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DETERMINANTS OF ENERGY SYSTEM RESILIENCE

The importance of energy resilience for the EU countries and Ukraine in the context of geopolitical conflicts and challenges caused by Russian aggression is emphasized. The author emphasizes the need to modernize energy networks, continuous monitoring and analysis of the energy situation. The purpose of the study was to identify the factors that influence energy resilience and the state policy of energy system resilience. It is hypothesized that in times of crisis, state regulation, in particular support for diversified energy sources, construction of efficient energy infrastructure, risk management systems and transparent regulatory policies, play an important role in ensuring the resilience of the energy system. To achieve the aim of the research, a complex of general scientific and special methods were used such as historical and logical; analyzing factors of energy resilience, statistical aggregation and comparison are used in compiling and analyzing energy resilience indices. Based on such indicators of energy resilience as The Global Energy Vulnerability Index and The Energy Sovereignty Index, the vulnerabilities of the energy systems of the EU and Ukraine are assessed and their path to energy independence is outlined. The analysis revealed a significant dependence of the EU countries on energy imports, which affects their self-sufficiency, while noting progress in

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ДЕТЕРМІНАНТИ СТІЙКОСТІ ЕНЕРГОСИСТЕМ

Зазначено важливість енергетичної стійкості для країн ЄС та України в умовах геополітичних конфліктів і викликів, спричинених російською агресією. Підкреслено необхідність модернізації енергетичних мереж, постійного моніторингу та аналізу енергетичної ситуації. Метою дослідження стало визначення факторів, що впливають на енергетичну стійкість і державну політику стійкості енергосистем. Висунуто гіпотезу, що у часи кризи державне регулювання, зокрема підтримка диверсифікованих джерел енергії, будівництво ефективної енергетичної інфраструктури, системи управління ризиками та прозора регуляторна політика, відіграє важливу роль у забезпеченні стійкості енергетичної системи. Для досягнення мети дослідження використано комплекс загальнонаукових і спеціальних методів: історичний та логічний – під час аналізу факторів енергетичної стійкості; статистичне агрегування та порівняння – для складання й аналізу індексів енергетичної стійкості. На основі таких показників енергетичної стійкості, як The Global Energy Vulnerability Index та The Energy Sovereignty Index, оцінено вразливості енергосистем країн ЄС і України та окреслено їх шлях до енергетичної незалежності. За результатами аналізу виявлено відчутну залежність країн ЄС від імпорту енергії, що впливає на показники *renewable energy, particularly in Denmark, Finland, and Sweden. Ukraine's position in this ranking is quite low and comparable to European countries such as Slovakia, Poland, and Lithuania, which is a consequence of its dependence on energy imports, as well as low economic resilience and energy efficiency. Most EU countries have achieved their performance targets by applying holistic approaches to energy security. The factors affectting energy resilience are identified, including geopolitical conflicts, availability of energy resources, reliable infrastructure, monitoring and risk management systems, energy efficient technologies, and transparent regulatory policies. The author emphasizes Ukraine's decision to harmonize its energy policy with the EU principles, which provides for the update of the Energy Strategy of Ukraine to ensure resilient economic development and climate neutrality by 2050.*

Keywords: energy resilience, European Union, energy crisis, energy sector, russian-ukrainian war.

самозабезпечення, водночас відзначено прогрес у відновлюваній енергетиці, зокрема в Данії, Фінляндії та Швеції. Позиція України в цьому рейтингу досить низька і може бути порівняна з такими європейськими країнами, як Словаччина, Польща і Литва, що є наслідком залежності від імпорту енергії, а також низької економічної стабільності та енергоефективності. Цільові показники ефективності досягнуті більшістю країн ЄС завдяки застосуванню цілісних підходів до енергетичної безпеки. Визначено фактори, що впливають на енергетичну стійкість, зокрема геополітичні конфлікти, наявність енергетичних ресурсів, надійна інфраструктура, системи моніторингу та управління ризиками, енергоефективні технології й прозора регуляторна політика. Підкреслено рішення України узгодити власну енергетичну політику з принципами ЄС, що передбачає оновлення Енергетичної стратегії України для забезпечення сталого економічного розвитку та кліматичної нейтральності до 2050 р.

Ключові слова: енергетична стійкість, Європейський Союз, енергетична криза, енергетичний сектор, російсько-українська війна.

JEL Classification: F40, F52, H56, L94, O19, P33, Q42, Q43, Q48.

Introduction

Energy systems produce, process, convert, transport, store, and distribute primary or secondary energy to meet the demands of economic activities (Hughes, 2012). Power systems are essential elements of national economies that facilitate economic activity. Reliable electricity grids are vital for ensuring the smooth operation of economies as any power fluctuations and blackouts can lead to economic losses. Thus, the resilience of energy systems to external volatility defines the future development in any economy.

As it can be seen from the history of economic development, the energy systems are susceptible to shock influences. The examples are the energy crisis of the 1970s, 2008 financial crisis and disturbances on the crude oil market in 2014, 2020 COVID-19 fluctuations that have affected the energy prices. Energy policy has always been a geopolitical issue, and this has become even more evident with Russia's war against Ukraine. In response to Russia's invasion of Ukraine, Western countries imposed sanctions against Russia. The Kremlin, taking advantage of the dependence of the EU countries on Russian gas, partially cut off its supply, which caused an energy crisis and provoked inflation. Thus, maintaining the functioning of an energy system is critical for energy governance and macroeconomic policy in the face of external shocks or disturbances (Jesse et al., 2019; Lebedeva & Moskalenko, 2021).

Ukrainian and foreign researchers are actively studying the problem of ensuring energy system resilience. To the research of aspects of Ukraine's energy system resilience and formulating of strategy of its development as well as other institutional aspects of development Heyets et al. (2020), Gerasymenko et al. (2022), Jesse et al. (2019), Boiko et al. (2022), Saukh (2018), Kulyk et al. (2017), Mazaraki, Melnyk (2024), Fedulova (2013), Halushchenko (2014) and others have devoted their studies. The works of Hughes (2012) is dedicated to the study of description and analysis of energy security in an energy system. A. Ranjan and L. Hughes, studied relationship between energy security and the diversity of an energy system's energy flows (Ranjan & Hughes, 2014). The most discussed topic among the scholars is the measurement of energy system resilience (Gatto & Drago, 2020; Fan et al., 2023a). To the measurement metrics of economic resilience for interdependent infrastructure, Pant et al. dedicated their work (Pant et al., 2014). Kharrazi investigated the resilience of global energy systems through an examination of a diversity measure of global embodied electricity trade and came to conclusion that secure and responsible consumption requires the diversification of not only energy generation but also energy imports (Kharrazi et al., 2015). It is also stated that the enhancement of the resilience of energy system by energy transition, infrastructure improvement, and research and development investment can contribute to economic sustainability because it mitigates the energy shocks and thus protects the productive foundation of an economic system (Fan et al., 2023*b*). D. Dumitrescu et al. stating that replacing fossil fuels in electricity generation with low-carbon sources, in particular wind researched the energy policy of the EU and its implications for economic development and hydro, is a beneficial path to achieve decarbonisation while also decreasing the EU's reliance on foreign oil and gas (Dumitrescu et al., 2023). Therefore, although many problematic aspects of energy resilience have already been revealed in the scientific literature, the issue of structuring and identifying factors influencing the resilience of energy systems in the EU and Ukraine, especially during times of armed conflict, requires further identification. This became the focus of the present study.

The aim of the research is to find significant factors influencing the EU and Ukraine energy resilience during russian-ukrainian war and government policies that helped to promote it. The hypothesis of the article is that in times of crisis, state regulation, in particular the support of diversified energy sources, building of efficient energy infrastructure, risk management systems and transparent regulatory policy play a vital role in ensuring energy system's resilience.

To fulfil of the research aim, a combination of general scientific and specialized methods were employed: the historical and logical approach to classification and understating the concept of energy system resilience; statistical aggregation and comparison for assessing the indexes of energy resilience within the EU; the logical method for practical recommendations to increase energy system resilience.

The research is divided into three parts. The concept of energy system resilience is presented in the first part. An assessment of energy resilience in EU and Ukraine is provided in the second. The practical recommendations to increase energy system resilience are proposed in the final third part.

1. The concept of energy system resilience

In economic literature, various understandings of energy system resilience can be found. Generally, the resilience of an energy system is the ability of an energy system to retain, react, overcome and overpass perturbations caused by a shock in economic, social, environmental and institutional terms, coming from the learning capacity to adapt to change (Gatto and Drago, 2020). The resilience of energy systems is also a specific to energy-economy systems, and its determinants include energy diversity, infrastructure, research and development (R&D), and governance (Fan et al., 2023*a*).

The UN (United Nations) 2030 Agenda emphasizes the development goal of "universal access to affordable, reliable, sustainable and modern energy" by enhancing the resilience of energy systems (UNECE, 2023). In the *Table 1* approaches to definition of energy system resilience by different organizations are presented.

Table 1

Approaches to understanding the resilience concept in the energy sector

Organisation	The essence
Cabinet of Ministers of Ukraine	The resilience of the energy sector's functioning is the ability of the energy sector to function normally, to adapt to constantly changing conditions, to withstand and quickly recover from threats of any kind (Cabinet of Ministers of Ukraine, 2021)
Ministry of Energy and Coal Industry of Ukraine	The resilience of the energy system is the ability to return to a stable mode after various types of disturbances without switching to an asynchronous mode, that is, to maintain synchronism between power plants. Resilience of energy systems is defined as static and dynamic. Static resilience is the ability of power systems to return to a steady state after small disturbances, in which the changes in parameters are very small compared to their average values. Dynamic resilience is the ability of power systems to return to a stable mode after significant disturbances (short circuit, disconnection of any element of the power system, sudden occurrence of an emergency power imbalance, etc.) (Ministry of Energy and Coal Industry of Ukraine, 2012)
Siemens	Resilience of energy infrastructure – the ability of electricity supply networks to anticipate, respond quickly, adapt and recover from threats of any kind through rapid, targeted and effective action directed at physical and digital infrastructure (Siemens, 2019)
United States Department of Energy	Energy resilience is the ability of the grid, buildings, and communities to withstand and rapidly recover from power outages and continue operating with electricity, heating, cooling, ventilation, and other energy-dependent services (United States Department of Energy, 2023)
United Nations Economic Commission for Europe	A resilient energy system is one where energy makes an optimal contribution to a country's social, economic, and environmental development, and that is able to withstand and recover quickly from any unanticipated shocks and reflects potential impacts of climate change on energy resources in its planning and operations (UNECE, 2023)

End the Table

Organisation	The essence
Enel North America	Energy resilience is the ability to ensure a reliable energy supply to maintain operations, even at times of grid disruption, like in the case of a power outage. Energy resilience is becoming an essential organizational priority across all industries to protect operations against extended power outages (Enel North America, 2023)
Union of the Electricity Industry	Energy resilience is the ability to avoid, prepare for, minimise, adapt to, and recover from anticipated and unanticipated energy disruptions in order to ensure energy availability and reliability that evolves maintaining a consistent supply of energy despite disruptions, whether they stem from natural disasters, cyberattacks, geopolitical tensions, or other unforeseen circumstances (Union of the Electricity Industry, 2023)

Source: compiled by authors.

The main component of the protection of the power supply system is to ensure its resilience. More resilient power supply networks have a greater ability to maintain operational efficiency in destructive conditions, reduce their impact and accelerate recovery. The resilience of power supply networks increases or decreases with the weakest (most vulnerable) component of the system. It is extremely important to identify all potential risk factors, predict accidents and provide preventive protection measures for the entire system (*Figure 1*).

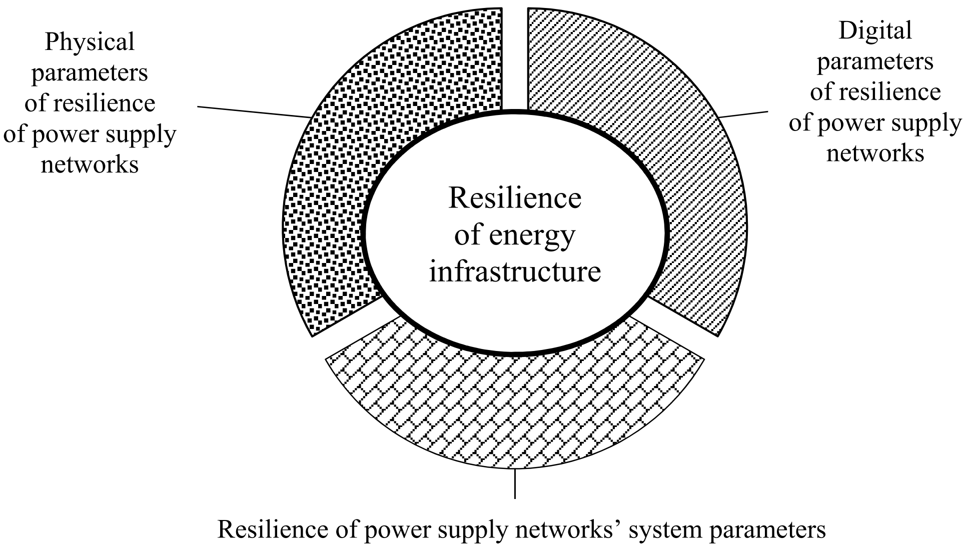

Figure 1. A comprehensive approach to ensuring the resilience of power supply systems

Source: compiled by the authors based on data (Siemens, 2019).

The physical parameters of the resilience of power supply networks include such elements as access protection and presence detection in all premises, as well as bulletproof transformer protection systems that can be installed on new and existing systems. It also includes protection of the structure itself from damage caused by natural influences, such as floods, storms, earthquakes, lightning strikes and geomagnetic storms. Another integral part of the increased resistance to physical influences is the current control of the condition. Continuous assessment of nominal and actual values in dynamics allows to detect wear at an early stage and to take measures in advance – even before destruction becomes probable.

Since the very beginning of the introduction of digital technologies, power supply systems have evolved from relatively autonomous, simple networks to complex intelligent infrastructures, vulnerable to accidents of a natural and man-made nature at various levels. The need to address issues ranging from the potential risks associated with these inevitable processes, including climate change, the growing adoption of distributed power systems, and the sharp rise in vandalism in some countries, necessitates resilience in terms of operation, optimization and designing the entire power supply system of the future.

Without the consistent implementation of digital technologies, it is impossible to meet modern requirements for the automation of power supply systems. However, given the current changes, which are characterized by increasing dynamism, flexibility and changing roles of various involved parties, the implementation of digital technologies implies the need to take into account new risks in terms of reliability. Ensuring energy resilience requires the use of modern methods and technologies of digital protection – from continuous analysis of the state of risk associated with ensuring information security, prevention of unauthorized access and third-party interference to protection against human factors and technical errors, as well as network failures.

The coherence and intelligent interaction of all power supply system components is the central element of sustainable power supply networks. It involves systematic protection against internal and external risks of all parameters, starting from the first stage of designing the power supply system of one size or another; the company applies the appropriate level of reservation, as well as specially designed rapid response services (Siemens, 2019).

It is impossible to exclude various incidents in power supply networks completely. However, resilient power systems can anticipate and mitigate the effects of such disruptive events, adapt to them, and quickly recover from an accident. In the USA, for example, the following groups of measures are distinguished, which are formed according to different stages of the cycle of response to the emergence of a crisis situation. Emergency reaction includes four phases: Preparedness, Mitigation, Response, and Recovery (National Institute for Strategic Studies, 2023). The phase of Preparedness includes planning of: energy system protection according to the defined level of threats / dangers; interaction plans of the involved entities and response plans; personnel training; exchange of information on best practices; analysis of the security situation and risk assessment. The Mitigation phase includes such actions as: modernization of energy facilities and equipment renewal in accordance with the identified threats and consequences of their influence (risks); reservation of systems; plans for replacement of damaged equipment, lost resources or functions; accumulation of own stocks and reserves. To the Response phase are included: use of project forces and resources in accordance with defined response threats plans; usage of additional forces and resources (local, regional, central and international); analysis of the situation and coordination of response; decision on the temporary restoration of the provision of functions / services. The Recovery phase includes such actions as: replacement / repair of energy system equipment; measures to restore full functioning, taking into account increased resilience in the future and new technological opportunities.

2. An assessment of energy infrastructure resilience

As of the end of 2023 there was USD 8.8 billion of assessment of the damage caused to the Ukrainian energy infrastructure due to the full-scale war that increases daily as these attacks continue. Since the beginning of the full-scale invasion, more than 270 Russian missiles have hit Ukrainian energy facilities. As a result, about 50% of Ukraine's energy facilities were damaged or completely destroyed, 27.5% of electricity production was lost. Namely the loses of NPP are 28%, TPP 35%, RES 36%, CHP 32% and other types of generation gained 11.4% (Top Lead, 2023).

On June 6, 2023, the Russian occupiers blew up the Kakhovka hydroelectric power station with a capacity of more than 300 MW. In the month after the detonation, Ukraine lost about 14.4 km^3 of water, which is 35% of the annual flow rate of the Dnipro River. Many settlements were under water, several regions were left without energy and water supply. The explosion of the Kakhovka HPP also had a significant impact on the environment. PJSC "Ukrhydroenergo" estimates the damage from the explosion of the Kakhovsky hydroelectric plant at more than EUR 2.5 billion, another EUR 500 million of damages were caused by Russian rocket and drone attacks on the company's facilities (Ukrhydroenergo, 2024).

War changed the EU energy policies. Russia's invasion of Ukraine has forced Europe to urgently reduce its dependence on Russian natural gas and oil imports and thus accelerated the deployment of renewable energy (*Figure 2*) (Top Lead, 2023). So, the EU renewable capacity in terms of solar energy increased by 39.5% and wind energy by 4.3% in 2023 compared to 2021 that is one of the crucial factors in energy systems resilience.

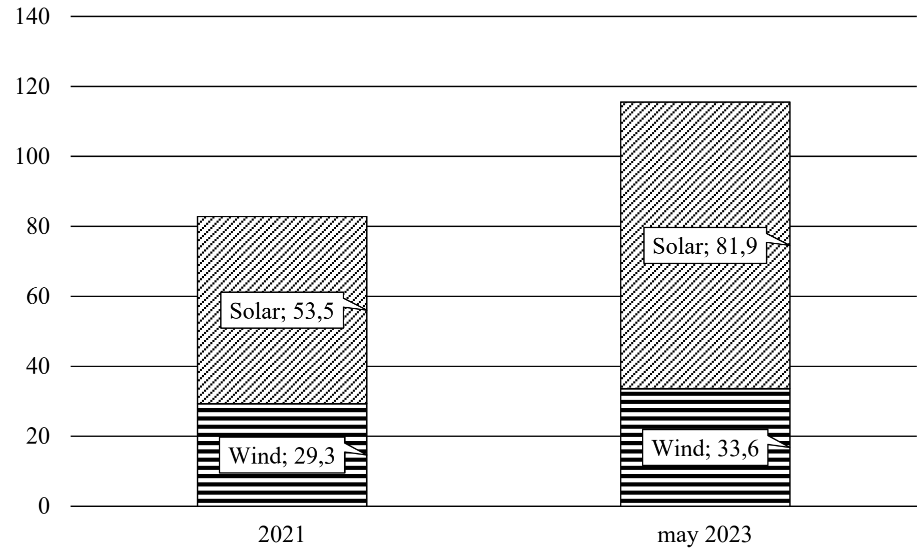

Figure 2. EU renewables capacity, GW

Source: (Top Lead, 2023).

The Global Energy Vulnerability Index is one of the tools for assessing the resilience of a country's energy infrastructure. The Global Energy Vulnerability Index seeks to evaluate the susceptibility of individual countries to energy shocks, identifying both the obstacles they encounter and the prospects they have to bolster their energy resilience. Factors such as substantial energy self-reliance, a varied energy portfolio, ample energy accessibility and efficiency, and economic prosperity contribute to a nation's ability to withstand potential energy market disruptions. Conversely, significant reliance on external energy sources and fossil fuels, inadequate infrastructure development, limited access to capital, and weak economic stability erode countries' energy resilience (Euromonitor International, 2023).

The Global Energy Vulnerability Index takes into account various aspects that affect the resilience of a country's energy system and its ability to overcome potential crisis situations. Euromonitor International used six groups of indicators to measure each country's level of energy vulnerability (Euromonitor International, 2023):

- Energy self-sufficiency (30% of total score (TS);
- Alternatives to fossils (35% TS);
- Energy reserves potential (10% TS);
- Energy accessibility (5% TS);
- Energy efficiency (10% TS);
- Economic stability (10% TS).

Index is ranged from 1 to 100 with the lowest points representing lesser vulnerability and higher points – greater. The results of the Global Energy Vulnerability Index for European Union member states and Ukraine represented in *Table 2*.

Table 2

Ukraine and EU member states in Global Energy Vulnerability Index, 2023

Country	Final rank	Energy self-sufficiency	Alternatives to fossils	Energy reserves potential	Energy accessibility	Energy efficiency	Economic stability
Sweden	7	42	1	60	6	14	16
Romania	13	53	9	18	58	30	53
Denmark	15	57	29	25	38	7	18
Slovenia	16	56	5	60	23	20	26
Germany	18	74	12	38	26	9	20
Finland	23	67	3	60	9	38	19
France	24	49	15	58	17	19	33
Spain	29	71	7	52	32	25	37
Italy	37	77	43	31	44	13	24
Netherlands	41	72	54	45	28	11	6
Croatia	45	62	26	60	50	29	38
Bulgaria	47	59	24	54	27	66	44
Portugal	50	79	22	60	43	15	35
Czech Republic	54	61	47	57	20	49	31
Hungary	55	66	41	49	53	41	32
Latvia	58	58	48	60	60	32	34
Estonia	63	40	70	60	36	34	36
Belgium	65	91	38	60	16	27	25
Greece	67	84	46	53	41	16	56
Ireland	70	94	61	60	29	1	15
Slovakia	72	82	34	60	37	52	28
Ukraine	77	45	55	35	54	100	91
Poland	78	65	78	36	45	43	45
Lithuania	90	93	75	60	73	24	40

Source: compiled by the authors according to (Euromonitor International, 2023).

The top 10 EU countries according to the Global Energy Vulnerability Index are Sweden, Romania, Denmark, Slovenia, Germany, Finland, France, Spain, Italy and the Netherlands. It must be mentioned that globally compared to Norway, Canada, Australia and the USA that rank at the top of the index due to their strong energy self-sufficiency, the EU countries have higher reliance on the energy imports. That is why the lack in the energy self-sufficiency pillar of the Index that greatly undermines the final scores of EU countries. Among the European Union countries, Sweden has the highest rank in the g Global Energy Vulnerability Index. It is due to it is high position in the alternatives to fossils pillar, high-energy accessibility, energy efficiency and economic stability. Finland and Spain have also high ranks in alternatives to fossils pillars, as well as energy accessibility, which give them high scores in the index. However, the Netherlands, Spain, Germany and Italy remain heavily dependent on energy imports that greatly undermine their rank. Therefore, as analysis shows we can conclude that the energy sources diversification and the availability of own energy resources are among the main factors of energy system resilience.

Ukraine’s rank is quite low in this index and close to such European countries as Slovakia, Poland, and Lithuania that is due to the dependency upon the energy imports, as well as a low economic stability and energy efficiency.

Russia’s full-scale invasion of Ukraine prompted the European Union and its member states to reconsider the imperative of bolstering their energy sovereignty. The energy crisis in Europe commenced in 2021, following a prolonged cold winter that depleted natural gas reserves. Apprehensions about scarce supplies escalated as Russia reduced gas exports to Europe, allegedly as a coercive measure to push for the approval of the Nord Stream 2 pipeline, particularly in Germany. By the summer of 2022, European gas prices soared, exceeding EUR 300 per MWh, exacerbated by Russia’s further reduction of gas supplies after the invasion of Ukraine, leveraging its gas reserves as a geopolitical tool (Forbes, 2024).

Energy sovereignty is important for ensuring the country’s energy resilience, contributing to its independence in energy matters and reducing risks associated with energy crises and fluctuations in world markets. The Energy Sovereignty Index (ESI) is a tool that allows determining the level of energy independence of a country and its ability to meet its needs in energy resources. The energy sovereignty index includes four components: energy cleanness (the share of renewables and fossil fuels in the energy mix), energy independence (dependence on energy imports), energy efficiency (domestic energy demand compared with actual use), and narrative (the depth and breadth of energy sovereignty discourse within EU member states) (ECFR, 2023).

The index is graded on a scale ranging from 0 to 10. The outcomes are categorized as follows: scores up to 5.4 are classified as "failing"; those between 5.5 and 7.0 are "satisfactory"; scores falling within the range of 7.1 to 8.4 are considered "good"; those between 8.5 and 9.4 are "very good"; and scores of 9.5 or higher are characterized as "excellent" (ECFR, 2023). Based on the countries’ overall scores, the index identifies four groups of countries – Laggards (Failing), Dependent achievers (Satisfactory), Emerging sovereigntists (Good), and Independent decarbonisers (Very good) – with regard to their overall energy sovereignty (ECFR, 2023).

Among European Union countries in 2023 the "very good" results has only one country – Denmark. "Good" results have four countries such as Estonia, Finland, Romania and Sweden. The "satisfactory" results have grease Greece, Croatia, Latvia, Austria, Spain, Czech Republic, Netherlands, Portugal, Slovenia, Germany, Cyprus, Italy, Luxembourg, Bulgaria, France, and Poland. The "failing" have – Ireland, Belgium, Slovakia, Hungary, Lithuania, and Malta.

The results of the Energy Sovereignty Index for European Union member states represented in *Table 3*.

Table 3

EU member states in Energy Sovereignty Index, 2023

Position	Country	Index	Cleanness	Independence	Efficiency	Narrative
1	Denmark	8.5	10.0	7.6	8.4	7.0
2	Estonia	8.3	8.0	9.5	8.3	5.5
3	Finland	8.0	9.6	5.7	8.8	7.5
4	Romania	7.7	6.2	7.7	10.0	5.5
5	Sweden	7.6	10.0	7.9	5.8	5.0
6	Greece	6.7	7.4	2.3	10.0	7.5
7	Croatia	6.5	8.1	2.9	8.4	6.5
8	Latvia	6.4	8.4	0.9	9.3	8.0
9	Austria	6.3	9.4	3.2	5.6	8.0
10	Spain	6.3	7.6	2.5	8.6	6.5
11	Czech Republic	6.2	4.9	5.9	7.5	7.0
12	Netherlands	6.2	7.6	2.6	7.5	8.5
13	Portugal	6.2	7.9	1.4	8.9	8.0
14	Slovenia	6.1	6.9	3.0	8.6	5.5
15	Germany	5.9	7.6	3.7	5.9	7.5
16	Cyprus	5.8	6.7	2.5	7.3	8.5
17	Italy	5.7	5.6	2.0	8.9	7.5
18	Luxembourg	5.6	8.3	0.0	7.8	7.5
19	Bulgaria	5.5	6.1	6.4	4.2	5.0
20	France	5.5	7.4	2.3	6.6	6.5
21	Poland	5.5	5.2	5.4	5.4	6.5
22	Ireland	5.3	6.9	2.5	6.6	5.5
23	Belgium	5.0	7.4	2.5	4.9	6.0
24	Slovakia	5.0	5.5	2.8	6.0	7.5
25	Hungary	4.8	4.9	2.5	6.7	6.0
26	Lithuania	4.6	8.4	0.1	4.0	9.0
27	Malta	4.1	2.2	1.1	8.0	7.5
EU average		6.1	7.2	3.6	7.3	6.9

Source: compiled by the authors according to (ECFR, 2023).

According to the Energy Sovereignty Index, the European union countries lack behind in the Energy independence with EU-wide average score at mere 3.6 out of 10. The lowest scores in this category have such countries as Greece, Latvia, Spain, Portugal, Cyprus, Luxembourg, Italy, Malta and Lithuania. European union countries have a progress in the European Energy Cleanness category with the EU-wide average score at 7.3 thanks to the growing renewable energy sector, the top performers here are Denmark, Finland, Sweden Austria, the lowest performer in this category is Malta with 2.2. With the category of Efficiency, the EU hits its own energy efficiency targets for 2020. In this category 16 countries score above 7, only three countries make it past 9, Greece and Romania are at the top and Lithuania lags behind. In the Narrative category that shows the depth and breadth of energy security approach (including efficient monitoring systems) such countries as Cypress, Finland, Greece, Lithuania, Luxembourg, the Netherlands, Portugal, and Slovakia have adopted a holistic approach at building the national energy security. Their policy takes into account not only the security of energy supply, but also climate goals and energy efficiency. So, the results of the analysis confirm the significance of diversified energy sources, efficient energy infrastructure, monitoring and risk management systems as the factors of energy system resilience.

To assess the energy resilience of a state, it is important to analyse the indicator of energy intensity. The analysis of energy intensity can be used to analyse the level of resource utilization efficiency. For example, high-energy intensity signifies inefficient use of energy and resources. High-energy intensity can also indicate a high dependency of a state on energy resources. If a country uses a lot of energy to produce one unit of output, it becomes more vulnerable to fluctuations in resource prices or supply issues. A high level of energy intensity also indicates significant energy expenditures in production and consumption. The dynamics of energy intensity by EU countries from 2013 to 2022 are presented in *Figure 3*.

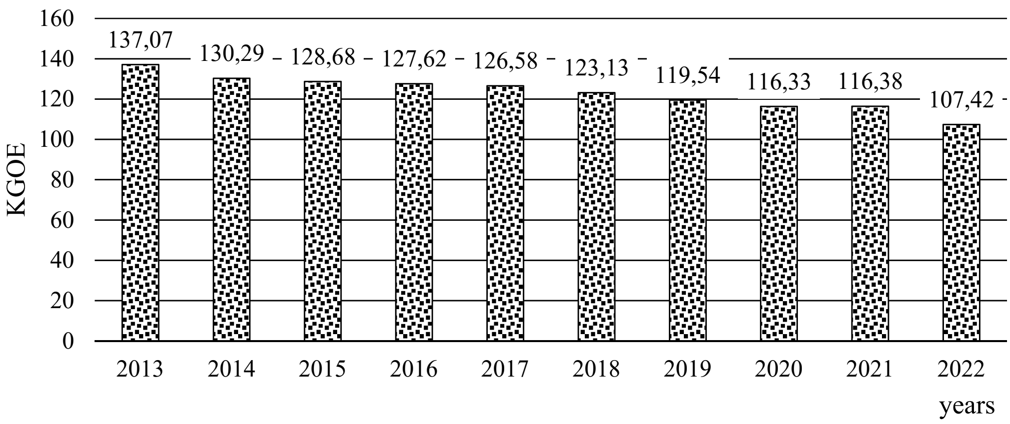

Figure 3. Energy intensity by EU countries in 2013–2022

Source: (Euroststat, n. d.).

Energy intensity is measured in kilograms of oil equivalent (KGOE) per thousand euros. From 2013 to 2022, the energy intensity of EU countries decreased by 29.65 KGOE. In recent years, the European Commission has been making significant efforts to reduce the energy intensity of member countries by implementing advanced technologies, energy efficiency programs, and promoting the use of renewable energy sources, which contributes to enhancing energy resilience.

3. Practical aspects to ensure energy system resilience

Increasing the resilience of the energy system of the EU countries requires a comprehensive approach and consideration at several levels, including infrastructural, technological, regulatory and strategic aspects. It is worth highlighting practical measures that ensure increased resilience of the EU energy system that form factors influencing the energy resilience of the country.

Geopolitical conflicts and the lack of diversified sources of energy. Reducing dependence on specific energy sources (such as coal or gas) through the development of renewable energy sources such as solar, wind, hydropower and biomass reduces the risk of crisis situations due to changes in fuel prices or geopolitical conflicts (Dinu et al., 2023).

The availability of own energy resources or reliable sources of energy supply from other sources (for example, import contracts). Development of network connections between countries that enables equalization of fluctuations in energy production and consumption, which increases the resilience of the system and provides more reliable access to energy.

A reliable and efficient energy infrastructure, including power plants, transmission and distribution networks as well as energy storage. There is the use of energy storage technologies such as batteries, mechanical storage or thermal storage systems that helps to smooth out fluctuations in energy production and consumption.

Monitoring and risk management systems help to identify potential threats to energy resilience and take timely measures to prevent or mitigate them. The introduction of modern energy system management technologies, such as monitoring and automation systems, that allows more effective response to changes in energy consumption and management of energy distribution in the network.

Decreasing energy consumption with the help of energy-efficient technologies and investments in green energy.

Quality and transparent regulatory policy in the energy sector promotes resilience and attracts investment in infrastructure development. Transparent regulatory policy in energy sector will attract new investment and boost economic growth.

These practical measures are implemented both as in individual countries as in European Union in general through joint programs and initiatives to increase the resilience of the energy system.

As associated member of EU Ukraine has made a decision to join European community that practically mean adjusting the governmental policies to the EU rules, in terms of energy policy it means adjusting to EU Energy strategy. The mission of the Energy Strategy of Ukraine until 2050 is to create conditions for the sustainable development of the national economy by ensuring access to reliable, sustainable and modern sources of energy and by 2050, the energy sector should be as close as possible to climate neutrality as noted in EU Energy strategy (European Commission, n. d.).

The energy strategy will be based on the target indicators of economic development in accordance with the National Economic Strategy for the period until 2030 and on the international obligations undertaken by Ukraine (Liga 360, 2015):

- achieving the maximum level of climate neutrality;
- maximum reduction of coal use in the energy sector;

- renewal and modernization of energy infrastructure;
- increasing the efficiency of the use of resources in the energy sector;
- comprehensive integration with the markets of the European Union and effective functioning of internal markets;
- providing the energy sector with its own resources, taking into account economic feasibility;
- development of alternative energy sources, new products and innovative solutions in the energy sector.

The Ministry of Energy of Ukraine operates a working group on the organization of humanitarian aid to the energy sector, which collects applications from Ukrainian energy companies regarding their needs, processes and forwards them to partners who are ready to provide appropriate assistance (*Figure 4*). Distribution of the provided materials and equipment is carried out primarily among the regions most affected by Russian aggression.

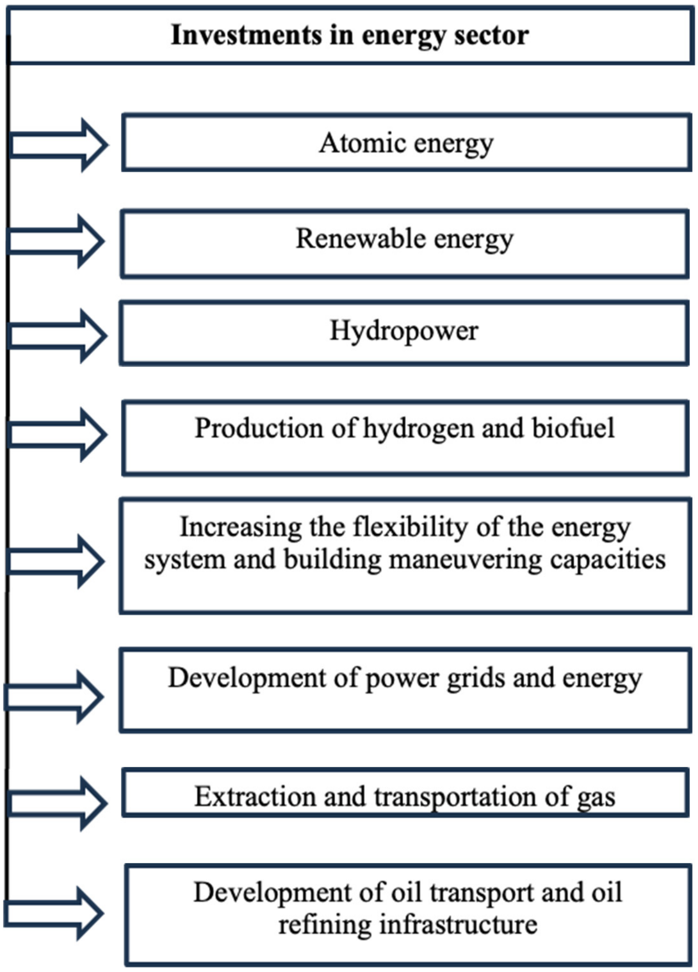

Figure 4. Key directions for investments in the energy sector of Ukraine

Source: (Ministry of Energy of Ukraine, 2022).

In April 2022, on the initiative of the European Commissioner for Energy, Kadri Simson, the Energy Community established the Energy Support Fund of Ukraine. Donors of the Fund are individual states, international companies and organizations. The main task of the Fund is to help energy companies promptly restore damaged or destroyed energy infrastructure as a result of Russian shelling. The funds of the Fund are directed to the purchase of equipment that cannot be provided by international partners in the form of humanitarian aid.

Conclusions

The policy of ensuring energy resilience of the country should be based on the modernization of energy networks, ensuring their reliability and resistance to man-made and natural disasters. Constant monitoring and analysis of the energy situation in the country and at the international level is also necessary. Understanding trends in the field of energy, the dynamics of energy prices and prospects for the development of new technologies will help the country predict risks and respond in time to changes in the global energy arena.

As the result of the research basing on the evaluation of energy resilience indicators, such as The Global Energy Vulnerability Index that ranks EU countries based on their energy vulnerability, we can conclude that EU nations, unlike Norway and Canada, heavily rely on energy imports, affecting their self-sufficiency pillar scores. Sweden leads among EU countries due to its strong performance in alternative energy sources, accessibility, and economic stability. However, countries like Netherlands and Italy struggle due to heavy energy import reliance. Ukraine’s low rank, similar to Slovakia and Poland, reflects its energy import dependence and economic instability.

The Energy Sovereignty Index highlights the European Union’s path towards energy independence, averaging a score of 3.6 out of 10, with countries like Greece, Spain, and Italy ranking lowest. However, EU nations excel in the European Energy Cleanness category, with Denmark, Finland, and Sweden leading due to their renewable energy advancements. Efficiency targets for 2020 are met by most EU countries, with Greece and Romania excelling, while Cyprus, Finland, and others adopt holistic energy security approaches encompassing supply security, climate goals, and efficiency.

Thus, according to analysis of the energy resilience indicators that prove the article hypothesis, the following factors influencing the energy resilience of the country can be determined:

- Geopolitical conflicts and the lack of diversified sources of energy.
- The availability of own energy resources or reliable sources of energy supply from other sources (for example, import contracts).
- A reliable and efficient energy infrastructure, including power plants, transmission and distribution networks.

- Monitoring and risk management systems that help to identify potential threats to energy resilience and take timely measures to prevent or mitigate them.
- Decreasing energy consumption with the help of energy-efficient technologies.
- Quality and transparent regulatory policy in the energy sector that promotes resilience and attracts investment in infrastructure development.

The analysis conducted highlighted the importance of the aforementioned factors for the resilience of energy systems. Future scientific research will focus on specifying these factors and assessing their impact on the components and overall level of energy resilience in EU and Ukraine.

Ukraine's decision to pursue full membership in the European Union after concluding the Association Agreement signals a significant shift in its development trajectory, necessitating alignment with EU principles and practices, notably in energy policy. The need to update Ukraine's Energy Strategy arises from both its EU aspirations and the challenges posed by energy security threats due to Russian aggression and occupation of certain territories. The updated Energy Strategy until 2050 aims to foster sustainable economic development by ensuring access to reliable, modern energy sources and achieving climate neutrality by prioritizing clean energy and innovation. Key principles guiding this strategy include economic viability, environmental sustainability, accessibility, social equity, and market integration, reflecting Ukraine's commitment to aligning with European standards and values.

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