



ARTICLE  
SPECIAL SECTION

# EU-Ukraine Cross-Border Energy Cooperation: Trends and Directions for Post-War Reconstruction

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*This paper is dedicated to exploring the essence of cross-border cooperation between Ukraine and the EU countries in the energy sector. The enhancement of such cooperation became possible after Ukraine joined the European Network of Transmission System Operators for Electricity, as the border regions gained broader opportunities for reconstructing existing and building new international power lines. This, in turn, creates new opportunities for energy cooperation and accelerates Ukraine's European integration. In the context of Russia's military aggression against Ukraine, the policy vector of cross-border cooperation has shifted towards regional projects in the humanitarian, military, and energy sectors. The present study contains an overview of the Ukrainian energy sector and the cross-border power transmission system, an analysis of the destruction of Ukraine's energy infrastructure, and an assessment of what will be needed for its restoration. This study addresses several European Union countries bordering Ukraine and connected by international power lines: Poland, Romania, Hungary, and Slovakia. It would appear that Ukraine and its neighboring EU member states have significant potential for cooperation in the energy sector. Finally, we identify the main venues of cross-border cooperation between Ukraine and EU countries in the energy sector.*

**Keywords:** cross-border cooperation, energy sector, power transmission lines, European integration, electricity.

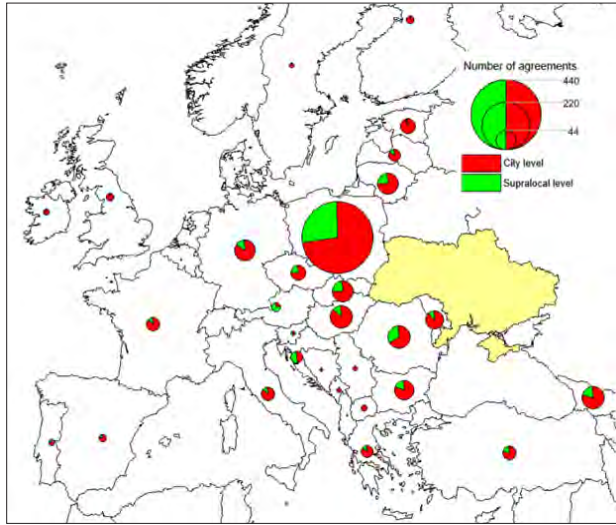
## Introduction

The problems of cross-border cooperation currently occupy a central place in the politics of European countries, which is explained by the increasing interdependence of national economies and a renewed understanding of the importance of integration in the context of international relations disrupted by the war in Ukraine. Cross-border interactions (economic, social, scientific-technical, environmental, cultural) between Ukraine and European Union (EU) member states are now determined primarily by military-political factors.

Moreover, Ukraine's European integration is taking place in conditions of large-scale Russian intervention.

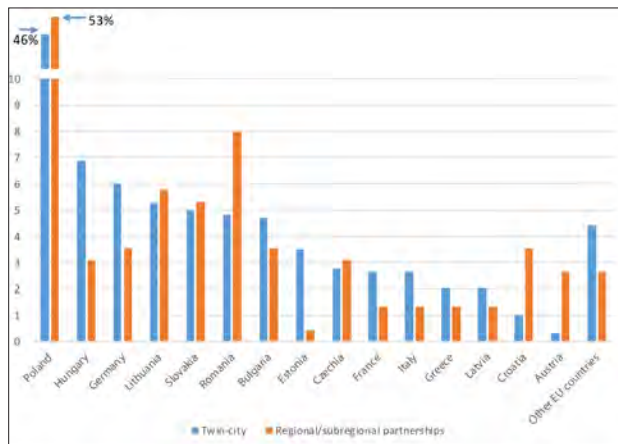
The EU is carrying out a number of ad hoc activities supporting Ukraine, as well as preparing for its post-war reconstruction process. European cities and regions are also able to participate in these activities and reconstruction. Existing and new partnership agreements with Ukrainian local and regional authorities (LRA) can be used for this purpose, as well as the experience of active territorial cooperation, including through EU-funded programs. Agreements with Ukrainian partners have been concluded mainly by cities and regions from countries that are in close proximity to Ukraine. Territorial cooperation of Ukrainian LRAs with European partners in 2022 is shown in Figure 1.

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**Figure 1. Territorial Cooperation of Ukrainian LRAs with European Partners in 2022.** Source: Smętkowski et al. (2023, 21), © European Union.

Most partnership agreements with Ukrainian LRAs were concluded by Polish local governments. The other main EU partners of Ukrainian cities were of similar importance as measured by the number of agreements signed. At the local level, Hungary came second (7%), not least because of its strongly developed contacts with the Zakarpattia Oblast inhabited by a significant Hungarian minority. In addition to Hungary, the other two EU countries bordering Ukraine—Slovakia (5%) and Romania (5%)—each had around 30 partnership agreements. Regional and local partnerships between Ukraine and EU countries in 2022 are shown in Figure 2.



**Figure 2. Regional and Local Partnerships Between UA and EU Countries (% of total), 2022.** Source: Smętkowski et al. (2023, 22), © European Union.

As a matter of fact, European Union programs and instruments are an important source of funding for territorial cooperation both within the EU and with neighbouring countries, including Ukraine. Sectoral

integration covers a wide range of areas of territorial cooperation, from energy to the digital market and ecology. Under current wartime conditions, security and military-technical cooperation have been prioritized. At the same time, there is a need to prioritize specific sectors of European integration, which, on the one hand, should become additional “drivers” of internal socio-economic transformations, and on the other hand, accelerate Ukraine’s integration into the EU in its most important areas. The EU has prioritized security of the energy supply in its cooperation with the Ukrainian energy sector. The task for developing cooperation in the energy sector between the EU and Ukraine is to ensure the stability of the energy supply, enhance the energy security of the region, promote economic growth, and facilitate Ukraine’s integration into European energy markets.

This research aims at reviewing both the current state of cooperation between Ukraine and EU countries in the field of energy, and Ukraine’s accession to the ENTSO-E and the use and expansion of its transit potential. The main research tasks include analyzing past experiences, as well as assessing future potential and opportunities for cooperation between the EU and its Ukrainian border regions in the energy sector. The first section of this paper provides an overview of the Ukrainian power sector and the cross-border transmission system. Due to the constant threat of rocket fire from the north-eastern border, the Ukrainian energy system experiences significant destruction of energy facilities within the Unified Energy System of Ukraine. Consequently, this section analyzes the destruction of Ukraine’s energy infrastructure and assesses the needs for its restoration. The second section examines the essence of cross-border cooperation in the energy sector between Ukraine and neighboring countries. Throughout this research, several European Union countries bordering Ukraine and possessing international power lines, including Poland, Romania, Hungary, and Slovakia, are analyzed. The third part is dedicated to defining the main venues of cross-border cooperation between Ukraine and EU countries in the energy sector.

## 1. Overview of the Ukrainian Power Sector

This part presents the generating capacities of the Unified Energy System of Ukraine. Electric power engineering includes all types of power plants and grid management. Electricity production in Ukraine is based on the use of nuclear energy (NPPs), coal, fuel oil, natural gas (TPPs), hydroelectric power (HPPs), pumped-storage hydroelectric power plants (PSPPs), solar energy (SEPs), and wind energy. The National Power Company (NPC) Ukrenergo is the transmission system operator (TSO) for electricity in Ukraine (Ukrenergo 2024). The total installed capacity of power plants in the Unified Energy System of Ukraine as of December 31, 2021 (excluding the energy generating facilities of the

Crimean power system and the temporarily occupied territories of Donetsk and Luhansk regions) amounts to 56.247 GW, of which 49.7% is accounted for by thermal power plants (including TPPs, CHPs, and block stations), 24.6% by nuclear power plants, 11.2% by hydroelectric power plants and pumped-storage hydroelectric power plants, and 14.5% by power plants operating on renewable energy sources including wind power plants, solar power plants, and bioenergy power plants. The dynamics of the installed capacity structure of the power stations of the Unified Energy System of Ukraine, excluding the temporarily occupied territories of the Autonomous Republic of Crimea, Donetsk, and Luhansk regions, is presented in Table 1.

Major generating capacities of the Unified Energy System of Ukraine (as of December 31, 2021) are concentrated at: 4 nuclear power plants; 10 hydroelectric power plants on the Dnipro, Dniester, Southern Bug rivers, as well as on the Tereblia and Rika rivers (Tereblia-Ritska hydroelectric power plant); 12 thermal power plants and 3 turbo generators, as well as 3 large combined heat and power plants (CHPs); RES plants (including stations using biofuels).

An overview map of power plants in Ukraine is shown in Figure 3. According to the figure, thermal power plants and hydroelectric power plants are the most numerous. However, the majority of electricity in Ukraine is generated by nuclear power plants. Additionally, renewable energy sources are developing, primarily represented by solar and wind power plants.

The pre-war (2021) total generation of the power system in Ukraine was 158 TWh. The generation was composed of the following: nuclear 86.2 TWh (55%); coal 36.5 TWh (23%); natural gas 14.3 TWh (9%); hydro 10.3 TWh (7%); solar 6.6 TWh (4%); wind 2.8 TWh (2%); biofuels and waste 0.8 TWh. There was an import/export balance of 2.0 TWh net export (1.5 TWh imports 3.5 TWh exports) (World Nuclear Association 2024).

Since 2014, the northern cross-border neighbor of Ukraine, the Russian Federation, has employed military tactics involving attacks on civilian utilities and energy

infrastructures. These tactics intensified on October 10, 2022, leading to significant damage to transmission and distribution (T&D) infrastructure and posing risks to the stability of power systems. These actions directly affect the operational conditions of energy facilities. In this regard, the installed capacity mix of power plants in Ukraine has decreased by more than 50%. Accordingly, losses of installed capacity of power plants in Ukraine in 2021, 2022, and 2023 are illustrated in the Figure 4.



**Figure 3. Overview Map of Power Plants in Ukraine.** Source: BiuroPTPiREE (2022). © Energia Elektryczna.



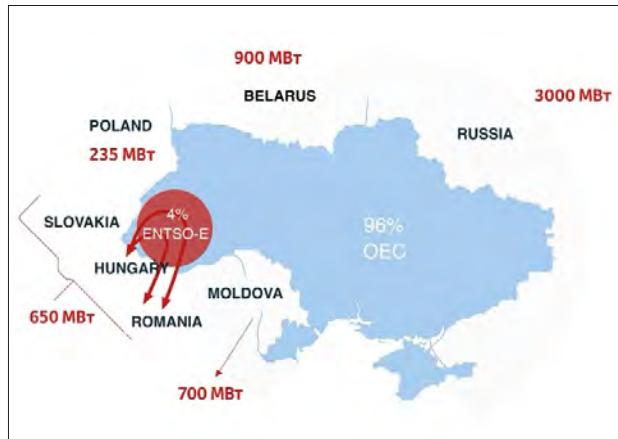
**Figure 4. Losses of Installed Capacity of Power Plants in Ukraine.** Source: author's adaptation from Cooperation for Restoring the Ukrainian Energy Infrastructure Project Task Force (2023b, 4).

**Table 1. The Dynamics of the Installed Capacity Mix of the Power Plants of Ukraine, GW.** Source: table adapted from National Council for the Recovery of Ukraine from the Consequences of the War (2022, 16).

Type of power station	2016	2017	2018	2019	2020	2021
Hydroelectric power plants (HPPs)/pumped-storage hydroelectric power plants (PSPPs)	6.2	6.2	6.2	6.3	6.3	6.3
RES plant	1.0	1.2	1.7	4.7	6.7	8.1
Combined heat and power plants (CHPs)	6.5	5.9	6.1	6.1	6.1	6.1
Thermal power plants (TPPs)	24.6	24.6	21.8	21.8	21.8	21.8
Nuclear power plants (NPPs)	13.8	13.8	13.8	13.8	13.8	13.8
<b>Total</b>	<b>52.1</b>	<b>51.7</b>	<b>49.6</b>	<b>52.7</b>	<b>54.7</b>	<b>56.2</b>

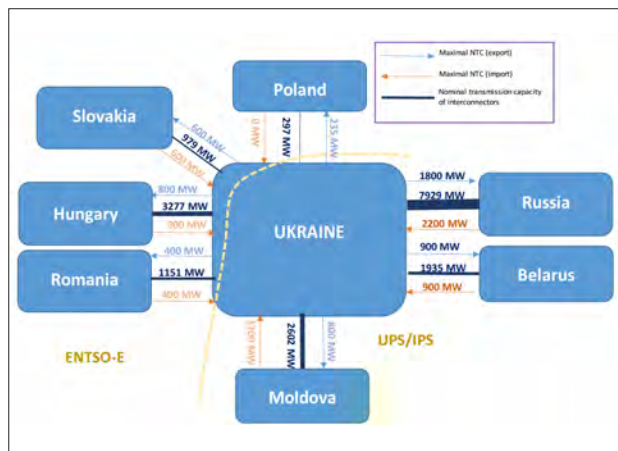


Regarding the electricity transmission system managed by NPC Ukrenergo, it comprises 23,600 km of overhead lines and 141 substations with voltages ranging from 110 to 750 kV. Prior to the beginning of March 2022, the power system of Ukraine consisted of two parts (see Figure 5): the main part synchronized with the power systems of the Commonwealth of Independent States (CIS) and the Baltic States (96% of the Integrated Power System (IPS) of Ukraine), and a small part (4%, Burshtynska Island) integrated into the European Network of Transmission System Operators for Electricity (ENTSO-E).



**Figure 5. The Two Parts of the Ukrainian Power System (pre-2022).** Prepared by the author.

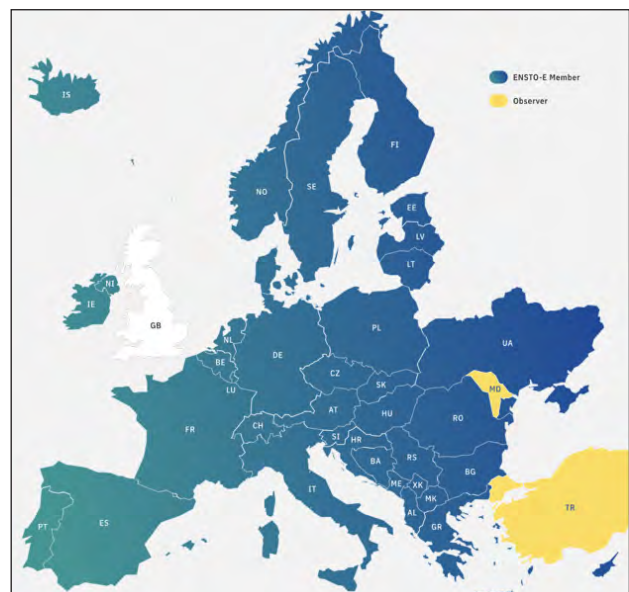
Electricity was exported from the "Burshtynska Island" to Hungary, Slovakia, and Romania. With the introduction of a new electricity market model in Ukraine on 1 July 2019, it became possible to import electricity to the island's trade zone (see Figure 6), as well as to the main part of the IPS of Ukraine (from Belarus, Russia, and Moldova) (Bajs 2021).



**Figure 6. Nominal Transmission Capacity of the Interconnectors at the Ukrainian Borders and Maximum NTC Values (Maximum Permitted Exchanges).** Source: Bajs (2021, 50). © Energy Community.

The issue of expanding the ENTSO-E synchronous zone due to the connection of the IPS of Ukraine was raised in 2005. Ukraine expressed its desire to follow European standards by signing the Agreement on the Conditions for the Future Interconnection of the Power System of Ukraine with the Power System of Continental Europe and adopting its new energy strategy in 2017. A chronology of events regarding the integration of Ukraine's energy system into the European energy system is presented in the Executive Summary of Studies for Synchronous Interconnection of Grids of Continental Europe and Ukraine/Moldova (Ukrenergo n.d.). During this time, the power units of Ukrainian nuclear power plants, thermal power plants, combined heat and power plants, and hydroelectric power stations were tested. A mathematical model of the energy systems of Ukraine and Moldova was created, based on which the ENTSO-E TSO Consortium conducted research on the static and dynamic stability of the energy systems of Ukraine and Moldova when operating with the Continental Europe network. The research results have demonstrated the technical feasibility of synchronization. Ukraine joined the unified energy system of Continental Europe ENTSO-E on March 16, 2022, one year ahead of schedule. The energy systems of Ukraine and Moldova are fully synchronized with the Continental Europe ENTSO-E energy grid.

Currently, ENTSO-E, the European Network of Transmission System Operators for Electricity, is the association for cooperation between European transmission system operators (TSOs). The 40 member TSOs, representing 36 countries, are responsible for the secure and coordinated operation of Europe's electricity system, the largest interconnected electrical grid in the world (see Figure 7) (ENTSO-E 2023).



**Figure 7. ENTSO-E Members as of December 2023.** Source: ENTSO-E (2023). © ENTSO-E.

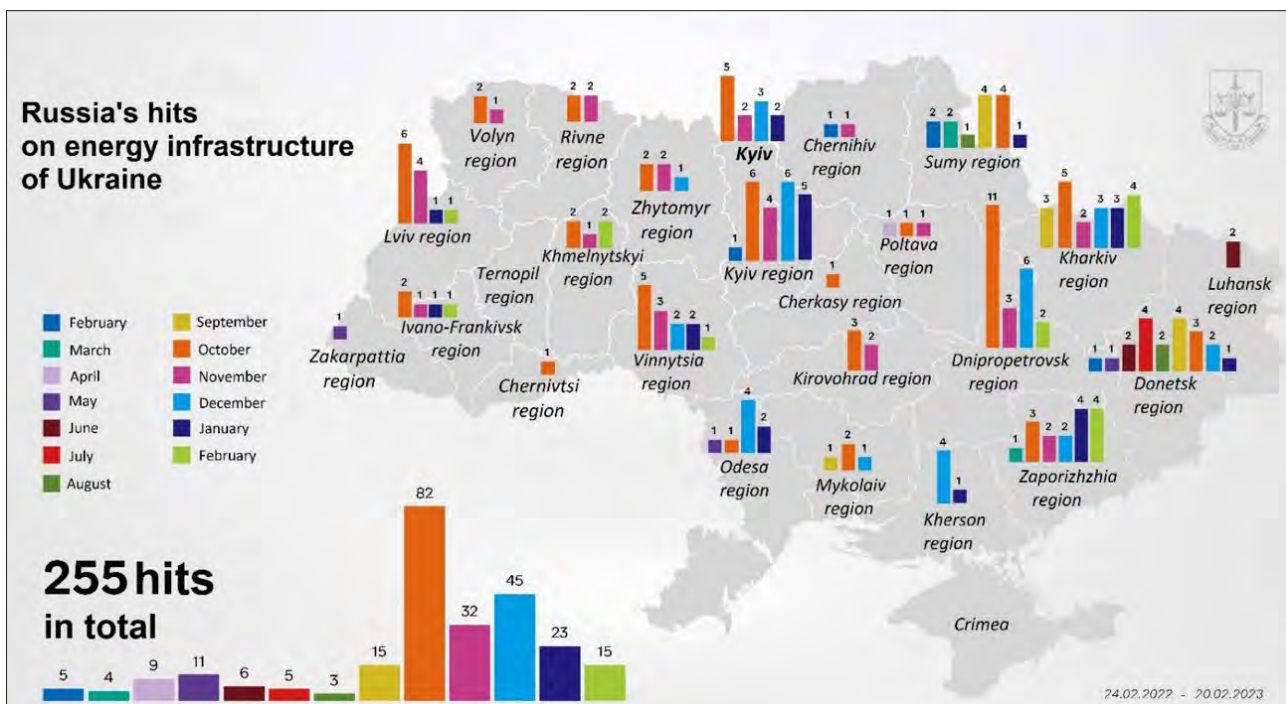
One of the greatest opportunities that Ukraine gained after synchronization with the Continental European network (ENTSO-E) was the export of electric energy. Typically, Ukraine's surplus energy system now has opportunities to sell excess electricity to neighboring Poland, Slovakia, Romania, Hungary, and Moldova. After two years of synchronous operation between the energy systems of Ukraine and Europe, the export of electricity to neighboring countries amounted to three million MWh, with imports from European countries reaching one million MWh (Ukrinform 2024). Significant destruction caused by the aggressor has affected both the country's internal energy balance and the prospects for selling energy to EU countries. Ukraine's export potential has significantly diminished.

The following part draws the readers' attention to damage in the power sector, which has faced persistent attacks on its infrastructure since February of 2022. Intensified assaults starting in early October 2022 inflicted widespread damage nationwide. Ukraine's energy infrastructure has since endured multiple attacks, including cyberattacks on energy companies, causing significant damage to the integrated energy system, including power generation and transmission infrastructure (see Figure 8).

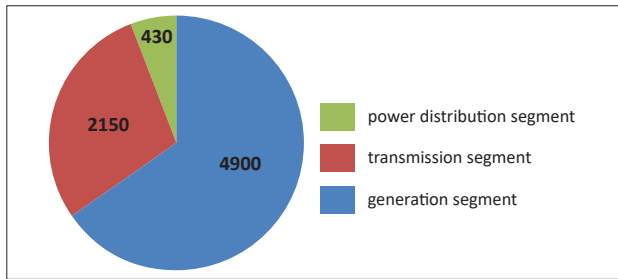
The electricity production and transmission sectors have suffered the most from Russian aggression. From October 2022 to February 2023, the Russian Federation launched large-scale attacks on electricity facilities. Regular shelling of energy infrastructure

continued in frontline regions. In early June 2023, Russia destroyed the Kakhovka Hydroelectric Power Station, with direct losses estimated at \$586 million. Rebuilding a similar capacity station will cost approximately \$1 billion. According to the Third Rapid Damage and Needs Assessment prepared by the World Bank, the Government of Ukraine, the European Union, and the United Nations (2024), the power sector has suffered the largest share of wartime damage, amounting to \$7.5 billion USD. Within this sector, the generation segment has incurred the most damage at \$4.9 billion USD, followed by the transmission segment with \$2.15 billion USD in damages. The damage to the power distribution sector is estimated at approximately \$430 million USD, though this figure does not include assets in territories temporarily not under the control of the Government of Ukraine (see Figure 9).

Revenue decline is happening as a result of assaults on energy infrastructure, mass displacement, economic downturn, and rising poverty. Revenue losses are worsened by decreased collection rates, especially near the front line. The power sector has lost \$31.97 billion, with recovery needs totaling \$40.4 billion over 10 years, including green transition efforts and EU alignment. The highest needs are in Zaporizska, Kharkivska, and Donetsk oblasts. So far, \$1.73 billion has been disbursed, and \$3.19 billion committed (World Bank et al. 2024). Fulfilled needs include repairing power transmission equipment, constructing protective infrastructure, establishing transmission connections, installing voltage-regulating devices, restoring hydropower plants,



**Figure 8. The RF's Hits on Energy Infrastructure of Ukraine.** Source: Cooperation for Restoring the Ukrainian Energy Infrastructure Project Task Force (2023a). © International Energy Charter.



**Figure 9. Direct Infrastructure Damage to Electricity Facilities, in Millions of Dollars.** Prepared by the author.

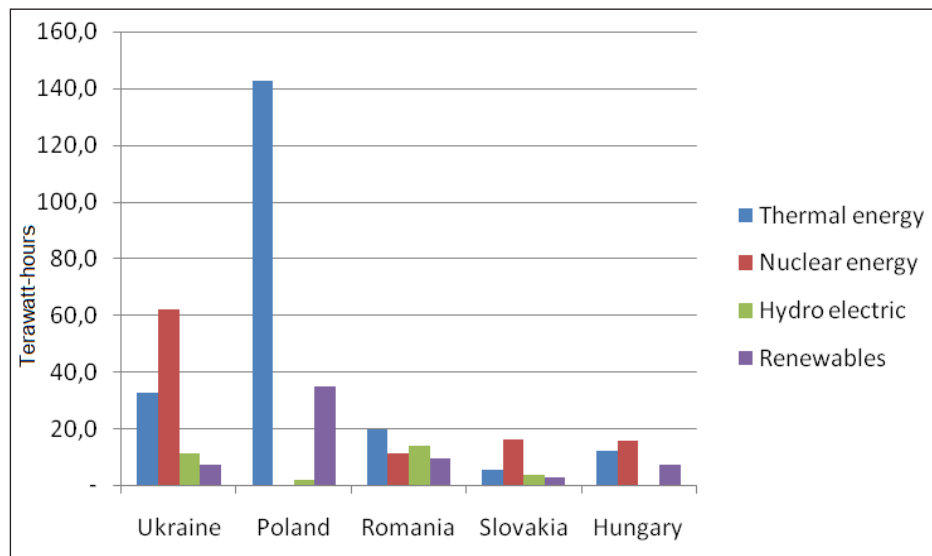
setting up distributed generation facilities, and procuring for the heating season. As of February 2024, Russia has not achieved its main objective of inflicting continuous and irreparable damage to the infrastructure for political purposes. It is worth noting that since February 2022, Ukraine has received a lot of help in renovating its power system from different international donors. A major part of it was provided by the Ukraine Energy Support Fund (Energy Community Secretariat n.d.-a) established by the Energy Community Secretariat (Energy Community Secretariat n.d.-b) in 2022. This initiative is part of broader efforts led by the Energy Community, an international organization that brings together the EU and its neighbouring countries to create a pan-European energy market.

## 2. Cross-Border Cooperation Between Ukraine and the EU Countries in the Energy Sector

This part highlights the role of borders, the state, and trends of EU-Ukraine cross-border energy cooperation. In today's conditions, cross-border cooperation in

Ukraine serves simultaneously as a tool for the development of border areas and as a driving force for the implementation of its European integration aspirations through the prism of European state and societal interaction. Cooperation between Ukraine and the EU in the energy sector is one of the important directions of sectoral European integration, which has developed dynamically. Recently, due to Russian missile attacks, it has gained decisive importance. Ukrainian energy infrastructure facilities have been targeted by Russia since the beginning of the full-scale invasion, and since October 2022, the Russians have been on a course to completely destroy it; "50% of Ukraine's energy infrastructure has been damaged—Russia must be held accountable", says Herman Galushchenko (Ministry of Energy of Ukraine 2023a). The successful synchronization of Ukraine and Moldova's electricity grids with the European Energy Network of Transmission System Operators (ENTSO-E) ensured grid stability for Ukraine and facilitated the import/export of electricity. The benefits for Ukraine were evident: enhanced investment opportunities and alignment with European energy standards, both of which are appealing to investors. For the EU, this marked a significant shift in the regional energy landscape, introducing Ukraine as a robust and dependable electricity supplier. Against the backdrop of the energy crisis resulting from Russia's war, Ukrainian electricity to the EU was poised to bolster energy security, diversify markets, and provide energy with neutral carbon emissions. On the whole, energy cross-border cooperation is a productive means of ensuring internal stability in the conditions of a large-scale war, as well as a tool for integration into the EU internal market.

The amount of electrical energy generated in Ukraine and Ukrainian border regions—Poland, Romania, Slovakia, and Hungary—during 2022 is shown in Figure 10 (Energy Institute 2023). Based on the analysis of



**Figure 10. Electrical Energy Generated by Ukraine, Poland, Romania, Slovakia, and Hungary.** Prepared by the author.



statistical data, it was established that, as of 2022, Poland produces the largest amount of electrical energy. However, a significant share of electrical energy in Poland is generated at thermal power plants, and therefore it has high-carbon greenhouse gas emissions. At the same time, Poland is also a leader in the generation of green electricity.

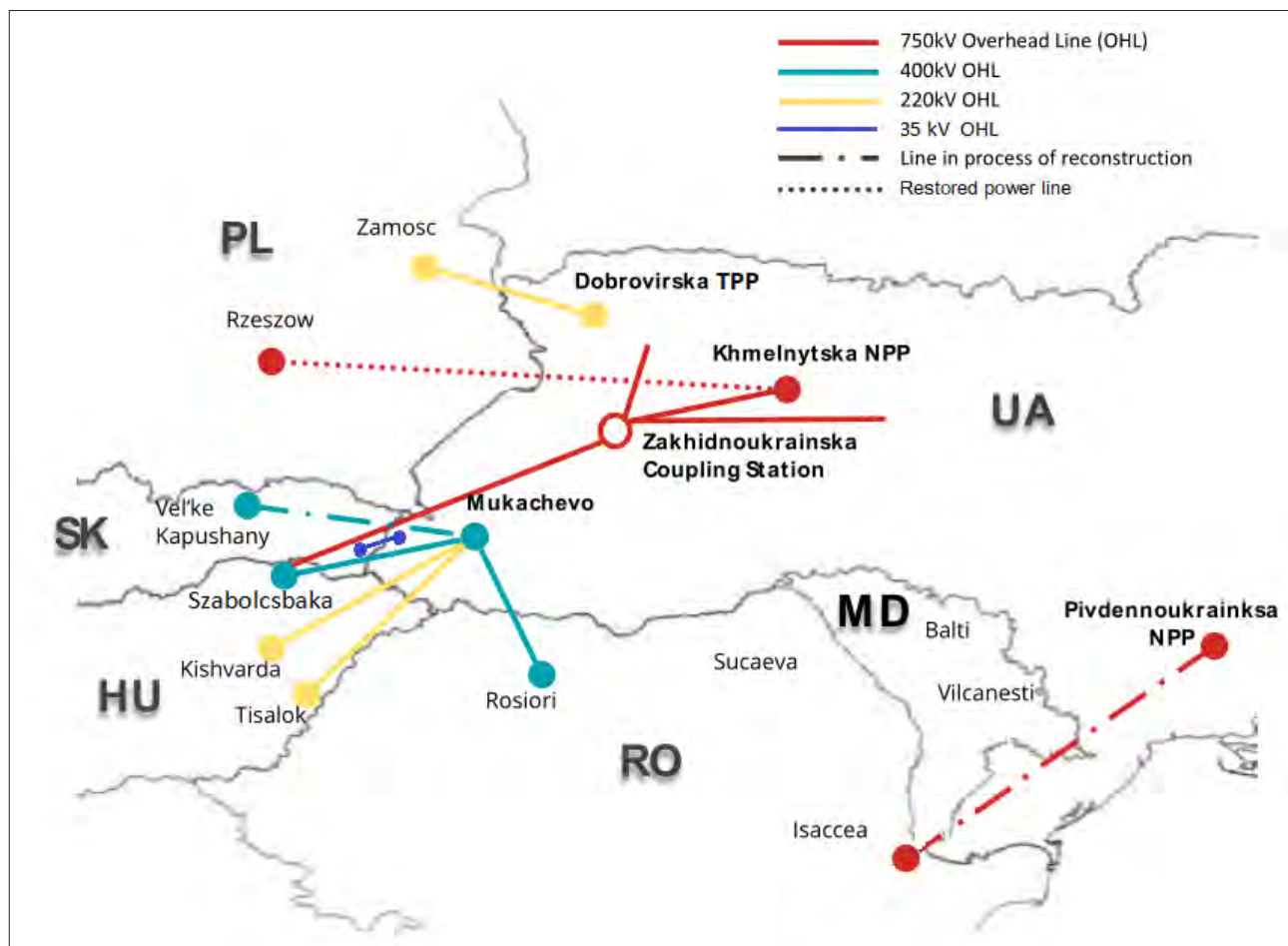
In particular, the development of renewable energy sources is also notable in Romania, Slovakia, and Hungary. As for Ukraine, currently, more than 70% of the electricity produced in the country is low-carbon in terms of greenhouse gas emissions. This achievement is attributed to a high proportion of nuclear and hydrogen generation, as well as an increasing share of renewable energy sources. Consequently, Ukraine can supply neighboring EU states with affordable and low-carbon electricity. An important factor in this regard is the availability of international power transmission lines, which are illustrated in Figure 11.

The number of existing cross-border transmission lines to Ukraine's neighbors, classified by voltage class, is shown in Table 2.

**Table 2. Number of existing cross-border transmission lines to Ukraine's neighbours, by voltage class.** Prepared by the author.

Country	Transmission lines, voltage class kV					
Ukraine to	750 kV	400 kV	330 kV	220 kV	35 kV	Total
Poland	1			1		2
Slovakia		1			1	2
Hungary	1	1		2		4
Romania	1	1				2

Hence, the presence of cross-border electricity transmission lines and the integration of Ukraine's energy system with ENTSO-E enable close cooperation with neighboring countries in the energy sector. Figure 12 illustrates the magnitude of imported and exported electrical energy to neighbouring countries in 2023. According to analytical data from the leading consulting company Exploration & Production Consulting (EXPRO Consulting 2024), for the entire year of 2023, the majority of electricity imports came from Slovakia, accounting for 69%. Ukraine exported the most electricity



**Figure 11. Transmission Lines Between Ukraine and Neighbouring EU States.** Prepared by the author.

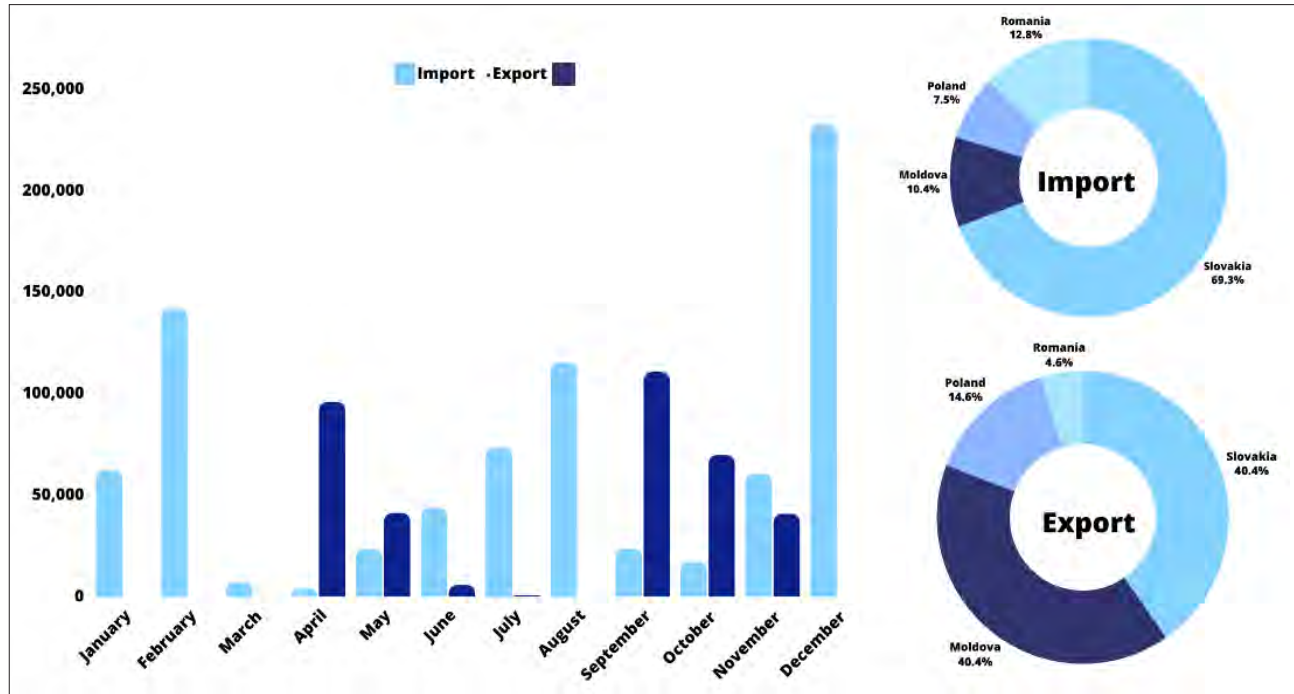


Figure 12. Import and Export of Electricity in 2023, MWh. Source: EXPRO Consulting (2024). © EXPRO Consulting

to Moldova and Slovakia, each accounting for 40% of the total electricity exports. There was no import or export of electricity between Ukraine and Hungary. In total, for the entire year of 2023, the volume of imports amounted to 806.4 thousand MWh, and exports totaled 366 thousand MWh.

## 2.1 Cross-border cooperation between Ukraine and Poland in the energy sector

By highlighting the cross-border cooperation between Ukraine and Poland in the energy sector, it must be noted that there are two cross-border power transmission lines between Ukraine and Poland at voltages of 220 kV and 750 kV (see Table 3).

Table 3. Cross-border Transmission Lines Between Ukraine and Poland. Prepared by the author.

Transmission lines, voltage class kV	Ukraine	Poland
OHL 750 kV	Khmelnyska Nuclear Power Plant	Rzeszow
OHL 220 kV	Dobrotvirska Thermal Power Plant	Zamostia

The 220 kV overhead cross-border power transmission line from Dobrotvirska Thermal Power Plant (UA) to Zamostia (PL) was the first export line between the Soviet Union and the former Polish People's Republic,

from which the "Mir" energy system (the Union of Energy Systems of the socialist bloc) originated. This 220 kV power transmission line connects substations in Zamostia (PL) and Dobrotvir Thermal Power Plant (UA). The line was operational for the needs of the Polish power system even before the war and Ukraine's synchronization with the continental European energy system. The maximum permissible export capacity of the line is up to 235 MW.

The 750 kV cross-border power transmission line from Khmelnytsky Nuclear Power Plant (UA) to Rzeszów (PL) lay dormant as of the early 1990s. However, in May 2023, Ukraine and Poland restored this line, which spanned nearly 400 km, with over 70% traversing Ukrainian territory. Connection to the main power grid occurred through an open distribution device at a Ukrainian energy facility, where the majority of the work was concentrated. Here, Ukrainian-generated electricity is converted to the European standard voltage of 400 kV for transmission to Europe. The project's total cost amounted to 350 million hryvnias, with essential equipment provided at no cost by Polish partners. Commissioning of that line augmented Ukraine's export potential by 25 to 30%, significantly reducing Poland's reliance on Russian gas and coal. Operating in synchronous mode, the line is accessible to all participants in the Ukrainian and European markets.

It should be noted that transboundary cooperation between Ukraine and Poland in the energy sector is of great importance for ensuring the energy security of



both countries. With the aim of expanding transboundary cooperation, in February 2024, the construction of three major power transmission lines to Poland was announced. These new transboundary lines are Novovolynsk (UA)–Chełm (PL), Lviv (UA)–Krosno (PL), and Drohobych (UA)–Krosno (PL). Additionally, Ukraine and Poland signed a memorandum of cooperation in the energy sector on March 28, 2024 (Ministry of Energy of Ukraine 2024). The implementation of this document will enable: the development of joint programs and projects of common interest aimed at restoring energy infrastructure affected by war, as well as steps towards greater integration of energy markets; collaborative work in the development of climate-neutral technologies and the expansion of distributed generation; and ensuring energy security through market integration, the development of climate-neutral generation, the formation of projects of common interest, and the development of interstate crossings.

## 2.2 Cross-border cooperation between Ukraine with Slovakia in the energy sector

Power systems of Ukraine and Slovakia are interconnected with two cross-border power transmission lines operating at voltages of 400 kV, Mukacheve (UA)–VelkeKapusany (SK), and 35 kV, Uzhhorod 2 (UA)–Sobrance (SK) (Table 4).

**Table 4. Cross-border Transmission Lines Between Ukraine and Slovakia.** Prepared by the author.

Transmission lines, voltage class kV	Ukraine	Slovakia
OHL 400 kV	Mukachevo	VelkeKapusany
OHL 35 kV	Uzhhorod 2	Sobrance

It is worth mentioning that the length of the 400 kV high-voltage line is 42 km on the territory of Ukraine and 11 km on the territory of Slovakia. Currently, ongoing reconstruction is being conducted on the international power transmission line between Ukraine and Slovakia. The reconstruction and modernization of the electrical interconnector "Mukacheve–Vel'keKapusany" were initially scheduled for completion by the end of 2028. However, in January 2024, both countries agreed to expedite the reconstruction process. These initiatives are expected to significantly enhance the capacity for electricity import and export. Through the reconstruction and upgrading of existing overhead lines (OHL) between Slovakia and Ukraine, along with related substations, transmission capacity is projected to increase by 30% between the Slovak and Ukrainian power systems. This project's implementation is anticipated to bolster system stability within the region. The removal of existing constraints on power flows between the Slovak and Ukrainian power systems, as well as between the Hungarian, Romanian, and Ukrainian power

systems, will have implications for pricing and conditions within the European electricity market. Ultimately, the reconstruction of the electrical interconnector will contribute to bolstering the energy security of both Slovakia and Ukraine. Additionally, there is a 35 kV power transmission line between Ukraine and Slovakia, Uzhhorod 2–Sobrance. This line has a low capacity of 10 MW. Strengthening bilateral cooperation between Ukraine and the Slovak Republic in the field of electric power engineering involves: developing the interconnection of energy systems between Ukraine and the Slovak Republic, and further exploring the potential of the Mukacheve–Vel'keKapusany interconnector as the next step after the successful synchronization of Ukrainian networks with the European continental network ENTSO-E (Communications Department of the Secretariat of the CMU 2024); activating cooperation in the field of nuclear energy, and supporting missions of the International Atomic Energy Agency (IAEA) in monitoring nuclear safety and security at nuclear power plants within the territory of Ukraine; organizing cross-border transportation of hydrogen by road; and developing border areas through the implementation of projects of mutual interest in energy efficiency, alternative fuel utilization, decarbonization, and renewable energy.

For this purpose, a Roadmap for cooperation between Ukraine and Slovakia was signed in April 2024 (Cabinet of Ministers of Ukraine 2024). The strategic area of bilateral cooperation in this Roadmap is energy security. The Parties agreed to the need to maintain and develop interconnectivity of energy systems between Ukraine and the Slovak Republic, guaranteeing non-discriminatory access to the Ukrainian energy market for Slovak energy companies, increasing the transparency of data exchange, eliminating the non-systemic tax burden imposed on cross-border trading, launching common energy projects to diversify energy sources and reduce dependence on Russian energy resources wherever possible, ensuring a high level of energy efficiency and development of renewable energy sources, as well as increasing the resilience of energy systems in Ukraine and the Slovak Republic and European energy security. Collaboration between Ukraine and Slovakia in the energy sector is already of significant importance for both countries. Furthermore, in April 2024, Ukraine and Slovakia agreed to establish a working group to deal with the diversification of nuclear fuel supply to nuclear power plants. That action aimed at further mitigation of Russian leverage in order to balance Russian influence.

## 2.3 Cross-border cooperation between Ukraine and Romania in the energy sector

There are two cross-border power transmission lines between Ukraine and Romania, operating at 400 kV and 750 kV respectively (see Table 5).

**Table 5. Cross-border Transmission Lines Between Ukraine and Romania.** Prepared by the author.

Voltage level (kV)	Ukraine	Romania
400 kV	Mukacheve	Roshior
750 kV	Pivdennoukrainska Nuclear Power Plant	Isaccea

The 750 kV overhead line from Pivdennoukrainska Nuclear Power Plant (UA) via Isaccea (RO) to Varna (BG) was initially part of the "Mir" energy system development, connecting three countries: the USSR, Romania, and Bulgaria, with a complex crossing of the Danube River. Constructed for exporting electricity to Romania and Bulgaria, the line gradually deteriorated after the dissolution of the USSR. The importance of enhanced cooperation between the energy systems of Romania and Ukraine was highlighted when Ukraine and Romania discussed the implementation of agreements on the restoration of an international overhead power line between the 750 kV South Ukrainian NPP and the 400 kV Isaccea substations in August 2023. This project is of great importance for increasing the capacity of cross-border grids, as well as enhancing the reliability of electricity supply to consumers in the southern regions of Ukraine and removing restrictions on the output of renewable energy generation capacity in these areas (Ministry of Energy of Ukraine 2023b).

The sole operational power transmission line between Ukraine and Romania is the 400 kV line between the Mukachevo and Roshior substations. The line has a capacity of 200 MW. The 76 km stretch of the 400 kV power line extends mainly through agricultural land in the Zakarpattia region to the state border with Romania. In 2018, reconstruction of this power line was carried out. During the maintenance, 36.87 km of lightning protection cable (23.5 tons), line hardware, and porcelain insulators were replaced. These works represent an important component in enhancing the reliability of cross-border connections in conditions of synchronous operation with ENTSO-E networks. Ukraine and Romania closely cooperate in the energy sector. As a result, from 2020 to 2022 the Cross-Border Cooperation Smart Energy project was implemented (Uzhhorod National University 2022). Main project outcomes include: increased usage of new technologies and innovations in the field of renewable energy, achieved through promotion and support of research and innovations in a sustainable manner in the border regions of Ukraine and Romania; and establishment of a robust platform for joint research actions and studies (including procurement of related equipment) in the field of renewable energy and resource efficiency.

To conclude, deepening the energy sector partnership between Kyiv and Bucharest would not only boost regional security and facilitate a smoother energy

transition, but could also yield economic dividends. In 2022, Romania offered Kyiv significant support, exporting electricity and helping to stabilize the Ukrainian system when Russian airstrikes plunged much of Ukraine into darkness. The bulk of Romanian power generation is concentrated in the southeastern region of Dobrogea, which possesses an excess of renewable output that cannot be easily transported to other regions. Unless major investments are made to reroute flows northward, Romania will not be able to build additional offshore wind capacity in its share of the Black Sea region. One option would be to export some of the excess generation to decongest the system. Southern Ukraine's region of Odessa, which shares a border with Romania, has a supply deficit and needs to import electricity to cover demand, particularly in a postwar scenario where its industrial base would be rebuilt.

## 2.4 Cross-border cooperation between Ukraine and Hungary in the energy sector

The highest quantity of cross-border power transmission lines is situated between Ukraine and Hungary (see Table 6).

**Table 6. Cross-border Transmission Lines Between Ukraine and Hungary.** Prepared by the author.

Voltage level (kV)	Ukraine	Hungary
750 kV	Zakhidnoukrainska	Szabolcsbaka
400 kV	Mukacheve	Szabolcsbaka
220 kV	Mukacheve	Tiszaok
220 kV	Mukacheve	Kishvarda

The 750 kV cross-border power line between the Zakhidnoukrainska (UA) and Szabolcsbaka (HU) substations is of significant importance for the transportation of electricity. It is part of the 750 kV corridor 'Vinnytsia-Zakhidnoukrainska-Albertirsha,' which was one of the ambitious projects of the USSR to implement the 'Mir' energy system and extended to the geographical center of Hungary. The length of the transmission line is 479 km. Currently, the line is one of the main connections of the UES of Ukraine with operators of the ENTSO-E transmission system. From 2017 to 2020, Hungary cut the Zakhidnoukrainska-Albertirsha line, installing a new 750/400 kV Szabolcsbaka substation and leaving only 19 km of the line on its territory to the Ukrainian border, which operates at a voltage class of 750 kV. The Szabolcsbaka-Albertirsha section has been converted to a voltage of 400 kV. The 400 kV cross-border power line is located between the Mukacheve (UA) and Szabolcsbaka (HU) substations. The length of the line is 26.5 km from the 400 kV Mukacheve substation to the state border with Hungary. In 2020, the reconstruction of this transmission line was completed, with the replacement of conventional lightning protection cables with optical fiber ones to provide optical

telecommunication links. This reconstruction allowed for the transmission of relay protection commands and emergency automation, as well as for the creation of an E-highway (Electronic Highway, a data transmission network of ENTSO-E transmission system operators) towards Hungary.

In 2020, reconstruction was completed for the 220 kV cross-border power lines between the Mukachevo (UA)–Kishvarda (HU) and Mukachevo (UA)–Tisalok (HU) substations, including the installation of telecommunication equipment to connect the telecommunication networks of Ukrenergo with those of ENTSO-E partner countries. Thus, the reconstruction of the Transboundary Power Transmission Lines between Ukraine and Hungary has ensured a modern level of communication between the facilities of the Western Energy System of Ukrenergo and has allowed for the integration of Ukrenergo's telecommunication networks with the networks of ENTSO-E partner countries. Commercial electricity exchange with Hungary has not taken place since February 2022, however, the transition to European electricity trading rules has allowed this exchange to resume. Specifically, in February 2024, Ukrenergo conducted the first joint auctions for the allocation of access to international interconnectors between Ukraine and Hungary on the European universal allocation platform JAO (Joint Allocation Office). Ukraine began commercial electricity exchange with Hungary according to European rules.

### 3. Conclusion and Policy Recommendations

Analysis of the capacity of the respective cross-border power transmission lines between Ukraine and Poland, Slovakia, Hungary, and Romania, as well as an assessment of electricity imports and exports in 2023, indicate close cooperation between Ukraine and neighboring countries in the energy sector. Additionally, implementing the project to construct a new fiber-optic communication line has provided a modern level of communication between Ukrenergo's energy system facilities and has allowed for the integration of Ukrenergo's telecommunication networks with the cross-border networks of ENTSO-E partner countries (Slovakia, Romania, and Hungary).

Based on the research conducted on the state of cross-border cooperation between Ukraine and EU countries in the energy sector, it has been established that there is a need to increase the volume of export and import operations as well as the throughput capacity of cross-border power lines. Increasing the volume of export operations and the throughput capacity of interstate crossings to 7.5 GW is possible through:

- with Poland—the construction of an additional 400 kV power line;
- with Romania—by rebuilding the 750 kV cross-border

transmission line from the Uzhnoukrainska (South Ukrainian Nuclear Power Plant) to Isaccea and retrofitting the double-circuit 400 kV Primorska–Isaccea power line;

- with Hungary—by removing balancing constraints and increasing the load on the 400 kV Mukacheve–Szabolcsbakacross-border transmission line;
- with Slovakia—by retrofitting the double-circuit 400 kV Mukacheve–VelkeKapusanycross-border transmission line.

To enhance cross-border cooperation, it will also be necessary to achieve “full” integration of the energy markets of Ukraine and the EU in the post-war period. To accomplish this, it is necessary to realize the export potential of Ukrainian nuclear energy; develop distributed energy generation, particularly from renewable sources, with equipment production in Ukraine; and establish a storage system for the complete cycle of energy.

Given the uncertainty of the duration of hostilities, and the continued risk of further destruction and the loss of Ukraine's control over infrastructure facilities, full stabilization of the situation in the energy sector is impossible at least until the end of the war. Therefore, the priority tasks for the short term are:

- preservation of the integrity of the United Energy System (UES) of Ukraine and prompt restoration of its facilities after each attack;
- elimination of territorial imbalance in the production and consumption of electric and thermal energy;
- restoration of fuel and energy supply to areas with destroyed infrastructure;
- development of backup, in particular between neighbouring states, and autonomous networks and systems that can be used in the event of a system accident;
- provision of continuous supply of energy resources across the western border of Ukraine in volumes sufficient for consumers;
- ensuring the reliable and safe functioning of currently operational energy facilities.

To implement these tasks, Ukraine needs international assistance, including from neighboring countries, and quick actions towards integration with the EU energy markets in the following directions:

- supply of equipment for the transmission and distribution of electrical energy, primarily high-voltage, and exclusively at the request of operators and generating companies, for replacement of equipment damaged as a result of hostilities;
- expansion of the capacity of international crossings with Poland, Romania, Slovakia, and Hungary to increase the reliability of the operation of the UES of Ukraine;



- unification of the day-ahead market and the intra-day market of Ukraine with the Single Day-ahead Coupling and Single Intraday Coupling markets to obtain the possibility of exporting electricity;
- supply of cogeneration units, gasoline and diesel generators, and energy storage and energy storage systems for guaranteed energy supply to consumers, especially critical infrastructure facilities, in the event of a system failure;
- guaranteeing the physical safety of the Zaporizhzhia NPP and returning control, in particular, control of its airspace.

Therefore, speaking about the further tactical and strategic prospects of cooperation across EU-Ukrainian borders in the field of energy and speeding up the European integration of Ukraine, it is worth highlighting the following priority directions:

- restoration of the Ukrainian energy industry based on new technologies and deepening of its integration into the European energy system (National Council for the Recovery of Ukraine from the Consequences of the War 2022; Communications Department of the Secretariat of the CMU 2022);
- creation of a national system of trading quotas for greenhouse gas emissions (European Commission n.d.);
- increasing energy efficiency (Verkhovna Rada of Ukraine 2022);
- development of the sector of renewable energy sources (State Energy Efficiency and Energy Saving Agency of Ukraine 2022);
- creation of a hydrogen industry;
- combating climate change, reducing GHG emissions (Omelchenko et al. 2022);
- implementation of the European Green Deal (International Energy Agency 2025).

The author submits the following proposals to improve Ukraine-EU cross-border energy cooperation:

- implement a set of measures for further liberalization of electricity markets for the future increase in electricity trade with EU countries. As a result, consumers from Central and Eastern Europe will start paying less for electricity;
- increase the capacity of the inter-network connection with neighboring Hungary, Poland, Romania, and Slovakia. As a result, Europe will annually save 5 billion cubic meters of gas used for electricity production;
- during large-scale reconstruction of Ukraine after the end of the war, the demand for electricity in the country may increase sharply. When the Ukrainian economy requires more energy, the connection with ENTSO-E will have to be put into reverse mode, and Ukrainian companies will start importing energy from the EU. The effect of the restoration of the Ukrainian energy demand will affect the entire region—for

European manufacturers it is an opportunity to increase and diversify production;

- expanding cooperation with European and global energy structures. Ukraine is now an associate member of the International Energy Agency (IEA), which gave Ukraine the opportunity to participate in the development of policies for global energy markets;
- reformatting of the energy sector of Ukraine within the framework of the European Green Deal. Ukraine's energy transition should be based on a powerful nuclear sector, an increase in wind and solar energy, and hydropower production;
- define an ambitious goal to reduce GHG emissions by more than 70% by 2030, compared to 1990, primarily by revising the goals for industries, increasing the share of RES in the electricity, transport, and heat supply sectors. (Climate goals should be revised after the war, but they should not be less ambitious given the growing importance of energy security and energy independence from fossil fuels);
- provide conditions for the development of the hydrogen industry of Ukraine, owing to EU investments. It is necessary to introduce relevant EU norms and standards into the legislation of Ukraine;
- actively introduce the criteria of sustainable development in the process of post-war reconstruction of energy facilities and infrastructure with a focus on the effective use of energy resources and "green" technologies. Revitalization of the energy industry should be based on innovation and development of smart networks. When developing a recovery concept, the carbon-neutral component is important;
- identify implementation of the energy efficiency policy, the development of renewable energy—including the use of hydrogen and biomethane—as well as decarbonization, which are components of the European integration process, as priority areas;
- jointly with the EU, start the process of determining and demanding subsequent compensation for damages and payment of appropriate reparations by the aggressor, in particular in the energy sector.

Therefore, an analysis of Ukraine's power sector and cross-border transmission system highlights both challenges and opportunities, emphasizing the urgent need for deeper cooperation with neighboring EU countries. The destruction of approximately 50% of Ukrainian power plants due to ongoing military aggression underscores the critical role of cross-border energy trade and integration with ENTSO-E in ensuring stability and supporting post-war reconstruction. In this context, strengthening partnerships with Poland, Romania, Hungary, and Slovakia not only enhances energy security and mutual economic benefits, but also accelerates the transition to a more resilient and sustainable energy system. Looking ahead, post-war cooperation should prioritize energy efficiency, renewable energy development, hydrogen technologies, distributed energy

generation, and climate change mitigation. Aligning these efforts with the European Green Deal will not only advance Ukraine's European integration, but also reinforce its strategic role in the regional energy market, fostering a stable and interconnected energy future.

## Works Cited

- Bajs, Davor. 2021. "Electricity Interconnection Targets in the Energy Community Contracting Parties" *Energy Community Secretariat*, Am Hof 4, 1010 Vienna, Austria. <https://www.energy-community.org/publications/studies.html>
- BiuroPTPIREE. 2022. "System Energetyczny Ukrainy" *Energia Elektryczna*3. <https://e-elektryczna.pl/rynek-i-regulacje/system-energetyczny-ukrainy/>
- Cabinet of Ministers of Ukraine. 2024. "Roadmap Joint Actions Between Ukraine and The Slovak Republic". <https://www.kmu.gov.ua/storage/app/sites/1/uploaded-files/Roadmap%20UA%20SK.pdf>
- Communications Department of the Secretariat of the CMU. 2022. "Joint Press Release Following the 8th Association Council Meeting Between the EU and Ukraine" *Cabinet of Ministers of Ukraine* (September 5). <https://www.kmu.gov.ua/en/news/spilnyi-pres-reliz-za-pidsumkami-8-ho-zasadannia-rady-asotsiatsii-mizh-ies-ta-ukrainoiu>
- Communications Department of the Secretariat of the CMU. 2024. "Joint Statement of the Prime Ministers of Ukraine and the Slovak Republic" *Cabinet of Ministers of Ukraine* (January 24). <https://www.kmu.gov.ua/en/news/spilna-zaiava-premier-ministriv-ukrainy-ta-slovatskoi-respubliki>
- Cooperation for Restoring the Ukrainian Energy Infrastructure Project Task Force. 2023a. *Ukrainian Energy Sector Evaluation and Damage Assessment – VII (as of February 24, 2023)*. Brussels: International Energy Charter. [https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2023\\_02\\_27\\_UA\\_sectoral\\_evaluation\\_and\\_damage\\_assessment\\_Version\\_VII.pdf](https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2023_02_27_UA_sectoral_evaluation_and_damage_assessment_Version_VII.pdf)
- Cooperation for Restoring the Ukrainian Energy Infrastructure Project Task Force. 2023b. *Ukrainian Energy Sector Evaluation and Damage Assessment – VII (as of May 24, 2023)*. Brussels: International Energy Charter. [https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2023\\_05\\_24\\_UA\\_sectoral\\_evaluation\\_and\\_damage\\_assessment\\_Version\\_X\\_final.pdf](https://www.energycharter.org/fileadmin/DocumentsMedia/Occasional/2023_05_24_UA_sectoral_evaluation_and_damage_assessment_Version_X_final.pdf)
- ENTSO-E. 2023. "Ukrainian Transmission System Operator, NPC Ukrenergo, Joins ENTSO-E as New Member" (December 14). <https://www.entsoe.eu/news/2023/12/14/ukrainian-transmission-system-operator-npc-ukrenergo-joins-entso-e-as-new-member/>
- Energy Community Secretariat. "Ukraine Energy Support Fund". <https://www.energy-community.org/Ukraine/Fund.html> and <https://www.energy-community.org/aboutus/secretariat.html>
- Energy Community Secretariat. "Who We Are". <https://www.energy-community.org/aboutus/whoweare.html>
- Energy Institute. 2023. "Statistical Review of World Energy". <https://www.energyinst.org/statistical-review>

- European Commission. "EU Emissions Trading System (EU ETS)". [https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets\\_en](https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en)
- EXPRO Consulting. 2024. "In December 2023, Ukraine Imported a Record Amount of Electricity for the Year" (January 4). <https://expro.com.ua/en/tidings/in-december-2023-ukraine-imported-a-record-amount-of-electricity-for-the-year>
- International Energy Agency. 2025. "Joint Communication to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions: EU External Energy Engagement in a Changing World" (June 24). <https://www.iea.org/policies/15693-joint-communication-to-the-european-parliament-the-council-the-european-economic-and-social-committee-and-the-committee-of-the-regions-eu-external-energy-engagement-in-a-changing-world>
- Ministry of Energy of Ukraine. 2023a. "50% of Ukraine's Energy Infrastructure Has Been Damaged – Russia Must Be Held Accountable, Says German Galushchenko" *Cabinet of Ministers of Ukraine* (March 4). <https://www.kmu.gov.ua/en/news/poshkodzeni-50-enerhetychnoi-infrastruktury-ukrainy-rosiia-maie-vidpovisty-za-tse-herman-halushchenko>
- Ministry of Energy of Ukraine. 2023b. "Energy Ministers of Ukraine and Romania Discuss Areas of Cooperation to Strengthen Energy Security in the Region" *Cabinet of Ministers of Ukraine* (August 22). <https://www.kmu.gov.ua/en/news/ministry-enerhetyky-ukrainy-i-rumunii-obhovoryly-napriamky-spivpratsi-dlia-posylennia-enerhetychnoi-bezpeky-v-rehioni>
- Ministry of Energy of Ukraine. 2024. "Ukraine and Poland Sign Memorandum of Cooperation in the Energy Sector" *Cabinet of Ministers of Ukraine* (March 28). <https://www.kmu.gov.ua/en/news/ukraina-ta-polshcha-pidpysaly-memorandum-pro-spivrobitnytstvo-u-sferi-enerhetyky>
- The National Council for the Recovery of Ukraine from the Consequences of the War. 2022. *Draft Ukraine Recovery Plan, Materials of the 'Energy Security' Working Group*. [https://uploads-ssl.webflow.com/621f88db25fbf24758792dd8/62daca8b804d22348c8d8c08\\_Energy%20Security.pdf](https://uploads-ssl.webflow.com/621f88db25fbf24758792dd8/62daca8b804d22348c8d8c08_Energy%20Security.pdf)
- Omelchenko, Volodymyr, Svitlana Chekunova, Maksim Bilyavskiy, Tetyana Khytryk, Andrii Konechenkov, Mykhailo Mishchenko, and Danylo Dobrovolskyi. 2022. *Dekarbonizaciya ukrayinskoyi energetiki (ekonomiki): vpliv rosijskoyi agresiyi, ambitni cili ta potencijni mozhlivosti dlya Ukrainy v pislyavoyennij period [Decarbonization of Ukrainian energy (economy): impact of Russian aggression, ambitious goals and potential opportunities for Ukraine in the post-war period]*. Kyiv: Razumkov Center, "Zavovit" Publishing House. <https://razumkov.org.ua/images/2022/10/26/2022-Decarbonisation.pdf>
- Smętkowski, Maciej, Anna Kniazevych, Agnieszka Olechnicka, Justyna Orchowska, and Ewelina Przekop-Wiszniewska. 2023. *Research for REGI Committee—Cooperation Between EU Cities and Regions with Their Ukrainian Partners*. Brussels: European Parliament, Policy Department for Structural and Cohesion Policies. [https://www.europarl.europa.eu/RegData/etudes/STUD/2023/733117/IPOL\\_STU\(2023\)733117\\_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2023/733117/IPOL_STU(2023)733117_EN.pdf)

- State Energy Efficiency and Energy Saving Agency of Ukraine. 2022. "The State Energy Efficiency Agency Cooperates with the Energy Community on the Implementation of the 4th Energy Package 'Clean Energy for Europeans'" *Cabinet of Ministers of Ukraine* (May 31). <https://www.kmu.gov.ua/news/derzhenergoefektivnosti-spivpracyuye-iz-energetichnim-spivtovaristvom-shchodo-implementaciyi-4-go-energetichnogo-paketa-chista-energiya-dlya-yevropejiv>
- Ukrenergo. N.d. "Integration with ENTSO-E". <https://ua.energy/european-integration/integration-entso-e/#1625234013591-14c34bbf-dff1>
- Ukrenergo. 2024. "NPC Ukrenergo". <https://ua.energy/en/>
- Ukrinform. 2024. "In Two Years, Ukraine Exported 3 Million MWh of Electricity to Europe - Ukrenergo" (March 16). <https://surl.li/ucpqod>
- Uzhhorod National University. 2022. "Cross-Border Cooperation Smart Energy CBCSmartEnergy (2SOFT/1.2/52)". <https://www.uzhnu.edu.ua/en/cat/projects-cbcs>
- Verkhovna Rada of Ukraine. 2022. "Law 'On Energy Efficiency'". <https://zakon.rada.gov.ua/laws/show/1818-20?lang=en#Text>
- World Bank, Government of Ukraine, European Union, and United Nations. 2024. *Ukraine. Third Rapid Damage and Needs Assessment (RDNA3), February 2022 – December 2023*. <https://ukraine.un.org/sites/default/files/2024-02/UA%20RDNA3%20report%20EN.pdf>
- World Nuclear Association. 2024. "Nuclear Power in Ukraine". <https://world-nuclear.org/information-library/country-profiles/countries-t-z/ukraine#ECSArticleLink0>