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Smart Grid and Electricity Security: Case of Azerbaijan as a Resource-Rich Country

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ABSTRACT

This study focuses and analyzes whether the current traditional electricity system of Azerbaijan is ready to absorb and incorporate a large share of intermittent and non-dispatchable renewable sources, assesses current reforms in country's electricity sector and determines the challenges in the prospect of smart grid development. Azerbaijan has almost 200 GW of technical potential in developing renewable energy sources, however, the penetration of renewables to the current conventional grid will rise another big issue of electricity security. The development of a smart grid system is considered as a solution to renewable energy transition. The study primarily uses interviews with industry experts to gain a comprehensive understanding of the current electricity system. The findings show that the legislative background and grid infrastructure are far behind the vision of the government in the prospect of green energy transition. The current grid may integrate up to 1.5 GW of renewables. However, conventional power facilities may struggle to penetrate the increasing volume of electricity production from solar and wind sources. It will pose additional challenges for policymakers. In this manner, relevant policies are suggested.

Keywords: Electricity Security; Azerbaijan; Smart Grid; Energy Transition; COP29.

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1. INTRODUCTION

The global electricity supply is in the process of expanding its infrastructure and capabilities due to growing demand coming up from increased industrialization, urbanization, and digitalization. To catch up with rapidly increasing electricity demand and to meet its commitment to the Paris Agreement on cutting CO_2 emissions, the global electricity sector relies upon renewable energy sources (RES) (Sarhan et al., 2021; IEA, 2021). Electricity demand increases by roughly 50% in 20 years, and this trend will likely continue to grow further to the point electricity will surpass oil as the main energy source by 2040 across the globe (IEA, 2021). Renewable energy generation capacity reached 507 GW worldwide in 2023 (IEA, 2023b), however, ageing electricity grids threaten green goals (Abnett, 2023) and remain a major bottleneck for renewables deployment, since failing to upgrade grids increases countries' dependence on natural gas and delays clean energy transitions (IEA, 2023b).

Azerbaijan is resource-rich country with proven natural gas and oil reserves and assessed highest energy self-sufficiency (IEA, 2023a). In 2022, 93.29% of electricity in Azerbaijan was generated by natural gas-fired power plants alone (Global Climatescope, 2023). On top of that, Azerbaijan has enormous potential in onshore and offshore renewable energy. According to the Ministry of Energy (MoE), the technical potential of Azerbaijan in the development of onshore renewable sources is 135 GW and economic potential is estimated at 27 GW, which is apportioned as 23 GW of solar energy, 3 GW of onshore wind energy and 1 GW hydro (MoE, 2022). On the other hand, Azerbaijan's offshore wind technical potential is 35 GW in shallow waters and 122 GW in deep waters. The economic potential is currently being evaluated.

The above given potential once realized will keep requiring up-to-date electricity grid network. About the electricity grid two details are worth to mention here: Azerbaijan`s electric grid equipment led to an incident at the Azerbaijan Thermal Power Plant in July 2018 (Yusifbayli & Nasibov, 2021). The incident had a countrywide impact, as electricity was cut off in 39 regions of Azerbaijan, including the capital city, Baku, and the second-largest city, Ganja (Aydin, 2019). The OECD (2021) reports that even though Azerbaijan's energy sector is equipped with better quality infrastructure, the electricity transmission and distribution systems underperform, resulting in electricity grid loss rate of 9.7%.

Given these challenges, Azerbaijan is now focusing on enhancing its energy security investing in renewable energy sources (O'Byrne, 2023). The ambition to export this offshore wind energy is also driven by Azerbaijan's commitment to the Paris Agreement, which includes a target of reducing greenhouse gas (GHG) emissions by 35% by 2030, and to COP 26's promise of 40% GHG emission reduction by 2050 (Azerbaijan, 2023). Increasing the share of natural gas consumption in the total energy mix at the expense of oil reduction has a true impact on reducing CO_2 emissions, however, it will not be sufficient to attain the 35% goal for Azerbaijan (Gurbanov, 2021). The MoE signed two pilot projects in January 2020. The first project was the construction 240 MW Khizi-Absheron Wind Power Plant by ACWA Power of Saudi Arabia and the second project was the construction of a 230 MW Garadagh Solar Power Plant by Masdar of United Arab Emirates. In addition, Azerbaijan has already signed relevant deals with Fortescue Future Industries (FFI) and Masdar with a total capacity of 22 GW. Australia's FFI will develop a total 12 GW capacity of renewable energy and green hydrogen and an exclusive concession was also agreed upon between Azerbaijan's MoE and Masdar to develop a 10 GW renewable energy program, which will incorporate onshore wind and solar projects, and offshore wind and green hydrogen projects.

Yet, solar and wind power are also known as variable renewable energy sources, meaning, these sources "are not continuously available at the same levels" (Timmons et al., 2022, p.8). The existing electric grid is not designed in a way to balance the variability and penetrate renewables in the right way. The development of a smart grid system is one of the options to adopt intermittent energy sources in the power supply and to address the issue of electricity security and energy efficiency in the country. Based on the IEA assessment of Azerbaijan's energy policy (2021), "investments are required in new and more efficient generating capacity and electricity grids" and it is recommended to develop or upgrade the grid to integrate a large share of renewable energy sources. Particularly, to unlock Azerbaijan's offshore wind capacity, investments are required in smart grid technology, storage, management system, and interconnectors to manage the challenge of variability.

Challenges related to smart grid is an essential topic for all resource-rich economies. This study depicts the current state electricity sector of Azerbaijan, what steps are being undertaken to reform it and the feasibility of integrating renewables into the existing traditional grid. Hence, this article will be useful for other resource-rich economies in the phase of green transition. The authors intend to provide policy advice and assess the prospect of smart grid development in Azerbaijan. The findings show that the legislative background and grid infrastructure are far behind the government's vision for a green energy transition. The current grid may integrate up to 1.5 GW of renewables, however, problems may occur even with lesser volumes.

The paper is arranged as follows: The next section describes the current condition of the electric grid in Azerbaijan and summarizes the latest reforms in the electricity sector. It is followed by literature review of smart grid. Section 4 reflects on the methodology used in this study. Section 5 presents the interview results. The final section presents conclusion with the policy implications.

2. CURRENT CONDITION OF THE ELECTRICITY SECTOR IN AZERBAIJAN

The existing grid in Azerbaijan dates to the 19th century, when the first 550 kW oil-fired power plant was built in Baku by the Nobel brothers. By 1913, Baku produced 110 MW of electricity, of which 95% was used by the oil industry and only 5% for the country's lighting (MoE, 2020a). By the 1970s the installed capacity of local power plants had reached 2882 MW, however, Azerbaijan had to import significant amounts to meet the growing electricity demand (MoE, 2020b). To reduce dependence on imports, Shamkir HPP and Azerbaijan TPP were built and the capacity rose to 5000 MW. At the same time, the electricity grid was also systematically updated to include new generation capacities. Right now, Azerbaijan TPP is considered the largest thermal power plant in the South Caucasus with a generating capacity of 2400 MW. Commissioning the Azerbaijan TPP is assumed to be the foundation for the energy security of Azerbaijan (MoE, 2020b).

Today state-owned companies continue to dominate the electricity sector. Two vertically integrated monopolies—Azerenergy and Azerishiq—are the main market players. Established in 1996, Azerenergy became the umbrella for all energy enterprises in the country. Currently, Azerenergy is the primary grid operator electricity generator in Azerbaijan that owns around 85% of the country's generating capacity, including Azerbaijan TPP and Mingachevir HPP, the key generation units (IEA, 2021). In total, 98.5% of all installed capacity belongs to state-owned companies and 1.5% is owned by the private sector. Azerenergy operates all existing power plants except 37 MW Balakhani Bioenergy Plant—a project implemented by French CNIM S.A. with a 20-year "Design-Build-Operate" contract—which generates roughly 1% of the country's electricity. Other three independent TPPs are owned by BP Azerbaijan (517 MW, off-grid), SOCAR (134 MW, off-grid) and Azersun Holding (32.8 MW). Several renewable pilot projects are under development, including Masdar's solar project (230 MW) in the Garadagh region and ACWA Power's project (240 MW) in the Khizi region. Azerenergy's central role here is purchasing the power under the Power Purchasing Agreement (PPA), which will be generated at these power plants, connecting them to the transmission grid and preparing technical data for them. Established by the Presidential Decree in 2015, Azerishiq is the distribution network operator, supplier, and service provider (metering and billing) at the same time. The decree passed distributional assets of Azerenergy to Azerishiq marking the first step towards unbundling and market reforms in Azerbaijan.

Following approval of the 2016 Strategic Roadmap for the Development of Utilities Services (electric energy, heating, water, and gas), the Azerbaijan Energy Regulatory Agency (AERA) was established in December 2017 under the MoE, for which the EBRD has shown support. By Presidential decree, the AERA carries out regulatory and supervisory activities in the field of electricity, heat and gas supply. The agency's functions include the preparation of draft laws, supervision of enterprises' activities, consumer protection and accessibility of services, dispute resolution and consideration of complaints, licensing and participation in the formation of tariffs. Moreover, the AERA plays a critical role in attracting investment in these sectors, financing power plants and privatization of non-strategic production units. The precise roles and responsibilities of the AERA will be clarified once the "Law on the Regulator in the field of energy and utilities" is adopted. This law—which has been modelled based on the EU Third Energy Package—was submitted to the Cabinet of Ministries in July 2019 and has been pending approval ever since. One of the interviewed experts argued that powerful actors in the energy sector are blocking the law since it will empower the AERA and grant it a key role in the electricity market.

In 2020, the Azerbaijan Renewable Energy Agency (AREA) was established under the MoE. The AREA is involved in the formation and execution of policies related to renewable energy and energy efficiency. Like the AERA, the AREA focuses on attracting foreign investors and the private sector to participate in renewable projects. The main objective of the agency is to meet Azerbaijan's targets under the Paris Agreement by 2030 and 2050.

Table 1. Key electricity market actors in Azerbaijan and their roles.

Azerenergy OJSC	- A vertically integrated state-owned monopoly. - Produces around 90% of the country's electricity consumption. - Transmission System Operator which owns transmission lines with a voltage of 110 kV and above (220, 330 and 500 kV), their substations, and dispatch control facilities. - Carries electricity import-export activities. - Sells electricity to a limited number of large consumers directly. - Purchases electricity from private generators based on PPA.
Azerishiq OJSC	- A vertically integrated state-owned monopoly. - Distributor and supplier of the electricity. - Provides customer services (connection, metering, and billing). - Distribution System Operator which owns power distribution lines up to 110 kV and associated substations and control rooms. - Azerishiq pays the Azerenergy wholesale tariff for electricity generation and its high-voltage transmission lines.
Tariff Council	- Sets electricity prices for generators and consumers. - Proposes changes to legal framework related to pricing.
AREA	The agency involved in the formation and execution of renewable energy policies.
AERA	Market regulator; main supervisory body.

Source: *Compiled by authors.*

In the early 2000s, all oil-fired capacities in Azerbaijan began to be replaced with gas-fired generation. Currently, the country's electricity supply relies heavily on increased domestic natural gas resources, with gas accounting for 94% of electricity generation today. A study by Gurbanov et al. (2023) confirmed that decreasing the natural gas allocated for electricity generation and substituting it with renewable sources will provide a two-fold benefit for Azerbaijan: enhancing electricity security and creating a path for decarbonization of the power sector. Besides, another study by Adebayo et al. (2022) examined impact of hydroelectricity and natural gas usage on CO_2 emissions in the US and underlined that natural gas consumption has a positive correlation with CO_2 emission, while hydroelectricity displayed a positive effect on decreasing CO_2 emission, meaning decreasing the use of fossil fuels while increasing the use of renewable energy source will help to reach carbon reduction goals. It seems that magnitude of the power generation matters.

The use of alternative sources for gas and oil in Azerbaijan dates to the construction of Mingachevir HPP (284 MW, later increased to 424 MW) in 1953, followed by Varvara HPP (17 MW) in 1956. With the current 5% share in electricity generation (see Fig. 1), hydropower is the second biggest source of energy. However, long-term reliance on hydroelectricity is deemed to be unsustainable, as in recent years Azerbaijan is experiencing a water shortage crisis. Hence, the development of alternative renewable energy sources is inevitable and the need for energy sources diversification is explicit. Among renewable generation capacities in Azerbaijan, there is Yeni Yashma WPP (50 MW) under Azerishiq. There were seven small SPPs, a hybrid WPP, a bioenergy plant and a hydro plant with a total capacity of 17 MW under the operation of Azalternativenerji, which was subordinate to the AREA. The entity was abolished due to internal issues—ineffectiveness and inability to manage assets properly, according to an interviewed adviser from a public entity—in August 2023 and its assets declared open for privatization.

During the interview, one of the experts from a private company argued that the capacities of these small units and Yeni Yashma have negligible impact on the grid. Two other experts stated that decommissioning the units and building new ones instead will be more effective than keeping current capacities.

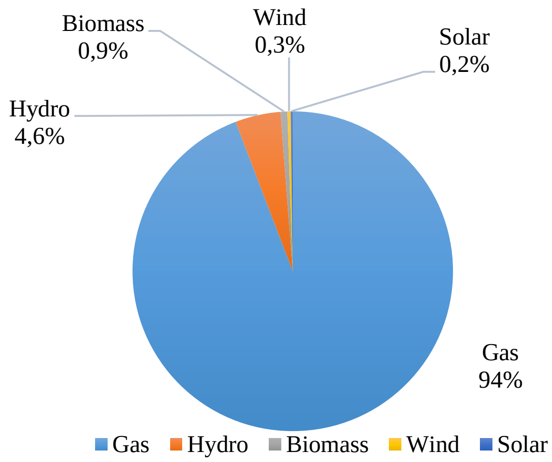
Table 2. Power plants included in the energy system of Azerbaijan (> 10 MW).

Name of the Power Plant	Source of Energy	Operator	Installed Capacity (MW) as of 2023
Azerbaijan TPP	Thermal	Azerenergy OJSC	2400
Shimal PP	Thermal	Azerenergy OJSC	800
Janub PP	Thermal	Azerenergy OJSC	780
Sumgait PP	Thermal	Azerenergy OJSC	525.5
Mingachevir HPP	Hydro	Azerenergy OJSC	424.6
Gobu PP	Thermal	Azerenergy OJSC	385
Shamkir HPP	Hydro	Azerenergy OJSC	380
Sangachal PP	Thermal	Azerenergy OJSC	299.3
Yenikend HPP	Hydro	Azerenergy OJSC	150
Baku TEC	Thermal	Azerenergy OJSC	107
Baku PP	Thermal	Azerenergy OJSC	104.4
Shahdagh PP	Thermal	Azerenergy OJSC	104.4
Astara PP	Thermal	Azerenergy OJSC	87
Shaki PP	Thermal	Azerenergy OJSC	87
Khachmaz PP	Thermal	Azerenergy OJSC	87
Tartar HPP	Hydro	Azerenergy OJSC	50
Fuzuli PP	Hydro	Azerenergy OJSC	25
Takhtakorpu HPP	Hydro	Azerenergy OJSC	24.42
Varvara HPP	Hydro	Azerenergy OJSC	17
Lerik PP	Thermal	Azerenergy OJSC	16.5
Jahangirbeyli	Hydro	Azerenergy OJSC	10.5
Hasanriz	Hydro	Azerenergy OJSC	10
Yeni Yashma WPP	Wind	Azerishig OJSC	50
Nakhchivan PP	Thermal	Nakchivan AR	87
Nakhchivan TPP	Thermal	Nakchivan AR	60
Araz HPP	Hydro	Nakchivan AR	22
Nakhchivan SPP	Solar	Nakchivan AR	22
Arpachay 1 HPP	Hydro	Nakchivan AR	20.5
Bilav HPP	Hydro	Nakchivan AR	20

BP Azerbaijan	Thermal	Independent	517.5
Garadagh SPP	Solar	Independent	230
SOCAR	Thermal	Independent	133.7
Balakhani SHWR	Biomass	Independent	37
Azersun Holding ASPU	Thermal	Independent	24
Shahdag Tourism Center CJSC	Thermal	Independent	10.5

Source: *MoE (2024).*

Figure 1. Share of electricity production in Azerbaijan by source (2021)



Source: *MoE (2022b).*

According to IRENA (2019), Azerbaijan has a 100% electrification rate, meaning the whole population has access to electricity. In 2016, Azerishiq implemented a metering program to rehabilitate power distribution networks across Azerbaijan and increase the availability of electricity for consumers. Asian Development Bank allocated a USD 750 million loan to improve the electricity supply. Currently, almost all consumers are metered in Azerbaijan. Supervisory Control and Data Acquisition system (SCADA) was installed in Azerishiq and Azerenergy. In addition, energy management systems, telecommunications and energy accounting systems were implemented within the framework of the "Electricity Transmission System Development" project in 2007-2011. According to the interview with the head of the department in one of the government entities, total installed electricity capacity currently exceeds 8 GW and the system's peak demand was around 4.5 GW in 2022, meaning electricity consumption is sufficiently covered by local production with excess generation capacity. During the nighttime, the demand is below 2 GW, and some power plants are kept on a low working load. The conventional power plants can be switched off easily, but some of them (especially with outdated equipment) cannot be turned off entirely, operating inefficiently on minimum loads. Investment expert told that the 2018 summer blackout in Azerbaijan happened during nighttime peak demand when plants operated on lower loads, and once demand soared, outdated equipment could not resist huge loading.

And yet further capacity additions are on the way. In February 2023, the President announced the construction of a 1280 MW Mingachevir TPP, the second largest in Azerbaijan. The project will be implemented by Azerenergy in cooperation with Italian company Ansaldo Energia. As the new plant is meeting modern standards, it will enable significant energy savings and emit less GHG (president.az, 2023). There are also plans to build a combined cycle gas turbine (CCGT) power plant with a capacity of 920 MW in Yashma village with the attraction of private investments. These projects will add 2200 MW to the installed capacity in 2025. Efficient and modern gas-fired power plants will allow balancing the grid once renewable energy sources are connected. There is, thus, a pressing need to decommission conventional plants and replace them with modern facilities equipped with flexible technologies for on-demand capacity adjustments.

The interview with experts from the public sector confirmed that the latest loss rate in grid is 2% in the transmission grid and around 8% in the distribution grid. While some efforts decreased the losses in the former to 2%, the distribution grid loss is still to be reduced to 5-6%. Experts mentioned the outdated regional distribution lines as the reason for high losses. The same holds for the transformers not being appropriate for the demand load of remote areas with a small number of residents.

The geographic distribution of the power plants in the region during the Soviet Union time led to the main TPP being built in Mingachevir city. The gas field being in Baku, the extracted gas is sent to Mingachevir to supply power back to Baku—the main demand point peak—again with cables. Back-and-forth transmission causes not only electricity but also energy and money losses. One expert mentioned that no detailed study has been conducted to understand the precise source of the losses.

Azerenergy and Azerishiq need to conduct a technical audit to determine the root problem. Some experts suggested that there were insufficient incentives for the two entities to embrace innovations. Thus, unbundling is necessary to advance the status quo in which innovations are hurdled.

Azerbaijan initiated market reforms to establish a competitive wholesale electricity market and attract foreign investment in renewable energy projects. As Mah et al. (2014, p.133) conclude, "to fully capitalize on the potential benefits of smart grid deployment, it requires not only technological advancement but also a good understanding of the regulatory barriers." Recently, the Law on Electricity promoting liberalization was approved during the third parliamentary reading (The Milli Majlis of the Azerbaijan Republic, 2023). This law outlines a three-phase roadmap for unbundling the electricity sector over five years, as detailed in Table 3.

Table 3. Timeline of the three-phased liberalization of the electricity sector in Azerbaijan.[1]

Phase 1	From the adoption date until June 30, 2023	Legal and Administrative unbundling of Production and Transmission (already separated from an accounting and functional point). Accounting and functional unbundling of Distribution and Supply.
Phase 2	From July 1st, 2025, to June 30, 2028	Legal and administrative unbundling of Distribution and Supply.
Phase 3	From July 1, 2028	The entry and operation of Independent Manufacturers and Supply entities into the market.

Under the new law, the government's main goal is to reduce its financial burden by allowing many private producers to enter the sector, privatizing current Azerenergy's power plants and abolishing subsidies. A market operator will be a separate legal entity under the transmission

[1] Four types of unbundling are distinguished in the Law:
Accounting unbundling – separate audit and annual accounts reports are produced; however, this form of unbundling does not imply independent decision-making power.
Functional unbundling – operational and managerial independence, however, still part of vertically integrated monopoly
Legal unbundling – a newly created legal form with independent decision with own management board, however still under supervision/ownership of the former vertically integrated monopoly.
Administrative unbundling – a separate independent entity is created with own task but shared operational activities within one central holding company.

system operator during the Phase 2. Its function will be to purchase electricity from private producers, sell it to various suppliers and only then the suppliers provide their service to customers. The government is to maintain the transmission and distribution functions within state regulations. For the phased transition, Azerbaijan Cabinet of Ministers approved the "Action Plan for the phased inductions of electricity market elements" in May 2024. Under this plan, the MoE, together with the Ministry of Economy and Azerenergy should submit a proposal for market operator establishment before December 31, 2025.

New Law stipulates the following players in the Azerbaijani future electricity market:

- Electricity producers
- Transmission system operator
- Distribution system operator
- Market operator
- Suppliers
- Prosumer
- Consumer
- Regulator

Curiously, in the Azerbaijani law prosumer is termed as "active consumer". It is judicially defined as a natural or legal person who consumes electricity and produces up to 150 kW of green energy in their homes or businesses. They can transfer the surplus of produced electricity to the electricity supply grid and receive a payment at appropriate wholesale rate approved by the Tariff Council. Draft regulations on prosumers have been prepared following EU and Turkish experience and submitted to the Cabinet of Ministers for consideration. In September 2023, three resolutions were approved: "Rules for the application of active consumer support mechanism", "Procedure and form for issuing a certificate on the source of electricity generated from renewable energy sources", "Regulation of the information system for renewable energy sources. The regulation puts the legal, organizational, and technological bases for the formation and operation of the information system on renewable energy sources, which integrates the resources of state bodies in one Electronic Government Information System. Along with a renewable energy certificate, applicable to prosumers and producers and certifying the source of electricity transmitted to the network, it will be monitored by the MoE and the AREA.

At present, the prices of utility services are administratively determined by the Tariff Council, rather than a result of interaction between supply and demand forces. A uniform tariff is applied for residential consumers and different tariffs for commercial and industrial applications. The Tariff Council is also authorized to set tariffs for any kind of renewable energy. During the market liberalization phases, this mechanism will be maintained for all utilities, including the price of electricity. After 2028 electricity prices are assumed to be formed based on market forces. Valid tariffs are represented in Table 4 below. On the other hand, with the adoption of the Law on Regulator, the AERA will be given certain normative powers, tariff regulation included. The agency has already prepared and submitted a tariff methodology plan to the Cabinet of Ministers.

In May 2021, the long-awaited Law on the Use of Renewable Energy Sources in the production of electricity was enacted, providing certain incentives for foreign investors to develop renewable projects in Azerbaijan. These incentives include guaranteed grid connection and guaranteed offtake through take-or-pay provision, ensuring priority access to transmission lines for these generators. The law also outlines two methods for selecting private generators: auctions or direct bilateral agreements with the government. Two renewable energy pilot projects were selected through a closed tender, and bilateral agreements were signed. In April 2024, the MoE with the support of EBRD announced its first renewable energy auction for a 100 MW SPP project in Garadagh region (Bitsadze, 2024).

Table 4. Electricity tariffs set by the Tariff Council.

	By service	Tariffs for 1 AZN/kWh (VAT incl.)
I	**Wholesale (**Purchase from the producer)	
	Private generation of small hydropower plants	0,05
	Wind power plants	0,055
	Other renewable sources	0,057
	Alternative sources	0,06
II	**Wholesale (except for consumers specified in Clause 8 of this Decision)**	0,066
	Aluminum industry with direct power supply via 35 and 110 kV transmission lines and has a stable daily load demand and has monthly average energy consumption for production purposes of not less than 5 million kWh	
	Daytime (from 08.00 to 22.00)	0,064
	Nighttime (from 22.00 to 08.00)	0,031
III	Transmission tariff	0,002
IV	**Retail**	
	Residential	
	Monthly consumption up to 200 kW (including 200 kW).	0,08
	Monthly consumption volume from 200 kW to 300 kW (300 kW included)	0,09
	Monthly consumption volume exceeding 300 kW	0,13
	Non-residential (except for consumers specified in Clause 8 of this Decision)	
	Trade and service	0,11
	Others	0,10

Source: *Tariff Council (n.d.).*

Note: *Tariffs are approved by decision No. 14 of the Tariff Council of the Republic of Azerbaijan dated October 16, 2021.*
1 USD = 1.7 AZN (Central Bank of Azerbaijan Republic, n.d.).

3. LITERATURE REVIEW

Renewable energy deployment set new records in 2022 and achieved almost a 50% record-high in 2023 (IEA, 2024). Sarhan et al. (2021) notes that while electricity security has traditionally been studied within the context of energy security, focusing on fossil fuels, the current landscape sees electricity security increasingly reliant on renewables. Electricity security, defined as the system's ability to ensure uninterrupted availability by withstanding and recovering from disturbances (IEA, 2021), is crucial.

Johansson (2013) concludes that the main advantage of renewables is their basis on energy flows instead of depletable stocks. Nevertheless, they heavily depend on weather patterns and efficient and technologically equipped systems. The existing grid was built when "generation was concentrated in a small number of large generators" (Varaiya et al., 2011, p.41) with passive load demands and controllable output. On one hand, the high penetration of variable renewable energy sources and interactive supply-demand response will, therefore, impose a great concern to the operation of the traditional grid. On the other hand, fossil fuel dependent electricity production keeps generating environmental degradation (Kartal et al. 2022). It is actually a very striking policy challenge. Additionally, Azerbaijan does not have plentiful water resources for power generation. Furthermore, as Ozcan et al. (2023) finds, electricity generation in hydro power plants (HPP) degrades environmental quality.

Although expensive to install—estimated network expansion and modernization USD 0.5 trillion investment annually to meet the 2030 Agenda (IRENA, 2023)—the transition to smarter grids is underway. The European Commission (2022) has released a EUR 584 billion investment plan to build a smarter electricity system by 2030. While in the US, a capacity of nearly 2 600 GW, 95% of this being solar, wind, and battery storage, is seeking connection to the grid (Gorman et al., 2024).

IEA describes (2007, p.6) the smart grid in the following way:

"*A smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users*."

It is critical to understand how the grid is becoming "smarter" compared to the conventional grid. As Poudineh and Jamasb (2012) conclude, the power sector is transforming into an "information-intensive" and competitive electricity market. Previously, the electricity was supplied by mostly state-owned monopolies in control of the generating power plants, transmission lines and distribution. However, the sector has been reformed substantially through liberalization and unbundling policies, breaking up these vertically integrated monopolies and allowing independent power producers to enter the newly established market. Liberalization refers to the "introduction of competition into the generation and supply sub-sectors", shifting the decision-making power from the state to the market and giving consumers the right to choose (IEA, 2000, p.9). Put simply, opening the energy and electricity market to free competition. Unbundling involves separation of vertically integrated monopolies from the other segments of the system where competition can be enforced through regulation (Morrison, 2022, p.477).

Unlike in a one-way traditional grid, a two-way electricity and information flow grid is required today. Smart meters enable a two-way communication, allowing consumers to manage their usage and supply while allowing providers to use the data for real-time pricing (Salkuti, 2020). The mechanism is referred to as demand response tariff. In contrast to traditional grids with static rates, demand response tariffs reflect the true cost of electricity, improving efficiency and service quality.

Electricity generation has shifted from large-scale facilities located far away to many small units located closer to end users (Ackermann et al., 2001, as cited in Aghaei & Alizadeh, 2012). The large power plants were built decades earlier for a different grid, demand load and operating conditions. The remote location of generating facilities may increase operating costs, energy and electricity losses. Placing units closer to the consumers is expected to reduce overall costs and energy losses while ensuring the stable supply (Gopstein et al., 2021). The main challenge is that the ageing infrastructure in combination with unutilized capacity possess greater risks (Gopstein et al., 2021).

Renewable energy's reliance on intermittent and non-dispatchable climate conditions makes storage technology critical for uninterrupted power supply. Consequently, backup power capacity is necessary during periods of low renewable energy availability (Pepermans, 2019). However, electricity is particularly challenging to store (Noussan, 2022). Generating electricity from renewables will require the operation of distributed storage capacities and distributed energy systems, facilitated by smart grids. This has led to a new concept of "prosumager"—a prosumer who has invested in additional storage, usually in the form of batteries (Woodhouse & Brown, 2022, p.621).

The smart grid is, therefore, "smarter" in two ways (Mah, 2014):

1) **Smart grids enable a two-way electricity and information flow**. Smart grid consolidates the data from the overall grid performance and provides price real-time pricing rates based on the current supply and demand metrics, allowing consumers to shift energy usage to off-peak hours (Poudineh & Jamasb, 2012). Consumers can monitor and manage their electricity use, make energy savings, or become prosumers by producing renewable energy at home and selling the excess back to the grid.

2) **Smart grids allow the integration of a variety of renewable energy sources from many small power producers.** The grid is significantly affected by the integration of a large share

of renewables due to their variability and limited predictability, and challenges such as energy storage management, grid stability, demand management systems, voltage control and forecasting issues arise (Eltigani & Masri, 2015). Smart grids can effectively coordinate all these components.

As existing literature on smart grid development shows, once a resource-rich country starts switching from natural gas to renewable energy sources, its power sector will remain unprepared and face a variety of challenges. In this manner, we should note that, Azerbaijan has multiple renewable electricity generation projects with multinational enterprises such as Masdar, ACWA Power, bp Azerbaijan, Nobel Energy and Fortescue Future Industries. From this standpoint, although there are studies on prospects of renewable energy sources in Azerbaijan and their economic and environmental impact, apparently, no study has ever examined whether current electricity system is ready to absorb newly introduced energy sources and adjust to global sector novelties. Our study shed additional light to this discussion with primary data. Upcoming projects and the preparation of conventional grid for additional electricity load will be a striking policy challenge during upcoming years. Traditional frameworks for ensuring electricity security, such as fuel availability and unexpected plant outage, will not be sufficient in the face of emerging trends and structural changes in the power system (IEA, 2021)**.** To become "smarter", the traditional grid should be modernized and updated based on current market conditions and technological advancement. Considering that full liberalization of the electricity market is expected to be achieved by mid-2028, this study provides insights for the policymaking challenges during the next four years. There is a notable literature gap about condition of electricity sector in Azerbaijan from this perspective, hence this study intends to fill this information and become a first of its kind.

4. METHODOLOGY

This study employs qualitative analysis through interviews. Primary data is collected via semi-structured interviews with local and foreign experts from the energy and electricity sector. In total, 10 interviews have been carried out, as per the information given in the table (see Appendix A, Table A1). All the interviews are audio-recorded and transcribed with the consent of the participants. The interview was chosen as the primary data collection method due to a lack of publicly available technical information and literature on the condition of the electric grid in Azerbaijan and industry insights. Therefore, this article makes primarily two main contributions. First, Azerbaijan is a resource-rich country that has started multiple efforts in energy transition and renewable energy. This being a worldwide challenge, current study will shed light on the necessity and feasibility of renewable's integration into the existing grid of the nation. It is not only for resource-rich countries. Second, it will address the current condition and ongoing reforms in the Azerbaijani electricity sector as well as contribute to the body of knowledge about electricity reforms in the developing world.

5. INTERPRETATION OF INTERVIEW RESULTS

5.1. INTERVIEW RESULTS

This study aimed to figure out challenges and evaluate Azerbaijan's prospects for smart grid development. Interviews with experts from 10 various entities were conducted to collect their exclusive insider knowledge and industry expertise and identify the focus areas for successful smart grid development in Azerbaijan.

Azerbaijani government has a strategy and priorities, one of which is to make sure smart technology is being utilized. The expected timeline for the integration of smart technologies is at least 5 years. Citing IEA's report on Electricity Grids (2023), "new grid infrastructure often takes five to 15 years to plan, permit and complete". World practice has shown that market liberalization has taken at least 10 to 15 years. As one of the public experts argued, it took them 5 years just to get the Law on Electricity approved.

Renewable energy sources are a new direction for Azerbaijan and requires massive, fixed capital investments. The government has targeted renewables development for several years and started making amendments to the legal environment 3 years ago to attract foreign investors. Being a net energy exporter of crude oil and natural gas, Azerbaijan did not require alternative energy sources before. The system, thus, was built to transmit electric power from a variety of distributed larger plants in a passive controllable manner.

Quoting the interview with one of the public experts, it was noted that:

"More than 90% of the GDP falls on the share of countries with a liberalized energy market. That is, 73-74% of the world's population already obtains electricity from the liberalized market. The non-liberalized markets are mainly in the islands where there is no need, or it is impossible to create competition. It is also in underdeveloped African countries and several authoritarian states."

An investment expert highlighted that:

"*The world club has approved electricity reforms and a new market strategy, and we need to start moving towards it, otherwise, Azerbaijan will stay much behind*".

6 out of 10 experts mentioned currently applied **tariffs** as being one of the main hindering factors in the prospect of renewable energy development. These tariffs are too low, which brings insufficient incentives for foreign investors to come. Azerbaijani tariffs for utilities are much lower than in the world, which means they are heavily subsidized. This is done to take off financial pressure from the citizens. However, the world standard is market-driven price creation. With the current tariff system, the process of unbundling is being prolonged and before unbundling is not in effect, it is impossible to adopt the market pricing approach. In addition, the current tariff methodology is not suitable for renewable energy sources. One of the experts assumed that the method used for renewable energy sources was the same as for thermal energy, and this is a wrong approach. Renewable energy is different; you do not pay for sun and wind, but you have high capital and operational costs. Today, wind energy is purchased for AZN 0,055 ($0,0323) and other renewables for 0,057 AZN ($0,0335) in Azerbaijan and these tariffs have not been changed since 2016. Time passed, but the tariffs have not changed, and the cost of raw materials has risen due to inflation.

There is no differentiation between onshore and offshore wind. A project expert has argued that there was three times project cost difference between them, the latter being the most expensive. In addition, there is no publicly available information on how these numbers were constructed. There are two systems relevant for providing impetus to renewable energy development: feed-in tariff and auction. Azerbaijan does not have feed-in tariff, and auction system was just introduced. However, to have a proper auction, first, unbundling—a liberal market, in which every bank and investor has an opportunity to assess the market risks—needs to be in place. Second, it should start with a feed-in tariff, when an investor has a guaranteed return, to be then smoothly replaced by different mechanisms and, finally, an auction system.

5 out of 10 experts pointed out **internal balancing issues** due to several existing deficiencies in the grid components. The capacities of Azerbaijan right now have been so negligible that discussions about challenges and larger volume integrations have not been even raised at all until recently:

1. First, overhead lines, transformers, and substations, the main parts of the transmission, were built during the Soviet period and pose limits to connecting renewable sources.
2. Second, renewables need a good planning system and network dispatch centres. SCADA system is applied at Azerenergy and Azerishiq, however, how well the scope of the software

is adopted and how well people are trained is the big question. The grid is partially manual and partially automated, therefore, controlling the electricity flow is still predominantly done by manpower. Lack of experience in the planning and operation of the mixed generation portfolio may bring substantial problems. It was stated that new software tools should be acquired for forecasting and planning scenarios, and real-time measurement systems, and the existing metering and telecommunication links should be upgraded for successful operations of renewable energy facilities. The establishment of control centers was stressed as well.

3. Third, there are plenty of old power plants which cannot work in line with renewable energy sources. There are overall three ways to balance the system: 1) Hydropower; 2) Storage capacities; and 3) CCGT power plants, which are always ready to balance the system once renewables share drops in the power generation. Due to the current situation with water resources, Azerbaijan is targeting the construction of new CCGT power plants. Two more projects have been already approved. It can be argued that Azerbaijan's electricity system is dominated by relatively new CCGTs, however, they are highly underutilized. Based on IEA's review of Azerbaijan's energy policy (2021), prioritizing the use of the most efficient power plants and, correspondingly, avoiding the use of the least efficient ones, would raise fleet-wide plant efficiency. Development and integration of the large share of variable renewable energy sources depend on the system's ability to balance the power system, meaning the capability of conventional power plants to change their power output based on the variability of the renewable energy output in real time.

According to a project expert from a private entity, in 2019, before the Azerbaijani government announced a closed tender for the renewable energy project, a world-renowned advisory company DNV assessed the electric system and the management model, and based on their report *the system could integrate up to 1.5 GW*. They could not make a detailed assessment, but they came to this conclusion based on information provided by Azerenergy. In their report, it was also noted that most of the conventional power facilities in Azerbaijan have flat active power output diagrams and they run on technical minimum during the lower demand hours. Now imagine, 1.5 GW is suddenly integrated into the grid. Take-or-pay contracts with ACWA Power and Masdar will provide them with the priority offtake and on the other side there are inefficiently used power plants running on their minimum. There is high uncertainty about how to correctly manage the network, and where and how the system operator needs to switch on or switch off the power plants. It might be that Azerbaijan can experience problems even with 1.5 GW incorporation or even less. It is unknown how the grid will react to this additional variable energy capacity.

The other side of the balancing issue is the **external interconnection** with neighboring countries. *Four experts* have stressed this moment. Azerbaijan's power system is interconnected with those of Russia, Georgia, Iran and with Turkey on the Nakhchivan border. However, the electricity system is synchronized only with Russia's, as Azerbaijan was previously part of the USSR's grid. Currently, Azerbaijan is not able to constantly stabilize its grid without a connection to Russia. Interviewers noted that to remain stable a grid needs to be connected to another bigger grid. One expert mentioned that this might be the only difference between European countries and Azerbaijan as in Europe every country is connected to another one via ENSTO-E cooperation, avoiding the challenge of grid stabilization in connection with renewables.

A private entity expert noted that Azerbaijan's geographical location adds risks to the unbundling process, making government control wise. They stressed that energy security is critical and uncertain should private companies take over the electricity sector.

Three experts noted the **limited role of the regulator** as a hindering factor for renewable energy development. Once the Law on Regulator is adopted, it will grant the AERA executive powers, but this law has been pending approval for a long time. Additionally, the AERA is currently overseen by the MoE, whereas, in most countries, such regulators are independent or under parliamentary subordination. Experts from financial and academic institutions agreed that the AERA should be fully independent to attract foreign investors. If the regulator remains within the government structure, it will create problems in attracting investors to the country.

In general, the goals and objectives of the regulator are to ensure the reliability of the service and the accessibility of the consumers and prosumers to the utility services, monitor trading strategies, punish market manipulation, create an attractive investment environment, and shape the competitive environment by regulating the relations between producers, transmitters, distributors, suppliers and consumers, and protect the rights of all. Independent regulation of these relationships is deemed necessary. Experts from the public entity noted that the main issue is not the status of the regulator but its empowerment: the MoE's supervision provides valuable support to the AERA with partner.

Investment expert noted that the **government was not aligned for liberalization reforms**. During the approval of the Law on Electricity, several parliamentarian representatives raised concerns about liberalization and opposed the law. This shows the opposition insight the government, Azerenergy particularly against such reforms. They have argued that market liberalization would result in a several-fold increase in electricity prices, raising social discontent. The tariffs are set at to keep services affordable and higher prices would affect poor the most. Some parliament members even offered to invite representatives of relevant state institutions to the law hearing for professional discussion (Apa.az, 2023). Another private sector expert additionally stated that there was a lack of coordination and communication between government agencies. Altogether this may present an obstacle to smart grid development.

Regarding **two-way electricity flow**, the experts responded that it was not economically feasible now. An analyst from a research center complained that one household must spend around 10 000 USD to install 10 kW of solar power on the rooftop of their house. In addition, same expert said that financial institution has conducted a study on small-scale distributed energy sources where the focus was making a cost-benefit analysis to understand whether prosumers could get any profit. It was revealed that it was not economically viable for people to adopt green energy sources as the tariffs were very low and the payback was almost negligible. There is little motivation from the government side, and it is highly costly for the local population. The government could potentially offer subsidies but has moved away from such measures in order to foster a market economy. Representatives from public entities expected prices to drop when the prosumer legislation is adopted but no visible effects have been observed yet.

5.2. DISCUSSION

The above-mentioned challenges show us that the legal base and physical grid infrastructure still need to be improved tremendously. For example, detailed and accurate Network Code for connection to the grid has not been issued and necessary legislative frameworks are blocked or pending for a long-time. However, it is said to be solved gradually by responsible entities and the government. The point is that in the current situation, Azerbaijan's risk is greater because all investments are made by the state budget. For instance, in 2018, after a country-wide blackout, the state allocated a lot of funds for the rehabilitation of the Azerbaijan TPP.

During the interviews, experts were asked about the roles of Azerenergy and Azerishiq in the liberalized market. There is a plan that structurally Nakhchivan AR will be connected to Azerenergy. The distribution lines are to be part of Azerishiq. It is planned to divide distribution system operator into regions and make around 9 companies in Azerbaijan. There, too, supply can be separated from distribution. But liberalization is expected in Azerishiq. Some of the Azerenergy-owned generation capacities are planned to be privatized. Privatization has not been carried out yet, and no legal base is present. The transmission system will unambiguously remain within the state's decision-making process. It was argued that Azerenergy will be split into two new entities: transmission system operator and market operator. Market operator is planned to be a separate legal entity under the transmission system operator. It was also noted that Azerenergy was also part of the state's privatization program under Azerbaijan Investment Holding, which carries out diagnostics (of loss-making companies working on subsidies), transformation (to become profitable with corporate governance enforced) and finally privatization of the state entities. The work in Azerenergy will take some time. This all cannot be done without the involvement of private investments.

State regulation is essential for electricity and energy security, which are a matter of the country's reputation. Given the geopolitical risks, this becomes quite a risky political issue. The state should aim to attract investment, support entrepreneurship, foster a competitive environment and the principle of fairness, as well as develop the market to balance the complex situation. It requires a delicate balance between electricity security and energy transition.

6. CONCLUSION AND POLICY IMPLICATIONS

6.1. CONCLUSION

This study compiles the challenges related to the smart-grid application in Azerbaijan and the shift out of fossil fuels toward renewables in electricity generation. Smart grid is especially important for the power generation from solar and wind. Azerbaijan is aiming to fulfill a generating potential of 5 GW of renewable until 2030 (president.az. 2024). Even though the government has an ambitious outlook for smart grid adaption to the current electricity system in Azerbaijan, the following challenges have been identified as a result of interviews conducted with the experts. The main hindering factor is the current tariff mechanism and electricity rates that are not suitable for renewables, and this fact prevents the attraction of foreign investors. Second, major legislative backgrounds, such as The Law on Regulator and Prosumer Regulations, have not yet been passed. Third, one prosumer must spend up to 10 000 USD to install 10 kW of solar power on a rooftop in Azerbaijan. This is economically inefficient for households, as for families of four persons the annual electricity bill will make around 600 AZN. The payback from rooftop green energy will not be achieved even in 15 years, all factors being the same. Fourth, it is worth mentioning, the study outcomes demonstrated that market regulator should be empowered and independent. The regulatory environment application of market principles is envisaged, and network codes are being prepared by the AERA. The electric grid project codes and 11 market monitoring rules have been drafted, however, they cannot be entered into force, since the Law on Regulator is not enacted. The same applies to the adoption of the prosumer regulation. Finally, the balancing issue is critical for Azerbaijan.

Based on interview results, Azerbaijan's electricity sector may be vulnerable due to high uncertainty arising from the limited predictability of the variable renewable energy sources which may result in frequent power outages. Nevertheless, it was argued that the integration of three pilot projects (total 710 MW) will not pose a problem but further additional variable capacities of mentioned 4 GW and higher should be analyzed and planned carefully. The adequacy of the offshore technical capacity of 157 GW should be considered separately. If these capacities are joined to the grid, the bigger will devour the system. In this matter, the government plans are to transition the economy from an oil and gas to electricity exporter derived from tremendous offshore wind capacity (Henley, 2024).

6.2. IMPLICATIONS

Considering all these challenges, the policy implications of this study are the following:

- The process of legislative background should be accelerated to facilitate consumers' transition to prosumers. The lack of any initiatives from the government side and high initial investment costs are major obstacles that impede the local community's switch to distributed renewable energy sources. Therefore, the long-lasting pending of necessary legislation should be sorted out gradually to promote the transition to two-way electricity and information flow.

- The AERA should be empowered to establish proper market monitoring rules and Network connection codes. Ideally, regulatory authority must be independent with separation from the government administration, for example, as the Central Bank of Azerbaijan. The independence of the regulator guarantees that the decision-making and market conditions are also independent of stakeholders' interests.
- The government does not want to be the main producer and investor anymore; therefore, the process of unbundling and introducing feed-in tariffs should be reinforced to attract private investors. Serious fixed capital investments are required: technical assessments and grid simulation should be conducted, new substations should be built, and transmission lines must be checked. Most importantly, control and research centers should be established, software should be updated, and people should be trained accordingly to mitigate forecasting moments. Inefficient power plants should be either decommissioned or privatized for further modernization works.

A paradigm shift is critical. The mindset should be changed from a conventional unidirectional electricity paradigm to a bidirectional and distributed smart grid system. Establishing the smart grid facilities in the same operating paradigm will not allow for to achieve systemwide efficiency. Everyone may understand the same smart grid in different ways. Smart grid is not only about conventional market liberalization and regulatory framework; it is more about technical engineering art: consumers, prosumers, demands and management, and DDD—decentralization, decarbonization and digitalization changing the power infrastructure.

6.3. LIMITATIONS AND FUTURE RESEARCH

As every study, this study has also limitations due to a small number of experts and its restricted scope. Further research may go deeper and analyze the current condition of the electric system in Azerbaijan from a technical perspective. Also, it is currently not known how foreign direct investment will create multiple imperatives in Azerbaijan electricity sector. For example, Acwa Power plans to invest about 5 billion US dollars in Azerbaijan renewable energy market (Azertag, 2024). Multiple foreign direct investments can provide financial relief and accelerate legislative amendments much earlier than expected by the experts in this study. COP29 which will take place in Azerbaijan in November 2024 has already triggered strong political will on adopting faster energy transition path (COP29, 2024). Moreover, policymakers can address the prospects for the development of an integrated energy system in Azerbaijan. As Azerbaijan has an excess installed capacity, this surplus electricity may be directed to other energy systems such as heating and cooling through systems coupling. Finally, a future study can be conducted on the prospects of Azerbaijan's export of offshore wind energy to Europe through the Black Sea Energy submarine cable project and its potential connection with Central Asia.

The table lists the main acronyms used in this paper.

Acronym	Meaning
AERA	Azerbaijan Energy Regulatory Agency
AR	Autonomous republic
AREA	Azerbaijan Renewable Energy Agency
CCGT	Combined cycle gas turbine
CO_2	Carbon dioxide

COP29	The 29th session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC)
COP	Conference of the Parties
EBRD	European Bank for Reconstruction and Development
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GW	Gigawatts
HPP	Hydro Power Plant
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
kW	kilowatts
MoE	Ministry of Energy of Azerbaijan
MW	Megawatts
OECD	Organization for Economic Cooperation and Development
PPA	Power Purchasing Agreement
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
SPP	Solar Power Plant
TPP	Thermal Power Plant
WPP	Wind Power Plant

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APPENDIX A

*Table A1. **List of interview participants.***

No.	Organization	Expert position	Interview method
1	Private Company	Senior Manager	Face to face
2	Private Company	Country Manager	Face to face
3	Research Center	Analyst	Online
4	Public Entity	Deputy Director and chief adviser	Face to face
5	Public Entity	Head of the department	Face to face
6	Public Entity	Head of the department and two advisers	Face to face
7	International Research & Advisory Institution	Senior Adviser	Online
8	Financial Institution	Energy sector investment expert	Face to face
9	Academic Institution	Professor, previous consultant in Financial Institution	Face to face
10	Public Entity	Head of the department and senior adviser	Face to face