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INSTITUTIONAL FACTORS OF THE IMPLEMENTATION OF INNOVATIVE RENEWABLE ENERGY PROJECTS IN EXTREME CONDITIONS

ІНСТИТУЦІЙНІ ЧИННИКИ ВТІЛЕННЯ ІННОВАЦІЙНИХ ПРОЄКТІВ ВІДНОВЛЮВАЛЬНОЇ ЕНЕРГЕТИКИ В ЕКСТРЕМАЛЬНИХ УМОВАХ

Gnylianska Lesia
PhD in Economics, Associate Professor, Associate Professor
of the Department of Management and International Entrepreneurship,
National University «Lviv Polytechnic»
ORCID: https://orcid.org/0000-0003-2924-7165

Shpak Nestor
Doctor of Economics, Professors,
Professor of the Department of Management and International Entrepreneurship,
National University «Lviv Polytechnic»
ORCID: https://orcid.org/0000-0003-0620-2458

Poburko Oleksiy
PhD in Economics, Associate Professor,
Associate Professor of the Department of Finance,
National University «Lviv Polytechnic»
ORCID: https://orcid.org/0000-0002-9140-4099

**Гнилянська Леся Йосифівна, Шпак Нестор Омелянович,
Побурко Олексій Ярославович**
Національний університет «Львівська політехніка»

The article examines the institutional aspects of the implementation of renewable energy projects in the face of extreme challenges, including hostilities, political instability, energy crises and climate disasters. The authors focus on the importance of forming a flexible, adaptive and resilient institutional environment capable of ensuring the effective functioning of energy systems in emergency circumstances. Based on a comparative analysis of international experience, in particular of countries that implemented renewable energy in post-conflict recovery or during crisis situations (for example, Denmark, Germany, Ukraine), key parameters of institutional capacity have been identified. Among them: the presence of a strategic vision for the development of the industry, the stability of the regulatory framework, the functioning of effective regulators, support from the state and local communities, the integration of the principles of energy security and sustainable development. The article proposes a conceptual model of institutional adaptation of RES projects to extreme conditions, including multi-level governance, crisis resilience of policies, as well as intersectoral interaction.

Keywords: renewable energy, institutional parameters, extreme conditions, energy policy, resilience, war, crisis, Ukraine.

Впровадження проєктів відновлюваної енергетики в екстремальних умовах вимагає ефективних інституційних рішень, здатних адаптуватися до нестабільного середовища та забезпечити безперервність енергопостачання. Особливої актуальності ця проблематика набуває для України, яка водночас проходить через етапи воєнного протистояння, відбудови та зеленої трансформації. У статті розглядаються інституційні аспекти реалізації проєктів у сфері відновлюваної енергетики в умовах екстремальних викликів, зокрема воєнних дій, політичної нестабільності, енергетичних криз та кліматичних катастроф. Автори акцентують увагу на важливості формування гнучкого, адаптивного та стійкого інституційного середовища, здатного забезпечити ефективне функціонування енергетичних систем за надзвичайних обставин. На основі порівняльного

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аналізу міжнародного досвіду, зокрема країн, які впроваджували відновлювальну енергетику в умовах постконфліктного відновлення або під час кризових ситуацій (наприклад, Данія, Німеччина, Україна), визначено ключові параметри інституційної спроможності. Серед них: наявність стратегічного бачення розвитку галузі, стабільність нормативно-правового поля, функціонування ефективних регуляторів, підтримка з боку держави та місцевих громад, інтеграція принципів енергетичної безпеки та сталого розвитку. Особлива увага приділена аналізу українського контексту, де впровадження відновлювальної енергетики відбувається під впливом повномасштабної війни. Визначено інституційні бар'єри та можливості, зокрема в контексті децентралізації енергетичного управління, розширення ролі громад та інвестиційної привабливості сектору. У статті запропоновано концептуальну модель інституційної адаптації проєктів ВДЕ до екстремальних умов, що включає багаторівневе управління, кризову стійкість політик, а також міжсекторальну взаємодію. Отримані результати мають практичну цінність для формування політик у сфері зеленої трансформації, а також для розробки стратегій енергетичної відбудови в країнах, що перебувають у стані кризи або постконфліктного відновлення.

Ключові слова: відновлювана енергетика, інституційні параметри, екстремальні умови, енергетична політика, стійкість, війна, криза, Україна.

Statement of the problem. Modern global challenges caused by climate change, growing energy instability and geopolitical crises actualize the need for rapid implementation of innovative solutions in the field of renewable energy.

At the same time, in countries and regions operating in extreme conditions – in particular in situations of armed conflict, natural disasters or deep institutional instability – the implementation of such projects faces numerous barriers.

Despite the availability of technical capabilities and innovative solutions, the implementation of green energy projects in extreme conditions is often complicated by the fragmentation of the regulatory framework, the lack of a stable financial environment, the weakness of institutional mechanisms to support innovation, and the low level of intersectoral interaction. This creates a critical need to analyze institutional parameters that can ensure the effective functioning of innovative projects in such conditions.

Thus, the issue of identifying and systematizing the key institutional factors that affect the implementation of renewable energy projects in extreme conditions, as well as developing approaches to adapting existing mechanisms to support innovations to the specific context of instability, is relevant.

Analysis of recent research and publications. In recent years, the attention of scientists to the role of institutions in the implementation of renewable energy, especially in conditions of instability, has increased.

In particular, research Kubatko, O., Kalinichenko, L., Treus, A., Lin, D., & Mishchenko, Y. analyze the impact of extreme weather events on energy systems, highlighting the need for adaptive institutional mechanisms to ensure the sustainability of energy supply.

Research Prykhodko, I., Ignatyshyn, V., & Prykhodko, Y. [3] carry out a systematic review of the institutional conditions for local planning and implementation of renewable energy projects in the EU, identifying the diversity of approaches and the need to adapt institutional structures to local conditions.

Yarmus, S. [4] emphasizes the importance of strategic vision and coalition building for the successful implementation of energy projects in difficult conditions.

In the field of social innovation, the SONNET project explores the role of social practices and changes in social relations in the transformation of energy systems, highlighting the importance of institutional support to ensure a just and inclusive energy transition. Despite these achievements, the issue of institutional support for innovative renewable energy projects in the face of extreme challenges, such as wars, natural disasters or deep socio-economic instability, remains insufficiently researched.

Especially relevant is the study of the adaptability of institutions, their ability to rapid transformation and integration of informal management mechanisms to ensure the resilience of energy systems in such conditions.

Highlighting previously unresolved parts of the overall problem. Despite the growing amount of research in the field of renewable energy, a significant part of the scientific works is focused mainly on technological aspects, financial models or environmental effects of the implementation of "green" projects in a stable socio-economic environment. At the same time, insufficient attention is paid to the study of the institutional conditions for the implementation of innovative energy initiatives in extreme contexts, in particular in the conditions of martial law, humanitarian crisis, political turbulence, or the destruction of basic infrastructure elements.

Among the unexplored aspects remain such important issues as: institutional adaptability –

the ability of institutions to quickly transform to support innovative solutions in conditions of instability; integration of formal and informal institutions into the process of development and implementation of energy projects; the role of local governments, communities and volunteer initiatives in the restoration of energy infrastructure based on RES (renewable energy sources); mechanisms for reducing institutional risks in the planning and implementation phases of projects in an unstable environment; institutional models of interaction between the state, business and civil society in a crisis context.

Thus, a comprehensive study of institutional parameters as a critical factor in the successful implementation of innovations in the field of RES in extreme conditions is relevant and insufficiently developed in the scientific literature.

Formation of the objectives of the article (task statement). To achieve this goal, it is planned to perform the following tasks: to analyze theoretical approaches to the interpretation of institutional factors in the implementation of innovative projects in the field of RES; to determine the specifics of the functioning of institutions in the context of extreme conditions (war, natural disasters, deep socio-economic instability); assess the barriers and limitations faced by innovative RES projects in such conditions; to identify effective institutional practices that promote the introduction of renewable energy in unstable regions (on the example of individual countries or territories). To propose approaches to the formation of an adaptive institutional model for supporting innovations in the field of RES in extreme conditions and to conduct a comparative analysis of institutional models in countries such as Ukraine, Denmark, Germany.

Summary of the main research material. In the current conditions of global economic development, climate change, energy security and resilience of energy systems to external shocks remain key challenges.

The exhaustiveness of traditional energy sources (coal, oil, natural gas), their environmental hazards and geopolitical risks stimulate the transition to clean, decentralized and innovative energy sources, in particular renewable energy sources (RES). The development of RES is not only part of the environmental strategy, but also an important tool, in particular: diversification of energy supply; reduction of import dependence; creation of new jobs; attraction of investments in high-tech sectors [1].

In particular, for Ukraine, the development of renewable energy is of vital importance given the significant destruction of traditional energy infrastructure as a result of the war; loss of control over part of the generating capacities (in particular, nuclear power plants and thermal power plants); the need to meet European standards within the framework of integration into the EU and the fulfillment of the terms of the European Green Deal; climate commitments within the framework of the Paris Climate Agreement.

In addition, renewable energy serves as the basis for the decentralization of energy supply, which increases the resilience of local communities to crises – from war to climate.

Investments in green energy also contribute to the formation of a new model of economic growth that combines environmental responsibility, innovation and social justice [2].

From the above, we can see that the development of RES is not only a strategic direction of energy policy, but also a necessary condition for shaping a sustainable future of the country and the world as a whole. It is also necessary to pay attention to the institutional adaptation of RES projects to extreme conditions (Figure 1).

Despite technological progress, the key deterrent is not only technology, but institutional constraints: legal gaps, insufficient interagency coordination, weak regulatory framework, etc.

Despite the intensification of the processes of "greening" the energy sector, the introduction of renewable energy sources faces a number of structural, regulatory, economic and social problems that slow down or make it impossible to realize the potential of this industry (Table 1).

The problems of renewable energy development are systemic and multi-level, and overcoming existing barriers requires an integrated approach – from improving the legislative framework and financial support to the formation of a favorable institutional environment and raising the level of public awareness. Taking into account the above information, we should investigate the essence and structure of institutional parameters that determine the effectiveness of the implementation of innovative projects in the field of RES. "Institutional parameters" are a set of formal (legislation, policy, management structure) and informal (norms, traditions, trust) elements that regulate the behavior of actors. "Institutional theory of development" - institutions as "rules of the game" that determine transaction costs. "Theory of innovative transformation of energy"

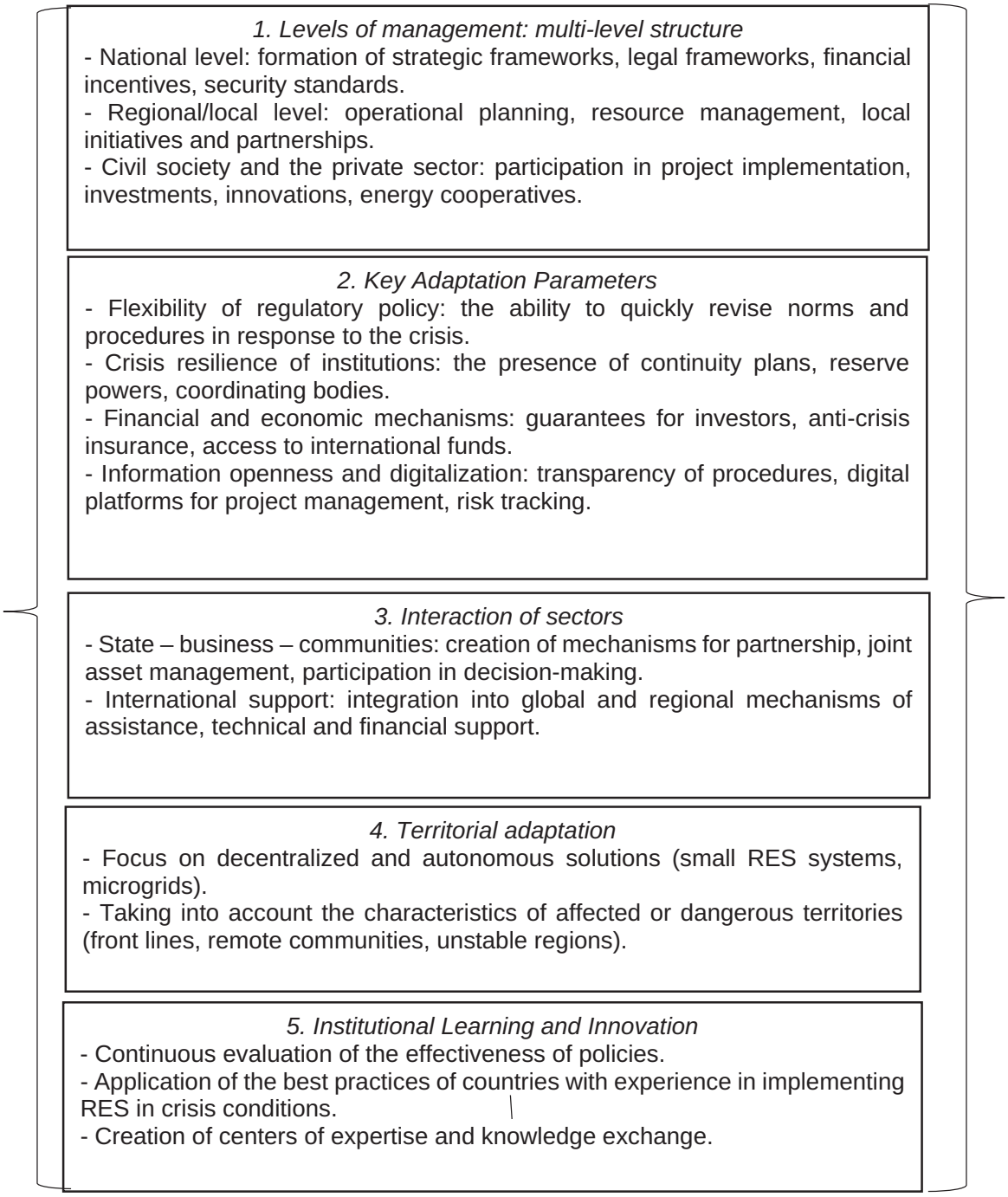

Figure 1. Model of institutional adaptation of RES projects to extreme conditions

Source: grouped and formed by the authors by [2; 3; 5]

is a transition from centralized to decentralized, intelligent systems.

In Figure 2 we will demonstrate the key institutional parameters of the implementation of innovative renewable energy projects [5].

Let us analyze and compare the institutional support for the development of renewable energy in Germany, Denmark and Ukraine (Table 2). Germany is an example of a systematic, long-term approach to the development of renewable energy sources. The Energiewende program includes a wide range of tools – from auctions and tariffs to social participation through energy cooperatives. A key feature is the predictability of policy, which facilitates large-scale investments. Denmark is a leader in the field of wind energy, with a high level of involvement of communities, municipalities and the private sector. The country actively promotes the idea of energy democracy, where the owners of wind

Table 1

Challenges in realizing the potential for the introduction of renewable energy sources

Problems	
Regulatory instability	Frequent changes in support mechanisms (e.g. revision of feed-in tariffs, reduction of government subsidies) create regulatory uncertainty for investors. Lack of a unified energy strategy with clear indicators until 2030/2050.
Bureaucratic and administrative barriers	Complex procedures for connecting to the grid, issuing permits, environmental impact assessment (EIA). Insufficient digitalization of processes and limited transparency at the regional level.
Infrastructure constraints	The technical inability of networks (especially in the regions) to integrate large volumes of "green" energy. Insufficient level of development of energy storage and load balancing systems.
Financial and investment risks	Limited access to long-term financing, especially for small and medium-sized investors. High start-up costs for the introduction of innovative technologies (e.g. hydrogen energy, battery systems).
Low level of localization of production	A significant part of the equipment is imported, which reduces the added value in the national economy. Lack of systematic support for domestic producers in supply chains for RES.
Socio-cultural factors	Resistance from local communities due to lack of awareness or fear of change (the NIMBY effect is "not in my backyard"). Lack of systemic ecological thinking in energy consumption.
Impact of hostilities	Destruction of energy infrastructure facilities. Complication of logistics and access to facilities located in war zones or occupied territories. Redirecting public resources from "green" investments to security needs.

Source: grouped by authors by [1; 3; 5–6]

farms can be citizens or local authorities. Ukraine, despite the significant natural potential of RES, faces numerous challenges: legal instability, war risks, incomplete reforms, low community participation, and lack of institutional support on the ground. However, even in wartime, Ukraine is showing growth in the segment of solar power plants and bioenergy.

A comparative analysis of institutional models of renewable energy development in Germany, Denmark and Ukraine showed a significant differentiation in the level of regulatory maturity, social integration and investment attractiveness of the industry.

Although Ukraine has significant natural and technical potential in the field of RES, its institutional model remains fragmented and vulnerable to external and internal shocks.

Ukraine is in the process of integration into the EU, which creates an imperative of harmonization with the European Union Directives on RES and energy efficiency. Among the most relevant directives are RED II/RED III, Governance Regulation and the Energy Package "Clean Energy for All Europeans". The presence of such international obligations forms a window of opportunity for: creating a transparent and long-term regulatory framework; strengthening the role of independent regulators; institutionalizing the participation of communities and local governments in RES projects.

European experience, which we will present in Table 3.

Despite the obvious advantages of European models, there are institutional limitations in Ukraine: weak decentralization of energy policy; distrust of regulators; high war risks and damaged infrastructure; limited access to cheap loans for small investors. We will also focus (Table 4) on information on the development of renewable energy in Ukraine for the period 2022–2025.

In 2024, the maximum volume of electricity production from renewable sources was recorded in August – 1.17 million MWh, and the minimum – in December. In January 2025, RES production decreased by 8% compared to January 2024, but increased by 14.5% compared to January 2023.

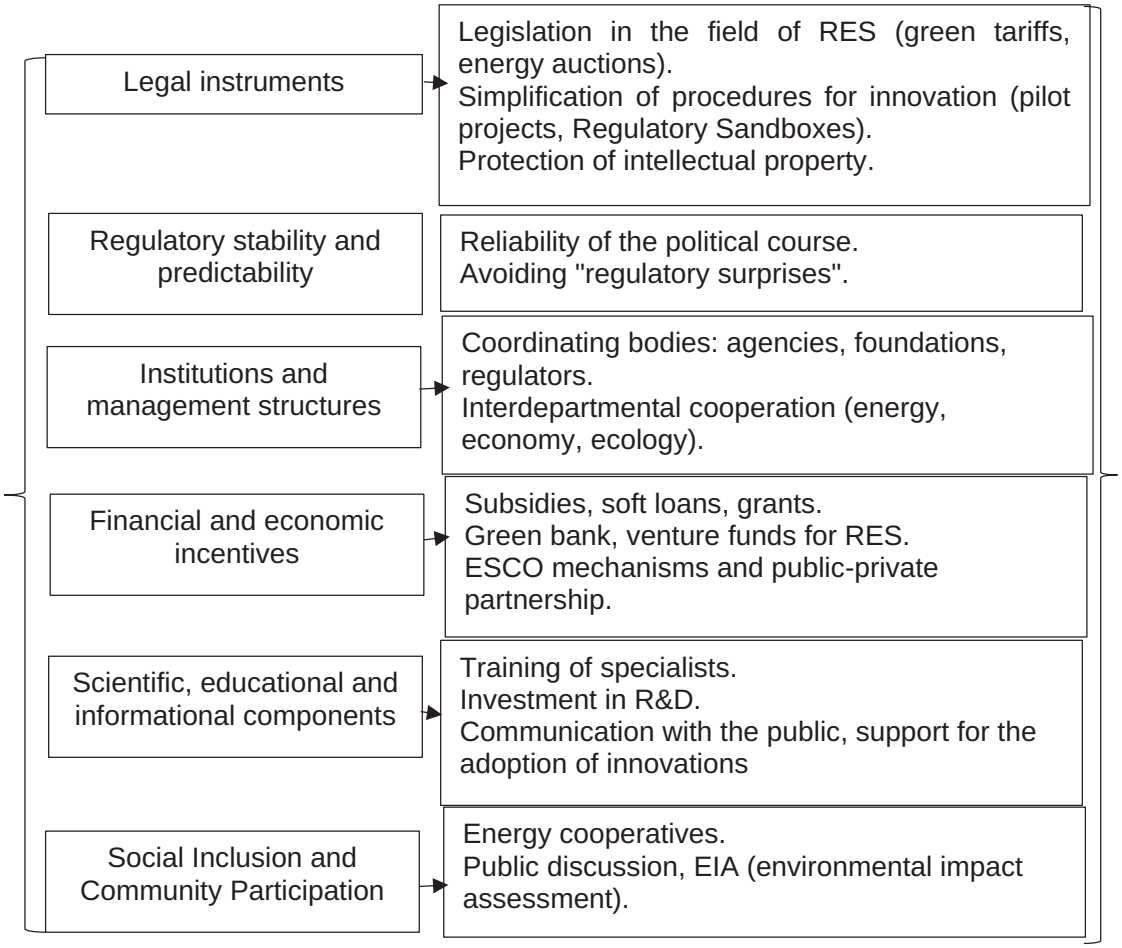

Figure 2. Key institutional parameters for the implementation of innovative RES projects

Source: generated by the authors

As of the beginning of 2025, the structure of electricity production from renewable sources in Ukraine is as follows: solar energy (SPP) – 56%; wind energy (WPP) **–** 33%; other sources (bioenergy, small hydroelectric power plants) **–** 11%. The total installed capacity of RES reached 9655.9 MW. In 2024, Ukraine imported 4.44 million MWh of electricity, which is the highest figure in the last 11 years. This is due to massive missile and drone attacks on the country's energy infrastructure. Despite the challenges, the share of renewable sources in Ukraine's energy balance increased to 11% in 2024.

Solar energy shows a significant increase in capacity, which indicates its attractiveness to investors. Hostilities significantly affect energy security, which requires additional measures to protect infrastructure. For the further development of RES, stable legal and economic conditions, as well as support from the state, are needed.

Below is an overview of successful projects that testify to the practical effectiveness of institutional decisions in Germany and Ukraine (Table 5). A comparison of institutional approaches to the development of renewable energy in Ukraine and the EU countries is incomplete without an analysis of specific implemented cases that illustrate the effectiveness or shortcomings of the relevant models.

The German experience confirms the key role of local institutions, financial guarantees and civic participation in the development of RES. At the same time, Ukrainian cases prove that even in conditions of war and regulatory instability, it is possible to implement effective projects – with the support of international partners, the mobilization of local businesses, and the growing initiative of communities.

Further institutional strengthening of these initiatives can serve as a basis for a broader transition to sustainable energy in Ukraine.

Table 2

Comparative analysis of RES institutions

Criterion	Germany	Denmark	Ukraine
National Strategy	Energiewende (energy transition) with clear targets for 2045	Energy Agreement for 100% RES by 2050	Energy Strategy 2035 (frequently updated)
Main institutions	Federal Ministry of Economic Affairs and Climate Protection; DENA Agency	Ministry of Climate, Danish Energy Agency (DEA)	Ministry of Energy, State Agency on Energy Efficiency and Energy Saving of Ukraine, National Energy and Utilities Regulatory Commission, Ukrenergo
Support mechanisms	Tenders, Contracts for Difference (CfD), Green Certificates	Government tenders, investment support, cooperative model of RES	“Green Tariff", auctions (introduced, but not fully implemented)
The role of municipalities	High – local programs, municipal energy companies	Vysoka – communities own a stake in wind farms/ solar power plants	Limited, non-formalized
Investment attractiveness	High (institutional stability, ESG investments)	High (predictability, efficient administration)	Low/medium (regulatory risks, war risks)
Community Participation Tools	Energy cooperatives, programs for households	Wind cooperatives, Smart grid networks	Limited – mostly private projects without broad community participation
Regulatory predictability	High: long-term goals, indicators, European standards	High, support from the parliament and local government	Medium/low: frequent tariff changes, regulatory instability
RES goals in the energy balance (as of 2023)	51% (goal – 80% by 2030)	76% (target is 100% by 2050)	~10–11% (target is 25% by 2035; the potential is much higher)

Source: grouped by authors by [7–8]

Table 3

Key elements to borrow from the European experience

Element	Denmark/Germany Experience	Relevance for Ukraine
Control localization	Communities own shares in wind farms, solar power plants; Municipalities are active subjects	Creation of municipal energy strategies; involvement of communities in RES
Energy cooperatives	40–50% of RES facilities in Germany are owned by communities/cooperatives	The need for legal regulation of such forms of ownership, tax benefits
Regulatory stability	Long-term goals (until 2045), predictability of tariffs, investment guarantees	Transition from the "green tariff" to transparent CfD/auction mechanisms
Digitalization	Smart Grid, digital platforms for consumer participation	The need for digital transformation of Ukrenergo, Prozorro for RES projects
Citizen participation	Educational programs, subsidies for household solar power plants, windmills, heat pumps	Mechanisms of "transparent energy choice" for households

Source: grouped by authors

Table 4

Main statistical indicators for the period 2022–2025 Years

Showman	2022	2023	2024	2025 (start)
Electricity production from RES	~10.3 million MWyear	~10.3 million MWyear	11 million MWyear	—
Share of RES in the energy balance	~10%	~10%	11%	8,1%
Increase in SPP capacity	—	—	+850 Mw	—
Increase in wind farm capacity	—	—	+20 Mw	—
Total installed capacity of RES	—	—	8773 Mw	9655,9 Mw
RES capacities in the occupied territories	—	—	~3,5 Gw	~3,5 GW
Electricity imports	—	806.4 thsd. MWh	4.44 million MWh	—
Electricity import costs	—	$154.7 million	$669.4 million	—

Source: formed by the authors according to [6–8]

Table 5

Overview of successful projects demonstrating the practical effectiveness of institutional solutions in Germany and Ukraine

Germany	Ukraine
Schönau Energy Cooperative (EWS) – One of the best-known examples of a public initiative in the field of energy is the EWS cooperative in Schönau (Baden-Württemberg). After the Chernobyl disaster, the community bought out local power grids and became a producer and supplier of electricity from renewable sources. Social cohesion and citizen participation in the "green transition".	**Households with household solar power plants** – The institutional model of the "green tariff", which was in force in Ukraine until 2023, gave impetus to the installation of more than 47 thousand private solar power plants with a total capacity of more than 1.3 GW. This case demonstrates the significant potential of decentralized generation even in the conditions of limited regulatory stability.
The energy self-sufficient village of Feldheim – The village of Feldheim (Brandenburg) is a unique example of local energy autonomy. Thanks to the institutional partnership between the municipality, a private investor (Energiequelle GmbH) and the municipality, a completely independent microgrid has been created, operating on the basis of wind farms, solar power plants, biogas and storage. This project demonstrates the potential of public-private partnership (PPP) in the implementation of grassroots energy transformation.	**Bioenergy clusters in the agricultural sector (Poltava region)** – Agro-industrial companies "Globyno" and "Astarta" implemented complex projects for the production of biogas based on agricultural waste. They were supported by grant programs from the EBRD and USAID, and were also accompanied by the modernization of thermal systems.
The "Marktanreizprogramm" program is a federal renewable heat market incentive program aimed at the introduction of biomass, geothermal energy and heat pumps in the private sector. The program uses tools such as subsidies, lending through KfW Bank and tax incentives. The program serves as an example of institutional stability and long-term demand support.	**Starokozache Solar Park (Odesa region)** – A powerful 40 MW solar power plant project was implemented with the participation of the Norwegian company Scatec Solar with the support of the EIB and the EBRD. As of 2021, this facility was one of the largest in Ukraine. An institutionally important feature was the availability of international arbitration guarantees, which partially neutralized the risks of legal instability.

Source: formed by the authors according to [1; 4–6]

Recommended areas of institutional development for Ukraine: Adoption of a framework law for the development of decentralized energy (with elements of cooperative and public ownership); Institutionalization of the State Fund "Green Transformation" – with international donors and open conditions for participation; Development of regional energy clusters – in particular in communities with damaged thermal power plants/networks; Digital public platforms for tracking the production and consumption of RES (like the "electronic cabinet of the manufacturer").

Conclusions. As you can see, institutional transformation is the key to scaling up RES in Ukraine. The use of European experience combined with local adaptations will create a sustainable, decentralized, and innovative energy system that will meet the challenges of both peacetime and wartime. Institutional parameters are no less important than technological innovations. The successful implementation of innovative projects in RES depends on: policy coherence; effective regulation; access to finance; and the level of trust between the state, business and society. Accordingly, we can provide the following recommendations: introduction of flexible regulatory zones; institutional strengthening of RES agencies; increasing market transparency and community engagement.

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