RENEWABLE ENERGY IN THE REPUBLIC OF ARMENIA

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Greater independence of domestic energy systems is quite important for the sustainable development of the Republic of Armenia. In Armenia's context this implies reduced dependence on imported fuel, which, in its turn, will have a positive impact on Armenia's trade balance, increased competitiveness on the international arena and security.

High importance is attached to the issue of revealing the renewable energy potential and its efficient application in the economy. The article provides an analysis of solar, wind, small hydro, biogas and hydrogen energy potential, demonstrates the development trends and application prospects thereof in Armenia, as well as presents the organizations and companies functioning in this sphere, and their achievements. The article also refers to the projects that are significant for the development of various renewable energy sources.

The development of renewable energy sources is of primary importance for the Republic of Armenia (RA) that lacks own fuel and is subjected to political blockade. Thus, in terms of renewable energy hydropower, biogas, solar and wind energy possess a significant potential. Despite high costs, research and development of hydrogen energy and its applications is currently underway in Armenia.

The drivers for development of renewable energy appeared in the 1970s in the light of the severe global energy crisis and its negative effects on economies. As a result, in 1975, the developed countries devised and introduced a number of programs concerning both the introduction of renewable energy sources to the economy and energy saving. In accordance with the results of the 1992 UN Conference on Environment and Development held in Rio de Janeiro and the 2002 World Summit on Sustainable Development in Johannesburg, a number of environmental conventions focusing on the problem of air pollution have been developed [1]. The promotion of alternative/renewable energy development and its

application in the economy was signified.

The RA has signed the Rio Declaration and most of its addenda, the Johannesburg Summit resolutions, has ratified the United Nations Framework Convention on Climate Change (UNFCCC, May 1993) and the Kyoto Protocol (KP, December 2002) [2, p. 67]. In October 1998, Armenia presented the First National Communication under the auspices of the UNDP [3]. In 2007, the RA Government, assisted by the United States Agency for International Development (USAID), adopted the National Program of the Republic of Armenia for Energy Saving and Alternative Energy [4].

The creation of the legal framework and its efficient enforcement are major prerequisites for renewable energy (RE) development. In the RA, the November 9, 2004 Law on Energy Saving and Renewable Energy can be regarded as the main legal act on the RE [5].

According to the Article 1, the purpose of the law is defining the principles of the state policy on development of the energy saving and renewable energy and the mechanisms of the enforcement of those aimed at:

- Strengthening the economic and energy independence of the Republic of Armenia;
- Increasing the economic and energy security and energy systems safety level of the Republic of Armenia;
- Establishment and development of new industry infrastructure and organization of services promoting energy saving and renewable energy;
- Reduction of adverse technogen impacts on the environment and human health.

For a country like Armenia with almost no fossil fuel resources of its own, in unfavorable geopolitical conditions and economic blockade, the integration of energy-related legal acts and norms in a single law allows reinforcing Armenia's energy independence and security in the future. In this respect the importance of both on energy saving and renewable energy development prospects in the Republic of Armenia is stressed.

Some favorable economic effects of RE development in Armenia are as follows:

1. reliable and affordable power supply which is possible by means of both small hydropower plants, and solar/wind energy;
2. reduction of the negative impact caused by the imported fuel price fluctuations in the international market;

3. reduction of the negative impact on the RA environment caused by traditional fuels, in accordance with the above mentioned international environmental commitments, that will also mitigate the adverse effect of hazardous emissions on the health of population,
4. creation of new jobs and attraction of new investments, as well as the development of new businesses will contribute to the state budget revenue increase;
5. taking into account the high demand for the RE in the international markets, the development of this sector in Armenia would boost the export potential of the Armenian companies.

In addition to the state agencies, a number of international organizations and programs are currently involved in the RE sector of Armenia:

- UNDP/GEF/ARM/95/G31/A/1G/99 (Armenia–Country Study on Climate Change (Phase II); the main purpose is the tackling problems of technologies required for abatement and adaptation to climate change, as well as the promotion of clean energy generation.
- UNDP/GEF/ARM/98/G41/A/1G/99 (Removing Barriers to Energy Efficiency in Municipal Heat and Hot Water Supply); the main purpose is the development of rational strategies and their introduction to the area of energy saving.
- TACIS (Energy Saving and Management); specializes in energy saving software development.
- TACIS Support to the Energy Policy of Armenia; the purpose is to assist the RA Government in energy-related problems and to establish an Internet portal dedicated to renewable energy.
- Advanced Engineering Associates International – USAID (Energy Efficiency, Demand Side Management and Renewable Energy Resources); the purpose is to promote the energy efficiency and development of renewable energy in Armenia;
- Alliance to Save Energy – USAID (Municipal Network for Energy Efficiency Program) the main purpose is to establish the Armenian energy saving board which will assist the RA Ministry of Energy under the Law on Energy Saving and Renewable Energy.
- R2E2, Armenian Fund for Renewable Resources and Energy Efficiency which implements loan and grant projects aimed at the development of energy saving and renewable energy.
- EnergyInvest PIU, etc.

Also, a number of private companies operate in this sector in Armenia that will be discussed later herein.

In Armenia, the RE potential can be categorized according to the following sectors:

- Hydropower
- Solar Energy
- Biogas
- Wind Energy
- Geothermal Energy
- Hydrogen Energy.

Hydropower Potential

The development of the hydropower potential in Armenia involves construction and operation of small and medium-size hydropower plants which has recently gained great momentum. This is mainly determined by favorable conditions for the construction of small hydropower plants in Armenia, namely, favorable tariffs on the power generated by the small hydropower plants and guaranteed 15-year power purchase (for small hydropower plants built on natural water flows AMD 18.274 or USD 0.053 /kWh). According to the report of the RA Ministry of Environment Protection at the 3rd International Renewable and Clean Energy Conference, in 2007 small hydropower plant indicators in Armenia are as follows (see Table 1) [6].

Table 1

Indicator	Unit of Measure	Functioning as of 01.09.2006	Under construction as of 01.09.2006	Total expected by 01.01.2011
No.	-	7	31	38
Capacity	kW	12500	93129	105629
Annual power generation	million kW	55.5	352.3	407.8

According to the National Program on Energy Saving and Renewable Energy of Republic of Armenia developed with USAID assistance, the available water resources in the RA (the rivers Debed, Aghstev, Akhurian, Hrazdan, the Lake Sevan, etc.) and their potential are sufficient for 313 small hydropower plants

with annual power output of 737.38 million kWh [4, p. 36]. According to this program, it is planned to build the Meghri and Loriberd hydropower plants by 2020, with 140 MW and 60 MW capacities respectively; with cumulative generation of 1.012 million kWh/per year.

Although the operation of small hydropower plants as a source of renewable energy does not lead to hazardous waste and green house gas emissions, it still has a significant negative impact on water ecosystems and, particularly, on the fish stock in natural water flows. This effect can be mitigated by the water intake limitations currently enforced by the government (environmental water releases and amounts of irretrievable drafts from surface water resources are defined in the May 22, 2003 RA Government Resolution No. 592-N), although presently the latter serve exclusively sanitation purposes.

As for large hydropower plants, it should be noted that their negative impact on the environment is much greater, and in terms of accepted international norms, unlike the small hydropower plants, the former ones are not even considered a RE source.

Solar Energy Potential

The Sun is the most widely used source of clean and inexhaustible energy. Over the past years the companies developing solar energy have become profitable, competing with those dealing with conventional energy both in terms of economic returns and safety. Solar energy has been broadly used both in water heating systems to generate thermal energy and electric power through photoelectric converters.

Table 2

Area	Radiation index, kWh/m²
Yerevan	1647.2
Gumri	1624
Sevan	1670
Martuni	1740
Jermuk	1682
Kochbek	1786.4

Armenia has a significant advantage in terms of solar energy: the country is situated in the proximity of subtropical zone; most provinces have favorable climatic conditions that make wide use of solar energy possible. The potential generation of solar energy can be described by annual solar radiation indices under actual weather conditions (Table 2) [4, p. 37-38].

According to the 2007 USAID program, the capital investment cost for a solar photoelectric power station in Armenia is around $2.520 for 1kW capacity.

The technically and economically justified solar energy capacity under 100 MW can be utilized by 2020, with total $250 million investment program. It has to be mentioned that for a solar energy plant with 100 MW power capacity the annual electricity generation would be 270 million kWh, reducing the yearly CO_2 emissions by 42.960 tons.

Assuming the estimated payback period for solar energy plants to be 13.5 years (for $0.07 kWh tariff in equivalent AMD), and taking into consideration the 25% cost reduction during a 10-year period due to the technological progress, the growth of solar energy use can be presented as follows: by 2010 – 10 MW, 2015 – 25 MW, and 2020 – 65 MW.

The following enterprises are involved in solar energy in Armenia: SolarEn LLC, Heliotekhnika laboratory at the State Engineering University of Armenia, ViaSolar, and Technokom/Sun Energy.

SolarEn LLC is specialized in manufacturing solar water heaters and, in addition, installs photovoltaic units. Solar photovoltaic (PV) modules are mostly imported. In the recent years, SolarEn LLC has installed a number of solar water heating systems of various capacities.

Technokom/Sun Energy also specializes in manufacturing and installation of solar water heaters. During its operation the company has installed about 2000 m^2 of water heating panels in Yerevan (Northern Avenue, Nork Marash hospital, etc.) and in various provinces of Armenia (50-60 small water heating units.) The company has also implemented monitoring of the efficiency increase of various water heaters[1].

So far, there is no solar PV panel manufacturing business in Armenia. Although since 1993 the Heliotekhnika Laboratory of the State Engineering University of Armenia has been working on the development and installation of photovoltaic modules, these activities are mostly experimental [7, pp. 97-101]. The efficiency of electric and thermal conversion of solar energy has been studied. The work is mainly focused on increasing the concentration of solar irradiation per

[1] Source: interview with Mikhail Martirosyan, President of *«TECHNOKOM»*.

unit of surface. Heliotekhnika laboratory has achieved 16% efficiency of the crystalline silicon PV cells. The solar panel elements are mostly imported.

The Heliotekhnika Laboratory has assembled and installed 2.1 kW PV system on the roof of St. Sarkis church in 1995; 2.5 kW solar unit on the roof of Hayastan movie theater in 1997; on apartment blocks, (350 W); in 2003 a 5 kW PV system was installed on the roof of the American University of Armenia. The monitoring of the latter has shown that it generates more than 5 kW power as a result of improved efficiency.

The Heliotekhnika laboratory receives base financing from the state. The laboratory also cooperates with the US-based Amonix Inc. for establishing a solar PV panel manufacturing business with the assistance of the company upon completion of the R&D work.

In 2006, ViaSolar installed a solar converter with a water pumping system, so far the first one in Armenia and the region[1]. The maximum capacity of the solar power plant is 5 kW and the annual average daily output is 3 kW. ViaSolar provided the system with an automatic sun tracking mechanism which makes the operation of the unit more efficient. Currently, the work is focused on the increased concentration of sun beams. The generated energy is mainly used to pump groundwater for a reservoir.

It also has to be noted that in 2007, H_2 ECOnomy installed a 4 kW system wherein solar energy is converted into hydrogen by the electrolyzer, which is then utilized by a fuel cell based backup/uninterruptible power supply system to generate electricity.

Academician Paris Herouni also works on solar energy applications to design, build and operate a new solar plant. At the 2007 International Renewable and Clean Energy Conference P. Herouni made a presentation on the new 100 kW solar power plant AREV-1 [8, p. 8]. The plant is currently built at the Aragats Scientific Center of the Radiophysics Research Institute. The AREV solar power plants are based on heat absorption of reflected sunbeams and rotating a compressor by the heated air to generate power.

Biogas Potential

Generation of energy from biogas in Armenia is in its initial stage, although lately it has gained some momentum. A number of foreign companies are interested in this technology. The interest in biogas as fuel is determined by its relatively short payback period of 7-8 years.

[1] Source: interview with Khachatur Khachikyan, Deputy Director of Viasphere Technopark.

In 2002-2003 two biogas plants were built. The methane production capacity of the first one is 50 m^3 with potential of expansion up to 3000 m^3. The methane capacity of the second one is 25 m^3.

Among the companies developing biogas applications is SolarEn LLC.

So far, the program for evaluation of biogas potential and plant construction at the Nubarashen city landfill is the main operational commercial project for power generation from biogas. In 2001 the Japanese company Shimizu jointly with the RA Government and Yerevan Municipality started to work on several projects in accordance with the CDM (Clean Develompent Mechanism) scheme. One of the projects involves generating methane from the Nubarashen city landfill and utilizing it as fuel. According to the 2004 UNDP and UNFCCC document, the loan repayment period is 16 years [9, p. 2-3]. The main purpose is the aggregate reduction of greenhouse gas emissions during this period for estimated $2.16*10^6$ ton-CO_2, as well as to contribute to the improvement of environment, reduce fire risks, etc. Three Japanese companies are involved in the project implementation (Shimizu, Hokkaido Electric Power and Mitsui) together with Municipality of Yerevan City, and the local authority owning Nubarashen landfill site.

Also, pig, cattle and poultry farms possess a great potential of biogas generation from manure. Currently, the landfills in other cities of Armenia are monitored in order to evaluate the available methane resources, and their potential for power generation is analyzed.

According to the 2007 USAID program, the RA biogas potential for 2006-2020 was estimated as follows: an investment of $34.17 million would provide for generation of 38.34 million m^3 of biogas annually, which will reduce greenhouse gas emissions by 544.6 thousand tons per annum in CO_2 equivalent [4, p. 37].

Biomass and the fuel produced of it are also worth mentioning. Biomass is the mass of specially cultivated crops or the residue left over after their harvesting, which can be processed to produce fuel. For example, ethanol (alcohol) and biodiesel obtained from biomass are used in some countries as fuel or fuel additives for internal combustion engines. As far as we know, currently no actual work is done in Armenia in this area, although the idea to study the potential of liquid bio-fuel has been voiced many times.

Wind Energy Potential

Wind energy in Armenia also is in the initial development phase. Despite Armenia's significant wind energy potential and the interest of international companies, most of the wind power plant construction projects have not been implemented yet.

Wind energy monitoring and resource assessment have been implemented in the country since 1999. In particular, following programs were aimed at wind energy potential evaluation [10, p. 39]:

- The monitoring program conducted by SolarEn in the Sotk (Zod) mountain pass area,
- The survey conducted in 4 regions of Armenia by the NREL/USAID program (Karakhach mountain pass, Aparan, Gagrin, and Vorotan mountain pass),
- The program implemented in 5 regions of Armenia by the ArmNedWind (Karakhach mountain pass, Selim mountain pass, Pushkin mountain pass, Artanish and Arpilich),
- The Iranian program, at Pushkin pass and Sisian mountain range,
- The KfW program, which evaluated the wind energy potential was in Goris district,
- Currently, the TACIS/DEM monitoring project is being implemented.

Sponsored by the RA Ministry of Energy and the USAID, ZodWind company compiled the Wind Atlas of Armenia jointly with the US National Renewable Energy Laboratory, in order to evaluate the wind energy potential. In addition, the evaluation of the regions with wind energy prospects is nearly completed, and the efficiency assessment of wind farms to be built in these areas is currently in progress under a KfW program.

The first 2.6 MW wind farm in the region has already been commissioned at the Pushkin pass, which was built within the framework of an Armenian-Iranian inter-state program. The facility generates about 5 million kWh annually. It should be also noted that commercial projects for the construction of 20 and 80 MW wind mills are being drafted.

Despite the interest of foreign companies in the development of wind energy in Armenia, so far no significant investments have been made in this sector of renewable energy. First, this technology is rather expensive: according to the 2007 program developed by the USAID, in Armenia the cost of installed power capacity of wind power plants is around $1.000 - $1.300 per kW. For having 100 MW wind power capacity installed before 2020, it is necessary to invest $100-130 million [4, p. 39]. State support is also needed for the development of wind energy, since the sector faces both technical and economic issues.

Geothermal Energy Potential

As a country situated in a volcanic zone, Armenia has significant geothermal resources that can be utilized in the renewable energy sector for energy generation.

Geothermal potential studies started in Armenia back in 1984 in Sisian area where the temperature of surface water reaches 32°C. During the investigations, geothermal sources as hot as 99°C were discovered at the depth of 920 m.

The geothermal studies revealed both fissure-vein (Jermuk: 64°C, Hankavan: 42°C, Arzakan: 54°C, Sisian: 45°C, Martuni: 52°C) and bedded (Azatavan: 42°C, 2600 m, Sevaberd: 83°C, 3100 m) deposits of thermal waters. Their main parameters have been collected (temperature, discharge, mineralization, etc.) and the obtained data ware analyzed [11, p. 62].

In 1998, within the framework of Yerevan Geothermal Pilot Project funded a World Bank grant, the Armenian-American geological survey entity drilled Azat-1 borehole in Garni area. As a result, a bedded deposit was discovered at the depth of 2280-2285 m. In 2000-2001, the Russian LUKOIL oil company determined the parameters of Azat-1 deposit (temperature, pressure, mineralization, etc.). However, the works were suspended for technical reasons. Later, the research was resumed by the Geoenergetica enterprise of the RA Ministry of Energy and as a result, the geothermal distribution in the area and its orientation towards Yerevan were revealed.

Nevertheless, there are no special projects in Armenia that would focus on geothermal energy as renewable energy resource.

Hydrogen Energy Potential

Hydrogen energy development is very topical worldwide and is supported by the public and private sector. This interest in hydrogen energy is determined by the following distinctive features:

- Used in fuel cells, hydrogen appears to be the only renewable fuel that can potentially displace the conventional engines in the vehicles, which are the main contributors to the air pollution (carbon dioxide accounts for 76.6% of air pollution in the US owing to the increasing number of automobiles);
- Hydrogen can be an efficient storage medium for the excess energy generated from renewable and traditional sources; later this energy can be used when needed;
- Unlike other renewable or conventional energy sources, fuel cells offer an extremely broad scope of applications. They can replace or supplement batteries, engines, and small power plants, serve a source of electric power

for portable devices (e.g., cell phones, videocameras) as well as vehicles, residential houses, industrial buildings, satellites, and many more;

- Even with the current high prices, the hydrogen fuel cell based uninterruptible power supply systems can compete with the conventional batteries both in terms of cost and size when the need for backup power exceeds 2-4 hours.

Fuel cell is a generator of electricity based on electrochemical reaction between hydrogen and oxygen. This is an environmentally sound process, because other than direct electric current, only pure water as waste is produced.

In principle, fuel cells can be considered a renewable energy source only if the hydrogen used by them is obtained from renewable sources. In this sense the storage of wind and solar energy in the form hydrogen is signified, which helps to overcome the intermittent nature of these sources. The excess electric energy generated by a wind turbine or photovoltaic module can be used for electrolysis, and the obtained hydrogen stored for continuing electricity generation by fuel cells in the absence of wind or sunlight.

H_2 ECOnomy Closed Joint Stock Company is the only enterprise in Armenia and the entire region that designs and commercializes fuel cells. Conceived in 2000, H_2 ECOnomy was incorporated in 2002 as an independent company that conducts research, manufacturing and commercialization of hydrogen proton exchange membrane fuel cell (PEMFC) stacks, components and complementary systems. The company's goal is introducing and developing innovative renewable energy resources in Armenia, establishing a production of fuel cells and reaching the global markets with these hi-tech products.

H_2 ECOnomy has successfully developed and tested 0.5 kW and 1 kW net output fuel cell based uninterruptible power supply (UPS) extender systems [12]. Presently, H_2 ECOnomy develops a 5 kW fuel cell backup power system that will enable to significantly extend the operating time of the conventional battery based UPS systems.

Supported by the US Department of Energy and in partnership with the US National Renewable Energy Laboratory, H_2 ECOnomy CJSC in 2007 created and operated a new model of a solar hydrogen system. The purpose of the project was to demonstrate how the renewables can efficiently complement each [13].

Thus, it can be concluded that the use of renewable and alternative sources in Armenia is miniscule and plays virtually no role in the country's energy mix.

This is at least regrettable for Armenia that appears to have a significant

potential and favoring natural conditions for developing renewable and alternative energy sources and at the same time is strongly dependent on imported fuels.

Undoubtedly, the Armenian authorities have taken certain measures in the recent years aimed at establishing the legislative and legal framework, however, no significant progress is recorded as far as the adoption of subordinate legislation and practical support is concerned.

International and commercial organizations also work on the development of renewable energy; however, the outcome so far is not too encouraging. In particular, presently most biogas, wind and geothermal projects still remain on paper. Moreover, despite the 1990s energy crisis in Armenia and still quite fresh memories of its social, economic and psychological consequences, the awareness of renewable energy sources and potential benefits of their use appears to be minimal in our society.

We believe the state must create incentives for the development of renewable energy the way it is practiced worldwide. It would be particularly helpful to organize public awareness campaigns and explain to the society the advantages of alternative/renewable energy, the benefits stemming from them and, of course, their positive impact on the environment and human health. It is also desirable to encourage the renewable energy companies and grant them certain privileges, especially, considering that many of them can potentially enter the global markets with their advanced technologies. These companies often face project funding and profitability issues, and in this respect the proper development of mechanisms for the attraction of foreign investment and favorable conditions for entrepreneurial activity is crucial in this sector. Indeed, the role of the state in this sector is also very important. As it was mentioned above, nearly all the sources of renewable energy in Armenia have a great application potential; in case of adequate funding they could significantly contribute to the country's power supply mix and energy independence.

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Reference Sources and Literature

1. "Rio Declaration on Environment and Development" UNEP, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=78&ArticleID=1163 and "Results of G8 Environment meeting" Summary: April 15, 2002, http://www.europa-eu-un.org/articles/en/article_1301_en.htm

2. *Marjanyan, A.,* "The Potential and Perspective of Renewable Energy Development in Armenia." Renewable Energy in Armenia: Reality and Perspectives, Conference Proceedings, Yerevan, 2003.
3. First National Communication of the Republic of Armenia under the United Nations Framework Convention on Climate change. Ministry of Environment Protection RA/ UNDP, October 1998.
4. National Program on Energy Saving and Renewable Energy of Republic of Armenia, RA/USAID 2007
5. RA Law on Energy Saving and Alternative Energy, November 9, 2004.
6. *Gabrielian, A.,* "The Problems of Nature Protection in the Context of Renewable Energy Development in Armenia," RA Ministry of Nature Protection, The 3rd International Renewable and Clean Energy Conference, June 27-29, Yerevan, 2007.
7. *Panosyan, Zh., Marukhyan, V.,* "The New Technologies for Production of High-Performance and Competitive Solar Power Stations," Renewable Energy in Armenia: Reality and Perspectives, Conference Proceedings, Yerevan, 2003.
8. *Herouni, P.,* "The New Type of a Powerful Solar Plant "AREV"", Scientific-Research Institute of Radiophysics, The 3rd International Renewable and Clean Energy Conference, June 27-29, Yerevan, 2007.
9. "Nubarashen Landfill Gas Capture and Power Generation Project in Yerevan" Clean Development Mechanism Project Design Document Form (CDM-PDD) Version 02 - in effect as of: July 1, 2004, UNDP/UNFCCC.
10. *Lalayan A.,* "Problems Associated with Implementation of Grid-Connected Wind Energy Projects in Armenia", The 3rd International Renewable and Clean Energy Conference, June 27-29, Yerevan, 2007.
11. *Aghabalyan A.,* "The prospects of geothermal energy development in Armenia," Department of Fuel and Energy Underground Resources of Ministry of Energy of RA, Renewable Energy in Armenia: Reality and Perspectives, Conference Proceedings, Yerevan, 2003.
12. *Odabashian V., Manoukian A.,* "A Hydrogen Outlook from a Transition Economy: Development of Hydrogen Fuel Cells by H_2 ECOnomy in Armenia". The International Seminar on the Hydrogen Economy for Sustainable Development, Reykjavik, Iceland, 28-29 September 2006.
13. www.h2economy.com