*Armenian Journal of Physics, 2022, vol. 15, issue 4, pp. 162-170*

# Energy Sector of Armenia and the Role of Internal Renewable Energy Resources

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(Received: October 28, 2022; Revised: November 30, 2022; Accepted: December 3, 2022)

**Abstract:** The paper presents the general characteristics of the energy system of the Republic of Armenia, including the main existing challenges, development prospects, and directions. The shares of different types of renewable energy in the total energy resources, the possibilities of their use, and the factors promoting and hindering the development of this sector are presented in detail. The advantages of autonomous, multifunctional, hybrid systems and their development prospects are clarified.

**DOI: 10.54503/18291171-2022.15.4-162**

**Keywords:** energy system, electricity, renewable energy, solar panel, PV, wind energy, power plan, hybrid plant

## 1. Introduction

The history of the Energy system of Armenia (ESA) is more than 100 years. The first Hydro power plant (HPP) in Armenia was founded in 1903. The SU collapse and economic situation dramatic changes brought the ESA crisis during 1992-1995. Armenian power companies and the ESA in general appeared in a very difficult situation: actual absence of control and record, very low-level collection rate for consumed energy, common misuses and mismanagement, frequent network overloads, and breakdowns of power and equipment. In 1997 the Law “On Energy” initiated the ESA restructuring and commercialization, based on the division of responsibilities among generation, transmission, dispatching, and distribution [1]. Thus, the transition from vertically integrated management to a horizontally integrated system was put into action. One of the largest benefits of reforms has been the removal of the government’s subsidies for ESA operations [2].

Currently, Armenia is striving to intensify its reforms to liberalize the ESA, open it for competition, improve the investment climate, enhance its Energy efficiency (EE) and sustainability, integrate with regional markets, etc. [3, 4].

## 2. The ESA current general profile

### a. Energy supply, consumption, and balance

The RA Total primary energy supply (TPES/TES) was near 2,900 kilotons of oil equivalent (ktoe) in 2014 [3, 5, 6], and nearly 3,600 ktoe in 2020 [3, 7] with about 37.7% increase since 2009, about 77% of which was imported. RA imports all of its oil, gas, and nuclear fuel, which are about 18% of all imports in Armenia. Gas is about 63% of the primary energy in Armenia. About 6.5 mln.m$^3$ gas is imported daily, of which about 80% are from Russia and 20% from Iran. Gas from Iran is imported in exchange for electricity export from Armenia with a 3 kWh/m$^3$ gas rate, which leaves about 30% of electricity generated from gas in RA.

Total final energy consumption (TFEC) in the RA was about 2,100 ktoe in 2013 and, as TPES, had a rising trend since 2015 reaching up to 2,600 ktoe in 2020 with about a 35.9% increase since 2009. Gas consumption is dominated in TFEC (about 62%), followed by electricity (22%) and oil (15.4%). The share of gas consumption has almost doubled since 2000, while the share of electricity and oil has decreased by 20% and 40%, respectively. The residential sector is the largest consumer with about 33% of final energy consumption, followed by transport (25%) and industry (18%).

**b. Electricity sector**

Armenia has more or less sufficient but not efficient and fully utilized various hydro, solar, wind, and geothermal electricity generating capacity. The expected annual growth of electricity demand is about 2-3% and it can overtake supply at a critical point when the Armenian nuclear power plant (ANPP) will end its lifetime and gas import from Russia expire [3-5, 8].

In 2020 the electricity total generation was about 7.8 TWh with about a 38.2% increase since 2009. In general, the produced electricity in Armenia is more than domestic consumption, which was about 5.9 TWh in 2020 (residential 34.3%, industry 28.0%, services 3.3%, agriculture 2.4%, transport 1.5%, unallocated consumption 30.4%), with about 31.2% increase since 2009 [3, 4, 7]. In 2020 about 1.33 TWh of electricity from a total of about 7.8 TWh of generated electricity was exported, while in the same year the electricity import was about 0.32 GWh with a total electricity balance of about 6.71 TWh [3, 4, 9, 10]. In Armenia, electricity is mainly generated by nuclear, hydro, and thermal plants where about 39% is generated by the ANPP while the remaining 60% is almost generated equally by hydro and thermal plants. The share of all the other plants (solar, wind, etc.) in the power system is quite low - up to 1% which is growing from year to year [4, 10].

The installed generation capacity in 2114 was 3.5 GW of which about 2.7 GW was used with an operating capacity of 2.4 GW, which was expected to decrease up to 2.0 GW after the Hrazdan thermal power plant's (TPP) retiring in 2019 -2021 [3-5, 9, 10]. Despite those predictions, as a comparison, the total available generating capacity in 2020 was about 2.9 GW, compared to a total installed capacity of around 3.6 GW (about 47% hydro, 38% gas-fired thermal, 14% nuclear, and less than 1% solar PV and wind), about 60% of which was built during the SU era [3, 4, 10]. In general, the electricity demand in Armenia is covered by 37% nuclear, 31.5% thermal, and 31.5% HPPs. The peak demand for electricity in Armenia is about 1,300 MW in winter, while the summer peak demand is about 900 MW. There are no seasonal deficits and the existing electricity balance surplus consists TPPs with export capacity.

The electricity sector in Armenia till 2021 in general was only partially liberalized through the separation into three main sub-sectors and unbundling of generation (many private and state generators), transmission (by 1 state transmission, dispatch, and settlement company), and distribution (private distribution supply company (DSC): The RA Electricity Networks - ENA). On 14 January 2021, the RA government approved the "Energy Sector Development Program to 2040" (ESDP or "Strategy") with a timetable for its implementing steps replacing the previous energy policy document adopted in 2015 [3, 4]. According to the 2021 Strategy, the ESA priorities through 2040 are [3-5]:

- Maximum use of renewable energy and energy efficiency internal potentials;
- Extending the life of the ANPP beyond 2026, and construction of a new NPP to replace it;
- Construction of a "North-South Corridor" (NSC) by increasing power transmission links with Georgia and Iran;
- Gradual liberalization of the domestic electricity market.

However, the sector factually till now, mostly is closed and relations are formed mostly on a "single buyer" scheme and direct sale-purchase contracts between generators and ENA at regulated tariffs. All market activities can be conducted only by legal persons licensed by the RA Public services regulatory commission (PSRC). Although Energy law [1] allows third-party access to transmission and distribution networks without discrimination, only electricity exporters can have “third-party access” as the distribution is a monopoly.

In any case, since publishing the International Energy Agency's (IEA) last review in 2014/15, the government has taken decisive steps towards implementing a liberalized electricity market with a planned launch in February 2022, featuring a new wholesale market model, direct contracts, a balancing mechanism, and long-term direct capacity contracts. Free and open trade, as well as cooperation among all energy market participants, as envisioned by these reforms, would help promote investments from the international community and strengthen regional integration [3-5].

According to the RA PSRC rules, now eligible wholesale consumers have the right to choose the electricity supplier [3-5, 11], and the internal power market (IPM) phase-by-phase liberalization is currently under realization, taking into account that:

- There is a lack of sufficient capacities and limitations on trans-border power flows and trading;
- Substantial increase of tariffs could be needed and cause social problems;
- Power purchase agreements (PPA) with existing plants shall be treated separately from the liberalized market, as problems may occur regarding the provision of the guaranteed purchase of electricity delivered by renewable energy (RE) sources effective for a period of 20 years.

Currently, the RA electricity generating system consists of the following power plants with a total installed capacity of 2,878.7 MW as of July 1, 2020:

- ANPP (815 MW initially installed and 407.5 MW currently operating and available): 30-50% needs, depending on plant uptime and nuclear fuel;
- HPPs (1,182 MW installed): 20-40% needs as of the rainfall, from which:
    - Vorotan Cascade of HPPs - 404.2 MW,
    - Sevan-Hrazdan Cascade of HPPs - 561.4 MW,
    - Small HPPs (under 30 MW) - about 380 MW;
- TPPs (2,433 MW installed and 1,380 MW currently available): remainder 20-50% from gas, from which:
    - Hrazdan TPP- 410 MW,
    - Hrazdan Unit 5 - 467 MW,
    - Yerevan CCGT -1 - 228.6 MW;
- RE power plants (without the above-listed HPPs): about 20 MW, from which 2.6 MW is from a wind pilot power plant (WPP).

Base load capacity is provided by the ANPP. The HPPs provide daily load, while the TPPs cover peak demands, especially in winter and when the ANPP is offline. Hrazdan-5 and Yerevan TPPs also generate for export based on swap arrangements with Iran. There are about 175 generators in total, many of which are Small HPPs (SHPP). About 2/3 of all generations are state-owned. About 60% of generation capacity is thermal and of this, 45% is owned by the Russian Federation and a third is owned by the RA. Armenia also owns the ANPP (The Russian RAO UES operates the ANPP) and around a third of the hydro capacity in the RA.

Due to the low efficiency of Hrazdan TPP, it is envisaged to close the plant after operating Iran - Armenia 400 kV transmission line and Yerevan CCGT-2 which were constructed into service [3-5]. In general, the following generating capacities were under construction during 2020-2022 [4]:

- Yerevan CCGT-2- 250 MW, by July 2022 (USD 250 million investment);
- Masrik-1 Solar PV PPP - 55 MW, by July 2022 (USD 60 million investment);
- SHPPs - 23 power plants, 50 MW, commissioned by 2023 (USD 60 million investment);
- Small Solar Plants - 48 plants, 197 MW, by 2022 with the assumption that the total installed capacity of such plants will comprise 210 MW in 2022;
- Wind Power Plant (WPP) - 4 MW, by 2021.

The ANPP’s safety upgrading and new capacity building are one of the highest priorities and challenges for the Government of the RA (GOAM), seeing the ANPP's special role in the ESA stability and security. In 2014, the GOAM decided to extend the NPP lifetime and replace it with III+ new generation NPP till 2027. In 2014, the RF agreed to a $300mln loan to upgrade the ANPP. Following the RA government's decision in March 2014 to extend operations at Unit No. 2, the ANPP launched a Design Lifetime Extension project on which it is cooperating closely with the RF state-owned nuclear power corporation, Rosatom [4].

In 2020 the ANPP took a decision to shut down Unit No. 2 for five months in order to implement additional upgrades to support the further lifetime extension of the plant through 2026 and possibly beyond. The refurbishment works include the replacement of power supply systems, automation and control systems, and turbine hall equipment, resulting in an increased electrical power output of around 10-15% without additional fuel consumption. Russia has provided USD 300 mln. in financial resources (grant and loan) for the ANPP life extension program, though Armenia decided in 2021 to not fully utilize the loan portion of this assistance and instead to allocate money from the state budget for much of the cost. According to the government's 2021 Energy Strategy, the ANPP will continue to operate through 2026, though "in the event that a safe operation of the ANPP Unit No. 2 is justified after 2026, the government intends to operate it at least until 2036". After this, the government's strategy envisions replacing the current plant with a new nuclear plant [3-5].

Besides the ANPP, about 50% of HPP and TPP generators are about 40 years old and many of them should be closed or upgraded. As for demand growth and the need to retire old generators, Armenia could possibly face a capacity gap in peak demands if appropriate steps will not be taken.

According to the RA Ministry of energy and natural resources (MENR) and other estimations, at least 1,000 MW of additional electricity generating capacity will be needed by 2026 to meet peak demand when the NPP will be closed. However, Armenia also can hurry its EE and RE efforts to improve the ESA security and stability and down needed investment for new nuclear or gas-based electricity big plants.

### c. Renewable Energy in the RA

The RA RE resources compete with used conventional resources in electricity generation. The RA Energy Law sets some measures for the RE use, i.e., the RE potential mapping, SHPPs electricity feed-in tariffs with 15 years guaranteed purchase, extended to 20 years for other RE technologies, a net-metering scheme for electricity self-consumption, RE guaranteed access and grid connection transparent methodology and priority dispatch [1]. So far, there are no serious breakthrough follow-up support measures and requirements to promote RE sources use in transport, lighting, heating, and cooling, towards which perhaps the first steps have only just begun.

In spite of that, the feed-in tariff has been a successful step in the SHPP investment stimulation. The RE generation was only 6% of total electricity generation (excluding SHPPs) in 2012 and 10% in 2015. As of 2016, about 312 MW / 700 GWh/y 170 SHPPs were operating and 94 MW SHPPs received licenses for development. Besides the above, also only 2.6 MW 1 WPP, several SPVPPs with about a total 0.5 MW capacity, and various growing solar heating systems were installed in public buildings in 2017. In 2014 the GOAM and the Strategic Climate Fund (SCF) adopted the original Scaling up RE Investment Plan (SREP) investment plan (IP) for Armenia with included three main Components [13]:

- Geothermal development (World Bank);
- Development of utility-scale solar PV (World Bank);
- Development of Distributed Geothermal Heat Pump and Solar Thermal (EBRD).

The main challenges for the RA SREP IP implementation were recognized:

- 70% of electricity generation is dependent on imported fuels – nuclear and gas;
- 100% of the natural gas required for all other sectors of the economy is imported;
- Impending supply capacity gap of 400 MW by 2020.

This above SREP initial IP presented the analyzed the RE potential, cost-benefit, and feasibility of main technologies and settled targets to reach a total generation of 21% by 2020 and 26% by 2025 (See Tables 1 and 2).

**Table 1.** RE resource potential in Armenia by different technologies [13].

| Technology | Capacity (MW) | Generation (GWh/yr) |
|---|---|---|
| Wind | **300** | **650** |
| Utility Scale PV | **830–1,200** | **1,700–2,100** |
| Concentrated Solar Power | **1,200** | **2,400** |
| Distributed Solar PV | **1,300** | **1,800** |
| Geothermal | **At least 150** | **At least 1,100** |
| Landfill Gas | **2** | **20** |
| Small Hydro | **100** | **340** |
| Biogas | **5** | **30** |
| Biomass | **30** | **230** |
| **Total (electricity)** | **3,800–4,300** | **7,400–8,700** |
| Solar Thermal Hot Water | **n/a** | **260** |
| Geothermal Heat Pumps | **n/a** | **4,430** |
| **Total (heat)** | | **4,690** |

**Table 2.** RE generation capacity and production targets 2020- 2030 (Excludes generation from the large HPPs) [13].

| Technology | Installed Capacity (MW) | | Generation (GWh) | |
|---|---|---|---|---|
| **Targeted Years** | **2020** | **2025** | **2020** | **2025** |
| Small Hydro | 377 | 397 | 1,049 | 1,106 |
| Wind | 50 | 100 | 117 | 232 |
| Geothermal | 50 | 100 | 373 | 745 |
| PV | 40 | 80 | 88 | 176 |
| **Total** | **492** | **677** | **1, 627** | **2,259** |

In line with the initial SREP, the GOAM took also regulatory steps to streamline the RE projects including decreased taxes for some investments, etc., as his RE rising commitment remains urgent and driven by primary goals to improve energy security, ensure tariff affordability and maximize the use of indigenous RE resources.

By the initial SREP, the GOAM identified the following areas for strategic investment in the RE which was proposed would lead to the RA energy system scale-up namely geothermal power, utility-scale solar PV, geothermal heat pumps, solar thermal projects, and HPPs development:

- Large HPPs and recently SHPPs were still considered the most advanced RE sectors with the following investment HPP projects:
    - Meghri HPP with about 130 MW capacity and 800 GWh/y generation on Araks River.
    - Shnogh HPP with about 75 MW capacity and 300 GWh/y generation on Debed River.
    - Lori berd HPP with about 66 MW capacity and 200 GWh/y generation on Dzoraget River.

It was proposed that the SHPPs could provide a greater percentage of electrical needs next decade, as about 23% of SHPPs' potential was still unrealized. So, SHPPs were considered one of

RE development's top courses. According to provided licenses as of 2016, new 44 SHPPs were under construction with a total design capacity of 86 MW and 310 GWh/y productions accordingly. Here main problems were in the SHPPs efficiency and in the cost of bank funding. Another main problem with SHPPs was the lack of automation and utilization of modern control technologies. Other factors were poor performance and low reliability of imported equipment and materials from the reuse of old piping from irrigation systems, substandard engineering design, and poor-quality control during construction, as well as uncontrolled hydro facilities that are no longer operational.

- Solar energy average annual flow on a horizontal surface is about 1,720 kWh/m$^2$ in Armenia and about 1/4 of the RA territory has solar energy resources at 1,850 kWh/m$^2$ level. Solar water heaters have been installed on the roofs of many kindergartens, houses, and medical centers by international donors and charitable organizations. Due to the taken development steps and PV costs decline, viable PV potential also has increased during the last decades, and already in 2017, the first successes were recorded when about 100 solar PV SPPs were implemented with a total power of about 0.5 MW.

  With the World Bank (WB) and Global environmental facility trust fund (GEF) assistance, the RA R2E2 examined RE/PV industry potential, prepared a RE/PV IP, published the RA Solar Map in 2016, and conducted an international tender to build the first Armenian utility-scale 55 MW SPVPP in Sevan region on a commercial basis.

  In general, as of July 2020, about 2,670 autonomous SPPs with a capacity of up to 500 kW, with a total installed capacity of about 50 MW were connected to the RA electricity network. The current SPP development trends allow anticipating that the total installed capacity of such plants will reach 100 MW for the next three years [4]. The RA government aims to increase the share of SPP by at least 15% or 1.8 billion kWh by 2030. For that purpose, SPPs with a total installed capacity of 1,000 MW including autonomous plants will be constructed. In the near future new tenders for the construction of seven SPPs with a total installed capacity of about 520 MW will be conducted, whereof the capacity of two plants will comprise 200 MW each [3-5].

  Solar sources can be used also to develop and reestablish district heating systems. One of the completed heating projects involved the implementation of solar thermal heating at a housing complex, and reduced gas consumption by 40%, which can stimulate expanding of similar projects. Greenhouses are the next major consumers of heat energy and could provide valuable demonstration benefits for this implementation of RE heat technologies.
- Wind energy economically justified potential in the RA is about 450 MW according to the RA Wind energy resource atlas created by the US National renewable energy laboratory (NREL) [3-5,12-18]. The GOAM target is 500 MW grid-connected capacity by 2025. Main perspective sites are in Zod, Jajur and Sevan passes, Bazum (Qaraqhach and Pushkin passes) and Geghama mountains, Aparan and Meghri regions, and highlands between Sisian and Goris [12-18].

  The SHPPs and WPPs are less expensive than thermal electricity generation-based PPs. However, there are many emerging problems that could slow future growth. These include inconsistencies and omissions in the legal and regulatory framework, technical shortfalls, and continuing business/commercial barriers.

In 2019 the GOAM and the SCF adopted the first revision of the SREP IP for Armenia [14] which provided the first revision to the original IP, an update on the IP's implementation status, and proposed modifications to the original SREP IP [13] with the aim to reallocate a remaining balance of USD 2.25 million from one of the Program's components to another component with expected higher impact towards the results framework [14].

However, in general, by 2014, there had been no relevant progress with the development of solar and wind-based electricity generating plans, which were estimated (with support from the WB, SREP, and other development partners) to have the highest potential for the ESA scale-up. At the same time, in spite of the above starting in 2017 Government's strategy to boost solar energy utilization recorded significant results. Thus, a 55 MW solar station (Masrik 1) and already licensed smaller-scale industrial PV plants with a total installed capacity of 110 MW are in the construction process. Another 100 MW of quota has been announced by the Government along with 5 bigger projects (with a cumulative installed capacity equivalent to 120 MW) that are in the preparation process for international tender with support from EBRD [15].

In recent years, the design and construction of small, autonomous, hybrid (combined) renewable energy plants have been gaining momentum in many countries (including the RA) [particularly see 19]. The growth of interest in such stations is due to:

- with the need for the energy supply of isolated institutions,
- with their low cost and quick cost recovery,
- with the need for diversification of the sector and other factors.

The spread of such installations in the RA can significantly accelerate the pace of development and usage of renewable energy, significantly increase the energy security of bordering rural communities, contribute to the implementation of business projects in these areas, and increase the country's energy and military security.

## 3. The ESA Some Core Problems and Challenges

Below are presented the ESA some core problems, resulting in poor use of energy resources, low level of innovation situation, weak energy security, and its dangerous dependency on imported resources from a single supplier:

- Weak use of the RA RE resources. In fact, in 2010, the electricity-producing RE plants installed total capacity (i.e., SHPPs with less than 30 MW and a WPP) was 260 MW, or only about 6% of total electricity output, although the total RE potential is more than 3 GW (over 1 GW each of solar thermal power and PV, 200 MW of wind power, and 450–500 MW of hydropower). The high cost of investing in RE technology and the limited available financing for it were one of the main reasons for this underutilization [3-5,12-18,20]. As of July 2020, 2669 autonomous solar power plants with a capacity of up to 500 KW, with a total installed capacity of 49.5 MW are connected to the electricity network. Taking into account current RE development technology trends according to the ESA development Strategy-2040 by the GOAM new tenders for the construction of seven more solar photovoltaic power plants with a total installed capacity of about 520 MW are planned to be conducted, whereof capacity of two plants will comprise 200 MW each. The current developments rates allow anticipate that the total installed capacity of the above-mentioned plants will reach 100 MW for the next three years. The RA government aims to increase the share of solar power generation by at least 15% or 1.8 billion KWh by 2030. For that purpose, solar power plants with a total installed capacity of 1000 MW including autonomous plants will be constructed [4].
- Low efficiency of TPPs, high operation and maintenance cost and low reliability of big HPPs, and relatively large electricity transmission and distribution losses. The main reason for this is that many electricity generation, transmission, and distribution assets are old and in poor condition with transmission and distribution losses about of 14.5% of total electricity output. Roughly 70% of installed HPPs are in operation for more than 30 years, and 50% - for more than 40 years [21].
- Electricity exporting current potential is not realized as of insufficient legislation, monopolized and closed markets, power transmission infrastructure, and limited interconnection with neighboring countries.
- Tenuous energy security and high dependence on imported gas, oil products, and uranium mostly from a single supplied country. This makes RA dependent on variations in energy prices, possible supply disruptions, etc. To enhance its energy security, Armenia must diversify the energy supply mix, expand the RE use, diversify the energy import, and improve the EE [3-5, 22].

- The NPP is vital for the RA energy security, bat the ANPP is old and is to be retired in 2026. Armenia must keep the plant safe and reliable and prepare for its retirement to ensure an adequate supply of electricity, but the funding for the project is not secured yet. Alternatives are the EE and RE significant improvement and expansion [3-5, 22].
- Electricity and in general energy tariffs should raise accordingly to attract more private investment to the ESA, expand the RE and EE, and secure funding for the new NPP without risking the sustainability of public debt. This is likely to intensify poverty; as poorer households tend to spend a larger proportion of their income on utilities than better households. A difficult challenge for GOAM is to increase social assistance to the poor and other vulnerable segments to mitigate the negative impact of tariff rises on poverty while keeping the fiscal deficit under control.
- Small, autonomous, hybrid (combined) renewable energy (solar PV, terminal, wind, etc.) plants are not yet produced and operating in Armenia, the design and construction of which have gained momentum in many countries (including RA) in recent years.
- Highest-cost and rundown Hrazdan TPP has to run to avoid a supply gap till new lower-cost CCGT cannot be constructed. The alternative is the EE and RE improvement and expansion.
- Several transmission assets are a danger to supply reliability. Many transmission lines and substations suffer high outage rates, which could lead to system-wide failures.
- Affordability is a growing concern, as raising energy costs and their share in household expenses to 10%, will get worse if the much needed are made new investments.
- Weakening of governance and financial standing of state power companies. In recent years' tariffs were frequently lagging cost-recovery, the financial management decisions were not always prudent, and key generation asset was sold through a direct negotiated sale.

## 4. Conclusions

1. Currently, the electricity in the RA is mainly produced by nuclear (about 39%), hydro (about 30%), and thermal (about 30%) plants [3-7].
2. Despite the high production growth rate of other forms of renewable energy (solar, wind, geothermal, etc.) in recent years, their share in the RA energy system remains quite low, up to 1% [3-7, 12-18].
3. In terms of local energy resources, however, solar, wind and geothermal energies can fully satisfy the growing demands of the RA.
4. It is necessary to take consistent steps in the direction of development of the RE sector and overcoming the existing and possible future challenges (see section 3).
5. The development production and spread of autonomous, hybrid, multifunctional RE installations can significantly accelerate the pace of development of the RE, and measurable increase the country's energy security.

## Acknowledgments

The authors would like to thank the Institute of Applied Problems of Physics (IAPP) at the NAS RA for providing the needed facilities and conditions to make this work complete.

## Funding

This work was not funded by any special source and was supported by the basic budgetary financing of the IAPP NAS RA.

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