Development Prospects of Alternative Energy Sources

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Abstract: The article examines current trends in the field of renewable energy and discusses Azerbaijan's development prospects in this field in an international context. The study used descriptive and comparative analysis methods to examine global trends and Azerbaijan's prospects in renewable energy development. The main data sources are based on official reports from the International Energy Agency (IEA) and other relevant international and national energy institutions. The study findings could be useful for alternative energy policymakers and energy planners. The recommendations provide practical advice for developing countries seeking to balance economic growth goals with environmental responsibilities. The study highlights the growing importance of wind and solar power in renewable energy development. The study shows that IT is not just an auxiliary tool, but a fundamental enabler of alternative energy sustainability, while also creating new system vulnerabilities that require active cyber-management. The article presents a critical, synthesised analysis of the convergence of IT and energy in the Azerbaijani context, including regional barriers to energy transition and a comparative analysis with developed alternative energy markets.

Keywords: alternative energy, smart grids, artificial intelligence, IoT, energy transition

1.Introduction

The article analyzes trends in renewable energy production. Unlike the traditional model, solar and wind energy are more accessible to people and cause less harm to the environment. In Azerbaijan, the development of clean energy is also supported by various incentive programs, the most obvious examples of which are SOCAR Green and MASDAR. Other developing countries are also taking steps in this area.

The main problem in the field of alternative energy is not related to production, but to storage. Since this energy, unlike traditional energy, is dependent on variable climate conditions, it requires special large storage systems. Nevertheless, work in this area continues, as it is an important step for the energy independence of countries. Azerbaijan is also in this process. As a country seeking to reduce its dependence on energy imports, the transition to a "green" infrastructure is on the agenda here.

2. Global Trends and Technological Development

In the 1990s, renewable energy accounted for 3% of total energy [1]. Since then, countries around the world have been working to decarbonize their energy systems to combat climate change. In the past five years, this figure has reached a record high. In 2023, renewable electricity accounted for 30.3% of global electricity generation, with most of the net growth coming from hydro and wind power [2]. But that doesn’t

tell the whole story. The main issue is how these systems are managed. Unlike traditional systems, solar power plants and wind turbines generate electricity based on weather conditions. Managing such a network was simply impossible twenty years ago. It requires forecasting, adaptation, and distributed decision-making on a scale that only digital systems can support.

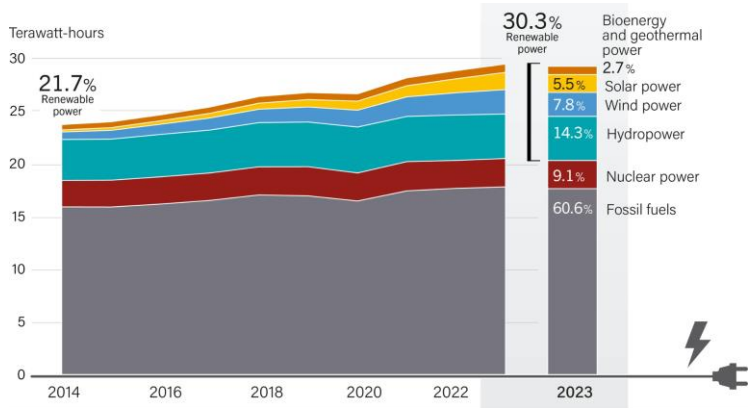


Figure 1. Global Electricity Generation by Source (2014–2023)

During 2020, global solar power capacity exceeded 142 GW, an increase of one-fifth. At the same time, while in 2010 there were only 7 countries in the world with solar power plants, in 2020 this figure increased to 43. China is still the leader in this field, but in recent years, other countries have managed to reduce the gap. The areas suitable for the development of solar energy are mainly desert areas, while for wind energy, these are coastal areas. Tables 1 and 2 show the largest solar power plants and wind farms in the world.

Table 1. Largest Solar Power Plants Globally by Installed Capacity

Solar Park	Country	Capacity (MW)
Talatan Solar Park	China	21,000
Ningdong Solar Park	China	18,320
Hobq Solar Park	China	10,020
Urtmorin Solar Park	China	5,440
Midong Solar Park	China	5,000
Ruoqiang Solar Park	China	4,000
Otog Front Banner Solar Park	China	4,000

Table 2. Largest Wind Farms Globally by Installed Capacity

Wind Farm	Country	Capacity (MW)
Gansu Wind Farm	China	30,000
Zhang Jiakou	China	21,235
Urat Zhongqi, Bayannur City	China	2,100

Mintyre & Herries Range, QLD	Australia	2,023
Markbygden Wind Farm	Sweden	2,000
Hami Wind Farm	China	2,000
Damao Qi, Baotou City	China	2,000

In Europe, wind and solar together accounted for more than a quarter of electricity generation in 2020 [3]. In Europe as a whole, including all alternative sources, such as hydroelectric power plants, the share of renewable energy sources has increased by almost half, overtaking fossil fuel-based electricity generation for the first time. The figure is even higher in Germany, the United Kingdom, Norway, Switzerland, and Sweden.

Alternative energy sources are of particular importance for Azerbaijan, whose economy has long been dependent on hydrocarbon exports. The Southern Gas Corridor is a prime example of this [4]. Azerbaijan's hosting of COP29 in 2024 is an indication that the country has taken important steps in this area.

3. IT as a Driver of Development

Information technology has greatly increased the efficiency of alternative energy through forecasting. Solar radiation and wind speed are weather-dependent and uncertain, but they are not random. Studies have shown that neural network-based forecasting models can reduce forecast errors by 20–40% [5].

The Internet of Things (IoT) brings this capability from the network level directly to devices. Hundreds of sensors installed on a modern wind turbine can transmit data such as vibration, temperature, and rotational speed. Studies show that these sensors can reduce the operating time of a wind turbine by 30–50% [6].

The integration of data collected from sensors poses a serious challenge in itself. A simple solar power plant generates terabytes of data every year. Central servers are not enough to process this data. Smart grid technology is the only solution to this problem [7]. In essence, a smart grid is an electrical network in which information flows in both directions simultaneously between the generator, the grid operator, and the consumer. Thanks to this, users can monitor electricity consumption in real time.

The value of renewable energy also depends on the intelligence of the grid it is connected to. This is an overlooked but fundamental problem. A solar panel on a simple grid is economically poor. The same panel on a smart grid with real-time assessment creates more value for both the user and the system. Some countries that invest in energy production without investing in digital infrastructure are wasting money.

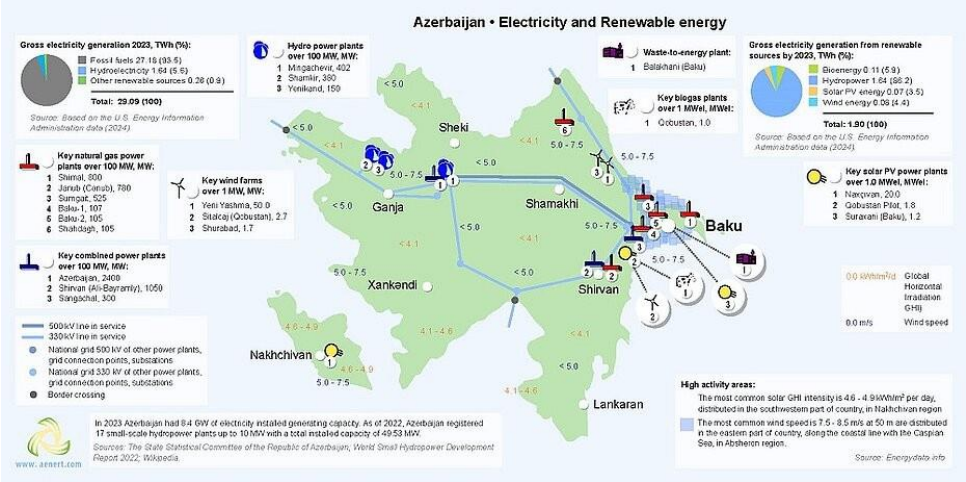
4. Development Prospects: Global Trends and Azerbaijan's Position

In recent years, the global development of alternative energy sources has exceeded expectations. The rapid decline in the cost of solar panels has led the International Energy Agency to revise its forecasts. Based on current trends, renewable energy is expected to account for almost half of global electricity production by 2030 [8]. The main drivers of this development have been the steps taken globally. The EU's REPowerEU program and the US Inflation Reduction Act of 2022 have pumped hundreds of billions of dollars into this sector [8]. Technology costs have fallen, and production chains have been restructured.

Azerbaijan is both a gas exporter and a country with significant renewable energy resources. The country also has significant wind resources along the Caspian coast. According to AREA figures, the technical potential is 27,000 MW: the main share is solar, with a small share from wind, and the rest from bioenergy and river energy [10]. Solar energy in the country has the largest technical potential. The government's goal is to obtain the majority of electricity from renewable sources by 2030 [11]. Hydropower plants also remain an untapped resource. The country's technical potential in this area is estimated at 520 MW. However, only

a small part of this capacity is currently used, and a large part of the potential remains untapped.

Figure 2



According to the Azerbaijan Renewable Energy Agency's 2023 data, one in six kilowatt-hours of total energy comes from renewable sources. The majority of this is hydropower. The majority of hydroelectric power comes from the two largest hydroelectric power plants located on the Kura River. The largest wind power system is installed in the Khizi district.

The creation of SOCAR Green is connected with the arrival of COP29 in Baku. Strategic partnerships with major energy companies such as 'Masdar' and 'ACWA Power' show that this step is taken with serious intention [12]. The result will be known in practice.

5. Challenges and Critical Gaps

The biggest technical challenge with renewable energy is its variability. Solar panels work in clear skies, while wind turbines work in windy conditions. When the weather changes, production drops. Traditional power grids are not designed to handle this kind of variability. As the share of renewable energy increases, storage systems and grid management systems are becoming increasingly important.

Solar farms and wind farms require large areas of land. This is becoming a serious competition for agricultural land. As a solution, some projects are looking to combine both uses. It has not yet been tested on a large scale, but the idea is interesting.

Cybersecurity is the least talked-about but most worrisome aspect of the energy transition. An example of this is the ransomware attack on the Colonial Pipeline in 2021. To prevent this, the company simply shut down its fuel distribution system. Some states in the eastern United States were unable to find fuel during the day. Although the incident affected a fuel pipeline, it demonstrated the potential consequences of cyberattacks on critical energy infrastructure. The smart grid is much more complex. A successful cyberattack on a digitally connected energy grid could potentially disrupt electricity supply across a large geographic area.

This represents a serious cybersecurity concern. Dozens of power grid intrusions have been reported in Europe and North America in recent years. This is a particularly serious concern for Azerbaijan, where the grid infrastructure is still in its infancy [13]. Systems built without a cybersecurity architecture are a huge risk.

The second issue that receives little attention is the digital divide. Artificial intelligence-based energy systems need a lot of data to operate. Countries that manage modern grid infrastructure have been collecting this data for decades. Countries that build new systems must collect this data from scratch. This means that simply "copying" AI algorithms that have been successfully tested, such as in European or North American contexts, and using them in different climates and infrastructure conditions, will not produce the same results in Azerbaijan or similar settings.

6. Conclusion

The transition to alternative energy has moved from a topic on the agenda to a real policy issue. This is an important step towards ensuring energy independence and restructuring national economies towards a greener economic model. It is good that Azerbaijan is joining this process. But "joining" is a start, not a goal. Conducted research and analysis show that the development of the alternative energy sector in Azerbaijan directly depends on the implementation of Information Systems in Management. The digitalization of the energy system, the inclusion of "Smart Grid" elements in a centralized system, brings with it several critical solutions:

1. Minimizes technical risks arising during the synchronization of renewable energy to the grid;
2. Ensures the active involvement of consumers in the energy management process (prosumer model);
3. It forms a reliable analytical and statistical database to help the state achieve its green energy goals.

Finally, it is advisable to develop automated reactive control algorithms that can be directly integrated with the local energy grid in future research

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