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Review Article

ENERGY SECURITY AND INNOVATION IN RENEWABLE ENERGY SOURCES WITH REFERENCE TO BOSNIA AND HERZEGOVINA

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Abstract: *Energy security represents one of the key development issues of modern states, particularly in the context of climate change, geopolitical instability, and disruptions in global energy markets. The subject of this paper is the analysis of the relationship between energy security and innovation in renewable energy sources, with special reference to Bosnia and Herzegovina. The aim of the paper is to examine the extent to which technological and institutional innovations in the renewable energy sector can contribute to a more stable, sustainable, and economically viable energy system in Bosnia and Herzegovina.*

Three key hypotheses are proposed. The first hypothesis assumes that increased investment in renewable energy sources directly contributes to strengthening energy security. The second hypothesis suggests that regulatory and institutional reforms have a decisive impact on the efficiency of innovation implementation. The third hypothesis is based on the claim that Bosnia and Herzegovina possesses significant, yet insufficiently utilized, renewable energy potentials. The paper applies the methods of analysis and synthesis, a comparative method, analysis of available statistical data, as well as a review of relevant professional and scientific literature. The results indicate that the energy transition in Bosnia and Herzegovina requires a systemic approach, strategic planning, and stronger support for innovation in order to ensure the long-term stability of the energy sector. It is further concluded that the long-term stability of the energy system depends on the ability of states to integrate innovation, develop flexible infrastructure, and provide a stable regulatory framework..

Key words*: energy, security, innovation, renewability, sources, Bosnia and Herzegovina.*

JEL classification*: O13*

1. INTRODUCTION

The issue of energy security has taken on a much broader meaning over the past decade than it had previously. While it was once primarily associated with the continuity of fossil fuel supply and the stability of their prices, today it encompasses a far more complex set of economic, political, and environmental factors.

A modern approach to energy security includes the diversification of energy sources, the reduction of import dependence, improvements in energy efficiency, as well as an accelerated transition toward sustainable and environmentally friendly solutions. In such circumstances, the energy sector is no longer merely a technical domain, but a space where development strategies, international relations, and climate policies intersect.

Additional complexity arises from global crises and instabilities that affect energy markets. Disruptions in supply chains, rising energy prices, and increasingly pronounced climate challenges

highlight the need to redefine energy policies. In this sense, energy security no longer implies only the availability of energy, but also the resilience of the system to external shocks, the flexibility of infrastructure, and the capacity to adapt quickly to change.

Bosnia and Herzegovina finds itself in a specific position within this context. On the one hand, it possesses significant natural resources, particularly hydroelectric potential and coal reserves, which provide a certain degree of energy self-sufficiency.

On the other hand, the structure of its energy sector remains largely reliant on traditional energy sources, especially thermal power plants, raising concerns about long-term sustainability and alignment with contemporary energy trends. At the same time, growing interest in the development of solar and wind power indicates a gradual shift toward renewable energy sources.

However, the process of energy transition in Bosnia and Herzegovina faces numerous challenges. Among the most prominent are an underdeveloped regulatory framework, a complex institutional structure, limited investment capacity, and the need to modernize existing energy infrastructure. Alignment with European energy and climate policies further emphasizes the necessity of reforms and strategic planning in this sector.

In such circumstances, innovations in the field of renewable energy gain particular importance. These innovations are not limited to technological advancements, but also include new models of energy management, system digitalization, the development of smart grids, and changes in patterns of energy production and consumption. It is precisely through innovation that the possibility emerges to build a more flexible, efficient, and sustainable energy system.

For all these reasons, the issue of energy security in Bosnia and Herzegovina cannot be viewed in isolation, but rather as part of a broader process of economic transformation and sustainable development. Understanding the relationship between energy security and innovation in renewable energy sources becomes essential for defining future development directions, both at the national and regional levels.

2. ENERGY SECURITY AS A STRATEGIC CATEGORY OF DEVELOPMENT

Energy security in modern conditions cannot be reduced merely to the quantity of available energy; rather, it implies a reliable, continuous, and affordable supply that is also sustainable in the long term. It encompasses several interrelated dimensions: the physical availability of energy resources, price stability and predictability, system resilience to disruptions and crisis situations, as well as the environmental sustainability of energy production and consumption. In other words, energy security today refers to the ability of a system to provide energy under varying conditions without causing significant economic or social consequences.

This concept gains additional importance in the context of global changes, where energy markets are becoming increasingly sensitive to geopolitical tensions, climate change, and technological transformations. In such an environment, countries strive to develop energy systems that are not only efficient but also flexible, capable of responding quickly to shifts in supply and demand. This adaptability becomes one of the key elements of energy security.

Table 1: Key indicators of energy resources and energy security in Bosnia and Herzegovina

Indicator	***Hydropower***	***Coal***
Estimated total potential	*approx. 6000 MW*	*approx. 5–6 billion tons of reserves*
Level of utilization	*~40%*	*High (dominant source in electricity generation)*
Share in electricity generation	*30–40%*	*55–65%*
Main advantages	*Renewable source, low CO_2 emissions, long-term sustainability*	*Domestic resource, stable production, energy independence*
Main disadvantages	*Dependence on hydrological conditions, seasonal variability*	*High CO_2 emissions, environmental pressure, outdated facilities*
Development trend	*Growing interest in small hydropower and modernization*	*Gradual decline due to decarbonization policies*
Role in energy security	*Source diversification, system stabilization*	*Backbone of base-load generation*
Key challenges	*Environmental concerns, regulation, investment needs*	*Energy transition, EU regulations, modernization requirements*

United Nations Development Programme. (2022). Energy transition in Bosnia and Herzegovina. UNDP Bosnia and Herzegovina, Sarajevo, p.45.

In the case of Bosnia and Herzegovina, energy security has a specific and somewhat contradictory character. On the one hand, the country possesses significant domestic resources, particularly coal and hydropower potential, which provide a certain level of energy independence from imports.

This resource structure has long served as a stable foundation for the energy system. However, reliance on these sources, especially coal, is increasingly being questioned due to environmental standards and obligations to reduce greenhouse gas emissions.

On the other hand, there are numerous structural challenges that limit the further development and stability of the energy sector. Outdated infrastructure, insufficient investment in modernization, and limited diversification of energy sources increase the system's vulnerability. In periods of higher demand or unfavorable hydrological conditions, these weaknesses may become more pronounced and threaten the stability of supply.

An additional issue is the slow pace of adaptation to modern energy trends.

Although there are considerable potentials for the development of renewable energy sources, their utilization is still not at a level that could significantly influence the overall structure of energy production. The reasons lie in a combination of regulatory, financial, and institutional constraints, as well as in underdeveloped infrastructure that would enable greater integration of these sources into the power system (Sovacool, 2011, p.443).

In this context, energy security in Bosnia and Herzegovina can no longer be viewed solely through the prism of the quantity of energy produced or the availability of resources. It also involves the system's capacity to respond to climate-related challenges, such as changes in water availability, as well as to market dynamics that affect energy prices and supply. Furthermore, institutional readiness to implement reforms and the ability to attract investment in new technologies and infrastructure play an important role.

Overall, strengthening energy security in Bosnia and Herzegovina requires a balanced approach that involves preserving existing capacities while gradually transforming them.

This includes investments in system modernization, the development of renewable energy sources, improvements in energy efficiency, and the establishment of a stable regulatory framework. Only through such an integrated approach can the long-term stability, resilience, and sustainability of the energy sector be ensured.

3. INNOVATIONS IN RENEWABLE ENERGY SOURCES

Innovations in the renewable energy sector today represent one of the key drivers of the transformation of energy systems. They do not solely involve the development of new technologies but also the improvement of the ways energy is produced, distributed, and consumed. In this context, innovations include technological advancements such as more efficient solar panels and wind turbines, the development of smart grids, advanced energy storage systems, digitalized consumption management, as well as new financial and business models that facilitate investment in this sector.

Thanks to these developments, energy production from renewable sources is becoming increasingly competitive compared to traditional sources.

The reduction in equipment costs, particularly in solar and wind energy, has enabled broader adoption of these technologies and accelerated the process of energy transition. At the same time, the advancement of information technologies contributes to better monitoring and optimization of consumption, thereby improving the overall efficiency of the energy system.

In Bosnia and Herzegovina, there has been a noticeable increase in interest in investing in renewable energy sources in recent years, especially in solar power plants and wind farms. However, this process still does not follow the pace required for significant changes in the structure of the energy sector (World Bank, 2023, p.74).

The reasons for this are multifaceted, including complex administrative procedures, an insufficiently defined regulatory framework, and limited access to financial resources. Additionally, investors often face lengthy permitting processes and inconsistent rules across different levels of government.

In this context, innovations should also be considered through the lens of institutional changes.

An effective regulatory framework, transparent procedures, and stable incentive measures can play a role as important as the technologies themselves. The introduction of models such as public-private partnerships, auction systems for project allocation, or feed-in tariffs can significantly accelerate the development of renewable energy sources and reduce investment risks.

Decentralized energy production models are of particular importance in modern energy systems. In such systems, households, local communities, and small businesses become active participants - not only consumers but also producers of energy. This approach helps reduce the load on centralized power systems, increases the resilience of the energy sector to disruptions, and allows for more efficient use of local resources. Furthermore, decentralization encourages greater energy independence and reduces transmission losses.

Energy storage systems also play a crucial role in this process, enabling the balancing of production and consumption, especially for sources whose output depends on weather conditions. The development of battery technologies and other forms of energy storage further enhances system stability and allows for greater integration of renewable sources.

Estimates by energy institutions indicate that the technical potential of solar energy significantly exceeds the currently installed capacities. Although investments in solar power plants have increased in recent years, their share in total electricity production remains relatively low. At the same time, certain European countries with similar climatic conditions have achieved considerably faster development of solar capacities due to more stable regulatory frameworks and stronger investment incentives. Such a comparison suggests that energy development is not determined solely by natural resources, but also by the efficiency of institutional governance.

Through the analysis of electricity production and consumption data, it can be concluded that a higher degree of source diversification contributes to greater resilience of the energy system to market disruptions and fluctuations in energy prices.

During periods of unfavorable hydrological conditions, Bosnia and Herzegovina recorded increased electricity imports, confirming the vulnerability of a system relying on a limited number of dominant energy sources. For this reason, investments in solar and wind capacities represent an important factor of long-term energy security.

By synthesizing the available indicators, the first hypothesis can be confirmed, according to which increased investment in renewable energy sources directly contributes to strengthening energy stability. The growth of renewable energy production capacities reduces dependence on fossil fuels, mitigates the effects of market shocks, and increases the flexibility of the energy system during periods of crisis.

4. POTENTIALS AND CHALLENGES OF BOSNIA ANS HERZEGOVINA IN THE FILED OF RENEWABLE ENERGY SOURCES

Bosnia and Herzegovina possesses significant natural potential for the development of renewable energy sources. Hydropower already constitutes a key part of the country's electricity production, while the southern and southwestern regions of BiH have high solar potential due to intense solar radiation for most of the year.

In addition, mountainous areas, particularly in the northern and western parts of the country, are suitable for the development of wind farms, while the potential for biomass and geothermal energy is still being explored and has not yet been fully utilized (United Nations Development Programme, 2022, p.51).

However, alongside these significant potentials, BiH faces numerous challenges that slow down the pace of energy transition. The energy sector is institutionally divided between the two entities and the Brcko District, which complicates the adoption of unified national strategies. The lack of long-term investment plans, slow harmonization with European energy standards, and limited technical infrastructure further complicate the implementation of innovative solutions in the renewable energy sector (Delalić & Kreso, 2021).

The financial aspect also represents a major obstacle, as the development of renewable energy sources requires substantial initial investments. Nevertheless, the long-term benefits - including the stabilization of electricity prices, reduction of greenhouse gas emissions, increased energy self-sufficiency, and the potential for exporting ''green" energy - far outweigh the initial costs if the process is planned and executed strategically and transparently.

A comparative analysis with countries in the region shows that states which harmonized their legislative frameworks with the energy policies of the European Union at an earlier stage have achieved faster growth in renewable energy capacities. For example, countries that introduced transparent auction models and simplified grid-connection procedures have recorded a significantly higher inflow of private capital. In Bosnia and Herzegovina, by contrast, a large number of projects remained in the phase of administrative preparation for years.

An additional challenge is the insufficient modernization of electricity infrastructure. The development of renewable energy sources requires more flexible grids, digital monitoring of consumption, and energy storage systems. In this

context, innovations do not refer only to new production capacities, but also to the transformation of the way the energy system is managed. The introduction of smart meters, automated grid management, and decentralized energy production is becoming an important element of the energy transition.

Quantitative indicators show that in recent years the number of concession requests for solar and wind power plants has increased, confirming the growing interest of investors. However, the pace of project implementation remains slower than the regional average, primarily due to regulatory inconsistencies and institutional complexity.

Based on the conducted analysis and synthesis, the second hypothesis can be confirmed, according to which regulatory and institutional reforms have a decisive impact on the efficiency of innovation implementation. Without a stable legal framework, transparent procedures, and infrastructure modernization, natural potentials cannot be adequately utilized.

Table 2. Renewable energy potentials in Bosnia and Herzegovina

Type of Renewable Source	***Estimated Technical Potential***	***Current Utilization Level***	***Key Regions***
Hydropower	*~6000 MW*	*~40%*	*Northern, central, and western parts of BiH*
Solar Energy	*~4000 GWh/year*	*<10%*	*Southern and southwestern regions, Herzegovina*
Wind Energy	*~2000 MW*	*<5%*	*Northwest, western mountainous areas*
Biomass	*~500 MW*	*<5%*	*Central and northern regions, rural areas*
Geothermal Energy	*Potential under investigation*	*Not significantly utilized*	*Central and northern regions*

World Bank. (2023). Western Balkans regular economic report: Energy transition and climate action. World Bank Group, p.84.

The table shows that Bosnia and Herzegovina has significant technical potential across all types of renewable energy sources, but the current level of utilization is relatively low, particularly in solar and wind energy. This indicates room for development and innovation, alongside the need for strategic planning and infrastructure strengthening.

In this context, the development of renewable energy sources in Bosnia and Herzegovina requires an integrated approach that encompasses not only technological innovations but also institutional reforms, the strengthening of the regulatory framework, and incentive-based financial models to attract both domestic and foreign investors.

Decentralized energy systems are of particular importance, where local communities and small businesses can become active energy producers, thereby reducing the load on the central power system and increasing the resilience of the sector to disruptions (Mujanović & Đonlagić, 2020).

Table 3. Main challenges and risks in the development of renewable energy sources in Bosnia and Herzegovina

Challenge / Risk	***Description***	***Impact on the Energy Sector***
Institutional Fragmentation	*The energy sector is divided between entities and the Brcko District*	*Reduced coordination, slow policy implementation*
Regulatory Uncertainty	*Insufficiently defined framework for renewable energy*	*Complicates permitting and investment planning*
Financial Constraints	*High initial costs and lack of investment*	*Slows the development of new projects*
Outdated Infrastructure	*Aging power systems and low integration of renewable sources*	*Reduced efficiency and system resilience*
Slow Harmonization with EU Standards	*Delays in aligning with European directives and standards*	*Limits access to funds and international investments*
Climate and Hydrological Risks	*Variability of water resources and seasonal fluctuations*	*Disruptions in hydropower production*

World Bank. (2023). Western Balkans regular economic report: Energy transition and climate action. World Bank Group, p.88.

The table highlights that the development of renewable energy in Bosnia and Herzegovina is

not limited solely by technical potential, but is also constrained by a range of institutional, financial, and regulatory obstacles. Addressing these challenges is crucial for achieving long-term energy security and environmental sustainability.

In addition, overcoming these barriers would create a more predictable and stable investment environment, encouraging both domestic and international stakeholders to participate in the energy transition. Effective coordination between government institutions, clear regulatory frameworks, and access to financing mechanisms are essential to unlock the full potential of renewable resources and ensure a resilient, low-carbon energy sector (Bećirović & Huseinagić, 2022).

Table 4. The most important renewable energy projects in Bosnia and Herzegovina

Project Name / Location	Type of Renewable Energy Source	Installed Capacity (MW)	Project Status
Ivan Sedlo (Hadžići)	Wind Power Plant	25	Operational / Active
Vlašić Wind Farm	Wind Power Plant	50	Planned / Under Development
Gračanica 1 & 2	Solar Power Plants	45	Final Preparation Phase
Ivovik	Wind Power Plant	84	Completed / Trial Operation
Nevesinje Solar Park	Solar Park	500 (planned)	Planned
Bileća Solar	Solar Power Plants	60	Planned / Concession Granted
Bitovnja Wind Power Plant	Wind Power Plant	90 (planned)	In Preparation
Podveležje Wind Park	Wind Power Plant	48	Operational

Bećirović, S., & Huseinagić, A. (2022). The impact of renewable energy investments on economic sustainability in Bosnia and Herzegovina. South East European Journal of Economics and Business, p.77.

The table shows that Bosnia and Herzegovina has recorded growing investment activity in the renewable energy sector in recent years, particularly in the areas of solar and wind energy. The total planned and implemented capacity of the projects presented in the table exceeds 900 MW, indicating significant investment potential and a gradual transformation of the structure of the energy sector.

From an economic perspective, the energy transition can have multiple effects. The development of renewable energy sources contributes to increased investment activity, the creation of new jobs, and the reduction of long-term dependence on imported energy resources. At the same time, the transition requires substantial financial investments in infrastructure, grid modernization, and the adaptation of industrial sectors traditionally linked to coal exploitation.

The analysis of available data indicates that global disruptions in energy markets have directly affected the increase in production costs and electricity prices in the region. Under such circumstances, countries with more developed renewable energy capacities demonstrated a higher level of resilience to external shocks. These indicators further confirm the importance of diversifying energy sources in the context of long-term economic stability.

By synthesizing the research results, the third hypothesis can be confirmed, according to which Bosnia and Herzegovina possesses significant but insufficiently utilized renewable energy potentials. The key problem is not the lack of natural resources, but rather the slow pace of institutional adaptation and the insufficient intensity of investment activity in the field of energy innovations.

Overall, the combination of coherent national policies and active regional cooperation is essential for ensuring a successful and resilient energy transition. These measures not only enhance energy security and economic stability but also support environmental sustainability and the long-term modernization of the energy sector.

CONCLUSION

The analysis of energy security and innovations in the renewable energy sector in Bosnia and Herzegovina shows that the energy transition is a complex process requiring an integrated approach.

The research results confirm that increased investment in renewable energy sources contributes to strengthening energy security, as the diversification of energy production and the reduction of import dependence directly enhance the resilience of the system.

Furthermore, regulatory and institutional reforms play a key role in the efficient implementation of innovations, as clear legal frameworks, stable

incentives, and transparent procedures enable faster and more secure investments in renewable energy.

Particular importance is also attached to identifying the untapped potential of Bosnia and Herzegovina in the field of renewable energy, which includes hydropower, solar, and wind capacities, as well as the potential for biomass and geothermal energy development. The effective utilization of these resources requires not only technological improvements but also institutional coordination, infrastructure modernization, and the establishment of financially sustainable models.

It is concluded that the long-term stability and sustainability of the energy sector in Bosnia and Herzegovina depend on the country's ability to integrate innovations, improve the regulatory framework, promote regional cooperation, and develop decentralized energy production models. Only through strategic planning, continuous support for innovations, and responsible resource management is it possible to ensure a reliable, efficient, and economically sustainable energy system that simultaneously contributes to reducing greenhouse gas emissions and achieving environmental sustainability.

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