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INNOVATION IN THE ENERGY SECTOR: THE TRANSITION TO RENEWABLE SOURCES AS A STRATEGIC STEP TOWARDS SUSTAINABLE DEVELOPMENT.

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ABSTRACT

Purpose: The purpose of the research is a comprehensive analysis of innovative technologies in renewable energy sources and their strategic importance for sustainable development.

Design/Methodology/Approach: This study employs a qualitative research design to explore the strategic transition to renewable energy sources to achieve sustainable development. A qualitative approach is chosen to provide in-depth insights into stakeholders' experiences, perceptions, and motivations in this transition. Relevant documents such as policy reports, strategic plans, and case studies were reviewed to provide contextual background and support the findings. The analysis considers the top 10 countries with the highest Energy Transition Index (ETI) scores for 2023. Data from documents were triangulated to enhance the credibility and reliability of the findings.

Findings: The results indicate the need for a paradigm shift in the energy sector by reducing dependence on imported fuels and reorienting to renewable sources.

Research Limitation/Implications: Realizing Europe's potential faces several barriers, including the need for significant investment, developing an enabling regulatory environment and overcoming technological challenges.

Practical Implication: The dynamism of the energy sector is having a significant impact on the transition of developed nations to renewable energy sources, as they play a pivotal role in shaping the sustainable future of global energy.

Social Implication: Innovations in renewable energy have the potential to radically transform the energy landscape, offering solutions to today's pressing environmental and economic challenges.

Originality/ Value: The novelty of the study lies in a comprehensive analysis of the energy sector and emphasising the strategic importance of renewable energy sources for sustainable development. The study highlights innovative achievements in the field of renewable energy and important challenges faced by the energy transformation process.

Keywords: *Climate resilience. decentralization. green transition. renewable energy sources. smart grid.*

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INTRODUCTION

The energy sector is facing unprecedented challenges that require an immediate search for new approaches and solutions. The growing dependence on fossil fuels, their limitation and their significant negative impact on the environment prompt a rethinking of traditional energy strategies. It is now even more urgent to ensure energy security, reduce greenhouse gas emissions, and transition to sustainable energy sources. Innovations in the energy sector manifest themselves in the creation and application of sustainable power sources. They are defined as an essential component in resolving global issues arising from the conflict in Ukraine. The search for efficient, cost-effective and environmentally friendly technologies is becoming a priority for governments, the scientific community and businesses around the world (Uyanik et al., 2022).

The war in Ukraine has significantly heightened awareness of the issue of energy dependence and the necessity to diversify energy sources globally. A large-scale military conflict revealed the vulnerability of the global world energy market to political and geopolitical risks, prompting the search for alternative ways to ensure energy security. Changing the paradigm of the global energy sector is a priority direction, with a focus on increasing the proportion of sustainable energy. Renewable energy technologies in the field of solar and wind energy offer new opportunities to reduce dependence on imported energy carriers and increase the stability of energy systems in the face of external shocks (Lukashevych, 2023).

The development of technologies in renewable energy sources is a key factor that ensures energy security and creates conditions for achieving the goals of sustainable development. Innovations in the field of solar energy are aimed at the development of highly efficient photovoltaic panels, and wind energy, where more and more powerful turbines appear, help reduce the cost of energy production and make renewable sources competitive compared to traditional ones. Significant progress has been made in the development of energy storage systems, which allow the efficient use of renewable sources even during periods of low production. The development of "smart" energy networks can provide new opportunities for optimizing consumption and increasing energy efficiency. Technological innovation, together with political and economic support, is shaping the future of the global energy sector, where renewable sources will become the basis of a sustainable energy supply (Grafström et al., 2023).

Therefore, it is necessary to conduct further research into the optimal strategies for the transition to renewable energy sources and ensuring the sustainability of energy systems in the context of growing demands for environmental safety and resource efficiency. Based on a quantitative analysis of the capitalization of the renewable energy market and the ETI indicators of countries, the paper attempts to identify the best ways to integrate renewable energy sources into modern energy infrastructure. The purpose of the study is to conduct a comprehensive examination of advancements in the energy sector and to evaluate the significance of the transition to renewable energy sources in the strategic advancement of sustainable energy. Additionally, it will assess the potential of technological advancements to address global environmental challenges and guarantee energy security. The research concerns

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African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
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the examination of the obstacles and opportunities for the incorporation of renewable energy into contemporary energy infrastructure, as well as the impact of technological advancements on the economic effectiveness and environmental sustainability of energy systems. The research entails the investigation of advanced renewable energy technologies, including solar, wind, and energy storage technologies, as well as the formulation of strategies to overcome the technical and policy obstacles hindering the widespread adoption of these technologies. The research focuses on identifying key innovative developments with the potential to fundamentally alter the energy landscape and analyzing international experiences and best practices in the field of renewable energy. Furthermore, the research focuses on evaluating the impact of transitioning to renewable energy on reducing greenhouse gas emissions and guaranteeing energy stability.

LITERATURE REVIEW

The study of innovation in the energy sector and the transition to renewable sources as a strategic step towards sustainable development is a subject of considerable interest in academic discourse. Meirinhos et al. (2022) argue that the integration of renewable energy sources is a key factor in achieving sustainable development, reducing dependence on fossil fuels and combating climate change. As defined Ostapchenko et al. (2021), virtually all renowned major global manufacturers of software and hardware platforms, including SAP, ORACLE, IBM, Siemens, and others, offer comprehensive solutions and tools for building computer systems for the organisational management of energy markets. The most well-known among them are NEMS, PLEXOS, and NEMSIM GEMS. However, most of these computer programs are used to model the entire energy industry and by government agencies to analyse plans for building energy complexes. Currently, as RES (Renewable Energy Sources) technologies are developed and implemented, new micro-markets are forming, and SmartGrid technologies are being applied, global energy markets are beginning to emerge, not just from large market participants but also from numerous of these participants with modest turnovers. The application of "smart" costly multifunctional computer systems for the broad masses of "small" players to aggregate available information on the functioning processes of energy markets, model and reproduce stages in the production process, and make management decisions regarding the strategy of market participants on its segments may be expensive and therefore impractical. Therefore, it is essential to implement an easy-to-use information modelling system for analysing competitive processes in the electricity market as a component of the organisational management system of energy markets. This information modelling system should be seamlessly integrated with other centralised organisational and technical systems.

Developing innovative solutions to ensure the stability and efficiency of energy systems

Pinheiro et al. (2023) emphasise the technological breakthrough in improving the efficiency of solar panels and the development of energy storage systems.

According to Arief and Fathalah (2022), innovations contribute the affordability of renewable energy has been reduced, thereby facilitating its widespread utilisation. This view is shared by Bayraktar and Pamik (2023), who add that political will and effective government policies are crucial to stimulate investment in innovation. Digitization of world industry, according to

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http://www.ajaronline.com
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Maksymova and Kurylyak (2022), plays a key role in achieving climate neutrality, allowing to optimise of production processes and reducing carbon emissions. The authors (Kulishov et al., 2023) note that the foundation for the development and implementation of digital solutions aimed at achieving an economy that doesn't affect the environment is the international structure of ecological digital projects.

Javed et al. (2023) note that the development of infrastructure for renewable sources is critically important shortly. According to Samir et al. (2023), international cooperation should strengthen global efforts to decarbonize the energy sector in conditions of global war. The scientists Rudenko and Tanasov (2022) lead a discussion of the problem of transition to renewable energy sources due to several problems and challenges of modernization. According to a study Binsaeed et al. (2023), one of the biggest challenges is the need to ensure the reliability and stability of energy supply in the conditions of a growing share of renewable sources. The scientists Sánchez-García et al. (2023) point to the importance of developing innovative solutions to balance energy systems, including smart grids and advanced forecasting technologies. The article (Fridgeirsson et al., 2023) focuses on the socio-economic challenges in retraining the workforce and creating new jobs in sectors related to renewable energy, as well as the need to ensure a just transition that takes into account the interests of all segments of the population. The study Tesfaye et al., (2022) provides recommendations and necessary measures to overcome the challenges and successfully transition to renewable sources, including strengthening political support at national and international levels.

Dathe et al. (2023) hold the belief that a heightened investment in exploration and the adoption of novel technologies ought to aid in the creation of comprehensive strategies. According to Laur and Berntzen (2023), the strategy of sustainable development includes energy efficiency, development of renewable sources and modernisation of infrastructure. The author (Mallick, 2023) emphasises the importance of creating a favourable investment climate through financial incentives, tax breaks and subsidies for the private sector. Sun et al. (2023) describe the importance of ensuring public and stakeholder participation in the decision-making process to ensure broad support for the transition and take into account diverse socio-economic interests. According to Ahmad et al. (2023), the integration of renewable energy sources requires technological innovation in regulatory policy and energy planning.

Recommendations for overcoming challenges and a successful transition to renewable energy sources.

In the work Ostapchenko et al., (2022), the structure of the operational data warehouse of the decision support system for organisational management of the electricity market was described, which is used in the construction of a computer modelling system. An example of such a computer system was described in the work of Evdokimov, (2023). The work of Lukashevych and Evdokimov, (2022) offers a method for monitoring the progress and dynamics of renewable energy power plants, encompassing their characteristics and structure. The above information pertains to RES objects, including their name, location address, type of energy source utilised for electricity generation, the installed capacity of the plant, type of connection network, and current operational status. Moreover, the information system comprises pre-

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African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
http://doi.org/10.26437/ajar.30.06.2024.03

formed and implemented Excel data arrays regarding RES objects in Ukraine, which can be utilized to evaluate previous experiences in generation development, its present state, and formulate recommendations for post-war recovery directions.

The hypothesis is supported by research by Zhang et al., (2024), which emphasizes the need to develop flexible storage networks and energy storage systems for the efficient use of renewable sources. At the same time, Majeed et al. (2023) draw attention to the significant potential of solar energy in the world and opportunities for international cooperation in this field. Barreto (2018) points to the complexities associated with the variability of renewable energy, which require the development of new approaches to managing the distribution of energy resources. Also, Miralles-Quirós and Miralles-Quirós (2019) highlight the economic challenges, including large initial investments and the need to create incentives for the private sector. The analysis performed by Franzo et al. (2023) focuses on the social aspects of the energy transition, including the need to ensure fair access to clean energy and the creation of new workplaces in renewable energy. Thus, the comprehensive approach of scientists is aimed at developing concepts for the successful implementation of innovations in the energy sector, but such an approach requires a solid foundation to achieve sustainable development in the future.

MATERIALS AND METHODS

This methodology outlines a systematic approach to analysing policy documents related to the transition to renewable energy as a strategic step towards sustainable development. By employing a content analysis framework, the study aims to provide a comprehensive understanding of policy strategies, challenges, and their alignment with sustainable development goals.

This study employs a qualitative research design to explore the strategic transition to renewable energy sources as a means of achieving sustainable development. A qualitative approach is chosen to provide in-depth insights into the experiences, perceptions, and motivations of stakeholders involved in this transition. Relevant documents such as policy reports, strategic plans, and case studies were reviewed to provide contextual background and support the findings.

An analysis of data on trends in energy production and consumption, investments in renewable sources, and the effectiveness of energy innovations was carried out. The analysis considers the top 10 countries with the highest Energy Transition Index (ETI) scores for 2023. Both deductive and inductive coding to the documents were carried out. This involved marking segments of text that correspond to the predefined categories or emerging themes. Codes were grouped into broader themes that answered the research questions. Data from documents were triangulated to enhance the credibility and reliability of the findings.

Modelling and scenario analysis were used to assess technological innovations and their impact on the efficiency and sustainability of the energy sector. This approach involves the formulation of varying recommendations for the transition to sustainable power, considering

ISSN: 2408-7920

African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
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the potential of innovative technologies, financial and societal elements, and possible modifications in international regulations and policies.

The use of the appropriate methodology made it possible to assess the possible consequences of technological innovations for the advancement of renewable energy and their impact on achieving the goals of sustainable development. The developed research methodology provides for the formation of a holistic vision of the role of innovations in the transition of the energy sector to sustainable development, taking into account the technical and socio-economic aspects of the global space.

Therefore, it becomes imperative to further investigate the most efficient means of embracing renewable energy sources and strengthening the resilience of energy frameworks in light of the increasing demands for environmental preservation and resource optimization. Through meticulous quantitative scrutiny of both the capitalization trends within the renewable energy market and the Energy Transition Index (ETI) metrics across various nations, this study attempts to pinpoint the optimal methodologies for seamlessly integrating renewable energy sources into contemporary energy frameworks.

RESULTS AND DISCUSSION

The renewable energy market is experiencing unprecedented growth globally, driven by increased focus on global warming, the need to reduce greenhouse gas emissions, and the rising demand for green power. In recent years, significant investments have been directed towards the development of solar and wind energy, which has led to a decrease in the cost of these technologies and made them competitive compared to traditional energy sources. However, despite these advances, the market faces challenges related to the integration of large volumes of renewable energy into the energy system, requiring significant investment in infrastructure and the latest storage and processing technologies. Innovation must include the development of smart grids, energy storage systems and improved cross-border energy trade to ensure the reliability and stability of energy supply.

Technological progress plays an important role in the further advancement of renewable energy, where innovations through solar panels, next-generation wind turbines and deep geothermal drilling methods open up new opportunities to increase efficiency and lower energy production costs. The development of hydrogen energy and bioenergy technologies can significantly expand the spectrum of renewable energy sources, providing solutions for sectors that are difficult to electrify, heavy industry and transport. Investments in scientific research and development require a favourable regulatory environment that supports innovation and promotes the commercialisation of new technologies. Financing is a crucial aspect of the advancement of sustainable power sources, requiring governments, the private sector and international financial institutions to join forces to ensure sufficient investment. The total capitalisation of the renewable energy market is constantly increasing, as can be seen in Figure 1.

ISSN: 2408-7920

African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
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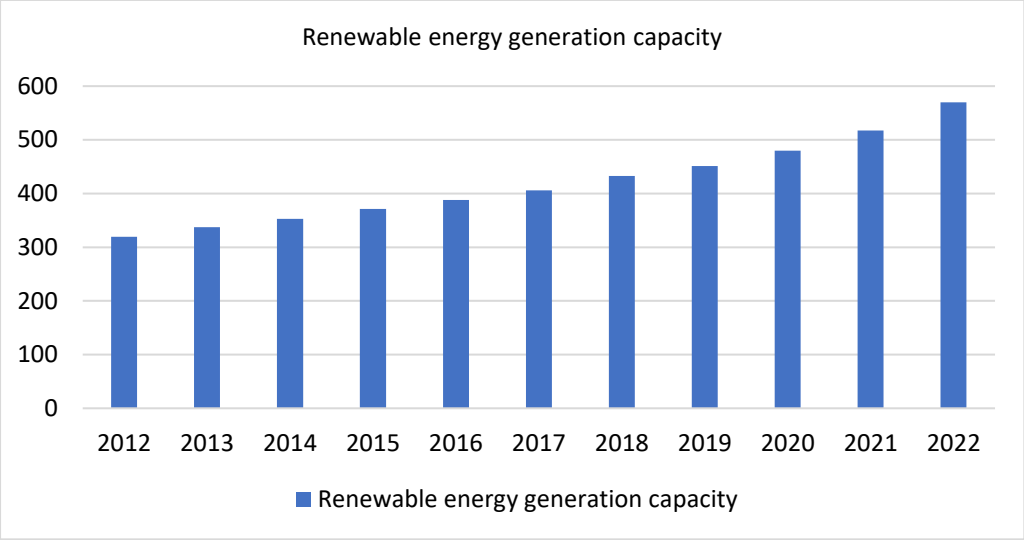

Figure 1: Renewable energy generation capacity in the European Union from 2012 to 2022 (in gigawatts)
Source: Compiled based on Statista (2023)

This figure indicates a gradual rise in renewable energy generation capacity within the European Union during the period from 2012 to 2022. According to this data, a stable and significant increase in energy production from renewable sources can be observed, which indicates the active development of the renewable energy sector in the region. This trend indicates the growing role of renewable energy sources in the overall energy system of the European Union and their important contribution to energy security and sustainable development.

In 2023, global investments in renewable energy reached record levels, in particular, according to the International Renewable Energy Agency, total investments in this area exceeded $300 billion. Solar and wind continued to dominate these investments, accounting for more than 70% of the total. Wind energy in particular attracted about $150 billion, and solar - about $148 billion. The trend will continue in 2024, given the growing confidence of investors in the stability and profitability of renewable energy projects. Significant investment growth in recent years has been accompanied by the expansion of green financing, which includes green bonds and funds. In 2023 and green bond issuance reached a record $400 billion, up 50% from 2022. Financial instruments have become key to attracting private capital to projects aimed at combating climate change and transitioning to clean energy. Green bond issuance is expected to continue to grow in 2024 as investors become increasingly focused on sustainability and ESG (environmental, social and governance) investing.

Europe's energy market faces numerous challenges and needs to change, especially in light of the growing need to transition to more sustainable and renewable energy sources. In recent decades, European countries have been pioneers in implementing policies aimed at reducing their reliance on fossil fuels and augmenting the proportion of renewable energy in the energy

ISSN: 2408-7920

African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
http://doi.org/10.26437/ajar.30.06.2024.03

balance. The need to diversify sources of supply, ensure energy security and achieve the goals of the Paris Agreement requires much greater efforts from Europe. The energy market is faced with the need to integrate large amounts of renewable energy, modernise infrastructure, including transmission and distribution networks, and implement innovative technologies to ensure the reliability and stability of energy supply. There is a need to reform market mechanisms through the introduction of carbon pricing to stimulate investment in clean technologies and reduce environmental impact.

The situation in the European energy market has become even more complicated due to the war in Ukraine, which began in 2022. The military conflict has resulted in significant human tragedies and has had serious consequences for energy security and stability on the continent, particularly due to Europe's heavy reliance on natural gas supplies from Russia. Following such consequences, European countries began to actively search for alternative energy sources and ways to increase energy independence, including through increased production of renewable energy, investment in infrastructure for liquefied natural gas (LNG) and strengthening cooperation between EU member states. The war in Ukraine accelerated discussions on the need to create a more flexible and resource-efficient energy market capable of adapting to rapid changes in the geopolitical situation and ensuring a stable energy supply. Innovations are being actively implemented among leaders in European countries due to the energy transition, more details in Table 1.

Table 1: Energy Transition Index (ETI) 2023 ranking TOP-10 countries

Rank	Country	ETI score 2023	System performance	Transition readiness
1	Sweden	78.5	81.0	74.8
2	Denmark	76.1	73.7	79.8
3	Norway	73.7	77.3	68.3
4	Finland	72.8	68.9	78.6
5	Switzerland	72.4	75.7	67.4
6	Iceland	70.6	73.9	65.6
7	France	70.6	73.3	66.5
8	Austria	69.3	69.2	69.5
9	Netherlands	68.8	65.7	73.5
10	Estonia	68.2	74.2	59.2

Source: World Economic Forum (2023)

These indicators indicate the high level of readiness of countries for the energy transition and their overall performance in the energy transformation system. Sweden's score is the highest (78.5), indicating high readiness for the transition to sustainable energy. High systemic performance (81.0) and readiness for transition (74.8) confirm the country's determination in this direction. In addition, it is worth noting that Estonia has the lowest IEP score (68.2) among the identified countries. This country is not ready to transition well (59.2) due to several factors, such as technical limitations and a lack of appropriate infrastructure, unlike, for example, Denmark (79.8) and Finland (78.6).

ISSN: 2408-7920

African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
http://doi.org/10.26437/ajar.30.06.2024.03

The transition to RES meets the needs of environmental sustainability and is critical to ensuring long-term energy security and stability on the European continent. Given global climate commitments and the need to reduce dependence on imported fossil fuels, Europe has intensified its efforts to develop renewable energy, setting ambitious goals to increase the share of green energy in its energy balance. Investments in solar and wind energy, the development of offshore wind farms, bioenergy and geothermal energy are increasing. The implementation of the initiatives requires significant financial investments and the development of new regulatory frameworks that will aid in the integration of renewable energy into the energy system while ensuring its stability and reliability. This approach will help Europe achieve its climate goals and create a more sustainable and independent energy system ready for the challenges of the future. The main strategic innovations in the energy sector, respectively, to ensure sustainable development are depicted in Table 2.

Table 2: Strategic innovations of renewable sources and implementation features in the energy sector

Innovation	**Potential opportunities**	**Implementation**
Wind turbines of a new generation	Increasing the capacity and efficiency of energy production, reducing the cost of electricity	General Electric's Haliade-X turbines, with blades 107 meters long
Perovskite solar panels	Higher efficiency of converting light into electricity, lower production costs	Perovskite solar panels developed by Oxford Photovoltaics
Energy-saving houses	Significant reduction of energy consumption and CO2 emissions, improvement of living comfort	The 'Passivhaus' project in Germany is aimed at maximum energy efficiency
Electric cars and charging stations	Reduction of dependence on fossil fuels and consequent reduction of greenhouse gas emissions.	Tesla Model S and the Supercharger network by Tesla Inc.
Energy storage systems	The possibility of using renewable energy during periods of peak consumption	Tesla Powerwall, a home battery for storing electricity
Smart electrical networks	Optimizing energy consumption, improving the reliability of electricity supply	A smart grid in Buffalo, New York for efficient energy distribution
Use of hydrogen as an energy carrier	Zero emissions during combustion, high potential energy efficiency	Hydrogen bus projects in London, UK
Geothermal energy	Stable energy production independent of weather conditions, low environmental impact	Hellisheiði geothermal power plant in Iceland

Source: compiled by the authors

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Vol. 10, No. 1 (2024), pp. 43-56
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Innovation in the energy sector, especially the transition to renewable energy sources, is becoming an increasingly important strategic step for achieving sustainable development at the global level. In recent decades, the world community has recognized the need to move away from traditional fossil energy sources, which not only cause significant harmful emissions into the atmosphere but are also limited and unreliable in the face of growing energy demand. RES such as solar, wind, hydropower, bioenergy, and geothermal energy offer a solution to these problems by providing clean, safe, and endless sources of energy. Innovations in this sector, including the development of more efficient photovoltaic panels, more powerful wind turbines, energy storage systems and improvements in biomass conversion technologies, are key to ensuring the economic viability and technical efficiency of renewable sources. These innovations not only help reduce the cost of renewable energy production but also increase its competitiveness compared to fossil sources. Thus, the transition to a sustainable energy system will be accelerated.

Active innovation in the energy sector and the transition to renewable sources is not only a technological or economic challenge, but also a strategic step that requires coordination at the level of governments, businesses and the public. This includes the development and implementation of policies that stimulate research and development in the field of renewable technologies, the establishment of tax incentives and subsidies for companies and households that invest in renewable sources, as well as the creation of a regulatory framework to ensure the integration of large volumes of renewable energy into the energy system. In addition, it is important to support international cooperation in the study of new technologies and the exchange of best practices in the field of renewable energy. The further development and integration of renewable sources into the energy landscape will not only help to reduce the impact on the environment and combat climate change but will also ensure long-term energy security, economic growth and social development, opening up new opportunities for job creation and improving the quality of life of people around the world.

Discussion

The study of innovation in the energy sector and the importance of the transition to renewable energy sources for sustainable development, the scientific discourse encountered a variety of views and conclusions. The obtained results are consistent with the analysis of Uyanik et al. (2022), which emphasizes the need for regulatory changes to integrate renewable sources. According to Wielechowski and Czech (2022), the importance of the development of energy storage systems in the context of the financial crisis increases and requires the implementation of information systems, which corresponds to their observations. The research by Grafström et al. (2023) confirms these focusing on the potential of solar energy in Europe and America, as there are significant opportunities for development and innovation in this field, especially regarding political support and investment programs.

This is confirmed by Dal Pozzo et al. (2023) which reflects the global nature of the challenges and opportunities associated with the transition to renewable energy sources. The issues highlighted by Pinheiro et al. (2023) on managing the variability of renewable energy correspond to our conclusions about the need for innovative technological solutions to ensure

ISSN: 2408-7920

African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 43-56
http://www.ajaronline.com
http://doi.org/10.26437/ajar.30.06.2024.03

the stability of the energy supply. Analysis by Dathe et al. (2023) on economic challenges also resonates with existing findings on the importance of financial support and incentives to accelerate the transition to renewables. The problems of the transition of the energy sector to renewable sources are described in the article (Laur & Berntzen, 2023), in particular, the challenges of the social aspects of the transition, which require deeper research, are emphasized.

In the direction of financing innovation, our findings support the recommendations by Fridgeirsson et al. (2023) to increase investment in research. Based on Mallick (2023), it was found that there is a critical need for mechanisms to support small and medium-sized enterprises in the field of renewable energy.

Establishing a decentralized, resilient energy system is one of the goals of the domestic energy sector to ensure energy independence and security for the citizens of Ukraine. The findings of the research presented by Lukashevych, (2023) demonstrate that approximately 90% of renewable energy storage capacities are linked to distribution grids, whereas only 10% are linked to higher-voltage ones. Furthermore, the development of RES is an important component of the adoption of distributed generation. According to Franzo (2023), public involvement and awareness raising are key to a successful transition, which is in line with our observations of the importance of information campaigns and education programs. Therefore, the obtained results confirm the conclusions of other researchers and indicate the importance of an integrated approach that includes technological development, economic support, social justice and international cooperation.

CONCLUSION

Thus, innovations in the energy sector are directed towards renewable energy sources as a strategic course towards sustainable development, as they represent the critical importance of this direction for the global energy system. The transition to renewable sources is a response to environmental challenges, climate change, environmental pollution and global warfare, which requires providing a path to energy security and social well-being. Innovations in the production and distribution of renewable energy, including technological breakthroughs in solar and wind energy, energy storage systems and energy efficiency, are playing a key role in the transformation of the energy sector. Modern technological solutions in the energy sector are a fundamental factor contributing to the acceleration of the global transition to sustainable development.

The energy transition faces several problems and global challenges. One of the main problems is the need for significant capital investments for the development and integration of renewable sources into national energy systems. The high initial cost of renewable energy infrastructure and the need to develop efficient energy storage systems may limit the speed of the transition, especially in developing countries. In Europe, there is an increasing need to harmonize policies and regulatory frameworks at the international level to ensure a fair and efficient distribution of resources and technologies. It is necessary to overcome the technical barriers associated with the integration of large volumes of renewable energy into a stable and reliable energy system

ISSN: 2408-7920

while ensuring a constant energy supply for the growing needs of the population and the economy, solving the problem of the war in Ukraine.

Comprehensive measures and recommendations are needed to overcome the challenges and effectively transition to renewable energy sources. It is imperative to augment investments in the research and development of novel technologies that will enable the reduction of the cost of renewable sources and the enhancement of their efficacy. A key aspect is the development of international cooperation for the exchange of knowledge, technologies and best practices in the field of renewable energy. Reform the energy market and create a favourable investment climate through flexible regulatory mechanisms, tax breaks and subsidies to support renewable projects. There is a need to focus on raising awareness and engaging the public in the transition to renewables by demonstrating their environmental, economic and social benefits. All these measures together will contribute to the development of a resilient, efficient and inclusive energy system of the future based on renewable sources.

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