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ENERGY SECURITY: CONTEMPORARY APPROACHES AND TRENDS

Abstract:

Energy security, which in its essence implies the ability to provide reliable, sustainable, and affordable energy, is a pressing global challenge of the modern era. Geopolitical instability, problems in the supply of energy resources and processes caused by climate change have made it a critical priority on the global agenda and forced countries to reconsider their energy strategies. Dependence on fossil fuels carries high risks, given supply difficulties, price volatility, and adverse environmental impacts. Accordingly, governments and industries are trying to develop modern approaches, which include diversification of energy sources, increasing the share of renewable energy, digitalization of energy infrastructure, development of predictive models for risk assessment, innovation, and greater investment in the creation of new, more sustainable systems. Increasing attention is being paid to the development of smart grids, energy storage systems and cross-border energy interconnections. Steps taken in this direction make energy networks more secure and provide flexible solutions in various critical situations.

Artificial intelligence is driving significant changes in the field of energy security. Its role is particularly important in energy demand forecasting, optimizing energy distribution, identifying causes of disruptions, and mitigating failures in the event of supply disruptions. Alongside the growth of digitization, cyber threats are also on the rise, representing a major challenge in the field of energy security. Strengthening cybersecurity measures is essential to prevent potential attacks on energy networks.

To ensure a secure and sustainable energy future, it is necessary to strengthen global cooperation, which includes both political and technological innovations. The aim of this article is to examine contemporary trends and approaches in energy security, analyze existing challenges, and emphasize the necessity of innovation and international cooperation in ensuring energy security, as the synergy of technological innovations, political reforms, and international collaboration is crucial for effectively

addressing energy challenges.

Keywords:

Energy security, Energy diversification, Innovations

JEL Classification: Q40, Q42, Q48

Introduction[1]

The concept of energy security first gained widespread attention in the mid-20th century, especially after the 1973 oil crisis, when OPEC members imposed an oil export embargo on several Western countries. This event represented an energy shock to Western countries and led to energy supply shortages, sharp price increases, and economic downturns. The International Energy Agency (IEA) was established in 1974 with the aim of ensuring energy security for developed countries during energy supply crises (IEA, 2023).

The theoretical foundations of energy security include various approaches that ensure the reliability and security of energy supply. On the one hand, this includes resource diversification and increasing the diversity of supplier countries, and on the other hand, increasing energy efficiency and developing domestic resources (Cherp & Jewell, 2014). Energy security is assessed by four main parameters: energy availability, continuity of supply, affordable price, and environmental sustainability (Sovacool, 2011).

In the 1980s and 1990s, energy security was complemented by new paradigms, such as environmental security and the fight against climate change. The adoption of the Kyoto Protocol in 1997 and the subsequent Paris Agreement in 2015 placed the principles of sustainable development at the center of energy policy (UNFCCC, 2015).

In the modern world, a safe, reliable and uninterrupted supply of energy resources is one of the main components of national security. Energy security is not only a prerequisite for economic development, but also affects social stability and the geopolitical dynamics of international relations. Growing global demand for energy resources, the impact of climate change and geopolitical tensions pose a significant threat to the stability of the energy sector. The extraction and transportation of strategic energy resources are associated with many risks, which include both economic and political and environmental aspects. This article discusses modern approaches - from the integration and digitalization of renewable energy to regulatory reforms - that are changing the energy security landscape. Drawing on the experience of the European Union (EU), which is actively transitioning away from fossil fuels, the article provides valuable insights into addressing supply chain vulnerabilities, infrastructure inadequacies, and regulatory constraints.

The main drivers of the transformation of global energy policy are the reduction of dependence on fossil fuels, the integration of renewable energy sources and the increase in energy efficiency. Ensuring the security of the energy sector requires a complex approach based on the diversification of energy resources, the development of energy infrastructure, the strengthening of international cooperation and the provision of cybersecurity. The article reviews the theoretical foundations of energy security, global trends and regional practices, including the situation in Georgia. Special

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attention is paid to the development of energy efficiency policies, the role of renewable energy sources and international cooperation, which are the prerequisites for a sustainable and secure future of the energy sector.

1. The evolution of the global energy landscape. The changing paradigm of energy security.

Global energy systems are undergoing an unprecedented transformation driven by climate change, technological disruptions, and emerging geopolitical alliances. The International Energy Agency (IEA) projects that global renewable energy capacity will triple by 2030. For countries like Georgia, where more than 80% of domestic electricity is generated from hydropower, energy security is closely linked to climate sustainability and regional cooperation. Georgia's strategic location between the European Union and Asia also offers opportunities to leverage cross-border energy corridors, such as the Black Sea Submarine Cable, to enhance regional stability.

Contemporary challenges to energy security

Modern challenges to energy security can be summarized in the following points:

- Global concentration of production and political risk: Fossil fuel production is increasingly concentrated in politically unstable regions, which increases the risks of supply disruptions.
- Sustainability and the 4A model: To ensure the reliability, economic and social sustainability of energy systems, modern energy strategies must combine the "4A model" (availability, accessibility, affordability, and acceptability) - physical and financial accessibility, resource availability.
- Digitalization and cybersecurity: Advances in smart grids and real-time monitoring systems improve efficiency, but also increase the impact of cyber threats, which requires enhanced cybersecurity measures.
- Market volatility and regulatory challenges: Fluctuations in global energy markets are exacerbated by supply-demand imbalances and geopolitical shocks. It is important to mitigate their negative impact and encourage long-term investments through adapted regulatory frameworks.
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Fossil Fuel Production Trends and Geopolitical Risks

Over the past two decades, global fossil fuel production has become more concentrated, particularly in the coal and oil markets. Coal production is increasingly dominated by China and Indonesia, whose combined share of global output has increased from 33% in 2000 to 60% by 2020 (IEA, 2020). Meanwhile, oil production has increased significantly in the United States,

Canada and Iraq. However, the top seven oil producers together account for less than 60% of global supply (IEA, 2020). In contrast, the natural gas market has remained relatively stable in terms of concentration, with modest changes in market shares among major players, with small increases in the shares of countries such as Qatar, Iran and China, offset by declines in the shares of Russia and Canada (IEA, 2020).

The geopolitical alignment between producers and consumers has also changed. While political proximity among oil trading partners has generally improved, natural gas exporters and importers have become more politically distant since 2010.

These dynamics create different risks to energy security. Coal and gas production are increasingly concentrated in regions characterized by authoritarian rule, internal instability and geopolitical disagreements with importers.

2. Geopolitical disruptions and the EU's response

In early 2022, a major geopolitical conflict in Eastern Europe dramatically changed the continent's energy landscape, exposing the vulnerability of reliance on imports from a single supplier. The subsequent energy crisis, compounded by rising energy prices and inflationary developments, forced European countries to quickly implement stringent energy security measures. In response to the challenge, the EU accelerated a series of strategic initiatives. Certain directives were issued, such as enhanced energy efficiency measures and sophisticated transition plans under the European Green Pact. It was introduced in early 2023 with the aim of stabilizing the energy market. In addition, a framework REPowerEU was created to diversify supply sources and reduce import dependence.

The objectives of the new energy policy include: a gradual reduction in annual energy consumption by around 1.5% per year from 2024 to 2030, increased integration of renewable energy into energy systems, improved energy efficiency in sectors such as heating and cooling of buildings, manufacturing and agriculture, and appropriate investments in new energy technologies. All of this is included in long-term strategies aimed at achieving carbon neutrality by 2050. This involves secure energy supplies, strengthened infrastructure and the development of low-carbon technologies. Although traditional energy sources still play a crucial role, especially in industry and transport, a steady transition to renewable energies has begun in the EU. This transition process is supported by significant research and scientific efforts underway to reduce the environmental impact of fossil fuels.

Modern approaches in the European Union

The EU's strategy for energy security is multifaceted, blending diversification, renewable integration, digitalization, and regulatory innovation. The examples from EU countries illustrate these approaches in practice.

Diversification and integration of renewable energies

Germany – Energiewende and integrated energy security:

Germany's policy framework and strategic vision – Energiewende – aims to reduce carbon emissions by switching from fossil fuels to nuclear power. By 2020, renewable energy sources would account for around 46% of the country's electricity consumption. For this figure, the German Renewable Energy Act has set a target of 80% for 2030. The strategy aims to reduce greenhouse gas emissions by 65% by 2030 compared to 1990 levels, which is in line with the EU's so-called Fit for 55 framework.

Significant work has been done to expand renewable capacity. More than 132 GW (2020) of renewable capacity has been installed, with onshore wind and solar photovoltaic (PV) plants accounting for almost 80% of this capacity.

The grid has been modernized. Investments in grid modernization have improved grid efficiency, reducing transmission losses to 3–4%. This has been achieved through advanced smart grid sensors that enable real-time monitoring and reduce response times to two minutes.

Germany has strengthened its cross-border connections. Between 2015 and 2020, it increased its interconnector capacity by more than 20%, thereby strengthening energy exchanges with neighboring countries and reducing regional supply risks.

The socio-economic impact and future prospects of the changes in the energy sector are important: the Energiewende has created around 300,000 jobs in the renewable energy sector. Ongoing research into hydrogen and energy storage technologies will help to strengthen Germany's role as a global leader in the energy transformation.

France – Balancing nuclear stability with digital innovation:

France relies on nuclear energy for almost 70% of its electricity, with one of the lowest carbon emissions in the EU. In 2022, France's nuclear reactors operated at an average capacity factor of 75%, underscoring their operational reliability.

A strong focus is being placed on digital technologies and cybersecurity. French transmission system operator RTE digitally controls 100% of its high-voltage transmission grid using advanced sensors and real-time analytics. This has reduced the time it takes to detect and diagnose network anomalies from 15 minutes a decade ago to 5 minutes today (RTE, 2023).

Significant work is underway to develop renewable energy sources. Although nuclear power remains dominant, the share of non-hydro renewable sources (wind, solar, bioenergy) was 11%, while the share of total renewable (including hydropower) energy sources was 23% by 2020. France aims to increase renewable energy sources to 40% by 2030, largely through the development of wind and solar energy.

Spain – Smart Grids and Renewable Energy Integration:

Spain is arguably experiencing a revolution in renewable energy. Spain's aggressive renewable policies enabled renewables to account for 44% (wind: 22%, hydropower: 12%, solar PV: 6%,

others: 4%) of its electricity in 2020. By 2030, government projections suggest this figure will increase to 81%.

Much attention is being paid to the introduction of modern technologies and the modernization of networks. In cities such as Barcelona, smart grid projects have significantly improved the overall efficiency of the network and reduced peak demand.

In 2022, more than 130,000 additional jobs were created in Spain's renewable energy sector.

Denmark – Wind power and grid flexibility:

Denmark's investments in wind farms have made the country one of the leaders in renewable energy production. In 2023, wind energy accounted for 53.4% of Denmark's total electricity production. As of 2023, Denmark operates wind farms with a combined capacity of more than 3 GW.

Significant investments have been made to improve the grid infrastructure, which has reduced energy losses by 25%.

Smart grids, digital infrastructure, and cybersecurity

Digital transformation is a cornerstone of the EU's approach to energy security. Smart grids enable dynamic load balancing, real-time data analytics and the efficient integration of renewable sources. Enhanced cybersecurity measures are essential to protect infrastructure from cyberattacks. As the advanced digitalisation of France's grid and the Netherlands' comprehensive real-time monitoring systems demonstrate, digital innovation significantly contributes to both operational efficiency and system resilience.

Artificial intelligence is driving significant changes in the field of energy security. Artificial intelligence (AI) plays an important role in the energy sector, especially in the direction of forecasting energy demand and optimizing distribution. AI-based helps to make accurate forecasts of energy demand, which allows for the efficient allocation of resources and reduction of costs. These technologies are also used to timely detect and eliminate energy supply disruptions, which has significantly reduced the dysfunctions of energy systems. The use of AI in managing smart grids, optimizing the efficient operation of renewable energy sources, and monitoring energy flows ensures significant progress and sustainability in the energy sector.

Cross-border interconnection and regulatory innovation

Strong cross-border infrastructure is vital for maintaining regional energy stability. Investments in submarine cables and high-voltage direct current (HVDC) connections, together with adaptive regulatory reforms, under initiatives such as the European Green Deal, have provided a stable environment for long-term energy progress and development. An optimal renewable energy mix can substantially reduce dependence on fossil fuels and increase energy security.

3. Linking EU trends with Georgia's energy security

The following are the steps needed to improve Georgia’s energy security:

1. Diversification and optimization of domestic resources

Georgia’s energy system is mainly based on hydropower, which is a renewable energy source, but is subject to seasonal fluctuations. Taking into account the EU’s diversified approach and integrating wind and solar power, the disruption caused by hydropower fluctuations can be avoided, while the modernization of thermal power plants and the introduction of smart technologies can further increase the stability of supply.

2. Digitalization and grid modernization

Although Georgia has initiated reforms in the electricity market and grid infrastructure, additional investments in digitalization - the introduction of smart grid technologies - are necessary. These measures will enhance real-time monitoring, network service efficiency and load management, which will also help ensure cybersecurity.

3. Policy reforms and international cooperation

A sustainable regulatory framework, in line with international best practices, is essential to attract sustainable investment in renewable energy. The Georgian regulatory authority should continue to align its policies with those of the European Union. Participation in regional initiatives will facilitate technology transfer, new investments and broader energy cooperation, thereby strengthening national energy security.

4. Managing Political and Economic Risks

Global trends indicate that energy production is increasingly concentrated in politically unstable regions. For Georgia, a diversified energy mix that incorporates comprehensive risk management strategies – such as the 4A model – will be crucial to ensuring stability and accessibility. By reducing dependence on volatile external sources and developing domestic renewable resources, Georgia can enhance both energy security and economic sustainability.

Here are some of the opportunities the country can exploit:

- Establish a regional energy transit hub through enhanced cross-border interconnections.
- Attract international investment through enabling state aid mechanisms and regulatory reforms.
- Use renewable resources to create a sustainable and competitive energy sector.

Here we must also consider the challenges of the energy sector and identify ways to overcome them:

- It is necessary to eliminate the instability caused by seasonal variations in hydropower by integrating additional renewable sources and energy storage systems.
- It is necessary to modernize outdated infrastructure and increase investments in digital network technologies.
- It is important to ensure long-term political stability to create a favorable environment for investments.

Conclusion

Modern energy security requires a comprehensive strategy that balances diversification and digital innovation. The EU's integrated approach, exemplified by initiatives such as REPowerEU, smart grid deployment, adaptive public policies, and the optimization of the renewable energy mix, represents a valuable blueprint for countries facing similar challenges. The evolution of energy security strategies in the EU shows that success relies on the integration of technological innovation, adaptive regulatory frameworks, and international cooperation. A balanced renewable energy mix based on wind, solar and other renewable sources can significantly enhance energy security and mitigate environmental and geopolitical risks. Adapting these strategies for Georgia involves harnessing its significant hydropower potential, actively diversifying its renewable energy portfolio, modernizing grid infrastructure, and aligning policy frameworks with regional best practices. These integrated approaches and transformations are necessary not only to ensure long-term energy security, but also to support broader socio-economic and environmental goals.

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