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AGRICULTURAL-ENERGY COOPERATIVES AS LOCAL CENTRES OF ENERGY AND ECONOMIC SECURITY

SPÓŁDZIELNIE ROLNO-ENERGETYCZNE JAKO LOKALNE OŚRODKI BEZPIECZEŃSTWA ENERGETYCZNEGO I GOSPODARCZEGO

Abstract: In the context of the ongoing decentralisation of energy systems and the increasing exposure of critical infrastructure to economic, environmental and geopolitical risks, local forms of energy production and governance are gaining strategic importance. The aim of this article is to analyse agricultural–energy cooperatives as potential local centres of energy and economic security in rural areas. The study adopts a systemic perspective that integrates energy security, economic security and agricultural conditions, with particular emphasis on distributed energy systems and local resilience-oriented energy structures. Methodologically, the article is based on a critical review of peer-reviewed scientific literature (Scopus and Web of Science), an analysis of institutional reports of the European Union and the author's own research. Agricultural–energy cooperatives are examined in relation to other organisational forms of local energy systems, such as agricultural energy islands and energy clusters, with a focus on their capacity for local energy balancing, cost stabilisation and the enhancement of system resilience in the face of disruptions. The results indicate that agricultural–energy cooperatives can function as local centres of energy and economic security only under specific technological, organisational and institutional conditions. Of particular importance is the integration of dispatchable energy sources – especially agricultural biogas – with other renewable energy

technologies, as well as the existence of stable regulatory and financial frameworks. At the same time, the analysis identifies significant barriers to development, including regulatory, financial and infrastructural constraints, which currently limit the full utilisation of the potential of these structures in Poland. The article contributes to the literature on energy security by proposing an interpretation of agricultural–energy cooperatives as components of a "system of systems", in which local energy subsystems collectively enhance the resilience of the overall energy system. The findings provide a basis for further empirical research and may inform the design of public policies supporting the development of local energy systems.

Zarys treści: W kontekście postępującej decentralizacji systemów energetycznych oraz faktu, że infrastruktura krytyczna jest coraz bardziej narażona na ryzyko gospodarcze, środowiskowe i geopolityczne, lokalne formy produkcji energii i zarządzania nabierają strategicznego znaczenia. Celem niniejszego artykułu jest analiza spółdzielni rolno-energetycznych jako potencjalnych lokalnych ośrodków bezpieczeństwa energetycznego i gospodarczego na obszarach wiejskich. W badaniu przyjęto perspektywę systemową, łączącą bezpieczeństwo energetyczne, bezpieczeństwo gospodarcze i uwarunkowania rolnicze, ze szczególnym uwzględnieniem rozproszonych systemów energetycznych oraz lokalnych struktur energetycznych zorientowanych na odporność. Pod względem metodologicznym artykuł opiera się na krytycznym przeglądzie recenzowanej literatury naukowej (Scopus, Web of Science), analizie raportów instytucjonalnych Unii Europejskiej oraz własnych badaniach autora. Spółdzielnie rolno-energetyczne są analizowane w kontekście innych form organizacyjnych lokalnych systemów energetycznych, takich jak rolnicze wyspy energetyczne i klastry energetyczne, ze szczególnym uwzględnieniem ich zdolności do lokalnego bilansowania energii, stabilizacji kosztów oraz zwiększania odporności systemu w obliczu zakłóceń. Wyniki wskazują, że spółdzielnie rolno-energetyczne mogą pełnić rolę lokalnych ośrodków bezpieczeństwa energetycznego i gospodarczego jedynie w określonych warunkach technologicznych, organizacyjnych i instytucjonalnych. Szczególne znaczenie ma integracja źródeł energii o regulowanej mocy – zwłaszcza biogazu rolniczego – z innymi technologiami energii odnawialnej, a także istnienie stabilnych ram regulacyjnych i finansowych. Jednocześnie analiza wskazuje na istotne bariery rozwoju, w tym ograniczenia regulacyjne, finansowe i infrastrukturalne, które obecnie hamują pełne wykorzystanie potencjału tych struktur w Polsce. Artykuł wnosi wkład do literatury poświęconej bezpieczeństwu energetycznemu, proponując interpretację spółdzielni rolno-energetycznych jako elementów „systemu systemów", w którym lokalne podsystemy energetyczne wspólnie zwiększają odporność całego systemu energetycznego. Wyniki badań stanowią podstawę do dalszych badań empirycznych i mogą

posłużyć jako podstawa do kształtowania polityki publicznej wspierającej rozwój lokalnych systemów energetycznych.

Keywords: agricultural–energy cooperatives, local energy security, economic security, renewable energy systems, decentralized energy systems.

Słowa kluczowe: spółdzielnie rolno-energetyczne, lokalne bezpieczeństwo energetyczne, bezpieczeństwo gospodarcze, systemy energii odnawialnej, zdecentralizowane systemy energetyczne.

Introduction

Energy security constitutes one of the key pillars of state security and socio-economic stability. Its importance has been significantly reinforced in recent years due to the accumulation of geopolitical, climatic and infrastructural threats. The experience of the war in Ukraine has revealed the vulnerability of centralised energy systems to disruptions in electricity and natural gas supplies through attacks on critical infrastructure and commodity pressure, while simultaneously leading to increased energy costs and reduced availability for the economy and households.[1] In the literature, it is increasingly emphasised that energy security cannot be analysed exclusively at the national level; it also requires examination at the regional and local scale, where the effects of energy crises are felt directly by local communities.[2]

In this context, the significance of distributed energy sources is growing. Unlike centralised generation units, they are characterised by greater resilience to systemic disruptions and by the possibility of operating in an autonomous mode. An analysis of RES development in Poland indicates that the development of local energy sources, including agricultural biogas plants, may significantly increase the resilience of the national energy system to external crises and reduce dependence on fossil fuels.[3] Rural areas are particularly important here:

[1] A. Koźmiński, *Rozproszone źródła energii jako fundament bezpieczeństwa energetycznego w Polsce*, "Środkowoeuropejskie Studia Polityczne" 2025, no. 2.

[2] P. Kwiatkiewicz, *Bezpieczeństwo energetyczne – ewolucja percepcji problemu i jej determinanty*, "Przegląd Naukowo-Metodyczny" 2018, no. 1.

[3] A. Koźmiński, *Rozproszone źródła energii*…, op. cit.

they possess substantial feedstock and spatial potential, while at the same time remaining more exposed to the effects of supply interruptions and energy price volatility.[4]

Previous research on distributed energy has focused primarily on technological, environmental and regulatory aspects, analysing the efficiency of RES installations, their impact on greenhouse-gas emission reductions and compliance with EU energy and climate policies.[5] Currently, increasing attention is also being paid to socio-institutional forms of local energy organisation, such as energy cooperatives and energy communities, which enable joint production, consumption and management of energy at the local level.[6] International literature indicates that such entities can play an important role in enhancing the resilience of local energy systems and strengthening social acceptance of the energy transition.[7]

In Poland, the potential of energy cooperatives operating in rural areas as local centres of energy and economic security – particularly in relation to farms – remains relatively under-explored. Empirical analyses show that locally generated energy can not only stabilise supply in crisis situations but also reduce operating costs for farms, diversify their income sources and strengthen local value chains.[8] This issue is rarely approached in a comprehensive manner that combines the energy-security perspective with the economic security of rural communities.

Therefore, the aim of this article is to analyse agricultural–energy cooperatives as a specific organisational form that can function as a local centre of energy and economic security. The article attempts to fill a research gap by integrating the achievements of research on distributed energy sources, energy cooperativism and critical-infrastructure security, with particular emphasis on the conditions of rural areas and the agricultural sector in Poland.[9]

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[4] A. Koźmiński, *Rolnicze wyspy energetyczne jako element bezpieczeństwa lokalnego*, in: R.P. Depczyński (ed.), *Rola sił zbrojnych i administracji w zapewnieniu bezpieczeństwa państwa*, Wydawnictwo Pomorskiej Szkoły Wyższej, Starogard Gdański 2025.

[5] L. Kalcher, *Choices for a more Strategic Europe*, Strategic Perspectives, Brussels 2023.

[6] D. Kostecka-Jurczyk, M. Struś, K. Marak, *The Role of Energy Cooperatives in Ensuring the Energy and Economic Security of Polish Municipalities*, "Energies" 2024, vol. 17, no. 13.

[7] A. Schreuer, D. Weismeier-Sammer, *Energy cooperatives and local ownership in the field of renewable energy technologies: A literature review*, RiCC – research report 2010/4, WU Vienna University of Economics and Business, Vienna 2010.

[8] A. Koźmiński, *Rolnicze wyspy energetyczne*…, op. cit.

[9] A. Koźmiński, *Rozproszone źródła energii, rolnicze wyspy energetyczne i spółdzielnie rolniczo-energetyczne jako fundament bezpieczeństwa energetycznego Polski*, "Rozprawy Społeczno-Ekonomiczne Łużyckiej Szkoły Wyższej" 2025, vol. 12.

Methodology and research assumptions

The aim of this article is to analyse the role of agricultural–energy cooperatives as local centres of energy and economic security, situated at the intersection of research on distributed energy, infrastructural security and rural development. Due to the interdisciplinary nature of the research problem, a qualitative approach was adopted, combining the analysis of scientific literature with the author's own research output, including empirical analyses and model concepts developed in earlier publications.[10]

Research design and approach

The study is conceptual and analytical. Its primary purpose is not statistical estimation of quantitative relationships, but rather the identification of mechanisms, functions and institutional conditions that determine the capacity of agricultural–energy cooperatives to perform stabilising functions at the local level. This approach is consistent with the dominant stream of research on energy cooperatives and energy communities, where qualitative analyses, case studies and literature syntheses are frequently used to capture complex social, economic and energy-related relationships.[11]

The analysis focuses on rural areas, particularly on farms. This results from their unique role in the energy system as simultaneous producers of biomass, consumers of energy and potential prosumers. The literature emphasises that rural areas, owing to the concentration of local resources (agricultural substrates, space for RES, thermal infrastructure), are conducive to the development of stable models of distributed energy.[12]

Literature selection and analysis procedure

The central methodological element of this study is a structured qualitative review of peer-reviewed literature and selected institutional reports. The selection was based on thematic criteria, including:[13]

[10] A. Koźmiński, *Rozproszone źródła energii*…, op. cit.
[11] A. Schreuer, D. Weismeier-Sammer, *Energy cooperatives*…, op. cit.
[12] A. Koźmiński, *Rolnicze wyspy energetyczne*…, op. cit.
[13] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.

- energy cooperatives and energy communities,
- energy security and system resilience,
- economic and development aspects of local energy,
- the context of rural areas and agriculture.

The analysis covers both empirical articles and review papers, as well as institutional reports that play an important role in the literature by structuring concepts and identifying development trends. Particular attention was paid to publications indicating the function of energy cooperatives in increasing the resilience of local energy systems and reducing the economic risks borne by members of such entities.[14]

Criteria for the selection of comparative country cases

Germany, Denmark and the Netherlands were selected as purposive comparative cases rather than as a statistically representative sample of European Union Member States. The selection was based on five criteria. First, all three countries have a relatively mature and well-documented tradition of community-based and cooperative renewable-energy initiatives. Second, they display significant forms of local ownership and citizen or farmer participation in energy projects. Third, they provide differentiated organisational and technological models relevant to the rural context: Germany offers extensive experience with bioenergy villages, agricultural biogas and cooperative heat-and-power systems; Denmark represents a long-standing cooperative tradition in wind energy, district heating and local participation; and the Netherlands provides examples of citizen energy cooperatives and multi-actor local energy initiatives.

Fourth, the cases are comparable with Poland at the European regulatory level because they operate within the common EU energy and climate-policy framework, while differing substantially in national institutional arrangements and market maturity. This makes it possible to identify which factors are associated with general challenges of decentralised energy and which are linked to national regulatory and organisational conditions. Fifth, the selected countries are extensively covered by peer-reviewed research and institutional reports, allowing for evidence-based comparison. The country cases are therefore used illustratively and analytically, not as a basis for statistical generalisation to all EU Member States.

[14] A. Wierling et al., *Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries*, "Sustainability" 2018, vol. 10, no. 9.

Use of the author's previous research

An important methodological element is the use of the author's earlier research results, including both empirical analyses and model concepts concerning distributed energy and agricultural energy islands. In particular, the study draws on survey results conducted among farmers and SWOT analyses, which enabled the identification of barriers, opportunities and operating mechanisms of local RES-based energy systems.[15]

This output serves here as reference material, enabling the confrontation of findings from international literature with the realities of Polish rural areas. Such an approach is consistent with research practice in analyses of energy cooperatives, where the importance of local institutional, legal and social context is emphasised.[16]

Research assumptions

On the basis of the literature review and the author's earlier research, the following assumptions were adopted:

1. Agricultural–energy cooperatives can serve as local centres of energy security by ensuring stable energy supply based on local resources and by limiting the effects of systemic disruptions.
2. The cooperative model supports farmers' economic security by reducing energy costs, diversifying income sources and increasing the predictability of farm operating conditions.
3. The effectiveness of agricultural–energy cooperatives is strongly dependent on institutional conditions, including legal frameworks, public support and local-government engagement, which is confirmed both by international literature and domestic experience.[17]

These assumptions constitute the starting point for the subsequent theoretical and comparative analysis developed in the following sections.

[15] A. Koźmiński, *Rolnicze wyspy energetyczne*…, op. cit.

[16] A. Caramizaru, A. Uihlein, *Energy communities: An overview of energy and social innovation*, Publications Office of the European Union, Luxembourg 2020.

[17] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.

Energy security: systemic and local perspectives

Energy security is a multidimensional category that includes not only continuity of supply but also the resilience of energy systems to disruptions of geopolitical, technical and climatic nature. Contemporary literature emphasises that classic, highly centralised energy systems are characterised by high vulnerability to failures of transmission infrastructure and to supply shocks resulting from restricted access to energy commodities.[18] Experiences of recent years, including the European energy crisis after 2022, have highlighted structural weaknesses of such systems and contributed to a redefinition of energy security towards greater emphasis on resilience and systemic flexibility.[19]

From a systemic perspective, energy security refers to the capacity of the entire energy system to operate stably under conditions of demand variability, supply unpredictability and external disruptions. Increasingly, researchers highlight the importance of system flexibility, understood as the ability to adapt the structure of generation, transmission and energy use to dynamic environmental conditions.[20] In this context, a particularly important role is attributed to distributed energy systems, which – through diversification of generation sources and shortening of energy supply chains – can reduce the impacts of failures of a system-wide nature.[21]

Distributed Energy Systems (DES) include local generation sources such as RES installations, co-generation systems, energy storage and microgrids, operating both in connection with the national grid and in autonomous mode. DES integration increases energy-system resilience by reducing risk concentration and improving the capacity for local balancing of energy demand and supply.[22] Research also indicates that the distribution of energy infrastructure reduces the scale of potential failure impacts, which is significant from the perspective of critical infrastructure protection.[23]

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[18] O. Carmon et al., *Evaluating energy security in decentralized systems: Review and new index*, "Energy Strategy Reviews" 2025, vol. 60.

[19] K. Zuo, L. Wu, *A review of decentralized and distributed control approaches for islanded microgrids: Novel designs, current trends and emerging challenges*, "The Electricity Journal" 2022, vol. 35, no. 5.

[20] A. Soussi et al., *Enhancing Energy Systems and Rural Communities through a System of Systems Approach: A Comprehensive Review*, "Energies" 2024, vol. 17, no. 19.

[21] N. Nadeem, *Distributed Energy Systems: A Review of Classification and Systemic Roles*, "Energy Reports" 2023.

[22] K. Zitelman, *Advancing Electric System Resilience with Distributed Energy Resources: Key Questions and Resources*, National Renewable Energy Laboratory, NREL/SR-7A40-90138, 2024.

[23] A. Wierling et al., *Statistical Evidence*…, op. cit.

Local energy security becomes particularly important in rural areas, which are often characterised by lower-quality grid infrastructure and greater sensitivity to supply interruptions. Analyses increasingly point to the role of local energy systems – including energy cooperatives and energy communities – as tools for strengthening energy self-sufficiency and the resilience of local socio-economic structures.[24] Empirical studies show that local energy production can significantly reduce communities' dependence on external suppliers and stabilise access to energy in crisis situations.[25]

From a socio-technical perspective, energy security is not solely a function of technical parameters; it is the result of interactions between technology, institutions and local energy users. Models based on active participation of local communities in energy generation and governance increase social acceptance of energy investments and strengthen the adaptive capacity of local systems.[26] This approach not only increases resilience but also improves long-term system performance by better matching local needs and resources.[27]

Energy security in systemic and local terms should be seen as the result of synergy between centralised energy infrastructure and distributed local systems. Contemporary research indicates that the development of local energy systems based on renewable energy sources and participatory organisational forms can significantly increase resilience, reduce vulnerability to external disruptions and strengthen the energy security of local communities.[28]

Economic security of rural areas and farmers

Economic security is a significant component of the socio-economic security of rural areas, determining the stability of farm operations and the resilience of local communities to external shocks. In the literature, farmers' economic security is primarily linked to predictability of production costs, income stability and the ability to maintain continuity of activity under conditions of volatile energy and commodity prices.[29] In recent years, the energy factor has become one of the key determinants

[24] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.

[25] J. Fouladvand et al., *Energy security in community energy systems: An agent-based modelling approach*, "Journal of Cleaner Production" 2022, vol. 366.

[26] A. Caramizaru, A. Uihlein, *Energy communities*…, op. cit.

[27] M. Adham, S. Keene, R.B. Bass, *Distributed Energy Resources: A Systematic Literature Review*, "Energy Reports" 2025, vol. 13.

[28] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.

[29] A. Cielo et al., *Renewable Energy Communities business models under the 2020 Italian regulation*, "Journal of Cleaner Production" 2021, vol. 316.

of farms' economic situation, particularly in the context of rising electricity and fuel prices after 2022.[30]

Research indicates that rural areas have a specific structure of economic vulnerability resulting from a high share of electricity costs in agricultural production, limited access to alternative energy sources and weaker bargaining power vis-à-vis energy suppliers.[31] This phenomenon is also analysed in the context of energy poverty. Although most studies focus on households, it is increasingly identified in the agricultural sector and in rural areas as well.[32] From this perspective, farmers' economic security is directly linked to the availability and affordability of energy.

Contemporary research on local energy highlights that distributed energy systems can play an important stabilising function economically. Local energy generation – especially within energy communities and cooperatives – reduces farms' exposure to wholesale market price volatility and lowers purchase costs.[33] Empirical analyses from EU countries show that participation in community-energy structures is associated with lower energy costs for members and improved predictability of energy expenditures.[34]

Economic security in rural areas is also linked to the ability to diversify income sources, which is recognised as a key mechanism for strengthening the resilience of farms. Renewable energy generation, including biogas, biomass or photovoltaic installations enables the creation of additional revenue streams independent of traditional agricultural markets.[35] Research on community-energy business models points to economic benefits that are not only individual but also local, contributing to increased value added retained in the region.[36]

The creation of local energy value chains – where energy production, distribution and consumption occur within a single community or region – helps retain capital locally, reduces financial outflows to external suppliers and strengthens the local economy.[37] This mechanism is particularly important in rural Europe, where alternative income sources are often limited.[38]

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[30] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.

[31] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.

[32] S. Bouzarovski, S. Petrova, *A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary*, "Energy Research & Social Science" 2015, vol. 10.

[33] J. Fouladvand et al., *Energy security*…, op. cit.

[34] A. Caramizaru, A. Uihlein, *Energy communities*…, op. cit.

[35] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.

[36] A. Wierling et al., *Statistical Evidence*…, op. cit.

[37] I.F.G. Reis et al., *Business models for energy communities: A review of key issues and trends*, "Renewable and Sustainable Energy Reviews" 2021, vol. 144.

[38] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.

The economic security of rural areas and farmers is closely tied to the functioning of energy systems. Local renewable energy, supported by organisational forms such as cooperatives and energy communities, can significantly reduce economic risks, stabilise energy costs and strengthen the resilience of farms and rural communities to external crises.[39] These issues provide essential background for the subsequent analysis of agricultural–energy cooperatives as a tool for integrating energy and economic security at the local level.

State of research on agricultural–energy cooperatives and local energy systems

The concept of energy cooperatives and energy communities has been widely discussed in international literature, particularly in the context of the decentralisation of energy systems and the social dimension of the energy transition. Research conducted in European Union countries indicates that energy cooperatives constitute one of the most effective organisational forms for integrating local renewable energy sources with the needs of local communities.[40] These entities enable collective investment, joint energy management and the sharing of economic benefits arising from local energy production.[41]

In countries such as Germany, Denmark and the Netherlands, energy cooperatives have become an important element of rural development strategies. Empirical studies show that they contribute not only to increased energy self-sufficiency but also to strengthening social capital, local entrepreneurship and acceptance of renewable energy investments.[42] The three countries are used in this article as analytically differentiated reference cases. Germany is particularly relevant because of the documented development of bioenergy villages, agricultural biogas plants and cooperative systems combining electricity and heat production. Denmark is included because of its long-standing cooperative tradition in renewable-energy development, especially in wind energy, district heating and local ownership structures. The Netherlands provides examples of citizen-led energy cooperatives and multi-actor local energy initiatives, which are useful for examining governance arrangements and

[39] J. Fouladvand et al., *Energy security*…, op. cit.
[40] A. Wierling et al., *Statistical Evidence*…, op. cit.
[41] M.L. Lode et al., *A transition perspective on Energy Communities: A systematic literature review and research agenda*, "Renewable and Sustainable Energy Reviews" 2022, vol. 163.
[42] T. Roesler, M. Hassler, *Creating niches – The role of policy for the implementation of bioenergy village cooperatives in Germany*, "Energy Policy" 2019, vol. 124.

business models. These experiences should not be treated as directly transferable to Poland. Instead, they are used to identify institutional, organisational and technological mechanisms that may be adapted to Polish rural conditions. In the German context, particular attention has been paid to so-called bioenergy villages, where local cooperatives manage integrated energy systems based on biomass, biogas and other renewable sources.[43]

The literature increasingly emphasises that energy cooperatives should be analysed not only as instruments of energy transition but also as mechanisms for enhancing energy security and resilience. Studies indicate that cooperative-based energy systems are more resistant to market volatility and supply disruptions, owing to their reliance on local resources and decentralised governance structures.[44] Moreover, participation in cooperatives has been shown to stabilise energy costs for members and reduce exposure to fluctuations in wholesale energy markets.[45]

In the Polish context, research on energy cooperatives remains limited and fragmented. Existing studies focus mainly on legal frameworks, regulatory barriers and the potential of renewable energy sources in rural areas.[46] Comprehensive analyses integrating energy security, economic security and organisational aspects are still scarce. This gap in the literature justifies the need for research that situates agricultural–energy cooperatives within a broader framework of local security and resilience.

Agricultural–energy cooperatives as a model of local energy and economic security

Agricultural–energy cooperatives represent a specific organisational model that integrates agricultural production with local energy generation and management. Their distinguishing feature lies in the use of local agricultural resources – such as biomass, biogas substrates and land – for energy purposes, combined with collective ownership and governance structures. This model enables the alignment of energy production with the needs of farms and rural communities, thereby enhancing both energy and economic security.[47]

[43] T. Jenssen, A. König, L. Eltrop, *Bioenergy villages in Germany: Bringing a low carbon energy supply for rural areas into practice*, "Renewable Energy" 2014, vol. 61.
[44] J. Fouladvand et al., *Energy security*…, op. cit.
[45] I.F.G. Reis et al., *Business models*…, op. cit.
[46] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.
[47] A. Koźmiński, *Spółdzielnia rolniczo-energetyczna*…, op. cit.

From the perspective of energy security, agricultural–energy cooperatives contribute to the diversification of energy sources and the decentralisation of energy generation. By relying on locally available resources, they reduce dependence on external suppliers and mitigate the risks associated with centralised energy systems. In crisis situations, such as grid failures or fuel supply disruptions, cooperative-managed installations – particularly biogas plants – can provide a stable and dispatchable source of energy, supporting the continuity of critical agricultural and municipal functions.[48]

Economic security is strengthened through the reduction and stabilisation of energy costs for cooperative members. Collective investment lowers entry barriers for individual farmers, while shared operation and maintenance reduce operational risks. In addition, revenue generated from surplus energy sales can be redistributed among members or reinvested in local development projects, further enhancing the economic resilience of rural areas.[49]

The cooperative model also plays an important institutional role by fostering cooperation between farmers, local governments and energy operators. Such collaboration enhances coordination in energy planning and crisis management, contributing to the creation of integrated local energy systems. The literature indicates that strong institutional support and clear legal frameworks are essential for the effective functioning of agricultural–energy cooperatives.[50]

Agricultural energy islands and energy clusters as organisational forms

Agricultural energy islands and energy clusters constitute complementary organisational forms within local energy systems. Energy islands refer to territorially defined systems capable of operating autonomously from the national grid, while energy clusters emphasise cooperation among multiple producers and consumers within a given area. Both forms are increasingly analysed as tools for enhancing local energy resilience.[51]

In rural areas, energy islands are particularly relevant due to the presence of dispatchable renewable sources, such as biogas plants, which enable stable local energy

[48] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.
[49] I.F.G. Reis et al., *Business models*…, op. cit.
[50] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.
[51] A. Koźmiński, *Rolnicze wyspy energetyczne*…, op. cit.

supply. Studies indicate that island-capable systems significantly reduce the vulnerability of rural infrastructure to large-scale grid failures.[52] Energy clusters, in turn, facilitate the coordination of multiple energy assets and stakeholders, improving efficiency and flexibility at the local level.[53]

Both organisational forms share common challenges, including regulatory complexity, limited access to financing and technical constraints related to grid integration. Nevertheless, their development provides valuable insights into the institutional and technical conditions necessary for the successful implementation of agricultural–energy cooperatives.[54]

Barriers to development and implementation conditions

Despite their potential benefits, the development of agricultural–energy cooperatives faces numerous barriers. The literature identifies regulatory and institutional constraints as the most significant obstacles, particularly in countries where legal frameworks for energy communities are underdeveloped.[55] In Poland, complex administrative procedures, unclear regulatory responsibilities and limited support for the pre-investment phase hinder cooperative initiatives.[56]

Financial barriers also play a critical role. High initial investment costs, limited access to tailored financing instruments and uncertainty regarding long-term revenue streams discourage farmers from engaging in collective energy projects.[57] Additionally, technical barriers – such as insufficient grid capacity and restrictive connection conditions – further constrain the development of local energy systems.[58]

Social and organisational factors, including low levels of trust, limited experience with cooperative governance and insufficient awareness of potential benefits also affect implementation. Research emphasises that overcoming these barriers requires coordinated policy interventions, capacity-building initiatives and stable regulatory environments.[59]

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[52] K. Zitelman, *Advancing Electric System Resilience*…, op. cit.
[53] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.
[54] T. Roesler, M. Hassler, *Creating niches*…, op. cit.
[55] M.L. Lode et al., *A transition perspective*…, op. cit.
[56] D. Kostecka-Jurczyk, M. Struś, K. Marak, *Rola spółdzielni energetycznych*…, op. cit.
[57] I.F.G. Reis et al., *Business models*…, op. cit.
[58] K. Zuo, L. Wu, *A review of decentralized*…, op. cit.
[59] A. Caramizaru, A. Uihlein, *Energy communities*…, op. cit.

Discussion

The analysis confirms that agricultural–energy cooperatives have the potential to function as local centres of energy and economic security, particularly in rural areas with access to agricultural resources and dispatchable renewable energy sources. The findings are consistent with international literature highlighting the role of cooperative energy systems in enhancing resilience and reducing economic vulnerability.[60]

However, the Polish case demonstrates that the absence of such cooperatives is not primarily due to a lack of technical or economic potential, but rather to institutional and regulatory barriers. This observation supports the argument that energy security should be analysed not only through technological indicators but also through governance and policy frameworks.[61]

Policy and regulatory recommendations for Poland

The analysis indicates that the development of agricultural–energy cooperatives in Poland requires a coherent package of institutional and regulatory changes. First, administrative procedures for establishing and operating energy cooperatives should be simplified, standardised and coordinated through a one-stop-shop model. Such a model should provide access to registration procedures, legal guidance, settlement rules, technical advice and information on available public support.

Second, the rules governing connection to the distribution grid should become more transparent and predictable. Distribution system operators should publish regularly updated information on available connection capacity and provide timely, substantiated decisions on connection applications. In areas with grid constraints, priority should be given to projects that combine renewable-energy generation with energy storage, demand-side management and local balancing.

Third, public support should cover not only the construction phase but also the pre-investment phase. Agricultural–energy cooperatives require financial support for feasibility studies, technical documentation, legal advice, environmental procedures and the organisation of cooperative governance. These preparation costs are often too high for individual farms and may prevent projects from reaching the investment stage.

[60] A. Wierling et al., *Statistical Evidence*…, op. cit.
[61] M. Adham et al., *Distributed Energy Resources*…, op. cit.

Fourth, stable long-term support mechanisms should be introduced for dispatchable renewable sources, especially agricultural biogas. Biogas installations should be recognised not only as electricity-generation assets but also as sources of flexibility, balancing capacity and continuity of supply during disturbances. This is particularly important in rural areas where photovoltaic and wind generation alone may not ensure stable local energy supply.

Fifth, energy storage and local energy-management systems should be included explicitly in financial-support programmes for energy cooperatives. Storage can increase self-consumption, improve local balancing and strengthen the capacity of local systems to operate during grid disturbances.

Finally, agricultural–energy cooperatives should be incorporated into municipal energy planning, rural-development strategies and local crisis-management plans. This would make it possible to treat them not only as renewable-energy projects but also as elements of local critical-infrastructure resilience and economic-security policy.

The results also underscore the importance of integrating local energy initiatives within broader system architectures, consistent with the "systems of systems" approach. In this perspective, agricultural–energy cooperatives are not isolated entities but components of interconnected local and national energy systems which contribute to overall system resilience.[62]

Synthesis of results and literature

The synthesis of the analysis indicates that agricultural–energy cooperatives represent a promising model for integrating energy security and economic security at the local level. By combining local resource utilisation, collective governance and institutional cooperation, these entities can enhance the resilience of rural areas to energy and economic shocks.[63]

This conceptual shift aligns with the "systems of systems" approach, which views local energy systems as interacting subsystems that collectively increase the interoperability, efficiency and resilience of the overall energy system.[64] From this perspective, the development of agricultural–energy cooperatives should be considered not

[62] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.
[63] J. Fouladvand et al., *Energy security*…, op. cit.
[64] A. Soussi et al., *Enhancing Energy Systems*…, op. cit.

merely as a component of energy transition policy, but as an element of national and local security strategies.

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Summary

The article analyses agricultural energy cooperatives as potential local centres of energy and economic security in rural areas. From a systemic perspective, it indicates that their importance is increasing along with the decentralisation of the energy sector and the growing

exposure to economic, environmental and geopolitical risks. Such cooperatives can support local energy balancing, cost stabilisation and system resilience in the face of disruptions, especially when agricultural biogas is combined with other renewable energy sources. However, their development requires appropriate technological, organisational, regulatory and financial conditions. At present, the potential of these structures in Poland is limited by legal, infrastructural and economic barriers.

In practical policy terms, the removal of these barriers requires: simplified and standardised administrative procedures; transparent and predictable grid-connection rules; financial instruments covering both pre-investment and investment stages; stable remuneration for dispatchable renewable energy, particularly agricultural biogas; support for energy storage and local balancing; and the integration of agricultural–energy cooperatives into municipal energy planning and local crisis-management systems. Without these changes, agricultural–energy cooperatives are likely to remain isolated initiatives rather than scalable components of local and national energy security.