Ukraine in Darkness:

Preventing the Worst-Case Scenario for Its Energy System

Maciej Zaniewicz

Warsaw/Kyiv, July 2024

Green Deal Ukraïna

Helmholtz-Zentrum Berlin für Materialien und Energie
Albert-Einstein-Str. 16, 12489 Berlin

Forum Energii

Wspólna 35/10

00-519 Warsaw

Contact the author

m.zaniewicz@forum-energii.eu

Content

1 INTRODUCTION 2

2 OPERATION 'DESTROY THE NETWORKS' 2

3 OPERATION 'TURN OFF UKRAINE' 2

4 TWO BLACK SCENARIOS 4

5 AND ONE BRIGHTER ONE 7

REFERENCES 9

1 Introduction

Compared to the energy system's resources available before the Russian invasion, Ukraine now has only a quarter of its production capacity. Insufficient energy supplies mean that this winter, many parts of Ukraine may be deprived of not only electricity but also heat and running water for significant portions of the day. Russia has consistently targeted and destroyed Ukrainian energy infrastructure to try to paralyse the economy and break the society's will to defend against Russian aggression and force the Kyiv authorities to capitulate to Russia on its terms. This report analyses the current state of the Ukrainian energy system and proposes solutions to reduce the risk of a humanitarian disaster in the country.

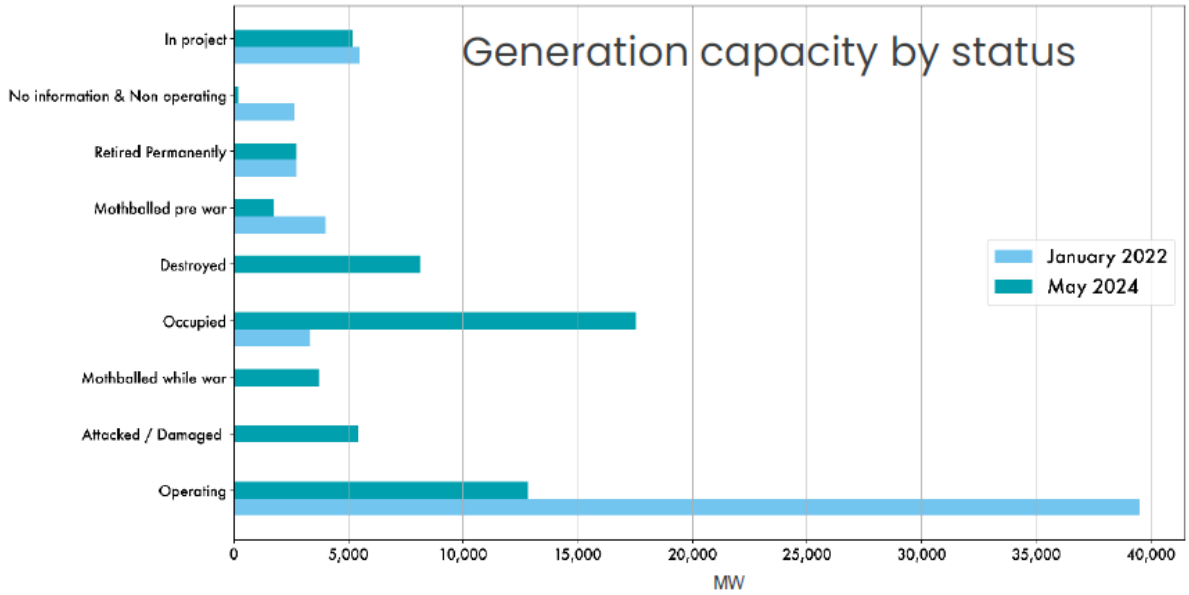
2 Operation 'Destroy the Networks'

Russia began attacking Ukrainian energy infrastructure intensively in October 2022. We reported the risks in the opinion 'Ukraine's Preparations for a Wartime Winter.' The Russian attacks, carried out in numerous waves, resulted in the need for scheduled load-shedding (rolling blackouts) by Ukrenergo, the national transmission system operator (TSO), and the temporary physical division of the Ukrainian power system into two parts. At first, the main targets were not power plants but power substations, the destruction of which prevented the distribution and transmission of energy to users. Thanks to foreign support, including from Poland (Energy Community, n.d.), Ukraine managed to rebuild most of the substations and some production capacity, allowing it to get through the winter of 2023/24 without significant disruptions to the power system (DiXi Group, 2024). Additionally, Ukraine secured more than 100 substations with physical reinforcements protecting against drones or shrapnel.

3 Operation 'Turn Off Ukraine'

The second attempt at destroying the Ukrainian energy system began in March 2024 and continues to this day (June 2024). This time, however, the main targets are not power substations but production capacity directly—coal and hydroelectric power plants. Although nuclear power plants (about 50% of the demand) and renewable energy sources (about 30%) are the most important for meeting demand in Ukraine (DTEK, 2024), for system balancing and covering peak power demand, coal and hydroelectric units, which are now regularly targeted by Russian attacks, are crucial.

Figure 1: Ukrainian generation capacity by status



Source: Green Deal Ukraïna, based on open sources.

Since March 2024, the attacks have primarily led to the elimination of balancing hydro and coal sources, with a total capacity of about 8 GW (Malenko & Polityuk, 2024). The available power of nuclear plants operating at the base of the Ukrainian system has also been reduced due to planned repairs and limiting the operation of remaining blocks to about 70%.

Estimates indicate that at the end of May, Ukraine had only about 10 GW of production capacity[1] (compared to about 40 GW before the war[2]). Currently, around 7 GW are provided by nuclear plants, the remaining thermal units (mainly coal), and hydroelectric plants. More than 2 GW in additional capacity comes from installed renewable energy sources (installed capacity around 5.6 GW from PV, around 0.46 GW from wind, and around 0.27 GW from biomass), mainly photovoltaics(Global Energy Monitor, 06/2024a, 06/2024b).

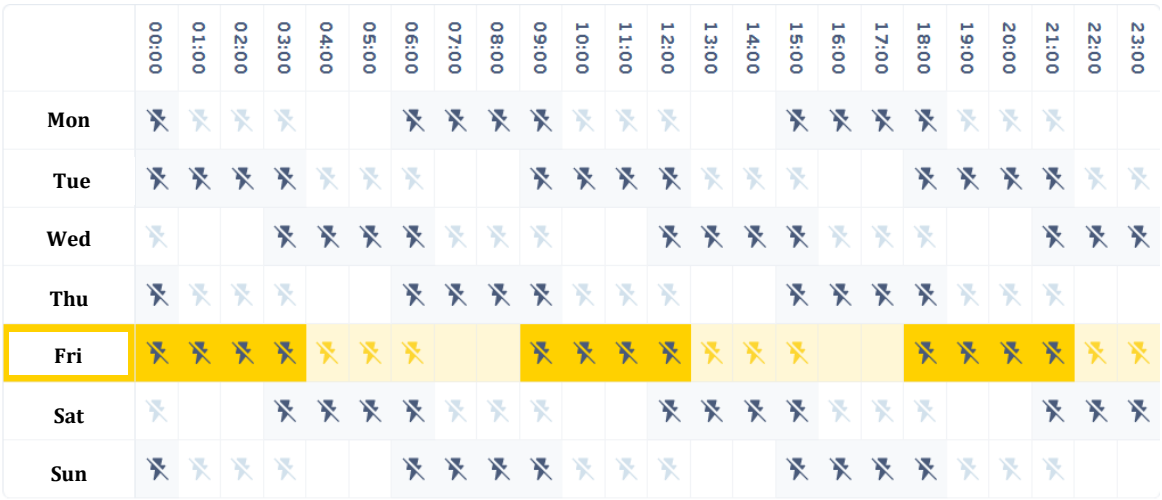
The scale of the difficulties in supplying the country with electricity is evident when comparing these figures with the demand. The current summer peak demand is about 12 GW (compared to about 16 GW before the war[3]) and the winter peak is 16 GW (compared to 22 GW before the war) (IEA, 2022). The deficit is mainly covered by importing electricity from the EU, which is now almost continuous and constitutes the second source of energy after nuclear power plants. Since increasingly neither domestic sources nor imports can cover the demand, the Ukrainian TSO is forced to apply regional power cuts/restrictions, known as load-shedding or rolling blackouts. Load-shedding affects both enterprises and individual consumers and covers

[1] Ukraine does not officially provide information on the state of its power system. The data presented in the article are estimates by the author based on information gathered from open sources and declarations by Ukrenergo and the Ministry of Energy. These estimates may differ from the actual situation due to further destruction and ongoing repairs.
[2] Official data indicate 55 GW of installed capacity at the end of 2021. However, installed capacity is never equal to available capacity due to repairs and failures. The estimates were conducted by the GDU team based on available data.
[3] The decrease in power demand is caused by the destruction of some industrial plants by Russia, the country's economic collapse, and emigration.

about 66% of the hours in a week. Users are informed of the hours of planned outages by their Distribution System Operator (DSO).[4]

Below is a sample schedule of planned outages from an application prepared for the country's residents. The blue, crossed-out lightning bolt indicates outage hours, while the grey lightning bolt represents possible additional outage hours. The white area indicates the hours when energy will be supplied.

Figure 2: Sample Schedule of Planned Outages



Source: Yasno (n.d.)

4 Two Black Scenarios

The damages caused by the current phase of Russian attacks on Ukraine's energy infrastructure are more difficult to repair than before. They involve elements of power plants, such as generators, turbines, or control and measurement instruments and automation (Povolotskiy, n.d.; Radio Svoboda, 2024).[5] [6] The units that are most destroyed lack both custom-made components and installation equipment. At the same time, repair teams must consider the high risk of further attacks during repairs, which effectively discourages foreign subcontractors. Ukrainian companies, on the other hand, struggle with a lack of manpower due to successive waves of mobilisation into the army and emigration (Urbis AIR, 2024; Zhuzha, 2023).

[4] Schedule for Kyiv is available here: https://kyiv.yasno.com.ua/schedule-turn-off-electricity
[5] See photographic documentation of one of the destroyed power plants at https://www.radiosvoboda.org/a/foto-zruynovana-elektrostantsiya/32903994.html.
[6] The list of necessary components was published, for example, by the company DTEK: https://dtek.com/en/we-need-your-help/

Table 1: List of needs to rebuild DTEK's damaged coal-fired generating capacity

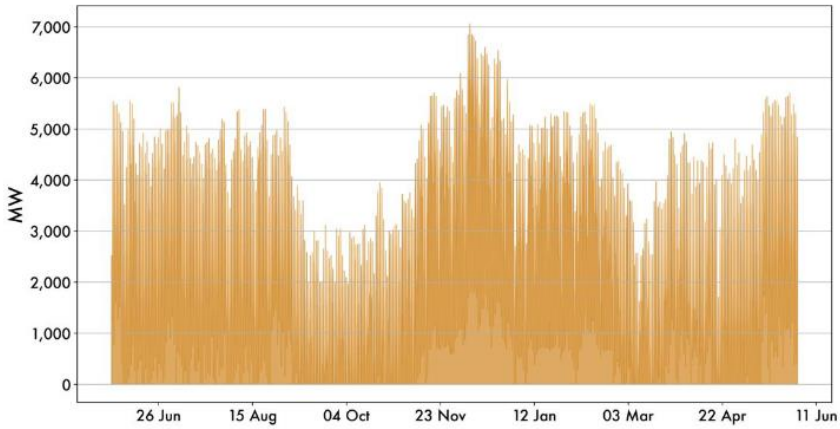
#	Item name and specification	Quantity	Unit price, mln $	Costs, mln $
1	Generator 300 MW	2	24	48
2	Turbine 300 MW	1	30	30
3	Power unit control system + TCS + turbine excitation system	2	2,1	4,2
4	Auxiliary transformer 40 MVA	1	0,8	0,8
1	Auxiliary transformer 35 MVA	5	0,55	2,75
2	Power unit transformer 250 MVA 220 kV / 15.75 kV	2	2,5	5
3	Power unit transformer 250 MVA 330 kV / 15.75 kV	1	2,5	2,5
4	Generator 200 MW	2	16	32
5	Other equipment to recover power unit #9	1	11,6	11,6
6	Autotransformer 240 MVA / 330 kV / 220 kV / Yauto/d-ll	1	2,3	2,3
7	Autotransformer 210 MVA / 400 kv / 330 kv / Yauto/d-ll	3	2,6	7,8
8	Autotransformer 133 MVA / 400 kV / 220 kV / Yauto/d-ll	1	2,3	2,3
1	Equipment to recover power unit #8	1	4,83	4,83
2	Power transformer 200 MVA / 220 kV	1	1,95	1,95
1	Power transformer 250 MVA /150 kV / 18 kV	1	2,9	2,9
2	Autotransformer 400 MVA / 330 kv / 150 kv	2	3,2	6,4
1	Autotransformer 250 MVA / 330 kV / 150 kV	2	3,5	7
2	Power transformer 400 MVA /154 kv / 20 kv	1	3,4	3,4
3	Generator 300 MW	1	24	24
4	Turbine 300 MIW	1	30	30

5	Auxiliary transformer 32 MVA / 20 kV / 6,3 kV	1	0,55	0,55
6	Start-up and backup transformer 32 MVA / 150 kV / 6,3 kV / 6,3 kV	1	0,55	0,55
7	Excitation transformer 20 kV / 0,4 kV	1	0,1	0,1
			Subtotal:	**230,93**
			Recovery works:	119,07
			Total:	**350**

Source: DTEK (n.d.)

If Ukraine's foreign partners do not provide additional support, the country's energy system will be in a catastrophic situation. Assuming a moderate scenario in which Russia does not cause further destruction, the power deficit during the winter peak-demand period could reach around 7 GW, leading to even more severe energy supply cuts during low-temperature periods.

Figure 3: Electricity Deficit in Ukraine for the Period June 2024-May 2025 (worst-case scenario)



Source: Meissner et al. (2024)

In the worst-case scenario, which is more likely, Russia will continue its attacks on generating units and—just before the heating season—will again massively attack power stations. This could even necessitate the temporary shutdown of nuclear power plants, resulting in a blackout (total lack of power for a significant part of the country) in the middle of winter. A similar situation occurred on November 23, 2022, due to Russian strikes on power stations. At that time, thanks to the operator and efficient coal and hydro units, the system was relatively quickly restored to synchronous operation (Energoatom, n.d.). Today, however, given the insufficient balancing capacities, this would be much more difficult.

The realisation of this scenario would be detrimental not only for Ukraine but also for Poland, leading to lasting destabilisation of its eastern neighbour and increasing the risk of its defeat in the war with Russia. Therefore, helping Ukraine prepare for the next winter is in the interest of Poland and the EU.

5 And Brighter One

In an optimistic scenario, with additional help from Western partners, Ukraine can restore production capacities and limit planned outages.

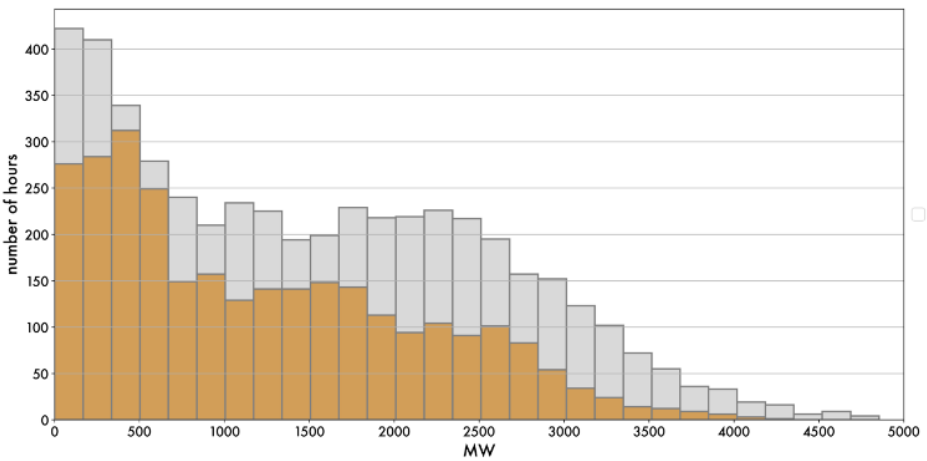
The priority is to ensure effective air defence for Ukraine. Although this extends beyond the energy sector, in wartime reality, no repairs will bring lasting results if Russia can continue to destroy subsequent Ukrainian power plants and substations effectively.

Preventing further attacks will protect the remaining power plants and substations from destruction and allow for the installation of new ones. Countries like Poland or Germany can also provide Ukraine with equipment from decommissioned coal blocks. However, the scale of destruction of Ukrainian coal units and the difficulty in repairing them prompted the search for optimal solutions elsewhere.

Modelling conducted by the Green Deal Ukraïna project team, with which Forum Energii is a strategic partner[7], shows that the most effective way to restore balancing capacities in Ukraine is to install small and dispersed gas units close to high-demand areas where gas networks are present (Meissner et al., 2024). Among the possibilities (and one already implemented with support from the U.S. Agency for International Development (USAID, 2024)) are container units with a capacity of up to 10 MW and open-cycle turbines with a capacity of up to 500 MW. Some of these installations could be located in neighbouring countries, including Poland. By implementing such solutions and repairing coal units, the total time of planned power outages would be reduced by over 60% compared to the moderate scenario.

The main challenges in this regard are mobilising financial resources and assets to install this type of unit in Ukraine and, in the longer term, the cost of purchasing natural gas.

Figure 4: Histogram of the power deficit with the installation of an additional 1.5 GW of gas units. (reduction in the deficit relative to its total value in the baseline scenario is marked in grey)



Source: Meissner et al. (2024)

It is also desirable to increase the capacity of electricity interconnectors at the EU-Ukraine border. The first step could be to remove bottlenecks in the EU and Ukraine that caused ENTSO-E operators to set a transmission capacity limit of 1.7 GW (ENTSO-E, 2023). Further expansion of

[7] Forum Energii is a strategic partner of the German-Polish-Ukrainian Green Deal Ukraïne project, which aims to support Ukraine in its accession to the EU in the areas of energy and climate, https://greendealukraina.org/.

connections, primarily the reconstruction of the Pivdennoukrainska-Isaccea line (with Romania), could provide an additional 1 GW of importable power.

On a local scale, where Poland's involvement can be most useful due to its experience in cooperation with Ukrainian local communities, an option is to provide more fuel generators and build PV installations with batteries, which will increase the independence of critical and public infrastructure such as hospitals, offices, or schools. However, a hindrance to such a scenario may be the tendency in Ukraine to centralise decisions and budget revenues, which would reduce the financial autonomy of local communities, limiting their ability to co-finance investments and reconstruction plans.

Ukraine is facing a humanitarian catastrophe this coming winter due to massive power outages. A lack of electricity also means problems with running water supplies. However, the most severe impact could be prolonged heating outages. The Russians are also destroying cogeneration plants, which are an important source of heat, especially in larger cities. As a result, people will be forced to heat themselves with electric sources, further burdening the weakened power system.

Russia aims to further degrade Ukrainian energy to the point where residents are deprived of power for most of the day. The goal is to paralyse the country's economy and cause a collapse in society's will to defend against the Russian invasion, forcing the authorities into peace negotiations on Russian terms. An additional consequence of this policy could be another wave of refugees leaving Ukraine in search of shelter with access to electricity and heating. For these reasons, it is in Poland and the EU's interest to support Ukraine as quickly as possible in rebuilding and securing its existing power system from further destruction.

References

DiXi Group. (2024, April 16). Проходження осінньо-зимових періодів 2022-2024 рр. Стан енергосистеми. *DiXi Group*. https://dixigroup.org/analytic/prohodzhennya-osinno-zymovyh-periodiv-2022-2024-rr-stan-energosystemy/

DTEK. (n.d.). *List of needed equipment to recover DTEK thermal energy power plants.* https://dtek.com/content/announces/equipment-need-list_pdf_s1439_t6470.pdf

DTEK. (2024). *Brief on Key business issues* (18/2024).

Energoatom. (n.d.). *Президент ДП «НАЕК «Енергоатом» Петро Котін прокоментував ситуацію, що склалась в атомній енергетиці після вчорашніх обстрілів об'єктів енергетичної інфраструктури*. Retrieved July 14, 2024, from https://old.energoatom.com.ua/o-2411221.html

Energy Community. (n.d.). *Ukraine Energy Support Activities*. Retrieved July 13, 2024, from https://www.energy-community.org/Ukraine/overview.html

ENTSO-E. (2023, November 28). *Continental European TSOs announce completion of synchronisation project with Ukrenergo and significant increase in export capacity from Continental Europe to Ukraine.* https://www.entsoe.eu/news/2023/11/28/continental-european-tsos-announce-completion-of-synchronisation-project-with-ukrenergo-and-significant-increase-in-export-capacity-from-continental-europe-to-ukraine/

Global Energy Monitor. (06/2024b). *Global Solar Power Tracker Summary Data—June 2024*. Google Docs. https://docs.google.com/spreadsheets/d/1zxx8JDhgzJlt8ScLxSjl_6pc9lShpdNUV33mwhf5vQ0/edit?gid=1977021392&usp=embed_facebook

Global Energy Monitor. (06/2024a). *Global Wind Power Tracker (GWPT) Summary Data—June 2024*. Google Docs. https://docs.google.com/spreadsheets/d/1zTnUWPgc3SPsZSnTb2dUHiB4GFgKJPq7cmjiWSRYl5U/edit?gid=0&usp=embed_facebook

IEA. (2022, April 19). *Ukraine Real-Time Electricity Data Explorer – Data Tools*. IEA. https://www.iea.org/data-and-statistics/data-tools/ukraine-real-time-electricity-data-explorer

Malenko, A., & Polityuk, P. (2024, May 9). Russia's biggest airstrike in weeks piles pressure on Ukraine power grid. *Reuters*. https://www.reuters.com/world/europe/russia-targets-energy-facilities-air-attack-ukraine-officials-say-2024-05-08/

Meissner, F., Carr, R., Mikhnych, V., & Zachmann, G. (2024, June). *Modelling the Electricity Deficit in Ukraine and Potential Policy Responses for the period June 2024 – May 2025*. Green Deal Ukraïna. https://greendealukraina.org/products/analytical-reports/modelling-the-electricity-deficit-in-ukraine-and-potential-policy-responses-for-the-period-june-2024-may-2025

Povolotskiy, O. (n.d.). *Emergency to restore light to Ukraine*. DTEK. Retrieved July 14, 2024, from https://dtek.com/en/we-need-your-help/Array

Radio Svoboda. (2024, April 14). *Photographic documentation of one of the destroyed power plants*. Radio Svoboda. https://www.radiosvoboda.org/a/foto-zruynovana-elektrostantsiya/32903994.html

Urbis AIR. (2024, June 3). Що відбувається на будівельному ринку Львова. *Urbis AIR*. https://urbisair.com.ua/news/shcho-vidbuvaietsia-na-budivelnomu-rynku-lvova/

USAID. (2024, September 5). *Helping Ukraine to keep energy infrastructure functional and secure*. USAID. https://energysecurityua.org/helping-ukraine/

Yasno. (n.d.). https://kyiv.yasno.com.ua/schedule-turn-off-electricity

Zhuzha, M. (2023, October 27). Тенденції в будівельній галузі під час воєнного стану. Як війна впливає на будівельну галузь. *Construction Law Consult Group*. https://clcgroup.com.ua/blog/tendencziyi-v-budivelnij-galuzi-pid-chas-voyennogo-stanu/