMPACT ON WATER RESOURCES.

Zokirov Islomjon Baxtiyor o‘g‘li
“Tashkent Institute of Irrigation and Agricultural Mechanization Engineers” National Research University. Master’s degree student
E-mail: islomjonzokirov10@gmail.com
Tel: +99893-948-64-55.

Abstract. The increasing demand for electrical energy, the gradual depletion of conventional fossil fuel resources, and the intensification of global environmental problems have significantly increased the scientific and practical importance of renewable energy technologies. Among renewable energy sources, micro-hydropower plants are considered one of the most promising solutions for decentralized electricity supply, particularly in mountainous, foothill, and remote rural areas where connection to centralized power grids is technically difficult or economically inefficient. However, under climate change conditions, variations in river runoff, seasonal fluctuations in water discharge, and changes in hydraulic head directly affect the operational reliability and energy efficiency of hydropower systems. This study investigates the efficient utilization of a garland turbine-based mobile micro-hydropower plant under climate change conditions and evaluates its potential impact on water resources. The research focuses on the influence of water flow velocity, turbine blade number, geometric parameters, and active blade surface area on the energy performance of the turbine. The Chodaksoy stream in Namangan region was selected as a case study to assess seasonal discharge variability and the suitability of mobile micro-hydropower applications. Numerical simulations were conducted using ANSYS software for turbine configurations with 6, 9, and 12 blades under different water flow velocities. The simulation results demonstrated that an increase in water velocity and blade number leads to a significant increase in output power. At a water velocity of 3 m/s, the output power reached 159.04 W for the 6-blade turbine, 330 W for the 9-blade turbine, and 355.1 W for the 12-blade turbine. Economic calculations indicated that an industrial prototype with an installed capacity of 3 kW can generate 26,280 kWh of electricity annually, with an estimated payback period of approximately 2.86 years. These findings confirm that garland turbine-based micro-hydropower plants can be regarded as technically feasible, economically justified, and environmentally sustainable solutions for low-power consumers in regions with variable water flow conditions.

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Keywords: micro-hydropower plant, garland turbine, climate change, water resources, renewable energy, ANSYS simulation, Chodaksoy stream, energy efficiency.

Аннотация. В данной статье научно оцениваются возможности эффективного использования мобильных микро-гидроэлектростанций с гирляндной турбиной в условиях изменения климата, а также их влияние на водные ресурсы. Особое внимание уделено обоснованию конструктивных и энергетических параметров микроГЭС, работающих в условиях низконапорных и свободно текущих водных потоков. В условиях изменения климата сезонные колебания расхода воды, уровня воды и скорости течения оказывают непосредственное влияние на устойчивость и энергетическую эффективность микро-гидроэнергетических установок. В связи с этим в статье рассматриваются преимущества мобильной, модульной и бесплотинной конструкции микроГЭС с гирляндной турбиной. В качестве объекта исследования рассмотрены гидрологические условия ручья Чодаксой, расположенного в Папском районе Наманганской области. Многолетние данные по расходу воды показывают значительную сезонную изменчивость водного потока, что свидетельствует о целесообразности применения мобильной и адаптивной микроГЭС вместо стационарной установки в подобных условиях . С использованием программного комплекса ANSYS было выполнено моделирование взаимодействия водного потока с лопастями турбины, а также оценено влияние числа лопастей, геометрических параметров турбины и скорости потока воды на выходную мощность установки. Полученные результаты показали, что эффективная работа устройства обеспечивается при скорости водного потока 2–3 м/с, длине турбины 1–2 м и числе лопастей в диапазоне 6–12 . Согласно экспериментальным и расчетным результатам, одна турбина способна вырабатывать в среднем до 345 W мощности. Увеличение общей мощности установки возможно за счет размещения нескольких турбин в гирляндной конфигурации. Экономический анализ подтвердил, что микроГЭС с гирляндной турбиной обладает потенциалом окупаемости инвестиционных затрат в относительно короткий срок .

Ключевые слова: микрогидроэлектростанция, турбина garland, изменение климата, водные ресурсы, возобновляемые источники энергии, моделирование ANSYS, поток Чодаксой, энергоэффективность.

Annotatsiya. Ushbu maqolada iqlim o‘zgarishi sharoitida girlyand turbinali mobil mikro gidroelektrostansiyalardan samarali foydalanish imkoniyatlari hamda ularning suv resurslariga ta’siri ilmiy jihatdan baholangan. Tadqiqotda past bosimli va erkin oqimli suv manbalarida ishlovchi mikroGESlarning

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konstruktiv va energetik parametrlarini asoslashga alohida e'tibor qaratildi. Iqlim o'zgarishi natijasida suv sarfi, suv sathi va oqim tezligining mavsumiy o'zgaruvchanligi mikroGESlarning barqaror ishlashiga bevosita ta'sir ko'rsatadi. Shu sababli maqolada mobil, modulli va dambasiz ishlaydigan girlyand turbinali mikroGES konstruksiyasining afzalliklari tahlil qilindi.Tadqiqot obyekti sifatida Namangan viloyati Pop tumanidagi Chodaksoy soyining gidrologik sharoitlari ko'rib chiqildi. Ko'p yillik suv sarfi ma'lumotlari Chodaksoyda suv oqimining oylar kesimida sezilarli darajada o'zgarishini ko'rsatadi, shu bois ushbu sharoitda statsionar mikroGESdan ko'ra mobil va moslashuvchan qurilmadan foydalanish maqsadga muvofiq hisoblanadi . ANSYS dasturi yordamida suv oqimi va turbina pichoqlari o'zaro ta'siri modellashtirilib, pichoqlar soni, turbina geometrik o'lchamlari va suv oqimi tezligining chiqish quvvatiga ta'siri baholandi. Natijalar suv oqimi tezligi 2–3 m/s, turbina uzunligi 1–2 m va pichoqlar soni 6–12 oralig'ida bo'lganda qurilma samarali ishlashini ko'rsatdi . Eksperimental va hisobiy natijalarga ko'ra, bitta turbina o'rtacha 345 W gacha quvvat ishlab chiqarishi mumkinligi aniqlangan. Bir nechta turbinalarni girlyand shaklida joylashtirish orqali umumiy quvvatni oshirish mumkin. Iqtisodiy tahlillar esa girlyand turbinali mikroGESning investitsiya xarajatlarini qisqa muddatda qoplash imkoniyatiga ega ekanini ko'rsatdi

Kalit so'zlar: mikro gidroelektrostantsiya, gulchambar turbinasi, iqlim o'zgarishi, suv resurslari, qayta tiklanadigan energiya, ANSYS simulyatsiyasi, Chodaksoy oqimi, energiya samaradorligi.

INTRODUCTION.

The sustainable development of modern society is closely associated with the availability of reliable, affordable, and environmentally safe energy resources [1,2]. In recent decades, the rapid growth of electricity consumption in industry, agriculture, transport, and residential sectors has increased the pressure on conventional energy systems [1]. Electricity generation based on fossil fuels remains one of the dominant sources of energy supply in many countries; however, this approach is accompanied by several long-term challenges, including resource depletion, environmental pollution, greenhouse gas emissions, and the acceleration of climate change processes [2,3].Climate change has a complex and multifactorial influence on natural and socio-economic systems [4,5]. In the context of water resources, its effects are manifested through changes in precipitation patterns, increased evaporation, glacier retreat, snow cover reduction, and seasonal redistribution of river runoff [4–6]. These hydrological changes directly influence the efficiency and stability of hydropower generation [3,7]. Since hydropower systems depend primarily on water discharge and

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hydraulic head, any long-term or seasonal change in these parameters may reduce power generation capacity and increase operational uncertainty [3,8].

In Uzbekistan, the issue of rational water and energy resource management is of particular importance. The country's water resources are largely dependent on transboundary river basins, especially the Amudarya and Syrdarya [6,7]. Under climate change conditions, the expected reduction in water availability, intensification of drought periods, and uneven seasonal distribution of river flows create additional challenges for agriculture, water management, and energy supply [4,6]. Therefore, the development of renewable energy technologies that can operate efficiently under variable hydrological conditions is of high scientific and practical relevance [2,9].

Micro-hydropower plants represent an effective technological solution for utilizing the energy potential of small rivers, streams, irrigation canals, and low-head water flows [9,10]. Compared with large hydropower plants, micro-hydropower systems require significantly lower capital investment, have shorter construction periods, and cause less environmental disturbance [10,11]. In addition, they can be used for decentralized electricity supply in remote areas, where the construction of transmission lines and connection to centralized power networks may be economically unjustified [9,12].Among various micro-hydropower technologies, garland turbine-based systems are particularly promising due to their simple design, modular structure, mobility, and adaptability to free-flowing water conditions [12,13]. Such systems do not require the construction of dams or large hydraulic structures. Instead, they utilize the kinetic energy of flowing water through several turbine units arranged in a garland configuration [13,15]. This allows the total power output to be increased by adding additional turbines, depending on the available water flow and the energy demand of consumers [15].

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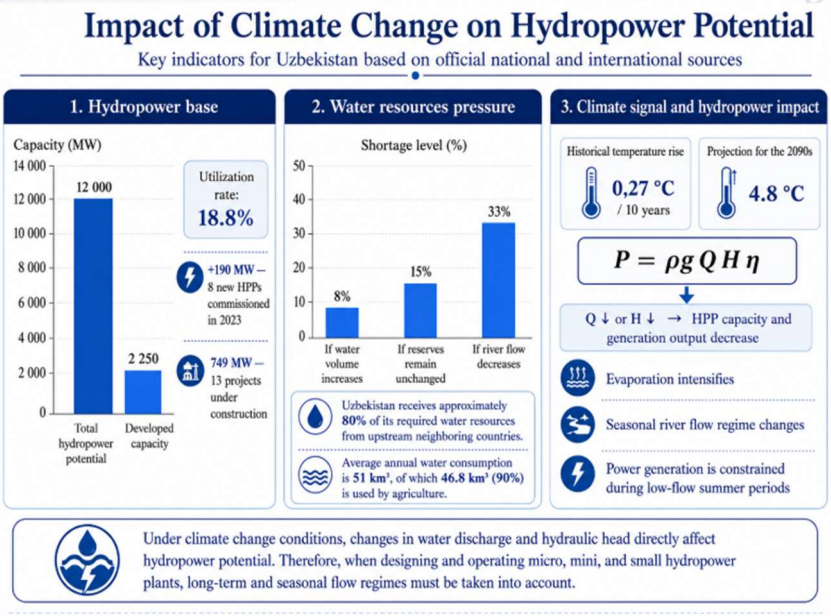


Figure 1. World bank, Uzbekistan Small Hydropower Development Project PID (2025); National Statistics Committee of the Republic of Uzbekistan, SDG 6 indicators; UNFCCC Uzbekistan BTR / Third NDC

The main objective of this study is to assess the efficiency of a garland turbine-based mobile micro-hydropower plant under climate change conditions and to evaluate its impact on water resources [15]. The study also aims to determine the effect of turbine blade number, water flow velocity, and geometric parameters on energy performance, as well as to justify the techno-economic feasibility of the proposed system [15].

Problem Statement. The operational efficiency of micro-hydropower plants is determined by several hydraulic and technical parameters, including water discharge, flow velocity, hydraulic head, turbine geometry, blade number, and generator characteristics [3,10]. Under stable hydrological conditions, these parameters can be selected relatively accurately during the design stage. However, under climate change conditions, water flow regimes become increasingly variable, which complicates the design and operation of micro-hydropower systems [4,5,8].One of the main problems in the practical application of micro-hydropower plants is the seasonal variability of water discharge [9,15]. In mountainous and foothill areas, river and stream flows are often characterized by significant seasonal fluctuations [5,6]. During the spring and early summer months, snowmelt and precipitation may increase water discharge, while in late summer, autumn, and winter, discharge may decrease considerably [4–6]. Such variability reduces the efficiency of stationary micro-hydropower plants designed for fixed hydraulic conditions [8,15].

A decrease in water level and flow velocity reduces the active interaction area between the water flow and turbine blades [10,13]. As a result, the

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hydrodynamic force acting on the turbine decreases, leading to a reduction in torque, rotational speed, and output power [10,15]. Conversely, during periods of high discharge, the system may experience increased mechanical loads, which can affect structural reliability [8,11]. Therefore, there is a need for micro-hydropower systems that can adapt to variable hydrological conditions without causing significant disturbance to the natural flow regime [9,12,15].The Chodaksoy stream, selected as the case study area, clearly demonstrates this problem [15]. The stream is located in Pop district of Namangan region and originates from the slopes of the Qurama mountain range. Its length is 76 km, its basin area is 566 km², and its average elevation is approximately 2370 m [15]. Long-term hydrological data show that the water discharge of the stream varies considerably from month to month [15]. This seasonal variability indicates that the use of a conventional stationary micro-hydropower plant may not always be technically and economically efficient in such conditions [15].

Table-1

Years	Long-term data on Chodaksoy water discharge, m³/s											
	January	February	March	April	May	June	July	August	September	October	November	December
2000	0,3	0,3	0,5	20	10	8	0,4	0,2	0,2	0,3	0,25	0,35
2001	0,32	0,32	0,52	20,02	10,02	8,02	0,42	0,22	0,22	0,32	0,27	0,37
2002	0,32	0,32	0,52	20,02	10,02	8,02	0,42	0,22	0,22	0,32	0,27	0,37
2003	0,33	0,33	0,53	20,03	10,03	8,03	0,43	0,23	0,23	0,33	0,28	0,38
2004	0,34	0,34	0,54	20,04	10,04	8,04	0,44	0,24	0,24	0,34	0,29	0,39
2005	0,27	0,27	0,47	19,97	9,97	7,97	0,37	0,17	0,17	0,27	0,22	0,32

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2006	0,28	0,28	0,48	19,98	9,98	7,98	0,38	0,18	0,18	0,28	0,23	0,33
2007	0,27	0,27	0,47	19,97	9,97	7,97	0,37	0,17	0,17	0,27	0,22	0,32
2008	0,28	0,28	0,48	19,98	9,98	7,98	0,38	0,18	0,18	0,28	0,23	0,33
2009	0,34	0,34	0,54	20,04	10,04	8,04	0,44	0,24	0,24	0,34	0,29	0,39
2010	0,33	0,33	0,53	20,03	10,03	8,03	0,43	0,23	0,23	0,33	0,28	0,38
2011	0,25	0,25	0,45	19,95	9,95	7,95	0,35	0,15	0,15	0,25	0,2	0,3
2012	0,23	0,23	0,43	19,93	9,93	7,93	0,33	0,13	0,13	0,23	0,18	0,28
2013	0,22	0,22	0,42	19,92	9,92	7,92	0,32	0,12	0,12	0,22	0,17	0,27
2014	0,27	0,27	0,47	19,97	9,97	7,97	0,37	0,17	0,17	0,27	0,22	0,32
2015	0,23	0,23	0,43	19,93	9,93	7,93	0,33	0,13	0,13	0,23	0,18	0,28
2016	0,24	0,24	0,44	19,94	9,94	7,94	0,34	0,14	0,14	0,24	0,19	0,29
2017	0,25	0,25	0,45	19,95	9,95	7,95	0,35	0,15	0,15	0,25	0,2	0,3

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2018	0,27	0,27	0,47	19,97	9,97	7,97	0,37	0,17	0,17	0,27	0,22	0,32
2019	0,23	0,23	0,43	19,93	9,93	7,93	0,33	0,13	0,13	0,23	0,18	0,28
2020	0,21	0,21	0,41	19,91	9,91	7,91	0,31	0,11	0,11	0,21	0,16	0,26
2021	0,2	0,2	0,4	19,9	9,9	7,9	0,3	0,1	0,1	0,2	0,15	0,25
2022	0,25	0,25	0,45	19,95	9,95	7,95	0,35	0,15	0,15	0,25	0,2	0,3
2023	0,21	0,21	0,41	19,91	9,91	7,91	0,31	0,11	0,11	0,21	0,16	0,26
2024	0,20	0,20	0,40	19,90	9,90	7,90	0,30	0,10	0,10	0,20	0,15	0,25
2025	0,20	0,20	0,40	19,90	9,90	7,90	0,30	0,10	0,10	0,20	0,15	0,25
Average value	0,26	0,26	0,46	19,96	9,96	7,96	0,36	0,16	0,16	0,26	0,21	0,31

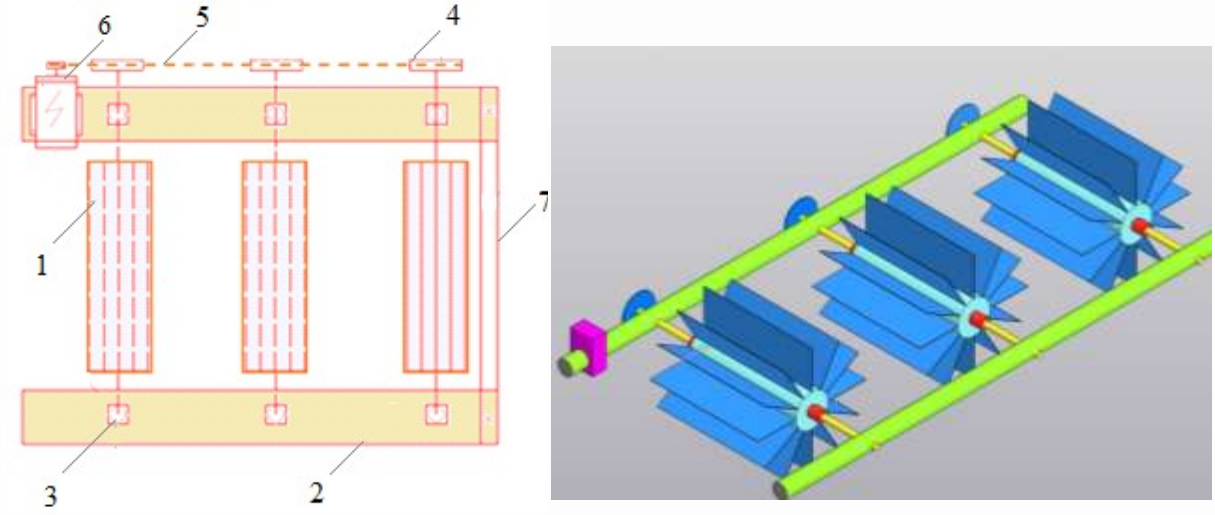
Thus, the scientific and practical problem addressed in this study is the development and justification of a compact, mobile, environmentally safe, and economically efficient micro-hydropower system capable of operating under variable water flow conditions [9,12,15]. The proposed solution should ensure electricity generation without requiring dam construction, without significantly altering the natural flow regime, and without negatively affecting water resources [11,12,15].

Proposed Technical Solution. To address the identified problem, this study proposes the use of a garland turbine-based mobile micro-hydropower plant [15]. The operating principle of the system is based on the conversion of the kinetic energy of flowing water into mechanical rotational energy and subsequently into electrical energy through a generator [3,10]. The turbine blades

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interact with the water flow, generating torque, which is transmitted to the generator by means of a mechanical transmission system [10,13].The garland-type configuration provides several important technical advantages [13,15]. First, the system has a modular structure, which allows the number of turbines to be adjusted according to the available water flow and required power output [15]. Second, the device can be installed directly in free-flowing water without the construction of dams, reservoirs, or pressure pipelines [11,12]. Third, the use of lightweight and corrosion-resistant polymer materials reduces the total mass of the system and improves its operational durability [15].

According to the dissertation results, one turbine can generate an average output power of up to 345 W [15]. By arranging several turbines in a garland configuration, the total installed capacity can be increased [15]. In the proposed industrial prototype, nine turbines are used, which makes it possible to form a system with a generator capacity of 3 kW [15]. This configuration is suitable for supplying electricity to low-power consumers such as rural households, farms, livestock facilities, and small production units [9,12,15].



a) **b)**

a) Structure **b) 3D view**

1 - water blades; 2 - hollow cylinder; 3 - bearings; 4 - pulley; 5 - belt transmission; 6 - generator; 7 - holder.

Figure 2. Schematic view of a floating garland-type micro-hydropower plant

The proposed system is particularly relevant under climate change conditions because it can be adapted to seasonal changes in water discharge [4,8,15]. During periods of sufficient water flow, several turbines may operate simultaneously, while during low-flow periods, the system can be relocated to a more suitable section of the stream or operated with fewer turbines [15]. This flexibility improves the reliability of local electricity supply and supports the rational use of water resources [9,12,15].

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Research Object and Methodology. The research object is a garland turbine-based mobile micro-hydropower plant designed for operation in low-head and free-flow water conditions [15]. The system is intended for the direct utilization of the kinetic energy of water flow in rivers, streams, and irrigation canals [10,13]. The main focus of the research is to evaluate the relationship between hydraulic parameters and turbine energy performance [10,15].The methodology of the study consists of analytical, numerical, hydrological, and techno-economic assessment stages [14,15]. At the first stage, scientific literature and existing technical solutions related to micro-hydropower plants were analyzed [9–13]. Particular attention was paid to free-flow turbines, water wheels, gravitational vortex systems, screw turbines, and garland-type hydropower plants [10,12,13].At the second stage, the main geometric parameters of the garland turbine were determined [15]. Based on the dissertation model, the turbine had an external diameter of 400 mm, an internal diameter of 100 mm, a blade height of 300 mm, a turbine length of 1000 mm, a blade thickness of 4 mm, and an initial blade number of 6 [15]. These parameters were used as the basis for further numerical modelling [14,15].

Table-2

Dimensions of the turbine of the garland-type micro-hydropower plant

№	Parameters	Dimensions (mm)
1	External diameter	400
2	Internal diameter	100
3	Height of turbine blades	300
4	Turbine length	1000
5	Thickness of turbine blades	4
6	Number of blades	6

Based on the dimensions presented in Table 2, the design shown in

At the third stage, numerical simulation was carried out using ANSYS software [14,15]. The purpose of the simulation was to evaluate the effect of water flow velocity and blade number on the output power of the turbine [15]. Three turbine configurations were considered: 6 blades, 9 blades, and 12 blades. Water velocity was varied from 1 m/s to 3 m/s [15].At the fourth stage, the hydrological characteristics of the selected case study area were analyzed [15]. The Chodaksoy stream was selected because it represents a typical mountainous stream with considerable seasonal variability in water discharge [15]. This analysis was used to justify the necessity of mobile and adaptable micro-hydropower systems [15].

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a) Tributaries of the Chodaksoy stream;



b) The section of Chodaksoy flowing through the center of the settlement.

Figure 3. Satellite images of the areas through which the Chodaksoy stream flows

At the fifth stage, the techno-economic performance of the proposed system was evaluated [15]. The calculations included annual electricity generation, capital cost, annual economic benefit, and investment payback period [15].

Results and Analysis. The numerical simulation results obtained using ANSYS software indicate that water flow velocity and turbine blade number have a significant influence on the output power of the garland turbine [14,15]. As the flow velocity increases, the kinetic energy of the water flow also increases [3,10]. This results in a greater hydrodynamic force acting on the turbine blades, higher torque, increased rotational speed, and higher power generation [10,13,15].The simulation results showed that at a water velocity of 1 m/s, the output power was 14.56 W for the 6-blade turbine, 23.1 W for the 9-blade turbine, and 37.2 W for the 12-blade turbine [15]. When the water velocity increased to 3 m/s, the corresponding output power values reached 159.04 W, 330 W, and 355.1 W, respectively [15]. These results confirm that both water velocity and blade number are key factors determining the energy performance of the turbine [10,13,15].

Table-3

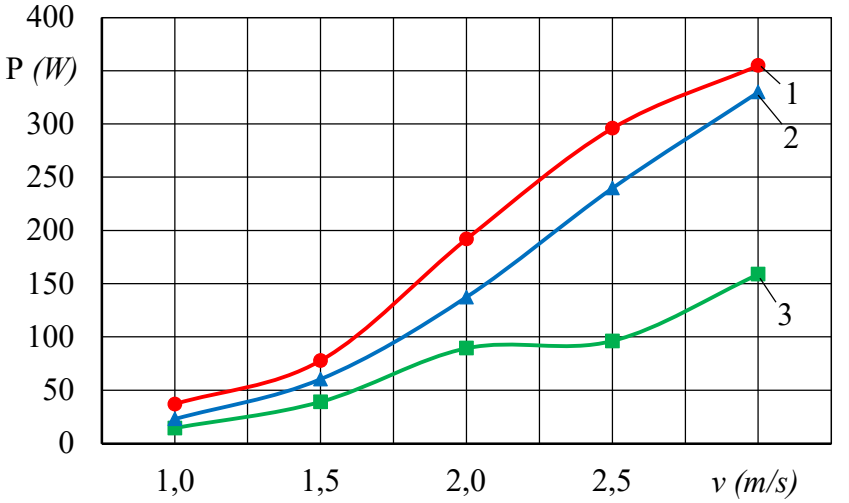
Simulation Model Results Obtained in ANSYS Software

№	*v* (m/s)	z_1=6 units	z_2=9 units	z_3=12 units
		P_1 (W)	P_2 (W)	P_3 (W)
1	1	14,56	23,1	37,2
2	1,5	39,2	60,5	78,4
3	2	89,6	137,5	192,5
4	2,5	96,32	239,8	296,7
5	3	159,04	330	355,1

The results also show that increasing the number of blades improves turbine performance; however, the increase in output power is not strictly proportional

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[10,13,15]. For example, the difference between the 9-blade and 12-blade turbine configurations becomes relatively smaller at higher flow velocities [15]. This indicates that there is an optimal range of blade numbers, beyond which further increases may lead to additional material consumption, higher structural complexity, and increased resistance without a proportional increase in useful power [13,15].



1 - when the number of turbine blades is z=6; 2 -when the number of turbine blades is z=9; 3 -when the number of turbine blades is z=12.

Figure 4. Dependence of power on water flow velocity (obtained in ANSYS software).

A comparison between numerical modelling and expected real operating conditions shows that the simulation values may be slightly higher than actual field values [14,15]. According to the dissertation, the difference between simulated and real values was approximately 9% for the 12-blade turbine, 10% for the 9-blade turbine, and 12% for the 6-blade turbine [15]. This discrepancy may be explained by the fact that some real flow characteristics, including water viscosity, turbulence, temperature, sediment content, and local hydraulic disturbances, were not fully represented in the numerical model [14,15].The analysis of turbine geometry also showed that an increase in turbine length and radius contributes to an increase in torque [10,13,15]. However, in shallow streams and small rivers, the external diameter of the turbine cannot be increased without limitation [15]. Therefore, from an engineering perspective, increasing the blade length and arranging several turbines in a garland configuration may be more appropriate than increasing the turbine diameter [13,15].

The hydrological analysis of the Chodaksoy stream confirmed that water discharge is highly seasonal [15]. High flow is observed mainly during spring and early summer, while low flow conditions occur during late summer, autumn, and winter [15]. This finding confirms that the design of micro-hydropower plants

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should not be based solely on average annual discharge [8,15]. Instead, minimum discharge, maximum discharge, flow duration, ecological requirements, and the needs of other water users should be considered [4,8,15].

Techno-Economic Assessment. The techno-economic feasibility of a micro-hydropower plant is one of the most important factors for its practical implementation [9,12]. A technically efficient system may not be widely adopted if its capital cost is too high or if its payback period is too long [9,15]. Therefore, the economic performance of the proposed garland turbine-based micro-hydropower plant was evaluated [15].

For the physical model, the installed capacity was 0.5 kW [15]. The annual electricity generation was calculated as:

$$Wyear = P \times tyear = 0.5 \times 8760 = 4380 \text{ kWh}$$

Assuming a green energy tariff of 600 UZS per 1 kWh, the annual economic benefit was calculated as:

$$Tyear = 4380 \times 600 = 2{,}628{,}000 \text{ UZS}$$

The total capital cost of the physical model was 4,450,000 UZS. Based on these values, the payback period was determined to be approximately 1.7 years [15].

For the industrial prototype, the installed capacity was 3 kW [15]. The annual electricity generation was calculated as:

$$Wyear = 3 \times 8760 = 26{,}280 \text{ kWh}$$

The annual economic benefit was calculated as:

$$Tyear = 26{,}280 \times 600 = 15{,}768{,}000 \text{ UZS}$$

Based on the capital cost and annual economic benefit, the payback period of the industrial prototype was estimated at approximately 2.86 years [15]. These results indicate that the proposed system is economically feasible for low-power consumers located in remote and mountainous regions [9,12,15].

Table-4

Costs related to the purchase of raw materials and components for the industrial prototype

№	Name of products/materials	Unit of measurement	Quantity	Price, million UZS	Total amount, million UZS
1	Polymer blades with bearings	pcs	9	0,8	7,2
2	Three-phase AC generator with permanent magnet	pcs	1	3,8	3,8

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	excitation, 3.0 kW				
3	Controller, 3.0 kW	pcs	1	5	5
4	Control and protection devices	set	1	2,2	2,2
5	Measuring instruments	pcs	3	-	3,5
6	Electrical conductors	m	210	0,005	1
8	Car trailer	pcs	1	6	6
9	Flexible cables	m	6	0,5	3
10	Reducer	pcs	1	2	2
11	Raw materials and components, including metal structures, polymer materials, insulation materials, etc.	kg	100	0,01	1
	Total:				34,7
	The service life of the garland-type micro-hydropower plant is 10 years.		Annual depreciation charge		10,41

The economic advantages of the proposed system become more significant when compared with the cost of extending centralized power grids to remote areas [9,12]. In such locations, the construction of transmission lines, installation of transformers, and maintenance of distribution infrastructure may require substantial investment [12]. Therefore, local electricity generation using available water flow can be considered a rational and cost-effective alternative [9,15].

DISCUSSION. The obtained results demonstrate that garland turbine-based micro-hydropower plants can serve as an effective renewable energy solution under climate change conditions [9,12,15]. Their main advantage is their ability to operate in free-flowing water without the construction of large hydraulic structures [11,12,15]. This reduces environmental disturbance and makes the system suitable for small rivers, streams, and irrigation canals [10,12,15].From a technical point of view, the proposed system is simple, modular, and adaptable [13,15]. Its power output can be increased by adding turbine units, and its location can be changed depending on water availability [15]. This characteristic is especially important in regions where water discharge varies seasonally [4,8,15].

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Table-5

Technical characteristics of micro-hydropower plants designed for free-flow water conditions

Characteristics	Water wheel	"Akula" water blade	Garland turbine
Water velocity	2-5 m/s	0,7-4 m/s	1-4 m/s
Efficiency	35-80%	75 %	24-80 %
Design construction	Simple	Complex	Simple
Project cost	Low	High	Low
System cost of the project	arzonLow	Low	Low
Maintenance capability	Easy and low-cost	Easy and low-cost	Easy and low-cost
Safety for the aquatic ecosystem	Safe	Hazardous	Safe
Type of mechanical transmission	Gearbox / pulley	Not available	Gearbox / pulley
Durability	Good	Good	Good
Possibility of using the hydropower potential of water flow	25 - 70%	30 - 50%	25-70%
Location	It is appropriate to design and install the system in rivers, streams, and irrigation canals with existing low-head water flows.		

Table-6

Comparative analysis of turbine technical efficiency indicators for free-flowing water streams

Characteristics	Water wheel	"Akula" micro-HPP	Garland turbine
Dimensions (m)	Diametri 1-2 m	0,75x1,14x2,15 m	0,7x2 m
Rotational speed (r/min)	50	120-180	80-120
Weight (kg)	250	110	50
Generator type	Synchronous / asynchronous	Permanent magnet synchronous generator	Permanent magnet synchronous generator
Type of mechanical transmission	Belt drive	Not available	Belt drive

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Selected generator power (kW)	2	3	3

Compared with other micro-hydropower technologies such as traditional water wheels and “Akula” micro-hydropower plants, the garland turbine system offers several advantages, including lower project cost, simpler construction, easier maintenance, and reduced environmental impact [10,12,15]. It is also safer for aquatic ecosystems because it does not require a dam and does not significantly obstruct the natural flow regime [11,12,15].Nevertheless, several limitations should be considered. First, the output power of the system is strongly dependent on water velocity [10,13,15]. During low-flow periods, the generated power may decrease significantly [8,15]. Second, natural watercourses may contain sediment, floating debris, vegetation, or ice, which can affect turbine operation [11,15]. Third, further long-term field experiments are required to validate the numerical simulation results under real environmental conditions [14,15].Despite these limitations, the proposed garland turbine-based micro-hydropower plant can contribute to the development of decentralized renewable energy systems, reduce dependence on fossil fuels, and improve the energy supply of remote rural areas [1,2,9]. In addition, its environmentally friendly operation supports the rational use of water resources under climate change conditions [4,6,12].

CONCLUSION.

Based on the conducted study, the following conclusions were formulated:

1. Climate change significantly affects the seasonal distribution of water resources, river runoff, and hydropower potential. Therefore, the design and operation of micro-hydropower plants should take into account not only average annual discharge but also minimum and maximum flow values, seasonal variability, and ecological flow requirements.

2. Garland turbine-based mobile micro-hydropower plants are suitable for low-head water flows, small rivers, mountain streams, and irrigation canals. Their damless operation reduces environmental impact and makes them appropriate for decentralized electricity generation.

3. The ANSYS simulation results confirmed that water flow velocity and turbine blade number are the main factors influencing turbine output power. At a water velocity of 3 m/s, the maximum output power reached 355.1 W for the 12-blade turbine.

4. The Chodaksoy stream case study demonstrated considerable seasonal variability in water discharge. This confirms that mobile and adaptable micro-

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hydropower systems are more appropriate than stationary systems for such hydrological conditions.

5. The techno-economic analysis showed that an industrial prototype with an installed capacity of 3 kW can generate 26,280 kWh of electricity per year. The estimated payback period is approximately 2.86 years, which confirms the economic feasibility of the proposed system.

6. Garland turbine-based micro-hydropower plants can be recommended as a promising renewable energy technology for rural households, farms, livestock facilities, small production enterprises, and mountainous areas located far from centralized power supply networks.

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