ASSESSMENT OF RENEWABLE ENERGY POTENTIAL IN ARMENIA

2017 UPDATE

ASSESSMENT OF RENEWABLE ENERGY POTENTIAL IN ARMENIA (UPDATE)

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Contents

LIST OF ACRONIMS

AMD	Armenian Dram	PSRC	Public Services Regulatory Commission
ANPP	Armenian Nuclear Power Plant	RES	Renewable Energy Sources
CANDU	Canada Deuterium Uranium	RoA	Republic of Armenia
CC	Combined Cycle	SHPP	Small Hydro Power Plant
CCGT	Combined Cycle Gas Turbine	TPP	Thermal Power Plant
EBRD	European Bank for Reconstruction and Development	USAID	U.S. Agency for International Development
EaP	Eastern Partnership	VVER	Water-Water-Energetic Reactor
EE	Energy Efficiency	VAT	Value Added Tax
ENA	Electric Networks of Armenia CJSC	WB	World Bank
EU	European Union	MJ	Mega joule (10^6J)
GoA	Government of Armenia	MW	Megawatt (10^6W)
HPP	Hydro Power Plant	PV	Photovoltaic
KfW	Kreditanstalt für Wiederaufbau ("Reconstruction Credit Institute"), Germany	MOEINR RA	Ministry of Energy Infrastructures and Natural Resources of RA
toe tce	tonne of oil equivalent = 10Gcal tonne of coal equivalent= 7 Gcal=29.3GJ	1 kWh = 3.6MJ	TWh = 0.086 Mtoe, 1 toe = 41.868 gigajoules (GJ)

Exchange rates used in this paper: 1 USD = 480 AMD, 1 Euro = 520 AMD (as of January, 2017)

1. INTRODUCTION

The issues of renewable energy sources development and improvement of energy efficiency play an important role in RA. The law of RA “On Energy Saving and Renewable Energy” was adopted in 09.11.2004. “Energy sector development strategy within the context of the RoA economy development” was adopted by the GoA on June 23, 2005 and updated in 2007. “National Program on Energy Saving and Renewable Energy” was developed and approved by protocol decision by the GoA as of 23.6.2007. Unfortunately targets for solar and wind use are not reached.

The Armenian government adopted the National Energy Security Concept in 2013. It envisages fuel diversification mainly through renewables, nuclear power, building up fuel reserves, increasing its electricity generation capacities, improving energy efficiency, diversification of primary energy resources and import/export routes, regional integration and cooperation.

In 2011, “Renewable Energy Roadmap for Armenia” was developed by Danish Energy Management A/S. “Scaling Up Renewable Energy Program, (SREP) Investment plan for Armenia [1] prepared by consortium of DH Infrastructure, Black&Veatch, SRIE (Armenia) became available for public in 2014. Assessments of unused RES potential (by technology, feasible) were done in their report.

The PSRC supports RE investments through feed-in tariffs (see Table 17). The Energy Law mandates that during the first 15 years of operations for small HPPs and 20 years of operation for other renewable energy sources, 100% of electricity produced from new RE stations must be purchased at fixed tariff levels. According to GoA decision as of September 8, 2011 the Small Hydropower Plant (SHHP) should have capacity 30MW or less, though, according to the law of RA “On Energy Saving and Renewable Energy”, HPPs with capacities 10MW or less were considered as Small HPP.

Current capacities and GoA planning of introduction of new renewable capacities in 2025 and 2036 according to Long-term (up to 2036) development pathways for RA energy sector [2] are shown below in the Table 1.

Table 1. Current capacities and GoA planning of introduction of new renewable capacities in 2025 and 2036 according to “Long-term (up to 2036) development pathways for RA energy sector”

Type of renewables	2015[1]	2025[2]	2036[2]
	Current Capacity (MW)	Cumulative Capacity (MW)	Cumulative Capacity (MW)
Solar (grid connected)	< 0.200	40	70
Wind	2.64	-	200
Geothermal	0	30	30
Small hydro	313	402	402
Large& Medium HPPs	960	1093	1223

[1]Data collected by author

[2] Data from [2]

In the end of 2016 GoA adopted new approaches to stimulate solar PV development and in its decision it proposed to consider to construct PV stations in Armenia with total capacity up to 110

MW. This new approach takes into account 80% reduction of prices on solar PV panels from 2011 to 2015 years. Feed-in-tariff on solar photovoltaic in the amount of 42.645AMD/kWh (VAT excluded) was introduced in November 2016.

Feed-in-Tariffs (excluding VAT) for Renewable Energy Sources are brought in Attachment 3 for 2011-2016 [Source: PSRC].

Residential electricity tariffs changes.

Effective since August 01, 2016 daytime residential electricity tariffs became 46.2 AMD/kWh and nighttime residential electricity tariffs – 36.2 AMD/kWh (approved by PSRC).

Since February 01, 2017, daytime residential electricity tariffs became 44.98 AMD/kWh and nighttime residential electricity tariffs – 34.98 AMD/kWh (approved by PSRC). Lower tariffs are introduced for socially vulnerable residential groups (40.0 AMD/kWh (day time) and 30AMD/kWh (night time)).

Table 2. Electricity production in Armenia in 2014-2015 [3]

Name of Power Plants	2014	2015	Difference, %
	TWh (%)	TWh (%)	
Armenian Nuclear Power Plant	2.46 (31.8)	2.79 (35.75)	+13.1
Thermal Power Plants	3.29 (42.4)	2.80 (35.9)	-14.8
Hydropower Plants, including small HPPs	1.99 (25.7)	2.21 (28.3)	10.7
Other sources (wind)	0.004 (0.05)	0.0037 (0.05)	-7.5
Total electrical energy	7.75 (100)	7.80 (100)	+0.6

2. HYDRO ENERGY POTENTIAL IN ARMENIA

Armenia’s rivers belong to the water basin of Caspian Sea and are tributaries of different orders of the Kura river. Separately stands the rivers flowing to The Lake Sevan from surrounding mountains. There are more than 200 rivers with length of 10km or more in Armenia. 73.5% of the territory of Armenia belongs to water basin of the Araks river – tributary of the Kura river. The theoretical potential for hydropower resources of Armenia has been estimated at 21.8 TWh/year. It includes 18.6 TWh/year for large and medium rivers, and 3.2 TWh/year for small rivers. Technically available potential is estimated around 7-8 TWh/year, and economically feasible potential – 3.2-3.5 TWh/year [4].

Large and medium HPPs

HPPs in operation. Hydropower sector includes Sevan-Hrazdan cascade of HPPs with capacity of 556 MW, and Vorotan Cascade of HPPs with total capacity of 404 MW. Both cascades of HPPS are now privately owned: the first one - by Russian company “International Energy Corporation” CJSC (RusHydro), the second one – by USA based company Contour Global.

Unused potential. Among the largest waterways of Armenia still unexploited are the Debed River with the Dzoraget tributary and the Arax River. The potential (not constructed) hydropower include: large HPPs with total design capacity of 270MW (Meghry HPP - 130MW, Loriberd HPP - 65MW, Shnokh HPP - 75MW) and annual average power generation of around 1.3 TWh; Medium-scale HPP (Pambak) with total design capacity of 20MW and annual average power generation of around 79 million kWh;

Table 3. Installed capacities of all HPPs, including small HPPs, in operation (as of December of 2015)

Name of power plants	MW
Sevan-Hrazdan cascade of HPPs	556
Vorotan cascade of HPPs	404
Small HPPs	313
Total	1293

Small HPPs

In 1991, "The Scheme of Development of Small Hydropower Engineering" was composed by Armhydroenergyproject Institute that revealed technical possibility to construct 371 small HPPs with total capacity of 392MW and annual power production of 1178 million kWh.

In 1997, according to "The Scheme of Small Hydropower Plants of Armenia" developed during joint project between CEEETA (Portugal) and Institute of Armhydroenergyproject, it has been envisaged to construct 325 small HPPs with total capacity of 274 MW and average annual electricity generation of 833 million kWh [4].

Of all 24 small HPPs constructed before 1957, 13 HPPs were privatized in late 1997, 8 HPPs – were written off. From 1997 to 2002 11 new HPPs have been constructed, 10 of them - privately. [5]. So, in 2002, 29 small hydropower plants were in operation with total capacity of 42.8 MW and average annual electricity generation of 107 million kWh (the Dzora HPP with capacity of 26.5 MW is not included in the list).

In 2008 "The Update of the Existing Scheme for Small Hydro Power Plants of the RA" was prepared by "Armhydroenergyproject Institute" CJSC by order of R2E2 Fund of Armenia (RENEWABLE ENERGY PROJECT GEF) [6]. According to this update, additionally 147 MW of Small HPPs was considered as feasible. In 2009 the Government of RA approved "Development scheme for small hydropower plants".

New "RA Hydropower development strategy program" was approved in 2011 by decision of GoA, that considered that most realistic is to evaluate total capacity of all small HPPs in future as around 400MW (without small HPPs to be located within Lake Sevan water basin) with annual electricity generation potential around 1TWh.

Electricity production by Small HHPs. As of December 31, 2015, 175 small HPPs were in operation with total capacity of 313 MW with designed average annual electricity production of 0.8572 TWh. In 2015 actual annual electricity production by small HPPs was 0.8399 TWh (in 2014 – 0.6889TWh) providing share of 10.7% in the total amount of annual generation of electricity. Moreover, 37 Small HPPs are under construction with designed capacity of 87 MW and designed annual electricity production of 0.310 TWh. That means that after completion of these small HPPs construction and commissioning there will be totally 212 small HPPs in operation with total capacity of 400 MW and designed annual electricity production of 1.14 TWh. For comparison purposes, in 2007 there were 52 Small HPPs in operation with total capacity of 64.4MW in Armenia.

Preliminary data for small HPPs as of December 31, 2016: number of SHPPs in operation 178, total capacity – 328MW, annual electricity production – 0.957TWh.

The share (in %) of all HPPs including small HPPs in total annual electricity generation from 2007 to 2015 is presented on Figure 1. The share of small HPPs was around 10.7% in 2015. To large extent the value of HPPs share is influenced by introduction of 2 new thermal power plants in 2011-2012.

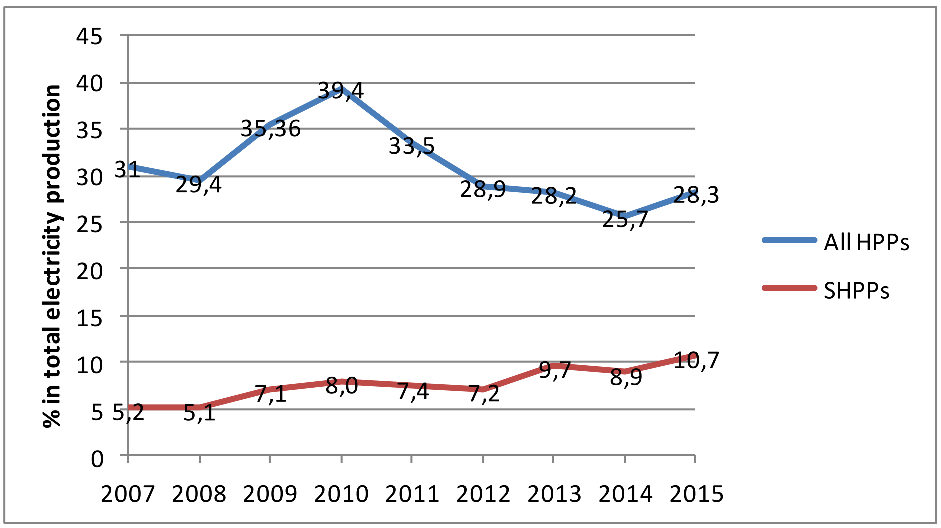


Figure 1. Share (in %) of all HPPs including small HPPs (upper curve) and share (in %) of small HPPs in total annual electricity generation from 2007 to 2015.

Several banks has provided loans at favorable rates for small HPPs construction. For example KfW provides financing and advisory support for construction and rehabilitation of privately-owned SHPPs. Under Phase 1, KfW supported 14 SHPPs through several commercial banks. Under Phase 2, KfW supported 20 SHPPs with a total capacity of 45 MW. Phase 3 includes up to EUR 40 million in financing SHPPs.

Some of constructed SHPPs raised significant environmental concerns in Armenia and that can be results that projects don't comply with environmental rules to be implemented with (inefficient fish passes, lack of updated data on water flows, improper designs). With that a lot of loans for Small HPPs constructions are provided from abroad. Currently, construction of small HPPs are not allowed within water basin of Lake Sevan (natural preserve), but the future of already constructed small HPPs over there is unclear.

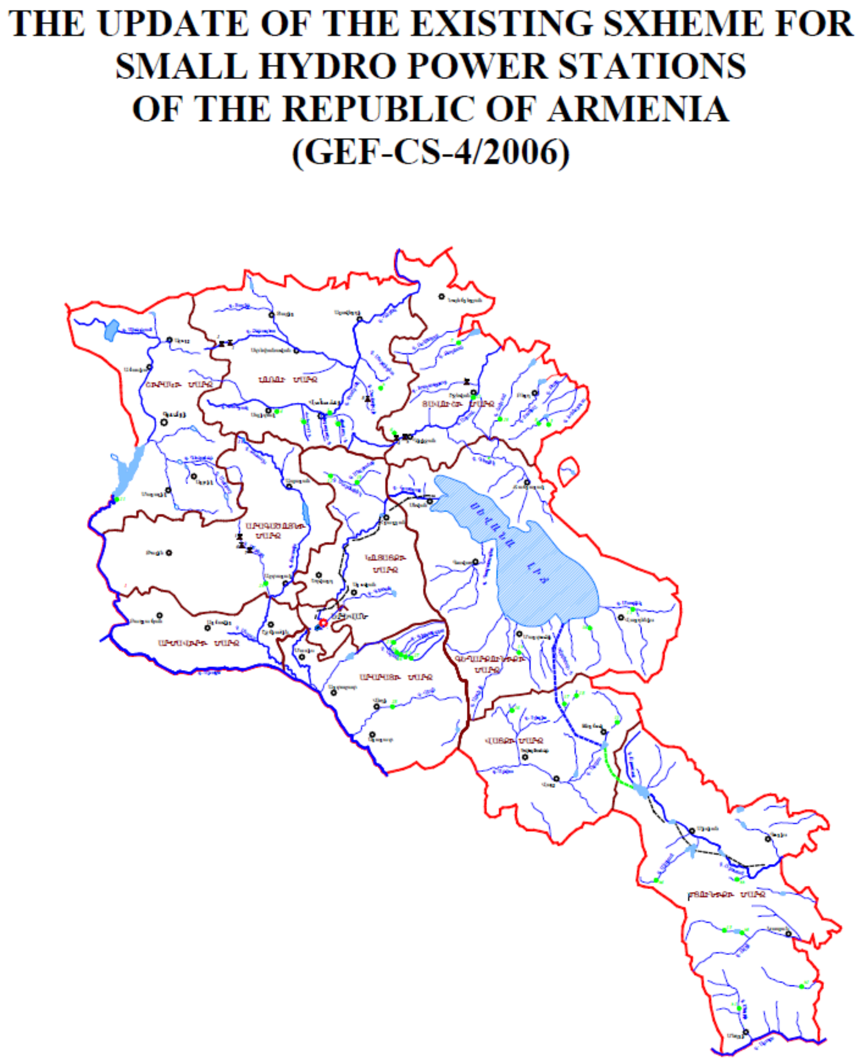


Figure 2. Map of Armenia with main rivers with indication of some small HPPs from The upgrade of the existing scheme for small hydropower stations of RA (2008).

During 2011-2014 the project "Sustainable Small Hydropower Development for Energy Security" was implemented by a consortium of Norwegian and Armenian partners, managed by Norsk Energi and funded by a grant from the Norwegian Ministry of Foreign Affairs. Project's aim: to improve the resource efficiency of small hydropower plants (SHPPs) in Armenia, and mitigate environmental and social impacts from construction of new SHHPs.

As we can see from Figure 1, the share of all hydropower in total electricity production even reduced within last 8 years from 31% to 28.3%, in spite of the construction of new small hydropower. This is because the reduced production from large hydro-power, where the power production is regulated by irrigation and energy needs as well as due to introduction of two CC thermal power plants (Hrazdan 5 unit - 445 MW, and Yerevan CCGT - 242 MW) in last 5 years.

3. SOLAR ENERGY POTENTIAL IN ARMENIA

There are very favorable natural climatic conditions in Armenia for solar energy use. Annual average value of sunshine hours is 2500 hours. Average annual flow of solar radiation on horizontal surface is 1720 kWh/m^2. For comparing purposes, in Central Europe this average value is 1000kWh/m^2, particularly, in Poland, Czech Republic, and Slovakia 950-1050kWh/m^2, in Hungary – 1200 kWh/m^2, in Bulgaria – 2000 kWh/m^2 [9].

On the territory of Armenia, actual annual average hours of sunshine (i.e. possible sunshine hours minus time period during which the sun is covered by clouds) depends on site of consideration and varies from 2000 to 2800hours/year [9] .This value constitutes more than 50% of possible sunshine hours. Actual sunshine hours for Yerevan are 2700, for Martuni -2750, for Ashtarak - 2837, for Vanadzor - 2019, for Idjevan - 1827 hours. For the territory of Armenia as a whole, actual annual average hours of sunshine are equal to 2500 hours [9]:Under different conditions on the territory of Armenia, annual average incident solar total irradiation (i.e. irradiation integrated within year per unit of horizontal surface) is from 140$kcal/cm^2$ to 155$kcal/cm^2$. There are some discrepancies in data received from different authors. The distribution of the annual total solar irradiation per 1m^2 of horizontal surface on the Armenian land area is given in Fig. 3 [10]. As can be seen from Fig. 3, for at least of one quarter of the territory of Armenia annual average solar total irradiation is 1850 kWh/m^2 or more.

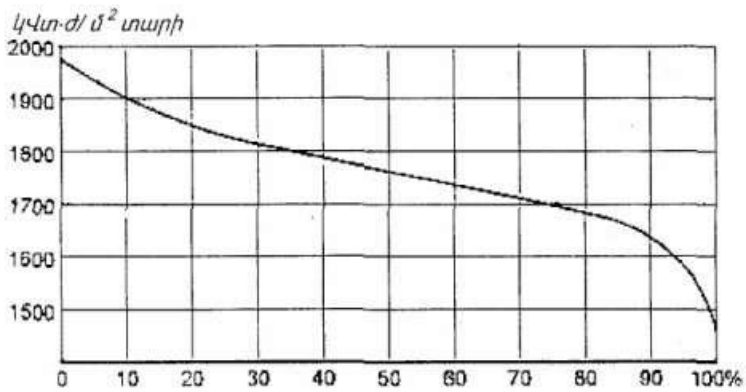


Figure 3. Distribution curve of the density of annual energy flow of total solar irradiation per 1m2 of horizontal surface

11-15% of annual average solar irradiation falls on winter months. This value grows as the elevation of the site increases. 60-65% of energy of total radiation is the energy of beam (direct) radiation.

Data on mean daily total (E_{tot}) and diffused (E_{dif}) irradiation (MJ/m_2) and ambient temperature T_{amb} (^0C) averaged for month as per months are shown for Yerevan in Table below [11]. The maximum values for total solar radiation are received for 6th-7th months, and the maximum values for solar diffused radiation – for 5th-6th months of the year (see Fig. 2). Average annual value of solar irradiation per unit of horizontal surface is 203.18MJ/m^2 (1693.2 kWh/m^2). Let's note that Yerevan-agro is at 10km from Yerevan, at open site in v. Parakar.

Data on mean daily total (E_{tot}) and diffused (E_{dif}) irradiation (MJ/m_2) and ambient temperature T_{amb} (^0C) averaged for month as per months on 1 m^2 of horizontal surface, Yerevan, 40.1^0 Northern Latitude [11] are brought in Table 4.

Table 4. Data on mean daily total (E_{tot}) and diffused (E_{dif}) irradiation (MJ/m^2) and ambient temperatures.

Parameter \ Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
E_{tot}	6.34	10.13	14.04	19.18	24.97	28.22	27	25.11	20.15	14.85	8.06	5.13
E_{dif}	4.05	5.96	7.02	8.2	8.23	7.78	6.88	6.34	5.38	4.86	3.89	3.1
T_{amb}	-3.7	-2.3	4	11.1	15.9	20.1	24	24.2	20	13.9	6.2	-1.2

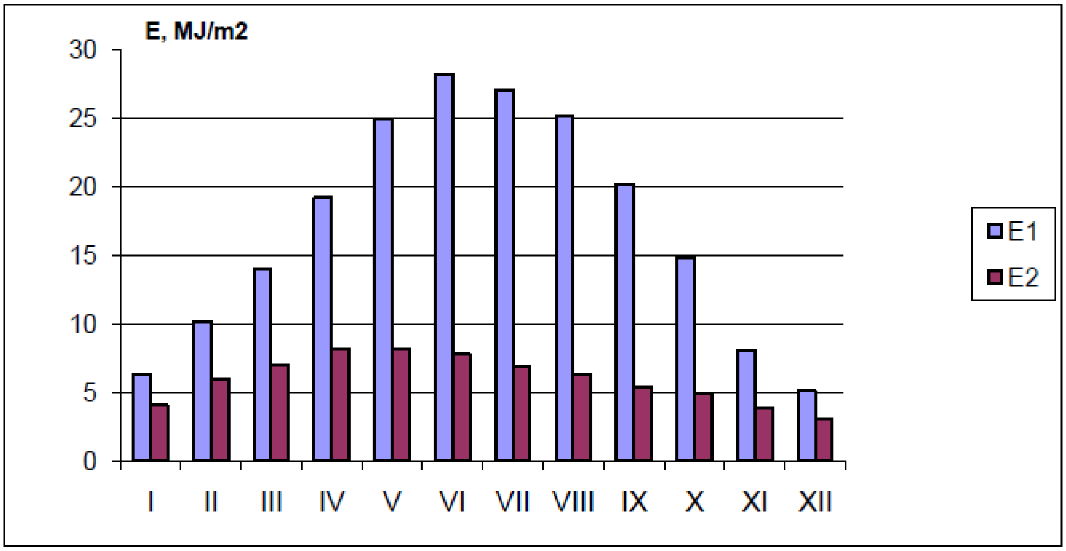


Figure 4. Data on mean daily total (E1) and diffused (E2) irradiation (MJ/m2) averaged for month as per months on 1 m2 of horizontal surface, Yerevan, 40.10 N.Lat. [11].

Updated map with solar radiation potential in Armenia based on radiation regime of Armenia has been prepared under the project financed by the World Bank through Energy Invest Co. in 2005 and is shown on the map of Armenia below. This map was brought in report of the project “Assessment of PV Industry Development Potential In Armenia” in 2008 [23] with funding from R2E2.

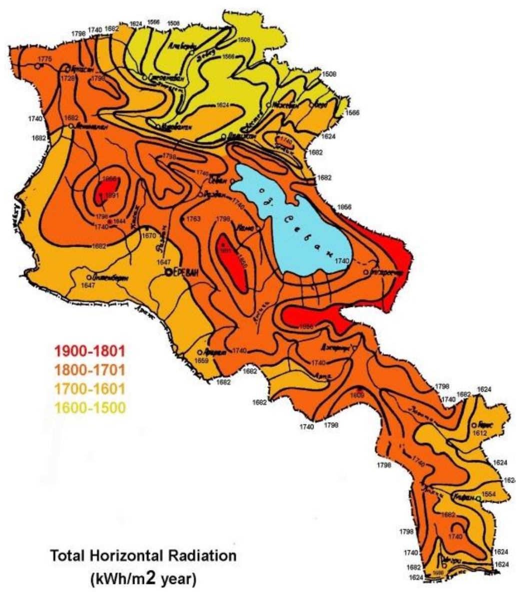


Figure 5. Solar map of Armenia (2005)

In "Scaling Up Renewable Energy Program, (SREP) Investment plan for Armenia (2014. SREP final report [1]) technical potential by technology was assessed and the data are brought in table below in Table 5.

Table 5. Assessments of PV potential in Armenia

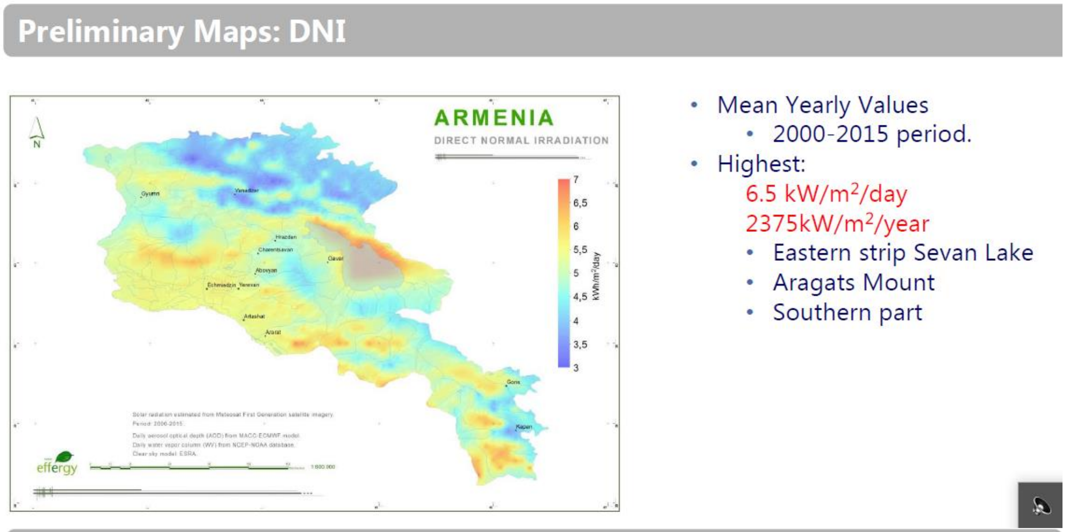
Technology	Capacity (MW)	Generation (GWh/yr)
Grid connected Solar PV	830-1,200[a]	1,700-2,100[a]
Concentrating Solar power	1,200	2,400
Distributed solar power	1,300	1800

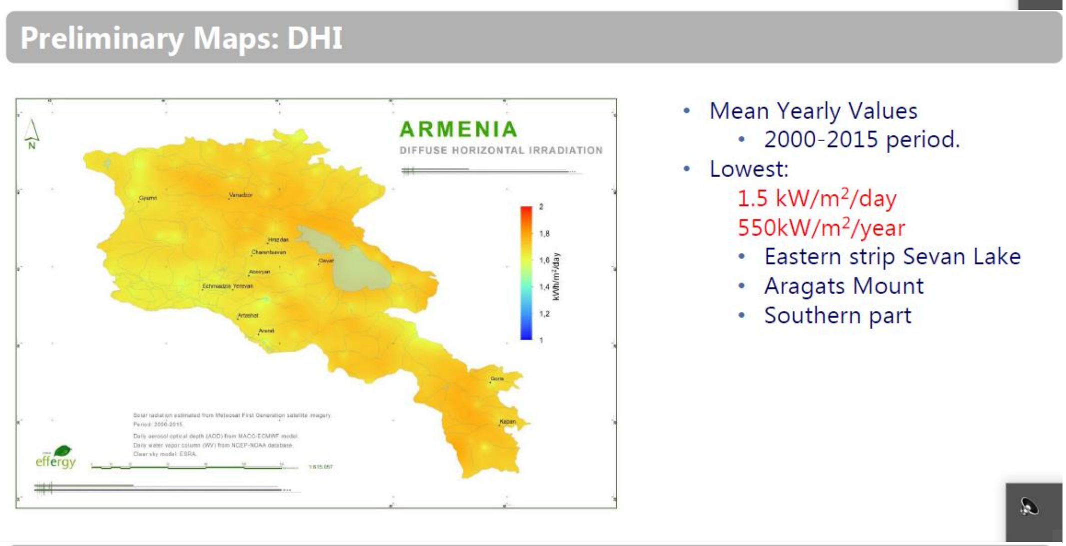
[a]Solar PV and CSP potentials were evaluated for the same areas. Therefore, the total resource potential includes only generating potential for one of these technologies (Solar PV). Total sum is not the same as the sum of the resource potential listed for each technology.

Since the SREP study was made in particular costs of grid connected PV have fallen substantially, so now it is possible that a larger potential is available, if some peak production of solar PV is unutilized.

There were several attempts to develop solar map in Armenia (see above and below). The preliminary results of last ones in 2017 (to be finalized in mid-2017) are brought below [13]. The maps are for direct normal irradiation (DNI), diffuse horizontal irradiation (DNI), Global irradiation on tilted surface at angle of 35^0 to horizon(GTI).

Data on solar radiation in Armenia can be also obtained from NASA (USA) data base (satellite measurements data) and Meteostat data base. During 2006-2008 Armstatehydromet and CM-SAF had implemented project to reveal correlation between metrological data based on satellite information and data of local actinometrical measurements. CM-SAF group was created under sponsorship of DWD (German meteorological service) and EUMETSTAT (EU) that provide data on energy radiation, air, cloudiness, moisture for registered users through Internet (www.cmSAF.eu). Data are available also for Armenia with resolution of 15 x 15 km^2.





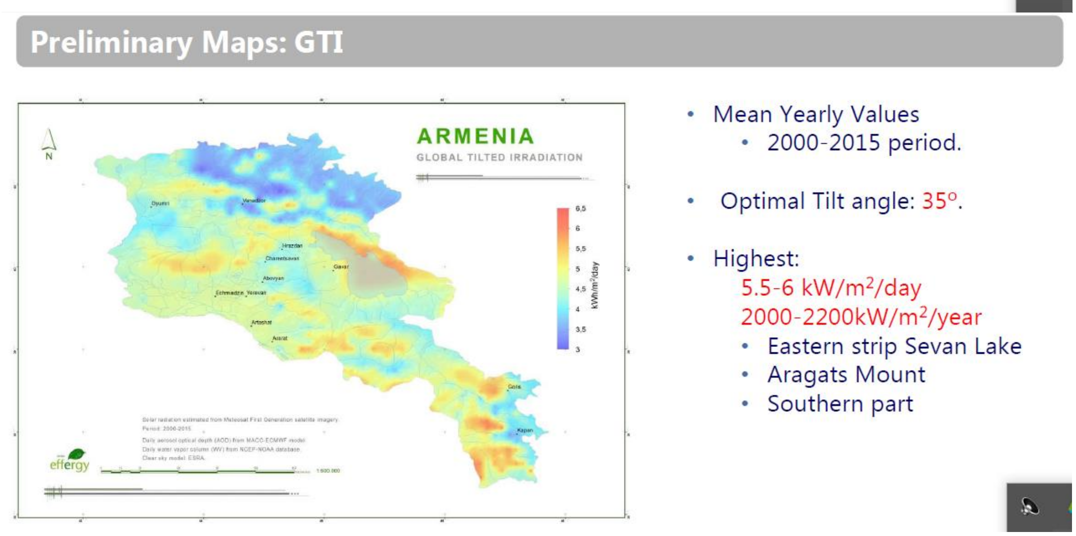


Figure 6. Solar recourse assessment for PV applications in Armenia. Sustainable Energy Week, Yerevan, 2017. Consortium of Effergy, Irsolav, Energy advisory (www.r2e2.am).

In spite of some good examples of PV station installation and operation in Armenia total capacity of all PV stations is less than 200kW. Development of PV stations is hindered by low feed-in tariffs until 2016. According to expert estimates 2000-3000m^2 of solar water heaters are installed in Armenia.

There exists local small scale production of solar water heaters. Many solar water heaters are imported from China.

Feed-in-tariff on solar photovoltaic in Armenia was introduced in November 2016 and is 42.645AMD/kWh (VAT excluded). PV stations up to 150 kW are not to be licensed. They can work in autonomous regime or be connected to electricity lines. Individual or company should apply to electricity distribution company's office, sign agreement with them, install multi-tariff electronic reversible meters with tumblers, cover expenses for connection with electricity lines. Excess of electricity between production of electricity through PV panels and consumed from distribution electricity company will be covered in the end of year at the price of half of the price for electricity it pay to electricity distribution company.

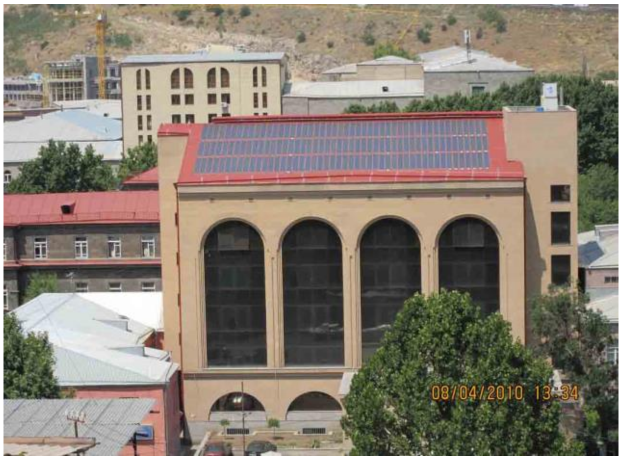


Figure 7. Grid-connected 10 kW solar photovoltaic station installed at Armenian-American Health Center (2007)

Figure 8. Grid-connected 17 kW Solar PV station at the roof of YMCA/Spitak building (2015)

Figure 9. 95kWp PV station in Armenia was installed in Gyumri in 2014 by Caritas Armenia NGO

Figure 10. Solar water heaters at the roof of Hotel Diana in t. Goris installed by Shtigen Co.

The largest PV station in Armenia was installed in Gyumri (North of Armenia) with capacity of around $95kW_p$ and was connected to grid in December 2014.

4. WIND ENERGY POTENTIAL IN ARMENIA

Wind energy theoretical potential in Armenia is estimated as 10 TWh annually. Wind Energy Resource Atlas of Armenia [14] indicates on 4900 MW of installed capacity at the altitude of 50m. According to expert estimations, economically feasible wind energy potential for grid connected plants totals 500 MW with annual electricity production of more than 1 TWh [14, 3].

Operation experience

In 1991, 4 small wind power installations (capacity each up to 4kW) were in operation at the Aragatsotn polygon. At the same polygon greed-connected wind power plant manufactured in Japan of 150 kW capacity was installed that is currently out of operation. In 1991, low-speed wind-driven water pump with capacity of 3-4 l/s was installed in v. Derek [15].

To investigate wind energy resources in several areas of Armenia, ArmNedWind program had been implemented in 1999- 2002 with funding from Netherlands government. 5 wind monitoring stations had been installed at Pushkin, Selim, Karakhach passes, in v. Artanish and at lake Arpi.

In 2006, Lori-1 wind power farm that includes 4 wind turbines each with capacity of 650kW (manufacturer-VESTAS company, Denmark) were installed at Pushkin pass in Armenia with funding from Iran Islamic Republic. Wind power plants are grid connected and operate in joint regime. The total capacity is equal to 2.6 MW. Capacity factor of the plant is approximately 11 per cent. Annual electricity production of wind plant in 2014 was 3.7 GWh and its share in net production of electricity was around 0.06%.

Wind Energy Resource Atlas of Armenia

In 2003, Wind Energy Resource Atlas of Armenia was developed by Renewable Energy National Laboratory (NREL) in collaboration with SolarEn International Corporation, and its Armenian subsidiary SolarEn LLC with funding from US AID. The Atlas was published in hard copy, as well as on CDs and is available through Internet [14]. During development of the Atlas both data from Armhydromet's 66 monitoring stations for several years at the height of 10m, and data from monitoring stations installed by SolarEn LLC were used. An advanced automated wind mapping techniques, developed at NREL that uses Geographic Information System (GIS) allows producing annual average wind resources maps with resolution of 1km^2 .

Data on wind power classification are brought in Table 10. Average wind speed is estimated altitudes of 2000m and Weibull distribution of wind speeds. Shape factor k is equal to 2.

Depending on wind speed actual distribution and actual elevation of sites actual average wind speed may differ from these values within 20 % [14].

Wind resource distribution in Armenia classified as per Table 6 is presented on the Map in Fig. 11. Most perspective regions for grid-connected wind energy plants are taken in circles.

Table 6. Wind power classification

Class	Resource potential (utility scale)	Wind power density (W/m^2)	Wind speed (m/s) at altitude of 50 m
1	Poor	0-200	0.0-6.0
2	Marginal	200-300	6.0-6.8
3	Moderate	300-400	6.8-7.5
4	Good	400-500	7.5-8.1
5	Excellent	500-600	8.1-8.6
6	Excellent	600-800	8.6-9.5
7	Excellent	>800	>9.5

According to Table 7, for average wind speeds related to class 7 it is possible to install wind power plants with total capacity of 500MW, and for average wind speeds related to classes 4-7 – up to 4900MW with assumption that installed capacity per $1km^2$ is 5MW.

Table 7. Good-to-excellent wind resources at the altitude of 50 m [14]

Wind Resource Utility Scale	Wind class	Wind Power at 50 m, W/m^2	Wind speed at 50m, m/s	Total area, km^2	Percent Windy Land	Total Capacity Installed, MW
Good	4	400-500	7.5-8.1	503	1.8	2500
Excellent	5	500-600	8.1-8.6	208	0.7	1050
Excellent	6	600-800	8.6-9.5	165	0.6	850
Excellent	7	>800	>9.5	103	0.4	500
Total				979	3.5	4900

Table 8. Moderate-to-excellent wind resources at the altitude of 50 m (utility scale) [14]

Wind Resource Utility Scale	Wind class	Wind Power at 50 m, W/m^2	Wind speed at 50m, m/s	Total area, km^2	Percent Windy Land	Total Capacity Installed, MW
Moderate	3	300-400	6.8-7.5	1,226	4.3	6150
Good	4	400-500	7.5-8.1	503	1.8	2500
Excellent	5	500-600	8.1-8.6	208	0.7	1050
Excellent	6	600-800	8.6-9.5	165	0.6	850
Excellent	7	>800	>9.5	103	0.4	500
Total				2205	7.5	11050

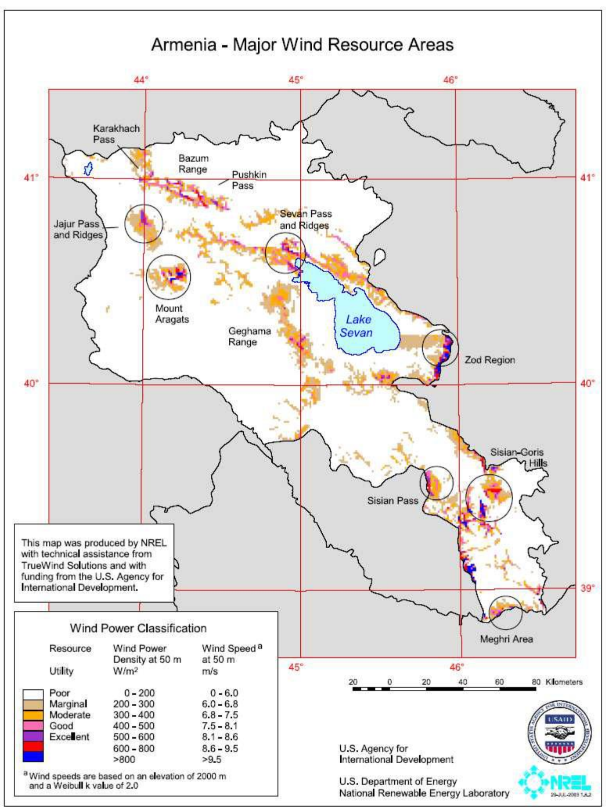


Figure 11. Armenia – major wind resource areas [14]

In 2008 the Armenian R2E2 Fund indicated 5 perspective sites in Armenia for wind energy development projects. They are described in Fig. 12.

Confirmed by monitoring	Currently (February 2008) not confirmed by monitoring
Pushkin pass: 19.5 MW total installed capacity, about 48.9 mln. kWh annual average production **Karakhach pass** (Eastern gate): 125 MW total installed capacity, about 320 mln. kWh annual average production. **Zod pass:** 50 MW total installed capacity, about 120 mln. kWh annual average production	**Karakhach pass** (Western gate): 125 MW total installed capacity, about 300-320 mln. kWh annual average production. **Sisian pass** (Bichanag pass): 155 MW total installed capacity, about 420-430 mln. kWh annual average production. **Charentsavan region (Fontan)**: 20 MW total installed capacity, about 45 mln. kWh annual average production.
Subtotal: 195 MW with about 490 mln. kWh	Subtotal: 300 MW with about 765 mln. kWh
495 MW total installed power, about 1.26 billon kWh annual average production	

Figure 12. 5 perspective sites in Armenia for wind energy development projects

In 2008, a wind potential study was funded the Greek government. It was based on data analysis on OptiRES and RETScreen software. The study highlighted about 5,000 MW wind capacity of which about 500 MW as economically feasible [16].

Figure 13. KP- Parakhach pass; PP – Pushkin pass; Z – Zod; SY – Sisian pass; F - Fontan; Topographic areas for six high potential wind power plants. Source: Wind Energy in Armenia: Overview of Potential and Development Perspectives[16].

According to analysis in [16] dated 2010 there are six main areas with over 10 perspective sites. The total installed capacity at those sites is preliminarily assessed to be about 800 MW with annual generation potential of over 1.6 TWh.

5. BIOMASS ENERGY POTENTIAL

Nowadays by biomass we understand any material of biological origin, products of biological activities, and organic wastes generated during their processing. Biomass is produced by plants through photosynthesis reaction when absorbing solar radiation. Different thermal, chemical or biotechnological pprocesses have been developed to produce energy or fuel from biomass. Biomass can be used for production of different types of fuel, including:

- Solid fuel: fuel wood, wood chips, and pellets,
- Liquid fuel: bio-ethanol, biodiesel fuel (methyl esters), bio-oil,
- Gaseous fuel: biogas, hydrogen, and other gases.

From commercial point of view in Armenia most attention was given to biogas and bioethanol options. With that in the villages and small cities burning of wood for home heating and food preparing purposes reach high scales and is an important reason for illegal cutting of trees.

It is difficult to evaluate the scale of wood use for these purposes and statistical data are not well proven. According to IEA Statistics solid fuel use in 2014 is 1419 TJ of which 99.9% is for residential use.

The SREP report findings "…the biomass resource assessment indicates that there are sufficient forestry residues to support a 4 MW power plant in Armenia and sufficient grain crop residues to support a 25 MW power plant, but collection costs from transporting forestry and crop residues from all around the country to central locations would make fuel costs very high".

Table 9. Unused potential of biogas (including landfill gas) at specific sites

Name of RES source	Plant capacity (MW)	Comments	Date of assessment
Nubarashen landfill (city of Yerevan)	Up to 2.5		[1]2001
[2]Aeratsia Wastewater treatment plant (city of Yerevan).	3		See SREP final
3 large livestock (poultry)farms	3.3		2010 (GEF/UNDP)

[1] Consortium of Japanese companies

[2] Currently the plant is not in operation. But there were plans to rehabilitate this plant and significant investments were needed. Assessment of 3 cogeneration plant of 3 MW capacity is done If anaerobic digesters are installed.

In 2006 within the RoA Energy Efficiency and Renewable Energy National Program, forecasts of biogas production in Armenia up to 2020 were done, if funding becomes available (mostly from abroad). These data are shown below.

Table 10. Forecasts of biogas production in Armenia in 2020

Source of biogas	Volumes of nvestments, Million USD	Annual volumes of biogas million m^3/year	Annual saving of organic fossil fuel, Thou. tce	Payback period, years	Reduction of GHG emissions, thou. t CO_2/ year	Ration of annual fossil fuel savings to investments, thou. tce/ million USD
Manure from cattle farms	0.73	1.06	0.83	8	15.57	1.15
Manure from pig farms	0.21	0.3	0.24	8	4.41	1.15
Manure from poultry farms	16.55	9.79	7.69	8	206.84	0.46
Nubarashen municipal landfill	6.83	9.72	7.62	8	135.0	1.12
Landfills of other cities of Armenia	3.85	5.47	4.29	8	76.08	1.12
Municipal sewage waters	6.01	12	9.43	8	106.7	1.57
Total	34.17	38.34	30.10		544.6	

1. Biogas production experience in Armenia

During last 15 years several projects were realized on biogas production in Armenia. In 1994 Ministry of Energy of RA introduced strategy "To develop and demonstrate a set of improved farm scale biogas concepts". The Armenian State Engineering University, Armenian Agrarian Academy, and the Institute of Biology assisted in technical design and construction of a few digesters

VISTAA expert center continued work on biogas systems and under USAID grant installed few demonstration units: 5 m^3 biogas digester in Aparan (Fig. 3), 5 m^3 biogas digester in Eghvard and 30m^3 biogas digester in Bartsrashen. In Aparan (1998) biogas system with processing cattle manure was constructed in combination with $5m^2$ solar collectors. In Bartsrashen the biogas system provided biogas to heat Green house. In 1997 VISTAA also organized training of farmers in regions of Armenia. The results of field study of these systems implemented by AEAI in 2002 showed that most systems were not operational.

Initially bio-digester with volume of $50m^3$ and gas holder of dry type with volume of $70m^3$ was installed at Lusakert poultry plant. Biogas daily production was estimated as 90-135m^3/day.

In 2003 the biogas system that included bioreactor with volume of 25 m^3 was installed at the territory of "Agroservice" OJSC (Fig. 5) by AEAI and Solaren. By processing cattle manure daily production of biogas was 14-15m^3. The system also provided high quality organic fermented fertilizers.

WB project (2005) on small biogas plants for farmers. Several small scale biogas digesters (volume of digester4.5-6m^3) were installed in Tashir and Gegharkunik marzes of Armenia. Due to insufficient operation of digesters subsequent project implementation was stopped. Initially it was planned to install 100 biogas digesters in Tashir and Gegharkunik marzes. Some field surveys are necessary to assess their current status but some evidences indicate that they are not in operation. Of these biogas stations one (digester is made of metal) was installed in v. Langeaghbyur (in operation as of 2007 data) and one was planned in v. Gegharkunik (Gegharkunik marz). Our survey data indicate that no one is in operation.

In 2004 SolarEn LLC (Armenia) installed biogas station based on $52m^3$ digester in one of Armenian farms. The project was commercial and no much information is available (Fig. 5).

In 2005, biogas digester was installed to process cattle manure in v. Tsovak (Gegharkunik marz) (Fig. 8-9). Digester is made of reinforced concrete with volume of 25 m^3. Designed rate of biogas production (mesophilic process) was 15m^3/day with daily load of 0.5 tones of cattle manure. Project had been implemented by ARD contractor with financing from US AID. Project was completed, but biogas production was not reached. Additional financing is required (around 5000USD) to improve design of the station.

In 2006 SolarEn LLC has assisted in implementation of solar integrated $25m^3$ digester based bio-gas pilot project at one of the Armenian farms, in Arzi village (Donor organization: PA/USAID). Daily production of biogas was 14-15m^3 i.e. around $0.56m^3/(m^3$ bioreactor*day). Solar collectors with total surface of 10 m^2 were installed for reactor heating to maintain the necessary temperature in the reactor (Fig 6).

Lusakert Biogas Plant (LBP). In 2008 Lusakert Biogas Plant that process daily 220t liquid wastes from Lusakert Poultry Factory was put into operation (see Fig. 10-12). This project has been implemented through Clean Development Mechanism (CDM) of Kyoto protocol. Installed capacity of the plant is 0.85 MW, annual electricity production is 7 mln kWh. Total investments –around 3.4 millions Euro. The largest in the region Lusakert biogas plant don't produce electricity since 2014 due to low amount of wastes as poultry plant operates at low capacity. The plant is also grid connected.

Electricity is produced with Jenbacher reciprocal gas engines manufactured in Austria. The produced electricity is used for factory's needs as well as is sold to Armenian Electricity Network at favorable tariff of around 7 US cent (VAT is not included). Favorable tariff for electricity from biomass are in force since 2003. By decision of Public Services Regulatory Commission (PSRC) adopted in November 2009 purchase price of electricity produced from biogas is 35.121 AMD/kW*h (VAT is not included) effective January 01, 2010.

If cogeneration scheme is used then the purchase price of thermal energy for population is around 16 AMD/kWh (VAT is not included). In cogeneration scheme electricity can be sold to Armenian Electricity network at the prize adopted for electricity purchased from Hrazdan Thermal Plant.

Table 11. Technical and economic data on biogas plants in Armenia and their current status.

No	Name of station	The volume of methane tank, m^3	Biogas output, m^3/day	Capital investments, USD	Start of opeation	Current status
1.	Small biogas station (manure from cattle) combined with solar collectors	6	8-10	3000	1988	In operation (under question)
2.	Experimental small biogas station at Lusakert poultry factory	50	90-135	30 000	2002	Not in operation
3.	Biogas production station at “Agrosevice” Ltd (manure from cattle) v. Shaumyan	25	50	12500	2003	Not in operation
4.	Small biogas plant in v. Tsovak, Gegharkuninc marz	25	15	15 000	2005	Not in operation
5.	Small biogas stations in Gegharkunik and Tavush marzes (manure from cattle) (WB program)	3-4,5	6-9	1250	2005	A few are in operation (under question)
6	Biogas plant in v. Arzni combined with solar collectors	25	14-15	n/a	2006	Not in operation
7	Lusakert biogas plant at Lusakert poultry factory	4400	9600	3.4 mln.Euro	2008	Not in operation

Figure 14. Biogas plant in Bartsrashen, Armenia (bioreactor 52m2)

Figure 15. Solar integrated 25m3 digester based bio-gas pilot project at farms in Arzni village

Figure 16. Jenbacher gas reciprocal engine with generator installed in container at LBP

Prospects of Bio-ethanol Production in Armenia

In 2008, ―A Preliminary Feasibility Assessment of the Preferred Alternative For Implementing a Commercial Scale Bio-Ethanol Fuels Program For Armenia in the Near to Mid Term‖ report implemented in the framework of ―Assistance to the Bio-Ethanol Production Development in Armenia‖ grant was submitted by Enertech International, Inc. and BBI International to the Renewable Resources and Energy Efficiency Fund of Armenia [10].

Resource for food stocks was selected to be plants in the lands that were not allocated for agriculture utilization due to climatic and other conditions of Armenia.

The best feedstock being able to be grown on non-used lands in Armenia, as well as being processed in plants utilizing commercially available processing technology in the near to midterm, include Jerusalem Artichoke, Feed Corn for livestock and poultry, Sweet Sorghum, and Chicory.

In this document it is envisaged to construct one plant based on inulin extraction process for 7000 tones of Jerusalem artichoke per annum and the other plants based on a dry milling process with fractionation utilizing 7000 tones feed corn per annum.

Two versions were considered in prefeasibility study. In the first version as a raw material Jerusalem artichoke was selected. Also opportunity of inulin extraction process for Jerusalem artichoke was taken into account. Plant is planned to be located in the vicinity of Sisian and Goris in Syunik Marz. In the second version as a raw material feed corn was selected, and plant location shall be in Tavush Marz.
Total capital investments for construction of bio-ethalon plant were estimated in the amount of 17 million USD as per the first version, and 19 million USD as per second version. Retail price of bio-ethanol fuel was estimated at 1.34 USD/l.

The proposals have not been realized. Besides, increasingly the proposed use of food-crops for ethanol is not recommended. It is being phased out in EU for sustainability reasons.

In the mid to longer term perspectives the best feedstock for cellulosic conversion include:
- Grain straw
- Fast growing hybrid trees (such as poplar, mulberry, and willow).

6. GEOTHERMAL ENERGY POTENTIAL

According to expert estimates, geothermal resources in Armenia have a high potential, as high as584PJ ($584x10^{15}$ J). Among areas with high petro thermal regimes were investigated south-western part of the Lake Sevan and north-eastern part of Syunik (Jermaghbyur and Angeghakot sites). According to Jermaghbyur borehole data, the temperature of rocks is equal to 99^0C at the depth of 920m. At the depth of 2-2.5km the temperature of rocks can reach $250\text{-}300^0$C. A target of construction of 30MW geothermal power station by 2025 was appoved by GoA [2]

In the framework of the program "Assistance to Armenia" in 1998 GeotherEx company prepared report on geothermal resources in Armenia according to which among 18 zones where research works were implemented the most interesting was the following areas: Martuni (T_{max}= 40^0C)[1], Jermuk (T_{max}= 63^0C), valley of r. Vorotan (T_{max}= 43^0C), Hankavan (T_{max}= 42^0C), Arzakan (T_{max}= 45^0C).

Nowadays hydro-geothermal resources (mineral thermal waters) are used in miserable volumes for health treatment purposes.

Data on hydro-geothermal resources in Armenia as per National Program on Energy Saving and Renewable Energy (2007) are shown in the Table 9 below [18].

Table 12. Hydro-geothermal energy potential in Armenia [18]

Area	Low potential t < 100^{o}C	High potential t > 100^{o}C	Depth, M	Thermal potential, TJ/year
Jermuk	64		>300	53.21
Jermuk	47.5			
Hankavan	42		>400	83.8
Hankavan*	36			
Arzakan	54	-	>800	23
Martuny	52	-	>800	92.18
Sisian	45		1100	423.19
Sisian*	37			
Sevaberd	83	-	3100	105.59 **
Azatavan	42		2600	**
Mkhchyan	-	-		2.51
Kechut	31.6			
Artashat	41			**
Ptghny	60			
Near Yerevan	79		2500	0.49
Near Yerevan	70		2400	
Near Yerevan		110-125	4000	
Jermaghbyur		115-310	1000-2500	more

* Research works are not completed

** High concentration of minerals

[1] Maximum temperatures are brought in parenthesis

Description of Geothermal Projects in Armenia

According to results of "Jermaghbyur geothermal power plant feasibility study" prepared in frames of GEF/WB TF 053910 program in 2006 by Ameria LLC, for Flash type geothermal power plant with installed capacity of 25 MW required investments should be in the amount of 17.6 billion AMD and specific costs per 1 kW of installed capacity should be 1564 USD. Annual average electricity production was estimated as 199.4 million kWh. It was required 6 production boreholes with depth of 3km and 2 boreholes with depth of 3km for return flow. Minimum temperature of geothermal resources at the depth of 2500-3000m were estimated as 250^0C. These results are based on results of research works carried out by different groups and obtained data over last years. Before that, research of this site was done in frames of GEF/WB programs. Nowadays, the right to implement this project belongs to private investor.

In the report "Identification of perspective high-potential geothermal zones" (2007) prepared under the contract with R2E2 Fund of Armenia, as perspective zone with high-potential of geothermal resources (more than 100^0C) was proposed the zone of Eratumber young (Holocene period) volcanoes group in the north-eastern part of Geghama volcano mountain plateau in the Central part of territory of Armenia.

Gridzor and Karkar zones were selected as high-potential perspective geothermal zones in 2009 to conduct researches with funding from government of RA.

Research works on heat pumps utilization in Armenia were summarized in "Assessments of Renewable Energy Resources in Armenia" report prepared by AEAI Inc. with funding from USAID in which perspective sites are described in detail (2002). In Armenia, only air source heat pumps are used, and they are imported from abroad. Since the source of heat in these devices is outside air, so their coefficient of performance is strongly reduced with temperature decrease in winter when the ambient temperature is low. For example, for -18^0C of ambient temperature their COP is close to 1.

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ATTACHMENT 1. Power System and Electricity Generation in Armenia

The total installed capacity of the power system of Armenia is around 4336.6 MW., Available capacity due to the condition of the aging equipment is 2589.6 MW. The installed capacity of thermal power plants (TPP) is 2347 MW. Currently the TPPs burn gas imported from Russia and Iran. The installed capacity of the Hrazdan TPP is 1110 MW (available – 370 MW), Yerevan TPP - 550 MW (is not operational now), Hrazdan 5 unit - 445 MW, and Yerevan CCGT - 242 MW. Available total capacity of all TPPS is 1030 MW. There is a need for installation additionally TPPS with total capacity of 620 MW starting 2018, as Hrazdan TPP is planned to write down by that time. During 2012 Armenia imported 98 million kWh of power mainly from Georgia (67.9 million kWh), as well as from Iran and Artsakh and at the same time it exported totally 1696 million kWh to Iran (1578,1 million kWh) and Artsakh (118.1 million kWh). The maximum system load of 1520 MW was registered on December 31, 2012. Number of customers connected to grid was 950,000.

The first unit (VVER-440/270 reactor) of Armenian Nuclear Power Plant (ANPP) was put into operation in 1976, and the second unit (VVER-440/270 reactor) - in 1980. Total installed capacity of ANPP was 815 MW. In 1989, after the earthquake in Spitak on December 7, 1988, the ANPP was stopped for safety considerations. In 1995, Unit No. 2 with the installed capacity of 407.5 MW) was re-commissioned. Now available capacity of ANPP is 385 MW. There are no economically justified alternatives to life extension of the existing Armenia Nuclear Power Plant (ANPP) through 2026. Several options were considered in Armenia Least-cost Energy Development Plan(Final Report) [21,2] to replace Armenian Nuclear Power Plant with the new one after 2026. Three NPP technologies were identified for replacement of the old 2nd Unit of ANNP: VVER-1000 design AES-92 with capacity of 1028MW (most suitable), the Enhanced CANDU 6 (EC 6) with capacity of 670 MW and the several Small Modular Reactor (SMR) designs with capacity of 385 MW, which offer the capability to add nuclear generation capacity in smaller increments although still unproven on a commercial scale.

The installed capacity of all HPPs is approximately 1182 MW, including 222 MW of Small HPPs [as of 2012]. There is one pilot wind farm with 2.64 MW installed capacity.

Table 13. Electricity delivered by energy companies of RA for internal consumption in RA in 2014 (Source: based on data from PSRC)

Name of the power plant	Power production	
	million kWh	%
Thermal power plants (TPP)	2076.2	32.8
Nuclear power plant	2290.4	36.2
Large and medium hydropower plants (HPPs)	1309.6	20.7
Small hydropower plants (small HPPs)	669.8	10.6
“Lori 1” Wind Energy Plant	3.7	0.06
“Lusakert Biogas Plant”	0	
Total electricity production	**6324.9**	**100**

Table A1.2. Data on the existing power plants in Armenia [1] for 2012

Table 14. Data on the existing power plants in Armenia [1] for 2012

Power Plant	Available Capacity (MW)	Efficiency, %	Annual Max. Generation (GWh/y)	VOM (€/MWh)	FOM (€/kW)	Last operation year
Armenian NPP	385	30.3	2124	0.44	84.09	2016
Yerevan CC	220 (200 In summer)	49	1888	-	42.41	2040
Hrazdan 5 Unit	440 (420 in summer)	45	3277	1.49	7.05	2040
Hrazdan TPP	370	34	2755	-	19.82	2019
Sevan-Hrazdan cascade of HPPs	550	88	472	0.44	15.18	2040
Vorotan cascade of HPPs	400	88	1120	9.41	25.01	2040
Small HPPs	222	90	558	39.29	-	2040
Lori Wind Farm	2.6		3	67.7	-	2040

* Based on water release limits from Lake Sevan for irrigation purposes

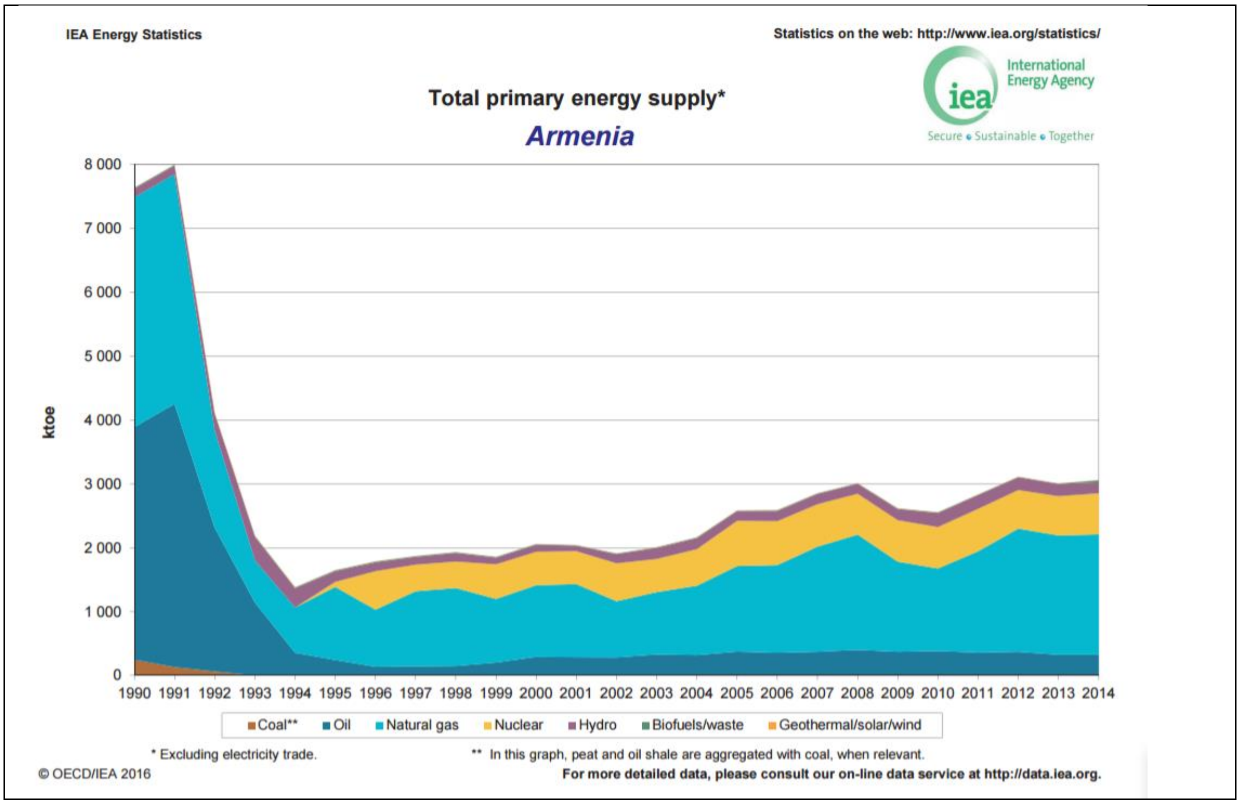

Figure 17. Total primary energy supply in Armenia for 1990 to 2014 (source www.iea.com)

ATTACHMENT 2. Renewable Energy Potential in Armenia by Technology

Table 15. RENEWABLE ENERGY POTENTIAL BY TECHNOLOGY [Source: Final version of SREP], 2014 [14]

Technology	Capacity, MW	Generation, GWh/yr
Wind	300	650
Solar PV	830-1,200[a]	1,700-2,100[a]
Concentrating Solar power	1,200	2,400
Distributed solar power	1,300	1,800
Geothermal power	At least 150	At least 1,100
Landfill gas	2	20
Small hydropower	100	340
Pumped storage hydropower	150	1,161-1,362[b]
Biogas	5	30
Biomass	30	230
Total electricity	**3,800-4300**	7,400-8,700
Solar thermal hot water	n/a	260
Geothermal heat pumps	n/a	4,430
Total (heat)		4,690

[a]The resource potential depends on which solar PV technology is deployed: Fixed PV, Single-Axis Tracking PV or Concentrating PV.

[b]Assumes flash technology is used. The actual capacity cannot be known without exploratory drilling. The geothermal capacity estimates are based on results of estimates for three potential sites, for which some geo-technical information was available. The potential can be significantly larger given several other potential sites, which have not been explored at all.

[c]Solar PV and CSP were evaluated as options for development in the same areas. Therefore, the total resource potential includes only the generating potential for one of these technologies (Solar PV). For this reason, the total is not the same as the sum of the resource potential listed for each technology.

Table 16. RENEWABLE ENERGY POTENTIAL BY TECHNOLOGY [Update of SREP as of Sept. 2013]

Technology	Capacity, MW	Generation, GWh/yr
Wind	795	1,640
Solar PV	835-1,169[a]	1,735-2,118[a]
Concentrating Solar power	1,169	2,358
Distributed solar power	93	128
Geothermal power	31-54	244-436
Landfill gas	2.5	19
Small hydropower	91	334
Pumped storage hydropower	150	1,161-1,362[b]
Biogas	3.3	26
Biomass	29	228
Total electricity	**1,876-2,208**	4,358-4,921
Solar thermal hot water	n/a	254
Geothermal heat pumps	n/a	4,423
Total (heat)		4,677

a - depends on which solar PV technology is assumed to be deployed: fixed-tilt polycrystalline PV, single-axis tracking polycrystalline PV, dual-axis tracking mono-crystalline concentrating PV.

b – pumped storage projects do not "generate" new renewable energy, but store energy that has been generated elsewhere. So, the pumped storage number is extracted from the total.

c - the total includes only the generating potential for one of these technologies, so as not to double count.

Comments. As we can see from Table above [SREP preliminary report, 2013] and in the roadmap data for wind energy potential were higher than in final SREP report, 2014 . Apparently they are influenced by government position on the modest data of wind potential, shift of interest to solar energy due to sharp reduction of prices on photovoltaics, lack of operating large wind facilities and small capacity factor

(11%) of only 2.64MW wind plant in Armenia, reconsideration of data on capacity factors for potential wind sites in smaller sites (capacity factors are now 19-30), etc.

Power system capacities are brought for 2012 in the table Attachment 1

Response from expert from SREP final report. The current operational small hydro (SHPP) capacity is around 240 MW, so the SHPP capacity is expected to increase by 140 MW by 2020. The Government targets for solar, geothermal and wind by 2020 are only 140 MW combined because: (a) the scale-up potential for wind is estimated to be lower than for solar and geothermal; thus, not much of wind capacity is expected to be developed; and (b) construction of geothermal power plant(s) is not likely to begin earlier than 2016 given the time needed for exploratory drilling to confirm the resource.

ATTACHMENT 3. Feed-in-tariffs (VAT excluded) in AMD for 2011-2016

Table 17. Feed-in-tariffs (VAT excluded) in AMD for 2011-2016

Feed-in-tariffs (VAT excluded) in AMD for grid connected RES								
		Duration of support	2011	2012	2013	2014	2015	2016
Small Hydro Power stations	Natural water streams	15 years	19.28	19.551	20.287	21.061	21.168	23.753
	Irrigation systems	15 years	12.853	13.033	13.523	14.039	14.110	15.832
	Natural drinking sources	15 years	8.57	8.690	9.017	9.361	9.308	10.556
Wind		20 years	33.756	35.339	34.957	37.007	38.005	42.645
Biomass		20 years	36.928	37.447	35.856	40.338	40.642	42.645
Solar	More than 150kW, less than 1MW	20 years						42.645

Source: PSRC of RA