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PROSPECTS FOR THE DEVELOPMENT OF ENERGY INFRASTRUCTURE AND ELECTRIC POWER SOURCES IN UZBEKISTAN

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Annotation: This article, using the example of the Republic of Uzbekistan, analyzes the potential and challenges of all types of energy resources currently in use through comparative and analytical approaches. It examines scientifically grounded methods for generating energy that meet the contemporary socio-economic development needs of society, as well as the future prioritization of emerging energy sources. Furthermore, it explores the possible outcomes of how countries' energy development strategies, encompassing all types of energy resources, may influence long-term sustainability and efficiency.

Keywords: Energy infrastructure of Uzbekistan, electricity generation sources, renewable energy sources, energy efficiency, wind energy, solar energy, geothermal energy, energy security, energy supply, electricity production, green energy, energy resources.

Introduction

It is well known that at the current stage of global development, the demand for energy consumption is increasing significantly faster than the rate of its production. Considering industrialization, economic growth, and the nearly twofold increase in the world's population in the 21st century, estimates suggest that the amount of energy humanity will consume over the next fifty years may exceed the total energy used throughout its entire history [1]. Therefore, the issue of energy supply is becoming increasingly acute, and the effort to improve the efficiency of utilizing various energy sources is turning into a global competitive arena.

Indeed, in the future, the most accurate indicator of a country's level of development is expected to be the amount of energy consumed per capita per unit of time. However, the question of how energy that meets all socio-economic development requirements of modern society should be generated, and which energy sources will become dominant in the future, remains unresolved. Different countries, based on their geographical location and internal conditions, prioritize certain types of energy resources over others.

In this context, one of the key challenges faced by all countries is to identify the most suitable and probable types of energy sources by considering all advantages and disadvantages associated with energy production, thereby ensuring sustainable economic development. It should be noted that, depending on geographical location, level of development, and natural potential, a single type of energy source may not be universally optimal for all countries. Thus, acquiring comprehensive practical and analytical knowledge about the potential future outcomes of various energy sources in national energy development is of critical importance.

This requires a thorough evaluation of the opportunities and constraints of all types of energy resources currently utilized by humanity, based on systematic analysis and comparison. At present, widely used energy sources such as fossil fuels-including oil, natural gas, and coal-are associated with increasing challenges. These include the limited nature of their reserves, the rising costs of their utilization, and the significant environmental damage they cause.

To address these issues, there is a growing global movement toward transitioning to alternative forms of green energy. Green energy, also referred to as renewable energy, is steadily increasing its share in the global energy mix, according to international agency reports [2]. Alternative energy sources include solar, wind, and geothermal power plants, small-scale hydroelectric stations, bioenergy systems, waste-to-energy complexes, as well as energy derived from ocean and sea tides. Table 1 below presents all types of energy sources [3].

Table 1

Primary natural resources underlying the generation of all types of electrical energy sources [4]

Usage Methods	Human User Energy	Initial Natural Sources
Solar Power Plants	Solar electromagnetic radiation	Solar nuclear synthesis
Wind Power Plants	Kinetic energy of wind	Solar nuclear synthesis in the movement of the Earth and Moon
Hydropower Plants	Water movement in rivers	Solar nuclear synthesis
Ocean Surface Current Power Plants	Water movement in seas and oceans	Movement of the Earth and Moon
Wave Power Plants	Energy from sea and ocean waves	Solar nuclear synthesis in the movement of the Earth and Moon

Geothermal Power Plants	Heat energy from hot sources	Earth's internal energy
Fossil Fuel Power Plants	Chemical energy of fossil fuels	Ancient solar nuclear synthesis
Renewable Fuel Power Plants	Chemical energy of renewable fuels	Solar nuclear synthesis
Nuclear Power Plants	Heat released from nuclear fission	Nuclear fission

All energy sources possess distinct characteristics, and their optimal utilization requires a comprehensive assessment of all associated causes and consequences. Therefore, one of the most pressing tasks today is to analyze and compare each type of energy source in terms of its social, economic, and future potential. Such an approach contributes to a clearer understanding of different energy resources and supports the development of a well-informed and balanced perspective toward their use.

Literature Review

The operating principles of various types of energy sources, their potential contributions to energy supply, specific features of stable operation, and the extent of their geographical feasibility have been sufficiently covered in the literature [5]. At the same time, information is also available regarding their environmental impact, safety levels, and the cost of energy production [6]. However, despite the availability of extensive data, there is still no consensus within the global community regarding the future role of nuclear energy, as reflected in existing studies.

At present, there is a lack of literature that convincingly demonstrates to students, particularly in the context of Uzbekistan, that nuclear power plants (NPPs) could be among the safest and most important energy sources. Such literature should comparatively analyze the depletion of fossil fuel resources, their environmental and health impacts associated with climate change, the safety of modern advanced NPPs, and the potential of blue energy. Existing works are mostly authored by specialists in nuclear energy and primarily emphasize the advantages of NPPs [6]. It should also be noted that there is a significant shortage of educational resources that scientifically present global developments in energy infrastructure and electricity generation, helping society to form a well-informed perspective on energy reforms.

Methodology

This article examines, using the example of the Republic of Uzbekistan, the potential and limitations of all types of energy sources currently in use through analytical and comparative

methods. It discusses how energy can be generated in ways that meet modern socio-economic development requirements, the future prioritization of emerging energy sources, and the possible outcomes of different energy development strategies adopted by countries.

Results

Currently, the global distribution of electricity generation by energy source is as follows: thermal energy—coal accounts for 39%, natural gas 22%, hydropower (energy of water flow) 17%, nuclear energy 11%, and other sources 11% [8]. This indicates that fossil fuels remain the dominant source of energy production. However, due to the reasons mentioned earlier, their future potential is steadily declining.

As a result, while some countries place great hope in the future of green energy, others consider nuclear energy to be a priority for economic development. In this regard, it is crucial to draw conclusions based on an evaluation of their respective potentials and limitations.

Among renewable energy sources, hydropower is the most widespread and is implemented at both small and large scales. Although large-scale hydropower is classified as a renewable source, it can create specific environmental challenges. Such facilities are typically constructed through large dam projects in downstream river areas or in regions with high water flow velocity and significant potential energy. Therefore, in addition to requiring substantial financial investment, they may also lead to disputes depending on geographical location. Issues such as ecological risks due to large reservoir areas, displacement of local populations, the risk of dam failure, and greenhouse gas emissions in tropical regions must be addressed. Furthermore, attracting investment for such projects can be quite complex.

Other energy sources—such as ocean current power plants, wave energy systems, geothermal power plants, bioenergy installations, and energy derived from waste processing—currently contribute less than one percent to total energy production and may be considered negligible in the present context.

Wind and solar energy sources also have their own advantages and disadvantages. On a global scale, the development of these sources is rapidly increasing due to the decreasing cost of production and gradual improvements in efficiency. Countries leading in wind and solar energy include China, the United States, Japan, Italy, Spain, Germany, the United Kingdom, and France. In these countries, strong support mechanisms, technological advancements, and cost reductions have led to a doubling of their share in total energy production over the past four years [9].

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It should be emphasized that renewable energy sources, fossil fuel-based energy, and nuclear energy all present significant environmental and human health challenges. Public concern regarding nuclear energy is understandable, as its early development was marked by accidents, explosions, and issues related to radioactive waste management. However, in the context of declining fossil fuel resources and their harmful environmental and health impacts linked to climate change, developed countries are increasingly achieving a balanced development of their energy sectors by combining nuclear energy with blue energy, supported by the improved safety of modern advanced NPPs.

For example, following the accident at the Fukushima nuclear power plant in Japan, the country temporarily restricted the use of nuclear energy. However, after a short period and significant societal adjustments, Japan resumed its use, demonstrating the indispensable role of nuclear energy in certain countries.

It is also important to note that, in the near future, the construction of 164 nuclear reactors is planned worldwide. In addition to existing facilities, 40 reactors are planned in China, 25 in Russia, 20 in India, 18 in the United States, 9 in Japan, and 8 in South Korea, with construction already underway for 60 of them. Figure 1 below presents the ranking of 20 countries based on the number and capacity of nuclear power plants commissioned to date [9, 11].

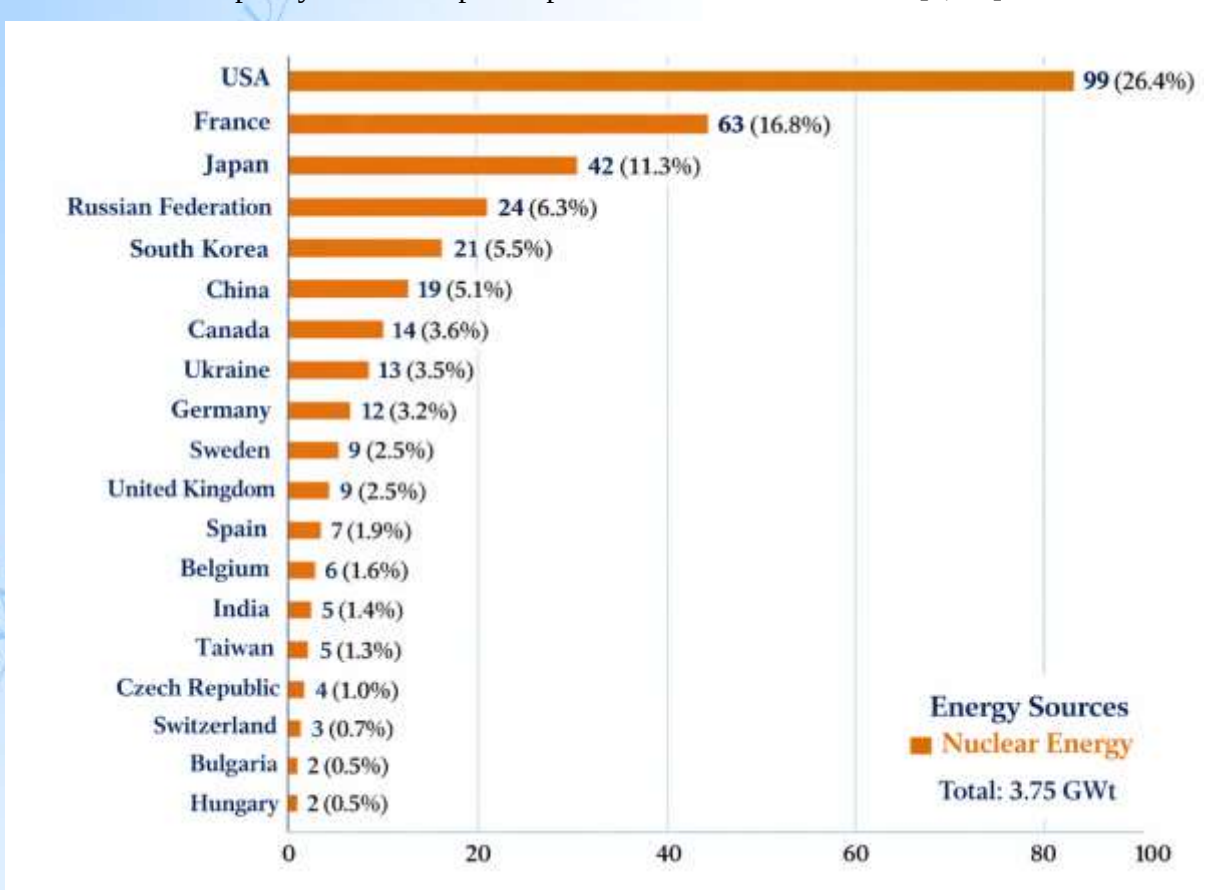

Figure 1. Number and capacity of nuclear power plants commissioned to date across 20 countries.

In addition, countries such as Turkey, Poland, Vietnam, and Indonesia, among others, are initiating the development of nuclear energy for the first time. All of this indicates that the share of nuclear energy among overall energy sources is steadily increasing. The advantages of nuclear energy sources lie in their ability to provide stable and relatively environmentally friendly energy supply compared to fossil fuels, provided they are developed with sufficient capacity.

The key requirements for all types of energy sources, evaluated through analytical approaches using five conditional indicators, are presented in Table 2 [2, 11].

Table 2

Key socio-economic characteristics of nuclear and other types of energy sources

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	Energy Source	Stability of Supply	Long-term Resource Availability	Environmental	Sufficiency of	Land Use	Safety Level	Public Acceptance	Public Acceptance	Efficiency	Long-term
1	Nuclear energy	+	+	∇	+	-	+	□	+	+	+
2	Small hydropower plants	∇	+	+	□	Δ	+	+	-	□	+
3	Small hydropower plants	+	+	∇	+	+	∇	Δ	-	□	+
4	Solar energy	Δ	+	+	-	-	+	+	+	-	□
5	Wind energy	Δ	+	+	-	-	+	+	+	-	□
6	Geothermal energy sources	-	-	+	-	-	+	+	-	-	□
7	Bioenergy systems	-	-	+	-	-	+	+	+	-	-
8	Ocean current power plants	-	+	+	-	+	-	+	-	-	+
9	Wave power plants	-	+	+	-	+	+	+	-	-	Δ
10	Waste-to-energy systems	-	-	+	-	-	+	+	-	-	-

Notation: "+" – high; "∇" – above average; "□" – average;

"Δ" – below average; "–" – low.

From this, it follows that among the most important criteria for energy supply—such as stability, long-term viability, sufficient capacity, environmental safety, and moderate construction costs—nuclear, hydro, wind, and solar energy sources demonstrate advantages compared to others [10–12].

The development of green energy largely depends on a country's geographical location, energy demand and supply, population size, and level of development. Based on these factors and the analysis of the data presented above, it can be stated that for Uzbekistan, it is critically important to develop energy sources that ensure both sufficient capacity and stable supply. In this regard, the emphasis placed by the country's leadership on developing nuclear energy alongside green energy is scientifically justified and represents an optimal strategic direction.

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Indeed, although renewable energy sources can contribute to the overall energy balance of Uzbekistan, achieving sufficient capacity solely through them is challenging. One of the reasons wind energy cannot have a large share is the country's distance from seas and oceans, which results in the absence of consistently strong winds and the occurrence of windless periods, making it difficult to ensure stable and high-capacity energy production. However, the Aral Sea region may be suitable for wind energy installations.

Similarly, despite Uzbekistan's high solar potential, the share of solar energy cannot be very large due to relatively low efficiency, the requirement for extensive land areas, and the gradual degradation of operational performance over time under external influences. These factors lead to fluctuations in long-term energy supply stability.

Hydropower, although more significant than the aforementioned sources, also has limited development potential in Uzbekistan due to geographical constraints. Insufficient river flow rates, the creation of large reservoirs occupying valuable land, and safety concerns related to dams all affect the feasibility of constructing large-scale hydropower plants.

On the other hand, small and medium-sized hydropower plants have greater potential and are environmentally cleaner. While they can contribute to overall energy supply, variations in water volume can affect their stability. Based on these considerations, for a rapidly developing country like Uzbekistan, with growing population and industry, the creation of stable and sufficiently powerful energy sources is essential. This necessitates either large-scale hydropower plants or nuclear power plants. However, due to insufficient river flow energy for large hydropower development, the construction of nuclear power plants is considered the most appropriate solution.

The advantages of nuclear energy sources over others lie in their ability to provide stable and environmentally cleaner energy compared to fossil fuels when designed with adequate capacity. It should be noted that nuclear power plants constructed by Russia in various countries demonstrate high levels of technical and environmental safety, having operated reliably for over 30 years. Currently, many countries are entering into agreements with Russia for the construction of nuclear power plants. Furthermore, following the successful completion of the "Hanhikivi" nuclear power plant project in Finland, designed by Rosatom, the expansion of such projects is expected even in developed markets.

The new-generation nuclear power plants planned for construction in Uzbekistan are fundamentally improved, designed to withstand earthquakes and technogenic impacts, equipped with double containment systems, and based on advanced automated technologies

that reduce the probability of radiation release into the atmosphere to nearly zero. In other words, the safety of such nuclear power plants is ensured at a very high level. Therefore, their use provides significant advantages in achieving stable and high-capacity energy production.

Conclusion

Achieving these goals requires that every citizen develops a clear understanding of why such energy sources are prioritized, whether they provide sufficient opportunities for economic development, and which types of energy resources are most suitable based on a country's geographical conditions. At the same time, it is important to recognize that for the future development of Uzbekistan's energy sector, nuclear energy—alongside green energy—has strong prospects, with high safety standards and the capacity to ensure stable and sufficient energy supply for economic growth.

In this context, fostering an informed and balanced public attitude toward energy sources plays a crucial role in achieving sustainable energy development.

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