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TROUBLESHOOTING STEPS IN ENERGY SECTOR OF UKRAINE

Abstract. The features of the development of the energy sector of Ukraine in the conditions of structural transformations and unprecedented challenges caused by the full-scale aggression of the Russian Federation in 2022 are analyzed. It is substantiated that the energy system of Ukraine operates in conditions of high instability, where physical destruction of infrastructure, institutional dysfunctions, financial constraints and cyber threats are combined. It is proven that the modern energy sector of Ukraine is formed under the influence of the so-called "energy trilemma", which implies the need to simultaneously ensure energy security, sustainability and availability of energy resources. The modern scientific discourse is studied, which demonstrates the transition from traditional resource-oriented approaches to integrated management models that take into account security, environmental and institutional aspects. It is established that renewable energy sources, hybrid energy systems and decentralized generation models play a special role, which contribute to increasing the stability of the energy system. Considerable attention is paid to the problems of critical infrastructure protection and the growth of cyber threats, which actualizes the need to integrate digital solutions and cybersecurity into the energy management system.

An analytical approach is proposed, which is characterized by paradigmaticity and allows us to consider the energy sector as a fragmented, but system with



interconnected elements. In view of this, the feasibility of treating troubleshooting as a comprehensive public management mechanism aimed at ensuring the stability, adaptability and continuity of the energy system is substantiated. In this context, the concept of adaptive management is proposed, which integrates a risk-oriented approach, digitalization, institutional interaction and the development of decentralized energy systems. In addition, a strategy for ensuring the sustainable functioning of the energy sector is specified.

Keywords: state regulation, energy, energy sector, energy resources, steps to solve problems, investments, post-war recovery, energy sector development strategy, critical infrastructure, public-private partnership.

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ШЛЯХИ ВИРІШЕННЯ ПРОБЛЕМ В ЕНЕРГЕТИЧНОМУ СЕКТОРІ УКРАЇНИ

Анотація. Проаналізовано особливості розвитку енергетичного сектору України в умовах структурних трансформацій та безпрецедентних викликів, спричинених повномасштабною агресією РФ у 2022 р. Обґрунтовано, що енергетична система України функціонує в умовах високої нестабільності, де поєднуються фізичні руйнування інфраструктури, інституційні дисфункції, фінансові обмеження та кіберзагрози. З'ясовано, що сучасний енергетичний сектор України формується під впливом так званої «енергетичної трилеми», яка передбачає необхідність одночасного забезпечення енергетичної безпеки, сталості та доступності енергоресурсів.

Досліджено сучасний науковий дискурс, який демонструє перехід від традиційних ресурсно-орієнтованих підходів до інтегрованих моделей управління, що враховують безпекові, екологічні та інституційні аспекти. Встановлено, що особливу роль відіграють відновлювані джерела енергії, гібридні енергетичні системи та децентралізовані моделі генерації, які сприяють підвищенню стійкості енергосистеми. Значну увагу приділено проблемам захисту критичної інфраструктури та зростанню кіберзагроз, що актуалізує необхідність інтеграції цифрових рішень і кібербезпеки в систему енергетичного управління.



Запропоновано аналектичний підхід, який відзначається парадигмальністю та дозволяє розглядати енергетичний сектор як фрагментовану, але систему з взаємопов'язаними елементами. З огляду на це обґрунтовано доцільність трактування troubleshooting як комплексного механізму публічного управління, спрямованого на забезпечення стійкості, адаптивності та безперервності функціонування енергетичної системи. У цьому контексті запропоновано концепцію адаптивного управління, що інтегрує ризик-орієнтований підхід, цифровізацію, інституційну взаємодію та розвиток децентралізованих енергетичних систем. Крім того, конкретизовано стратегію забезпечення стійкого функціонування енергетичного сектору.

Ключові слова: державне регулювання, енергетика, енергетичний сектор, енергоресурси, кроки з вирішення проблем, інвестиції, повоєнне відновлення, стратегія розвитку енергетичного сектору, критична інфраструктура, публічно-приватне партнерство.

Problem setting. The energy sector of Ukraine has undergone significant impact due to both structural reforms and external shocks, particularly the full-scale war since 2022. Energy infrastructure has become a critical target, resulting in systemic disruptions and requiring urgent troubleshooting strategies. Recent studies highlight that the Ukrainian energy system must simultaneously address energy security, sustainability, and affordability, forming a complex “energy trilemma” in crisis conditions [17]. Scientific discourse increasingly focuses on adaptive governance and resilience-building mechanisms. For instance, research by Sabishchenko et al. emphasizes the importance of hybrid renewable systems in ensuring energy stability, while T. Zatonatska and M. Soboliev underline the need for transforming regulatory frameworks under wartime conditions [20].

Recent research and publications analysis. The contemporary academic discourse on the development of the energy sector demonstrates a gradual shift from traditional resource-based approaches toward integrated, security-oriented, and sustainability-driven models. The analyzed body of literature reflects a multidimensional understanding of energy systems, particularly in the context of geopolitical instability, technological transformation, and climate challenges.

A significant cluster of studies focuses on energy security as a foundational concept for sectoral development. In particular, B. Sovacool [14] conceptualizes energy security as a complex and multidimensional phenomenon that encompasses availability, affordability, and environmental sustainability. This approach is further expanded by A. Goldthau [7], who emphasizes the role of global governance, institutional coordination, and geopolitical factors in shaping energy systems. These foundational works establish a theoretical basis for understanding energy sector development as a politically and institutionally embedded process, rather than a purely technical or economic one.



The relationship between energy security and macroeconomic stability is further explored by A. Stavytskyy et al. [15], who demonstrate a strong interdependence between energy indicators and economic performance in European countries. Their findings are particularly relevant for Ukraine, as they highlight the need for aligning energy policy with broader economic strategies. Similarly, D. Štreimikienė et al. [16] provide a comparative assessment of sustainable energy development, emphasizing the importance of integrating environmental and economic objectives within national energy systems.

A distinct line of research addresses the role of renewable energy in strengthening energy security, particularly in the Ukrainian context. G. Kharlamova, S. Nate, and O. Chernyak [9] argue that renewable energy represents not only an environmental solution but also a strategic instrument for reducing dependence on external energy sources. This perspective is reinforced by O. Sabishchenko et al. [13], who analyze hybrid renewable energy systems and demonstrate their potential to enhance system flexibility and resilience. Furthermore, C. Winkler et al. [18] provide empirical evidence on the significant potential of rooftop photovoltaic systems in Ukraine, highlighting opportunities for decentralized energy production and increased energy independence.

Another important research direction concerns the classification and conceptualization of energy sources. R. Rybár et al. [12] critically examine the definition of renewable energy, pointing to inconsistencies in classification frameworks. This issue is crucial for policy development, as it affects regulatory approaches, investment decisions, and the overall structure of the energy mix. Complementing this perspective, A. Prokil [11] explores modern approaches to energy supply within the paradigm of sustainable development, emphasizing the transition toward resource-efficient and environmentally friendly systems.

The growing importance of hybrid threats and energy infrastructure protection is highlighted in studies focusing on security challenges. T. Plėta et al. [10] analyze the protection of critical energy infrastructure in the context of hybrid warfare, using Ukraine as a case study. Their findings underscore the vulnerability of energy systems to both physical and non-physical threats. This is further developed by T. Aljohani [6], who examines cyberattacks on energy infrastructure as a new form of warfare, emphasizing the need for integrating cybersecurity into energy governance. These studies collectively demonstrate that energy sector development cannot be separated from national security considerations.

The concept of the energy trilemma—balancing security, sustainability, and affordability – is addressed by R.S.J. Tol [17], who highlights the increasing complexity of decision-making in the context of geopolitical and environmental crises. This framework is particularly relevant for Ukraine, where energy policy must simultaneously address wartime challenges, economic constraints, and long-term sustainability goals.



In parallel, the issue of energy efficiency and demand-side management is explored by R. Zhesan [21], who identifies significant potential for energy saving in the household sector. This perspective shifts the focus from supply-side solutions to consumer behavior and energy consumption patterns, which are critical for achieving overall system efficiency.

Recent national-level studies provide insights into the institutional and regulatory dimensions of energy sector development. T. Zatonatska and O. Soboliev [20] analyze state regulation mechanisms in Ukraine, emphasizing the need for modernization of governance frameworks in line with European integration processes. Their work highlights persistent challenges such as regulatory fragmentation, limited institutional capacity, and the need for increased transparency and accountability.

Finally, D. Yergin [19] offers a broader geopolitical perspective, linking energy development with global power dynamics, climate policy, and international conflicts. His analysis reinforces the idea that energy systems are deeply embedded in global political processes, which directly influence national energy strategies, including those of Ukraine.

Paper objective. The purpose of the article is to conceptually understand the solution to problems that arise within the energy sector of Ukraine.

Paper main body. The energy sector of Ukraine represents one of the most strategically significant components of national security and socio-economic stability. In the context of globalization and European integration, the energy system traditionally functioned as a complex, multi-level structure combining centralized generation capacities, extensive transmission networks, and a diversified consumption system. However, since 2022, the sector has been subjected to unprecedented stress due to large-scale military aggression, which has fundamentally altered its operational logic and exposed systemic vulnerabilities [2; 3; 5].

The destruction of critical infrastructure, including thermal power plants, substations, and transmission lines, has significantly reduced generation capacity and disrupted energy flows. These challenges have led to a paradigm shift in energy governance – from a model focused primarily on efficiency and market liberalization to one emphasizing resilience, adaptability, and crisis response.

In this context, troubleshooting becomes not merely a technical activity but a strategic governance function, aimed at identifying, diagnosing, and resolving systemic failures within the energy system. It encompasses a wide range of processes, including rapid restoration of infrastructure, risk assessment, policy adaptation, and technological innovation [1; 2; 3; 18; 20].

The relevance of this study is further reinforced by Ukraine's ongoing synchronization with the European energy system (ENTSO-E), which introduces new regulatory requirements and operational standards. Thus, the Ukrainian energy sector must simultaneously address internal disruptions and external integration challenges.



The methodological framework of this research is constructed as a multi-layered analytical system, designed to capture the complexity, instability, and dynamic transformation of the Ukrainian energy sector under conditions of war, crisis, and post-war recovery. Unlike conventional linear methodologies, this approach is based on the integration of complementary analytical tools, each of which reveals a specific dimension of the problem while collectively forming a coherent research architecture [5].

At its core, the study employs system analysis, which enables the examination of the energy sector not as a set of isolated components, but as an interconnected and interdependent system. Through this lens, infrastructure, governance, markets, and digital systems are interpreted as mutually influencing subsystems. This allows for identifying cascading effects, where disruptions in one segment (e.g., physical destruction of power facilities) generate secondary and tertiary consequences across the entire system [ibid.].

In parallel, a risk-oriented modeling approach is applied, focusing on the identification, classification, and prioritization of threats. The study also integrates comparative analysis, particularly benchmarking Ukraine's energy governance mechanisms against European Union practices. This comparison is not limited to institutional structures but extends to regulatory frameworks, crisis response mechanisms, and digital transformation strategies. Such an approach enables the identification of gaps, asymmetries, and potential pathways for convergence within the European integration context.

Another important methodological component is content analysis of scientific literature, which provides a structured evaluation of existing academic discourse. Finally, the research incorporates scenario modeling, which serves as a forward-looking tool for forecasting the development of the energy sector under different conditions. This method allows for testing the robustness of proposed solutions and identifying adaptive strategies under uncertainty.

A key innovation of this methodological framework lies in its analectic nature. The concept of an analectic approach implies that the system is composed of fragmented yet interconnected elements. Instead of forcing artificial coherence, the methodology acknowledges fragmentation as an inherent characteristic of the Ukrainian energy sector and seeks to integrate these fragments through governance, risk management, and technological coordination.

Thus, the proposed methodology represents a shift from static, descriptive research toward dynamic, operational, and adaptive analysis, combining risk, governance, and technological dimensions into a unified analytical model.

The results of the study demonstrate that troubleshooting in the Ukrainian energy sector should not be interpreted as a purely technical or reactive activity. Instead, it emerges as a systemic governance mechanism, aimed at ensuring resilience, adaptability, and continuity of energy supply under conditions of persistent disruption (table 1).



Table 1 – Systemic Problems of the Ukrainian Energy Sector and Expanded Troubleshooting Approaches

№	Problem	Systemic Nature	Troubleshooting Approach
1	Infrastructure destruction	This problem reflects not only the physical damage or loss of energy infrastructure (power plants, transmission lines, substations), but also its strategic implications for national security and system resilience. Destruction disrupts supply chains, creates regional energy deficits, and increases vulnerability to further external shocks. It transforms energy infrastructure into a critical target within hybrid warfare.	The solution lies in decentralization and the development of modular energy systems, including distributed generation, microgrids, and localized renewable energy sources. These systems reduce dependence on centralized infrastructure, enhance flexibility, and ensure continuity of supply even in conditions of partial system collapse or targeted attacks.
2	Institutional fragmentation	Institutional fragmentation represents a governance failure characterized by weak coordination between state authorities, regulatory bodies, private sector actors, and international stakeholders. It leads to duplication of functions, slow decision-making, lack of accountability, and reduced crisis-response capacity.	The implementation of integrated coordination platforms is essential. These platforms ensure interoperability between institutions, enable real-time data exchange, and support synchronized decision-making processes. Strengthening governance networks improves policy coherence and enhances the system's ability to respond to complex and rapidly evolving challenges.
3	Energy imbalance	Energy imbalance arises from the interaction of market inefficiencies and technical constraints within the energy system. It includes fluctuations in supply and demand, outdated infrastructure, and insufficient integration of renewable energy sources. This imbalance leads to instability, inefficiency, and increased operational risks.	The adoption of smart grids and demand response mechanisms provides a technologically advanced solution. Smart grids enable real-time monitoring and optimization of energy flows, while demand response systems allow consumers to adjust consumption patterns. Together, these tools increase system flexibility, improve efficiency, and support the integration of renewable energy sources.
4	Cyber threats	Cyber threats represent a growing digital vulnerability due to the increasing reliance on information and communication technologies in the energy sector. Critical infrastructure becomes exposed to cyberattacks that can disrupt operations, compromise sensitive data, and destabilize the entire system.	The development and implementation of comprehensive cybersecurity systems is crucial. This includes advanced threat detection, protection of critical infrastructure, regular system audits, and the creation of institutional capacities for cyber resilience. Cybersecurity must be integrated into overall energy governance as a strategic priority.
5	Financial instability	Financial instability reflects limited domestic funding capacity, high reconstruction costs, and dependence on external financial resources. It constrains modernization efforts, delays infrastructure recovery, and reduces the sector's investment attractiveness.	The use of international funding mechanisms and PPP provides a sustainable solution. These approaches enable access to financial resources, facilitate risk-sharing, and promote the transfer of technologies and expertise. They also support long-term investment strategies aligned with European integration goals.

Source: compiled based on [8; 9; 12; 13; 18; 20]



The presented framework can be interpreted as a systemic analytical model of key challenges in the Ukrainian energy sector and the corresponding troubleshooting approaches, reflecting the multidimensional nature of current disruptions and the necessity of integrated, adaptive responses. Each identified problem is not isolated but embedded within a broader system of interdependencies, which requires moving beyond purely technical solutions toward comprehensive governance mechanisms.

First, infrastructure destruction should be understood not merely as physical damage to energy facilities, but as a strategic disruption affecting national security, economic stability, and societal resilience. In the context of large-scale military aggression, the loss of centralized energy assets exposes the vulnerability of traditional energy systems. Therefore, the proposed troubleshooting approach—decentralization and the development of modular energy systems—represents a paradigm shift toward distributed generation. Such systems, including microgrids and localized energy units, enhance flexibility, reduce dependency on large-scale infrastructure, and ensure continuity of supply even under conditions of targeted attacks or system failures [18].

Second, institutional fragmentation reflects a deeper governance failure, characterized by a lack of coordination among state institutions, overlapping responsibilities, and insufficient communication between stakeholders [20]. This fragmentation reduces the overall responsiveness and effectiveness of the energy sector, particularly in crisis situations. The implementation of integrated coordination platforms is therefore essential, as it enables interoperability between governmental bodies, regulatory agencies, private actors, and international partners. Such platforms facilitate real-time information exchange, coordinated decision-making, and the alignment of strategic objectives across different levels of governance.

Third, the issue of energy imbalance represents a hybrid challenge combining both market inefficiencies and technical constraints. Addressing this problem requires the adoption of smart grids and demand response mechanisms, which introduce digital intelligence into energy management. Smart grids allow for real-time monitoring and optimization of energy flows, while demand response programs enable consumers to adjust their energy usage based on system conditions. Together, these tools contribute to a more flexible, efficient, and resilient energy system.

Fourth, cyber threats have emerged as a critical dimension of vulnerability due to the increasing digitalization of the energy sector. Energy infrastructure is now deeply interconnected with information systems, making it susceptible to cyberattacks that can disrupt operations, compromise data, and even cause large-scale blackouts. Consequently, the deployment of advanced cybersecurity systems



is not only a technical necessity but also a strategic priority [6; 8; 14; 21]. This includes the protection of critical infrastructure, implementation of threat detection systems, and development of institutional capacities for cyber resilience.

Finally, financial instability highlights the economic constraints that limit the capacity of the energy sector to recover and modernize. The scale of destruction and the need for technological transformation require substantial financial resources that exceed domestic capabilities. In this context, the use of international funding mechanisms and public-private partnerships (PPP) becomes essential. These instruments not only provide access to capital but also facilitate the transfer of expertise, innovation, and best practices from global partners. Moreover, PPP models enable risk-sharing between the public and private sectors, increasing the efficiency and sustainability of investment projects. In summary, this model demonstrates that each problem within the energy sector possesses a complex, multi-layered nature, requiring troubleshooting approaches that integrate technological innovation, institutional reform, and economic support mechanisms.

In view of the above, it is necessary to dwell in more detail on the strategy for solving problems arising within the energy sector in Ukraine (Table 2). The strategic troubleshooting model proposed in this study should be understood as a continuous and iterative cycle, rather than a linear sequence of actions. Each component is interconnected, forming a feedback-driven system that evolves over time.

Table 2 – Strategic Troubleshooting Model

№	Component	Content	Function
1	Risk identification	Mapping threats	Early warning
2	Monitoring	Data systems	Real-time control
3	Response	Rapid intervention	Damage limitation
4	Adaptation	Policy & tech change	System evolution
5	Learning	Feedback loops	Long-term resilience

Source: compiled based on [7; 10; 11; 15; 16; 21]

The process begins with risk identification, which involves comprehensive mapping of threats across all levels of the energy system. This stage establishes the foundation for proactive governance by enabling early detection of vulnerabilities.

The monitoring phase relies on digital data systems, which provide real-time information about system performance. This allows decision-makers to maintain situational awareness and respond promptly to emerging disruptions.

The response component focuses on rapid intervention measures aimed at minimizing damage and ensuring continuity of energy supply. This includes both technical actions (e.g., rerouting energy flows) and organizational decisions (e.g., emergency coordination).

Adaptation represents a higher level of system functionality, where policies and technologies are adjusted based on observed outcomes and changing conditions.



This ensures that the system remains relevant and effective in a dynamic environment.

Finally, the learning component introduces feedback loops, which transform past experiences into knowledge. This knowledge is then used to improve future responses, thereby enhancing long-term resilience.

The findings of this research provide a basis for developing an original conceptual framework that redefines troubleshooting as a core element of energy governance rather than a supplementary technical function [1–5]:

1. **Troubleshooting as an Analectic System.** The Ukrainian energy sector is best understood as an analectic system, characterized by fragmentation, instability, and constant transformation. Unlike classical system models that assume equilibrium and predictability, the analectic approach recognizes that disorder and disruption are not anomalies but structural features. In this context, troubleshooting becomes a mechanism for integrating fragmented elements through governance, digitalization, and risk management. It ensures that despite systemic disruptions, the energy sector continues to function as a coherent whole.

2. **Critique of Existing Approaches.** A critical analysis of existing academic literature reveals several limitations. Most studies tend to conceptualize energy security as a static condition, focusing on resource availability and infrastructure capacity. However, such approaches fail to capture the dynamic nature of disruptions, particularly in wartime conditions. Moreover, many frameworks lack operational governance tools, which are necessary for real-time decision-making. As a result, they provide limited practical value for policymakers dealing with high uncertainty and rapid system transformation.

3. **Proposed Concept: Adaptive Troubleshooting Governance.** In response to these limitations, this study proposes the concept of adaptive troubleshooting governance, which integrates four main results: risk-oriented governance, digital integration, decentralized energy systems, institutional interoperability. This model transforms troubleshooting from a reactive process into a proactive and strategic function, enabling anticipation of risks, rapid response, and continuous adaptation.

4. **Strategic Implications.** The proposed conceptual framework has several important implications. First, troubleshooting should be institutionalized as a central function of state energy policy, rather than treated as an auxiliary activity. Second, energy systems should evolve into adaptive networks, capable of functioning under conditions of disruption. Third, governance models must shift toward real-time, data-driven decision-making, supported by digital technologies and integrated platforms.

Conclusions of the research. The conducted research demonstrates that the Ukrainian energy sector operates within a high-risk, volatile, and dynamically changing environment, where traditional governance models are no longer



sufficient. The complexity of challenges – ranging from physical destruction and cyber threats to institutional fragmentation and financial instability – requires a fundamentally new approach to managing the sector. Troubleshooting, in this context, should be reconceptualized as a systemic, continuous, and adaptive process, embedded within the broader framework of energy governance. It integrates technological, institutional, and policy dimensions, ensuring not only the resolution of current problems but also the prevention of future disruptions. The proposed analectic and risk-oriented model provides a novel theoretical and practical foundation for transforming the energy sector. Its implementation is particularly relevant for Ukraine's post-war recovery and its strategic course toward European integration, as it enables the creation of a resilient, flexible, and future-oriented energy system.

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