TOWARDS A GREEN TRANSITION OF THE ENERGY SECTOR IN UKRAINE

Update on the Energy Damage Assessment

June 2023

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List of abbreviations and acronyms

CHP	Combined Heat and Power
DSO	Distribution System Operator
EUR	Euro currency
GDP	Gross domestic product
GoU	Government of Ukraine
GW	Gigawatt
GWh	Gigawatt hours
HPP	Hydroelectric power plant
IES	Integrated Energy System
IPS	Integrated Power System
Ktoe	Thousand tons of oil equivalent
MoE	Ministry of Energy
MW	Megawatt
MVA	Megavolt-Amperes
MWe	Megawatt electric
NPP	Nuclear power plant
NSDC	National Security and Defence Council
OHCHR	United Nations Office of the High Commissioner for Human Rights
PS	Power Substation
PSPP	Pumped storage power plant
RDNA	Rapid Damage and Needs Assessment
RES	Renewable energy source
RF	Russian Federation
TPP	Thermal power plant
TSO	Transmission System Operator
TWh	Terawatt Hours
UAV	Unmanned aerial vehicle
UN	United Nations
UNDP	United Nations Development Programme
UNHCR	United Nations High Commissioner for Refugees
WPP	Wind power plant
ZNPP	Zaporizhzhia Nuclear Power Plant

STATE-OWNED ENTERPRISES IN THE ENERGY SECTOR

Energoatom	NNEGC Energoatom – Operator of nuclear power plants in Ukraine
Naftogaz	NJSC Naftogaz Ukraine – National oil and gas company
Ukrenergo	NPC Ukrenergo – National electricity transmission system operator
Ukrhydroenergo	PJSC Ukrhydroenergo – Operator of hydropower plants in Ukraine
UGTSO	Ukraine Gas Transmission System Operator

ACKNOWLEDGMENTS

The current report builds on the Ukraine Energy Damage Assessment 2022[1] prepared by UNDP and the World Bank. It presents updated information on the level and scope of damage to the energy sector. It has benefited from data gathered and made available by the Government of Ukraine, specifically by the National Security and Defence Council (NSDC), Ukrenergo, and the Ministry of Energy.

UNDP experts carried out technical analysis for the current Damage Assessment Update. The initial recommendations for the alignment of immediate response and medium-term recovery priorities have been synchronized with the National Energy Strategy of Ukraine approved by the Government of Ukraine (Order of the Cabinet of Ministers of Ukraine dated 21 April 2023, No. 373-p). The recommendations have been prepared based on the report on the assessment of the adequacy (sufficiency) of generating capacities to cover the forecasted demand for electricity and ensure the required reserve prepared by Ukrenergo, and the international commitments of Ukraine, including the National Emission Reduction Plan (NERP) and Ukraine's National Energy and Climate Plan (NECP).

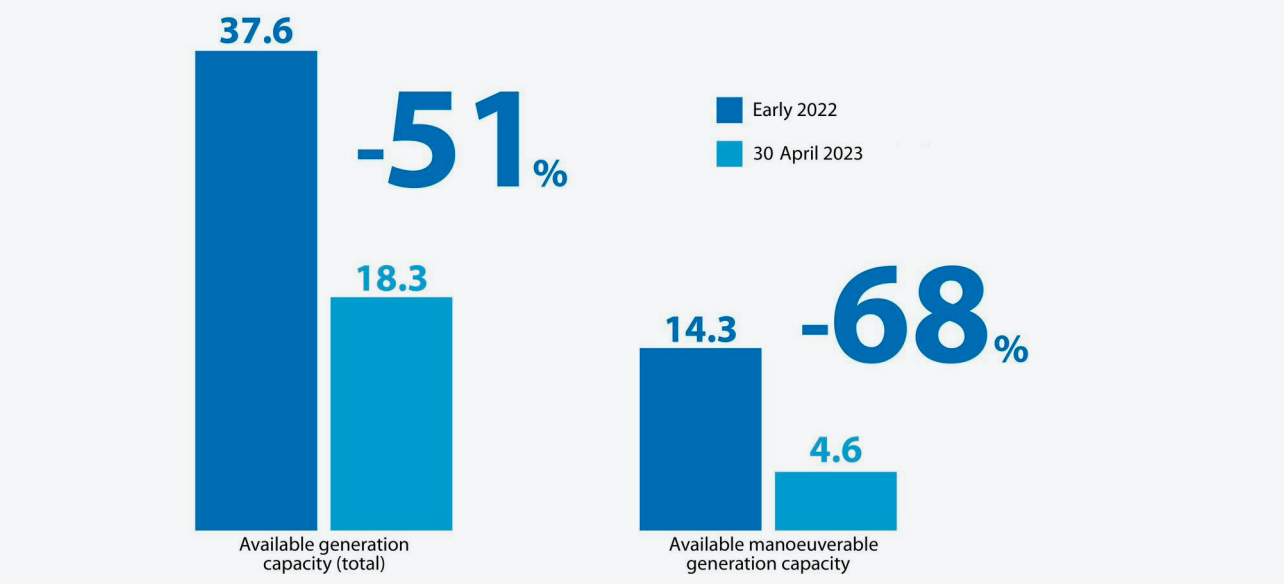
[1] https://ukraine.un.org/sites/default/files/2023-04/UNDPUkraineEnergy_ExecutiveSummary_eng.pdf

EXECUTIVE SUMMARY

Damage in January-April 2023

Ukraine's power system remains extremely vulnerable and continues to operate in emergency mode with hardly any safety margin for both power grids and generation. Generation capacity has decreased by more than half, from 37.6 GW to 18.3 GW as of 30 April 2023. Manoeuvering capacity in the system has suffered the most and decreased by 68 percent from 14.3 GW to 4.6 GW, primarily in thermal power plants. Available nuclear generation capacity decreased by 44 percent from 13.8 GW to 7.7 GW. Available hydro generation capacity decreased 29 percent from 6.6 GW to 4.7 GW. Available RES capacity decreased by 24 percent from 8.1 GW to 6.2 GW. In the transmission network, 42 out of 94 crucial high-voltage transformers have been damaged or destroyed. According to World Bank estimates, damage to power, gas, heating infrastructure, and coal mining exceeds US$10 billion and is increasing. Short-term priority areas to be included in the emergency response continue to be increasing the resilience of the transmission network and providing backup/generation capacities for critical infrastructure. **In the mid-term, the loss of obsolete coal-fired generation opens an opportunity for their replacement using greener alternatives and decentralizing generation capacities**. To achieve this, Ukraine will have to increase transparency through energy market reforms and implement good governance practices as critical prerequisites for private and public investments required for sustainable green transformation.

Figure1. Decline in power generation available capacity, early 2022 – April 2023, total and manoeuverable, GW[2]



From January to April 2023, Ukrenergo's high-voltage substations continued to be attacked, albeit at a significantly lower rate compared to the period from October-December 2022. Four 750 kV substations, three of which were hit more than once, and 18 330 kV substations were affected, with seven hit multiple times and one being damaged for the first time. Most assaults consistently targeted the same energy infrastructure objects as in 2022. Ongoing repairs necessitate further evaluation to ascertain the post-repair condition and capacity of the equipment.

Despite increased generating capacities and partial restoration of electricity transmission and distribution networks, the power system remains highly vulnerable to many factors. These include ongoing attacks

[2] Manoeverable capacities include thermal power plant capacities.

on energy infrastructure, droughts reducing hydroelectric power plant capacity, lengthy repairs of nuclear power plants, and rapid demand recovery. Following the seasonal floods, the power system could face electricity shortages again, especially if several nuclear power plant units are out of service.

Recommendations for immediate response alignment with mid-term priorities

The Government of Ukraine (GoU) has approved the National Energy Strategy of Ukraine (Order of the Cabinet of Ministers of Ukraine dated 21 April 2023 No. 373-p). The Strategy correlates with the report's conclusions on the sufficiency (adequacy) of power generation capacities and is aligned with the Sustainable Development Goals. The GoU has defined the following objectives:

- Energy security and independence: To provide secure and sustainable energy as demonstrated by an increase in power generation capacities from 108 to 176 bn kWh and a shift from energy shortage to a net export of 9 bn kWh.
- Green transition and decentralization: Partially achieved through developing carbon-neutral generation capacities and further harmonizing with European Union (EU) markets to deliver affordable, reliable, and modern energy. This is demonstrated by the construction and installation of 1.4 GW of new high manoeuvering capacities controlling at least 80 percent of the installed capacity with a startup time not exceeding 15 minutes and by building new generating capacities using biogas, biomass, and similar resources.

Ensuring immediate response actions align with the mid-term objectives outlined in the National Energy Strategy is essential. These actions should contribute to energy security and independence, a green transition, decarbonization, and further synchronization with EU energy markets. Key areas of focus should include:

1. Distributing generation sources nationwide and decentralizing the power system;
2. Enhancing manoeuvering capacities in the power system by introducing modern, highly manoeuverable, and environmentally friendly generation facilities;
3. Increasing the share of renewable energy sources in the power system;
4. Gradually reducing and eventually eliminating coal generation in accordance with Ukraine's commitments to reduce CO_2 emissions;
5. Exploring further opportunities to improve the efficiency of the use of nuclear capacities.

Next steps and conclusions

The *de facto* loss of obsolete coal-fired generation presents an opportunity to accelerate the sector's green transformation, including phasing out coal and decentralizing generation capacities. A sustainable and green recovery of Ukraine's energy sector will need to leverage new technology, a greener energy mix, robust governance, and access to financing. Infrastructure investments should be integrated with consistent efforts to strengthen governance and facilitate access to financing. UNDP will continue to design and support the implementation of pilot projects across Ukraine while concurrently establishing a system to expedite their upscaling.

Both planning and implementation of Ukraine's energy sector recovery require data transparency and regular updates. UNDP has supported the efforts of the Government of Ukraine to set up and develop a database of energy sector losses and will continue its assistance with data consolidation and cross-checking during the war, accompanied by monitoring of the recovery efforts and related analysis of prerequisites for sustainable and green recovery. In addition to revising the data about the overall situation and deepening the analysis of the power sector, it is important to engage with the initial assessment of the actual state of the energy and critical municipal infrastructure and analysis of prerequisites for reaching locally led sustainable recovery goals both on a national and a local level.

The collapse of the Kakhovka Dam on 6 June 2023 has dramatically affected critical infrastructure in the Kherson area and the surroundings. This event occurred as the current report was nearing completion, and reliable and precise information on the consequences are not yet available. Preliminary assessments indicate that more than 200 distribution power substations have been completely destroyed, along with dozens of boiler houses. As of the time of this report's release, UNDP has started to collect data and the findings will be presented in the next iteration of the Rapid Damage and Needs Assessment (RDNA).

FOREWORD

Russia's invasion of Ukraine has resulted in civilian casualties, displacement of millions of people, and widespread and significant destruction to homes, businesses, social institutions, and productive and economic activity. As of 21 May 2023, verified civilian casualties in the country amounted to 24,012, including 8,895 killed and 15,117 injured. OHCHR believes the actual figures are considerably higher, given delays in receiving information from locations experiencing intense hostilities and many reports awaiting confirmation. This applies notably to areas like Mariupol (Donetsk region), and Lysychansk, Popasna, and Sievierodonetsk (Luhansk region), where there are allegations of numerous civilian casualties.[3]

The invasion of Ukraine has also triggered the world's largest current human displacement crisis. Since the onset of the war, approximately 5.9 million people have been displaced within Ukraine, and over 8.2 million have moved to neighbouring countries (UNHCR). Ukraine's GDP contracted by about 29 percent in 2022,[4] with economic activity marred by the destruction of productive capacity, damage to arable land, and reduced labour supply. Poverty is estimated to have surged from 5.5 percent in 2021 to 24.2 percent[5] in 2022. Annual inflation reached 26.6 percent[6] in 2022, with high food price inflation hurting the poor.

Targeted attacks have caused extensive damage to energy infrastructure across the country, leading to disruptions in gas and district heating networks and electricity supplies. This has significantly affected the delivery of essential services like water access in major cities and affected the telecommunication and banking sector, including payment processing.

UNDP and the World Bank, in cooperation with the Government of Ukraine, carried out an Energy Sector Damage Assessment 2022 for Ukraine as part of an ongoing and continuous process. This assessment adhered to the internationally accepted RDNA methodology jointly developed by UNDP and the World Bank.[7]

In collaboration with the Government of Ukraine and the National Security and Defence Council of Ukraine, UNDP continues to consolidate data and maintain an updated sector overview. Compared to the Damage Assessment report, the scope and structure of this report have been expanded to cover a broader range of factors pertinent to decision making regarding energy sector recovery. It also includes preliminary recommendations for aligning immediate responses with mid-term recovery priorities. This report includes, verifies, and assesses damages incurred between 1 January and 30 April 2023. The energy infrastructure remains a target as the war continues, and significant additional damage is likely.

As a continuation of this report, which includes a revised damage assessment and recommendations for aligning immediate responses with mid-term energy sector priorities, subsequent technical reports should consolidate and analyse the prerequisites for achieving these goals at national and local levels. Furthermore, evaluating the actual state of the energy and critical municipal infrastructure is necessary for designing and implementing a comprehensive approach to energy sector recovery and decentralization.

Reconstruction planning should help balance and prioritize investments, considering the absorptive capacity, financing availability, and the development of common systems and processes to ensure maximum efficiency. In addition, attention should be given to enhancing managerial and technical capacity, mobilizing funds for project preparation, and developing financial strategies for the energy sector.[8]

[3] According to OHCHR.

[4] According to the State Statistics Service of Ukraine.

[5] According to the World Bank.

[6] According to the Bank of Ukraine.

[7] Ukrainian Energy Sector Damage Assessment Report 2022.

[8] https://www.ohchr.org/en/news/2023/04/ukraine-civilian-casualty-update-24-april-2023#:~:text=From percent2024 percent20February percent202022 percent2C percent20which,8 percent2C574 percent20killed percent20and percent2014 percent2C441 percent20injured
https://data.unhcr.org/en/situations/ukraine

1. INTRODUCTION AND METHODOLOGY

The purpose of this report is to provide an overview of the damage to the energy infrastructure from January to April 2023 and to propose preliminary recommendations to align immediate responses with mid-term energy sector recovery and decentralization goals in line with the National Energy Strategy of Ukraine and approved by the Cabinet of Ministers of Ukraine on 21 April 2023.

The continuation of the war requires appropriate restrictions on the disclosure of technical information related to the energy sector. In addition, the completeness of the data also differs depending on the sector and the proximity of the territories to the contact line. The current review has identified priority energy sector sub-sectors that have the most significant impact on the situation at the national level and for which technical damage data can be properly verified.

1.1. Methodology

The energy sector assessment included the collection and analysis of data provided by the NSDC and collected from the Ministry of Energy, energy companies, and regional military administrations. Unless specified otherwise, the data were sourced from NSDC. The data collection process was sometimes challenging and limited due to the escalation of the conflict and the ongoing deterioration of the humanitarian situation in areas where fighting continues. The revised damage assessment in the energy sector aligns with the RDNA methodology used and recognized worldwide as the Damage and Loss Assessment (DaLA), jointly developed by the European Union, the World Bank Group, and the United Nations. This approach is used worldwide after disasters and conflicts to inform recovery and reconstruction planning. This transparent, standardized assessment methodology promotes coordinated and harmonized efforts at the national and international levels.

To assess the dynamics and condition of the energy sector in January-April 2023, data comparison is made with two datasets: 2021, as the last year not affected by the war, and Q4/2022, as the lowest point of the condition of the system to date. The corresponding data from January to April 2022 included a period when the energy sector was already under the influence of hostilities.

The amount of available nuclear generation capacity was determined based on the fact that nuclear generation facilities, except for Zaporizhzhya Nuclear Power Plant (ZNPP) , which is located in territory under the temporary military control of the Russian Federation, did not suffer significant damage. The amount of available thermal generation capacity was calculated based on the following data: a list of units that generated electricity in January-April 2023, information on each unit's installed and available capacity, and information on damage to units due to missile attacks. The amount of available hydroelectric generation capacity was calculated based on the following data: summary information of Ukrhydroenergo on the amount of damage and available capacity, information on the available capacity of small hydropower plants and pumped storage power plants (PSPPs) that are not part of Ukrhydroenergo (Tashlyk PSPP).

The initial recommendations for alignment of immediate response and medium-term recovery and decentralization priorities have been synchronized with Ukraine's National Energy Strategy, recently adopted by the Government of Ukraine, and are meant to directly contribute to its implementation. These have been prepared based on an assessment of the adequacy (sufficiency) of generating capacities to cover the forecasted demand for electricity and to ensure the required reserve prepared by Ukrenergo, and the international commitments of Ukraine, including the National Emission Reduction Plan (NERP) and Ukraine's National Energy and Climate Plan (NECP).

Time period: The analysis of data on the state of the energy sector was carried out from 24 February 2022 to 30 April 2023. This report separately highlights the changes in the state of the energy sector that occurred between January and April 2023. Some data are given as of the end of March if data for April were unavailable at the time of writing of the current report. The forecast of natural gas and coal demand is calculated for the period from October 2023 to April 2024.

Geographical coverage: This report covers all territories controlled by the Government of Ukraine as of 1 January 2022. The results are presented by oblast and sector and at the aggregate level in general.[9] There are restrictions on obtaining data in temporarily non-government-controlled areas and areas where intense hostilities are ongoing.

Sectoral coverage: The report includes data on the state of energy infrastructure, including electricity, gas, and district heating facilities.

Limitations: The data on the number and capacity of damaged facilities are based on the status of the facilities as of the date indicated. They do not include facilities that have been repaired and facilities that have been damaged again.

1.2. Data sources and data validation and verification

A large number of sources were used in the process of preparing the report; the majority of the data were collected by the NSDC from the Ministry of Energy, energy companies, and regional military administrations. In addition, information from energy sector companies was collected directly from individual companies, such as NPC Ukrenergo and GTSOU, and information related to alternative energy from renewable energy associations. Unless otherwise indicated, the source of data is the NSDC.

During the preparation of this report, additional information not available at the time of the 2022 Energy Sector Damage Assessment Report was collected. This includes information on **damage to the electricity distribution system** from October 2022 to April 2023. In addition, available generation capacity figures have been updated compared to the Energy Damage Assessment 2022 Report.

In this report, the reference number used for available power generation capacity at the beginning of 2022 is 37.6 GW, while the Ukrainian Energy Sector Damage Assessment Report referred to 36.0 GW. The difference of 1.6 GW is explained by the inclusion of 1.2 GW small regional CHP plant capacities and 0.4 GW capacities related to thermal power plant (TPP) repairs based on data that recently became available. Discrepancies in calculating available TPP capacity are due to incomplete information on repairs of individual TPP units at the time of writing of the Energy Damage Assessment 2022.

[9] The damage assessment covers Vinnytsia, Volyn, Dnipropetrovs'k, Donetsk, Zhytomyr, Zakarpattia, Zaporizhzhia, Ivano-Frankivsk, Kyiv, Kirovohrad, Luhansk, Lviv, Mykolaiv, Odesa, Poltava, Rivne, Sumy, Ternopil, Kharkiv, Kherson, Khmelnytsky, Cherkasy, Chernivtsi and Chernihiv regions, as well as the cities of Kyiv, Vinnytsia, Lviv, Odesa, Kharkiv, Irpin, Bucha and Mariupol.

2. OVERVIEW OF DAMAGE TO ENERGY INFRASTRUCTURE FROM JANUARY TO APRIL 2023

2.1. Context and the main findings of the Energy Sector Damage Assessment 2022

As shown in the previous report, Ukraine's energy sector has been the target of continuous attacks aimed at disrupting access to electricity supply for millions of Ukrainians as well as critical social infrastructure, including heating, potable water, wastewater treatment, and communication. Recovery of both power transmission and power generation capacities is still a national priority for the upcoming 2023 /24 winter and in the longer term.

Since the beginning of the war, the electricity sector in Ukraine has undergone dramatic changes. Until October 2022, this decline was primarily due to parts of Ukraine being under the temporary military control of the Russian Federation, a decrease in industrial production, and the relocation of a significant number of people to safer regions of Ukraine or abroad. The decreased generation capacity was sufficient for the regular operation of the power system.

The situation changed dramatically in October 2022, when consistent and targeted missile and drone attacks on the energy infrastructure began. According to NSDC, the Russian military fired more than 1,500 missiles and drones, as well as a large number of shells and grenades, at Ukraine's energy infrastructure from October to December 2022. Continuous and regular waves of attacks on energy infrastructure left 12 million people with no or limited electricity and disrupted water supplies and heating systems at a time when temperatures fell below zero in most parts of the country. Consistent attacks on critical energy infrastructure, which started in October 2022, and the loss of access to the assets located in areas beyond the control of the Government of Ukraine have caused an involuntary decrease in consumption of 41 percent, according to Ukrenergo. The average Ukrainian household had to endure five cumulative weeks without electricity from 10 October to the end of December 2022, according to estimates based on Ukrenergo data.

The attacks have primarily targeted Ukraine's Integrated Energy System. Thus, the main focus of the Energy Sector Damage Assessment 2022 was on the two areas that suffered the most damage. In the power generation sector, the available capacity of Ukrainian power plants has fallen from 36 GW to 13.9 GW in 2022, according to the National Security and Defence Council; the ability to produce electricity declined by 61 percent within a year. Out of a total of 75 power units,[10] 6 were destroyed, 16 were damaged, 1 was located under the temporary military control of the Russian Federation, and 22 were out of operation due to logistical problems with gas or coal supplies, according to Ukrenergo. As for power transmission, 41 out of 94 crucial high-voltage transformers located in government-controlled territories have been damaged or destroyed by missiles or drones; more than half of them have been hit more than once to prevent them from ever being repaired. This reduced capacity of the electricity distribution system has further limited the power supply across the country.

[10] Excluding Myronivska TTP.

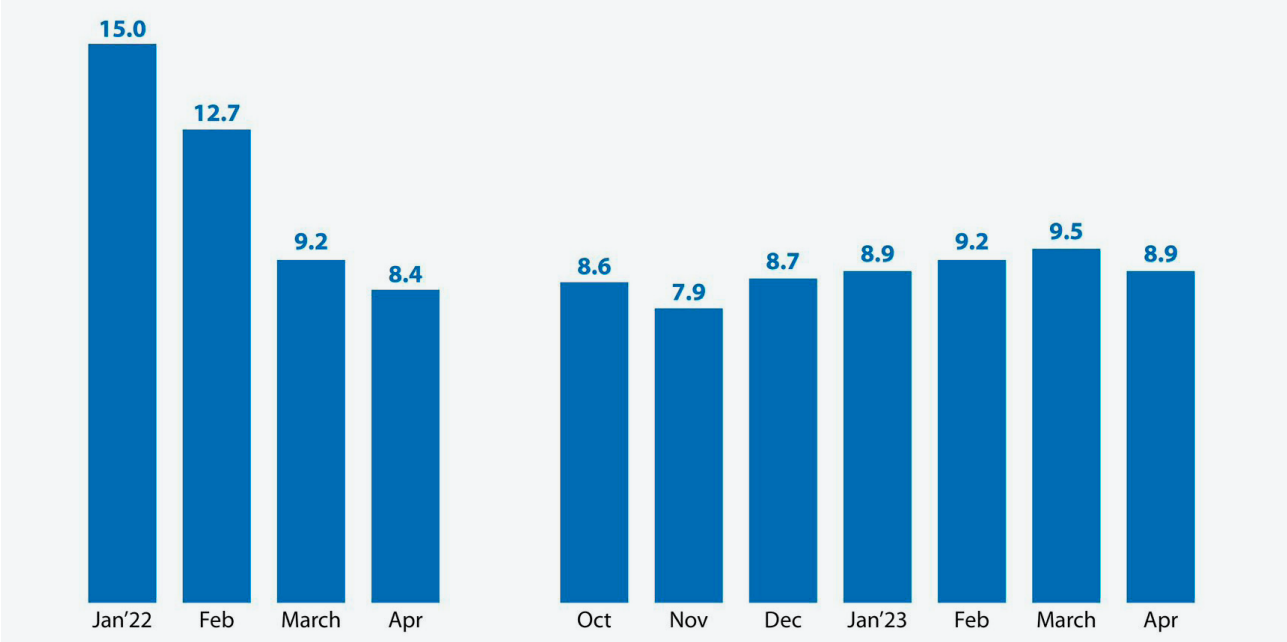
2.2. Attacks on energy infrastructure and electricity shortages

Due to three primary factors, the power system continues to operate in emergency mode with hardly any safety margin for both power grids and generation. First, there needs to be more reserve generation capacity as available power generation capacity has nearly halved, falling from 37.6 GW at the beginning of 2022 to 18.3 GW.[11] Second, the system was critically short on manoeuvering capacities. The available capacity of TPPs, the primary source of manoeuvering capacities, has dropped 68 percent from 14.3 GW to 4.6 GW. Lastly, the transmission network capacity has yet to be fully restored. Only one additional substation was hit between January and April 2023; all the others have been repeatedly targeted.

Despite all efforts, hardly any new equipment will be delivered and installed before the beginning of the winter season 2023/24 due to a six-month lag time for equipment delivery. **This means the system remains highly vulnerable to a wide range of threats,** including **continuous attacks on the energy infrastructure, draughts causing reduction of generation capacity of hydroelectric power plants (HPPs), lengthy repairs of nuclear power plants, and rapid demand recovery, among others.**

Electricity production of all types of generation from January to April 2023 decreased by 32.5 percent compared to the same period in 2021 and amounted to 36.5 TWh due to missile attacks on energy infrastructure and a drop in electricity consumption, according to Ukrenergo. Electricity generation increased by 9.7 percent in the first quarter of 2023 compared to the fourth quarter of 2022, when the available capacity of Ukrainian power plants did not exceed 13.9 GW. The situation in the power system has been temporarily stabilized due to the efforts of Ukrainian power engineers and the support of international partners.

Figure 2. Electricity generation dynamics in 2022-2023, TWh



Between January and April 2023, Ukraine's power system was partially restored. Starting from mid-February 2023, the electricity shortage that had been observed in the system since October was mostly absent, with stabilization blackouts applied locally, mainly after regular shelling. In March and April, no stabilization blackouts were applied in Ukraine. The relative increase in available generating capacity and partial restoration of electricity transmission and distribution networks improved the operational security of the power system and reduced the risk of shortages. However, after the seasonal floods pass and if several nuclear power plant (NPP) units are out of service, the power system may experience an energy shortage.

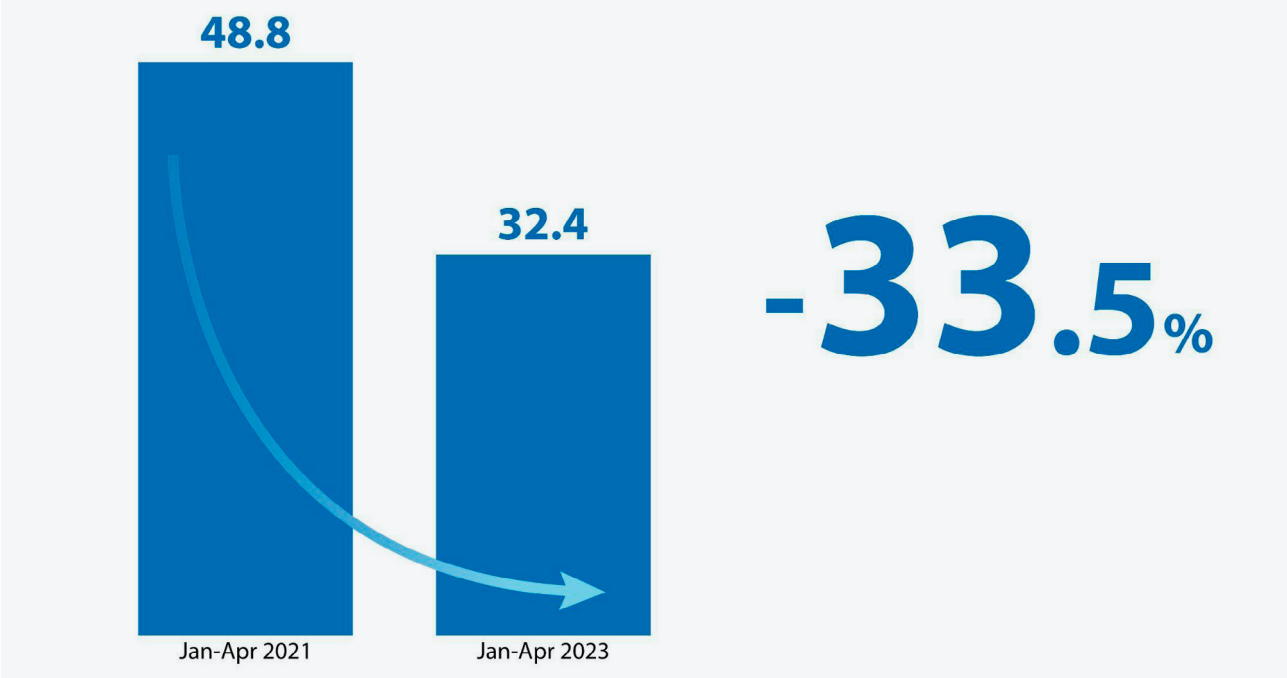
[11] According to NPC Ukrenergo

A combination of the following factors determined the state of the power system from January to April 2023:

- An increase in the number and efficiency of air defence systems, which made it possible to intercept the vast majority of missiles and drones;
- Stabilization of Ukraine's energy system and greater resilience to damage;
- High rates of emergency restoration of energy infrastructure facilities due to the skilled work of specialists and international assistance to increase the grid's capacity;
- Increased experience in emergency stabilization of the system after significant damage, along with contingency plans in case of damage to individual power system facilities;
- Use of the method of unloading the power system, i.e., suspension of operation of individual generation units in the periods immediately before missile attacks, and preservation of the integrity of the power system as a result. This approach minimized damage to the power system caused by their destruction and, as a result, accelerated the restoration of lost capacity;
- The entry into force in January 2023 of the Law of Ukraine "On Amendments to the Tax Code of Ukraine to Facilitate the Restoration of Ukraine's Energy Infrastructure," which temporarily exempts goods intended for the restoration of energy infrastructure from value added tax for the period of martial law;
- Electricity imports from Europe. Import volumes were insignificant, but this allowed Ukraine's power system to be supported in January/February 2023. Import volumes fell again to a minimum in the period following mid-February;
- Lower electricity consumption due to a drop in industrial production areas of Ukraine falling under the temporary military control of the Russian Federation.

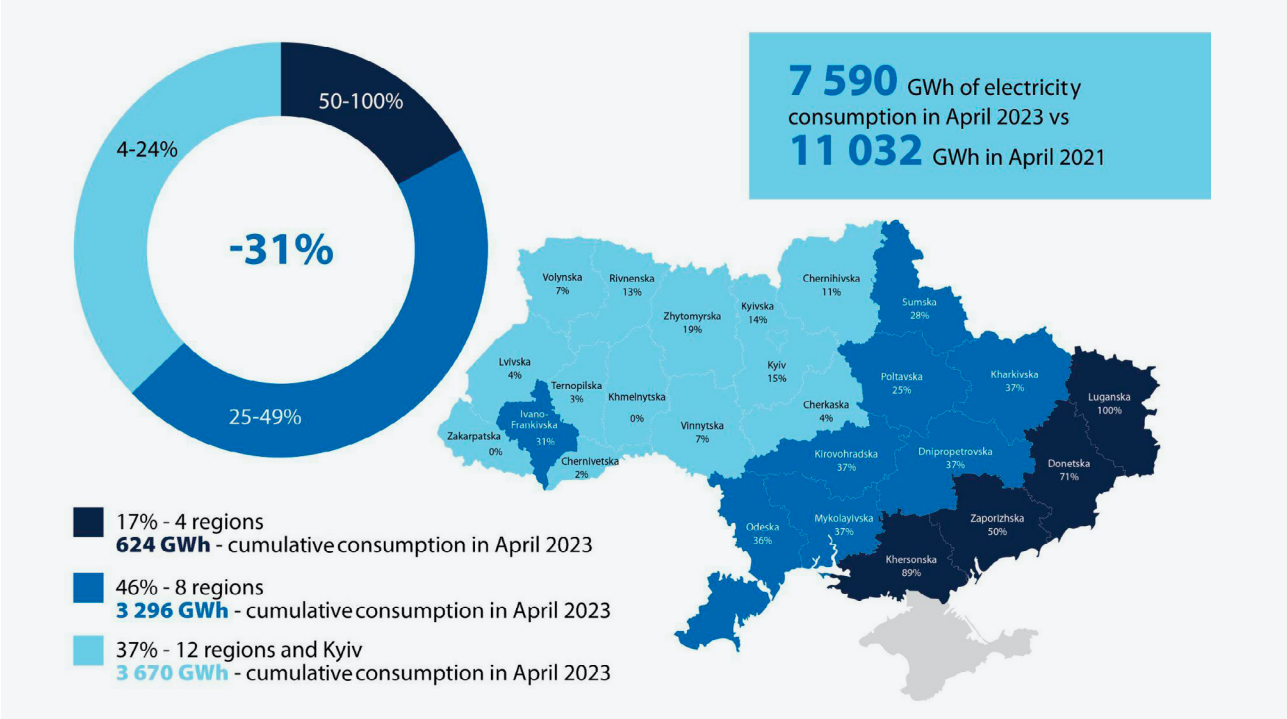
The total electricity consumption from January to April 2023 totaled 32.4 TWh, 18.9 percent less than in 2022 and 33.5 percent less than in 2021, the most recent comparable period unaffected by the war. Consumption in the first quarter of 2023 increased by 12.7 percent compared to the fourth quarter of 2022.

Figure 3. Electricity consumption in Ukraine in January-April 2023, TWh



The reduction in electricity consumption varies significantly by region of the country. An inventory categorization (ABC) analysis identified three groups of regions: A – reduction of consumption by more than 50 percent; B – reduction of consumption by 25-49 percent; C – reduction of consumption by 4-24 percent. The results of the analysis are shown in the graph below.

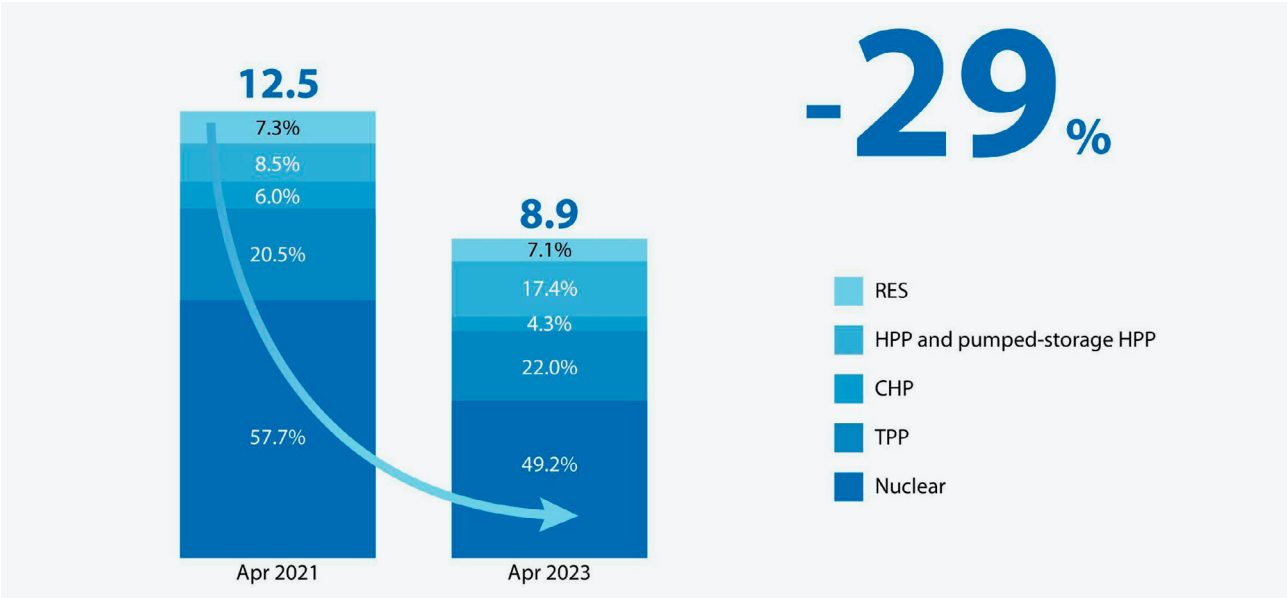
Figure 4. Reduction of electricity consumption in Ukraine by regions, April 2023 and April 2021, GWh



2.2.1. Damage and losses caused to the electricity generation sector

At the end of April 2023, there was not a single TPP or HPP in Ukraine that was not damaged to some extent due to military activities and missile attacks on energy infrastructure facilities. In total, over 90 percent of wind generation, about 75 percent of thermal generation, almost half of the nuclear generation (due to Zaporizhzhia NPP, which is located in the territories outside of the government control), over 30 percent of solar generation and block TPPs have been damaged or are in the territories outside of the government control during the war. Available capacity has decreased from 37.6 GW as of the beginning of 2022 to 18.3 GW.[12]

Figure 5. Dynamics and structure of generation in April 2023, TWh



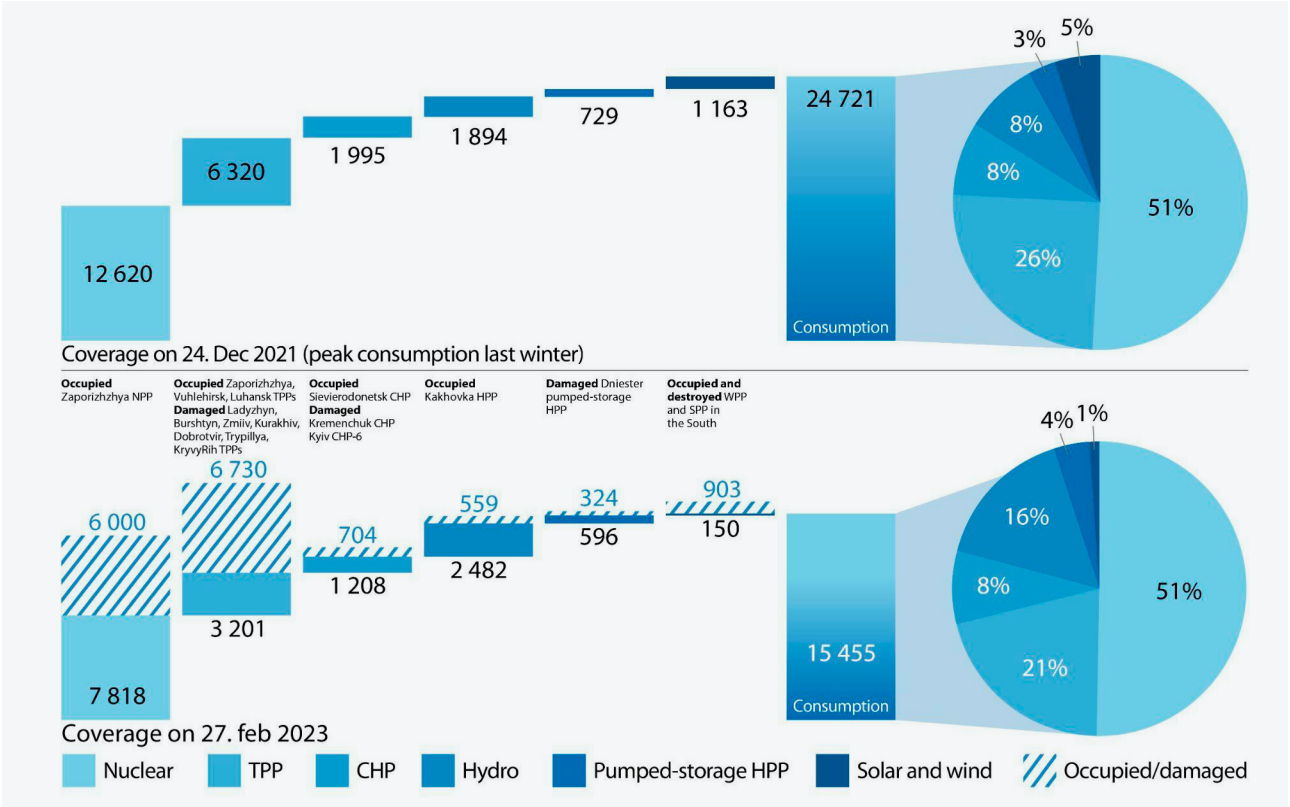
[12] According to NPC Ukrenergo.

By the end of April 2023, due to a decrease in the intensity of missile attacks, high recovery rates, and significant international assistance, some generating facilities managed to return to critical operation; however, consolidated information about the repairs and actual condition of the equipment is not yet available. As of the end of April 2023, all types of power plants are operational, with hydroelectric power plants benefiting significantly from the spring floods. A seasonally high level of generation from renewable energy sources is also being maintained.

From January to April 2023, the structure of electricity generation changed as follows:

- Nuclear power plants' electricity production decreased from the same period in 2021 (the most recent comparable period unaffected by the war). Generation dropped from 29.0 TWh to 19.5 TWh, with its share in the national electricity mix slightly changing from 53.6 percent to 53.4 percent. This is due to the shutdown of Zaporizhzhia NPP, the largest nuclear facility in the country, which remained in the territory under the temporary military control of the Russian Federation.
- Thermal power plant's generation decreased from 13.9 TWh to 7.6 TWh. Consequently, this type of electricity generation's share in the national electricity structure decreased from 25.6 percent to 20.8 percent.
- Electricity generation at CHPs decreased from 4.8 TWh to 2.8 TWh, and the share of this type of generation in the overall structure decreased from 8.8 percent to 7.8 percent;
- Generation from renewable sources decreased from 3.2 TWh to 2.1 TWh, or from 5.9 percent to 5.7 percent of the electricity generation structure, as a large number of wind and solar power plants located in southern Ukraine are currently in areas under the temporary military control of the Russian Federation, are damaged or are in the combat zone.
- Electricity production at HPPs and PSPPs increased from 3.3 TWh to 4.5 TWh. Thus, the share of such electricity in the structure of the national electricity sector increased significantly from 6.1 percent to 12.3 percent. This increase is primarily due to a natural rise in water levels, as well as a lower level of damage to hydropower generation facilities compared to TPPs and CHPs.

Figure 6. Electricity consumption coverage on 24 December 2021 (peak load in 2021) and 27 February 2023, MW[13]



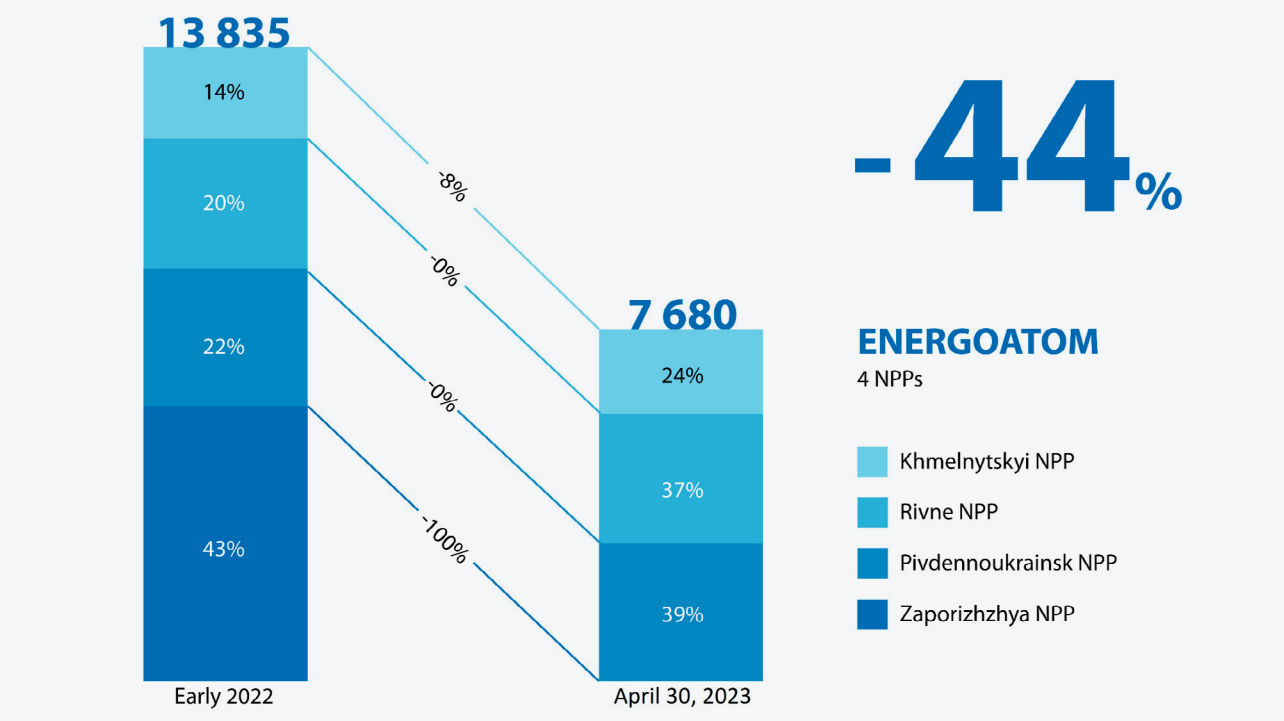
[13] According to NPC Ukrenergo.

The increase in the share of hydro generation in covering peak consumption is explained by the fact that HPPs and PSPPs did not suffer such significant damage as TPPs, as well as favourable weather conditions, particularly early and high flooding on rivers.

2.2.1.1. Damage to the nuclear generation sector

Three of the four nuclear power plants operating at the beginning of the war continue to operate in the Integrated Power System of Ukraine as of the end of April 2023: South Ukrainian NPP, Rivne NPP, and Khmelnytsky NPP. Available nuclear generation capacity in April 2023 decreased by 44.2 percent compared to April 2021, the most recent comparable period, unaffected by the war. Compared to the end of 2022, the situation has not changed much.

Figure 7. Available NPP generation capacity, MW



Since 4 March 2022, Russian forces have taken control of the ZNPP site.[14] Prior to the full-scale Russian invasion of Ukraine, the plant was the largest operating nuclear power plant in Europe; in 2021, its capacity accounted for 43 percent of the total nuclear generation capacity in Ukraine, and its operating capacity exceeded 20 percent of the total generation of the Integrated Power System (IPS).

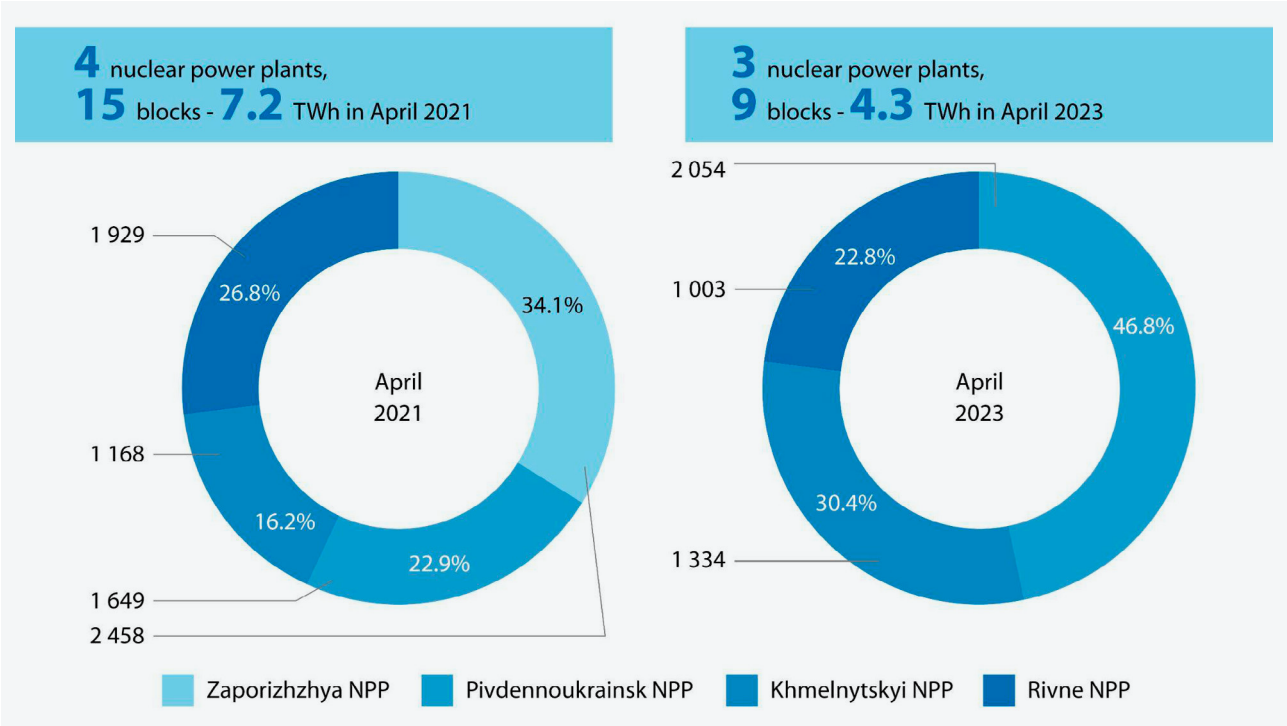
Until August 2022, despite the deployment of military equipment and Russian personnel on the territory of ZNPP, its two units continued to operate and supply electricity to the IPS of Ukraine, according to Energoatom. Since September 2022, the plant has been out of operation but remains connected to the Ukrainian power grid to power the cooling and safety systems of the power units. As of the end of April 2023, four of the plant's six power units were in cold shutdown, and two – the fifth and sixth – were in hot shutdown, but the reactors were shut down.

As a result of the shelling, the only line of communication between the plant and the IPS of Ukraine was damaged six times, leaving the plant's security and cooling systems de-energized and powered by generators, according to Energoatom. All other NPPs continue to operate in the Ukrainian power system, and no significant damage has been reported.

NPP generation volumes in January-April 2023 decreased from 29.0 TWh to 19.5 TWh, or by 32.8 percent, compared to the corresponding period of 2021. The absence of ZNPP in the system is partially compensated for by an increase in the generation volumes of three operating stations.

[14] According to IAEA, Nuclear Safety, Security and Safeguards in Ukraine: Second Summary Report by the Director General 28 April – 5 September 2022. www.iaea.org/sites/default/files/22/09/ukraine-2ndsummaryreport_sept2022.pdf

Figure 8. Electricity generation by NPPs in April 2023, TWh



Available nuclear generation capacity decreased from 13.8 GW at the end of 2021 to 7.7 GW at the end of April 2023.

2.2.1.2. Damage to TPPs and cogeneration units

As of the end of April 2023, there was not a single TPP or large CHP in the government-controlled area that had not sustained varying degrees of damage due to hostilities and rocket attacks, according to Ukrenergo. Despite this, all 9 TPPs and the largest CHPs in the government-controlled area are operating at partial capacity. Due to the high pace of restoration works, between January and April 2023 it was possible to increase the available thermal power generation capacity (TTP and CHP) from 4.5 GW at the end of December 2022 to 6.0 GW[15] at the end of April 2023. However, 11.1 GW of the 17.1 GW of available capacity as of 30 April 2023 remains damaged, located under the temporary military control of the Russian Federation, or cannot be connected to the IPS of Ukraine for various reasons.

Out of 13 TPPs (77 units), 9 TPPs (22 units) were in operation as of the end of 2023, with an available capacity of 4.6 GW, which is 68 percent less than at the end of 2021, the most recent comparable period unaffected by the war. 6.6 GW or 46.2 percent of the available TPP capacity was damaged as a result of hostilities and rocket attacks, and 3.1 GW or 21.7 percent are located under the temporary military control of the Russian Federation. In the first quarter of 2023, 6 TPPs (13 power units in total) sustained varying degrees of damage due to rocket and artillery shelling.

The capacities of the CHPs also suffered significant damage. As of 30 April 2023, some units of large CHPs were out of operation due to missile attacks. Out of the 25 largest small CHPs, eight do not generate electricity, and most of the others are damaged. This has led to a reduction in the available CHP capacity from 2.9 GW as of the end of 2021 to 1.4 GW as of the end of April 2023. Damaged capacity amount to 1.4 GW or 48.3 percent, while 0.1 GW or 3.4 percent remain in territory that is under the temporary military control of the Russian Federation.[16] From January to April 2023, four TPPs sustained damage from rocket and artillery shelling.

[15] According to NPC Ukrenergo.

[16] According to NPC Ukrenergo.

Figure 9. State of TPP power units as of the end of April 2023, units

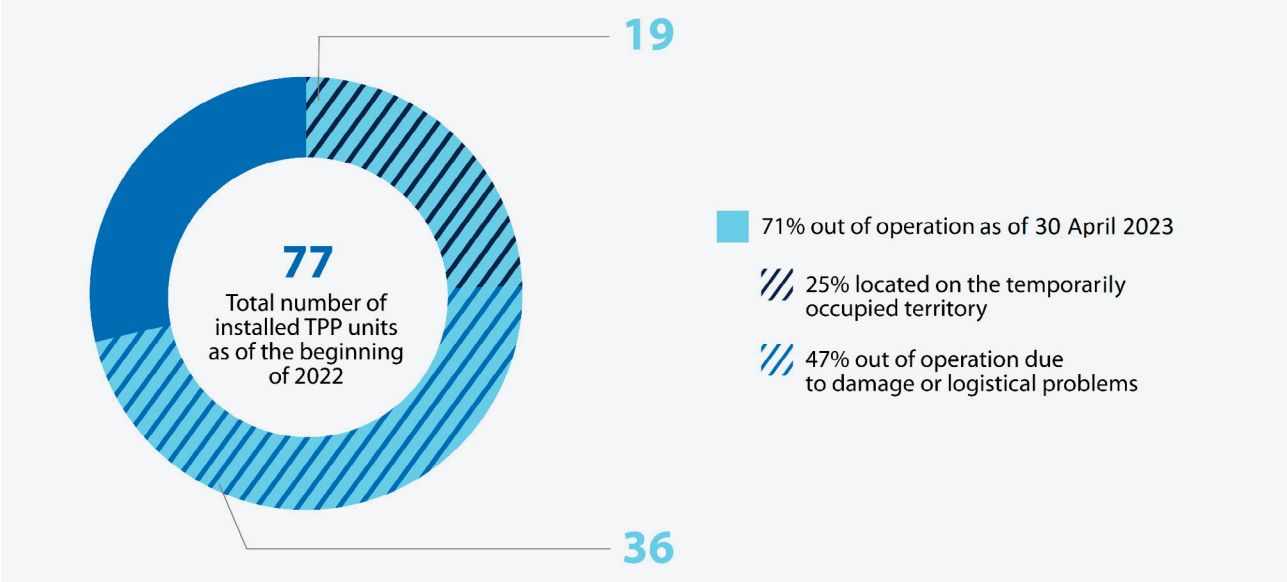
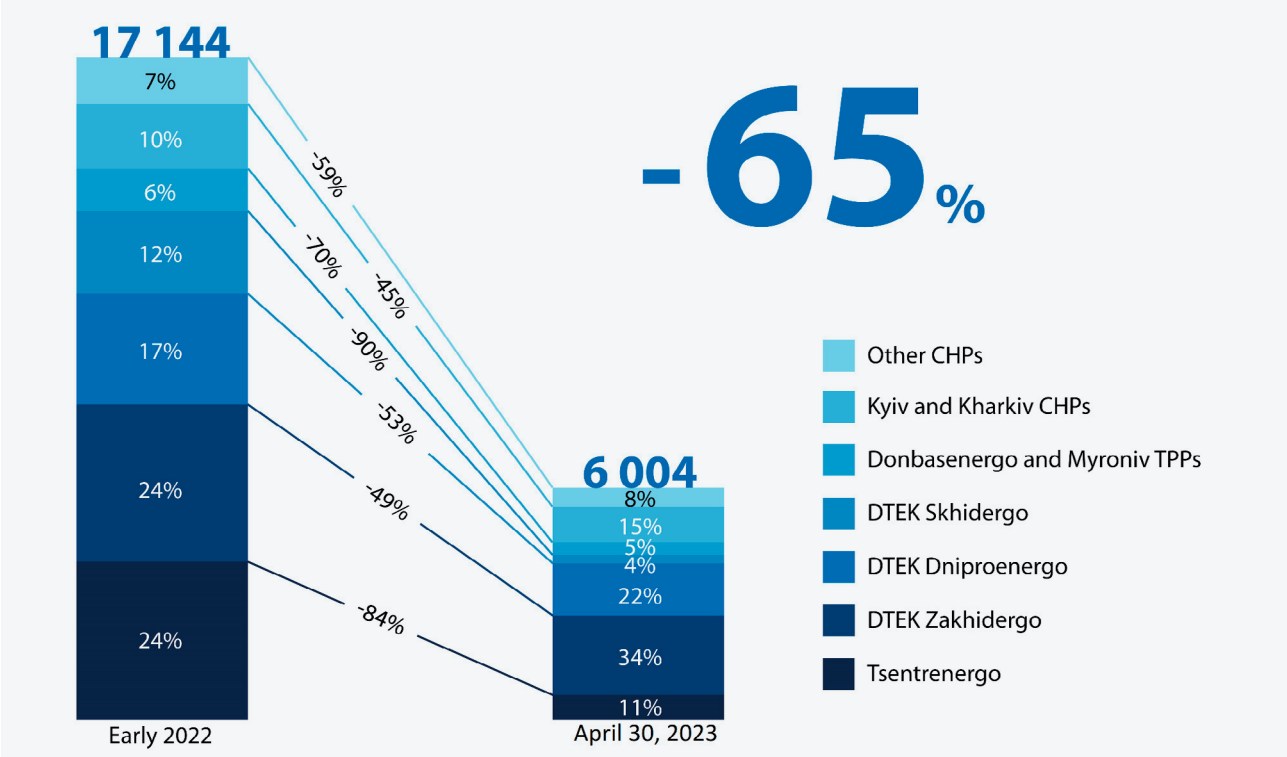


Figure 10. Available capacities of TPPs, MW



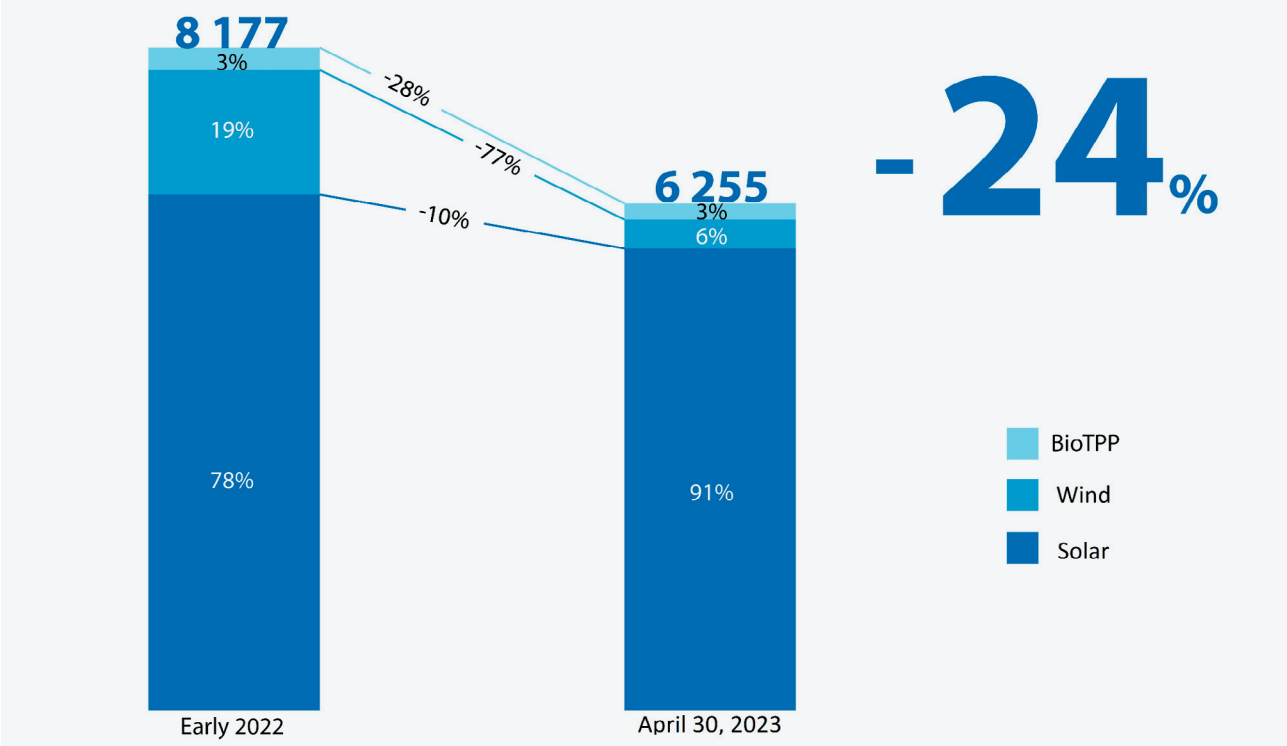
2.2.1.3. Damage to the RES sector

As of 30 April 2023, up to 40 percent of renewable energy facilities had been affected in various ways, primarily in Ukraine's southern and southeastern regions. Wind and solar power generation decreased by a third. A more accurate assessment of the damage will be possible after these territories return under the control of the Government of Ukraine. The available generation capacity from renewable sources decreased from 8.2 GW at the end of 2021 to 6.3 GW.[17] Most of the damage occurred due to the placement of generation facilities in combat zones or a change in their control in the first months of the full-scale invasion.

Compared to the end of 2022, the situation has not changed much. No significant additional damage to renewable energy facilities was recorded from January to April 2023.

[17] According to the UWEA.

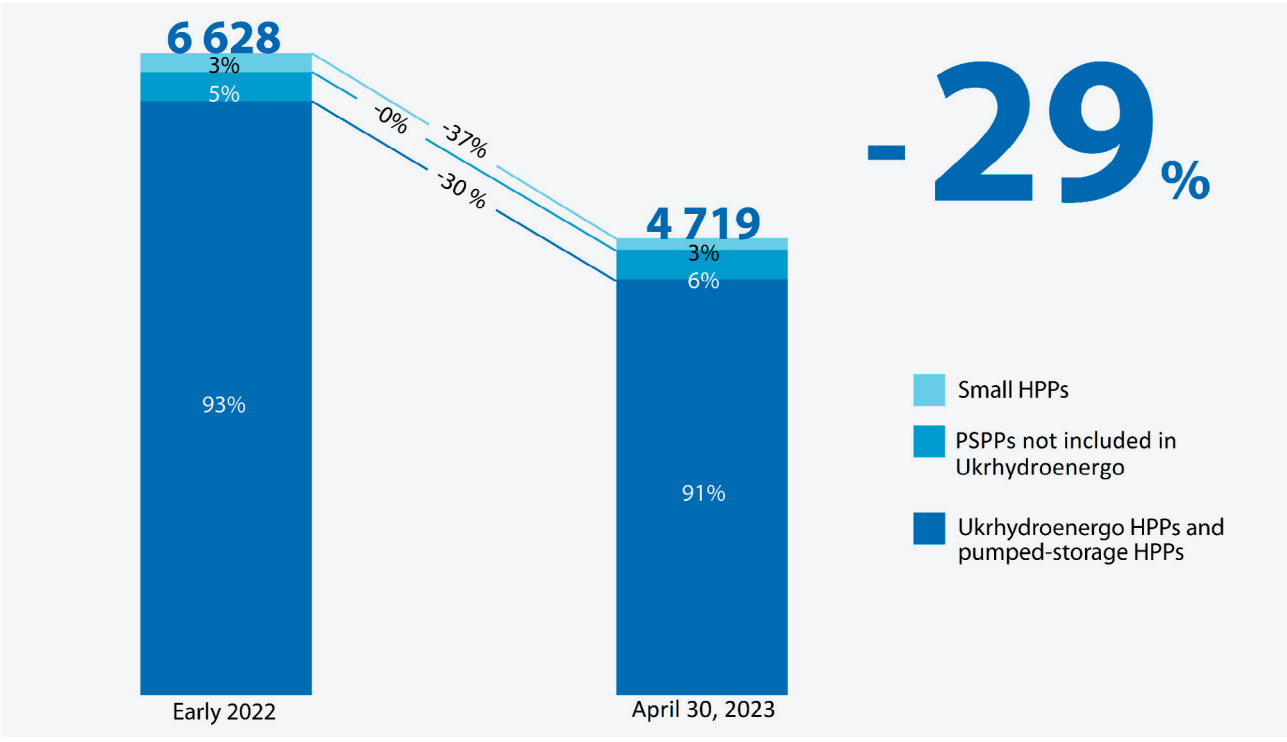
Figure 11. Available capacities of RES, MW



2.2.1.4. Damage and losses caused to the hydropower sector

As of the end of April 2023, available hydropower capacity decreased to 4.7 GW or by 29.8 percent from 6.7 GW[18] **at the end of 2021.** From October 2022 to April 2023, most of the power plants sustained damage to their main or auxiliary equipment, with three hydroelectric power plants and one pumped storage plant severely damaged by missile attacks, mainly targeting electrical equipment and machine rooms at HPPs. A total of 2.1 GW of available HPP and PSPP capacity was damaged, and 500 MW of damaged capacity was restored.

Figure 12. Available generation capacity of HPPs and PSPPs, MW

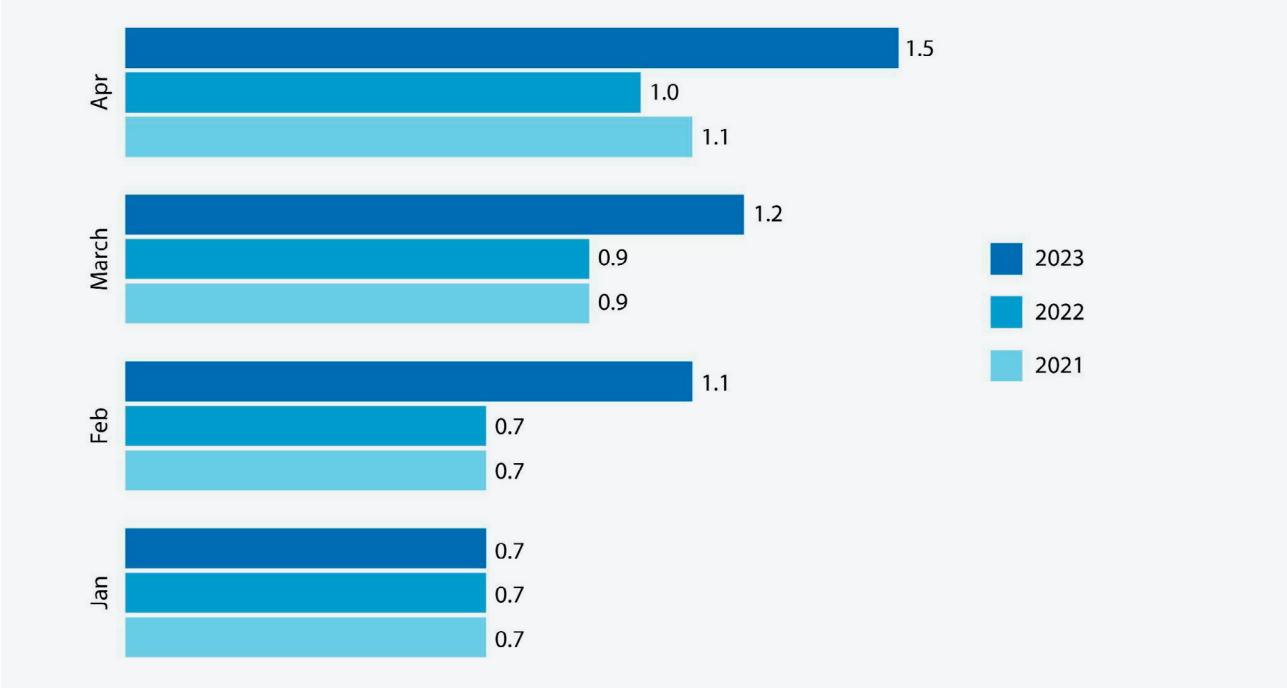


[18] According to Ukrhydroenergo PJSC.

Between January and April 2023, one HPP was damaged by rocket attacks. As of 30 April 2023, all large hydroelectric power generation enterprises except for one station, which is not under the control of the Government of Ukraine, were operating in the Ukrainian power system. Still, most operated at only partial capacity due to damage to both generating equipment and the distribution system.

At the same time, there was a temporary increase in hydropower generation from 3.3 TWh in January-April 2021 to 4.5 TWh in January-April 2023, primarily due to favourable weather conditions, particularly early and high flooding on rivers. The floods began in early February and are expected to last until June, which will help maintain high generation volumes. Given the significant damage to thermal generation facilities, the importance of hydropower generation for balancing the power system is increasing (the share of hydropower generation increased to 12.9 percent in March and 17.4 percent in April 2023.

Figure 13. Dynamics of HPP and PSPP generation volumes in January-April 2021-2023, TWh



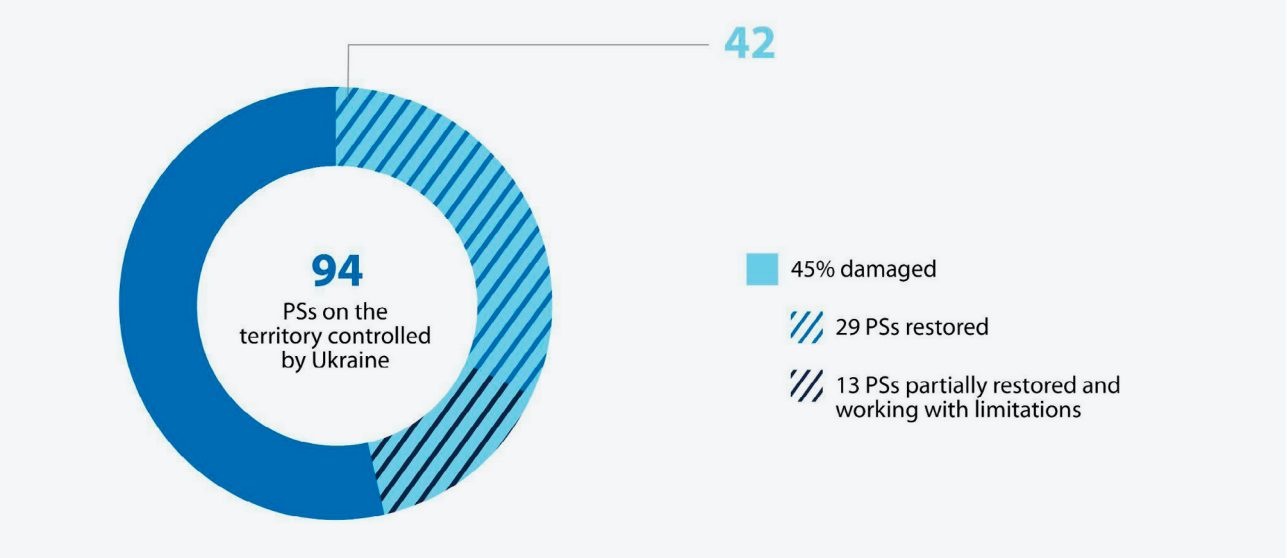
2.2.2. Damage and losses caused to the electricity transmission sector

In general, from October 2022 to March 2023, almost all critical high-voltage substations operated by NPC Ukrenergo were attacked by missiles or drones at least 3-4 times, according to NSDC. Out of 94 high-voltage substations of the IPS of Ukraine, 42 substations were damaged, according to Ukrenergo. As of the end of the first quarter, 29 substations have been fully restored, while another 13 substations have been partially restored and operate with restrictions. Two high-voltage substations located near the contact line are out of operation on the government-controlled territory, and eight substations are under the temporary military control of the Russian Federation; their condition will be determined only after they have been brought back under the control of the Government of Ukraine. Primarily due to the intensive restoration of damaged substations, power system stabilization and a gradual lifting of grid restrictions became possible in the first quarter of 2023.

Rocket attacks decimated the entire 750 kV high-voltage network used to distribute electricity from nuclear power plants throughout Ukraine. This has created significant difficulties in meeting the country's energy consumption needs and complicated electricity transmission from the western regions to the east. As of the end of the first quarter of 2023, a significant part of the damaged network had been restored; however, the restoration works continue, and the system's resilience margin remains limited.

During the first quarter of 2023, attacks on Ukrenergo's high-voltage substations continued, but the intensity of the attacks was significantly lower than in October-December 2022. Four 750 kV substations were damaged (three were hit twice or more) along with 17 330 kV substations (seven were hit twice or more, and one substation was damaged for the first time).

Figure 14. Status of high-voltage substations (excluding those located in the temporarily occupied territory and the combat zone), SSs



Restoring the electricity transmission infrastructure is regarded as a national priority and has been carried out with utmost urgency. The damage to substations, the power transmission network, and control rooms primarily constrained the ability to supply electricity to consumers, leading to hourly and emergency outages. In several cases, restoration of the substations' operability was limited to replacing some elements of switchgear located near transformers, such as current transformers, voltage transformers, etc. Repairing more significant damage would require the complete replacement of high-voltage transformers.

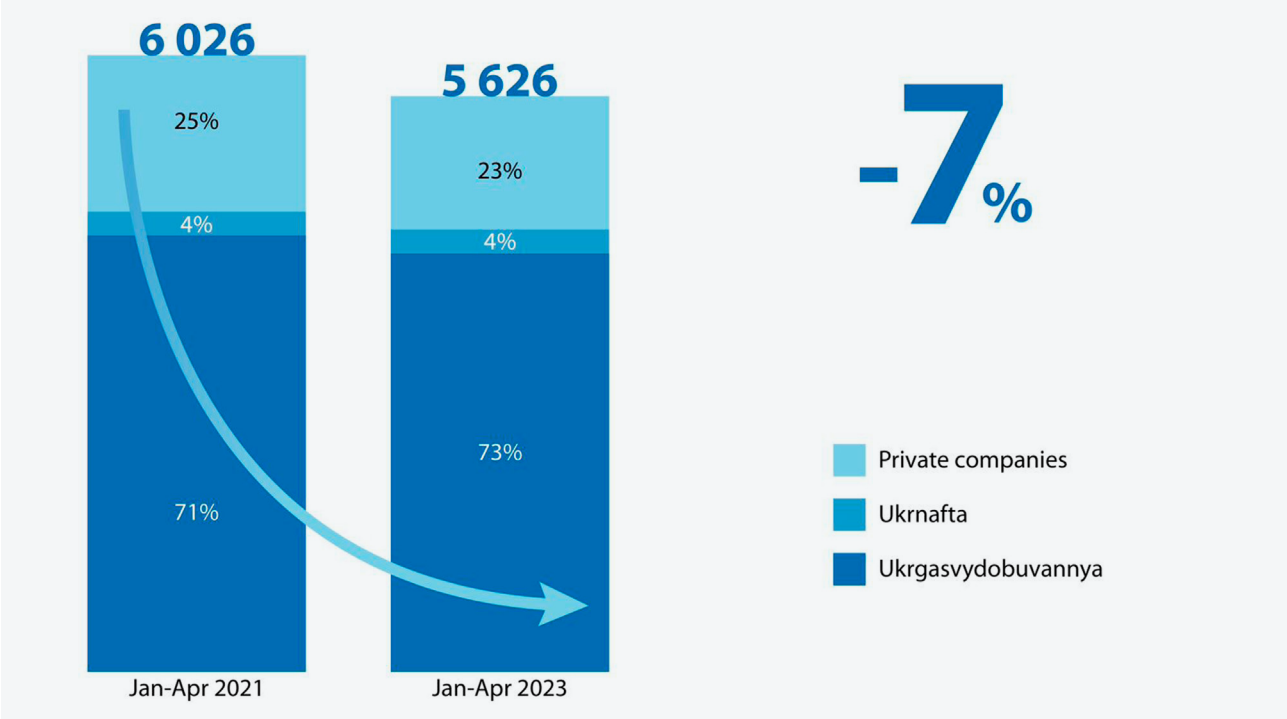
2.2.3 Damage to the electricity distribution sector

Between October 2022 and March 2023, 37 distribution substations were damaged: two 150 kV, nine 110 kV, and twenty-six 35 kV substations. Damages to the distribution network were recorded throughout Ukraine, but the most critical ones were in the regions located in the combat zone and along the contact line. Between October and December 2022, 24 distribution substations were damaged due to hostilities and shelling, including one 150 kV substation, seven 110 kV substations, and fifteen 35 kV substations. In the first quarter of 2023, 14 distribution network substations owned by Oblenergoes were damaged, including eleven 35 kV, two 110 kV, and one 150 kV substation. Trunk and regional power lines also sustained significant damage. The speed of restoration of the distribution network depends primarily on the security situation in the region and the ability to carry out repairs, as well as on funding and equipment availability.

2.3 Damage and losses to the gas sector

The gas transmission and distribution systems are operating throughout the government-controlled territory of Ukraine. Natural gas production in January-April 2023 decreased by 6.6 percent compared to the same period in 2021. The average daily natural gas production in April 2023 amounted to 47.8 million cubic metres, 5.3 percent less than in April 2021.

Figure 15. Natural gas production in January-April 2021 and 2023



2.4. Damage and losses caused to the district heating sector

During Q1 2023, 11 boiler houses were damaged due to hostilities (mainly shelling), primarily in the contact line regions. In total, 591 boiler houses have sustained various types of damage since the beginning of the war, which is 2.4 percent of the total number of 24,548 boiler houses.

Damage to district heating facilities (CHPs, boiler houses, and heating mains) is critical in the frontline regions and territories under the temporary military control of the Russian Federation. In the other areas, district heating facilities were not significantly damaged. Still, electricity supply interruptions remain a critical risk for the operations of the district heating facilities for the next winter season.

2.5. Damage and losses caused to the coal mining sector

As of the end of April 2023, about 25 percent of state-owned and some private mines are under the temporary military control of the Russian Federation. Coal production has declined by approximately 35 percent. A significant challenge for the sector, which also carries significant environmental risks, is uncontrolled flooding of mines due to the shutdown of pumps caused by the lack of electricity supply or the location of mines in the combat zone or the territories beyond/not under the control of the Government of Ukraine.

Ukraine's coal mining sector suffered significant losses from the hostilities even before the full-scale invasion. A considerable number of mines, including almost all anthracite coal mines, are located in areas of Donetsk, Luhansk, Kherson, and Zaporizhzhia oblasts under the temporary military control of the Russian Federation since 2014-2015. After the start of the full-scale invasion, due to the temporary loss of control of the Government of Ukraine over the territory of Donbas, which is traditionally the main coal-producing region, approximately 25 percent of state-owned and a significant part of private mines remained in the territories beyond/not under the control of the Government of Ukraine. Also, for security reasons, production has been suspended at some mines located near the war zone.

Coal-fired power generation has traditionally been the main consumer of coal in Ukraine, with a pre-war share exceeding 50 percent.[19] During the war, the share has further increased because of a significant decline in industrial production and related consumption. Most of the coal-fired power generation facilities suffered considerable damage in 2022. Out of 77 TPP units, only 22 were in operation as of the end of Q1 2023.

[19] Includes coal consumption at TPPs and CHPs.

3. RECOMMENDATIONS FOR IMMEDIATE RESPONSE ALIGNMENT WITH MID-TERM ENERGY SECTOR PRIORITIES

3.1. Energy sector mid-term objectives and priorities

The Government of Ukraine has approved the National Energy Strategy of Ukraine (Order of the Cabinet of Ministers of Ukraine dated 21 April 2023 No. 373-p). The Strategy correlates with the report's conclusions on the sufficiency (adequacy) of power generation capacities and is aligned with the Sustainable Development Goals. **The GoU has defined the following objectives and priorities:**

- **Energy security and independence** to provide secure and sustainable energy as indicated by the increase of power generation capacities from 108 to 176 bn kWh and a shift from energy shortage to a net export of 9 bn kWh;
- **The pursuit of green transition and decentralization** through developing carbon-neutral generation capacities and further harmonization with the EU markets. The aim is to provide affordable, reliable, and modern energy. This is indicated by the construction and installation of 1.4 GW of new high manoeuvering capacities with a control range of at least 80 percent of installed capacity and a startup time not exceeding 15 minutes. Furthermore, building new generating capacities utilizing biogas, biomass, and other sources reinforces these objectives.

According to the GoU, private sector partners can address other elements of the Strategy's implementation, e.g., the development of photovoltaic and wind power plants.

Ensuring that immediate response actions align with the mid-term objectives and priorities indicated in the National Energy Strategy is critical. These actions should contribute to energy security and independence, support a green transition, promote decarbonization, and facilitate further synchronization with the EU energy markets. To achieve these goals, the following tasks should be prioritized for immediate action:

1. Dispersing generation sources throughout the country and decentralizing the power system;
2. Building up manoeuvering capacities in the power system by introducing modern, highly manoeuverable, and environmentally friendly generation facilities;
3. Increasing the share of renewable energy sources in the power system;
4. Gradual reducing and ultimately completely phasing out coal generation in line with Ukraine's commitments to reduce CO_2 emissions; and
5. Exploring further opportunities to improve the efficiency of the use of nuclear capacities.

Figure 16. Target indicators of the electricity generation structure as per the National Energy Strategy 2023 to 2033, TWh

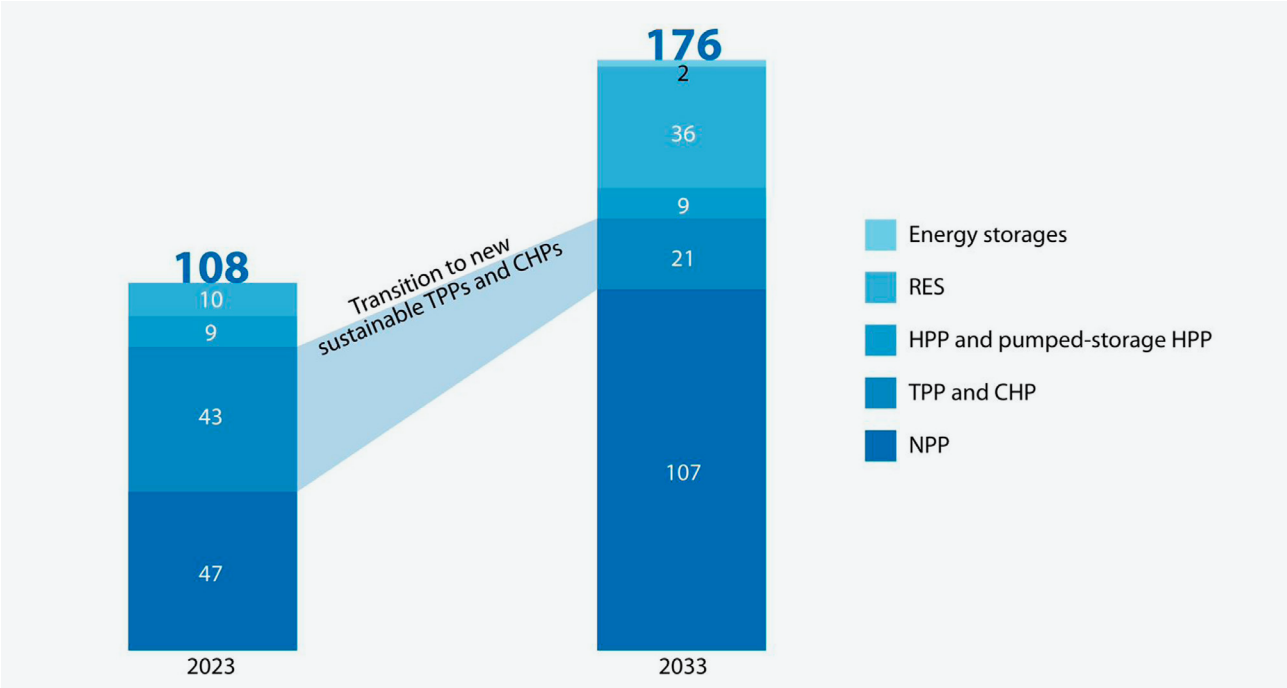


Figure 17. Targets for the commissioning of generating capacity in the IPS of Ukraine as per the National Energy Strategy by 2033, GW[20]

Type of generation	Nuclear	TPPs, incl.	New highly manoeuverable TPPs	New biofuel TPPs	Solar	Wind	Energy storage	PSPPs
Current installed capacity, GW	13.8	0.3	0	0.3	6.2	0.5	0	2.0
Need for new capacity, GW	7.2	2.5	1.4	1.1	3.8	4.5	0.8	2.0
Projected installed capacity, GW	21.0	2.8	1.4	1.4	10.0	5.0	0.8	4.0
Capacities to be built	Units No.3, No. 4 and No. 5 at KhNPP and construction of 23 SMRs		New highly manoeuverable capacities (gas turbines)	New generating capacity using biogas, biomass etc. as fuel	New capacities of SPPs and WPPs to replace existing TPPs, that will be decommissioned as part of the National Emission Reduction Plan		Energy storage systems for balancing power system with a large number of SPPs and WPPs	New units at HPPs, Reequipping of Dniester and Dnipro HPPs and PSPPs

3.1.1. Dispersion of generation sources throughout the country and decentralization of the power system

To enhance the energy security of cities, the highest priority should be given to ensuring power supply to critical infrastructure facilities during power outages caused by systemic failures in the power grid. Currently, large cities and agglomerations are the primary centres of electricity consumption. Around 70 percent of Ukraine's population lives in these urban areas, requiring a significant amount of electricity, heat and water supply, and sewage systems, all concentrated within a relatively small area. Interruptions or even complete shutdowns of critical city infrastructure due to a lack of electricity often result in the absence of those essential services for the population.

The IPS of Ukraine is a large centralized system with a high concentration of generating capacities in specific regions and large consumption nodes in others. As a result, it is vulnerable to shelling, and damage to certain facilities, primarily key substations and large generation facilities, causes maximum

[20] According to the Office of the Prime Minister of Ukraine.

damage. Also, large thermal power plants and CHPs, on which the vital activity of large cities and entire regions depends, are a priority target for missile attacks, as indicated by 71.5 percent share of damages to the baseline for TPPs and CHPs, the highest, compared to all the other types of energy infrastructure assets in 2022.

High concentration and centralization of generation also cause significant problems with manoeuverability in the grid. This makes it challenging to regulate consumption and poses a significant barrier to increasing the share of renewables, such as solar and wind, in the system. This is an important consideration given Ukraine's commitment to reducing CO_2 emissions, which involves reducing coal generation and increasing the share of renewables in the generation mix.

3.1.2. Building up manoeuvering capacities in the power system by introducing modern, highly manoeuverable, and environmentally friendly generation facilities

Considering the large share of nuclear generation and the need to increase the volume of renewable energy sources (RES), a priority for developing the energy sector, the power system will need additional manoeuvering capacities. Moreover, a significant portion of the existing TPP capacities was out of service or in an emergency state before the war due to outdated and inefficient equipment. Damage to TPPs due to missile attacks has significantly worsened the situation. The high accident rate of the existing TPPs in the system increases the risk of a capacity shortage, primarily manoeuvering capacity.

Therefore, it is necessary to build new highly manoeuvering generation facilities of lower capacity but in a more significant number, which will be dispersed across the territory. Such facilities could include:

- Thermal generation from biomass (conversion of existing TPPs and CHPs from fossil fuels to biomass and construction of biomass-fired CHPs instead of fossil fuel boilers);
- Electricity storage systems based on high-capacity batteries that can release the stored energy within a few hours to balance the power system; and
- Hydroelectric storage facilities.

3.1.3. Increasing the share of renewable energy sources

As mentioned above, one of the priorities for developing the power generation sector is to increase the share of renewable energy sources in the power system. This would necessitate the construction of new solar and wind generation capacities. However, further development in this segment is possible only if there is a sufficient amount of manoeuvering capacity in the power system. Therefore, it seems necessary to impose strict restrictions on constructing medium and large-scale solar power plants without installed energy storage devices (batteries) and a ban on further introducing so-called "grid-tied" solar power plants. The construction of new wind generation capacities should also be strictly linked and coordinated with plans to increase manoeuvering capacities in the system.

3.1.4. Gradual phase-out of coal generation

Amidst wartime and unprecedented attacks on the power system, the required volumes of electricity were provided, in part, by increasing the share of coal generation. However, the post-war restoration and development of the energy system should be planned to completely phase out coal. The phasing out of coal is necessary not only in the context of Ukraine's international commitments to reduce carbon emissions but also due to the inefficiency of existing coal-fired generation in Ukraine. Although considered shunting, it is semi-shunting and does not provide sufficient flexibility for the power system. Another critical factor is that all coal-fired generation capacities in Ukraine are obsolete, inefficient, and entirely worn out, with all of them exceeding their intended lifespan.

It is also important to note that coal mining is concentrated in certain regions that are not consumption centres after the outbreak of hostilities, thereby requiring significant transportation costs, and mining companies and coal-fired power plants are vulnerable to attacks. Thus, the abandonment of coal-fired generation will increase the environmental friendliness of the energy sector and its sustainability and efficiency.

The phasing out of coal should coincide with the development of natural gas production, which should act as a transitional substitute for coal generation while progressing toward a complete fossil fuel phase out. The priority for the gas production industry should be to satisfy the existing demand for gas as much as possible with domestic production. This approach will significantly enhance the country's energy security and ensure the functioning of critical urban infrastructure in the event of systemic power system failures. The development of domestic natural gas production requires the implementation of modern technologies and the engagement of private investors.

3.1.5. Improving the efficiency of nuclear power and large hydropower

One of the main conditions for ensuring the country's energy security is the development of nuclear generation, which will remain the foundational power source, providing at least half of the required capacity. To support the nuclear sector, it is necessary to promote the implementation of existing Energoatom projects at the highest national and international levels. At the same time, it is essential to ensure the gradual modernization of the reactor fleet and introduce dispersed nuclear generation based on small modular reactor technology.

Further development of large hydropower is also seen as necessary, focusing on increasing the number and capacity of pumped storage power plants. The country's strategy for further hydropower development is set out in the Strategic Development Plan of Ukrhydroenergo for 2023-2027 and its investment plan. Successful implementation of the Strategic Plan will increase the available hydropower generation capacity, primarily pumped storage, which will increase the ability to use hydropower to balance the power system.

3.2. Technical implications of the mid-term energy sector recovery and decentralization priorities for the immediate response

While analysing the projects for dispersing generation sources and creating a backup power supply for critical infrastructure facilities in individual cities, international experiences were explored, and consultations were held with representatives of eight focus cities, NPC Ukrenergo, and regional electricity distribution companies. Main criteria were identified that the proposed solution should meet: operation on affordable fuel, quick start up, the ability for long-term operation at maximum capacity, the possibility of deep power manoeuverability, energy efficiency, safety, a sufficient level of centralization, environmental friendliness, the capacity to use the equipment in everyday work, and the ability to operate in a "peak" mode.

As a result, the most effective solution was identified as a combination of gas turbine and gas piston engine generators, including step-up transformers for connection to the distribution network and auxiliary equipment (gas compressors, high-voltage cables, etc.). In addition to quickly ensuring a full emergency power supply to critical infrastructure, installing highly manoeuverable distributed gas-fired generating units across the country under stable operating conditions will increase the flexibility and manoeuverability of the power system as a whole. The use of gas turbines will also contribute to the decentralization of generation. The cities' energy security (winterization) project concept is presented in *Attachment 1.*

Using biomass is the easiest way to significantly reduce fossil fuel consumption in thermal generation and cogeneration and significantly reduce CO_2 emissions, as biomass is a carbon-neutral fuel. To replace fossil fuels with biofuels in thermal power generation and cogeneration, it is most efficient to use agricultural waste, primarily wheat and rye straw. Ukraine has significant volumes of these wastes, most of which are currently unused. Straw has a higher energy content than wood waste and is a much cheaper option than pellets with similar energy content.

Additional manoeuvering capacities can also be obtained by implementing projects for constructing or reconstructing thermal generation using biogas instead of fossil fuels. To do this, it is necessary to consider the possibility of reconstructing municipal sewage facilities in large cities by introducing a biogas capture mechanism (mainly pure methane) and constructing power generation or cogeneration facilities. This will reduce the use of fossil fuels and the amount of harmful emissions and overall environmental pollution from the municipal sewage system.

4. CONCLUSIONS AND NEXT STEPS

The *de facto* loss of obsolete coal-fired generation presents an opportunity to accelerate the sector's green transformation, recovery, and decentralization. This includes phasing out coal and decentralizing generation capacities, necessitating a blend of superior technology, a greener energy mix, more robust governance, and access to financing. Considering, among other factors, the limitations on the availability of grant financing, infrastructure projects financed by grants from international partners should be treated as pilots. These projects will need to be scaled up by applying private and blended private-public financing and viewed as elements of a multi-step transformation. Examples of better technologies might include upgrading standards and high voltage transmission technologies, developing decentralized generation to ensure power backup and improve the energy system's flexibility, and introducing energy storage systems to catalyse the development of wind and solar capacities. Achieving a greener energy mix requires enabling green energy sources through support for biogas and biomass-fired cogeneration, as well as fostering policy and investments in green technologies, including wastewater treatment, coal phase-out, and reduction of CO_2 and methane emissions.

Infrastructure investments will require parallel, consistent efforts to strengthen governance and provide transparent access to financing. An "Accelerator" needs to be established to identify and scale up priority projects to bolster the Government of Ukraine's current recovery efforts. Institutional partnerships should be established to unite investment attraction and infrastructure project implementation capabilities with consistent efforts to enhance good governance. This includes improving management capacity at all levels, particularly within municipal utilities; engaging the private sector in recovery; introducing de-risking mechanisms, and advancing carbon financing.

Both planning and implementation of Ukraine's energy sector recovery require data transparency and regular updates. UNDP has supported the efforts of the Government of Ukraine to set up and develop a database of energy sector losses and will continue its assistance with data consolidation and cross-checking during the war, accompanied by monitoring of the recovery efforts and related analysis of prerequisites for sustainable and green recovery. In addition to revising the data about the overall situation and deepening the analysis of the power sector, it is important to engage with the initial assessment of the actual state of the energy and critical municipal infrastructure and analysis of prerequisites for reaching locally led sustainable recovery goals both at national and local levels.

The collapse of the Kakhovka Dam has drastically affected critical infrastructure in the Kherson area and its surroundings. This event occurred just as this report was nearing completion, and reliable information regarding its effects on the power system has yet to be made available. According to a preliminary evaluation, over 200 distribution power substations have been utterly destroyed, along with dozens of boiler houses. UNDP has already begun data collection and will present the findings in the next RDNA.

ATTACHMENT 1

CITIES' ENERGY SECURITY (WINTERIZATION) PROJECT CONCEPT

The Russian Federation's invasion of Ukraine, which began on 24 February 2022, has caused significant civilian casualties and damage to infrastructure and productive assets across the country. Missile and drone attacks on Ukrainian critical infrastructure, especially on energy infrastructure and housing, started in early October 2022 and continued through the autumn and winter of 2022/2023, resulting in power outages across the country and shortages of food, heating, and water. Lack of power leaves critical municipal infrastructure – water supply, sewage, and heat supply – vulnerable, and causes interruption or even complete absence of key services to the population.

Consequently, a significant challenge for municipalities is ensuring electricity supply to their critical infrastructure facilities in the event of systemic failures. These failures could be caused by both direct attacks and related accidents in the main and/or distribution power grids. Thus, it is necessary to develop standardized recommendations for ensuring the electricity supply to critical urban infrastructure, regardless of whether the power grid is available. The proposed solutions should also consider the sufficient level of energy and economic efficiency.

It is particularly important to consider critical urban infrastructure separately. The share of the population living in cities in Ukraine is gradually increasing from 67.2 percent in 2002 to 69.7 percent in 2022, according to Ukrstat, the national statistics agency. Thus, over two thirds of the country's population lives in cities and needs large-scale electricity, heat, water, and sewage services concentrated in a relatively small area.

Among all medium and large cities, eight have been chosen as key focus cities for programme development. These cities are Kyiv, Lviv, Odesa, Mykolayiv, Kherson, Dnipro, Zaporizhzhia, and Kharkiv. The selection was made based on the following criteria:

A. Population size, with priority given to the cities having the highest number of inhabitants;

B. Vulnerability in terms of power supply; and

C. Strategic importance for the country.

Below is the information on how the chosen cities stand by the criteria.

Kyiv: 3.5 million inhabitants (highest in the country), highest vulnerability (major attacks on power infrastructure in and around the city), highest importance (capital, decision centre);

Lviv: 1 million inhabitants, medium vulnerability, highest importance (main logistical centre for international support and travel abroad, main centre for internally displaced persons);

Odesa: 1 million inhabitants, highest vulnerability (underdeveloped power grid, major attacks on power infrastructure), high importance (main port for "grain deal");

Mykolayiv: 0.3 million inhabitants, high vulnerability, high importance (logistical centre for southern military direction);

Kherson: 0.15 million inhabitants, highest vulnerability (under constant shelling), high importance (contact line, newly liberated);

Dnipro: 1 million inhabitants, high vulnerability, high importance (logistical centre for eastern military direction);

Zaporizhzhia: 0.2 million inhabitants, highest vulnerability (under constant shelling), high importance (near the battlefront line, gateway for internally displaced persons from occupied territories);

Kharkiv: 1 million inhabitants, high vulnerability (major attacks on power infrastructure), high importance (logistical centre for eastern military direction, near the border with the Russian Federation).

The limiting factor for the cities' choice for the programme was internal capacity for programme/project development and the possibility to raise sufficient financial resources. Yet, it is possible to expand the initiative beyond the list of key cities, depending on the availability of resources. Potential first-choice cities for expansion include Sumy, Chernihiv, Zhytomyr, Kryvyi Rih, and Kremenchuk. If resources become available, the programme could be extended even further – to other regional (oblast) centres and big population centres.

The analysis of international experience and the results of consultations held in eight key cities with the relevant service providers indicate that the proposed solutions should meet several criteria:

1. Work on available and accessible (and preferably not too expensive) fuel;
2. Fastest possible start and reaching operating capacity;
3. Long-term operation at maximum power;
4. Possibility of deep power manoeuver;
5. High energy efficiency;
6. Security;
7. Sufficient level of centralization;
8. Sufficiently environmentally friendly.

Over the course of work on the development of these recommendations, consultations with the national electricity grid operator (NPC Ukrenergo) were held. Regional electricity distribution companies (Oblenergos) also took part in consultations with the cities mentioned above. As a result, two additional criteria were developed:

9. Possibility to use the equipment in daily operations;
10. Possibility to run the generators in a "peak" mode.

One of the distinctive characteristics of Ukraine's energy sector is its domestic natural gas production, an efficient yet redundant gas transportation system, and almost complete gasification of large and medium-sized cities. Conversely, fuels such as gasoline and diesel are currently not produced domestically in Ukraine and are entirely imported. Alternative fuels, such as biomass/biogas, are neither consistently available nor in sufficient quantities. Furthermore, while coal and similar fuels are readily available and accessible in Ukraine, they are environmentally harmful and require significant additional space and efforts to organize fuel supply to the generators. Therefore, considering these factors, natural gas should be the fuel of first choice, which meets criteria 1 and 8.

The analysis of the power generation equipment market shows that, given the choice of fuel, gas-turbine and gas-piston generating units meet criteria 2, 3, 4, and 5.

The UNDP analysis of potential layout schemes, along with additional consultations with municipal utilities and power grid operators, reveal that both gas turbines and gas-piston engines also meet criteria 9 and 10. This is particularly true when they are appropriately scaled (fulfilling criterion 7), equipped with heat utilization manifolds, and operated by municipal district heating companies. Consequently, it is crucial to propose options for system solutions that would meet criteria 6 and 7 based on gas turbine and/or gas-piston generating units.

A sufficient level of centralization (criterion 7) is crucial for any proposed solution for various reasons such as equipment efficiency, ecological impact, and sustainability, among others. However, the most significant reason is that it allows for additional manoeuvering generating facilities of appropriate capacity to the national power grid. This is currently lacking and very much needed to ensure grid stability and security and to facilitate the integration of more renewable sources into the energy grid in the medium- and long-term post-war recovery period. The primary challenge in fulfilling criterion 7 lies within the power supply to the water supply and sewage pumping stations. Despite their capacities often falling below 1 MW, mainly within the range of 1–2 MW, these stations are scattered throughout the cities. Consequently, there is a need to find a solution to ensure the supply of power to such installations from a single source with sufficient capacity (preferably over 10 MW) using existing electricity distribution networks.

On the other hand, an overly centralized solution (e.g., installation of all needed capacity on one site) would undermine, or even completely violate, the security criterion (criterion 6). This criterion means that the solution must ensure a proper level of physical security (e.g., direct defence from bullets/shrapnel/debris, etc.) and exclude the possibility of complete dysfunction by one single targeted strike.

Taking into consideration the following:

- The results of discussions with relevant utilities (including electricity distribution companies);
- Analysis of the typical overall capacity of critical infrastructure to be covered by the solution in all focus cities (50 MW+);
- The distribution of capacities of critical infrastructure main equipment (0.5…30 MW per offtake point);
- An analysis of potential security risks and mitigation techniques;
- Demands for a sufficient level of centralization (source capacity level) (not less than 5 MW, preferably 10 MW+),

leads to the conclusion that the proposed solution should meet the following criteria:

- The possibility of covering the overall needed capacity with 3 to 5 sources;
- The capability of constant operation in manoeuvering regime;
- Independent of heat offtake;
- A sufficient level of redundancy of connected electricity distribution networks;
- With (preferably) some level of overlap of coverage areas of generation sources.

Thus, **the generic solution has to be based on a mix of gas-turbine and gas-piston engine generators** and include step-up transformers to connect to the electricity distribution network and auxiliary equipment (booster gas compressors, high-voltage cables, etc.).

It is important to note that in most cases, the pumping equipment of water supply, sewage, and district heating networks is not equipped with frequency converters. Therefore, the solution should either cover starting power capacity (3 to 7 time higher than working power ratings depending on the age and overall state of pumps) or ensure the installation of frequency converters on all necessary pumping equipment. The latter option is significantly less expensive.

Given the typical equipment used at urban infrastructure facilities throughout Ukraine and the similarity of design solutions in network construction, it is possible to conduct a more detailed study and develop proposals using the example of the City of Kyiv, the largest consumer of all municipal services among Ukrainian cities and third in the world in terms of heat energy consumption.

GENERIC SOLUTION DESCRIPTION

The solution will ensure reliable power supply backup for critical municipal infrastructure, including water supply, sewage, and district heating, tailored individually for each participating city in the event of a total blackout. At the same time, it will deploy a set of highly-manoeuverable distributed gas-fired power-generating facilities throughout the country, thereby enhancing the flexibility of the national grid and the ability to incorporate more renewables.

TECHNOLOGY	Gas turbines and gas-piston engines are identified as the most feasible technology based on equipment availability, security, implementation speed, CO_2 emissions, fuel accessibility, and cost. This equipment will cover the power consumption of the city's critical infrastructure and be connected to the power grid. This connection will offer much-needed network flexibility and enhance the economic viability of the solution.
STAGES	• Development of a backup power supply solution scheme jointly with municipal authorities and municipal utilities; • Approval of optimal locations and equipment parameters with relevant authorities; • Procurement of the equipment via the UNDP tendering system; • Delivery of the equipment and transfer to the local authorities; • Oversight of installation and launch of the equipment; • Project assessment and reporting.
CITIES	Stage 1: **Kyiv** (tenders launched) and **Odesa** (tenders in preparation) Stage 2: **Zaporizhzhia** and **Mykolayiv** (tenders expected to launch in 2023) Stage 3: **Kharkiv**, **Dnipro**, **Lviv,** and **Kherson** (feasibility study, tenders may launch in 2023) Stage 4: Potential project extension Stage 4.1: **Sumy**, **Chernihiv**, **Zhytomyr**, **Kryvyi Rih,** and **Kremenchuk** Stage 4.2: other regional (oblast) centres and big population centres.
ESTIMATED COST	US$40–85 million per project, depending on capacity.
ASSESSED IMPACT	It is estimated that over 15 million people will benefit from a reliable supply of critical municipal services even in case of a blackout or another major transmission network failure, including more than 5 million at Stages 1 and 2. and more than 10 million people at Stages 3 and 4.

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