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Research Article

Feasibility Study for the Use of an Autonomous Solar Photovoltaic Water-Lifting Installation in the Karakum Desert

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Abstract: One of the urgent problems of Turkmenistan is the development of the Karakum desert, which occupies 80% of the entire territory of the country. For the development of this territory, scientists are faced with the problem of energy and water supply. The priority direction of energy supply is the use of renewable energy sources (RES), and for water supply-the use of groundwater resources. The article considers the energy resources of solar energy for lifting water from various depths with the help of solar photovoltaic water-lifting installations (SFWL). The paper evaluates the technical and economic characteristics of SFWL, capital investments, investment costs, and energy efficiency of operating parameters when used in transhumance in the Karakum Desert. The results of the study will be useful in the preparation of a feasibility study (FS) for the introduction of autonomous SFWLs for the development of transhumance in the desert zone of Karakum.

***Keywords*:** solar energy, solar energy and water supply, capital investments, development of the Karakum, groundwater, development of transhumance, Turkmenistan

1. Introduction

The issue of water supply to the desert territories of Turkmenistan is solved in several ways-by collecting atmospheric precipitation and with the help of water carriers at a distance of 100-150 km. At the same time, the cost of one water tank with a capacity of 3 m^3 costs 30 US dollars, which significantly affects the budget of livestock breeders. In the presence of wells, desert dwellers raise water with the help of manual labor or animals. This method of water supply seems to be inefficient and laborious. Some people in remote areas use diesel generators to raise water from wells with an electric pump. In this case, there are a number of serious shortcomings in energy and water supply, they are associated with environmental pollution, and transporting fuel over long distances by car carrier across the desert is very expensive, so this problem of energy and water supply for the development of the desert zone is relevant [1-5].

The use of innovative technologies in matters of energy and water supply for the life of the population of the Karakum desert can be partially solved with the use of renewable energy sources (RES). Turkmenistan has significant resources of low-potential solar energy, which is equivalent to 1.4 10^9 tons of reference fuel per year [6-11].

The issues of energy and water supply based on renewable energy sources in the Karakum desert zone have not been studied enough due to the lack of specific data on groundwater, the uncertainty of the resource potentials of renewable energy sources and technical and economic feasibility. Taking into account these shortcomings, the scientific

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work considers the issues of energy and water supply using solar photovoltaic water-lifting installations (SFWL) for lifting groundwater from various depths to provide water to sparsely populated livestock pasture farms in the Karakum Desert. To date, technical and economic features have not been substantiated: capital investments, investment costs and energy efficiency of operational parameters for use in transhumance. The results obtained will be useful in preparing a feasibility study (FS) for the introduction of autonomous solar photovoltaic water-lifting stations for the development of transhumance in the Karakum desert zone, which will increase the production of butter and dairy products.

The scientific novelty of the work lies in the fact that a graphic nomogram has been developed, calculated, and created to determine the power of the generated energy of the SFWL depending on the depth of the wells in the pasture areas of the Karakum desert. Using modern methods, the technical and economic characteristics of capital investments, investment costs are calculated and the results are presented, the energy efficiency of the regime parameters of SFWL for use in transhumance livestock farms is estimated.

*The methodology and calculation method*s are based on the theoretical and practical results of using the energy and technical and economic characteristics of SFWL for the natural and climatic conditions of Turkmenistan. The subject of the study is the energy efficiency of energy and water supply in the Karakum desert. The methodological base is based on the methods of physical and mathematical modeling, technical and economic results of pilot studies.

2. Technical and economic assessment of the use of an autonomous solar photovoltaic water-lifting installation

A feasibility study for the application of an autonomous solar photovoltaic water lifting installation is characterized by pump performance, water lift by volume, suction head, head and efficiency. At present, diesel generators are used to lift water from wells, from experimental studies conducted in the Central Karakum Desert, water is lifted from wells with a depth of 30 m or more using diesel generators, while the annual consumption of diesel fuel was 14.6 tons, while 46.72 tons of carbon dioxide (CO_2) were released into the environment [7-12].

There are more than 5,000 shaft wells of various depths and debits on the territory of Turkmenistan. Most of the wells in the desert pastures of Turkmenistan are low-yielding, shallow. According to a preliminary analysis, 40% of all wells have a flow rate of less than 0.1 l/s, 30%-less than 0.2 l/s. Wells with a depth of less than 40 m account for 77.0%. Thus, 85% of wells in the pastures of the northwestern part of Turkmenistan (in the Turkmenbashi region, the Central Karakum, the right bank of the Amu Darya) require less than 80 W of useful power to raise water. The wells of the Zaunguz Karakum and especially the southeastern part of the country are characterized by a significant increase in the level of required power up to 1 kW or more.

However, there are very deep wells up to 300 m. According to the flow rate and depth of the well, it is possible to determine the power required to lift water from the well. Calculations and analyses show that for the vast majority of wells in Turkmenistan (60.8%), the useful power of SFWL for lifting water does not exceed 80 W, although in some cases the power of the installation increases due to depth. up to 6 kW [7-9, 13, 14].

The lack of exact geographic coordinates of most wells makes it impossible to determine any other way to determine the thickness, except for attributing the data obtained to the entire territory of the region under consideration within its administrative boundaries [7, 9].

From the above analytical analysis, it can be seen that most of the country's territory is characterized by minimum power levels.

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To lift water from different depths of mine wells, theoretical calculations were carried out and a nomogram was constructed for the dependence of the pump load power on the pressure at various powers, a graphical representation is shown in Figure 1.

Thus, the calculated data obtained are of direct interest to developers of autonomous solar photovoltaic water-lifting devices. When developing SFWL, it is necessary to take into account the water-lifting installation does not work around the clock, therefore, it is necessary to provide for recharging batteries from photo modules in the daytime as backup battery elements. It should be noted that SFWLs do not pollute the environment, have a sufficiently long service life (at least 15-20 years) and high reliability, there are practically no operating costs and, importantly, there are no highly qualified personnel and a repair base is not required for their maintenance [7-9].

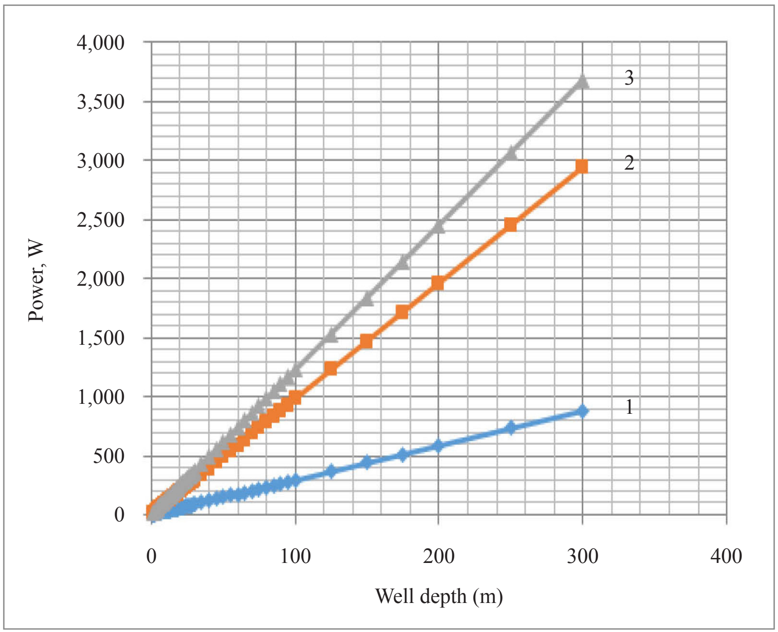

Figure 1. Nomogram of the load according to the energy intensity of the SFWL for lifting water at different depths of the well: 1-the required load power; 2-pump power; 3-power of the water-lifting installation

Preliminary results of comparative calculations of financial, economic and environmental indicators of a diesel generator and SFWL for 1 and 30 units. with a service life of installations of 10 years, to be: reduction of CO_2 emissions from the operation of a diesel generator that burns 0.04 tons of diesel fuel per day is 46.720 tons of CO_2/year, over 10 years, emissions will be reduced by 467.2 tons, fuel economy will be 146 tons, the financial cost of diesel fuel will decrease by 43,800 US dollars [7-9].

The main type of maintenance is the seasonal azimuthal adjustment of the photovoltaic module for more efficient operation and periodic cleaning of the surface of the blocks from dust.

The installation can also be used for water supply of garden, gardens, economic and farm enterprises and other objects.

Taking into account the obtained scientifically based theoretical calculations, experimental studies and the results of calculations of the potentials of solar energy resources using power plants in Turkmenistan, it is possible to solve the energy and socio-economic problems of regions remote from centralized energy systems, villages, settlements, objects of dai khan and pasture farms, formally located in areas of centralized power supply, but in hard-to-reach areas. Another significant factor in the use of solar energy resources and potentials is the possibility of maintaining environmental safety and improving the ecosystem of the region.

Turkmenistan has more than 40 million hectares of pasture land in the arid zone of mountain regions, which contain a significant number of sheep, goats, cattle, and camels. Pasture technologies for raising animals due to the use of natural fodder resources are the most cost-effective and allow the population of Turkmenistan to be provided with meat products, as well as raw materials for the light industry (wool, leather products, etc.) [2-4, 7-9].

Also, on the basis of experimental studies of the energy performance of photovoltaic modules, empirical formulas were obtained that take into account the gross, technical, economic potential of solar energy in the regions of Turkmenistan, with the help of which it is possible to predict the energy, economic and environmental performance of solar technological installations, equipment, facilities for the development of technologies and the development of technical-economic justifications for the use of solar energy in various regions of Turkmenistan.

As can be seen from the above calculations, the development of solar energy in desert areas will solve a number of social problems, improve the quality of life of the population, and accelerate the development of pastoral animal husbandry and agriculture in general.

3. Calculation of capital costs

The cost of connecting to the nearest distribution network, as well as the quality and reliability of the electricity supply, are important factors influencing the profitability of intensive livestock grazing in the Karakum desert.

Currently, the use of SFWL is directed toward the following [3-4, 8]:

• Increasing the reliability of the installation, reducing the cost of power supply and the cost of products obtained from animals;

• Minimization of production losses of energy in the network power supply, rational use of standby gasoline and diesel generators and reduce anthropogenic impacts on the environment.

Calculation of capital investments (K) is calculated by the formula:

$$K = K_o + K_{sop}, \tag{1}$$

where K_o-capital investments in operating machinery and equipment, including the costs of their purchase and installation; K_{sop}-related investments.

The results of the calculation of capital investments in the developed system used Kob н an estimate was made for the installed automation equipment (Table 1).

Table 1. Estimated cost of installed HLF equipment in the Karakum desert in dollar terms

Name/Quantity	Piece cost	To US dollar	
		Units	General
Basic version-diesel generator			
FUBAGDS 3600 2.7 diesel generator, generator cost $32,870.	1	547.8333	547.8333
Other materials	Kit	116.6667	166.6667
Cost of equipment Sob, USD	-	-	714.5
Installation and commissioning, man	-	-	142.9
Total capital investment K, USD	-	-	857.4
Basic option-SFWL, 3 kW			
Solar module, 200 W	8	195.85	1,566.8
Inverter “Akpert KS 3K 24V”	1	461.6667	461.6667
Battery SPG12-200GE	3	364.5833	1,093.75
60 A Charge controller PC16-6015F 60 A MPRT	1	313	313

Table 1. (cont.)

Name/Quantity	Piece cost	To US dollar	
		Units	General
Other Materials Needed-Wire, fencing, clamps, connectors, fasteners, steel structures, building materials, etc.	Kit	250	250
Cost of equipment Sob, US dollars	-	3,685.217	3,685.217
Installation and commissioning, USD	-	500	500
General. Capital investments K, USD	-	4,185.217	4,185.217
Additional investments in US dollars	-	900	900

Source [9]

Capital investments in equipment in aggregate form Kob :

$$Kob = Sob\left(1 + \frac{Ktr}{100} + \frac{Km}{100}\right), \quad (2)$$

where Sob is the selling price of the equipment; Ktr-coefficient of costs for packaging and transportation, (8-10% of the selling price (contractual value)); Km-cost factor for installation and commissioning of equipment; Kob, Km-the cost of equipment and its installation.

The results of the SFWL equipment cost as a percentage of capital costs are shown in Figure 2.

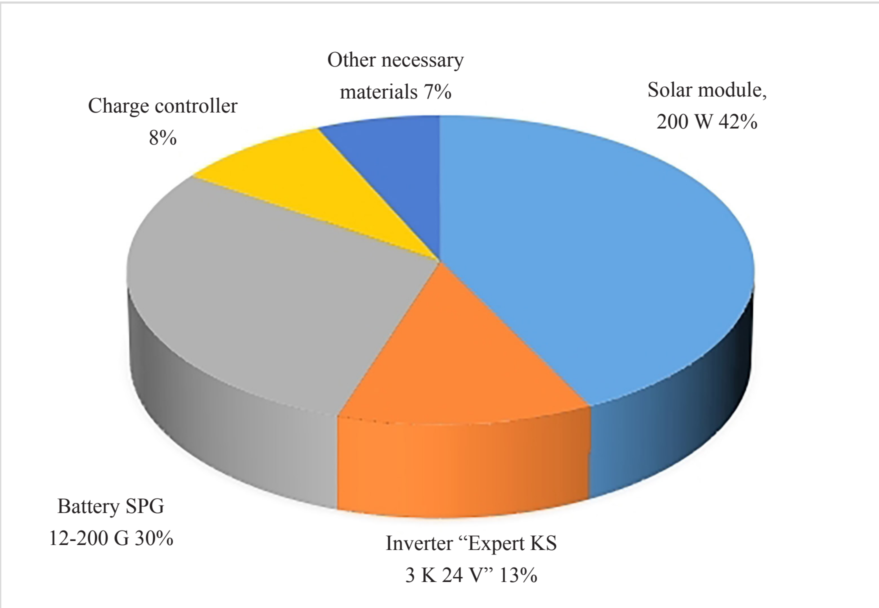

Figure 2. The cost of SFWL equipment in percentage terms

Source [2-7].

Energy efficiency calculation SFWL characterized by such parameters as the cost of implementation and subsequent operation.

Current costs (Tz) associated with the use of technical means:

$$\mathrm{Tz} = \mathrm{Z_P} + \mathrm{G} + \mathrm{A} + \mathrm{R} + \mathrm{E}, \quad (3)$$

where Zp-the cost of paying maintenance personnel, $; G-general production and general business expenses (accepted in the amount of 10% Zp);

A-depreciation deductions for the renewal of fixed assets, $; R-the cost of current, current and major repairs, $; E-the cost of consumed energy resources (electricity, fuel), $.

The depreciation charge can be expressed as follows:

$$\mathrm{A} = \frac{H_a}{100} K, \quad (4)$$

where: H_a-annual depreciation rate, %.

Maintenance and repair cost:

$$\mathrm{P} = \frac{H_r}{100} K, \quad (5)$$

r de H_r-the annual rate of deductions for maintenance and repair, we accept 20%.

The cost of electricity (C_{des}), generated by a liquid fuel generator:

$$C_{des} = \frac{K_{gen} \cdot A \cdot t + C_{top} \cdot W_{sr\ sut} \cdot n_i \cdot t}{W_{sut} \cdot n_i \cdot t}, \quad (6)$$

where K_{gen}-investment in the generator set, $; *t*-is the number of settlement periods, $; n_i-number of days in settlement periods, $; $W_{sr\ sut}$-average daily electricity consumption, kWh; C_{top}-cost of fuel, $.

The cost of generated energy of a photovoltaic installation (C_{SFWL}):

$$C_{SPWL} = \frac{Ie}{P * 8,760 * t_p * N * k}, \quad (7)$$

where: *P*-rated power, kW; *N*-installation service life, years; *k*-is the coefficient of the duration of work (when calculating, we take it equal to 0.6).

The average purchase price of diesel fuel is $500/t.

The estimated cost of fuel and lubricants is $200/year.

With a resource of 8,000 hours at a load factor of more than 70%, the diesel power plant will have to be overhauled or replaced every 5 years.

4. Determining the effectiveness of investments from the introduction of a photovoltaic installation

Calculation of investments. In the conditions of solar activity on the territory of the Krasnodar Territory, the SFWL operates 290 days a year for 7 hours with maximum efficiency. Based on this, the Researcher calculated the annual cost of electricity generated by the station with a capacity of 2.5 kW.

$$W_{yea} = P_{\max} \cdot t \cdot n, \tag{8}$$

where: P_{max}-maximum power of SFWL, kW; t-time of effective operation during daylight hours, h; n-is the number of days.

Payback period of investments t_0:

$$t_0 = \frac{K + I_e}{W_{yea}}. \tag{9}$$

Increasing profits by reducing operating costs:

$$\Delta Ch = I_1 - I_2, \tag{10}$$

where-I_1, I_2 the corresponding costs for the compared options.

Calculation of indicators of economic efficiency of investments net present value (Net present Value, NPV) is defined as the difference between the present value of future revenues and the present value of future project costs over the entire service life [7]:

Net Present Value NPV:

$$NPV = \sum_{t=0}^{n-1} \frac{CF_t}{(1+r)^t} \tag{11}$$

or

$$NPV = -K + \Delta Ch \frac{1-(1+r)^{-n}}{r}, \tag{12}$$

NPV(r_1) < 0, NPV(r_2) > 0

Where CF_t is income received in year t; r = 0.1 discount rate. Calculations are made in US dollars in August 2017 prices. Discount rate E = 10%; settlement period T = 10 years. Internal rate of return (IRR):

Static payback:

$$T_{0KC} = \frac{K}{\Delta Ch}. \tag{13}$$

Dynamic payback period

$$T_{0KД} = \frac{\ln\left(1 - \frac{K}{\Delta Ch} r\right)}{\ln(1+r)}. \tag{14}$$

The results of the feasibility study carried out are presented in Table 2.

Table 2. Technical and economic indicators of KSF in the Karakum desert in US dollars in dollar terms

Name Quantity	Piece cost	In US dollars	
		Units	General
	Basic option-diesel generator		
Diesel generator FUBAGDS 36002.7, generator cost USD	1	547.8333	547.8333
Other materials	Kit	116.6667	166.6667
Cost of equipment Sob, USD	-	-	714.5
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Source [2-7].

To assess the dynamics of movement (outflow and inflow) of funds, planning is carried out according to the CashFlow methodology. Using the PVSOL7.0 program, we will simulate an autonomous SFWL with a rated power of 3 kW. We accept the safety factor PR as 80% [7-9, 13, 14].

As a result, the calculated values of capital and operating costs for an autonomous SFWL with a rated power of 2.5 kW for 20 years were obtained.

5. Conclusion

In order to solve the country's food programs, it is necessary to develop distant pasture animal husbandry in the desert zone of the Karakum. The issue of watering based on SFWL in the conditions of the Karakum is not well studied due to the lack of specific data on groundwater. Having studied the possibilities of energy and water supply of the desert zone, the scientifically substantiated environmental and energy resources and the potentials of solar energy in the desert zone of the Karakum came to the following conclusions:

• The desert zone of the Karakum has enough groundwater, the issue of development, reducing the cost of the desert product can be solved with the help of renewable energy sources, in particular, solar and wind energy;

• The developed, calculated and created nomogram, the location of the SFWL in terms of the power of the generated energy, depending on the depth of the wells in the pasture areas of Turkmenistan, will provide an opportunity for energy and water supply, the development of animal husbandry and the development of the Karakum desert zone;

• The methodology for calculating the technical and economic characteristics: capital investments, investment costs and assessing the energy efficiency of parameters for use in transhumance will be useful in preparing a feasibility study (FS);

• The capital investment for a 2.5 kW photovoltaic plant is $4,185.2. Compared to the base case, operating expenses for 1 year decreased by $1,217.1. The net present value of using a solar photovoltaic installation compared to a diesel-electric installation over a 10-year billing period and a discount rate of 0.1 was $8,694.72. The cost of electricity generated by the PV plant was $0.113/kWh.

• The payback period for investments in a battery photovoltaic installation is 4.1 years, in a photovoltaic installation with hybrid storage-4.6 years. As a result of the use of investors' batteries, a 30% reduction in operating costs is provided by increasing the battery life by 1.8 times.

• The calculation results show that when 5,000 diesel mobile pumping stations are involved in the circulation, 73 thousand tons of diesel fuel are burned annually, approximately 233.5 thousand tons of CO_2 are emitted into the atmosphere per year. When using a solar photovoltaic plant, emissions will decrease by 5.6 times, or by 82.2%. When using SFWL, it is possible to reduce by 50% the annual consumption of energy resources and save in US dollars: gasoline from 3,408.9 to 1,704.45; diesel fuel from 3,368.0 to 1,684.0; liquefied gas-from 1,540.5 to 760.0. Detailed energy, economic and environmental indicators are given [7-12].

Conflict of interest

The author declares no competing financial interest.

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