DOI: 10.52694/LES.126/2025.10

Piotr F. Borowski
Faculty of Business and International Relations, Vistula University, Warsaw, PL
ORCID: 0000-0002-4900-514X
p.borowski@vistula.edu.pl

Paweł Lewandowski
College of Legal Sciences, Nicolaus Copernicus Superior School, Lublin, PL
ORCID: 0000-0003-4543-4382
ks.lewandowski@gmail.com

Miłosz Stanisławski
College of Economic Sciences and Management, Nicolaus Copernicus Superior School, Warsaw, PL
ORCID: 0009-0000-6714-1877

Filip Czepło
Polish Photovoltaic Installation, Jabłonna, PL
ORCID: 0009-0005-9181-2323

Legal and Economic Issues of Energy Security

Prawne i ekonomiczne aspekty bezpieczeństwa energetycznego

The article examines legal and economic aspects of energy security, emphasizing its critical role in economic and social stability. Legally, it discusses the International Energy Agency's definition (availability, affordability, sustainability) and EU/Polish regulations, including the National Energy and Climate Plan (KPEiK), diversification of sources, and infrastructure. It highlights the transition to renewables, nuclear energy, and gas as a transitional fuel. Economically, it addresses challenges: modernization costs, coal dependency, energy poverty, and geopolitics.

The need for synergy between EU funds, private investments, and stable regulations to achieve climate neutrality is stressed.

Key words: energy security, energy transformation, diversification of sources, energy infrastructure, renewable energy

Artykuł analizuje prawne i ekonomiczne aspekty bezpieczeństwa energetycznego, podkreślając jego kluczową rolę dla stabilności gospodarczej i społecznej. W ujęciu prawnym omówiono definicję Międzynarodowej Agencji Energii (dostępność, przystępność cenowa, zrównoważoność) oraz unijne i krajowe regulacje, w tym Krajowy Plan Energii i Klimatu (KPEiK), dywersyfikację źródeł i infrastrukturę. Wskazano na znaczenie transformacji w kierunku OZE, energetyki jądrowej i gazu jako paliwa przejściowego. W części ekonomicznej poruszono wyzwania: koszty modernizacji, uzależnienie od węgla, ubóstwo energetyczne i geopolitykę. Podkreślono konieczność synergii funduszy unijnych, inwestycji prywatnych oraz stabilnych regulacji dla osiągnięcia neutralności klimatycznej.

Słowa kluczowe: bezpieczeństwo energetyczne, transformacja energetyczna, dywersyfikacja źródeł, infrastruktura energetyczna, polityka klimatyczna, odnawialne źródła energii

Introduction

Energy security is a key element not only for the smooth functioning of the economy but also for societal stability and the daily lives of citizens. Ensuring an adequate energy supply supports essential economic sectors, making energy security the foundation of infrastructure at national, regional, and local levels[1].

Reliable energy supplies are particularly crucial for public services. Public lighting systems enhance safety in urban spaces, reducing accidents and crime. Public transport, including metros, trams, and electric buses, depends entirely on energy, and disruptions can lead to traffic paralysis. Similarly, medical infrastructure—hospitals, clinics, and

[1] Y. Samusevych, A. Vysochyna, T. Vasylieva, S. Lyeonov, S. Pokhylko, *Environmental, energy and economic security: Assessment and interaction*, [in:] *E3S Web of Conferences*, EDP Sciences, 2011, vol. 234, p. 12.

life-saving equipment—requires a stable power supply for operations, directly impacting public health and safety.

Energy security is also vital in protecting populations from extreme weather. During heat waves, air conditioning in homes and public buildings can save lives, while in harsh winters, heating becomes essential for survival. Power outages can cause frozen water pipes, restricted access to clean water, and communication breakdowns, increasing the risk of social crises. Transport hubs like airports and train stations depend on reliable power for navigation, baggage handling, and lighting systems. Additionally, energy security supports waste management, as recycling centers and disposal plants require power to process waste efficiently and sustainably[2].

In the broader context of social security, energy access plays a significant role in crime prevention and enhancing citizens' sense of safety. Poorly lit areas—such as streets, parks, and industrial zones—are more prone to crimes like theft, robbery, and assault. Insufficient lighting reduces visibility and control over public spaces, encouraging criminal activity and heightening residents' concerns about personal safety[3]. Adequate public lighting serves as a key preventive measure, improving both actual security and the perceived sense of safety among citizens.

Studies worldwide show that well-lit public spaces significantly reduce crime rates, as potential offenders are deterred by increased visibility and the higher likelihood of detection[4]. Furthermore, proper lighting improves urban accessibility, especially in the evening and at night, fostering greater pedestrian activity and natural surveillance[5].

From an urban policy and planning perspective, ensuring a stable energy supply for public lighting should be a priority for local authorities. Reliable infrastructure not only protects citizens' health and safety but also fosters social trust and the smooth coexistence of diverse communities[6].

---

[2] D. Mara, S. Nate, A. Stavytskyy, G. Kharlamova, *The place of energy security in the national security framework: an assessment approach*, "Energies" 2022, 15(2), p. 658.

[3] A. Chalfin, B. Hansen, J. Lerner, L. Parker, *Reducing crime through environmental design: Evidence from a randomized experiment of street lighting in New York City*, "Journal of Quantitative Criminology" 2022, p. 1-31.

[4] B.C. Welsh, D.P. Farrington, *Effects of improved street lighting on crime*, "Campbell Systematic Reviews" 2008, 4(1), p. 1-51.

[5] D.P. Farrington, B.C. Welsh, *Improved street lighting and crime prevention*, "Justice Quarterly" 2002, 19(2), p. 313-342.

[6] Y. Cho, H. Jeong, A. Choi, M. Sung, *Design of a connected security lighting system for pedestrian safety in smart cities*, "Sustainability" 2019, 11(5), p. 1308.

Energy security Energy security according to the International Energy Agency

Energy security refers to the ability of a country or region to ensure the continuity of energy supplies in adequate quantities while minimizing the risk of disruptions and guaranteeing access to energy at affordable prices[7]. According to the definition included in the reports of the International Energy Agency (IEA)[8], energy security includes three main pillars: availability (broad access to energy in adequate quantities), affordability (access to energy at prices that support economic development and social well-being), and sustainability (minimizing the negative impact of energy production on the environment and ensuring resources for future generations)[9].

Energy security in the contemporary context is also associated with the need to consider renewable energy sources and the transition towards a zero-emission economy, which aims to reduce dependence on fossil fuels and improve the resilience of energy systems to climate change (International Energy Agency, 2014).

The International Energy Agency defines three key pillars of energy security: availability, affordability, and sustainability. Each of these elements plays a significant role in ensuring the stability of energy systems. The following is an elaboration of these concepts:

Energy availability refers to the physical capacity of the energy system to supply adequate amounts of energy when needed[10]. Energy availability relies on several key aspects aimed at ensuring the stability and reliability of the energy system. A fundamental element is the continuity of supply, which requires countries to source energy from diverse sources, such as coal, gas, or renewable energy, and to utilize multiple supply routes, including pipelines, wind farms, and photovoltaic panels.

---

7 M. Asif, *Handbook of Energy and Environmental Security*, Academic Press 2022, *passim*.

8 *Reliable, affordable access to all fuels and energy sources. Energy Security*, https://www.iea.org/topics/energy-security [accessed: 14.01.2025].

9 P.F. Borowski, I. Patuk, *Environmental, social and economic factors in sustainable development with food, energy and eco-space aspect security*, "Present Environment & Sustainable Development" 2021, 15(1), p. 153-169.

10 J. Zhu, X. Xu, *Available energy and environmental economics*, "MDPI – Multidisciplinary Digital Publishing Institute" 2023, p. 280.

Energy affordability refers to the ability to access energy at prices that are sustainable for both consumers and the economy[11]. Affordability means that energy prices must be set at a level that supports economic development and meets basic social needs without placing an excessive financial burden on consumers. It is essential that prices are determined transparently and fairly, helping to prevent negative consequences such as market speculation or monopolistic practices.

Sustainability in the context of energy security means ensuring an energy production and consumption model that not only meets present needs but also does not jeopardize the ability of future generations to meet their energy demands[12]. Sustainability in energy involves minimizing the negative impact of energy production on the environment, including reducing greenhouse gas emissions, air pollution, and ecosystem degradation.

Energy security in terms of the National Energy Plan

According to the National Energy and Climate Plan (NECP)[13], energy security is based on several key pillars: diversification of supply sources and routes, development of energy infrastructure, as well as actions for energy efficiency and development of renewable energy sources (RES). This plan emphasizes the long-term energy stability of the country, taking into account various strategies aimed at reducing dependence on individual energy sources and increasing the resilience of the energy system to external threats. National energy planning in Poland takes into account the need to ensure the continuity and reliability of energy supplies, which requires not only the expansion of infrastructure, but also the modernization of existing networks and the implementation of new technologies. Another key element is preparation for future challenges, such as climate change, which may affect the stability of the energy system, and energy transformation, related to the transition to more ecological energy sources.

---

[11] M.F. Rabbi, J. Popp, D. Máté, S. Kovács, *Energy security and energy transition to achieve carbon neutrality*, "Energies" 2022, 15(21), p. 8126.

[12] C.J. Axon, R.C. Darton, *Sustainability and risk–a review of energy security*, "Sustainable Production and Consumption" 2021, 27, p. 1195-1204.

[13] *Krajowy Plan w dziedzinie Energii i Klimatu do 2030 r.*, https://www.gov.pl/web/premier/krajowy-plan-w-dziedzinie-energii-i-klimatu-do-2030-r [accessed: 17.01.2025].

Diversification of energy sources

Diversification of energy sources is one of the fundamental pillars of ensuring energy security within National Energy Planning. It involves diversifying the structure of energy production by utilizing various energy carriers, such as renewable energy sources (RES), nuclear power, natural gas, and coal, as well as diversifying the origins and suppliers of energy resources. This approach minimizes the risk of dependence on a single dominant source, which may be vulnerable to fluctuations in raw material prices, disruptions in supply chains, or geopolitical tensions[14].

By increasing the diversity of the national energy mix and investing in modern technologies, a country can enhance its resilience to energy crises, stabilize energy prices, and strengthen economic competitiveness.

Diversification also includes the modernization of transmission networks and the expansion of LNG infrastructure, energy interconnectors, and new transport routes for energy resources. Consequently, diversification is a key element of the country's energy strategy, ensuring not only independence from individual energy sources but also creating stable conditions for sustainable economic development. The pursuit of diversification includes:

Increasing the share of renewable energy sources (RES): In Poland, according to the National Energy and Climate Plan (NECP), one of the key goals is to significantly increase the share of renewable energy in the national energy mix. Renewable energy sources, such as wind energy, photovoltaic energy, biomass or hydropower, are not only an alternative to fossil fuels, but also contribute to reducing greenhouse gas emissions and increasing the country's energy security. Increasing the efficiency of coal us: Although coal is still an important element of the national energy mix, the National Energy Planning assumes the modernization of existing coal-fired power plants and the introduction of carbon capture and storage (CCS) technology, which will reduce emissions while maintaining partial dependence on this raw material. Coal can play a key role in the national energy system, especially due to large deposits of high-calorie raw material, which are a strategic resource and can ensure the stability of energy supplies. Modern technologies, such as coal

[14] L. Gitelman, M. Kozhevnikov, Y. Visotskaya, *Diversification as a Method of Ensuring the Sustainability of Energy Supply within the Energy Transition*, "Resources" 2023, 12(2), p. 19.

gasification, high-efficiency cogeneration or hybrid co-firing systems with biomass, can additionally contribute to reducing the negative impact on the environment and improving energy efficiency.

Development of natural gas as a transition fuel: Natural gas is treated as a transition fuel that is to support the energy transformation in Poland, enabling a gradual move away from coal in favour of more ecological energy sources. Thanks to lower CO_2 emissions compared to coal and greater flexibility in adapting energy production to current demand, gas can become an important transitional element towards a more sustainable energy mix. Its use allows for stabilization of the power system during the development of renewable energy sources, which are characterized by variable efficiency depending on weather conditions.

Search for new energy sources: The state is also focusing on the development of technologies such as nuclear energy, the role of which is seen in the long-term energy stability of the country. Although nuclear energy is not yet developed in Poland, investments in nuclear power plants are planned as an element of diversification of the energy mix and securing energy supplies in the long term. Large-scale nuclear power plants are expected to provide a stable, low-emission source of energy, capable of meeting a significant portion of domestic demand. Although these investments require high initial outlays, in the long term they will reduce operating costs and increase energy security by becoming independent from fossil fuels.

In parallel with the development of traditional large nuclear power plants, Poland is also considering innovative solutions based on small modular reactors (SMRs). SMRs offer a more flexible approach to nuclear power, as they can be implemented in smaller locations, and their modular design allows for a gradual increase in power depending on demand. Thanks to shorter construction times and lower investment costs compared to large-scale power plants, SMRs can provide significant support for the energy transformation, especially in industrial regions and areas requiring a decentralized power supply system.

Diversification of energy supply routes

Diversification of energy supply routes involves creating and maintaining various import channels for energy resources and finished energy products (e.g., gas, oil, electricity) to reduce the risks associated with supplier monopolies or geopolitical tensions. This approach enhances a country's energy security by reducing dependence on specific import routes and minimizing the impact of potential supply disruptions caused by political, technical, or natural factors.

In the case of oil and natural gas, diversification includes both importing raw materials via pipelines from various regions and developing LNG (liquefied natural gas) infrastructure, which enables the transportation of these resources by sea from global markets. The construction of LNG terminals and supply contracts with multiple countries—such as the USA, Qatar, or Norway—increase supply flexibility and allow for better adaptation to price fluctuations and geopolitical conditions.

For electricity, an essential aspect of diversification is the development of cross-border connections, known as interconnectors, which facilitate the import and export of electricity between countries. These connections help balance the national power system during crises and enable access to cheaper energy from international markets.

Additionally, diversification includes the expansion of renewable energy sources (RES) and energy storage technologies, which reduce reliance on imported fossil fuels[15]. Integrating RES-based systems with modern grid infrastructure and energy storage solutions enhances the management of domestic resources and strengthens the energy system's resilience to external threats.

Thus, the energy supply diversification strategy focuses on expanding import routes, developing alternative energy generation sources, and modernizing transmission infrastructure—collectively contributing to greater national energy stability and security.

Key elements in this regard include: development of transmission and storage infrastructure; international connections and the energy market; diversification of gas and oil supply routes.

[15] M. De Rosa, K. Gainsford, F. Pallonetto, D.P. Finn, *Diversification, concentration and renewability of the energy supply in the European Union*, "Energy", 2022, 253, *passim*.

Legal solutions to support the energy sector

Energy security is an absolutely key element of any country's legal security, determining to a significant extent the specific and directional actions taken by individual governments in the international arena[16]. The regulatory basis of the current European Union (hereinafter: EU) energy policy is Article 194 of the Treaty on the Functioning of the European Union (TFEU), according to which EU policy in the field under review aims to: 1) ensure the functioning of the energy market; 2) ensure security of energy supply in the EU; 3) promote energy efficiency and energy saving, as well as the development of new and renewable forms of energy; 4) promote the interconnection of energy networks[17]. Detailed norms are additionally contained in Article 122 TFEU (on security of energy supply), Articles 170-172 TFEU (on energy networks), Protocol No. 37, which sets forth the financial consequences of the expiration of the Treaty establishing the European Coal and Steel Community in 2002[18], the Treaty establishing the European Atomic Energy Community[19], which provides the legal basis for most of the EU's nuclear activities. Other provisions affecting energy policy are Article 114 of the TFEU (governing the internal market in electricity) and Articles 216-218 of the TFEU (normalizing the EU's external energy policy).

An important influence on the shaping of the national energy strategy is the EU's climate and energy policy, in particular its long-term vision of moving towards climate neutrality by 2050 and the regulatory mechanisms to stimulate the achievement of effects in the coming decades[20]. Leaving aside the political strands of the proposed undertaking, which have been criticized by a number of governments, including Poland and Hungary, among others, the European Council assumes a series of measures resulting in a reduction in net greenhouse gas emissions in the coming years, in the first instance by 2030 compared to 1990 levels. In

[16] K. Żęgota, *Bezpieczeństwo energetyczne*, [in:] *Podstawowe kategorie bezpieczeństwa narodowego*, edited by A. Żukowski, M. Hartliński, W.T. Modzelewski, J. Więcławski, Olsztyn 2015, p. 166.

[17] Treaty on the Functioning of the European Union, 2016/C 202/01, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:12016ME/TXT [accessed: 05.02.2024].

[18] Protocol (No 37) on the financial consequences of the expiry of the ECSC treaty and on the Research fund for Coal and Steel, http://data.europa.eu/eli/treaty/teu_2008/pro_37/oj [accessed: 05.02.2024].

[19] Treaty establishing the European Atomic Energy Community, http://data.europa.eu/eli/treaty/euratom_2016/2024-09-01 [accessed: 05.02.2024].

[20] Ministry of Climate and Environment, *Polityka energetyczna Polski do 2040 r.*, https://www.gov.pl/web/klimat/polityka-energetyczna-polski [accessed: 05.02.2024], p. 2.

order for the planned measures to be effective, they must be implemented on the basis of solidarity contributions from member states, taking into account national circumstances and specific reduction potentials, maintaining the principle of sovereignty in shaping the national energy balance, and taking into account the need to guarantee EU and national energy security in the most rational way possible[21]. Such outlined tasks, implying the application of a number of complex economic processes, on a macro and micro scale, require specific legal solutions.

Security of energy supply and protection of critical infrastructure the energy sector

The armed invasion of Ukraine by the Russian Federation, which began on February 24, 2022, constituting an escalation of the war that had been going on since 2014, preceded by President Vladimir Vladimirovich Putin's demands to exclude the possibility of further expansion of the North Atlantic Treaty Organization and a significant reduction of military capabilities in Central and Eastern Europe, has had significant consequences for the energy policy of both the European Union itself and individual member states. Security of energy supply has become a key priority, prompting the EU to introduce a series of measures aimed primarily at securing energy supplies and minimizing the risk of supply disruptions. Accordingly, the EU has put in place mechanisms for coordinating action among individual member states to ensure maximum consistency in energy security efforts. An example of such collective action may be the implementation of the so-called gas purchasing platform by European companies through the AggregateEU mechanism, which is intended to enable price negotiations and ultimately reduce dependence on single gas suppliers[22]. In addition, the EU has updated energy market regulations, including the Gas Directive[23] and the Renewable Energy

[21] Ibid.

[22] *Unijna platforma energetyczna*, https://ec.europa.eu/commission/presscorner/detail/pl/ip_23_2403 [accessed: 07.02.2025].

[23] Directive (EU) 2024/1788 of the European Parliament and of the Council of 13 June 2024 on common rules for the internal markets for renewable gas, natural gas and hydrogen, amending Directive (EU) 2023/1791 and repealing Directive 2009/73/EC, http://data.europa.eu/eli/dir/2024/1788/oj [accessed: 07.02.2025].

Directive[24]. These changes are aimed at increasing market flexibility and facilitating the integration of renewable energy sources.

Following Russia's invasion of Ukraine in 2022, it considers as an absolute priority task that such infrastructure includes all kinds of energy supply systems, energy resources and fuels. Since these systems ensure the energy security of the state through the production, transmission and storage of both the energy itself and the carriers of this energy, they play a not inconsiderable role for the proper functioning of the entire state[25]. As of October 18, 2024, the Directive on the Resilience of Critical Entities[26], which aims to reduce the vulnerability of and strengthening the physical resilience of critical entities. This protection should include not only countering the impact of external factors, such as at least third-party interference, but also preventing the negative impact of internal factors, including the negative impact of property management by the energy company that owns the infrastructure in question[27]. In this regard, in the order of Polish law, legal protection is provided by the Act of 18 March 2010 on Specific Rights Vested to the Minister Responsible for State Assets and their Exercise in Certain Capital Companies or Capital Groups Operating in the Electricity, Oil and Gas Fuel Sectors[28] granting

[24] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources. The goal of the said directive is to increase the use of renewable energy to combat climate change, protect the environment and reduce the European Union's energy dependence. The EU expects that the directive will also contribute to the EU's technological and industrial leadership and the creation of jobs and growth, including in rural and isolated areas, which may, however, be difficult to actually achieve. *Energia odnawialna*, https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=legissum:4372645 [accessed: 07.02.2025].

[25] D. Dragan, *Ochrona infrastruktury krytycznej w sektorze energetycznym. Wybrane zagadnienia*, [in:] K. Śmiałek (ed.), *Zarządzanie kryzysowe. Wymiar narodowy i międzynarodowy*, Warszawa 2020, p. 25. See also: M. Domagała, *Bezpieczeństwo energetyczne. Aspekty administracyjno-prawne*, Lublin 2008; N. Stępnicka, *Prawne podstawy bezpieczeństwa energetycznego Unii Europejskiej*, [in:] A. Gałecki, A. Bolewski (ed.), *Bezpieczeństwo – wielorakie perspektywy. Bezpieczeństwo energetyczne wyzwaniem XXI wieku*, Poznań 2017, p. 119-128; M. Bainczyk, *Bezpieczeństwo energetyczne UE – wybrane aspekty prawne*, [in:] B. Bednarczyk, M. Lasoń (ed.), *Współczesne determinanty stosunków międzynarodowych*, Kraków 2006, p. 161-175; K. Księżopolski, *Bezpieczeństwo energetyczne*, [in:] R. Zięba (ed.), *Bezpieczeństwo międzynarodowe w XXI wieku*, Warszawa 2018, p. 71-90; M. Nowacki, *Prawne aspekty bezpieczeństwa energetycznego w UE*, Warszawa 2008; M. Błoński, *Bezpieczeństwo energetyczne jako element systemu bezpieczeństwa zbiorowego Unii Europejskiej*, [in:] Z. Lach (ed.), *Bezpieczeństwo energetyczne wyzwaniem XXI wieku*, Warszawa 2013, p. 15-24; M. Koziński, *Bezpieczeństwo energetyczne Polski*, Gdańsk 2014; K. Żukrowska, *Bezpieczeństwo energetyczne*, [in:] K. Żukrowska (ed.), *Bezpieczeństwo międzynarodowe. Przegląd aktualnego stanu*, Warszawa 2011, p. 396-426.

[26] Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC, http://data.europa.eu/eli/dir/2022/2557/oj [accessed: 07.02.2025].

[27] D. Dragan, *Ochrona infrastruktury krytycznej w sektorze energetycznym. Wybrane zagadnienia*, [in:] K. Śmiałek (ed.), *Zarządzanie kryzysowe. Wymiar narodowy i międzynarodowy*, Warszawa 2020, p. 25-40.

[28] Journal of Laws of 2020, item 2173.

the minister responsible for energy special and very specialized powers in the analyzed scope.

Energy efficiency and renewable energy

The second very important legal area requiring prudent action is the idea of EU energy efficiency, which is directly linked to the development of renewable energy sources. The cornerstone of the EU's energy efficiency policy is the new Energy Efficiency Directive[29], which sets a very ambitious target of reducing the EU's primary and final energy consumption by 11.7% by 2030 compared to projections for 2020. For example, in order for emission reduction targets for buildings at both the EU and national levels to be met, all new buildings in the EU will have to be zero-emission from 2030. For non-residential buildings, EU countries are required to set minimum energy performance standards to renovate 16% of the worst-performing buildings by 2030 and 26% by 2033, while for residential buildings, EU countries are to secure a path for the gradual renovation of the entire building stock, reducing average primary energy consumption by at least 16% by 2030 and in the range of 20-22% by 2035[30].

Meanwhile, the basis of the EU's renewable energy policy is the new Renewable Energy Directive[31]. The directive plans to raise the overall target for the share of renewable energy in final energy consumption to at least 40% by 2030. In addition, sectoral targets were indicated, such as a 14% share of renewable energy in transport by 2030. Special support was decided for the development of renewable energy in the industrial and construction sectors, and the promotion of biofuels, biogas and biomethane as sustainable energy sources. Investment in innovative technologies, such as renewable hydrogen and energy storage, and the

[29] Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955, http://data.europa.eu/eli/dir/2023/1791/oj [accessed: 07.02.2025].
[30] *Efektywność energetyczna*, https://www.europarl.europa.eu/factsheets/pl/sheet/69/efektywnosc-energetyczna [accessed: 08.02.2025].
[31] Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, http://data.europa.eu/eli/dir/2023/2413/oj [accessed: 08.02.2025].

development of infrastructure for offshore wind and solar energy were also encouraged.

Since it will be enormously costly to meet the planned goals of energy efficiency and the concept of developing renewable energy sources, negotiating efforts should be made to urgently reform the legal mechanisms of EU climate policy in such a direction that the planned energy transition should be carried out more slowly, without incurring excessive costs, and throughout this long-term process, investments should also be made to minimize the risk of energy supply shortages caused by reducing stable sources of generation[32].

Economic aspects concerning energy security

Energy security, understood as the ability to ensure uninterrupted, stable energy supply while optimizing economic, social and environmental costs, is the foundation for the functioning of a modern economy. In Poland, a country historically basing its energy stability on its hard coal and lignite resources, we are witnessing dynamic transformation processes that result from both EU climate commitments (including the Fit for 55 package) and growing global trends of decarbonization and technological progress. This transformation, while necessary, comes with a number of financial challenges, systemic costs and the need to break established institutional patterns. An economic analysis and study of the financial determinants of Poland's energy security, including the costs of infrastructure modernization, the selection of appropriate investment strategies, and consideration of the macroeconomic and geopolitical context of the energy transition is key to determining the future directions of the Polish energy sector and the systemic challenges of transformation[33].

[32] Ministry of Climate and Environment, *Założenia do aktualizacji Polityki energetycznej Polski do 2040 r. (PEP2040). Wzmacnianie bezpieczeństwa i niezależności energetycznej*, https://www.gov.pl/web/klimat/zalozenia-do-aktualizacji-polityki-energetycznej-polski-do-2040-r [accessed: 08.02.2025], p. 4.

[33] R. Adamski, P. Malinowski, *Ekonomiczne aspekty transformacji energetycznej w Polsce*, „Ekonomia i Zarządzanie" 2018, 15(4), p. 77-92; S. Bouzarovski, *Energy Justice: Key Concepts and Case Studies*, MIT Press 2023, *passim*; Cambridge Energy Research, *Energy Market Dynamics in Poland*, Cambridge 2022, *passim*.

Coal heritage and modernization challenges

Poland's energy sector, largely built on fossil fuels (68% in 2023), particularly hard coal and lignite, is an example of so-called "technological lock-in". According to Szulecki, historical financial support for mining—estimated at around □1.5 billion per year between 2000 and 2020—has perpetuated a "path dependence" on coal[34], which in turn, according to Unruh, in the carbon lock-in mechanism he describes, generates serious external costs, including negative health and environmental impacts, the total value of which could reach up to PLN 120 billion per year[35]. The perpetuation of this investment path complicates the process of diversifying energy sources and is a significant barrier to the energy transition.

Another financial challenge facing Poland's electricity system is its outdated transmission infrastructure. In Poland, about 60% of the transmission grid is more than three decades old, which not only hinders the integration of renewable energy sources (RES), but also raises the risk of system failures such as blackouts. Kaczmarek and Mirowski point out that delays in modernization can translate into a loss in the value of Poland's GDP of up to 0.5% per year[36]. For example, the Polish Power Grid (PSE) modernization project, valued at about PLN 50 billion by 2030, requires fine-tuning to regional conditions and cross-sector cooperation to avoid increases in energy prices for end users.

From an economic point of view, maintaining Poland's current model of energy security based on hard coal and lignite not only generates high subsidy costs for the industry, but also limits innovation opportunities, as funds allocated to support traditional sources could be directed to the development of modern energy technologies. Thus, the coal legacy is both, in positive terms, the cause of Poland's historical and present energy stability, as well as a source of serious financial burdens that should be minimized as part of the transition process[37].

---

[34] M. Szulecki, *Subsydia, lock-in technologiczny i koszty zewnętrzne w polskim sektorze energetycznym*, "Journal of Energy Policy" 2022, 27(3), p. 45-67.

[35] G. Unruh, *Carbon Lock-in and the Challenge of Clean Technology Transitions*, "Energy Policy" 2000, 28(12), p. 817-830.

[36] P. Kaczmarek, T. Mirowski, *Modernizacja infrastruktury przesyłowej w Polsce – ryzyka i koszty*, "Przegląd Energetyczny" 2022, 12(1), p. 33-49.

[37] A. Nowak, J. Kowalski, *Bezpieczeństwo energetyczne w Polsce: wyzwania i perspektywy*, "Journal of Energy Policy" 2019, 27(3), p. 45-67.

Investment and energy transition in the context of financial and technological aspects

The future of the Polish energy sector depends mainly on the effective implementation of technological transformation, based on strategic investments and the use of innovative solutions. The most important directions of modernization include three areas: 1) the development of renewable energy; 2) the construction of nuclear power plants and 3) the development of new technologies, such as biogas or green hydrogen.

Investments in offshore wind energy are one of the pillars of the new energy strategy. The program of building offshore wind farms in the Baltic Sea, assuming the achievement of a capacity of 11 GW by 2040, allows for the reduction of average unit costs of energy (LCOE) to about 45 EUR/MWh. However, as Mitchell and Connor point out, the need to build extensive transmission infrastructure and storage systems entails high investment outlays—estimated at a total amount of PLN 130 billion[38]. Additionally, the financing model of such projects often requires subsidy support, which in Western Europe reaches up to 40% of the investment value, and in Poland—due to limited experience and scale—may generate additional financial risks.

The construction of a nuclear power plant, with a planned total capacity of around 3.6 GW by 2033, is another strategic option in the transformation process. OECD/NEA emphasizes in its reports that nuclear energy contributes to the stabilization of the energy system, guaranteeing base load independent of weather conditions[39]. However, the financing model based on the Contract for Difference (CfD) mechanism is met with criticism, as it transfers most of the risk to the state budget. Sovacool notes that the cost of implementing such an investment, amounting to around PLN 150 billion, compared to dispersed investments in renewable energy sources, may not be optimal from the perspective of effective capital allocation[40].

In parallel, projects in the biogas and green hydrogen production sectors are being intensively developed. Poland, with significant resources of agricultural biomass, has the potential to become one of the leaders in

[38] C. Mitchell, P. Connor, *Renewable Energy Policy in Europe*, Routledge 2022, *passim*.
[39] OECD/NEA, *Rola energetyki jądrowej w stabilizacji systemów energetycznych*, OECD Reports 2022.
[40] B.K. Sovacool, *Global Energy Politics*, Polity Press, Cambridge 2022, *passim*.

biogas production. Nevertheless, as Woźniak points out, the lack of stable legal regulations and institutional support frameworks limits the scale of investment[41]. In the hydrogen area, Cieśliński's research suggests using surplus renewable energy to produce "green H_2", which could significantly improve the competitiveness of Polish industry, provided that sources of financing are properly secured and a legal framework is created[42].

Energy transformation is not only about investing in new energy sources, but also modernizing network management systems and implementing modern information technologies. Projects to build energy storage facilities, such as the installation in Żarnowiec (200 MW for PLN 1.2 billion), require the implementation of new business models, including the concept of virtual power plants (VPP) integrating prosumers[43]. The use of artificial intelligence algorithms, such as those tested by DeepMind for the Polish Power Grids, allows for a reduction of transmission losses by about 15%, although this requires gaining public trust in autonomous systems[44].

The integration of digital technologies in the energy sector is also associated with the need to increase expenditure on cybersecurity, which has a direct impact on the stability of the entire system. Investments in blockchain technologies and the development of SCADA systems enable not only better control, but also reduce the risk of disruptions caused by cyberattacks[45]. The economic aspects of these investments require a detailed analysis of the return on capital, because although the initial outlay is high, long-term savings and increased operational efficiency can significantly improve the financial balance of the entire power sector in Poland.

[41] J. Woźniak, *Bariery instytucjonalne w rozwoju biogazowni w Polsce*, "Energy Studies Journal" 2023, 19(2), p. 89-105.

[42] J. Cieśliński, *Energy Transition in Poland: Challenges and Opportunities*, Springer 2021, *passim*.

[43] R. Sioshansi, *Nowe modele biznesowe w sektorze magazynowania energii*, "Energy Storage Journal" 2023, 8(1), p. 15-29.

[44] DeepMind & PSE, *Redukcja strat przesyłowych w sieci elektroenergetycznej – zastosowanie AI*, "IEEE Transactions on Smart Grid" 2023, 14(2), p. 112-121.

[45] M. Zieliński, K. Wójcik, *Cybersecurity i systemy SCADA w ochronie infrastruktury energetycznej*, "International Journal of Energy Research" 2023, 15(1), p. 50-65.

Conclusions

Analysis of the economic and financial aspects of energy security and Poland's energy transformation indicates that a comprehensive approach is necessary, integrating the coal heritage, investments in modern technologies and macroeconomic and geopolitical challenges. The established model based on subsidies and coal generates high external costs, which can be reduced by modernizing outdated infrastructure and implementing solutions based on renewable energy sources, nuclear energy and alternative technologies, such as biogas and green hydrogen. Investments in digital technologies also play a key role, improving the efficiency of network management and increasing the system's resilience to cyber threats.

In summary, the economic and financial aspects of Poland's energy security require a multidimensional approach, in which infrastructure modernization, development of innovative technologies and macroeconomic stabilization go hand in hand with a responsible investment policy. Only through the synergy of these elements will it be possible to achieve lasting energy stability, increase the competitiveness of the economy and minimize the negative effects of transformation on society.

Bibliography

Sources of law

Act of 18 March 2010 on Specific Rights Vested to the Minister Responsible for State Assets and their Exercise in Certain Capital Companies or Capital Groups Operating in the Electricity, Oil and Gas Fuel Sectors, Journal of Laws of 2020, item 2173.

Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=legissum:4372645 [accessed: 07.02.2025].

Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955, http://data.europa.eu/eli/dir/2023/1791/oj [accessed: 07.02.2025].

Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, http://data.europa.eu/eli/dir/2023/2413/oj [accessed: 08.02.2025].

Directive (EU) 2024/1788 of the European Parliament and of the Council of 13 June 2024 on common rules for the internal markets for renewable gas, natural gas and hydrogen, amending Directive (EU) 2023/1791 and repealing Directive 2009/73/EC, http://data.europa.eu/eli/dir/2024/1788/oj [accessed: 07.02.2025].

Directive (EU) 2022/2557 of the European Parliament and of the Council of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC, http://data.europa.eu/eli/dir/2022/2557/oj [accessed: 07.02.2025].

Protocol (No 37) on the financial consequences of the expiry of the ECSC treaty and on the Research fund for Coal and Steel, http://data.europa.eu/eli/treaty/teu_2008/pro_37/oj [accessed: 05.02.2024].

Treaty establishing the European Atomic Energy Community, http://data.europa.eu/eli/treaty/euratom_2016/2024-09-01 [accessed: 05.02.2024].

Treaty on the Functioning of the European Union, 2016/C 202/01, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:12016ME/TXT [accessed: 05.02.2024].

Literature

Adamski R., Malinowski P., *Ekonomiczne aspekty transformacji energetycznej w Polsce*, "Ekonomia i Zarządzanie" 2018, 15(4).

Asif M., *Handbook of Energy and Environmental Security*, Academic Press 2022.

Axon, C.J., Darton, R. C., *Sustainability and risk–a review of energy security*, "Sustainable Production and Consumption" 2021, 27.

Bainczyk M., *Bezpieczeństwo energetyczne UE – wybrane aspekty prawne*, [in:] B. Bednarczyk, M. Lasoń (ed.), *Współczesne determinanty stosunków międzynarodowych*, Kraków 2006.

Błoński M., *Bezpieczeństwo energetyczne jako element systemu bezpieczeństwa zbiorowego Unii Europejskiej*, [in:] Z. Lach (ed.), *Bezpieczeństwo energetyczne wyzwaniem XXI wieku*, Warszawa 2013.

Borowski P.F., Patuk I., *Environmental, social and economic factors in sustainable development with food, energy and eco-space aspect security*, "Present Environment & Sustainable Development" 2021, 15(1).

Bouzarovski S., *Energy Justice: Key Concepts and Case Studies*, MIT Press 2023.

Cambridge Energy Research, *Energy Market Dynamics in Poland*, Cambridge 2022.

Chalfin A., Hansen B., Lerner J., Parker L., *Reducing crime through environmental design: Evidence from a randomized experiment of street lighting in New York City*, "Journal of Quantitative Criminology" 2022.

Cho Y., Jeong H., Choi A., Sung M., *Design of a connected security lighting system for pedestrian safety in smart cities*, "Sustainability" 2019, 11(5).

Cieśliński J., *Energy Transition in Poland: Challenges and Opportunities*, Springer 2021.

De Rosa M., Gainsford K., Pallonetto F., Finn D.P., *Diversification, concentration and renewability of the energy supply in the European Union*, "Energy" 2022, 253, 124097.

DeepMind & PSE, *Redukcja strat przesyłowych w sieci elektroenergetycznej – zastosowanie AI*, "IEEE Transactions on Smart Grid" 2023, 14(2).

Domagała M., *Bezpieczeństwo energetyczne. Aspekty administracyjno-prawne*, Lublin 2008.

Dragan D., *Ochrona infrastruktury krytycznej w sektorze energetycznym. Wybrane zagadnienia*, [in:] K. Śmiałek (ed.), *Zarządzanie kryzysowe. Wymiar narodowy i międzynarodowy*, Warszawa 2020.

Farrington D.P., Welsh B.C., *Improved street lighting and crime prevention*, "Justice quarterly" 2002, 19(2).

Gitelman L., Kozhevnikov M., Visotskaya Y., *Diversification as a Method of Ensuring the Sustainability of Energy Supply within the Energy Transition*, "Resources" 2023, 12(2), 19.

Gondášová I., Wirthová L., *Pipeline politics: Balancing energy needs and environmental concerns in European Union-Russian Federation relations?*, "Energy Research & Social Science" 2024, 116, 103698.

Grabowska M., *Rozwój morskiej energetyki wiatrowej i wyzwania rynku pracy w regionie Pomorza*, "Journal of Regional Studies" 11(1).

Kaczmarek P., Mirowski T., *Modernizacja infrastruktury przesyłowej w Polsce – ryzyka i koszty*, "Przegląd Energetyczny" 2022, 12(1).

Koziński M., *Bezpieczeństwo energetyczne Polski*, Gdańsk 2014.

Księżopolski K., *Bezpieczeństwo energetyczne*, [in:] R. Zięba (ed.), *Bezpieczeństwo międzynarodowe w XXI wieku*, Warszawa 2018.

Mara D., Nate S., Stavytskyy A., Kharlamova, G., *The place of energy security in the national security framework: an assessment approach*, "Energies" 2022, 15(2).

Mitchell C., Connor P., *Renewable Energy Policy in Europe*, Routledge 2022.

Nowacki M., *Prawne aspekty bezpieczeństwa energetycznego w UE*, Warszawa 2008.

Nowak A., Kowalski J., *Bezpieczeństwo energetyczne w Polsce: wyzwania i perspektywy*, "Journal of Energy Policy" 2019, 27(3).

OECD/NEA, *Rola energetyki jądrowej w stabilizacji systemów energetycznych*, OECD Reports 2022.

Rabbi M.F., Popp J., Máté D., Kovács S., *Energy security and energy transition to achieve carbon neutrality*, "Energies" 2022, 15(21).

Samusevych, Y., Vysochyna, A., Vasylieva, T., Lyeonov, S., Pokhylko, S., *Environmental, energy and economic security: Assessment and interaction*, [in:] *E3S Web of Conferences*, EDP Sciences, 2011, vol. 234.

Sioshansi R., *Nowe modele biznesowe w sektorze magazynowania energii*, "Energy Storage Journal" 2023, 8(1).

Sovacool B.K., *Global Energy Politics*, Polity Press, Cambridge 2020.

Stępnicka N., *Prawne podstawy bezpieczeństwa energetycznego Unii Europejskiej*, [in:] A. Gałecki, A. Bolewski (ed.), *Bezpieczeństwo – wielorakie perspektywy. Bezpieczeństwo energetyczne wyzwaniem XXI wieku*, Poznań 2017.

Szulecki M., *Subsydia, lock-in technologiczny i koszty zewnętrzne w polskim sektorze energetycznym*, "Journal of Energy Policy" 2020, 27(3).

Unruh G., *Carbon Lock-in and the Challenge of Clean Technology Transitions*, "Energy Policy" 2000, 28(12).

Welsh B.C., Farrington D.P., *Effects of improved street lighting on crime*, "Campbell Systematic Reviews" 2008, 4(1).

Woźniak J., *Bariery instytucjonalne w rozwoju biogazowni w Polsce*, "Energy Studies Journal" 2023, 19(2).

Zhu J., Xu X., *Available energy and environmental economics*, "MDPI – Multidisciplinary Digital Publishing Institute" 2023.

Zieliński M., Wójcik K., *Cybersecurity i systemy SCADA w ochronie infrastruktury energetycznej*, "International Journal of Energy Research" 2023, 15(1).

Żęgota K., *Bezpieczeństwo energetyczne*, [in:] A. Żukowski, M. Hartliński, W.T. Modzelewski, J. Więcławski (ed.), *Podstawowe kategorie bezpieczeństwa narodowego*, Olsztyn 2015.

Żukrowska K., *Bezpieczeństwo energetyczne*, [in:] K. Żukrowska (ed.), *Bezpieczeństwo międzynarodowe. Przegląd aktualnego stanu*, Warszawa 2011.

Netography

Efektywność energetyczna, https://www.europarl.europa.eu/factsheets/pl/sheet/69/efektywnosc-energetyczna [accessed: 08.02.2025].

Energia odnawialna, https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=legissum:4372645 [accessed: 07.02.2025].

Krajowy Plan w dziedzinie Energii i Klimatu do 2030 r., https://www.gov.pl/web/premier/krajowy-plan-w-dziedzinie-energii-i-klimatu-do-2030-r [accessed: 17.01.2025].

Ministry of Climate and Environment, *Polityka energetyczna Polski do 2040 r.*, https://www.gov.pl/web/klimat/polityka-energetyczna-polski [accessed: 05.02.2024].

Ministry of Climate and Environment, *Założenia do aktualizacji Polityki energetycznej Polski do 2040 r. (PEP2040). Wzmacnianie bezpieczeństwa i niezależności energetycznej*, https://www.gov.pl/web/klimat/zalozenia-do-aktualizacji-polityki-energetycznej-polski-do-2040-r [accessed: 08.02.2025].

Reliable, affordable access to all fuels and energy sources. Energy Security, https://www.iea.org/topics/energy-security [accessed: 14.01.2025].

Unijna platforma energetyczna, https://ec.europa.eu/commission/presscorner/detail/pl/ip_23_2403 [accessed: 07.02.2025].