Environmental and Climate Technologies
2026, vol. 30, no. 1, pp. 471–482
https://doi.org/10.2478/rtuect-2026-0032
https://content.sciendo.com

Technical and Market Aspects of Pumped Storage Hydropower Operation in the Ukrainian Energy System During Military Conflict

Oleksandr RIABENKO[1], Eva BILKOVA[2], Petr NOWAK[3], Oksana HALYCH[4*]

[1,4]*Department of Energy, National University of Water and Environmental Engineering, Rivne, Ukraine*
[2,3]*Department of Hydraulic Structures, Faculty of Civil Engineering, CTU in Prague, Czech Republic*

Received 18.03.2026; accepted 17.07.2026

***Abstract* – The ongoing military aggression against Ukraine has significantly affected the stability and operation of the national energy system, creating unprecedented challenges for electricity security and market functioning. While previous studies have primarily focused on infrastructure damage and generation losses, limited attention has been given to the role of hydropower plants (HPPs) and pumped-storage power plants (PSPPs) in maintaining power system resilience under wartime conditions. This study aims to assess the current state of Ukraine's energy sector and evaluate the contribution of HPPs and PSPPs to system stability during periods of severe generation shortages. The research is based on the analysis of statistical data on electricity generation in Ukraine, operational information from the national electricity market, and international experience in the development of pumped-storage technologies. Comparative and analytical methods were applied to assess changes in generation capacity, infrastructure damage, and the operational role of PSPPs in balancing electricity supply and demand. The novelty of the study lies in its assessment of the evolving role of PSPPs in ensuring energy system resilience during wartime and its analysis of their increased contribution to balancing electricity supply and demand under conditions of large-scale infrastructure disruption. The results emphasize the importance of expanding pumped-storage capacity and strengthening integration with the European electricity market to enhance the long-term sustainability of Ukraine's energy sector.**

***Keywords* – Energy market; energy system resilience; hydropower plants; pumped storage power plants; renewable energy sources.**

Nomenclature		
BPP	Bio Power Plant	–
CHP	Combined Heat and Power Plant	–
ENTSO-E	European Network of Transmission System Operators for Electricity	–
HPP	Hydropower Plants	–
IRENA	International Renewable Energy Agency	–

* Corresponding author.
E-mail address: o.o.halych@nuwm.edu.ua

Oleksandr RIABENKO https://orcid.org/0000-0002-1923-3061
Eva BILKOVA https://orcid.org/0000-0001-9235-8058
Petr NOWAK https://orcid.org/0000-0003-4496-2853
Oksana HALYCH https://orcid.org/0009-0001-5800-2231

©2026 Author(s). This is an open access article licensed under the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0).

NPP	Nuclear Power Plant	–
PSPPs	PUMPED STORAGE POWER PLANTS	–
SPP	Solar Power Plant	–
TPP	Thermal Power Plant	–
WPP	Wind Power Plant	–

1. INTRODUCTION

The operation and regulation of modern power systems rely heavily on conventional hydropower plants and pumped-storage power plants. Owing to their high operational flexibility, rapid response capabilities, and ability to regulate power output, PSPPs play a vital role in maintaining the balance between electricity generation and consumption. Consequently, these facilities constitute an essential component of power systems worldwide.

At present, approximately 460 pumped-storage power plants are in operation globally, with numerous additional projects currently under development and construction. By 2021, the total installed PSPP capacity worldwide had reached 164.76 GW [1]. The largest capacities are concentrated in China (36.0 GW), Japan (27.47 GW), and the United States (approximately 21.9 GW). According to projections by the International Renewable Energy Agency (IRENA), global pumped-storage capacity is expected to increase to approximately 325 GW by 2050 [2], reflecting the growing importance of large-scale energy storage in the transition toward low-carbon energy systems.

The evolution of contemporary electricity markets has further expanded the functional significance of PSPPs. In addition to their traditional role in energy storage, these facilities provide a wide range of ancillary services, including peak-load coverage, frequency regulation, reserve capacity, and system balancing. Moreover, PSPPs facilitate the integration of renewable energy sources, whose intermittent and variable generation profiles require flexible resources capable of compensating for fluctuations in electricity supply and demand.

Against this background, the Ukrainian energy system is currently facing unprecedented challenges resulting from extensive damage to energy infrastructure caused by ongoing military actions [3]. The destruction of generation facilities and transmission assets has reduced available generating capacity, constrained power transmission capabilities, and adversely affected the reliability of electricity supply. These disruptions have also influenced the functioning of the electricity market by affecting market operations, price formation, and investment attractiveness [4]. Under such conditions, a comprehensive assessment of the current state of Ukraine's energy sector, together with an evaluation of the role of PSPPs in maintaining system stability and market resilience, is of particular scientific and practical importance. Such an assessment is essential for developing effective measures aimed at ensuring the reliable operation and sustainable recovery of the national energy system.

2. MATERIALS AND METHODS

The present study is based on the analysis of statistical data on the structure and operation of the Ukrainian energy system, as well as information on the global development of pumped storage power plants. The research also analyses the functioning of the energy market under conditions of military conflict, in which damage to energy infrastructure and increased operational risks significantly affect electricity supply, market prices, and system balancing mechanisms. Data from international organizations, national energy reports, energy market

statistics, and operational information from Ukrainian power facilities were used in the analysis.

The research methodology includes:

- analysis of the structure of Ukraine's generating capacities before and during the period of hostilities;
- assessment of the current condition of the Ukrainian energy system and the extent of infrastructure damage;
- evaluation of the operational role of pumped storage power plants in maintaining system flexibility and balancing supply and demand under disrupted operating conditions;
- examination of the participation of hydropower and pumped storage facilities in the Ukrainian energy market, particularly in balancing and ancillary service segments during periods of system stress.

In addition, a comparative analysis was conducted to evaluate the role of pumped storage power plants in other countries, including their contributions to energy system stability and market regulation, to identify potential directions for the further development of this technology in Ukraine under conditions of infrastructure recovery and market transformation.

3. RESULTS

3.1. Structure of Ukrainian Generating Capacities and Current State of the Energy System of Ukraine

Ukraine uses all available electricity generation sources to ensure its energy, economic, and political independence [5]. In 2018, prior to the onset of the active phase of hostilities, nuclear power plants (NPPs) contributed 48.8 % of total electricity generation, thermal power plants (TPPs) accounted for 33.5 %, and renewable energy sources supplied 19.7 %, including hydropower plants, which represented 7.84 %. Notably, hydropower and pumped storage plants collectively accounted for 48.3 % of system load-balancing, underscoring their critical role in maintaining grid stability [6]–[8].

As a result of damage to key components of Ukraine's energy system caused by Russian military actions, the structure of Ukraine's generating capacity has undergone substantial changes.

Fig. 1 illustrates the trends observed during the 2019–2022 period and compares them with corresponding data for the European Union, France, and Germany. The years 2019 and 2022 were selected to represent the periods immediately before the war and following the onset of the full-scale Russian invasion of Ukraine, respectively [9], [11].

Analysis of the data indicates a marked increase in electricity production from nuclear power plants during this period, while generation from other sources declined correspondingly. It is noteworthy that the post-2019 structure of Ukraine's generating capacities remains broadly comparable with the configurations observed in France and Germany, which possess energy systems with similar structural and operational features, thereby providing a relevant basis for comparative analysis.

Currently, the energy system of Ukraine is in a critical condition. As a result of active hostilities, approximately 10 GW of generating capacity has already been lost. During the first years of the active phase of the war, Russian forces seized the Zaporizhzhia Nuclear Power Plant (NPP) with an installed capacity of 6000 MW, destroyed the Kakhovka Hydropower Plant (HPP) with a capacity of 334.8 MW, and damaged or disabled a significant number of thermal, hydropower, solar, and wind power plants.

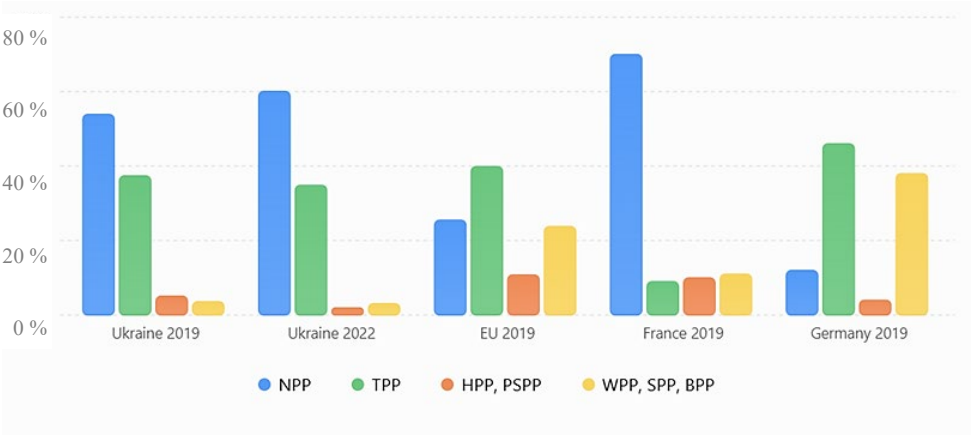


Fig. 1. Structure of generating capacities of Ukraine, the EU, France and Germany.

As the Russian-Ukrainian war continued to escalate over the subsequent four years, several major thermal power plants – including Zmiiv TPP, Trypillya TPP, and Ladyzhyn TPP – were severely damaged and taken out of operation. In addition, Burshtyn TPP, Dobrotvir TPP, as well as numerous combined heat and power plants (CHPs) and thermal power facilities in Kyiv, Kharkiv, and other cities sustained extensive destruction. Overall, the losses in the thermal power sector are estimated at approximately 85 % of its infrastructure.

Significant damage was also inflicted on major hydropower facilities, including Dnipro HPP-1, Dnipro HPP-2, Kyiv HPP, Kaniv HPP, Kremenchuk HPP, Middle Dnipro HPP, and other plants. Furthermore, a considerable portion of critical energy system infrastructure – such as electrical substations, power transformers, switchgear installations, and transmission lines – has been disabled. Fig. 2 demonstrates the dynamics of electricity generation from different energy sources, incorporating the effects of damage to and destruction of power generation facilities resulting from the ongoing conflict [12].

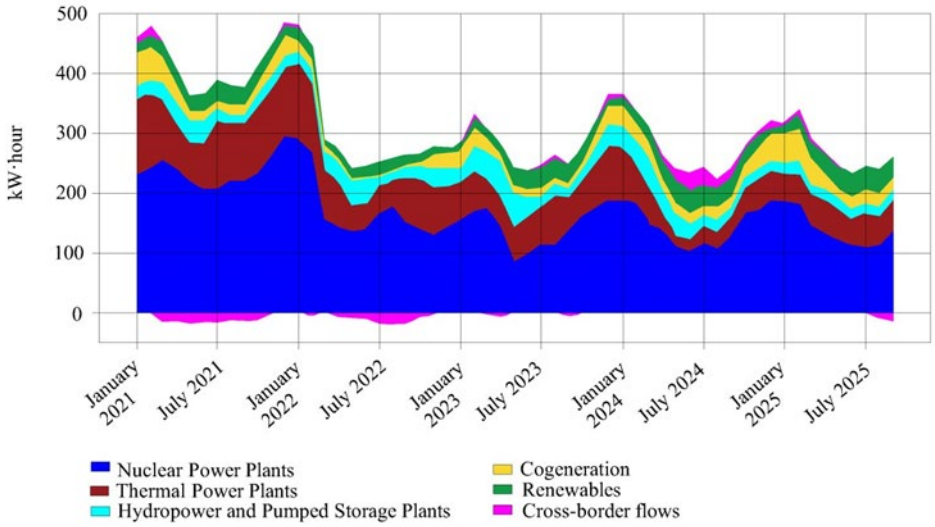


Fig. 2. Average daily electricity generation in Ukraine by month from 2021 till 2025.

Since the beginning of 2026, the contribution of hydroelectric power plants (HPPs) and pumped-storage power stations (PSPs) to total electricity generation has fluctuated between 8 % and 10 %, reaching 14–16 % in April 2026. This represents an almost threefold increase compared with the corresponding share recorded in 2019 [13]. These findings highlight the strategic importance of HPPs and PSPs in enhancing system flexibility and maintaining electricity supply during periods of generation shortages. However, despite their increased contribution, the overall capacity of the Ukrainian power system remains insufficient to fully meet demand. Consequently, the Ukrainian energy system currently operates under conditions of a substantial capacity deficit. As of late February to early March 2026, national electricity demand was estimated at approximately 18 GW, while available generation capacity amounted to only 11 GW, resulting in a deficit of around 7 GW [14]. Nevertheless, despite the extensive damage inflicted on energy infrastructure, Russian forces have not succeeded in completely disabling Ukraine's energy sector, which continues to maintain functionality through adaptive operational measures and the increased utilization of flexible generation sources.

3.2. Ensuring the Operation of the Ukrainian Energy System in Conditions of Hostilities

The large-scale destruction and damage to Ukraine's energy infrastructure, caused by extensive shelling and systematic missile attacks by Russian forces, necessitate rapid response measures and the implementation of comprehensive actions aimed at restoring electricity supply. The key emergency measures include the following areas of activity:

1. The implementation of scheduled and emergency power outages for consumers in conditions of a significant electricity deficit.
2. Repair and restoration of damaged power plants and critical energy infrastructure components, including transformers, switchgear, transmission lines, and other electrical equipment.
3. The usage of existing power supply networks and the development of additional backup transmission routes.
4. The redistribution transmission of electricity from neighbouring regions to affected areas.
5. The import of substantial volumes of electricity from external sources.
6. The use of industrial and household diesel and gasoline generators, as well as heat pumps, to provide alternative energy supply.

It should be emphasized that the restoration of Ukrainian energy system is being carried out with the support of international partners, who provide financial assistance as well as energy equipment and technological resources. At the same time, the reconstruction of the energy sector is being implemented on a new technological basis in accordance with modern European standards and with consideration of existing military risks.

In many cases, the restoration of large-scale power plants requires not only repair works but also the complete replacement of destroyed equipment. The production of specialized energy equipment – such as high-capacity transformers, generators, turbines, and other critical components – is technologically complex, time-consuming, and requires substantial financial resources. The repair process is further complicated by the fact that a considerable portion of restoration work must be carried out under conditions of ongoing military threats, including shelling and the presence of mine hazards. Moreover, the current military situation does not exclude the possibility of further missile strikes and attacks on energy infrastructure.

A decisive step toward strengthening Ukraine's energy security and improving the stability of its energy system was the disconnection from the energy systems of Russia and Belarus and the synchronization of the Ukrainian grid with the European energy system ENTSO-E.

This organization unites 43 transmission system operators from 36 European countries and coordinates the operation of the continental European electricity network.

The establishment of the energy bridge between Ukraine and the European Union in March 2022 enabled the country to conduct essential electricity export and import operations with European partners. It should be noted that such integration and cooperation with the European energy market requires maintaining a reserve transmission capacity of approximately 200 MW.

3.3. Features of the Energy Market of Ukraine

The development of the global energy sector over the past decades has been characterized by the gradual formation and dynamic expansion of competitive energy markets. These markets operate as complex economic systems that facilitate the trade of electrical energy and serve as an intermediary mechanism between electricity producers and consumers. Within this framework, electricity is treated as a specific type of commodity whose economic and technical characteristics differ significantly from those of conventional goods. Unlike most commodities, electrical energy must be generated, transmitted, and consumed almost simultaneously, while large-scale storage remains technologically limited and economically costly. Consequently, the functioning of energy markets requires sophisticated infrastructure, coordinated system operation, and strict regulatory mechanisms governing production, transmission, distribution, and consumption [15], [16].

The energy market of Ukraine possesses a number of distinctive features that stem from the structural characteristics of the national energy system and the regulatory framework governing its operation. These features have become particularly evident under the conditions of ongoing hostilities, which have significantly affected the stability, operational reliability, and generation capacity of the country's energy infrastructure. Despite these challenges, the Ukrainian energy market continues to function and adapt, relying on both internal resources and increasing integration with the European energy system.

An important participant in the Ukrainian energy market is PJSC Ukrhydroenergo, one of the key state-owned energy companies responsible for the operation of major hydropower and pumped-storage power plants in Ukraine. The company actively uses the unique operational capabilities of hydropower and pumped storage power plants, which are particularly valuable for maintaining system stability and balancing electricity supply and demand. These facilities provide significant flexibility in power generation, enabling rapid response to fluctuations in electricity consumption and generation within the unified energy system.

In addition, PJSC Ukrhydroenergo operates certified equipment that complies with both national technical standards and European regulatory requirements. This allows the company to participate effectively in various segments of the energy market, including the provision of ancillary services. In particular, the company supplies services related to frequency regulation and active power balancing within the Unified Energy System of Ukraine. These services include maintaining operational reserves, supporting automatic and manual frequency restoration, and ensuring the stability of the power grid during fluctuations in supply and demand.

The structure of the Ukrainian energy market includes several key segments that enable the efficient organization of electricity trade and system balancing. According to the current market model, the main segments of the Ukrainian energy market include the following [17]:

- the bilateral contracts market, where electricity producers and consumers conclude long-term or medium-term contracts for the supply of electricity at agreed prices;
- the day-ahead market, where electricity is traded one day before actual delivery,

allowing market participants to plan generation and consumption schedules;
- the intraday market, which enables participants to adjust their positions closer to the real time of electricity delivery in response to changing demand and generation conditions;
- the ancillary services market, which ensures the technical stability and reliability of the energy system through services such as frequency control, reserve capacity provision, and system balancing.

Despite the existing institutional structure, the Ukrainian energy market still requires further development and modernization in order to improve its operational efficiency, transparency, and resilience. One of the most important strategic directions for this development is the deeper integration of Ukraine's energy system with the European energy infrastructure. In particular, the synchronization of the Unified Energy System of Ukraine with the European electricity network operated by ENTSO-E represents a crucial step toward strengthening the country's energy security and expanding its participation in the European energy market.

The integration and gradual unification of energy markets between Ukraine and the European Union create significant opportunities for improving the efficiency, reliability, and security of the national energy system. Furthermore, such cooperation promotes the adoption of modern regulatory standards, encourages technological modernization of energy infrastructure, and enhances the stability of electricity supply under both normal operating conditions and emergency situations.

3.4. Operation and Functional Expansion of PSPPs in the Energy System and Energy Market

Hydropower plants (HPPs) and pumped storage power plants (PSPPs) play a crucial role in ensuring the reliable and stable operation of modern energy systems. In Ukraine, hydropower facilities represent an important component of the national electricity infrastructure due to their operational flexibility, ability to rapidly regulate power output, and capacity to support the balancing of electricity supply and demand. Traditionally, hydropower and pumped storage power plants have been used primarily to generate peak and semi-peak electricity and to regulate daily load fluctuations within the energy system.

In recent decades, however, the role of pumped storage power plants has expanded significantly. Modern energy markets require greater operational flexibility and rapid response capabilities to maintain system stability. Consequently, PSPPs are increasingly being used not only for traditional peak-load generation but also as multifunctional facilities that provide a wide range of system services within the energy market. These additional functions contribute to the efficient operation of the energy system and enhance the stability of energy markets.

Among the most important additional functions of pumped storage power plants are the regulation of key operational parameters of the energy system, including active power, system frequency, and reactive power. By rapidly adjusting their operating modes, PSPPs can provide frequency control and maintain the balance between electricity generation and consumption in real time. Another important function is the improvement of electricity quality supplied to consumers, including the stabilization of voltage levels and reduction of fluctuations in system frequency. In addition, pumped storage plants are capable of forming operational reserves required for frequency support and automatic or manual restoration of system frequency after disturbances.

The expanded operational role of PSPPs inevitably leads to an increase in the number of start-ups and shutdowns of generating units. In modern energy systems, the number of

operating mode changes for pumped storage units can reach 4000–8000 cycles per year. For comparison, the planned annual operational indicators for several major international PSPPs are approximately 8000 cycles/y for the Drakensberg pumped storage plant in South Africa, about 6000 cycles/y for the Gilboa pumped storage plant in the United States, and approximately 5000 cycles/y for the Dinorwig pumped storage plant in the United Kingdom. These examples illustrate the growing importance of pumped storage facilities as highly flexible components of modern electricity systems.

Another increasingly important function of pumped storage power plants is related to their ability to store surplus electricity generated by renewable energy sources. The rapid expansion of wind and solar power generation has introduced new challenges for energy system operators because the output of these sources depends heavily on weather conditions and is therefore inherently variable and difficult to predict. In situations where electricity generation from renewable sources exceeds consumer demand, significant imbalances can arise within the energy system. Pumped storage plants can effectively address this problem by using excess electricity to pump water into the upper reservoir, thereby storing energy that can later be released during periods of higher demand. This capability makes PSPPs one of the most effective large-scale energy storage technologies currently available and an essential component for integrating renewable energy into modern energy markets.

Various technologies for large-scale electricity storage exist today, including hydraulic storage in pumped storage plants, compressed-air energy storage systems, and electrochemical storage technologies such as lithium-ion, lead-acid, nickel-cadmium, sodium-sulphur, and vanadium redox batteries. However, when selecting an energy storage technology, it is necessary to consider not only technical characteristics but also economic factors such as capital costs, operational lifetime, maintenance requirements, and disposal costs. Comparative studies demonstrate that pumped storage power plants remain one of the most economically efficient large-scale energy storage solutions. Their typical service life can reach 70–80 years, which significantly exceeds the operational lifetime of most battery storage systems and leads to lower long-term costs.

At present, several pumped storage power plants operate within Ukrainian energy system, including the Kyiv, Tashlyk, and Dniester PSPPs (Table 1) [18]. These facilities play an important role in balancing electricity supply and demand, supporting system frequency, and ensuring the stable operation of the national grid.

TABLE 1. CHARACTERISTICS OF UKRAINIAN PUMPED STORAGE POWER PLANTS

PSPP name	Existing data		Year of construction	Design data		Annual electricity production ($\times 10^6$ kW·h)	Maximum head (m)	Useful volume of the upper reservoir ($\times 10^6$ m^3)
	Capacity of generating mode (MW)	Number of units		Capacity of generating mode (MW)	Number of units			
Kyiv	235.5	6	1972	235	6	200	74.0	3.79
Tashlyk	302	2	2007 (2nd unit)	906	6	873	88.5	14.40
Dniester	1296	4	2021 (4th unit)	2268	7	2720	154.9	32.70
Kaniv	–	–	project	1000	4	1025	108.4	1700

Among these facilities, the Dniester Pumped Storage Power Plant is particularly noteworthy. This plant represents one of the largest hydropower engineering projects in Europe. After the commissioning of all seven generating units, the installed capacity of the plant will reach approximately 2268 MW in turbine mode and 2947 MW in pumping mode. According to these parameters, the plant is expected to become the largest pumped storage

power plant in Europe and one of the largest in the world. The reversible hydropower units installed at the plant have a capacity of approximately 324 MW in generator mode and 421 MW in pumping mode, placing them among the most powerful units of this type globally.

The development and modernization of Ukrainian hydropower facilities are carried out with the participation of leading international engineering companies. Equipment such as SF_6 circuit breakers, electromechanical systems, and hydropower turbines supplied by major manufacturers – including Alstom, ABB, and Andritz Hydro – has been installed at the Dniester pumped storage plant and other facilities operated by PJSC Ukrhydroenergo. Ukraine also actively cooperates with international professional organizations, including the International Hydropower Association, the International Commission on Large Dams, the CIGRÉ, and the International Renewable Energy Agency.

The importance of pumped storage power plants has increased significantly during the period of military conflict in Ukraine, when large portions of the national energy infrastructure have suffered damage. Under such conditions, PSPPs serve as critical balancing resources capable of stabilizing the energy system and preventing large-scale blackouts. To maintain system stability, operators are often required to increase the frequency of unit start-ups and shutdowns in response to rapidly changing operating conditions.

Given the growing demand for flexible generation and energy storage, further development of pumped storage capacity in Ukraine appears highly promising. The completion of existing hydropower projects and the construction of new pumped storage plants – especially in regions with favourable geographical conditions such as the Carpathian Mountains – could significantly enhance the flexibility, reliability, and resilience of the national energy system while facilitating deeper integration into the European energy market.

3.5. Operation and Functional Expansion of PSPPs in the Energy System and Energy Market

The program for the development of the national energy sector under peacetime conditions was outlined in the Energy Strategy of Ukraine until 2035 [19]. However, the current condition of the energy system, shaped by ongoing hostilities and the substantial damage inflicted on energy infrastructure facilities, necessitates significant adjustments to the previously developed plans.

An analysis of the available information makes it possible to identify several promising directions for the development of Ukraine's energy sector at the present stage:

1. Diversification of energy sources and the spatial dispersion of power plants of various types across the country.
2. Expansion of the existing electricity transmission network, including the construction and operation of backup (bypass) transmission lines to enhance system resilience and reliability.
3. More efficient usage of the existing generation capacity, including nuclear, thermal, hydropower, pumped-storage, wind, solar, and other types of power plants.
4. Completion of the construction of the Dniester and Tashlyk pumped-storage power plants, as well as the construction of the Kaniv pumped-storage power plant with an installed capacity of approximately 1000 MW.
5. Active development and integration of renewable energy sources, including the construction of new large, medium, and small hydropower plants, wind and solar power facilities, as well as power plants operating on waste and biofuels.
6. Continuation and expansion of cooperation between Ukraine and the European Union, particularly in the synchronization of the Ukrainian energy system with the European electricity grid, enabling greater opportunities for electricity export and import.

4. CONCLUSION

The operation of Ukraine's energy system under conditions of active military conflict, including large-scale missile attacks and sustained damage to energy infrastructure, has demonstrated a considerable degree of resilience. Despite significant losses in generation capacity and extensive destruction of critical facilities, the power system has continued to perform its essential function of ensuring a stable electricity supply. This experience has confirmed the effectiveness of the fundamental principles underlying the design and development of Ukraine's energy sector. The existing configuration of generation assets, network infrastructure, and technological equipment has proven capable of maintaining system reliability and operational stability even under extreme wartime conditions.

The study also highlights the increasing strategic importance of pumped-storage power plants (PSPPs) in ensuring the flexibility and resilience of modern energy systems. Both international and domestic experience indicate that the functional role of PSPPs has expanded substantially over recent decades, extending beyond energy storage to include load balancing, frequency regulation, reserve provision, and support for the integration of renewable energy sources. Under current conditions of generation shortages and heightened operational uncertainty, PSPPs have become a critical component of Ukraine's energy system, and their significance is expected to increase further as the sector undergoes reconstruction and modernization.

Ensuring the long-term sustainability of Ukraine's energy sector requires not only the continued implementation and improvement of emergency recovery measures but also the adoption of comprehensive modernization strategies. Particular attention should be devoted to the development of flexible generation and energy storage capacities, the restoration and upgrading of damaged infrastructure, and the enhancement of system resilience to future disruptions. These efforts should be accompanied by the further development of a transparent, competitive, and well-regulated electricity market capable of facilitating efficient resource allocation, attracting domestic and foreign investment, and supporting the recovery of the energy sector. Strengthening market mechanisms, improving regulatory frameworks, and fostering the participation of independent energy producers will contribute to greater operational flexibility and market efficiency.

Furthermore, deeper integration with the European energy market remains a strategic priority for Ukraine. Expanding cross-border electricity trade, harmonizing regulatory and technical standards with European requirements, and strengthening cooperation with the European Union will enhance opportunities for balancing electricity supply and demand, improving system reliability, and accelerating the transition toward a more sustainable and resilient energy sector. In the long term, these measures will play a crucial role in strengthening Ukraine's energy security, supporting economic recovery, and facilitating its full integration into the European energy space.

REFERENCES

[1] Hydropower Status Report. Sector trends and insights. 2022. [Online]. [Accessed 15.03.2026]. Available: https://www.hydropower.org/publications/2022-hydropower-status-report

[2] Innovation landscape brief: Innovative operation of pumped hydropower storage, International Renewable Energy Agency, Abu Dhabi. 2020. [Online]. [Accessed 15.03.2026]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Innovative_PHS_operation_2020.pdf

[3] Skob Y., Yakovlev S., Pichugina O., Kalinichenk M., Kartashov O. Numerical Evaluation of Harmful Consequences after Accidental Explosion at a Hydrogen Filling Station. *Environmental and Climate Technologies* 2024:28(1):181–194. https://doi.org/10.2478/rtuect-2024-0015

[4] Dwijendra N. K. A., Arsana I. G. N. K., Al-Hawary S. I. S., Prakaash A. S., Romero Parra R. M., Turki Jalil A., Hammid A. T. Operation of the Multiple Energy System with Optimal Coordination of the Consumers in Energy Market. *Environmental and Climate Technologies* 2023:27(1):1–13. https://doi.org/10.2478/rtuect-2023-0006

[5] Halych O., Bilkova E., Nowak P., Riabenko, O. Analysis of Hydropotential and Prospects for Small Hydropower Development in Ukraine. *Environmental and Climate Technologies* 2023:27(1):763–774. https://doi.org/10.2478/rtuect-2023-0056

[6] Riabenko O. A. Hydropower Plants in Special Natural and Climatic Conditions. Textbook. NUWEE, Rivne, 2024.

[7] Kalinina L. G. The Use of Hydropower Plants in Regulating the Frequency and Power of the Ukrainian Energy system and Possibilities of Expanding the Control Range of Hydropower Units. *Hydropower Engineering of Ukraine* 2020:3–4:77–81.

[8] Landau Y. O., Bondarenko Y. M., Tsuryk S. A. The importance of PSPPs in the development of the integrated energy system (IPS) of Ukraine. *Industrial Electricity and Electrical Engineering* 2020:3(123):38–45.

[9] Nuclear Power in France. 2022. [Online]. [Accessed 15.03.2026]. Available: https://world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

[10] Nuclear Power in Germany. 2022. [Online]. [Accessed 15.03.2026]. Available: https://world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx

[11] Annibaldi V., Condemi A., Cucchiella F., Gastaldi M., Rotilio M. Renewable Energy Policies: Bibliometric Review and Policy Implications. *Environmental and Climate Technologies* 2020:24(3):403–417. https://doi.org/10.2478/rtuect-2020-0112

[12] Carr R. D., Kalynych T., Meisser F., Mikhnych V., Stubbe R., Zachmann G. Electricity and gas supply in Ukraine: winter 2025/26. Green dear Ukraima, 2026. 29 ps. [Online]. [Accessed 15.03.2026]. Available: https://greendealukraina.org/uk/assets/images/reports/winter-outlook-2025-2026-jan-ukr.pdf

[13] Rozumkov centre. [Online]. [Accessed 15.06.2026]. Available: https://razumkov.org.ua/en

[14] Electricity deficit in Ukraine. 2026. [Online]. [Accessed 15.03.2026]. Available https://cv.znaj.ua/540843-yakiy-stan-energosistemi-ta-shcho-z-vidklyuchennyami

[15] Anh-Tu N. The Moderating Role of Foreign Direct Investment in the Electricity Consumption and Carbon Emissions Nexus: Evidence from Developing Countries. *Environmental and Climate Technologies* 2026:30(1):142–154. https://doi.org/10.2478/rtuect-2026-0010

[16] Lauka D., Vicmane L. K., Bohvalovs G., Dzenajavičienė E. F., Vītoliņš V., Rošā M., Cenian A., Blumberga D. Modeling Energy Transition in Baltic Municipalities. *Environmental and Climate Technologies* 2025:29(1):641–657. https://doi.org/10.2478/rtuect-2025-0044

[17] Interview with the General Director of PJSC *Ukrhydroenergo* I. Syrota. *Hydropower Engineering of Ukraine* 2021:1–2:1–3.

[18] Halych O., Bilkova E., Nowak P., Riabenko O. A review on hydropower in Ukraine – its state, role in the energy system and potential for post-war recovery. *Energy Strategy Reviews* 2025:62:101997. https://doi.org/10.1016/j.esr.2025.101997.

[19] Energy Strategy of Ukraine for the period until 2035. Security, Energy Efficiency, Competitiveness. 2017. [Online]. [Accessed 15.03.2026]. Available: https://www.kmu.gov.ua/news/250302738