REPUBLIC OF AZERBAIJAN

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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

GEOGRAPHICAL INVESTIGATION OF AZERBAIJAN'S RENEWABLE ENERGY RESOURCES AND CREATION OF INFORMATION BASE

Speciality: 5401.01 – Economic geography

Field of science: Geography

Applicant: **Nijat Sohrab Imamverdiyev**

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The work was performed at "Economic and Political Geography of Azerbaijan" department of the Institute of Geography named after Academician H.A.Aliyev, Ministry of Science and Education of the Republic of Azerbaijan.

Scientific supervisor: Doctor of Geography, docent
Nariman Aziz Pashayev

Official opponents: Doctor of geographical sciences docent,
Malikmammad Khanoglan Mammadov

Doctor of Philosophy in Geography, docent
Matanat Ramazan Musayeva

Doctor of Philosophy in Geography
Vugar Sattar Dargahov

Dissertation council FD 2.51 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the Faculty of Geography of Baku State University.

Chairman of the Dissertation council:

Doctor of Geography, professor **Chingiz Niyazi Ismayilov**

Scientific secretary of the Dissertation council:
Doctor of Philosophy in Geography, docent

Sahila Abish Allahverdiyeva

Chairman of the scientific seminar: Doctor of Geography, docent

Aydin Ismayil Ibrahimov

Azərbaycan Respublikasının Elm və Təhsil Nazirliyi
BAKI DÖVLƏT UNİVERSİTETİ
ELMİ KATİB
SCIENTIFIC SECRETARY
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GENERAL CHARACTERISTIC OF THE WORK

The actuality of the topic and level of research on the topic. In connection with the transition to green energy in Azerbaijan, the potential of solar, wind, biomass, hydropower, and geothermal energy resources and economic-geographical assessment is of great relevance in terms of meeting the country's growing electricity demand, diversifying energy sources, and protecting the environment. In order to achieve high energy efficiency, it is important to choose suitable areas for locating photovoltaic (PV) systems and wind turbines and optimize the amount of investment in plants with other renewable energy sources (RES).

There is a need to conduct an economic-geographical assessment of RES geographical distribution zones and areas of the most efficient use of energy sources and energy resources. Thus, the construction of a power plant requires a detailed geographical analysis of the area (relief factor, land use, effects on the ecosystem, biological diversity, etc.). For this purpose, in the country, R.H.Gardashov, K.M.Abdullayev, T.D.Agayev, Sh.P.Bayramov, M.F.Jalilov, Ch.M.Chuvarli, R.N.Aliyev, S.G.Amirov, Sh.G.Askerov, M.H.Hamidov, M.H.Kazimov, V.A.Gasimli, S.F.Guliyev, F.F.Mammadov, A.M.Namazova, O.M.Salamov, R.I.Talishynski, N.A.Yusifbeyli, etc., the issues of territorial organization and development of solar, wind, hydro, biomass, and geothermal sources were analyzed in the scientific works of scientists.

The object and subject of the research. The object of the study is the economic-geographical study of renewable solar, wind, geothermal, bioenergy, and hydropower sources in Azerbaijan. The subject of the research is the economic importance of renewable energy sources, the determination of suitable locations for the construction of power plants for territorial organizations, and the calculation of the possible amount of electricity production.

The purpose and the missions of investigation. The main goal of the dissertation is to examine the economic importance of power plants, the economic-geographical assessment, and the suitability classification of areas for the construction of power plants. The regionalization includes RES's calculation of electricity potential for economic-geographic analysis and the study of incentives to promote individual use. To achieve this goal, the following tasks have been set:

- The role of alternative energy sources in the prevention of environmental pollution and climate change; the study of the state of use and environmental importance of RES on a global scale;
- Determination of energy potential areas with RES in Azerbaijan;
- Selection of optimal sites for placement of power plants outside restricted areas (productive lands, residential zones, forests, agricultural lands, nature reserves, national parks, etc.);
- Determination of territorial suitability for the construction of power plants using the analytical hierarchy process model;
- Types of solar panels and wind turbines, production capacity, efficiency, etc. Calculating the amount of energy production by fields by analyzing factors such as;
- Creation of an energy reserve of biomass, hydropower, and geothermal energy sources and their information base.

The methods of research. The dissertation work was studied by the AHP method included in the multi-criteria decision model, statistical, spatial analysis in GIS, and cartographic research methods. In addition, Pvsyst and Wind Pro programs were used for modeling power plants in energy potential zones and relevant formulas for calculating the possible amount of electricity production in the areas.

The main provisions defended:

1. Determination of energy potential areas based on direct, scattered, and general distribution of solar radiation by regions, as well as cloudiness and air clarity index;
2. Research of the speed, power, and intensity of wind resources at relative heights based on meteorological indicators and calculation of technical energy potential;
3. Analysis of geothermal, hydropower, and bio-energy resources; research of suitable areas for the placement of resource stations; study of economic importance as a source of electricity and

prospects of use;

4. Determining the optimal locations for the construction of a power plant according to RES, calculating the potential amount of electricity production of each plant, and studying the factors that promote individual use.

The scientific novelty of the research.

The following is a summary of the scientific innovations resulting from the systematization, analysis, and justification of RES's spatial features research data.

- The AHP method was applied for the first time to evaluate the technical energy potential of the sun and wind using stationary observation stations and a satellite database;
- In the GIS environment, the compatibility of solar energy potential areas in three categories was calculated, and optimal places for placing power plants were determined with the joint application of AHP and GIS;
- Maps reflecting the areas of optimal use of solar and wind energy sources outside the restricted areas were drawn up, and the amount of energy production was calculated with appropriate programs and formulas;
- Optimum sites for placing hydroelectric power plants (HPP) on rivers with energy potential were identified, the feasibility of the construction of geothermal power plants based on the annual discharge of thermal wells and the water temperature was determined, and an information base was created;
- Prospects of meeting the country's electricity demand at the expense of RES were studied, and, for this purpose, the price of possible electricity production was calculated for individual energy sources.

Theoretical and practical significance of the research.

The scientific analysis of the dissertation work and the theoretical and practical significance of the obtained results and recommendations consist of the evaluation of the potential of RES and the identification of suitable places for the construction of power plants through thematic maps. In addition, identifying potential areas based on solar radiation and wind regimes and justifying their economic efficiency is an important condition for sustainable development, such as energy security, diversification of energy sources, and environmental protection. For this purpose, the results of the study can be used in future studies related to the identification of alternative energy potential sites, possible electricity generation, environmental benefits, and implementation of the energy project development plan.

Approbation and application of the research.

The main results and provisions of the dissertation were presented at the following scientific conferences: The International scientific conference on "The Role of a Multidisciplinary Approach in Solving the Current Problems of Fundamental and Applied Sciences" (Baku, 2013), the International Scientific Conference on "Geography: Theory, practice and innovation" (Baku, 2015), international scientific conference on "Geographic problems of Azerbaijan regions" (Baku, 2016), conference dedicated to "110th anniversary of H.A.Aliyev" (Baku, 2017), " Scientific forum: Innovative science, collection of articles based on the materials of the XXIX International Scientific and Practical Conference (Moscow, 2019, "Multidisciplinary approaches in solving modern problems of fundamental and applied sciences" (Baku, 2020), "Innovation in Geology, Geophysics and Geography" 6th International Scientific and Practical Conference (Moscow, 2021), "The role of Heydar Aliyev in the development of science and education in Azerbaijan" (Baku, 2023), "The proceedings of the 6th Intercontinental Geo-information Days" (Mersin, 2023), "Actual problems of mathematics and natural sciences" XI International Scientific and Practical Conference (Petropavlovsk, 2023) and Geography, Environment and Anthropology (Paris, 2023). In total, 20 articles were published on the topic of the research work.

In the dissertation, methodologically justified proposals and recommendations on RES can be used in scientific research institutes, especially in the energy sector, in determining the optimal places for the construction of energy potential areas, especially power plants.

The name of the organization where the dissertation work

was implemented:

The dissertation work was performed in the "Economic and political geography of Azerbaijan" department of the Institute of Geography, named after academician H.A. Aliyev of the Ministry of Science and Education.

The volume, structure and main content of the dissertation. The volume, structure, and main content of the dissertation. The total volume of the dissertation, including the introduction, 4 chapters, 13 subchapters, conclusions, and suggestions (excluding the list of references and abbreviations), consists of 234 thousand 342 characters. Introduction 8763 signs, Chapter I 64413 signs, Chapter II 40731 signs, Chapter III 73349 signs, Chapter IV 41211 signs, conclusion and proposals 5875 signs, 174 titles from the bibliography, 34 tables, 19 pictures, 6 schemes, and 155 computer pages.

THE MAIN CONTENT OF THE RESEARCH

In the "**Introduction**" part of the dissertation, the relevance and degree of development of the topic, goals and tasks, methods, main propositions defending scientific innovations, theoretical and practical significance, and approval and application of the research are given.

Chapter I, called "**Geographic Aspects and Theoretical-Methodological Foundations of the Use of Renewable Energy Sources**,” covers the theoretical foundations of energy resources. This chapter examines the importance of researching solar and wind energy sources and methods of selecting suitable geographic locations for power plants. In addition, the state of use of geothermal, bio-energy, and hydropower sources and research directions in this direction were interpreted.

There are studies by F.F.Mammadov, N.A.Pashayev, T.G.Hasanov, Z.N.Eminov, F.A.Imanov, C.N.Ismayilov, Kh.Sh.Rahimov, R.N.Mahmudov, M.Y.Khalilov, Sh.Y.Goychaily, M.Y.Khalilov, S.H.Safarov, and others. In addition, there is a need for a comprehensive study of renewable energy sources from an economic-geographic point of view. This includes the role of the use of RES in the energy industry and the economic development of the country, the territorial organization of separate energy sources, the use of labor resources in the renewable energy industry, etc.

J.T.Berken, S.D.Perkins, M.E.Bogogno, C.M.Candelise, H.E.Colak, V.M.Delmotte, and H.A.Effat, as an example of the selection of zones with solar energy sources in the world and the optimal areas for the construction of power plants based on these sources, the geographical distribution of energy resources, and the study of individual sources, N.V.Hartchenko, A.A.Merrouni, H.E.Murdock, G.R.Randal, and M.K.Rumbayan. Examples include T.L.Saaty, M.L.Sabo, J.M.Sanchez, J.J.Watson, and others.

F.E.Salmanova investigated the ways of hot water supply based on solar and wind energy in the natural conditions of the Absheron and Caspian Sea coastlines in the investigation of suitable areas for the construction of wind turbines. Research on geothermal sources was mainly conducted by C.S.Aliyev, and he compiled a heat flow map. The potential of energy sources, discharge of thermal wells, and hydrogeological characteristics of underground waters were studied by Y.Israfilov, A.Nuriyev, I.Mammadov, and E.Rustamov and collected in the electronic database. A.Mukhtarov and V.Mammadov conducted geothermal research in the thermal wells of the Lankaran zone. Also, R.J.Bagirli, C.S.Aliyev, A.A.Feyzullayev, F.F.Mahmudov, A.Sh.Mukhtarov, R.S.Nadirov, A.V.Mahmadova, and V.A. Mahmadov investigated the geological conditions and business opportunities for the development of geothermal energy. The hydrography and ecological condition of lakes and reservoirs in the republic were studied by M.M.Hasanov, K.D.Zamanov, R.B.Tarverdiyev, Sh.B.Khalilov, and V.A.Mammadov. Also, S.H. Rahimov conducted hydrometeorological studies on the hydrological features of rivers, and M.A.Mammadova studied the hydrography of Azerbaijan, water consumption of rivers, geographical aspects of formation, passage, and use of river flow. In addition, R.M.Qashqai determined the connection of river flows in Azerbaijan according to the height of the basin and compiled an annual flow map.

Chapter II, "**Research of Renewable Energy Sources in**

Azerbaijan and Creation of an Information Base," is devoted to the economic-geographical analysis of RES, the creation of a spatial database of energy resources, and the determination of the potential of energy sources. RES's projected capacity, which is economically geographically favorable and technically feasible, is three times its current production capacity. Using this potential, electricity production in 2022 will be 1740 million kWh (8.1%) (excluding hydropower, 350 million kWh)[1].

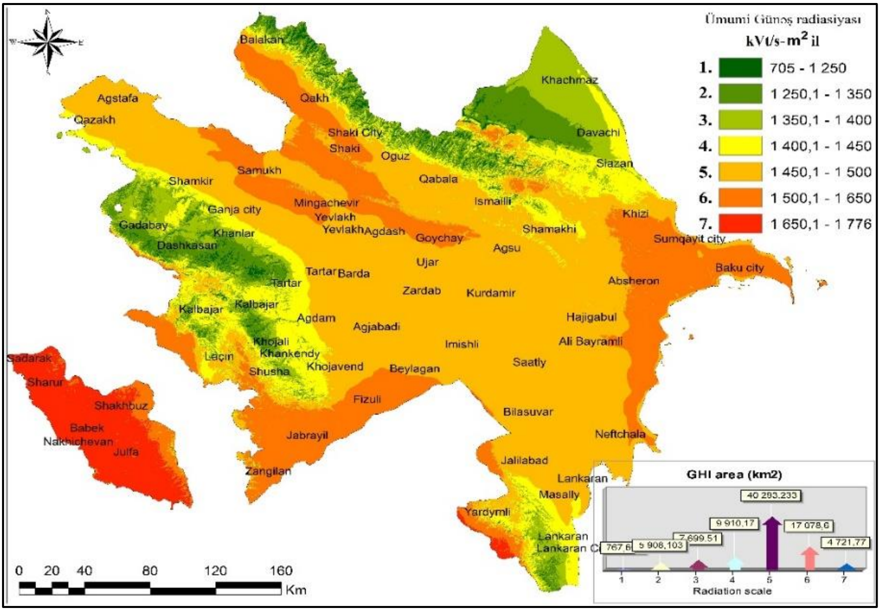

Figure 1. Total solar radiation map of Azerbaijan
(Compiled by the author in GIS)

As can be seen from Figure 1, the total radiation indicators of solar energy in the republic are an average daily 3.4 kWh/m^2 or an average annual 1240 kWh/m^2 (min. 705, max. 1776 kWh/m^2). The amount of radiation in 21.8 thousand km^2, or 18.9% of the total area, with the highest efficiency for the construction of PV in the country is 1501 kWh/m^2 and above (6th and 7th divisions). The area of 40.3

[1] Energy of Azerbaijan / State Statistical Committee of the Republic of Azerbaijan – Baku: Statistical collection, – 2023. – 164 p. (In Aze.)

thousand km^2 (46.5%) (5th division) covering the Aran region with the second average radiation (1450–1500 kWh/m^2) is also satisfactory for placing solar panels[2].

Wind energy potential was determined by the calculation of possible intervals and correlation coefficients of wind speed indicators based on indicators received from meteorological stations. The assessment of wind electrical energy potential is determined based on wind speed, intensity, and power density (V/m2) at relative heights. These data are considered to be the main indicator in the selection of the site for the construction of wind turbines. The power of the wind flow P (Watt) is proportional to the power of the wind speed V (m/s) and is determined by the following formula (1).

$$P = (\rho/2)\,Av^3 \qquad (1)$$

Here, A is the cross-sectional area perpendicular to the wind direction; ρ=1.225 kg/m^3 is the density of air. If the radius of the turbine wheel is equal to r, then $A=\pi r^2$. The P/A quantity is the wind power density.

Based on the average wind speed indicators in Azerbaijan for 1981–2020, the areas with low power (3.51–4.5 m/s) energy production potential for placing turbines are grouped within III and IV divisions, and separately, 20 thousand km^2 (23%) and 16 thousand km^2 (18%) were calculated[3]. The area of medium-strength areas of V and VI divisions with wind speeds between 4.51 and 5.5 m/s is 8 thousand km2 (9%) and 17 thousand km^2 (20%), respectively. The area of the territories within the VII and VIII divisions with high wind reserve (5.51–6.5 m/s) and technical potential is 5.1 thousand (6%) and 4.1 thousand km^2 (5%) (Fig. 2). Sitalchay, Yeni Yashma, Shurabad, etc., covering the shores of the Caspian Sea with a total area of 9.2 thousand km^2. Potential areas are the most suitable places for

[2] Solar resource maps of Azerbaijan, Solar resource data: Global Solar Atlas 2.0, URL: https://solargis.com/maps-and-gis-data/download/azerbaijan. June 12, 2022.
[3] NASA, MERRA-2 Data, POWER Data Access Viewer v2.0.0, Prediction of Worldwide Energy Resource: GMAO-5, MERRA-2 satellite. – December 1, 2020.

the construction of KES. The average annual wind speed in these areas is 5.6 m/s, and the average power density is 390 W/m^2.

Based on the MERRA-2 satellite database, wind speed data for 84 stations was analyzed, and the average annual wind speed was determined to be 4.41 m/s. Although an increase in wind speed by 0.1 m/s was observed in the annual dynamics (from 4.4 to 4.5), the speed remained stable compared to the overall period.

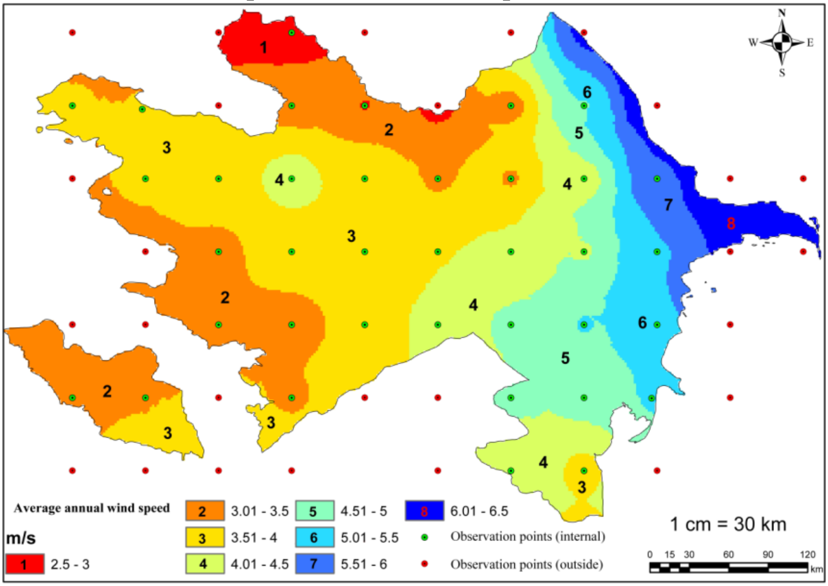

Figure 2. Map of wind speed distribution in Azerbaijan (50 m RH) (Compiled by the author in GIS)

The amount of energy production corresponding to the wind speed in the areas was calculated using the Wind Pro program with a 2 MW turbine of the "Camesa G90" type as an example[4]. The amount of energy production varies depending on the duration of the windy hours, between 3 and 21 m/s. In areas with a high wind speed duration

[4] Imamverdiyev, N.S. Site selection for solar photovoltaic system installation using an analytical hierarchy process model in Azerbaijan // Minsk: Journal of the Belarusian State University, Geography and Geology, – 2021. №1, – p. 75-92.

of 6 m/s, the annual energy production amount will be 1200 hours and 132 thousand kW. In areas where the wind speed is stable between 8 and 12 m/s, the annual energy production is 4.96 million kW (capacity factor 18%).

Forecasted exploitation reserves of thermal waters in Azerbaijan 2000 m^3/day on the southern slope of the Greater Caucasus (t = 30–50 °C), 21000 m^3/day (t = 40–85 °C) in the Guba-Khachmaz zone, and 20000 m^3/day on the Absheron Peninsula (t = 40–90 °C) were determined. These include 17 wells in Guba, 10 wells with a total discharge of 30 thousand/day in Khachmaz, 10 sources with a discharge of 3.1 million/day in Gakh, 10 thermal wells with a discharge of 27.5 thousand/day in Shabran, and 8 wells with a discharge of 505 thousand/day in Shamakhi[5]. The temperature of the thermal and 7 thermal wells in Ismailli with a discharge of 440 thousand m^3/day ranges from 4°C to 97°C, and the operating reserve is 245 thousand m^3/day.

The amount of production and consumption waste generated in the country in 2022 for bio-energy was 3985.1 thousand tons, of which 20% (802 thousand tons) was used or neutralized[6]. The amount of household waste in the Republic has the potential to produce more energy than what is produced in the existing household waste incineration plant. In addition, fruits, vegetables, cereals, vegetable oils, tea and tobacco production and processing wastes (113.5 thousand tons), sugar processing wastes (20.1 thousand tons), and cotton ginning industry wastes that can be used as biomass (83.5 thousand tons) are also available. It is possible to use these wastes directly (by incineration) and indirectly (by fermentation process) as electricity.

Hydropower has the largest production capacity in RES in 2022,

[5] Namazova, A.M. Economic-geographical study of thermal and mineral water resources of the Greater Caucasus: /PhD in geography. Abstract. – Baku, 2017. 26 p. (in Aze)

[6] Environment in Azerbaijan / State Statistical Committee of the Republic of Azerbaijan. – Baku: Statistical collection, – 2023. – 139 p. (In Aze)

with 86.2% (1164.7 MW) of 14 HPPs[7]. Because of the 21.3% decrease in water resources in the republic compared to 1990, total electricity production in 2020 decreased by 4.36%. The country has the potential to build power plants in 280 locations on various rivers, irrigation canals, and reservoirs. Through these stations, the total production capacity is 1512.6 MW, and it is possible to produce electricity of, 6287 million kWh (capacity factor 18%).

Chapter III of the dissertation is dedicated to the "**Identification of suitable areas for the construction of solar and wind power plants in Azerbaijan**". Areas with radiation indicators above 1400 kWh/m^2, which are more effective for installing solar panels, were selected. Since the air temperature for PV panels to produce energy at their highest power is 25°C, regions with an average annual temperature of 10–18 °C are considered as the basis for site selection.

In the Aran economic region, which has a great potential for the placement of hydropower plants, the total area, excluding settlements, protected areas, and areas suitable for agriculture, is 1256 km^2, and the area of technically favorable areas is 51 km^2.

It is possible to build hydroelectric power plants with a capacity of up to 30 MW through solar panels in the Boyukduz plain, which is the most suitable region for placing photovoltaic panels in NMR[8]. This is equal to the annual energy production of 47 million kilowatts. Sharur, Babek, and Julfa regions located on the banks of the Araz River differ in terms of higher solar insolation, the intensity of solar rays, and the number of cloudless days.

The Karabakh region is divided into 3 groups with low, medium, and high radiation quantities (Fig. 3)[9]. Annual solar

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[7] Energy of Azerbaijan / State Statistical Committee of the Republic of Azerbaijan – Baku: Statistical collection, – 2023. – 164 p. (In Aze.)

[8] Kazimov, M.H. Alternative energy resources of Nakhchivan MR and prospects of their use: / abstract of the PhD thesis on technology. - Nakhchivan, 2015. – 24 p. (in Aze)

[9] Imamverdiyev, N.S. Gardashov, R.H., Gardashov, E.R. Solar and wind energy reserves of the Karabakh region // − Baku: Geography and natural resources, − 2023. − №2(20), − p. 91-96.

radiation varies from 976 to 1450 kWh/m^2 in I-group areas with weak solar energy potential. The total area of the areas corresponding to this radiation range is 5.6 thousand km^2 (33%), mainly covering Lachin, Shusha, Khojaly, and Khojavend regions, the foothills of the Karabakh volcanic plateau, and the Karabakh plain. Areas with moderate (group II) solar radiation characteristics (1450–1500 kWh/m^2/year) cover 6.7 thousand km^2 (39%).

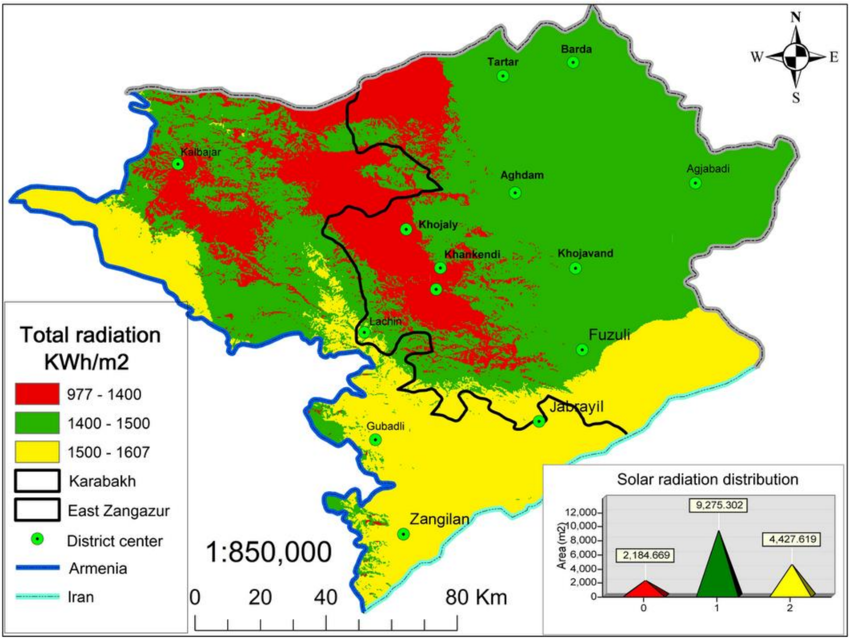


Figure 3. Solar radiation distribution map in the Karabakh region (Compiled by the author in GIS)

The highlands of the Karabakh, Mikhtokan, and Sarıbulagdag ridges, as well as the southeastern slope of the Murovdag ridge (14% of the area), are low-potential, where the annual solar radiation varies from 977 to 1400 kW/m^2 and the solar energy is about 2.5×106 GWh determined to be the year;

The Karabakh and Mil (western part) plains, the slopes of the Karabakh, Mykhtokan, and Eastern Goyche ridges, the southern slope of the Murovdag ridge, and the southeastern part of the Karabakh highland (58% of the area) had an average potential, where the annual solar radiation was 1401 to 1500 kW/m^2 and total solar energy is estimated at 13.5×106 GW/year;

The annual solar radiation is in the northwestern part of the Karabakh mountain, Pilasar-Susandag, the middle and lower reaches of the Hekari River, the southeastern lowland of the Karabakh range, the Araz sloping plain, and the southwestern part of the high-potential Mill plain (28% of the area). With a variation from 1501 to 1607 kW/m^2, the total solar energy consumption is 6.8×106 GW/year.

Based on the principle of establishment of PV, sparse vegetation and semi-desert zones cover 29.1 thousand km^2 (33.6%) and 35.7 thousand km^2 (41.2%), respectively. In regions with solar energy potential, suitable areas (residential areas, natural objects, highways, power transmission lines, solar radiation, environment, and land use) were determined by the joint application of AIP-GIS. In the final map, 1.17% of the surveyed area (1.02 billion m^2) has suitable indicators for placing solar power plants. These areas include Absheron, Nakhchivan, and the Aran region, which have relatively weak solar radiation (1450 kWh/m^2/year). Also, Khizi, Hajigabul, and Gobustan regions are considered promising areas for the installation of medium-power PV plants because of low electricity consumption, not widely used areas, and high direct solar radiation falling on the horizontal surface.

Because of the calculation according to the classification carried out for the placement of hydropower plants, it was determined that 11% (109.2 km^2) of the suitable areas have a high coefficient, 28% (284.6 km^2) have an average coefficient, and 61% (623 km^2) have a low utility coefficient. As a result of the analysis of economic-geographical, ecological, and meteorological criteria, suitable points for the installation of photovoltaic stations are located in Nakhchivan, Absheron, Jeyranchol, and Aran. In total, 40 areas for the placement of solar photovoltaic plants with high, medium, and low suitability have been identified in the country.

Nakhchivan MR has 8 areas, and its total area is 109.2 km^2, or 2% of the MR, which corresponds to the highest level of usability in the country (table 1)[10]. There is a high potential for the installation of PV in the economic region with annual insolation values above 1500 kWh/m^2. The following formula was used to calculate the solar energy potential of the area.

$$E = A \times r \times H \times PR \times P \qquad (2)$$

Here E = energy, kW; A = total area of the photovoltaic panel, m^2; r = solar panel efficiency, CF (%); H = annual mean irradiance value on inclined panels (excluding shadow); PR = performance ratio (standard value–0.75%); and P = station loss factor (0.30%).

Table 1

Highly optimal areas for setting up solar panels
(Prepared by the author)

	Suitable locations	Coordinate (lat - long)	Area km^2	Total rad. kWh/y	The capacity of PV MW/y	Annual output million kWh/y
1	Gulistan (Julfa)	38.97–45.73	2.1	1755	101	151.6
2	Diza (Julfa)	38.97–45.65	9.2	1753	440	661.1
3	Yayci (Julfa)	39.18–45.54	4.0	1749	193	290
4	Boyukduz (Babek)	39.29–45.32	45.5	1737	2170	3256
5	Julfa c. (SmSh part)	39.02–45.57	1.3	1735	61	92.4
6	Tananam (Sharur)	39.48–45.13	10.6	1730	507	761.3
7	Yeni Kerki (Babek)	39.25–45.22	22.8	1728	1089	1634
8	Karaagac (Sadarak)	39.69–44.93	13.7	1719	653	980.4

The calculation is carried out by the appropriate formula (2) (E = 109.2 × 13.7 × 1500 × 0.75 × 0.30), and the energy capacity of solar power stations in Nakhchivan is 5.2 GW, and the maximum energy production is 7.8 billion kW is defined.

The number of stations with average efficiency is 12, which covers 0.32% of the country's territory (284.6 km^2) (table 2). Theoretically, it is possible to install a 13.6 GW (1.0 MW-21 thousand m^2) hydroelectric power plant on the territory with a total area of

[10]. Imamverdiev, N.S. Choosing the optimal location for installing solar power plants in the Nakhchivan Autonomous Republic // − Moscow: Bulletin of Moscow University, Series 5, Geography, – 2022. No. 4, – p. 36-51. (In Russ.)

284.6 km^2. This annual 16.3 billion kWh (1.0 MW=1.2 million kWh) is equivalent to electricity production[11].

Table 2

Average optimal areas for setting up solar panels
(Prepared by the author)

	Suitable locations	Coordinate (lat. – lon.)	Area km^2	Total rad. kWh/ year	The cap. of PV MW/y	Annual output million kWh/y.
1	III Agalı (Zan.)	39.21-46.87	28,3	1574	1348	1618,7
2	Zira (Baku)	40.34-50.33	1,3	1523	65	78,0
3	Horadiz (SW part)	39.37-47.20	1,9	1530	92	110,5
4	Sangachal (W part)	40.22-49.42	26,8	1529	1278	1533,6
5	Cheyildagh (Absh.)	40.30-49.37	44,6	1527	2128	2553,9
6	Gobu (Absheron)	40.35-49.72	4,9	1525	234	280,8
7	Kichik Dahne (Sh.)	41.03-46.88	103	1521	4900	5880
8	Pirakeshkul (Abs.)	40.52-49.58	1,9	1510	94	113,1
9	Jeyranchol (Poylu)	41.09-46.18	59,7	1506	2844	3412,9
10	Zeynalabdin T. set.	40.67-49.43	7,8	1505	373	447,6
11	Arabgadim (Gob.)	40.47-49.06	2,7	1503	128	154,4
12	Chilov Island	40.33-50.59	1,8	1502	89	106,8

Suitable sites for GES were classified according to the criteria of insolation values, clarity index, topography, duration of sunny days, land use, and proximity to roads and power lines in seven categories. If the areas with a total area of 1016.8 km^2 are completely covered with photovoltaic panels, the total electricity production capacity will be 48.5 GW and energy production will be 55.2 billion kWh (capacity factor 13%)[12]. This is 29 billion kWh produced in the country in 2022, which is 1.9 times more than electricity.

During the selection of suitable places for the placement of wind

[11] Imamverdiyev, N.S. Site selection for solar photovoltaic system installation using analytical hierarchy process model in Azerbaijan // – Minsk: Journal of the Belarusian State University, Geography and Geology, – 2021. №1, – p. 75-92.

[12] Imamverdiyev, N.S. Geospatial analysis of wind indicators and terrain impacts in determining optimal wind farm sites in Azerbaijan // − Almaty: Khabarshi. Geography Series, − 2023. Vol. 71, No. 4, − p. 22-31.

power plants in Azerbaijan and the calculation of the economic-geographical potential, the areas with the highest efficiency in all categories were selected, taking into account the economic-geographical factors, with an annual wind speed of more than 3.5 m/s. Areas with a wind intensity of 180 days per year and an average speed above 4.5 m/s are economically and geographically favorable for the construction of wind power plants, covering 5% of the territory of the republic (4.33 thousand km^2). It was determined by evaluating the optimal height and exclusion zones in areas with medium-high wind speed potential that only 15% of the technically usable area of 2.24 thousand km^2 or 0.37 thousand km^2 is considered economically suitable for the construction of wind power plants. According to the technical characteristics of the wind turbine, it is possible to build power plants with a total capacity of 108.7 MW in coastal areas with an average annual wind speed of 5–6 m/s.

The high wind potential in Absheron is 1.95 billion by building a hybrid system with PV panels. It is possible to produce electricity in kWh[13]. This is equal to 36% of Absheron's energy demand. Five wind power plants with a capacity of 350 MW have been identified in 20 locations in the economic region. 420 million through these stations with a capacity factor of 15%. It is possible to produce electricity in kWh. A total of 782 km^2 and 5 regions have been identified for the construction of wind turbines in the Caspian Sea. In these areas, the average annual wind speed at a height of 50 m is 6.4 m/s, which is equivalent to the annual production capacity of 469.2 MW of power plants at full utilization.

Windy zones in Nakhchivan are Nasirvaz and Aghdara villages of Ordubad district, Batabat pass of Shahbuz district, and Araz River banks. The second zone includes the city of Nakhchivan, the villages of Kermachatag in the Shahbuz district, the village of Lekatag in the Julfa district, and the slopes of Ilanli Mountain, etc. The third zone

[13] Imamverdiyev, N.S. Determining wind energy potential areas in Azerbaijan by using GIS multi-criteria decision analysis method // – Baku: ANAS Transactions Earth Sciences, – 2020, №1, – p. 44-53.

includes Sharur, Sadarak, and Kangarli districts. The wind speed in this zone varies from 2 m/s to 4 m/s. Only 22% of the 1.51 thousand km^2 area belonging to the usable high-use zone has a high index for the construction of wind power plants. It is possible to meet 7.7% of the country's electricity demand with the production of kWh.

The average annual wind speed in the Karabakh economic region varies between 2-4 m/s. The area of the regions with wind speeds in the range of 2 m/s is 9.8 thousand km^2 and includes the Tartar, Barda, Agdam, and Aghjabadi regions and the banks of the Araz River (Fig. 4). Here, the number of days with an annual wind speed higher than 15 m/s is 10 days per year. The number of days with wind speed exceeding 15 m/s is between 10 and 20 days per year, including the 4.6 thousand km^2 areas with wind speed between 2-4 m/s, the low mountainous part of Kalbajar, Lachin districts, and the surrounding areas of Shusha city[14].

For the construction of wind turbines in the region, the number of days exceeding 15 m/s per year in the 1.08 thousand km^2 part where the average annual wind speed is 4 m/s is around 25 days[15]. Areas with high energy potential include the Kalbajar region along the border with Armenia and surrounding areas of the Murovdag range. The calculated average wind power of wind turbines in the area was 31.43 $W \times m^2$.

The wind potential in the East Zangezur region belongs to the 3rd category zone after the Absheron and Nakhchivan regions in the republic because of the possibility of establishing limited-capacity wind turbines. In the Karabakh region, the seasonal wind speed varies from the lowlands to the highlands (0.1–8.7 m/s). Areas where the average annual wind speed is higher than 4.1 m/s at a relative height of 50 meters have been selected here (Fig. 4). The total area of these highly usable zones covers 1.08 thousand km^2, or 7% of the country's

[14] The Global Wind Atlas: Azerbaijan and regions / The Danish Energy Agency, The World Bank. URL: https://globalwindatlas.info/area/Azerbaijan. 21 Mart 2022.
[15] Imamverdiyev, N.S., Gardashov, R.H. Renewable energy resources // Geography of Karabakh and Eastern Zangezur: Natural-geographic conditions and socio-economic development potential. Baku: OPTIMIST, − 2021. − 536 p.

territory. These areas mainly include the Karabakh plateau located in the western part of Kalbajar district, Delidag, and the Sarchali Mountains at an altitude of 3000 meters in the Mykhtoken range. The other part, being a small area, covers the southwestern part of Zangilan district and the heights of the Murovdag range.

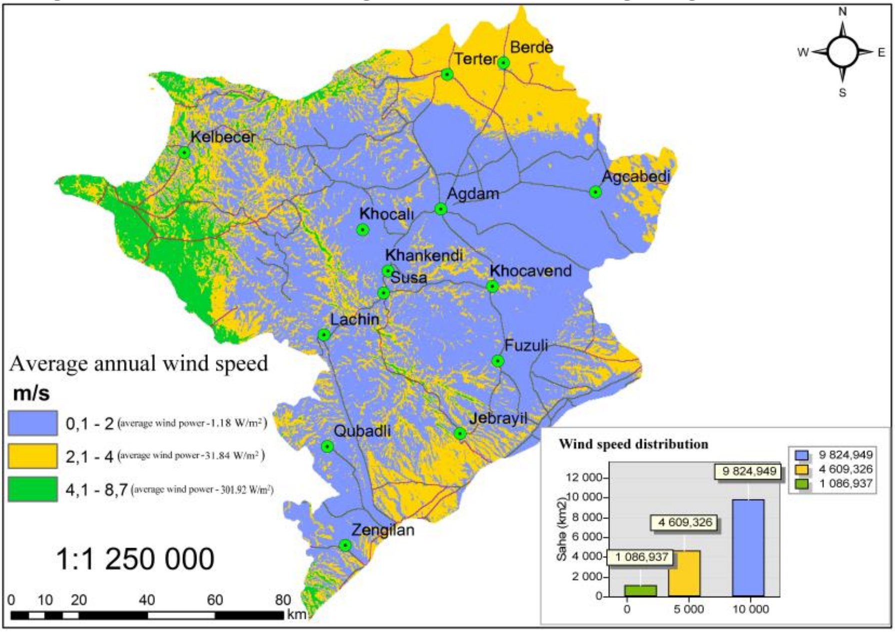
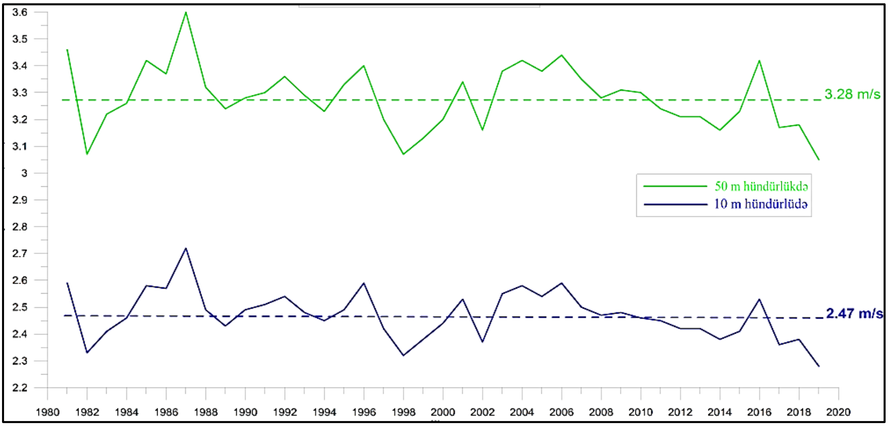


Figure 4. Average annual wind speed index map of Karabakh (50 m RH.) (Compiled by the author in GIS)

Based on the Global Wind Atlas data, the wind resources of the Kalbajar and Lachin regions during the period covering 2008–2017 were calculated using the Wasp program. It was determined that the areas corresponding to the annual wind speed of 0.2–3.5 m/s are 1984 km^2, 3.5–6.5 m/s = 1092 km^2, and 6.5–13.8 m/s = 582 km^2. Although the total potential is set at 2000 MW, due to the complex relief structure, there is a need to create appropriate infrastructure conditions for the transportation and installation of turbines in these zones[16].

Based on the analysis of "Merra 2" satellite data, an analysis of wind speed data for 1981–2020 was carried out in 23 locations. The average annual wind speed in the region is 2.47 m/s at a relative height of 10 meters and 3.28 at 50 meters (graph). The period when the average annual wind speed was higher than 3.5 m/s covers only 1987[17]. In other years, the speed was around 3 m/s and continued with a decreasing trend since 2006. As a result, it was only determined that installing small-power wind turbines is efficient.



Graph. Wind speed in Karabakh at 10- and 50-meters relative height (Prepared by the author based on satellite data)

As a result of the analyses carried out using the hydrological data of the rivers with hydropower potential in the republic, 27 locations where it is possible to build small hydropower plants on rivers with a water flow speed higher than the minimum of 3 m/s have been determined. Nakhchivan MR was selected as a model area for

[16] Imamverdiyev, N.S. Gardashov, R.H., Gardashov, E.R. Solar and wind energy reserves of the Karabakh region // − Bakı: Coğrafiya və təbii resurslar, − 2023, − №2 (20), − s. 91-96.

[17] NASA MERRA-2 Data, POWER Data Access Viewer v2.0.0, Prediction of Worldwide Energy Resource: // GMAO-5, MERRA-2 satellite. URL: https://power.larc.nasa.gov/data-access-viewer. December 1, 2021.

obtaining electricity using the kinetic energy of the river. The total production capacity of a station built at this height is 38.1 MW, and energy production is 215.5 million kWh, calculated.

Another potential zone in the republic is the Karabakh region, where large and other small rivers such as Tartar, Bazarchay (Bargushadchay), and Hekari have high energy potential. In addition, there are rivers with hydropower potential in Karabakh, such as Kondalanchay, Okchuchay, Khachinchay, Gargarchay, Ildirimsu, Zabukhchay and Incechay.

The thermal source with the highest temperature in Azerbaijan is Carly well No. 3 (90°C). The flow rate of the well is 20,000 m^3/day. When evaluating the geothermal potential, it was determined that the energy potential of the well will be 70 MW when the temperature is cooled to 20°C[18]. Using only 5% of this potential, it is possible to build a 2-3 MW power plant. Also, there is a thermal source with a temperature of 45.5°C in Gazanbulag settlement, Goranboy region. The temperature of the well at a depth of 1000 m is 63°C, and at a deeper level (3000–4000 m), thermal water with high energy potential can be obtained and used as a source of geothermal energy[19].

The reason for the weak potential of geothermal energy in the republic is that the temperature of 80% of thermal water resources is around 40°C and the volume is 245.6 thousand m^3/day. As an example of thermal wells, the Daridag thermal energy source, which is the largest field in Nakhchivan MR, with a capacity of 10 MW, can be shown. Other wells are Ilisu and Oglanbulag, where the water temperature is 41.2°C.

In 2021, 3778 thousand tons of waste were generated in the republic, the main part of which was the mining industry, processing

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[18] Mukhtarov, A.SH. Geothermal waters and geothermal energy resources of the Republic of Azerbaijan: / Science Development Fund (Project number: EIF-KETPL-2-2015-1 (25)-56/31/2-M-20). - Baku, - 2019. - 24 p. (In Aze.)

[19] Mukhtarov, A.Sh., Geological conditions and business opportunities for geothermal energy development in Azerbaijan / A.Sh.Mukhtarov, R.S.Nadirov, A.V.Mammadova [et al.] // Proceedings of Azerbaijan national academy of sciences, the sciences of earth, – Baku: – 2015. №3, – p. 54-59.

industry, and solid household waste[20]. The volume of solid household waste was 2581.2 thousand tons, and 29.8 thousand tons for agriculture. There is great potential for using plant residues as biomass energy in agriculture. Biomass potential covers 14.4 thousand km^2 of the territory of the republic[21]. Thus, in the Aran region, there are favorable conditions for the placement of biomass facilities as a regional center using cotton boll resources formed after harvesting in cotton plantations that occupy a large area. In 2021, the cultivated area of cotton was 100.6 thousand ha, which was 571.2 thousand ha, and barley was 369.5 thousand ha, which is 2.1 million tons of cotton, 0.8 million for wheat, and 0.5 million for barley, which means a ton of stubble. At the expense of these sources, it is possible to create 300 MW of new generation capacities for bio-energy.

Chapter IV, called "**Prospects and Development Problems of Using Renewable Energy Sources in Azerbaijan**," analyzed the prospects of using RES in electricity supply, the role of stimulating factors, and state programs and international conventions regulating the use of energy sources. Thus, although the electricity production capacity in Azerbaijan is 7.9 GW, we have calculated the potential of RES at 48.5 GW, and it is possible to meet the energy demand of the country under the conditions of full use of this power.

To develop the RES in the country, the geographical location areas of the stations by sources were determined, and their total area was calculated. Thus, the area of hydropower potential in the country is 15.9 thousand km^2, wind energy 3.1 km^2, solar energy 9.5 thousand km^2, solar-wind hybrid 1.5 thousand km^2, and solar-hydro hybrid 8.2 thousand km^2 in total. 38.2 thousand km^2 have been determined.

Although the proportion of energy produced through RES in Azerbaijan was 10.3% in 2008, it has decreased to 5.8%, and the highest was in 2010 with 18.4%[22]. However, with the construction of

[20] Environment in Azerbaijan / State Statistical Committee of the Republic of Azerbaijan. – Baku: Statistical collection, - 2023. – 139 p. (In Aze.)

[21] Aliyev, R.N. Alternative energy and Ecology / R.N. Aliyev. - Baku: Teknur, - 2015. - 368 p. (In Aze.)

[22] Energy of Azerbaijan / State Statistical Committee of the Republic of Azerbaijan

three new solar and wind power plants projected for 2022, this figure will rise to 15%.

According to the preliminary assessment in the Karabakh region, the solar energy potential of the area is determined to be 7200 MW. In addition, the technical wind energy potential in the mountainous areas of Tartarchay, the Hekari River, Lachin, and Kalbajar is estimated at 2000 MW. Also, 41 small HPP stations in the region have become unusable, with a total capacity of 241.3 MW.

It is considered advantageous to build 16 small HPPs in 56 locations, which are located on small rivers effectively and efficiently, and on 27 rivers economically. Examples of these are small HPPs with a capacity of 30 MW in Ismailli, Guba, and Zagatala, 124 MW in the Oguz region, and 60 MW in the Sheki region.

The construction of Ordubad, 15.6 MW Tivi, and Marazad HPPs on the Araz River in Nakhchivan is important for the energy security of Nakhchivan. In addition, there are great prospects for the reconstruction of the 4.4 MW Kalbajar-1 small HPP and the Mingachevir HPP, and the construction of Tovuz and Ordubad HPPs on the Lev River.

The development of agriculture, especially cotton and grain farms in the country, creates favorable conditions for investment in energy production using biomass. Thus, in 2021, 336.8 thousand tons of cotton were supplied from 100.3 thousand hectares of land in our republic[23]. In 2021, the total grain cultivation area was 989.1 thousand ha, and the total harvest was 3257.1 thousand tons. There are great potential opportunities for building 20 MW bio-energy plants in seven locations in the lowland region.

The basis of RES development is the investment environment for the construction of stations. For this purpose, a policy oriented towards the transition to a green economy should be carried out to develop alternative energy sources in the country by studying the

– Baku: Statistical collection, - 2023. – 164 p. (In Aze.)

[23] Agriculture of Azerbaijan / State Statistical Committee of the Republic of Azerbaijan. – Baku: Statistical collection, - 2022. – 774 p. (In Aze.)

international experience. These include support with tax incentives for the use of clean energy in various areas and subsidies that encourage the use of RES in environmentally harmful production areas.

For the sustainable development of RES, a more efficient result can be achieved by providing long-term low-interest loans (up to 2.5%) with promotional methods. Examples of these are the promotion activities conducted by AREA regarding the application of RES in the energy supply of Samukh Agro complexes and the production of bio-energy using the waste generated there.

Agreements on climate change in Azerbaijan to reduce greenhouse gases released into the atmosphere form the legal basis for ensuring environmental safety and participating in solving environmental problems. The country has joined 15 other international conventions in environmental protection; besides the main obligations it has taken within the framework of Irena, the Clean Development Mechanism (CDM) of the Kyoto Protocol, and the Paris Climate Agreement. These measures encourage increased investment in the country and the improvement of the legislative framework for the transition to green energy.

CONCLUSION

1. Solar energy. To efficiently use solar energy resources in the republic, the most suitable areas are the Nakhchivan and Absheron regions, and the total usable area is 1016.8 km^2. 11% (109.2 km^2) of optimal regions are in high power (Gulüstan, Diza, Yaychi, etc.), 28% (284.6 km^2) are in medium power (Uçuncü Agalı, Zira, Sangachal, etc.), and 61% (623 km^2) is divided into 3 groups with low energy (Khoylu, Zanjbar, Khachinabad, etc.). 40 sites with high, medium, and low suitability levels for the placement of solar photovoltaic plants have been identified. The total electricity production capacity of these areas is 48.5 GW, and electricity production is calculated at 55.2 billion kWh.

2. Wind energy. Because of the analysis carried out in the ArcGIS program using the "GMOs-Merra 2" and "Global Wind

Atlas" databases, it was determined that the highly useful area (Caspian coast of Khizi district, Shuban, Pirallahi, Chilov, etc.) is 0.33 thousand km^2. The wind energy potential areas of Azerbaijan are weak (2-4 m/s, 2.66 thousand km^2-45.19%), moderate (4-5 m/s, 1.72 thousand km^2-29.17%), and good (5-7 m/s, 1.51 thousand km^2-25.64%). They were grouped into 3 classes, and the most optimal locations were determined. The total energy production by us through stations in these areas was calculated to be 3.6 billion kW.

3. Bioenergy. Because of the analysis of biomass reserves in Azerbaijan, it was determined that only 3.4% of the 133,000 tons of total waste with significant potential as a source of bio-energy is used. With full use of this resource, it is possible to build bio-energy plants with a production capacity of 300 MW. Thus, the use of 2581.2 thousand tons of household waste as biomass every year in the republic is of great importance both in terms of economic and ecological cleanliness.

4. Hydropower. Hydropower resources in Azerbaijan and 17 rivers with energy potential for obtaining electricity from them were analyzed. It was determined that there are suitable indicators for the installation of HPP in 27 locations on these rivers. These include Balakenchay, Talachay, Kumrukchay, Ayrichay, Gudyalchay, Shamkirchay, Hekari, Bargushad, iron-bearing, etc. rivers. With a projected capacity of 365 MW, these plants can produce 496.4 million kW of electricity per year.

5. Geothermal energy. In accordance with the criteria for the establishment of geothermal power plants, it was determined that thermal waters can only be used as a source of heat in the republic. Because the water temperature of 80% of wells is around 400°C and the volume of thermal water reserves is 245.6 thousand m3/day, the density of thermal waters in the Cuba-Khachmaz, Nakhchivan, and Lankaran regions is 1.19 km^2 at 300°C, which is equal to 43 MW in energy equivalent. This is a weak indicator and constitutes 0.5% of the country's total production capacity.

6. To ensure the development of individual use of renewable energy, subsidies should be given to green energy in the republic,

campaign events should be organized for direct and indirect support, environmental tax reforms should be carried out, fines should be applied for environmental pollution, and an appropriate legislative framework should be created.

Recommendations

1. There are 11 residential houses on average in 265 settlements in the Republic where natural gas extraction is technically impossible or economically unprofitable, and it is considered appropriate to build energy equipment according to the energy reserves of these areas.

2. The country's solar energy has a higher potential than other sources. Thus, the total potential of PVs is 48.5 GW, and energy production is 55.2 billion kW, which is twice as much as the country's electricity demand. 5.2 GW of this potential is located in Nakhchivan MR, where we propose to transform the region from an energy-importing to an energy-exporting region with solar energy.

3. The technical potential of small HPPs in Azerbaijan is determined to be 5 GW, which means, 4508 billion kWh of hydro energy production on all small rivers. The construction of small HPPs in the country would be more economically efficient, and profitable in terms of investment profitability and environmental impact, as opposed to large HPPs.

4. The bio-energy potential of crop production (cotton, wheat, and barley) and the animal husbandry complex in the Republic was calculated to be equivalent to 1408 MW in total. In the country, 2.1 million tons of cotton straw, 0.8 million tons of wheat, and 0.5 million tons of stubble from barley are obtained from the cotton cultivation area. In 2021, the number of cattle in the livestock complex was 2648.8 thousand, and the number of sheep and goats was 7899.7 thousand. The region where biomass is more concentrated is the Aran economic region, where we consider it necessary to build bio-energy and biofuel production stations to use labor resources.

5. From 2022, domestic energy tariffs (1 kW) for RES are 0.057 (0.055 for wind) and 0.08–0.013 AZN for thermal power plants. In this price range, RES is not competitive compared to conventional

energy sources. For this purpose, we suggest that the energy sales tariffs for the individual use of RES and the development of entrepreneurial activity based on the sale of energy should be appropriate. In this direction, we recommend the creation of a legislative framework in the country for the adoption of incentive programs, the allocation of funds on preferential terms to those who use RES, and the guarantee of buying the produced energy at a higher price.

The main content of the dissertation is reflected in the following articles and theses of the author:

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Address: AZ1148, Baku city, academician Zahid Khalilov 33. BSU, main building.

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