MANAGEMENT AND BUSINESS

Vol. 2, No. 2. 2024

Journal homepage: https://emsesd.com.ua/en

Article's History: Received: 14.10.2024 Revised: 09.01.2025 Accepted: 25.02.2025

UDC 620.92:330.341.1]:330.34:502.131.1

DOI: 10.59214/mb/2.2024.43

Renewable energy innovations: Synergy of technology and sustainable development

Alla Tkachenko*

Doctor of Economic Sciences, Professor
National University of Zaporizhzhia Polytechnic
69063, 64 Zhukovskoho Str., Zaporizhzhia, Ukraine
https://orcid.org/0000-0002-1843-2579

Vilayat Ibrahim oglu Ismaylov

Doctor of Economic Sciences, Professor
Azerbaijan Academy of Labor and Social Relations
AZ1130, 181 Azadliq Ave., Baku, Azerbaijan
https://orcid.org/0000-0003-0892-0365

Abstract. The paper highlighted the relevance of the topic in the context of global challenges, including climate change, population growth, and the need to decarbonise the economy. The purpose of this article was to substantiate the role of renewable energy innovations, as well as the impact of modern projects, such as new generation offshore wind turbines (Haliade-X, WindFloat Atlantic) on achieving sustainable development. Various types of data analysis and visualisation were used in the writing of the paper. Data and information analysis methods, cross-sectional and descriptive analysis were applied. The main focus was on innovative solutions such as perovskite solar panels, bladeless wind turbines, hydrogen energy systems, new generation battery systems, and integrated smart grids. The authors assume that by 2033, global investment in renewable energy sources will reach $1 trillion per year, and annual savings from lower energy costs and energy efficiency will be up to $450 billion. For Ukraine, investments are projected to grow from $2 billion in 2023 to $40 billion in 2033, which will contribute to energy independence and post-war infrastructure restoration. Developing renewable energy sources will not only diversify exports but also create an environmentally friendly sector of the economy. The article described how innovations in renewable energy sources can reduce dependence on fossil fuels, contribute to the decarbonisation of industry, and improve energy security. The paper considered a synergistic approach to the integration of various technologies, such as solar and wind energy, hydrogen systems, and smart grids. This allowed optimising energy flows and reducing losses, which was important for energy systems. The work created a scientific and practical basis for further research and development, as well as for the widespread introduction of innovations in the field of renewable energy sources. This will ensure sustainable economic growth, economic competitiveness, and environmental issues

Keywords: smart grids; investment; cost; economic effect; decarbonisation; profit; economic recovery

Introduction

Renewable energy was the basis for the transition to sustainable development, given the global need to decarbonise the economy and reduce the negative impact of traditional energy sources. Innovative technologies played a key role in improving renewable energy sources (RES) and their integration into the energy system. The development of renewable energy was a key factor in ensuring sustainable development at the global level. The world is facing numerous challenges that necessitate the transformation of the energy sector. First and foremost, it is global warming caused by greenhouse gas emissions, which poses a threat not only to the environment but also to social and

Suggested Citation:

Tkachenko, A., & Ismaylov, V.I. (2024). Renewable energy innovations: Synergy of technology and sustainable development. *Management and Business*, 2(2), 43-51. doi: 10.59214/mb/2.2024.43.

*Corresponding author

economic stability. Innovations in this area allowed not only to replace fossil fuels but also to increase the efficiency of energy systems. Global population growth and economic development are steadily increasing the demand for new energy sources. Traditional energy sources cannot meet this demand without significant environmental consequences. Renewable energy sources provided a stable energy supply thanks to the latest technologies in energy production, storage and distribution. Geopolitical conflicts have demonstrated the vulnerability of countries that are dependent on fossil fuel imports. The introduction of innovations in RES contributed to the creation of energy-independent systems, which was especially important for Ukraine in the context of post-war reconstruction.

Innovations in renewable energy created new opportunities for investment, technology development, and job creation. According to the International Renewable Energy Agency (IRENA & AfDB, 2022; IRENA, 2023), every investment in renewable energy had a multiplier effect on the economy, creating additional employment sectors. Innovative solutions, such as perovskite solar panels, hydrogen energy systems, offshore wind farms, and artificial intelligence in power grids, were changing the way the energy sector is viewed. These and other technologies can provide the desired flexibility and adaptability of energy networks in the future. For Ukraine, innovations in renewable energy have a double meaning: a way to reduce dependence on fossil fuels, while renewable energy can become a driver of infrastructure reconstruction in the post-conflict period, and the export of Ukrainian "green" technologies will help strengthen the country's international credibility. Innovation is becoming a factor that not only contributes to solving environmental and energy problems, but also ensures sustainable growth and competitiveness of the economy.

The literature analysis focused on works that explore current trends in renewable energy development and innovation. They emphasised the importance of technological progress in reducing the cost of energy, in particular through perovskite panels and new generation batteries. According to Ukrainian scientists L. Melnyk *et al*. (2019), renewable energy sources had undeniable prerogatives. IT was more environmentally friendly than conventional means of energy production based on the combustion of natural fossil fuels and had a number of undoubted qualities that distinguish them from traditional energy facilities. These scientists emphasised that renewable energy sources were relatively stable, which allowed them to cover the sustainable operation of energy systems. S. Kudrya (2020) emphasised that the use of environmentally friendly renewable energy sources to cover the country's energy needs was very valuable for Ukraine. In most civilised countries, the use of renewable energy sources was a priority vector for the development of the energy sector, due to the tendency to eliminate energy instability in countries associated with existing energy crises and reduce the number of toxic emissions that occur when using conventional energy sources. A notable aspect was the prospect of creating reserves of natural raw materials for non-energy needs and preserving energy resources in the future.

Based on the position of the Executive Director of the International Energy Agency (IEA) Fatih Birol, A. Frangoul (2022) emphasised that the energy crisis has become a catalyst for the transition to the newest stage of development of renewable energy sources, accompanied by their intensive growth, driven by the desire of states to strengthen their energy security. This study noted that according to the International Energy Agency, by the middle of this decade, renewable energy sources will outgrow the use of coal and become the most powerful source of electricity in the world. The IEA report (2022a) predicted a significant reshaping of the global energy balance amid growing global instability and geopolitical tensions. It is noted that the first truly global energy crisis caused by the Russian Federation's invasion of Ukraine has given an unprecedented impetus to the development of renewable energy.

D. Orlova & D. Sydoro (2021) pointed out that there has been a steady increase due to the transition of the modern economy to green energy. Offshore wind energy was being deployed in Europe due to large partial capacities. In Ukraine, the situation was still different – the country needs to consume resources for onshore wind farms. The focus was on adapting innovations to national conditions, overcoming regulatory barriers and developing the necessary infrastructure. Scientists have focused on the economic effects of innovations, exploring the synergistic approach to the integration of different technologies, which reduces energy losses and increases the stability of the power system. The purpose of the article was to analyse the role of innovation in the development of renewable energy, identify key technological breakthroughs and outline their impact on sustainable development.

Materials and Methods

The research was based on reliable analytical sources, statistical reports of international and national organisations, as well as scientific papers covering current technological trends in the field of renewable energy. The basis of the source base was formed by IRENA's annual reports (IRENA, 2023; IRENA & AfDB, 2022), and IEA analytical reviews (IEA, 2022a; IEA, 2022b; IEA, 2024). A separate group included reviews and forecasts of investment flows in the RES sector, presented in the reports Bloomberg New Energy Finance (2023) and Global clean energy investment jumps 17%, hits $1.8 trillion in 2023, according to BloombergNEF report (2024), which assess the dynamics of capital attraction in green technologies. This data was used both to describe global trends and to forecast investment activity in Ukraine. The national context of the study was covered on the basis of official publications by National Power Company Ukrenergo (n.d.), State Agency on Energy Efficiency and Energy Saving of Ukraine (n.d.), and Energy strategy (2022).

The study was based on a combination of quantitative and qualitative methods of analysis. Factor analysis was used to identify the key determinants of innovative development of renewable energy sources. Correlation analysis was used to establish the relationship between the level of innovation, energy cost and investment volume. Regression modelling allowed for a quantitative assessment of the impact of innovation on the economic performance of energy systems. The long-term effects of technology adoption in the period up to 2033 were modelled using scenario analysis. To empirically test the formulated hypotheses, the cases of the Hybrit (Sweden) and Hornsea One (Denmark) projects were analysed. Statistical data were processed using descriptive analysis and further visualisation of data in the form of graphs and tables. Life Cycle Analysis (LCA) was applied to assess the environmental impacts.

The reliability of statistical data was ensured by cross-checking information from several independent sources. The combination of these methods made it possible to achieve high analytical accuracy and comprehensiveness of the results obtained, which were presented in detail in the following sections of the study. In writing the paper, a method of verifying information such as assessing the credibility of the source was used. If the work referred to another source, the reliability of the information provided was checked, in particular, the reliability of quoting the source. Cross-checking was used: comparing information from several sources. This method was used if it was difficult to find the original source or if the information was quoted. The use of cross-checking made it possible to reduce the likelihood of using questionable information, which allowed for greater accuracy in obtaining results.

In preparing the article, the following methods of information analysis were used: factor analysis (which identified the primary factors that determine the role of innovation in the development of renewable energy) and descriptive analysis of indicators (which presented information in the form of visualisation in graphs and tables, which in turn is aimed at deepening the perception of the study, and also allows for a more comprehensive disclosure of trends and illustration of their dynamics), for example, sorting, filtering and visualisation were used. Regression analysis of indicators (to determine the correlation of the impact on renewable energy cost reduction), correlation analysis (to formulate the relationship between different aspects of renewable energy development and innovation), as well as data decomposition and hypothesis analysis were used in writing the paper. Among other things, trend analysis was used to understand and predict various trends and developments in the development of renewable energy, which is a key factor in ensuring sustainable development at the global level.

Results and Discussion

The article described in detail the main approaches to the analysis of the systems approach, which will allow to consider RES innovations as an integral part of the energy, environmental and economic systems, studied the role of innovations in the creation of smart grids and integration of RES into traditional energy systems, assess the impact of energy storage technologies and decentralised energy systems, analysed the economic effects of large-scale implementation of RES innovations, in particular the impact on the cost of electricity (Jacobson & Delucchi, 2011). The use of SWOT and PESTEL analysed is also an effective tool for the introduction of RES (IRENA & AfDB, 2022). At the same time, empirical analysis cannot be ignored, and most importantly, quantitative analysis (analysis of the dynamics of investment in RES, changes in energy costs, and the level of innovation) and case studies (research on successful projects such as Hybrit in Sweden (hydrogen energy) or offshore wind projects in Denmark), as the use of real statistical data allowed assessing the impact of innovations on the energy system (Bloomberg New Energy Finance, 2023).

One of the key technological breakthroughs was made by perovskite solar panels, which significantly changed the economics of solar generation. The high efficiency (25-30% on average) and significantly lower production costs compared to traditional silicon analogues made this technology promising for mass adoption by small and medium-sized businesses and the private sector. An example of commercial implementation is the development of Oxford PV (UK), where the innovative composition of the material helped to reduce the cost of electricity by more than 30%. Hydrogen power systems were equally important, as they allow the accumulation of excess energy from renewable sources and its use in industry or transport. The Hybrit project in Sweden was an example of the effective use of hydrogen for decarbonising steel production, with a 90% reduction in CO_2 emissions. The implementation of such systems allowed energy-intensive enterprises to reduce their dependence on fossil fuels while reducing the cost of utilising excess energy.

Offshore wind farms also had significant potential, as they demonstrate a significant increase in electricity production due to better wind conditions offshore. One of the largest completed projects is Hornsea One (Denmark), which has increased energy production by almost 50% compared to onshore wind farms. For countries with access to the sea coast, the implementation of such projects meant the possibility of strengthening energy independence without putting a significant burden on land infrastructure. All of these examples demonstrate that renewable energy innovations not only had a technical advantage, but also created economically viable incentives for commercial implementation, including at the level of enterprises of various industries. It was also important to note that the decline in the cost of renewable energy in 2010-2023 had a positive trend (Fig. 1)

According to IRENA & AfDB (2022), Bloomberg New Energy Finance (2023), IEA (2022b), the share of innovations in RES by technology in 2023 was as follows (Fig. 2).

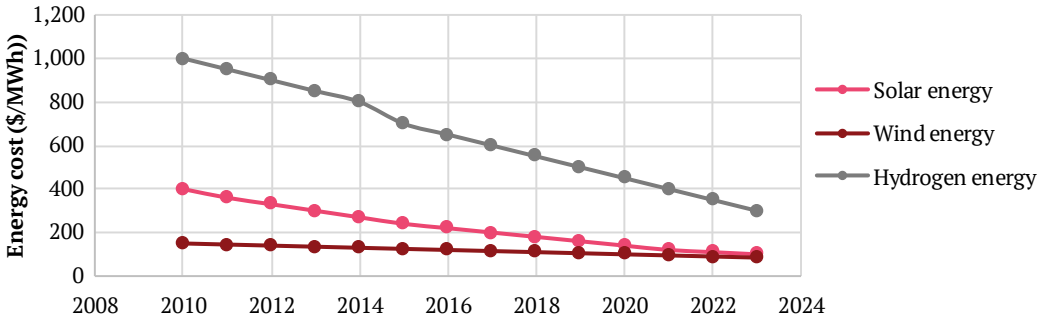

Figure 1. Dynamics of renewable energy cost reduction (2010-2023)
Source: created by the authors based on IRENA & AfDB (2022), IEA (2022a), Bloomberg New Energy Finance (2023)

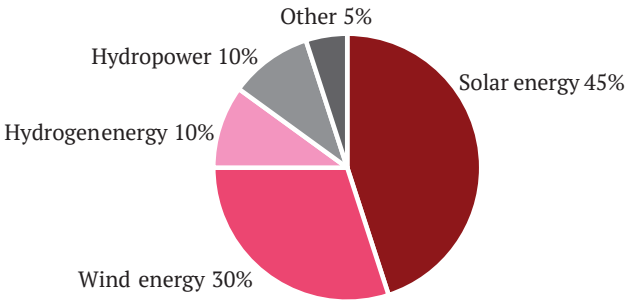

Figure 2. Share of innovations in RES by technology (2023)
Source: Systematised based on analytical materials of IRENA (2023), Bloomberg New Energy Finance (2023), L. Mykhailova, & O. Dumansky (2024)

Modern offshore wind turbines were primarily characterised by innovative designs with increased capacity and efficiency. Thus, it was worth considering a synergistic approach to the introduction of renewable energy. Such a scheme should demonstrate the interconnection between solar energy (solar panels), wind energy (turbines), hydrogen energy (electrolysis plants) and energy storage systems (batteries, grid integration). The central hub was represented as a smart grid that coordinates all the components. The connections between the elements illustrated energy flows and optimisation through monitoring and feedback. Thus, it was a combination of four elements: production (solar and wind farms), storage (batteries, hydrogen), distribution (smart grids) and consumption (smart homes, transport). To compare the key RES technologies, Table 1 showed the rationale for this approach.

Table 1. Comparison of key RES technologies

Technology	Efficiency (%)	Cost ($/MWh)	Environmental impact (low/medium/high)	Potential for use
Solar panels (perovskite)	25-30	40-60	Low	High
Wind turbines (offshore)	35-50	50-70	Medium	High
Hydrogen energy	45-55	60-100	Low	Medium
Hydropower	80-90	30-50	High	Limited

Source: compiled from IRENA & AfDB (2022), IEA (2022a), Bloomberg New Energy Finance (2023), G. Squadrito *et al.* (2023), O. Fedorenko (2024)

The comparative analysis of key renewable energy innovations allowed to form a holistic view of the potential of each technology in the context of its practical implementation in the economy. The data showed a significant difference between technologies not only in terms of efficiency and cost, but also in terms of environmental impact and the extent of adaptation to market conditions. For example, the high efficiency of hydropower was combined with limited potential for expansion due to environmental constraints and geographical specificity. In contrast, hydrogen power and new generation battery systems had an average power level, but offer high flexibility in use and scalability. Perovskite panels strike a balance between low cost and high application potential, making them strategically attractive for energy-active businesses. Offshore wind power, despite its complexity, demonstrated the highest generation stability and long-term economic returns. It was the integration of these technologies at the level of enterprises and territorial communities that was the best way to achieve economic efficiency, decarbonise production and reduce the energy dependence of national economies. This approach met the current challenges of sustainable development and forms the basis for new business models in the green economy. The growth rate of installed RES capacities from 2010 to 2023 was shown in Figure 3. Table 2 provided a comprehensive overview of the key renewable energy innovations, including their advantages, disadvantages, implementation opportunities and estimated timeframes. These technologies were important for achieving energy independence, decarbonising the economy and integrating Ukraine into the global energy market.

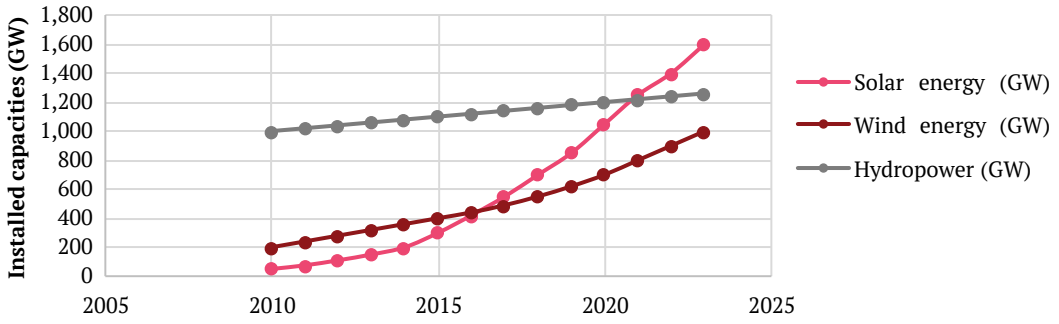

Figure 3. Growth rates of installed RES capacities (2010-2023)
Source: built by the author based on the analysis of IRENA & AfDB (2022), Bloomberg New Energy Finance (2023), O. Fedorenko (2024)

Table 2. Modern innovations in the field of renewable energy

Innovation	Advantages	Disadvantages	Opportunities for implementation	Estimated year of implementation
Perovskite solar panels	Higher efficiency and cheaper production compared to standard panels	Shorter service life, need for large-scale production	Widespread use in residential and industrial buildings	2025-2030
Bladeless wind turbines	Less noise, less impact on wildlife, easier maintenance	Require new structures and infrastructure for installation	Suitable for remote regions and offshore wind farms	2028-2035
Hydrogen fuel cells	Possibility of energy storage and transportation, low emissions	High production costs, insufficient infrastructure	Ensuring the decarbonisation of heavy industry and transport	2025-2040
New generation battery systems (solid-state batteries)	Higher energy density, faster charging, longer service life	High cost, need to improve technology	Use in electric vehicles and stationary energy storage	2025-2030
Smart grids	Optimisation of energy flows, reduction of grid losses	Requires significant investment in digitalisation	Integrating renewables into the national grid	2025-2035

Source: compiled based on IEA (2022b), IRENA (2023), G. Squadrito *et al*. (2023), L. Mykhailova *et al*. (2023), Global clean energy investment jumped 17% to $1.8 trillion in 2023, according to BloombergNEF (2024)

Perovskite solar panels offered higher efficiency in energy production and had lower manufacturing costs than standard silicon panels, which was important for Ukraine. The main problem was the shorter lifespan and the need for large-scale production, which was not yet established in Ukraine. The next innovation, bladeless wind turbines, were more environmentally friendly (less impact on wildlife) and easier to maintain than traditional turbines. It also reduced noise, making it more acceptable to the public, and was suitable for use in remote regions of Ukraine and in the Black Sea, where offshore turbines can operate efficiently. However, its implementation required an installation infrastructure that was not yet available in Ukraine. The scientific community was actively considering the possibilities of hydrogen energy, which allowed storing excess energy from renewable sources, which in turn was important for the stability of the power system.

Hydrogen can be used in industry and transport, and for Ukraine, this was a real chance to decarbonise heavy industry (e.g., metallurgy) and develop green hydrogen exports to the EU. The biggest obstacle to the introduction of hydrogen energy was the high cost of hydrogen production and insufficient infrastructure for its transportation and storage. New generation battery systems (solid-state batteries) were increasingly being used in transport, providing a longer service life, higher energy capacity and faster charging, which was critical for the development of the electric vehicle sector and energy storage in Ukraine. This technology was relatively expensive and required large-scale production, but its potential for use in transport and for stabilising the power system, especially during peak loads, cannot be overestimated. It was worth emphasising the importance of building a smart grid, a system that allowed for the integration of different energy sources into a single network, optimising its operation and reducing losses, and can reduce dependence on fossil fuels. Despite the high level of digitalisation, such a system required significant investments in further digitalisation and infrastructure modernisation. For Ukraine, the introduction of these technologies was strategically important. The development of RES will contribute to energy independence, economic growth and environmental sustainability. Attracting investment, adopting advanced technologies and integrating into European energy markets will make these innovations a reality in the coming decades.

Azerbaijan was a striking example of a successful transition to alternative energy sources with huge renewable energy potential. Despite the fact that the formation of modern Azerbaijan was inextricably linked to oil production, it was a leader in the region in applying innovative

approaches aimed at the transition to green energy and makes a significant contribution to combating the effects of climate change. It was worth noting that the 29th session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP29) was held under the Azerbaijani presidency on 11-22 November 2024. By order of the President of Azerbaijan, 2024 has been declared the 'Year of Solidarity for a Greener World', and the country intends to reduce greenhouse gas emissions by 35% by 2030 and 40% by 2050 compared to 1990. In terms of Azerbaijan's potential, important memoranda of understanding and agreements have been signed between Azerbaijan and international energy companies that will allow for the production of up to 22 GW of wind and solar energy onshore, 10 GW of wind and solar energy in the territories liberated during the 2020 war, and 157 GW of wind energy in the Azerbaijani sector of the Caspian Sea. In total, this potential is almost 200 GW. While Azerbaijan has previously accumulated a large amount of investment in the oil and gas sector, in 2024, the country's main goal is to develop renewable energy sources and maintain leadership in the region.

As for the economic effect of the introduction of renewable energy, global investment in renewable energy is expected to grow from $200 billion to $1 trillion per year by 2033. This is due to the large-scale introduction of new technologies such as perovskite panels, hydrogen systems and smart grids. Thanks to lower energy costs, reduced expenditures on fossil fuels and improved energy efficiency, annual savings of up to $450 billion are expected by 2033 (Fig. 4).

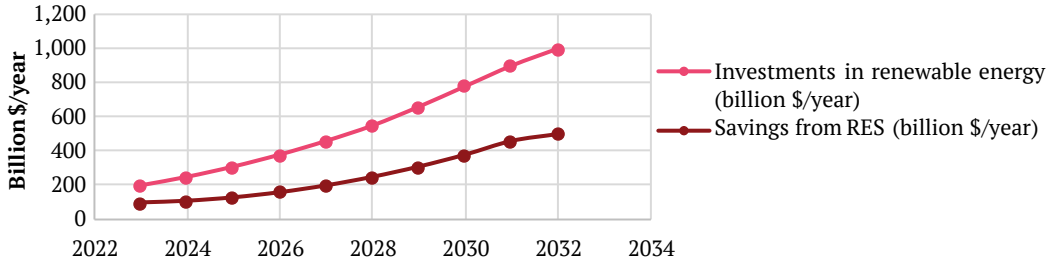

Figure 4. Economic impact of RES innovations in the world (forecast 2023-2033)
Source: IRENA & AfDB (2022), G. Squadrito *et al.* (2023), IEA (2024)

The economic effect of innovations in Ukraine (2023-2033) was projected to be achieved through an increase in investment in the Ukrainian renewable energy sector from $2 billion in 2023 to $40 billion in 2033. This was due to the post-war rebuilding of infrastructure, attracting international assistance and developing export potential. The introduction of new technologies will allow Ukraine to save up to $12 billion annually by reducing energy import costs, decarbonising the industry, and improving energy security (Fig. 5).

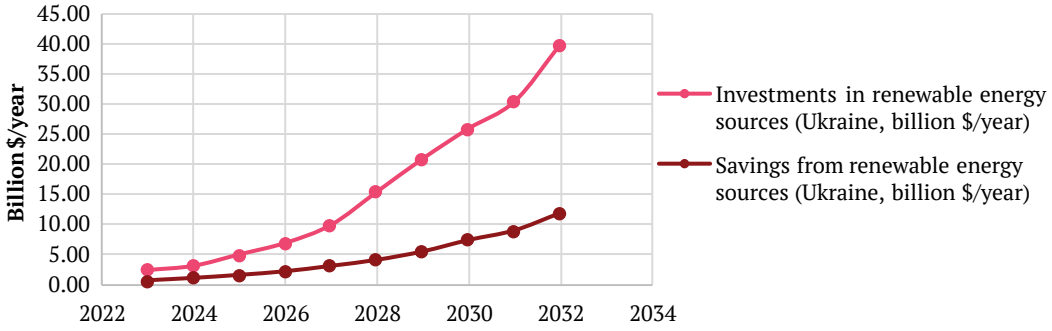

Figure 5. Economic impact of RES innovations in Ukraine (forecast 2023-2033)
Source: IRENA & AfDB (2022), Energy strategy (2022), G. Squadrito *et al.* (2023), IEA (2024)

Thus, intensifying innovative development in the renewable energy sector was a key task for countries seeking to achieve energy independence and to reduce their carbon footprint and ensure economic sustainability. In this context, it was necessary to focus on several strategic areas. Governments and the private sector should invest in research aimed at reducing the cost of technologies and increasing their efficiency. The development of perovskite solar panels, which were more cost-effective than silicon, but required large-scale testing. Another important role was to stimulate research in higher education institutions and cooperation with industrial partners that will promote innovation, as well as support for research and development, since the development of innovations in renewable energy depended on the creation of new materials, technologies and solutions. In addition, favourable conditions for investors will also contribute to the development of innovations, as investment is the main driver of innovation, and

therefore the introduction of tax breaks, grants and subsidies for companies investing in RES will help accelerate their development. Infrastructure development has also been an important focus of this development vector, as high-tech infrastructure is the basis for integrating renewable energy sources into national energy systems. The integration of smart grids will enable more efficient management of power flows, reduce losses and stabilise the power system. Investments in new generation battery systems will help solve the problem of uneven power generation. The development of the regulatory framework should also be taken into account, as modern legislation should stimulate the development of RES and ensure a level playing field for market participants, which in turn will help make investments in RES more attractive for businesses. International cooperation, exchange of experience and technologies with developed countries will help accelerate innovation development. Education and training of personnel are also important for the successful development of renewable energy, which may include the introduction of specialised courses on renewable energy in higher education institutions, organisation of training for energy sector employees on how to work with new technologies, etc. Raising public awareness by disseminating information about the benefits of RES through the media and educational programmes, as public support is an important factor for innovation, and creating local RES projects with the involvement of the public, which will help to increase confidence in the technologies.

Ya. Kotyk (2024) focused on the implementation of the mechanism of guarantees of electricity origin as a tool to stimulate the development of renewable energy in Ukraine, comparing the EU experience. The authors agreed with these findings, as such mechanisms do promote investment and transparency in energy markets. This was consistent with this research on renewable energy innovation as a driver of energy security and sustainable development. The authors G. Squadrito *et al*. (2023) investigated the advantages and disadvantages of different green hydrogen production technologies, including biomass pyrolysis and water electrolysis, favouring the latter as the most promising for large-scale implementation. The authors also analysed geopolitical and economic challenges, in particular the threat of an aggravation of the water crisis. This position should be agreed with, since the integration of green hydrogen really requires a comprehensive approach that takes into account not only technological but also socio-economic aspects.

Population growth and the development of national economies were leading to an increase in demand for energy resources. Traditional energy sources were unable to meet this growth without significant negative impact on the environment. In this context, renewable energy sources (RES) were a tool for ensuring stable energy supply through the introduction of modern technologies in the field of energy production, storage and distribution. Geopolitical instability, in particular the dependence of some countries on fossil fuel imports, has highlighted the need to move to energy self-sufficient systems. For Ukraine, this approach was of particular importance in the context of post-war reconstruction. As noted by S. Kudrya (2020), the use of environmentally friendly RES contributed to the energy security of Ukraine, which was characterised by a shortage of its own energy resources. The introduction of RES has been identified as a priority area of energy development in most developed countries. This was driven by the need to eliminate energy instability and reduce emissions of harmful substances typical of traditional energy sources.

An additional advantage was the preservation of natural raw materials for non-energy needs and the formation of strategic reserves. According to the position of IEA Executive Director Fatih Birol, quoted in A. Frangoul (2022), and which the authors of the study consider to be correct, the energy crisis has intensified the transition to a new stage of RES development, accompanied by their rapid growth, driven by the desire of states to strengthen energy autonomy. The IEA report (2022b) predicted a significant change in the structure of the global energy balance in the face of geopolitical tensions. The document stated that the first global energy crisis caused by the Russian Federation's armed aggression against Ukraine has strengthened the momentum of renewable energy development.

L. Mykhailova & O. Dumanskyi (2024) analysed the introduction of innovative technologies in Ukraine's green energy sector in the context of European integration and sustainable development, in particular artificial intelligence, smart grids and green auctions. The authors pointed out the prospects of solar energy and the role of IT solutions in restoring the energy system. This approach seemed appropriate as it combined technological modernisation with the environmental and economic strategy of post-war transformation. The study by the State Agency on Energy Efficiency and Energy Saving of Ukraine (n.d.) and the BloombergNEF analytical report (2024) highlighted the growth of global investment in the RES sector, as well as the expansion of smart grids. It was noted that clean energy sources, green technologies, hydrogen, electric transport, and carbon reduction initiatives have become key determinants of investment growth. In 2023, total investment in low-carbon projects reached USD 1.77 trillion, a record high. This data demonstrated the sustainability of the global energy transition.

The reports, in particular, by National Power Company Ukrenergo (n.d.) and the European Bank for Reconstruction and Development (n.d.), focused on the specifics of RES development in Ukraine. The analysis of innovations in this area required an interdisciplinary approach, taking into account economic, technological, environmental and social factors. According to the recommendations of the IEA (2022a; 2022b), methods of analysing innovation development should include economic modelling, which involves forecasting the structure of the energy market, costs and revenues, as well as scenario analysis to determine the long-term consequences of the introduction of new technologies, including the transition to hydrogen

energy. Authors E.G. Hertwich & R. Wood (2018) considered that environmental assessment should be carried out using LCA (Life Cycle Assessment) methodology, which includes determining carbon footprint, biodiversity and water resource impacts. Enhancing the innovative development of renewable energy required a comprehensive approach that includes support for research, favourable conditions for investment, infrastructure development and training of qualified personnel. In the context of Ukraine, these measures should be seen as the basis for energy independence and sustainable economic growth.

Conclusions

Innovations in renewable energy were key to transforming modern energy systems. Technologies such as perovskite solar panels, bladeless wind turbines, hydrogen systems and smart grids not only contributed to decarbonisation, but also created significant economic benefits by reducing energy costs. Innovations helped to reduce the cost of energy production and increase its availability. Global investment in renewable energy is expected to reach $1 trillion annually by 2033, with savings of $450 billion, which will help develop renewable energy innovations, energy independence, attract international investment and restore infrastructure. The development of renewable energy was not only a challenge but also a chance to become a leader, and Azerbaijan was a vivid example of such development for Ukraine.

Important areas included the integration of innovations into the national energy system, the development of smart grids, and the transition to a closed-loop economy. To boost innovation development, it was necessary to focus on government support for research, creating a favourable investment climate, infrastructure modernisation, international cooperation and training. Further research should focus on the adaptation of advanced technologies to the conditions of specific countries, including Ukraine, the development of integrated energy systems, the use of digital tools for energy management, and the development of economic models for assessing the impact of innovations on national economies. Further research will help create more effective models for implementing innovations, ensuring sustainable development of the economy and society. A review of the collected sources indicated the need for further development of models for assessing the economic efficiency of innovations, the development of energy storage technologies, and the use of Big Data to manage energy flows, and thus the development of RES was a complex challenge that requires the efforts of the scientific community, governments and businesses.

Acknowledgements

None.

Conflict of Interest

None.

References

[1] Bloomberg New Energy Finance. (2023). *Energy transition investment trends*. Retrieved from https://assets.bbhub.io/professional/sites/24/energy-transition-investment-trends-2023.pdf.
[2] Energy strategy. (2022). Retrieved from https://mev.gov.ua/reforma/enerhetychna-stratehiya-0.
[3] European Bank for Reconstruction and Development. (n.d.). Retrieved from https://www.ebrd.com.
[4] Fedorenko, O. (2024). *Japanese vertical wind turbines: A new stage in the development of offshore energy*. Retrieved from https://kreschatic.kiev.ua/tehno/2024/09/12/yaponski-vertykalni-vitryaky-novyj-etap-u-rozvytku-ofshornoyi-energetyky.html.
[5] Frangoul, A. (2022). *Renewables to overtake coal and become world's biggest source of electricity generation by 2025, IEA says*. Retrieved from https://www.cnbc.com/2022/12/06/renewables-to-be-main-source-of-electricity-generation-by-2025-iea.html.
[6] Global clean energy investment jumps 17%, hits $1.8 trillion in 2023, according to BloombergNEF report. (2024). Retrieved from https://about.bnef.com/blog/global-clean-energy-investment-jumps-17-hits-1-8-trillion-in-2023-according-to-bloombergnef-report/.
[7] Hertwich, E.G., & Wood, R. (2018). The growing importance of scope 3 greenhouse gas emissions from industry. *Environmental Research Letters*, 13(10), article number 104013. doi: 10.1088/1748-9326/aae19a.
[8] IEA. (2022a). *World Energy Outlook 2022*. Paris: International Energy Agency.
[9] IEA. (2022b). *Renewables 2022*. Vienna: IEA.
[10] IEA. (2024). *Renewables 2023: Analysis and forecast to 2028*. Paris: International Energy Agency.
[11] IRENA & AfDB. (2022). *Renewable energy market analysis: Africa and its regions*. Abu Dhabi: International Renewable Energy Agency.
[12] IRENA. (2023). *World energy transitions outlook 2023*. Retrieved from https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2023.
[13] Jacobson, M.Z., & Delucchi, M.A. (2011). Providing all global energy with wind, water, and solar power, part I: Technologies, energy resources, quantities and areas of infrastructure, and materials. *Energy Policy*, 39(3), 1154-1169. doi: 10.1016/j.enpol.2010.11.040.
[14] Kotyk, Ya. (2024). Guarantees of electricity origin as a financial mechanism to increase investment attractiveness in the energy sector. *University Economic Bulletin*, 19(1), 17-25. doi: 10.69587/ueb/1.2024.17.

[15] Kudrya, S. (Ed.). (2020). *Renewable energy sources*. Kyiv: The Institute of Renewable energy of the National Academy of Sciences of Ukraine.
[16] Melnyk, L., Karintseva,O., & Dehtyarova, I. (2019). "Green" energy as a leading link of the "green" economy: The experience of the European Union. In P. Makarenko, O. Kalinichenko & V. Aranchii (Eds.), *Energy efficiency and energy saving: Economic, technical, technological and ecological aspects* (pp. 85-91). Poltava: PC "Astraya".
[17] Mykhailova, L., & Dumansky, O. (2024). Innovative technologies in green energy: Prospects and challenges. *Science and Technology Today*, 2(30), 899-909. doi: 10.52058/2786-6025-2024-2(30)-899-909.
[18] Mykhailova, L., Semenyshyna, I., & Shpatakova, O. (2023). Green energy as a factor of energy independence of Ukraine. *Economy and Society*, 47. doi: 10.32782/2524-0072/2023-47-10.
[19] National Power Company Ukrenergo. (n.d.). Retrieved from https://ua.energy/en/.
[20] Orlova, D., & Sydoro, D. (2021). *Igor Nus: "The peak of wind farm construction in Ukraine is far ahead of us"*. Retrieved from https://expro.com.ua/statti/gor-nus-pk-budvnictva-ves-v-ukran-cheka-nas-daleko-poperedu.
[21] Squadrito, G., Maggio, G., & Nicita, A. (2023). The green hydrogen revolution. *Renewable Energy*, 216, article number 119041. doi: 10.1016/j.renene.2023.119041.
[22] State Agency on Energy Efficiency and Energy Saving of Ukraine. (n.d). Retrieved from https://saee.gov.ua/en.

Інновації у сфері відновлюваної енергетики: синергія технологій та сталого розвитку

Алла Ткаченко
Доктор економічних наук, професор
Національний університет «Запорізька політехніка»
69063, вул. Жуковського, 64, м. Запоріжжя, Україна
https://orcid.org/0000-0002-1843-2579

Вілаят Ібрагім огли Ісмайлов
Доктор економічних наук, професор
Азербайджанська академія праці та соціальних відносин
AZ1130, просп. Азадлиг, 181, м. Баку, Азербайджан
https://orcid.org/0000-0003-0892-0365

Анотація. У роботі висвітлено актуальність теми в контексті глобальних викликів, зокрема кліматичних змін, зростання населення, та необхідності декарбонізації економіки. Мета даної статті – обґрунтування ролі інновацій для відновлюваної енергетики, а також вплив сучасних проектів, таких як офшорні вітрові турбіни нового покоління (Haliade-X, WindFloat Atlantic) на досягнення сталого розвитку. Під час написання роботи використовувались різні види аналізу та візуалізації даних. Було застосовано методи аналізу даних та інформації, перехресний та описовий аналіз. Основний акцент зроблено на таких інноваційних рішеннях, як перовськітні сонячні панелі, безлопатеві вітрові турбіни, водневі системи енергозабезпечення, акумуляторні системи нового покоління та інтегровані смарт-мережі. Авторами передбачається, що до 2033 року світові інвестиції у відновлювані джерела енергії сягнуть $1 трлн на рік, а щорічна економія від зниження собівартості енергії та енергоефективності становитиме до $450 млрд. Для України прогнозується зростання інвестицій з $2 млрд у 2023 році до $40 млрд у 2033 році, що сприятиме енергетичній незалежності та післявоєнному відновленню інфраструктури. Зазначено, що, розвиваючи сферу відновлюваних джерел енергії вдасться не лише диверсифікувати експорт, а й створити екологічно чистий сектор економіки. Описано, як інновації у відновлюваних джерел енергії дозволяють зменшити залежність від викопного палива, сприяють декарбонізації промисловості, а також покращують енергетичну безпеку. Робота розглядає синергетичний підхід до інтеграції різних технологій, таких як сонячна та вітрова енергетика, водневі системи та смарт-мережі. Це дозволяє оптимізувати енергетичні потоки та зменшити втрати, що актуально для енергетичних систем. Робота створює науково-практичну базу для подальших досліджень і розробок, а також для широкого впровадження інновацій у сфері відновлюваних джерел енергії, що забезпечить стале економічне зростання, конкурентоспроможність економіки та вирішення екологічних проблем

Ключові слова: смарт-мережі; інвестування; собівартість; економічний ефект; декарбонізація; прибуток; економічне відновлення