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Electricity Grids, Smart Grids, and Micro Grids

Implications for Electricity Security in Azerbaijan Beyond COP29

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"Electric grids are really a blind spot for clean electricity everywhere."

– Fatih Birol

Grid Bottlenecks: Harbinger for a Gloomy Energy Transition

Policymakers around the world continue experimenting with different approaches to produce more renewable power in an attempt to achieve their obligations within the framework of the UNFCCC. On the one hand, wind and solar energy projects are on the agendas of numerous governments worldwide. On the other hand, producing renewable energy requires developing electricity infrastructure at the same pace. Consequently, electricity grids are currently evolving into a significant impediment and bottleneck to the swift implementation of renewable energy generation.

For instance, 8,100 energy projects—mostly involving wind, solar, and storage batteries—are awaiting regulatory approval to link up to electrical networks in the United States. This example illustrates the fact that global climate plans have a hidden weakness: electric grids. If electricity grids do not evolve quickly enough, soon renewable electricity supply will have nowhere to go.

In order to link sunny and/or windy locations in isolated rural areas with major cities, wind and solar energy frequently need long-distance transmission lines. According to

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IEA projections, by 2040, countries worldwide will need to build or upgrade about 80 million kilometers of power lines.

The Black Sea Submarine Cable (BSSC) project, which is 1,195 km long and is supposed to be fully operational in 2029, is the most recent example of a major planned addition to a transnational electricity grid. The bottleneck is quite visible now: on a global scale, projects involving at least 3,000 GW of renewable energy (of which 1500 GW are in advanced stages) are waiting for permission to connect to the electricity grid. Global investment in this critical infrastructure network has remained relatively constant at about $300 billion annually, whereas investment in renewables has been growing quickly, nearly doubling since 2010 (it still represents a small percentage of global energy consumption, however). As IEA Director Fatih Birol has put it, "Policymakers are all thinking about building new renewable power plants, but they haven't paid the same attention to building grids. It's like being focused on building the fastest, most beautiful car you possibly can, but then you forget to build the roads for it."

There are numerous examples from all around the world of how countries are desperately in need of better electricity grid networks. Here is one: Ukraine's thermal-power generation is running at 20 percent capacity, with 30 percent of the country's hydropower generation having so far been destroyed by the war. The estimated cost of restoring Ukraine's energy system stands at $50 billion. Another example is the boom in the solar panel market: the UK has plans to spend $68 billion to upgrade its electricity network to accommodate the growth in the offshore wind industry. A third involves China, which installed 217 GW worth of solar power in 2023 with more than 500 million solar panels. Wind-energy installation additions produced 76 GW with more than 20000 new turbines. Along with other countries, China is also supposed to upgrade its grid. Rationally, China uses renewable energy investments as a main driver of economic growth. In 2023, with $890 billion invested in the renewable energy sector, we see that it is a component of the largest driver of China's economic growth. This figure is similar to the entire GDP of Türkiye.

Furthermore, the far future is dismal in terms of upgrading the infrastructure for power generation. BloombergNEF estimates that the length of the world's cable network will have to double by 2050 to reach 152 million kilometers—this is longer than the distance between the Sun and Earth. In financial terms, this amounts to $21 trillion in fixed capital investments globally. As the head of a British business-led net-zero lobbying coalition put it recently, "the network will soak up 30 per cent of all the investment required by the energy transition."

Various global initiatives are emerging to overcome this challenge. An outstanding example is the Green Grids Initiative – One Sun One World One Grid (OSOWOG), which has also been endorsed by Azerbaijan. OSOWOG is a supergrid intended to enable cross-border power trading. The development of supergrids was previously hampered by political and technological issues. Currently, with technological advancement, declining

costs, and ambitious climate targets, the project is a relatively feasible one. The main technical study, undertaken by the EDF-led consortium (EDF is the French electricity supplier Electricité de France SA), is currently in progress.

One thing needs to be made clear, at this point: even if there is no energy transition—or if it does not happen fully in the way that its proponents advocate—something like that gigantic number ($21 trillion in fixed capital investments around the world) will still be required. There is, therefore, a chance that "grid delay" could generate extra demand for natural gas and coal for power generation, which suggests more carbon dioxide emissions. But the point is this: to meet national climate targets, grid investment allocations around the world should be doubled by 2030 to over $600 billion per year, with an emphasis on digitalizing and modernizing distribution grids.

This brings us to the importance of smart grids. The power flow and communication in a conventional grid are unidirectional. Put differently, electricity flows from the power generation facility to the substation and the end-user. But a smart grid establishes a power communication network between the supplier and the consumer with the help of smart sensors, smart meters, electric vehicles, and power-generating utilities. End-user consumers that generate their own electricity using renewable energy sources (later, we will call them "prosumers")—including solar photovoltaic (PV) systems and wind turbines—are able to sell their excess energy and feed them into traditional grids. In a conventional grid, the power grid may break down and even shut down entirely when the load demand exceeds the power generation. Here we can refer to an Azerbaijani example: power outages took place in 39 cities and regions of Azerbaijan on 3 July 2018 as a result of an accident in the Azerbaijan Thermal Power Plant (TPP) in Mingachevir. This illustrates one of the flaws of conventional grids.

Moreover, smart grid architecture enables multiple power sources like wind and solar to be integrated into the grid. In turn, this technology is supposed to balance out the load during peak hours and, therefore, eliminate the possibility of a complete blackout.

The Importance of Power Grids: The Case of Azerbaijan

Azerbaijan has taken great strides to become a renewable electricity exporter. Policymakers have designated AzerEnerji—the largest power producer in Azerbaijan—to be the main stakeholder in the most recent agreements: it is supposed to be the sole offtaker of renewable energy. In this manner, Azerbaijan looks to be decreasing the role of SOCAR in the energy transition. Nevertheless, SOCAR has established a daughter company, SOCAR Green, to oversee renewable energy projects and formulate carbon reduction strategies. AzerEnerji, as an alternative state body gaining importance in the country's renewable energy strategy, is also a stakeholder in the Black Sea Submarine Cable (BSSC) project, which is designed inter alia to enable Azerbaijan to integrate with the EU's internal electricity market. Meanwhile, the World Bank has invested $35 million into BSSC.

As the COP process creates a strong political imperative for the Parties to "contribute [...], in a nationally determined manner, [...] pathways and approaches [to transition] away from fossil fuels in energy systems, in a just, orderly and equitable manner" (to quote from the COP28 decision text), the expectation is that fossil fuel consumption will decline over time. The expectation is also that various fossil fuels will, over time, cease to be the largest source of electricity generation worldwide (in 2023, fossil fuels accounted for 60 percent of the global power generation mix).

To that end, we can say that *power grids can become the new pipelines in a post-hydrocarbon era*. Projections suggest that electricity will make up about 70 percent of the world's energy mix in the time ahead; currently, this share is 20 percent. It would thus be prudent for policymakers to increase their respective countries' preparedness for the massive construction of new power grids by increasingly adopting smart grids.

Since the full liberalization of the electricity market in Azerbaijan is scheduled to take place after mid-2028, power grids and smart grids will keep growing in importance. In the case of Azerbaijan, *one can liken electricity power lines to the existing network of export pipelines serving its oil and gas industry*. All these exist for servicing international energy markets. To facilitate the consumption of solar and wind power in the context of the domestic market, smart grids will play a pivotal role.

The smart grid is a technological advance that effectively balances the supply and demand of electricity and mitigates the intermittency stemming from renewable electricity supply that mainly relies on solar and wind. In Azerbaijan, wind and solar power currently makes up less than 1 percent of the country's total electricity production. Considering the productivity of hydro power plants, about 70 percent of Azerbaijan's water comes from sources that are located outside of its borders: Azerbaijan is a country facing water stress, which means that the production of renewable electricity will mainly rely on solar and wind sources. In this case, once renewable energy projects come online, power lines, as well as their digitization and modernization, should be there to transmit energy to end users.

As Azerbaijani decisionmakers considers their country's enormous potential in renewable energy, Saudi Arabia-based Acwa Power plans to invest almost $5 billion in the country. In addition, AzerEnerji contracted with UAE-based Masdar to produce 1,000 MW (1 GW) of solar and wind power plants. Azerbaijan has almost 200 GW of technical potential in developing renewable energy sources. This means that the contract with Masdar has tapped just 0.5 percent of this total potential. The room for growth is thus incredible. Azerbaijani policymakers should make sure that grid bottlenecks will not delay the country's energy transition; they should also ensure that its energy strategy indicates clearly that it seeks to become a renewable electricity exporter. The construction of power lines and the deployment of smart grid technology should proceed in tandem with the supply of renewable electricity.

The IEA defines electricity security thusly: "Electricity security is the electricity system's capability to ensure uninterrupted availability of electricity by withstanding and recovering from disturbances and contingencies." Here we need to examine the relationship between electricity security and smart grids: the conventional grid was constructed at a time when controllable output and passive load requirements were present and when "generation was concentrated in a small number of large generators." The large-scale adoption of variable renewable energy sources and interactive supply-demand response would, consequently, put the existing grid's functionality in jeopardy. The modern grid for communication and power transmission must be two-way—as opposed to one-way, as in the past. Through two-way communication made possible by smart grids, suppliers may use the resulting data to provide real-time pricing while customers can control their supply and usage.

Survey with Industry Experts

We surveyed ten industry experts to evaluate Azerbaijan's prospects for smart grid development. Our findings are summarized below.

First, even though businesses do not pay for the sun or the wind, their operating and capital expenses are significant. Six out of ten experts stated that one of the primary obstacles to the development of the renewable energy sector in Azerbaijan is the currently applied **tariff mechanism**, which is heavily subsidized. Current tariffs regarding renewable electricity generation may not create sufficient incentives for foreign investors to enter the Azerbaijan power generation market, as full market liberalization will take place only in mid-2028.

Second, the Azerbaijan Energy Regulatory Agency (AERA) needs to be completely independent in order to draw in international investment. In this manner, the **limited role of the regulator** (i.e., AERA) was identified by three experts as a barrier to the advancement of renewable energy. Once the Law on the Energy Regulator is adopted, it will grant AERA executive powers and secure its independence. Azerbaijani policymakers and lawmakers can accelerate this process.

Third, five out of ten experts identified **internal balancing issues** pose limits to connecting renewable sources. These include existing deficiencies in the grid components: overhead lines, transformers, and substations inherited from the Soviet era. Additionally, there are plenty of old power plants that cannot be utilized in line with renewable energy sources. Even though the Supervisory Control and Data Acquisition (SCADA) system is applied at both AzerEnerji and Azerishiq, the grid is partially manual and partially automated, therefore, controlling the electricity flow is still predominantly done by manpower.

Fourth, since Azerbaijan was part of the USSR's electrical grid, its electrical system has not been synchronized with many countries in the post-Soviet period. The experience of much of the European continent sheds some light on this issue. The problem of grid stabilization in relation to renewables is avoided most of the European continent since all of the countries are interconnected and collaborate through the European Network of Transmission System Operators (ENTSO-E). Azerbaijani policymakers can adopt a strategy that will **develop proper external interconnection** as a balancing issue. As the 4-GW Black Sea Submarine Cable (BSSC) project is likely to be functional by 2029, the prior enabling of cooperation through ENTSO-E for Azerbaijan could constitute a farsighted and prudent step.

Fifth, several of the experts that we polled raised concerns about the liberalization of the electricity market and opposed the Law on Electricity. They argued that market liberalization would result in a several-fold increase in electricity prices, which clearly represents an additional financial burden for consumers. Other experts that participated in our survey noted the delay in executing **electricity market liberalization reforms**. Although eleven market monitoring regulations and a Network Code for enabling renewable grid connections have been drafted, the necessary Law on Regulator is still pending. Nothing can be put into effect whilst the Regulator does not have enforcement power.

We can get to the *sixth* finding of our survey through an explanation of the term "prosumer," as introduced briefly above. As they both consume and produce power, active energy consumers are often called "prosumers" in Western sources. In this manner, regarding two-way electricity flow, the experts responded that it was not economically feasible now. One prosumer household should spend up to $10,000 to install panels that produce 10-KW of solar power on its rooftop. This is economically inefficient for households, as the annual electricity bill for a typical family of four in Azerbaijan comes out to about 600 AZN (around $350). The return on investment from having purchased the equipment to generate rooftop renewable electricity would thus take more than 15 years, at current prices. Thus, an argument can be made about reconfiguring both Azerbaijan's subsidy and custom tariff regime. In other parts of the world (mostly in developed countries) where a relatively higher level of renewable electricity penetration is currently present, prosumers can sell their excess supply to the grid and earn money. **Making microgrids financially attractive for households and establishing a favorable environment for them to be prosumers can boost Azerbaijan's electricity grid security**. There are two main public policy arguments for moving forward in this direction. One, adopting smart grids will optimize electricity flow using advanced technology. Two, enabling microgrids that are localized grids and can thus operate independently of the main grid will generate resilience for electricity grid systems. Microgrids can become especially vital for rural communities. When Hurricane Fiona hit Puerto Rico, for example, fossil fuel power plants were knocked out of commission. Microgrids served as lifelines for rural families, businesses, and hospitals.

Policy Implications

In this IDD Working Paper, we have sought mainly to emphasize the importance of power lines, smart grids, super grids, and microgrids. All these technologies are evaluated considering Azerbaijan's enormous potential for solar and wind power sources, which ranges between 150-200 GW. As natural gas-fired power plants now account for 92 percent of the country's electricity production, it is imperative for Azerbaijan to diversify its power generation away from fossil fuels to remain in compliance with the documents resulting from various UNFCCC processes. The government aims to achieve a 5 GW renewable potential by 2030, which is realistic. What follows are the main policy implications of the foregoing.

The evolution of end-users from consumers to prosumers is possible. To create a favorable climate for prosumers, the legislative framework should be expanded. In Azerbaijani law, a prosumer is termed an "active consumer." A prosumer is judicially defined as a natural person or legal entity who consumes electricity and produces up to 150 KW of renewable energy. Those in this category are allowed to transfer the excess of produced electricity to the main grid and receive payment at an appropriate wholesale rate approved by the Tariff Council. End-users need further clarity and awareness on this issue; indeed, it is not being actively promoted. Moreover, the existing one-way conventional grid system is not flexible enough to provide what is allowed in the aforementioned law.

There should be a comprehensive study to determine the volume of investments needed in electricity infrastructure, especially regarding the grid, in order to assess the preparedness of existing power systems for future renewable energy projects. By 2030, Masdar plans to develop up to 10 GW of renewable energy in Azerbaijan. The World Bank reports that Azerbaijan has a technical offshore wind potential of approximately 157 GW, which is more than 20 times its installed energy capacity. It is important to make sure that grid bottlenecks do not impede its development.

The shift to distributed renewable energy sources is hampered by high initial investment costs. Subsidies that favor microgrid-related devices and custom tariffs could be encouraged for both individuals and businesses.

The authority to create appropriate network connection codes and market monitoring regulations should be granted to a fully empowered AERA. Pending approval of legislation (modeled on the EU's Third Energy Package) granting independence to AERA should proceed faster.

Technical evaluations, grid simulations, new substation construction, and transmission line inspections are all examples of the types of significant fixed capital investments that are needed. Tariffs in the electricity market should be attractive for foreign and domestic investors to fund additional modernization projects.

In order to optimize fleetwide power plant performance, inefficient power facilities should be either shut down or privatized. Modern power plants should enable the grid system to balance variable renewable energy output in real-time.

The full liberalization of the electricity sector in Azerbaijan is scheduled to take place on 1 July 2028. Policymakers (including lawmakers) are supposed to make sure that the development of power grids and smart grids proceed perfectly in tandem with this calendar. The legislative process should thus not cause unnecessary delay. Moreover, electricity market liberalization-related laws should be adopted concurrently. Put differently, all these legal amendments should take place before 1 July 2028. Only in this case will there be an absence of legislative ambiguity.