Distributed is Harder to Hit

An energy system with thousands of small sources as an element of Poland's national interest

Lessons from Ukraine's experience

GREENPEACE

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1. Introduction

Poland is currently undergoing a major transition of its energy sector. In the coming years, a number of coal-fired units are scheduled to be phased out and replaced by new power generation facilities – including large gas-fired units. The decisions taken today will shape the structure of the power system for decades to come. For a long time, a model based on large-scale centralised generation was the dominant approach to organising power systems in Europe. However, it was not designed to account for scenarios involving prolonged armed conflict. Such a scenario is now a reality in Europe: in Ukraine, energy infrastructure has become a primary target of military operations. Ukraine's experience has shown that large power plants, substations and transmission networks can be systematically destroyed with the aim of destabilising the state.

This raises a fundamental question about the resilience of power systems – namely, how the generation structure and spatial distribution of generating capacity affect the country's ability to operate during a prolonged crisis.

This analysis provides an overview of Ukraine's experiences between 2022 and 2026, that is, from the beginning of Russia's full-scale invasion of the country. It outlines the process of gradual degradation of the Ukrainian energy system, describes the mechanisms that enabled it to continue operating despite significant losses, and analyses the strategic shift towards a more decentralised energy generation structure that emerged during the war. It also points to the conclusions Poland must draw from these experiences.

2. Key conclusions

Russia's full-scale invasion of Ukraine, ongoing since early 2022, has become an unprecedented **test of Ukraine's existing energy security framework** and has provided important lessons regarding the functioning and degradation of power systems under conditions of prolonged warfare. The numerous studies describing the impact of military operations on the Ukrainian energy sector clearly show that the targets of the attacks were – and continue to be – not only power plants and combined heat and power plants, but also transmission infrastructure, high-voltage substations, fuel storage facilities and extraction infrastructure. Substantial losses in generation capacity, together with damage caused by systematic shelling of transmission nodes, exposed the structural vulnerability of systems relying on generation capacity concentrated in large-scale facilities. An analysis of these developments, together with the direction of Poland's planned transition of its energy sector, makes it possible to draw the following conclusions:

1

Ukraine's experience clearly shows that a power system based on concentrating generation capacity in large conventional power units poses a serious risk in wartime. Concentrating a significant share of generation capacity in a small number of locations means that a single strike can produce a disproportionately large systemic effect. In the context of modern warfare, this implies a structural vulnerability to destabilisation.

2

Despite these experiences, Poland, in planning its energy transition, is to a large extent replicating the model of highly concentrated generation capacity. Replacing large coal-fired units with large gas-fired units does not change the structure of the system; on the contrary, it reinforces that structure. This means maintaining a limited number of facilities critical to national energy supply, which in wartime conditions may become priority targets for attack. In light of Ukraine's experience, continued reliance on large, centralised generation facilities means perpetuating vulnerability to destabilisation, which in wartime could have serious consequences for national security.

3

Ukraine's experience shows that repeated attacks on facilities with high installed capacity inflict the greatest losses on the system. Ukraine has lost nearly 90% of its conventional power generation capacity (coal- and gas-fired plants) and, under wartime conditions, is unable to restore this capacity effectively. Combined heat and power plants are particularly vulnerable, as their destruction means the simultaneous loss of both electricity and heat supply for large cities.

4

Poland is increasing its dependence on imported gas. Its gas infrastructure – including the LNG terminal in Świnoujście, the planned FSRU (Floating Storage and Regasification Unit), the Baltic Pipe gas pipeline, and large gas-fired power plants – consists of concentrated critical infrastructure nodes. In the event of a military escalation, these facilities could become targets of missile and drone attacks, sabotage or hybrid operations. **The assumption that advanced air defence systems will provide full protection for such infrastructure is not supported by Ukraine's experience.** Even with international support in the form of equipment supplies, the effectiveness of air defence remains limited when faced with waves of drones and missiles, tactics involving repeated strikes, and limited ammunition stocks. Every successful hit on a large energy facility generates long-lasting systemic consequences.

A system based on renewable energy sources, energy storage and distributed generation increases resilience through territorial dispersion and infrastructure modularity. A large number of sources with low installed capacity means that the loss of a single unit does not lead to the immediate destabilisation of the national system. For a potential aggressor, this means having to conduct numerous dispersed operations with high operational costs and limited strategic impact. **Dispersion does not eliminate the risk of damage, but it significantly increases the cost of a successful attack.** 5

Ukraine's experience shows that the structure of the energy system has a direct impact on a state's ability to maintain the continuity of public administration, healthcare, water supply and sanitation, transport and industry. In this sense, energy policy should be treated as an integral element of national security. 6

Building a more decentralised system – based on thousands of generation sources, energy storage facilities, energy efficiency, high cross-border interconnection capacity, flexible demand management and the ability of critical infrastructure to operate in island mode – is not merely a climate-related or economic decision. It is a strategic decision that affects the state's resilience in crisis and wartime situations.

The development of such an architecture must be accompanied by systemic measures to strengthen the entire critical infrastructure. These include:

1. **increasing the energy independence of key facilities** (hospitals, water supply systems, emergency management centres, industrial infrastructure) from the central transmission grid by developing their island mode operating capabilities;

2. **strengthening the cybersecurity** of energy infrastructure, given that in conditions of hybrid warfare, ICT systems are targets of equal importance to physical infrastructure;

3. **strengthening the passive protection of key grid components** – in particular high-voltage substations, which constitute nodes of strategic importance;

4. **developing smart grids** to enable dynamic demand management (Demand Side Response, DSR) and rapid **isolation of damaged segments of the system without shutting down entire regions;**

5. **ensuring the availability of qualified personnel** capable of managing the energy system and carrying out repairs under crisis conditions.

3. Evolution of Russia's attacks on Ukraine's energy system

Since the full-scale invasion of Ukraine began in February 2022, Russia's actions targeting Ukraine's energy infrastructure have gone through successive phases, reflecting shifts in the aggressor's tactics and operational objectives. An analysis of each phase allows for an understanding of the mechanisms by which an energy system is degraded under wartime conditions.

Phase 1: February 2022–September 2022

PHYSICAL SEIZURE OF INFRASTRUCTURE

In the early stages of the war, Russia focused on seizing key components of Ukraine's energy infrastructure located within the range of its ground operations. The most significant event was the capture of the Zaporizhzhia Nuclear Power Plant (ZNPP), representing the loss of approximately 6 GW of firm baseload capacity. Russia also seized a significant proportion of Ukraine's wind farms.

Phase 2: October 2022–March 2023

DRONE AND MISSILE CAMPAIGN AGAINST THE TRANSMISSION NETWORK AND GENERATION FACILITIES.

On 10 October 2022, Russia launched a large-scale drone and missile campaign targeting Ukraine's energy system[1]. The attacks primarily targeted components of the transmission network, as well as power generation facilities. The tactic involved triggering cascading failures and inducing blackouts, particularly during the winter period. Air defence and ammunition availability proved to be absolutely critical factors in defending Ukraine's energy system at that time.

Phase 3: March 2024–August 2024

ESCALATION AND THE PHYSICAL DESTRUCTION OF GENERATION CAPACITY

In 2024, Russia clearly changed its tactics. Attacks concentrated on the direct destruction of conventional and hydroelectric power plants. Over a six-month period, nine coordinated strikes were carried out[2].

Between March and July 2024, Ukraine lost approximately 9.2 GW of its generation capacity[3]. In the summer of 2024, the power shortage reached 2.5 GW, and Kyiv experienced regular blackouts[4].

In total, during phases 2 and 3 (from October 2022 to September 2024), Ukraine's energy infrastructure got attacked more than a thousand times (1,024 documented incidents[5]).

[1] EESC: *Lessons of War: Ukraine's Energy, Infrastructure Damage, Resilience and Future, Opportunities,* 10 May 2024.

[2] The Kyiv Independent: *Russia has destroyed all thermal power plants, nearly all hydroelectric capacity in Ukraine ahead of winter, Zelensky says,* 25 September 2024.

[3] IEA: *Empowering Ukraine Through a Decentralised Electricity System,* 17 December 2024.

[4] The Kyiv Independent: *Russia has destroyed all thermal power plants, nearly all hydroelectric capacity in Ukraine ahead of winter, Zelensky says,* 25 September 2024.

[5] Ibid.

Phase 4: year 2025 and the beginning of 2026

COMPLEX, REPEATED ATTACKS

In 2025, the attacks became more complex and coordinated. Russia combined mass strikes using Shahed-type drones (designed to overwhelm air defences) with precision attacks using ballistic and cruise missiles. Combined heat and power plants supplying heating to large cities became the main target.

In November 2025, as part of a single large-scale attack, Russia launched over 450 drones and 45 missiles of various types, including 32 ballistic missiles, against Ukraine. Most of the missiles reached their intended targets[6]. Energy infrastructure facilities rebuilt in 2024 were targeted[7], as well as substations supplying the Khmelnytskyi and Rivne nuclear power plants[8]), which led to a temporary reduction in generating capacity[9]. Between 25 March and November 2025, more than 4,400 attacks on energy infrastructure were recorded[10].

Further large-scale attacks took place on 9 and 20 January 2026. In January, around 60% of Kyiv was periodically without electricity, and thousands of households were left without heating[11]. The most severe consequences resulted from repeated strikes using ballistic missiles, which are especially difficult to intercept[12].

Systemic consequences

Over time, power cuts have become more frequent and prolonged in time – including for industry. Ukraine has introduced scheduled power cuts to allow for repairs and to stabilise the grid. Around 6.3 million people a day experience power cuts lasting between 8 and 16 hours[13].

At the same time, energy imports from European Union countries to Ukraine have risen significantly. January 2026 was a record month in this respect. Cross-border transmission capacity between the European Union and the Moldova-Ukraine bloc also rose to a record level of 2.45 GW[14].

[6, 8] Oko.press: *To nie apokalipsa, choć będzie ciężko. Skutki największego rosyjskiego ataku na ukraińską energetykę* [Not an apocalypse, though it will be difficult. The consequences of Russia's largest attack on Ukraine's energy infrastructure], 25 November 2025.

[7] Business Insider Polska: *Najsilniejszy dotąd atak Rosji na elektrownie cieplne Ukrainy. „Produkcja energii wynosi zero" [Russia's most powerful attack yet on Ukraine's thermal power plants. „Energy production is at zero"],* 8 November 2025.

[9] Energetyka24: *Rosja ostrzelała podstacje zasilające elektrownie jądrowe na Ukrainie[Russia strikes substations supplying Ukraine's nuclear power plants],* 31 October 2025.

[10, 13] XYZ: *ReBuild Ukraine. Wiceminister energii: Ukraina utraciła 6,8 GW mocy i 40 proc. produkcji gazu [ReBuild Ukraine. Deputy Minister of Energy: Ukraine has lost 6.8 GW of capacity and 40% of gas production],* 13 November 2025.

[11] Gazeta Prawna: *Kryzys energetyczny na Ukrainie: 60 proc. Kijowa bez prądu i ogrzewania. W całym kraju awaryjne wyłączenia [Energy crisis in Ukraine: 60% of Kyiv without electricity or heating. Emergency blackouts across the country],* 23 January 2026.

[12] Oko.press: *To nie apokalipsa, choć będzie ciężko. Skutki największego rosyjskiego ataku na ukraińską energetykę [Russia's most powerful attack yet on Ukraine's thermal power plants. „Energy production is at zero"],* 25 November 2025.

[14] Dixi Group: *Electricity imports to Ukraine reached a historic high in January,* 4 February 2026.

4. A centralised system based on large-scale conventional units as a factor leading to state destabilisation in wartime conditions

Ukraine's experience shows that, in times of war, what matters is not only how much generation capacity the energy system has, but also how quickly it can be lost as a result of attacks. From this perspective, a centralised system based on large conventional power plants reveals its structural vulnerability under wartime conditions and contributes to the accelerated destabilisation of the state. Concentration of capacity in a limited number of facilities means that a single strike can set off a systemic disruption with consequences extending far beyond the energy sector. Any seizure or destruction of a major generation facility directly limits a state's capacity to generate power, balance the system, and maintain grid stability. The faster the loss of capacity, the greater the risk of cascading failures, widespread blackouts, and economic and social destabilisation. The pace of system degradation translates directly into the scale of financial losses (costs of reconstructing power generation facilities or building new ones), disruptions to industrial production, and a reduction in the state's capacity to provide basic public services, maintain the functioning of critical infrastructure, and carry out defence operations.

Equally important is the ability to restore damaged power generation capacity. In wartime conditions, it depends on: the feasibility of technical repairs to the facility, the time required to carry them out, and the risk of further attacks. The time required for restoration depends on the technology used, the availability of specialised components, the logistics of their delivery, and the availability of skilled personnel. The adversary's tactics also have a significant impact, particularly repeated shelling of the same targets. Rebuilding large-scale conventional units is a complex, time-consuming and costly process. In wartime, this means that a capacity deficit can persist for many months or even years.

Therefore, a model based on large, centralised power generation units increases the impacts of a single attack and extends the period of destabilisation following it. In a wartime scenario, this means accelerating the process of weakening a state by targeting the foundations of its energy system.

The rate of capacity loss outpaces the ability to restore it

In a system reliant on large power generation facilities, the loss of a single facility results in an immediate and significant reduction in national power generation capacity. This can rapidly lead to a production deficit, difficulties in balancing the system, and an increased risk of blackouts.

Prior to the start of the full-scale Russian invasion in 2022, Ukraine's energy system had approximately 56 GW of installed capacity[15]. It relied primarily on large nuclear power plants (four facilities with

[15] ACAPS: *Ukraine: Energy infrastructure attacks: updated outlook and impact during the 2024–2025 cold season,* **19 February 2025.**

a combined capacity of approximately 14 GW[16]) as well as coal and gas-fired power plants (approximately 25 GW). Nuclear power plants supplied around 50% of the country's electricity.

Since 2022, Ukraine has lost approximately two-thirds of its system's capacity – as a result of destruction, disruption or the seizure of infrastructure[17]. Despite intensive defence efforts, it has not been possible to prevent losses of such magnitude.

The table below illustrates the scale of power generation capacity loss by 2024, broken down by energy source.

Table 1. Scale of capacity losses in Ukraine's energy system by source

Source	Installed Capacity **GW** prior to the 2021/2022 invasion	Installed Capacity **GW** 2024	Estimated Loss **%**
Nuclear Power Plants	**13,8**	**7,8**	**43%***
Conventional Power Plants and Combined Heat and Power Plants – total	**25,1**	**3,5**	**86%**
→ Out of which coal and gas-fired conventional power plants account for	**21,6**	**1,9**	**91%**
→ Out of which combined heat and power plants account for	**3,5**	**1,6**	**54%**
Hydropower (including pumped-storage power plants)	**6,4**	**3,4**	**47%**
RES – Wind Farms	**1,9**	**0,5**	**74%****
RES – Photovoltaics	**8,3**	**7,1*****	**14%**

* Losing ZNPP – a single nuclear power plant.

** Losses related to territorial concentration and occupation of land.

*** Data as of 2024, for the sake of comparability. In the case of photovoltaics, some new installations (largely prosumer-based) partially offset the losses (more on this in Chapter 5). Source: own compilation based on Instrat analysis and other sources[18].

Despite efforts to restore lost capacity, by January 2026 the system was able to meet only approximately 60% of domestic electricity demand, resulting in multi-hour power cuts across the country[19].

[16] International Energy Charter: *Ukrainian energy sector evaluation and damage assessment – I (as of August 24, 2022).*

[17] Instrat (in its report Ukraine Against Darkness, November 2024) cites 60% as of mid-2024. Other sources (The Kyiv Independent: As Ukrainians freeze, donated energy equipment sits unused, 4 February 2026) add that since October 2025 alone, 8.5 GW of capacity has been lost from the system. The IEA, in its report Empowering Ukraine Through a Decentralised Electricity System (17 December 2024), assesses that by spring 2024 Ukraine had already lost two thirds of its power system's available capacity. The Russia Matters portal (The Russia–Ukraine War Report Card, 4 February 2026) states that in autumn 2025 Ukraine was operating at one third of the power system capacity it had prior to the full-scale invasion. Euromaidan Press likewise reports the loss of two thirds of Ukraine's power system capacity (Ukraine completes first phase of power grid armor, 5 September 2026).

[18] Data sources:
1) Instrat: *Ukraine against darkness;*
2) International Energy Charter: *Ukrainian energy sector evaluation and damage assessment – I (as of August 24, 2022);*
3) Energy Partnership Ukraine-Germany: *Ukraine wind energy market analysis;*
4) ACAPS: *Ukraine: Energy infrastructure attacks: outlook and impact during 2024–2025 cold season;*
5) PV Magazine.

[19] CSIS: *Russia's Grinding War in Ukraine,* 27 January 2026.

Concentration of capacity is a factor that accelerates system destabilisation

Prior to Russia's invasion, conventional coal and gas-fired power plants as well as combined heat and power plants constituted the largest share of the system's generation capacity and accounted for a significant portion of electricity and heat production. These were the facilities that suffered the greatest losses.

loss of generation capacity at Centrenergo

Case study

On 11 April 2024, Russian forces launched a missile attack on the 1.8 GW Trypilska Power Plant, located in the Kyiv region. Eleven missiles were fired at the facility. Seven were intercepted by Ukrainian air defences, while four hit their target once ammunition supplies were exhausted. The fire and destruction of the turbine hall put the power plant out of operation for years.

A similar fate befell the Zmiyevskaya Power Plant in the Kharkiv region in March 2024. Combined with the Russian forces' takeover of the Vuhlehirsk Power Plant in the Donetsk region in July 2022, this led to the loss of 100% of the power generation capacity at the state-owned Centrenergo. Despite attempts to restore the lost capacity, it could not be done due to intensified drone attacks[20].

[20] The Kyiv Independent: *Ukraine's state-owned energy company says all of its power plants are down after Russia's ‚largest-ever attack',* **8 November 2025.**

This case illustrates the vulnerability of large, centralised conventional facilities with known locations to missile and drone strikes. Rebuilding such facilities is time-consuming and costly. Moreover, they remain exposed to further attacks.

It is precisely this asymmetry – rapid losses and slow or even impossible reconstruction – that increases the risk of prolonged power system destabilisation in a centralised model.

However, the problem of rapid capacity loss does not affect conventional power plants alone. Hydropower, which plays a vital role in Ukraine in balancing the grid and meeting peak demand, has also been the target of repeated, concentrated attacks, resulting in the loss of around 50% of the country's hydropower capacity. The most severe damage was sustained by the Kakhovka Hydroelectric Power Plant (approx. 350 MW), which was completely destroyed when the dam on the Dnieper River was blown up in June 2023, and by the Dnipro Hydropower Plant – the country's largest hydropower facility (approx. 1.6 GW) – which was put out of operation following large-scale Russian attacks in March 2024. The time required to restore the Dnipro facility is estimated at several years[21].

[21] The Kyiv Independent: *Repair of Ukraine's largest hydroelectric power plant to take at least 3 years due to Russian attacks,* **16 July 2024.**

In the case of nuclear power plants, the most significant loss of generation capacity resulted from the seizure of the Zaporizhzhia Nuclear Power Plant by Russian forces. As for the other facilities, although they were not, as a rule, directly shelled, they became instruments of coercion and nuclear blackmail. Russia avoided direct strikes on the reactors, but systematically destroyed substations at the nuclear power plants, with the aim of forcing an emergency shutdown of the units and cutting them off from the transmission network. Given that nuclear power plants require a continuous power supply, this posed a risk of a radiation disaster. In January 2026, Ukrainian intelligence reported plans for massive strikes on transmission nodes connecting nuclear power plants to the grid, which could have led to a nationwide blackout[22]. Additionally, Russia is using the seized nuclear power plant in Zaporizhzhia to store military equipment and conduct attacks on other locations in Ukraine.

[22] Ukrainska Pravda: *Russia considering strikes on substations serving Ukraine's nuclear power plants, Ukrainian intelligence says,* 17 January 2026.

Lengthy restoration and vulnerability to further destruction

Repairing a damaged conventional coal-fired power plant or a combined heat and power plant can take several years – and that is only assuming that reconstruction and repair operations can be carried out without interruption. Ukraine's experience shows that this is unfeasible in wartime conditions.

Russia employs a tactic of re-striking damaged or partially reconstructed facilities – sometimes within a few dozen minutes of the first strike, sometimes after a longer period. This poses a direct threat to repair crews, firefighters, and engineers, and also increases the risk of wasting the time and resources invested in the reconstruction. The repair timelines are also significantly extended by work interruptions caused by air raid alerts.

Energy companies point out that the reconstruction of large power plants requires ensuring air defence systems that would protect against drones and missiles. The lack of such systems or a shortage of ammunition directly hinders repair work. The reconstruction process therefore depends not only on financial resources and technical expertise, but also on the availability of military resources.

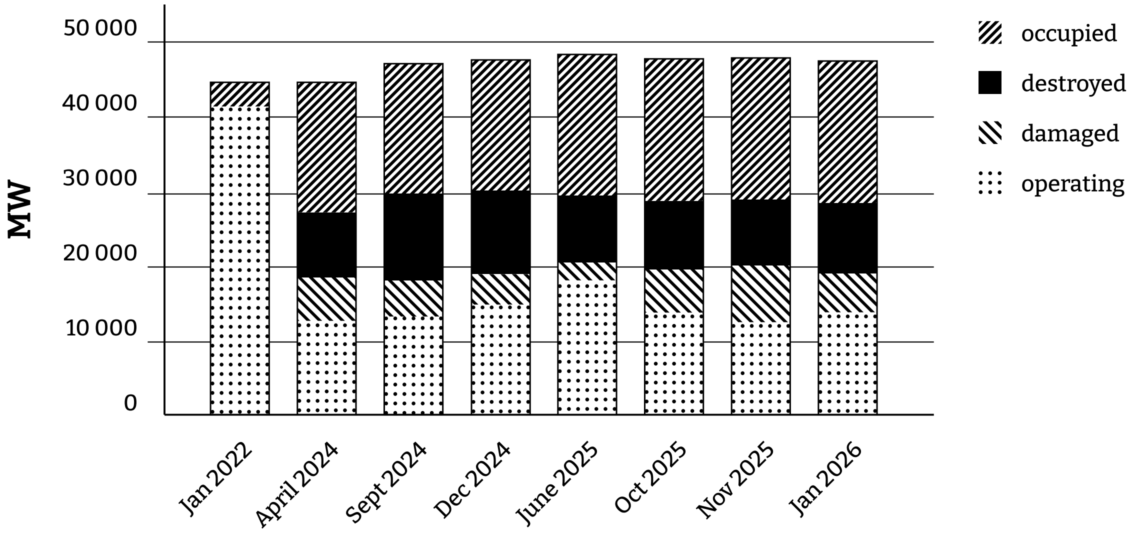
The tactic of repeated strikes is particularly effective against large, centralised facilities. It would be far less effective, both economically and operationally, if the targets were thousands of smaller, distributed energy sources and network nodes. Concentration of capacity translates into concentration of risk – including at the reconstruction stage.

The availability of spare parts also remains a significant challenge. Components for large power units are not mass-produced and are often not immediately available. In the case of Ukraine, an additional complication is the specific nature of the power plants, whose key components were designed and manufactured back in the days of the Soviet Union. Limited compatibility with modern components and disrupted supply chains significantly hinder the rapid procurement of replacements[23].

[23] AP: *Ukrainian energy workers carry out repairs despite Russia's pounding of the country's power grid,* 29 November 2024.

As a result, rebuilding a large conventional power plant in wartime is a lengthy and costly process with a high risk of failure. This is yet another mechanism by which the centralised model increases the likelihood of long-term energy system destabilisation.

Figure 1. Installed capacity at conventional power plants and the share of operational capacity in the Ukrainian power system over time.



The chart above shows that, under wartime conditions, Ukraine has not been able to restore a significant share of its generation capacity within its energy system.

Source: Green Deal Ukraina: *Electricty and gas supply in Ukraine: Winter 2025/26 Update January 2026.*

The electricity grid – a critical point of state resilience

The vulnerability of the energy system to destabilisation stems not only from large power generation facilities, but also from the associated high-voltage transmission networks.

Ukraine's experience shows that transmission infrastructure has become the target of systematic, repeated attacks. Strikes against high-voltage substations have been used to cut off power supplies on a large scale and to force the shutdown of power generation units. It is estimated that as many as 50% of substations have been destroyed or seriously damaged[24].

The scale of the damage revealed the critical role of high-voltage transformers (330 and 750 kV[25]) and distribution network transformers (35–110 kV). Their production is time-consuming, costly, and dependent on global supply chains. In wartime conditions, the unavailability of these transmission network components directly affects the pace at which power supply can be restored.

In order to protect the transmission infrastructure from attacks, the Ukraine's grid operator Ukrenergo has implemented a three-level passive protection system[26] – that is, defences that do not stop an attack but ensure it causes less damage – ranging from mesh baskets filled with stones, through concrete shielding structures, to missile-proof shelters[27] for key transformers. The very necessity of building shelters for grid components illustrates the scale of the threat and the cost of maintaining a highly centralised system.

[24] Kyiv School of Economics: *Damages and losses to Ukraine's energy sector due to Russia's full-scale invasion exceeded $56 billion – KSE Institute estimate as of May 2024.*

[25] Oko.press: *To nie apokalipsa, choć będzie ciężko. Skutki największego rosyjskiego ataku na ukraińską energetykę* [Russia's most powerful attack yet on Ukraine's thermal power plants. „Energy production is at zero"], **25 November 2025.**

[26] Euromaidan Press: *Ukraine completes first phase of power grid armor,* **5 September 2025.**

[27] The Kyiv Independent: *Ukraine moves its power grid underground to shield it from Russian attacks,* **10 February 2026.**

Cybersecurity as a component of system resilience

The vulnerability of the power system to attacks is not limited to physical infrastructure. Modern energy systems are heavily reliant on ICT systems, which are equally targeted.

Ukraine's experience shows that attacks on control systems can also lead to power cuts even when the facilities are not physically destroyed. As early as in 2015, a cyberattack on distribution network operators resulted in the disruption of power supply to hundreds of thousands of consumers[28] – achieved by compromising SCADA systems and remotely shutting down power substations. In subsequent years, Russia developed tools specifically designed to target the energy sector (e.g. the Industroyer malware), and in 2022 attempted to carry out coordinated cyberattacks on power infrastructure in parallel with its military operations.

[28] BiznesAlert: *Ukrenergo: Blackout w Kijowie to skutek cyberataku* [Ukrenergo: Kyiv Blackout Caused by Cyberattack], 18 January 2017.

In this context, the growing role of renewable energy sources is changing the nature of the risks involved. A system based on distributed generation reduces the significance of individual critical points and lowers the risk of a systemic blackout. On the other hand, it increases the number of devices connected to the grid that may be potential targets for cyberattacks. Distribution therefore increases the physical resilience of the system, but requires a parallel strengthening of cybersecurity standards across the entire infrastructure.

The asymmetry of costs and effectiveness between attacking and defending centralised energy infrastructure

Ukraine's experience shows that energy infrastructure is one of the main targets of military operations. Russia uses both unmanned aerial vehicles and various types of missiles, including cruise missiles and ballistic missiles, in its attacks. In recent years, there has been a growing use of ballistic missiles, which are more difficult to intercept by air defence systems.

The cost of such missiles is estimated at several to over a dozen million US dollars each. Despite the high unit cost of this weaponry, its use in attacks on energy infrastructure is cost-effective for the aggressor, as striking large power generation facilities or key substations can have significant systemic consequences for the functioning of Ukraine's power grid and contribute to state destabilisation.

Protecting large energy facilities requires advanced air defence systems. When it comes to ballistic missiles, one of the few technologies offering a high interception rate remains the Patriot system, which costs around one billion US dollars per battery[29]. Its deployment depends on missile supplies from the United States..

According to Ukrainian estimates, effective airspace protection would require around 25 Patriot systems (each with six to eight launchers[30]), whereas Ukraine currently has eight. By comparison, Poland currently

[29] Bankier.pl: *Cena systemu Patriot to ok. miliard dolarów. Ukraina „domknie niebo" z 25 zestawami* [The price of a Patriot system is approximately one billion dollars. Ukraine will „close the sky" with 25 batteries], 6 May 2025.

[30] Ibid.

has two Patriot batteries (purchased in 2018 for USD 4.75 billion), with a further six due to be delivered between 2027 and 2029 (purchased in 2023 for USD 9.3 billion)[31].

Even with highly effective air defence systems – intercepting around 80% of drones and missiles[32] – the remaining strikes can cause serious damage to critical infrastructure. In the event of massive attacks involving dozens of missiles and hundreds of drones simultaneously, even a sophisticated defence system cannot guarantee complete protection.

In a power system based on a small number of large generation facilities, the destruction of a few key facilities can lead to serious disruptions across the entire network. In a system based on many distributed energy sources, achieving a similar effect would require a much greater number of strikes in different locations.

In a wartime scenario, the way the energy system is organised therefore becomes a key element of a country's strategic resilience to disruptions and attacks on critical infrastructure.

Why an energy system based on capacity concentrated in large generation facilities is prone to destabilisation – summary

Table 2 (next page): Analysis of the vulnerability of a centralised energy system in wartime conditions

[31] Ibid.

[32] Defence24: *Jak Ukraina broni nieba: wzór do naśladowania?* [How Ukraine Defends its Skies: A Model to Follow?], 8 February 2026.

Analysed Item	Centralised System (Large Units)	Systemic Consequences
Magnitude of a Single Loss	The loss of a single unit or facility results in reducing hundreds of MW to several GW.	Immediate nationwide capacity deficit.
Vulnerability of System Architecture	The system's heavy reliance on a centralised high-voltage transmission infrastructure and key components with long lead times.	Large-scale power cuts, forced shutdowns of generation facilities, and a lengthy system restoration process due to limited availability of components and the high cost of replacing them.
Power Grid Control and Management Systems	The concentration of power system control and management functions in centralised systems (e.g. control centres, SCADA systems), which constitute single points of failure.	A cyberattack on key control systems could lead to the simultaneous loss of control over a large part of the power system, causing widespread disruption or power cuts without the need to physically damage the infrastructure.
Rate of Capacity Loss	Rapid – a large part of the system could be lost in a short period of time. The attack targets large facilities with known locations. Waves of drones and ballistic missiles, combined with limited defensive ammunition supplies, cause severe damage to infrastructure.	Risk of cascading failures and a blackout.
Balancing Capability	Limited – no equivalent reserves.	Problems with frequency and voltage stability.
Restoration Time	Long (months to years). Ukraine's experience indicates a lack of any realistic prospect of restoration under wartime conditions (due in part to the recurring nature of shelling).	Prolonged system destabilisation.
Reliance on Components	High – specialised turbines and transformers are essential. Extended supply chains present a further challenge.	Limited repair capacity.
Risk of Further Attacks	High – large facilities are easy to be re-targeted.	The reconstruction may be interrupted.
Costs	The costs of conducting strikes (using drones and missiles) are relatively low for the aggressor, yet yield a measurable result in the form of damage to a generation unit or power plant, and the costs of any subsequent reconstruction.	The country under attack is rapidly incurring heavy financial losses. It is cost-effective for the aggressor to attack a centralised power system.
Impact on Economy	Large individual capacity losses.	Restrictions on industrial production, power cuts.
Strategic Effect	High risk concentration.	Accelerated destabilisation of the state.

5. Renewable energy sources in times of war – resilience, reconstruction and decentralisation

Prior to Russia's full-scale invasion of Ukraine, over 40% of renewable energy sources (photovoltaics and wind turbines) generation capacity was located in territories now occupied by Russia. Renewable energy sources were therefore relatively concentrated geographically. This was particularly true of wind power, with its main generation capacity located in the Kherson and Zaporizhzhia region[33]. The occupation of these areas thus resulted directly in a significant loss of capacity, even though the wind turbines themselves were not always physically destroyed.

The wartime boom in photovoltaics

Photovoltaics (PV) has proved to be one of the fastest-growing segments of Ukraine's energy sector amidst the war. By 2024, Ukraine had lost around 14% of its PV capacity (from around 8.3 GW prior to the invasion), with the losses mainly affecting large, commercial industrial installations[34]. Compared to the losses in conventional coal and gas-fired power plants, the magnitude of losses in PV capacity was significantly lower.

The subsequent period saw rapid restoration and the addition of new capacity. According to the Solar Energy Association of Ukraine (SEAU), 1.5 GW of new PV capacity was installed in 2025 – almost twice the approximately 800 MW built in 2024. In January 2026, total PV capacity exceeded 8.5 GW, surpassing pre-full-scale invasion levels. Current growth is largely driven by prosumers[35]. The International Energy Agency (IEA) estimates that Ukraine's PV capacity could reach approximately 31 GW by 2030[36].

Experts point to photovoltaics as one of the key components in addressing Ukraine's energy deficit[37]. PV systems, which are not the primary targets of shelling, have proved to be a valuable asset. From the aggressor's perspective, attacking large, centralised power plants is a far cheaper and more effective way of destabilising the system than targeting thousands of small PV installations.

The modular PV panels used in Ukraine demonstrate relatively high resilience. One example coin be panels made from polymers, which remain functional even after being struck by a projectile and do not produce dangerous shrapnel in the event of an explosion[38]. Their compact size makes them easier to conceal and disperse. A drone may disable several modules; however, replacement is quick, relies on standard components, and rarely requires heavy equipment. The installation of solar panels on the roofs of numerous buildings creates a decentralised power supply system, the systematic destruction of which is logistically and economically unviable for an aggressor[39]. The loss of a single installation has an incomparably smaller impact on the system than the loss of a large generation facility[40].

PV installations are increasingly being used as local power supply for critical infrastructure. Examples include a 340 kW PV project in the city of Chortkiv, a 30 kW installation with energy storage in the town

[33] European Union Institute for Security Studies: *Keeping the lights on: How Ukraine can build a resilient energy system (and why this matters to the EU),* 28 March 2025.

[34] IEA: *Policy Options to Accelerate Distributed Solar PV in Ukraine,* November 2025.

[35] PV Magazine: *Ukraine deploys 1.5 GW of solar in 2025,* 26 January 2026.

[36] IEA: *Policy Options to Accelerate Distributed Solar PV in Ukraine,* November 2025.

[37] Instrat: *Ukraine against darkness,* 26 November 2024.

[38] Netherlands Enterprise Agency: *The road to sustainable energy is paved with solar panels,* 28 August 2025.

[39] The Crucial Years: *It's hard to drone a solar panel,* 4 October 2025.

[40] IEA: *Empowering Ukraine Through a Decentralised Electricity System.*

of Donets providing access to water, a hospital in Slobozhanske[41], and a health centre in the village of Horenka[42]. Photovoltaics combined with energy storage is currently the fastest technology to deploy – and restoration time is of critical importance in wartime conditions.

Wind power – heavy losses as a result of the occupation

As a result of Russia's full-scale invasion, Ukraine has lost around 74% of its onshore wind power capacity. The main reason was the concentration of wind farms in the Kherson and Zaporizhzhia regions, which are currently largely under occupation.

Wind farms are usually not the primary target of an attack – destroying them would require striking dozens of towers spread over a large area. However, they are vulnerable to takeover in the event of an occupation of the area[43]. This clearly shows that the regional concentration of generation capacity increases the system's vulnerability to destabilisation, regardless of the technology used.

Despite the war, Ukraine had managed to build 230 MW of new wind power capacity by mid-2024, with further projects totalling over 7 GW currently at various stages of development (20 MW was installed in 2024)[44].

A distributed energy system comprising thousands of sources, including RES, favours the system's resilience in times of war

Ukraine's experience shows that the resilience of an energy system depends not only on the type of technology used, but also on the architecture of the system itself. A decentralised system, based on renewable energy sources and energy storage, combined with high cross-border interconnection capacity, reduces the risk of national destabilisation and shortens restoration time.

Distributed generation sources, located close to demand centres, reduce the system's reliance on high-voltage transmission lines. Generating power closer to the end consumer limits the scale of potential supply interruptions in the event of damage to a single grid node.

Striking a single installation – such as a solar farm – does not have significant systemic consequences, as other sources can take over part of the load. A distributed system also allows for the use of additional forms of passive protection and faster infrastructure reconstruction, due to the smaller scale of damage and greater availability of components.

Distributed generation does not eliminate threats, but significantly raises the threshold for effective system destabilisation. This clearly demonstrates that decisions regarding the structure of future generating capacity have a direct bearing on national security.

[41] PV Magazine: *Ukrainian city switches on solar arrays for local water utility,* 25 September 2025.

[42] Greenpeace Ukraine: *Building Ukrainian resilience: the green reconstruction of Horenka hospital,* 1 February 2023.

[43] European Union Institute for Security Studies: *Keeping the lights on: How Ukraine can build a resilient energy system (and why this matters to the EU),* 28 March 2025.

[44] Energy Partnership Ukraine-Germany: *Ukraine wind energy market analysis,* July 2025.

6. Summary and conclusions for Poland

Ukraine's experience between 2022 and 2026 demonstrates that the resilience of the energy system in wartime depends primarily on its structure. The heaviest losses were suffered by large, centralised conventional coal- and gas-fired power plants and high-voltage transmission infrastructure. The loss of individual high-capacity units caused an immediate deficit in the system, balancing disruptions, and an increased risk of blackout. Rebuilding these units turns out to be a process that takes many years, is costly, and leaves them vulnerable to repeated attacks – and is therefore largely ineffective.

Distributed renewable energy sources – particularly photovoltaics supported by energy storage – demonstrate significantly greater resilience, and their reconstruction as well as the construction of new facilities are possible even under wartime conditions. This demonstrates that a system based on many smaller generation units may be potentially more difficult to destabilise quickly than a system centred around a few large energy infrastructure facilities.

For Poland, this means that the choice between concentration and distribution is not purely a technological decision – it is a strategic decision concerning the level of national security. Replacing large coal-fired units with large gas-fired units perpetuates the concentration of capacity in a small number of facilities and, consequently, a high risk of energy system destabilisation. System resilience depends on the degree of concentration of critical components, the ability to operate in island mode, the level of source dispersal, and the development of energy storage and flexible demand management.

Planning for the National Power System should therefore take into account not only costs and climate objectives, but also structural resilience against military and hybrid threat scenarios. Basing it on a high concentration of capacity in a limited number of locations means maintaining a high single-strike effect, as well as a strong reliance on trunk transmission infrastructure, the damage to which could lead to nationwide consequences.

Ukraine's experience clearly shows that designing an energy system without taking various military scenarios into account is a serious strategic mistake. Poland should urgently reduce the concentration of capacity in individual locations, halt the further entrenchment of a model based on large generation units, and accelerate the development of distributed renewables supported by energy storage, whilst also improving energy efficiency and demand management capabilities. It is essential to strengthen the island-mode operating capability of critical infrastructure, ensure the geographical diversification of new capacity, and grid development that ensures adequate protection and the ability to rapidly integrate new capacity. Every investment in new generating capacity should be assessed not only in terms of cost and emissions, but also in terms of risk concentration under a potential wartime scenario. The National Power System cannot continue to rely on further large gas-fired units and must be redesigned so that the potential loss of a single component does not lead to nationwide consequences – this is now a matter of national security, not merely energy transition.

Table 3. Summary: centralised system vs. decentralised system (based on Ukraine's experience from 2022 to 2026)

Criterion	Centralised System (large generation units, few facilities)	Distributed System (with a high share of renewables and energy storage, thousands of sources)
Impact of a Single Strike	Very high – the loss of a single unit results in a reduction of hundreds of MW or of the capacity measured in GW.	Low – the loss of a single installation has a marginal impact on the system.
Blackout Risk	High – in a centralised system, the likelihood of cascading failures is greater.	Lower – distributed generation and the ability to operate in island mode reduces the domino effect.
Reliance on the Transmission Network	High – a centralised system requires an extensive high-voltage network (220–400 kV in Poland). Under wartime conditions, substations and transformers become targets.	Lower – energy is generated closer to end consumers; sources are connected to the local distribution network.
Defence Capabilities	Defending components of a centralised system is costly and not fully effective. It requires advanced anti-aircraft (AA) air defence systems (e.g. Patriot) and the availability of ammunition for those systems.	Multiple and dispersed facilities make a simultaneous attack on all of them difficult. Passive protection and risk dispersal are possible.
Restoration Time	Years – large, specialised components and complex logistics are required. No realistic prospect of restoration under wartime conditions.	Months – modularity, standardisation, and ease of transport facilitate restoration.
Flexibility of Energy Investment Financing	High investment risk translates into more difficult access to financing and a higher costs of raising capital.	In the case of numerous smaller projects, financing from a variety of sources is more readily available.
Structural Resilience Against Full System Destabilisation	Low – the concentration of capacity in few installations generates high systemic risk.	Higher – the dispersion and large number of facilities, some of which can operate in island mode and are quick to restore, limit the ability to effectively destabilise the entire system.

Distributed is Harder to Hit

An energy system with thousands of small sources as an element of Poland's national interest. Lessons from Ukraine's experience.

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