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ASSESSMENT OF THE CURRENT STATE AND STRATEGIC GUIDELINES FOR THE DEVELOPMENT OF ALTERNATIVE ENERGY ENTERPRISES IN UKRAINE

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ОЦІНЮВАННЯ СТАНУ ТА СТРАТЕГІЧНІ ОРІЄНТИРИ РОЗВИТКУ ПІДПРИЄМСТВ АЛЬТЕРНАТИВНОЇ ЕНЕРГЕТИКИ УКРАЇНИ

The purpose of the article is to comprehensively cover the peculiarities of the functioning and strategic development of renewable energy enterprises in Ukraine in conditions of military instability, as well as to determine the priorities for their further transformation, taking into account the needs of energy security and the state's international integration guidelines. The relevance of the topic is due to the fact that renewable energy has become one of the key mechanisms for maintaining the stability of the energy system, responding to infrastructure destruction and forming a new energy supply model capable of withstanding external threats. The work uses structural and comparative analysis methods, strategic diagnostic tools, and production capacity transformation assessment tools, which made it possible to study the dynamics of the industry, outline changes in the spatial distribution of capacities, and identify key factors that determine the sustainability and innovative capacity of alternative energy companies. The results obtained show that the war has caused a significant shift in the focus of the sector's development: the role of decentralised solutions has grown, the importance of flexible technologies has increased, and bioenergy and small generating capacities have become strategically important for ensuring the autonomy of territories.

At the same time, the persistence of imbalances in the regulatory environment, pricing policy and financial architecture of the market affects investment potential and the pace of modernisation. The practical value of the study lies in the formation of a system of strategic guidelines aimed at improving the management mechanisms of enterprises in the industry, strengthening their sustainability, restoring damaged assets, attracting investment, and building an effective model of integration into the European energy space. Particular importance is attached to the development of human capital and the introduction of technological innovations capable of ensuring the long-term competitiveness of alternative energy enterprises and facilitating Ukraine's transition to a low-carbon economy.

Метою статті є комплексне висвітлення особливостей функціонування та стратегічного розвитку підприємств відновлюваної енергетики України в умовах воєнної нестабільності, а також визначення пріоритетів їхньої подальшої трансформації з урахуванням потреб енергетичної безпеки та міжнародних інтеграційних орієнтирів держави. Актуальність теми зумовлена тим, що відновлювана енергетика стала одним із ключових механізмів підтримання стійкості енергосистеми, реагування на руйнування інфраструктури та формування нової моделі енергозабезпечення, здатної протистояти зовнішнім загрозам. У роботі застосовано методи структурного та порівняльного аналізу, інструменти стратегічної діагностики та оцінювання трансформацій виробничого потенціалу, що дало можливість дослідити динаміку галузі, окреслити зміни у просторовому розміщенні потужностей, а також виявити ключові чинники, які визначають стійкість та інноваційну здатність підприємств альтернативної енергетики. Отримані результати засвідчують, що воєнні події спричинили суттєве зрушення акцентів у розвитку сектору: зросла роль децентралізованих рішень, підвищилася значущість гнучких технологій, а біоенергетика та малі генеруючі потужності набули стратегічного змісту для забезпечення автономності територій. Водночас збереження дисбалансів у регуляторному середовищі, цінovій політиці та фінансовій архітектурі ринку впливає на інвестиційний потенціал і темпи модернізації. Практична цінність дослідження полягає у формуванні системи стратегічних орієнтирів, спрямованих на удосконалення механізмів управління підприємствами галузі, зміцнення їхньої стійкості, відновлення пошкоджених активів, залучення інвестицій і побудову ефективної моделі інтеграції у європейський енергетичний простір. Окремого значення набуває акцент на розвитку людського капіталу та впровадженні технологічних інновацій, здатних забезпечити довгострокову конкурентоздатність підприємств альтернативної енергетики і сприяти переходу України до низьковуглецевої економіки.

Keywords: *alternative energy enterprises; renewable energy sources; energy security; strategic development guidelines; decentralised generation; green transition; decarbonisation.*

Ключові слова: *підприємства альтернативної енергетики, відновлювальні джерела енергії, енергетична безпека, стратегічні орієнтири розвитку, децентралізована генерація, «зелений» перехід, декарбонізація.*

Problem statement. Renewable energy is one of the key determinants of Ukraine's energy security, as it is capable of reducing dependence on imported fossil fuels, diversifying energy sources, and ensuring compliance with international decarbonisation commitments. Before the beginning of the full-scale war, Ukraine imported about 35–40% of the natural gas and more than 70% of petroleum products for domestic consumption [1]. In the structure of primary energy supply, the share of fossil fuels exceeded 60%, whereas renewable energy sources accounted for only about 8–9% [2]. Such dependence on imported resources generated high risks of the country's energy vulnerability. However, the current conditions in which the energy sector operates have been radically complicated by the war. The full-scale invasion has not only destroyed a significant share of conventional generation, but has also created a permanent threat to new and existing renewable energy facilities. This has confronted enterprises in the sector with a dual challenge: along with the need to preserve their production potential, they are forced to adapt to wartime uncertainty and to a deficit of financial and technological resources.

In this context, the problem of renewable energy development lies not only in restoring destroyed capacities, but also in the need to form strategic guidelines for its further functioning. The extent to which barriers related to security, market regulation and state support are effectively removed will determine the sector's ability to perform a stabilising role in the structure of the national power system and to contribute to post-war reconstruction.

An important integration dimension is that Ukraine has already been synchronised with the European ENTSO-E network and is oriented towards the implementation of the European Green Deal. However, compliance with these standards requires not only technical solutions, but also a profound transformation of management models of renewable energy enterprises, the development of new support instruments and mechanisms for attracting investment.

Therefore, the scientific problem consists in identifying the specific features of the transformation of the strategic development of Ukraine's alternative energy enterprises under the influence of wartime factors and in substantiating the directions of their adaptation to the new conditions of economic activity and further integration into the European energy market.

Analysis of recent research and publications. The issues of development and strategic management of renewable energy enterprises in Ukraine attract considerable attention from both domestic and foreign scholars. In particular, Yu. Shpontak [3] examines the risks and challenges of the development of alternative energy and the new energy economy, emphasising the need for state support of innovations in the field of RES. O. Yerokhin and T. Kovalchuk [4] investigate financial and economic mechanisms for the development of the electricity market based on renewable sources, highlighting the problems of tariff regulation and the solvency of producers. N. Shpak and O. Bilorus [5] analyse innovative approaches to enterprise management in the sector in the context of European integration processes, defining the role of strategic management in shaping competitive advantages.

A significant contribution to the study of energy security and geopolitical risks has been made by foreign researchers. D. Scholten, M. Bazilian, I. Overland and K. Westphal [6] analyse the geopolitics of renewable energy, underlining the impact of global crises on the energy strategies of states. G. Cretti, J. Soldatiuk-Westerveld and L. van Schaik [7] explore energy security issues in crisis regions, proposing models for integrating renewable energy into the European energy market that are relevant for Ukraine. B. Cahill and A. Dawes [8] focus in their

works on practical instruments for RES development in Ukraine, in particular on attracting investment and fostering international partnerships.

Despite the existence of substantial research, the issues of adapting alternative energy enterprises to the conditions of wartime turbulence, as well as defining strategic guidelines for their development in the post-war period, remain insufficiently elaborated. This determines the scientific and practical relevance of further research in the field of managing the development of RES enterprises, taking into account the challenges of security, financial stability and integration into the European energy space.

Formulating the purposes of the article. The purpose of the article is to assess the state and development trends of renewable energy enterprises in Ukraine under wartime and post-war conditions, to identify structural changes in the sector, key resilience factors and risks, as well as to substantiate strategic guidelines for their further development, taking into account the tasks of ensuring the state's energy security, decarbonising the economy and integrating into the European energy space.

Presentation of the main research material. Before the onset of the full-scale war, Ukraine's renewable energy sector demonstrated intensive growth. As of early 2022, the total installed capacity of RES facilities (excluding large hydropower plants) reached approximately 9.9 GW, of which 8.06 GW accounted for solar power plants (SPPs) and 1.76 GW for wind power plants (WPPs) [9]. For comparison, in 2010 the total capacity of RES facilities was less than 0.1 GW, that is, over a decade the sector expanded dozens of times, largely driven by one of the highest feed-in tariffs in Europe [10]. In 2019, Ukraine entered the global top 10 countries in terms of the pace of renewable energy development, while total investments in the sector exceeded USD 12 billion over the last decade [11]. The share of alternative generation in the country's energy balance reached 10% [12].

However, 2022 became a turning point: due to Russian military aggression, the commissioning of new RES facilities virtually stopped, and a significant part of the existing capacities was lost or mothballed. According to estimates, energy

enterprises with a total capacity of about 2 GW, primarily large WPPs in the south of Ukraine, found themselves in the zone of occupation or active hostilities. In addition, direct strikes destroyed or damaged up to 14% of industrial SPPs. As a result, the total operational capacity of renewable energy in Ukraine declined. According to government data, about 8.7 GW of RES capacity remained available [11].

In 2023, the sector gradually adapted to the new conditions and even resumed a growth trend in the government-controlled territory. Despite all the difficulties, a number of new facilities were commissioned. In particular, DTEK completed the construction of the first stage of the Tyligulska wind power plant (78 MW) in relative proximity to the frontline, in Mykolaiv region. Overall, during 2023, grid operators connected more than 1,400 new distributed generation facilities based on RES, including 182.3 MW of new wind capacity and 500 MW of solar capacity [11]. This indicates an active development of predominantly small-scale installations oriented towards self-consumption or local markets. It should be noted that the number of owners of household solar power plants for self-consumption and sale of surplus electricity continued to grow even under wartime conditions: during 2022–2023 their number increased from 45 thousand to more than 54 thousand (totalling 1.2 GW of installed capacity of household SPPs) [13]. Thus, in 2023 the RES sector avoided further decline, and the commissioning of new capacities partially offset the losses caused by the war.

Crisis conditions also transformed the structure of generation. The share of renewables in Ukraine's energy balance paradoxically increased, as electricity production at thermal power plants fell sharply due to their destruction by the enemy [6]. By the end of 2023, about 22% of total electricity generation in Ukraine (including large hydropower) was provided by RES. For comparison, the average figure for Europe was 42% (see Fig. 1) [11].

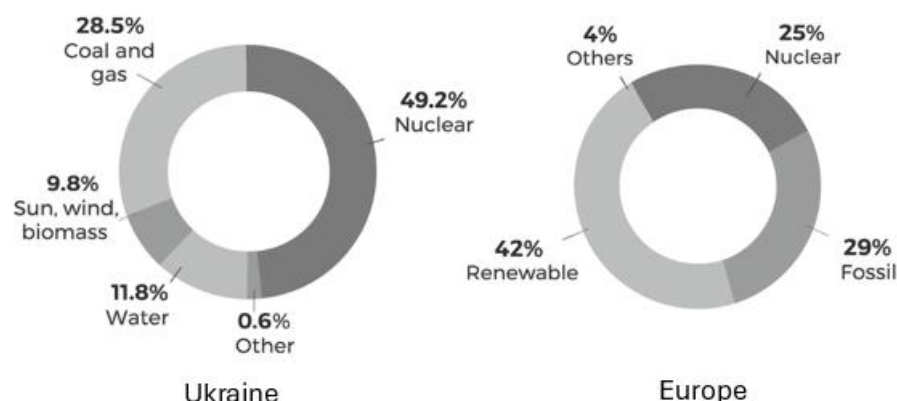


Fig. 1. Sources of electricity generation in Ukraine and Europe in 2023

Source: [11]

Thus, almost every fifth kilowatt-hour in Ukraine in 2023 was generated from clean sources, although the primary reason for this was not so much a breakthrough in the development of green energy as the forced reduction of electricity production at coal- and gas-fired thermal power plants. Figure 1 presents the structure of the energy balance: it shows the dominance of nuclear energy (49.2%) and the significant share of fossil fuels (28.5%) in Ukraine's electricity generation in 2023, whereas the combined share of solar, wind and biomass amounted to only 9.8% [14]. This reflects substantial untapped potential: in order to achieve decarbonisation targets, the share of RES must increase at least two- to threefold.

Solar energy is the leading segment of Ukraine's renewable energy sector. As of early 2022, the total installed capacity of industrial solar power plants amounted to about 6.3 GW, and that of household installations to 1.4 GW. Military actions caused substantial losses: approximately 14% of industrial SPPs were destroyed or damaged, while more than 950 MW of capacity ended up in temporarily occupied territories. In 2023, around 5.9 GW of industrial and 1.2 GW of household SPPs remained in operation. Despite this, 2023 witnessed active growth of distributed generation: about 500 MW of new small solar plants were commissioned, a significant part of which supplies the needs of critical infrastructure facilities, healthcare institutions and local communities. A key systemic challenge remains the indebtedness of the state-owned enterprise

«Guaranteed Buyer» to producers of electricity from renewable sources: the level of payments for supplied renewable electricity amounted to only 55% in 2022 and 77% in 2023, while the total amount of arrears exceeded UAH 22.8 billion [11, 13].

Before the onset of the full-scale war, wind energy was represented by 1.7 GW of installed capacity, concentrated mainly in the southern regions of Ukraine. Approximately 80% of this capacity was taken out of operation due to occupation, and part of the turbines was damaged as a result of missile strikes and drone attacks. An important milestone in the recovery of the sector was the commissioning in 2023 of the Tyligulska wind power plant with a capacity of 114 MW – the first large-scale project implemented under martial law. The total potential for the development of wind energy is estimated at over 16 GW of onshore wind and several hundred megawatts of offshore WPPs in the Black Sea. Further development of the sector requires the modernisation of power grids, the deployment of energy storage systems and the introduction of advanced technologies for load balancing [11, 15].

Bioenergy encompasses the production of energy from biomass, biogas and biofuels. In 2021, about 200 MW of bioenergy power plants were in operation in Ukraine, while the share of biomass in the structure of heat supply reached approximately 8%. The full-scale war led to the suspension of a number of large investment projects; however, it simultaneously stimulated the development of biomethane technologies due to the deficit of natural gas. In 2023, several agricultural enterprises launched the first industrial biomethane production lines and established its export. The most resilient segment proved to be biogas plants, which are capable of operating autonomously and ensuring continuity of generation. In the post-war perspective, bioenergy has the potential to substitute more than 20 billion cubic metres of natural gas annually, thereby significantly strengthening the state's energy independence [11, 16].

Ukraine's hydropower sector is represented predominantly by small hydropower plants (HPPs), of which there were about 50 with a total capacity of

100 MW before the full-scale invasion. The destruction of the Kakhovka HPP in 2023 and damage to other large hydropower hubs led to a reduction of total hydropower generation capacity by almost 45%. Despite the destruction of certain facilities in the east, most small plants in the Carpathian region continued to operate, providing electricity supply to local communities during periods of energy deficit. In the post-war period, the restoration of destroyed hydropower capacities and the expansion of a network of small HPPs focused on decentralised energy production in line with EU environmental standards are expected [11].

The state of the RES segments in Ukraine is summarised in Table 1.

Table 1. Summary of the state of RES segments in Ukraine

Segment	Pre-war installed capacity	Losses/damage
Solar energy	6.3 GW industrial + 1.4 GW household	13–14% of industrial SPPs destroyed; 950 MW located in occupied territories
Wind energy	1.7 GW	about 80% of capacity shut down; turbine damage and dismantling of structures by the enemy
Bioenergy	200 MW	suspension of part of the projects in front-line regions
Small hydropower plants	up to 100 MW (50 plants)	destruction of individual plants; losses in the HPP sector of about 45% (including the Kakhovka HPP)

Source: compiled by the author on the basis of [11, 13, 15, 16].

Before the full-scale war, the Ukrainian alternative energy market was characterised by a concentration of assets in the hands of several large companies. The leader was DTEK Renewables LLC (1 GW of SPPs and WPPs), whose largest projects included the Prymorska and Orlovska WPPs and the Nikopol SPP. The second major player was Elementum energy (Ukraine) LLC (a portfolio of more than 630 MW), which in 2023 became the largest producer of renewable electricity in Ukraine, while the third was UDP Renewables LLC (100 MW of SPPs) [17].

The top group also included Scatec solar solutions Ukraine LLC (336 MW of SPPs), CNBM in Ukraine LLC (267 MW of SPPs), Eko-optima LLC (217 MW of RES) and Management Company WPV LLC (174 MW of WPPs). In total, the top 20 companies accumulated about 4.4 GW of RES capacity in the government-controlled territory [17].

The full-scale war radically changed this balance: DTEK Renewables LLC lost up to 90% of its generation, as a significant share of its assets ended up in the occupied territories. Elementum energy (Ukraine) LLC retained all its plants and became the market leader. UDP Renewables LLC and a number of new entrants began to invest in safer regions [17].

The sector has been financially affected by non-payments under the feed-in tariff, forcing investors to restructure debts and adjust their business models [13].

The conditions of wartime turbulence caused by external aggression have generated significant challenges for Ukraine's renewable energy enterprises. These challenges have affected all elements of the energy system: production capacities, infrastructure, finances and regulatory mechanisms.

The most tangible have been the physical losses of infrastructure. The destruction of RES facilities as a result of shelling and mined territories has led to the loss of a substantial part of installed capacity. The Azov–Black Sea wind energy cluster (Kherson and Zaporizhzhia regions) has almost completely ceased operation, while dozens of solar power plants in Mykolaiv, Kherson and Donetsk regions have been destroyed or damaged. The value of the lost equipment – solar panels, inverters and wind turbines – is estimated at hundreds of millions of US dollars. Damage to transmission lines and substations complicates the operation even of those facilities that remain technically functional, as the number of interruptions in the transmission of generated electricity is increasing.

An additional challenge has been the occupied territories where RES facilities are located. The loss of control has led to the shutdown of plants, financial losses for owners and cases of illegal dismantling of equipment. There have been reported attempts to connect Ukrainian plants to the Russian power system; however, most WPPs and SPPs remain idle. The future of these assets directly depends on the pace of de-occupation, while the risks of mining and deliberate destruction during retreat remain high.

The deterioration of the financial situation has become another serious constraint for the sector. The problem of arrears under the feed-in tariff, which had

emerged even before the war, evolved into a systemic crisis in 2022–2023. Non-payments by the state-owned enterprise «Guaranteed Buyer» force companies to cut staff, suspend new investment projects and revise production plans. Government regulation of electricity prices introduced during martial law has additionally reduced market liquidity and worsened the solvency of the state buyer. The suspension of auctions for the construction of new RES facilities has deprived investors of long-term support guarantees, while the rising cost of loans, insurance and logistics has increased the financial burden on projects.

Regulatory uncertainty is another significant problem. Although the key strategic documents – the National Energy and Climate Plan until 2030 and the Energy Strategy of Ukraine until 2050 – declare the intention to increase the share of renewable energy sources, the institutional mechanisms for implementing these intentions remain inconsistent [18]. Investors expect transparent rules for the functioning of the market after the phase-out of the feed-in tariff. In practice, it is necessary to introduce an auction system, contracts for difference or green certificates adapted to post-war conditions. The absence of these instruments slows down capital inflows and restrains the deployment of new projects.

The technological dimension also remains critical. Extensive damage to the power system has reduced its flexibility and stability, complicating the integration of RES. Due to a shortage of flexible generation capacities, system operators are forced to curtail the output of solar and wind power plants during periods of low demand. Such cases, in particular in spring 2023, when solar generation increased while demand declined, became a common phenomenon. The lack of energy storage systems and backup capacities limits the efficiency of existing RES even in relatively safe regions.

Despite the difficult conditions, enterprises in the sector seek to maintain production wherever possible and to contribute to stabilising the power system. Industry associations – the Ukrainian Wind Energy Association, the Solar Energy Association of Ukraine and the Bioenergy Association of Ukraine – actively cooperate with state institutions and international partners to attract financing,

grants and war-risk guarantees. The consolidation of these problems and barriers forms the basis for strategic decisions on the recovery and modernisation of the sector in the post-war period.

The war has radically changed the priorities of Ukraine's energy policy. In the short term, the main task has become ensuring the resilience and continuity of energy supply. Massive attacks on thermal, hydro and nuclear power plants have demonstrated the high vulnerability of the centralised power system, which necessitates the development of decentralised generation based on renewable energy sources and energy storage systems [19]. In particular, rooftop solar power plants with batteries installed on hospitals, educational institutions, administrative buildings and «Points of Invincibility» have proved effective in providing autonomous power supply during blackouts [20]. Such solutions demonstrate the potential of local energy as an instrument for enhancing energy security and should receive systematic support from the state and donor programmes.

One of the key priorities is substituting scarce imported gas and fuels with bioenergy resources. The use of agricultural residues, wood and biogas for heat supply makes it possible to reduce energy imports and support the functioning of settlements during the winter period. The active deployment of mobile boiler units running on biofuels and hybrid microgrids (combining solar power plants with diesel generators) contributes to increasing autonomy and reducing fuel consumption. Studies by the US National Renewable Energy Laboratory indicate that a combination of solar panels with generators can double the duration of autonomous operation of critical facilities without refuelling, which is of particular importance for frontline areas [20].

In parallel with this priority, another key direction is the restoration of damaged energy infrastructure facilities. Even partial restoration of the operation of solar and wind power plants can significantly enhance the stability of the power system. The implementation of such projects requires simplified permitting procedures and access to finance. International partners, including the European Investment Bank, the European Bank for Reconstruction and Development and

donor funds, are already prepared to provide loans and grants for the reconstruction of RES facilities, including small hydropower plants. For the private sector, it is advisable to establish mechanisms for compensating war-related losses and to introduce state guarantees for investments in reconstruction.

Considerable attention should also be paid to the human capital of the sector. A part of engineering and technical personnel has been mobilised or is abroad, which creates a risk of losing professional potential. To preserve it, distance learning and retraining programmes are needed, as well as support for research centres that study the integration of RES with energy storage, smart grids and hydrogen technologies. Investments in human potential today will determine the pace of sectoral development in the post-war period.

International coordination plays an important role. Ukraine should strengthen its participation in the initiatives of the G7+ Coordination Group, the Energy Community and other international platforms that provide access to technical and grant assistance. The concept of renewable energy as an element of national security can become a convincing argument for attracting external support, particularly within energy resilience programmes.

In the long-term perspective, the strategy for the development of alternative energy should combine the restoration of destroyed assets with the expansion of new capacities, based on the principles of the green transition and European integration. This is not only about restoring pre-war indicators, but also about the structural modernisation of the energy sector and the transition to a low-carbon economic model. According to the draft National Energy and Climate Plan of Ukraine until 2030, it is planned to commission up to 10 GW of new RES capacity, to create energy storage systems with a total capacity of at least 0.8 GW, and to deploy the production of green hydrogen and biomethane for domestic consumption and export [10].

Key priorities will include the reconstruction and modernisation of damaged plants using advanced technologies: more powerful turbines, highly efficient solar

panels and modern monitoring systems. This will make it possible to increase generation volumes without expanding the area occupied by power plants.

To stimulate investment, it is necessary to introduce tax incentives, war-risk insurance and a system of international guarantees. Updating the RES support model is critically important for restoring investor confidence. Ukraine should gradually phase out the feed-in tariff, replacing it with competitive auctions and contracts for difference, which have already proven effective in EU countries. This approach will ensure the integration of Ukrainian producers into the European market for guarantees of origin of electricity and create additional revenue streams.

European integration opens up new opportunities for the export of renewable electricity. The development of interconnector capacities will make it possible to export 5–6 GW of electricity to EU countries, stimulating the construction of new WPPs and SPPs in the western regions of Ukraine. A promising direction is the production of green hydrogen and biomethane using Ukraine's gas transmission system as a transit corridor [19].

The localisation of energy equipment production – solar panels, wind turbines, batteries – is gaining additional importance. This will contribute to job creation and reduce dependence on imports. The relocation in 2022 of the «Fuhrlaender Windtechnology» plant from Kramatorsk to Zakarpattia became an illustrative example of business adaptation and can serve as a foundation for forming a new industrial base together with European partners.

The development of RES must proceed in compliance with environmental standards and with the involvement of local communities. Improving environmental impact assessment procedures, taking into account nature conservation requirements and communicating with local communities increase the social acceptance of energy projects.

Thus, the strategic vision for the development of alternative energy in Ukraine is to transform wartime challenges into an opportunity for a green breakthrough. By 2030, the country has a chance to achieve a substantial increase

in the share of renewables in the energy mix and to lay the foundations for a climate-neutral economy by 2050.

Conclusions. Renewable energy in Ukraine remains one of the most dynamic segments of the energy sector, demonstrating an ability to adapt even under conditions of wartime turbulence. By 2022, its installed capacity reached about 10 GW. The full-scale aggression resulted in the loss of more than 1.2 GW of capacity, primarily in the wind energy segment. At the same time, solar generation has retained its leading position, while bioenergy and small hydropower plants exhibit growing potential in the context of the gas crisis and the decentralisation of energy supply. The market is characterised by a high level of concentration, and changes in the geographical structure of assets have led to a redistribution of leading positions among companies. The main challenges remain the physical destruction of facilities, arrears under the feed-in tariff and the uncertainty of state regulatory policy.

The comprehensive analysis of the strategic development of alternative energy enterprises under conditions of turbulence has made it possible to refine the key factors of their resilience and innovation potential. The analytical provisions put forward contribute to the formation of practical recommendations aimed at improving the effectiveness of strategic management of enterprises in the sector.

The prospects for further research lie in the development of an integrated adaptive model of the strategic development of alternative energy enterprises in the post-war period, taking into account European standards of decarbonisation and energy security.

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