

Managing load shedding in Ukraine: rationing rules, imports and demand response

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Ukraine's strained power system needs to rely more on market signals

Management of power system imbalances leaves scope for market mechanisms

- Destruction of generation and transmission assets has caused severe power shortages, especially before and during heating seasons as well as in summer when nuclear power stations undergo maintenance.
- Heavily regulated retail and wholesale markets, including price caps, prevent efficient use of price signals. As a result, electricity supply needs to be rationed through both planned and unplanned outages.
- Scheduling and publishing outages has become increasingly complex and opaque, reducing predictability and limiting consumer choices.
- Business and industry consumers may exclude themselves from scheduled outages by importing electricity or self-generation, but these options are costly, risky and subject to bureaucratic hurdles.
- High premiums for imports and self-generation reflect strong willingness to pay for reliable supply.

Recommendations

- **Households**
 - Long term: Integrate Ukrainian market into European power system including removal of retail price caps.
 - Short term: Strengthen demand-side management by increasing tariff on consumption exceeding 80% threshold of pre-war household demand in a pilot project.
 - Couple pilot-project with lump-sum reimbursements for vulnerable households.
- **Business and industry**
 - Long term: Fully liberalize wholesale electricity markets and harmonize regulation with EU standards.
 - Short term: Gradually phase out wholesale price caps and expand import capacity.



Challenges for Ukraine's power system and policy responses

Challenges through Russian attacks

- As the heating season 2025/26 advances, Ukraine's power infrastructure is again the primary target of Russian attacks, even exceeding the intensity of earlier attack waves.
- Once an energy exporter, generation capacity now falls regularly short of demand, becoming especially severe already since 2024.

Policy responses

- Administrative bodies safeguard the power system and protect households e.g. by providing incentives for self-generation, expanding imports and a system of price caps.
- While these market interventions are meant to alleviate supply deficits, consumers cannot properly respond to market signals and therefore demand regularly exceeds supply, creating the need for load shedding including scheduled outages.
- This document describes the legal framework and the process of scheduled outages, the consequences and outlines actionable long- and short-term advice.

Content overview

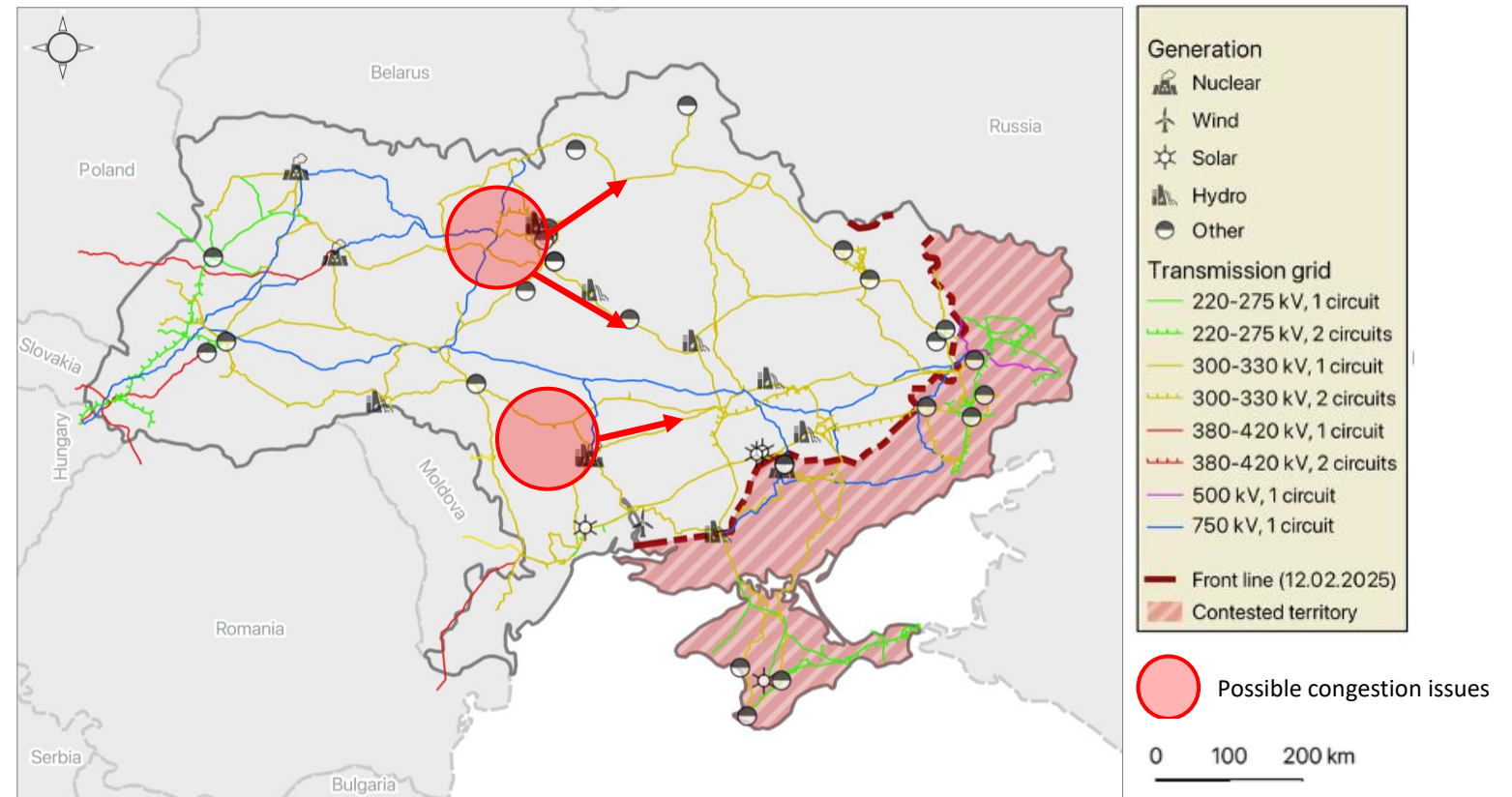
1. Introduction
2. Status-quo
3. Recommendations
4. Summary



Power generation capacity, transmission and import connections in Ukraine

- Ukraine’s generation capacity consists of a wide mix of sources dominated by nuclear power plus hydro, renewables, coal and gas.
- National transmission is needed to resolve regional imbalances.
- In the Western regions, power deficits can be more easily met by imports from the EU.
- Transmission east is constrained by the 330 kV connections at the Kyiv Energy Hub and the South Ukraine Nuclear Power Plant.

Power infrastructure in Ukraine



Sources: Open Street Map 2025, Powerplantmatching, LiveUAmapping.com



Ukraine has lost about 2/3 of its generation capacity during the war

Generation

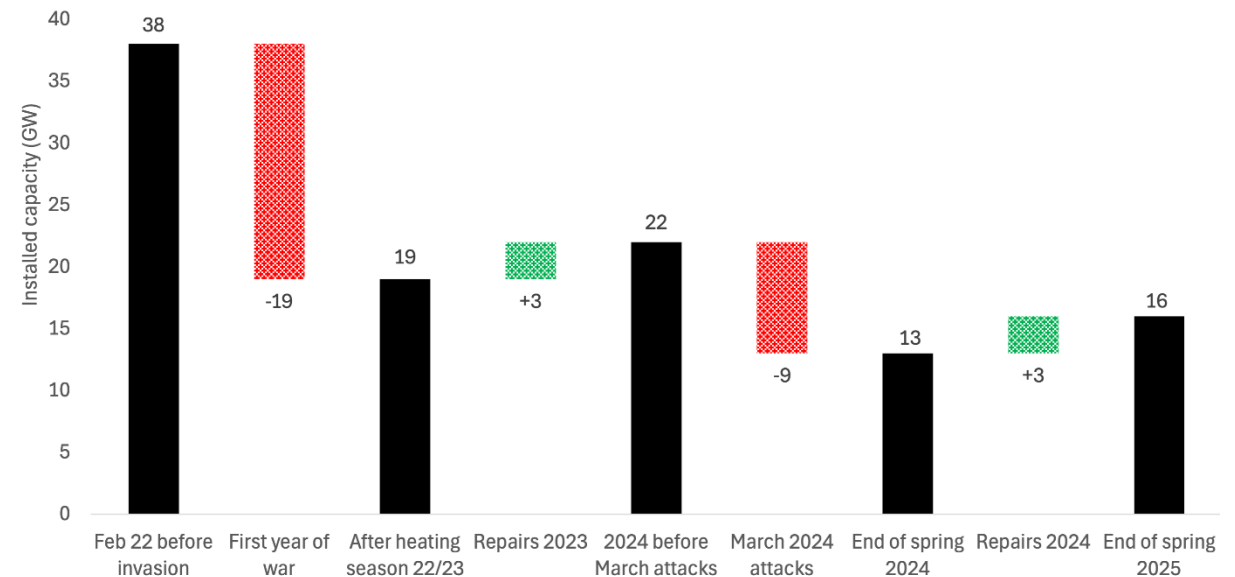
- Originally, Ukraine was a net electricity exporter especially due to its large nuclear power stations.
- Russia has attacked the system thousands of times and thereby reduced generation capacity from 38 GW to 16 GW already by November 2024.
- Since especially manoeuvrable generation facilities (gas, coal, hydro) have been lost, balancing the system has become even more difficult.

Consumption

- The share of household-consumption has increased alongside declining industrial consumption.
- Peak winter demand can be up to 18.5 GW [IEA: 1]*

* See sources at the end of the document

Available installed capacity of dispatchable power generation in Ukraine



Source: IEA 2024, License: CC by 4.0



How regulation in Ukraine's electricity markets impacts demand response

Theory vs. reality in Ukraine's electricity markets

1. Efficient markets: textbook case

Supply shortages trigger price increases, reducing demand and incentivizing new capacity investment until equilibrium is restored.

2. Power markets: physical and billing constraints

Generation and consumption must balance continuously, while demand and supply fluctuate significantly.

Retail consumers face fixed monthly/annual tariffs that prevent real-time demand response.

On wholesale markets, generation with differing marginal costs such as nuclear, thermal and renewables.

3. Ukraine's power markets: state interventions

Ukraine caps retail prices to ensure household access, eliminating demand response mechanisms even long-term.

The regulator (NEURC) also imposes price caps on wholesale day-ahead, intraday, and balancing markets.

[UABIO:2]

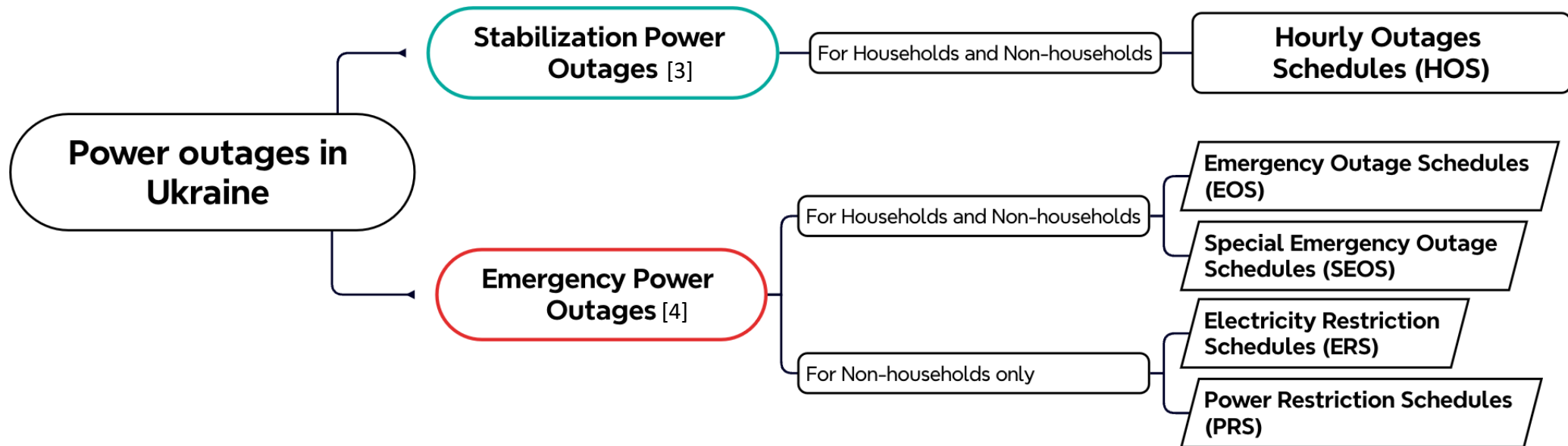
Consequences of price caps in Ukraine's power markets

- 1. Household customers:** Regulated price ceilings prevent prices from rising to balance demand and supply, often resulting in excess demand. Operators must ration electricity, a process that is costly, bureaucratic, and inefficient. As a result, consumers increasingly turn to alternatives like small generators, solar panels, or batteries.
- 2. Non-household customers:** These users also seek alternatives but face additional barriers. Imports become unattractive if international prices exceed capped domestic rates. Self-generation is expensive and often not fully integrated into the national grid.
- 3. Traders and generators:** Wholesale price caps and regulatory constraints discourage both energy imports and investment in new generation capacity, undermining long-term market efficiency and reliability.



Types of power outages in Ukraine

- **Stabilization power outages:** Occur during system-wide shortages. Analysed and planned by transmission system operator Ukrenergo.
- **Emergency power outages:** primarily impact large-scale systems after abrupt reduction in supply or disruptions in generation due to attacks.
- **Localized accidents:** Result of technical failures in specific areas: frequent even before the full-scale war.





Main actors in outage management

Ministry of Energy:

- **Minenergo** sets up legislation, notifies TSO and DSOs of the electricity supply situation and the need (or not) to apply outages.

Transmission system operator:

- **Ukrenergo** defines general consumption limits / black-out volumes.

Regional dispatch centers (RDCs) of Ukrenergo

- six in total, each responsible for multiple DSOs
- distribute outage volumes determined by the TSO among their DSOs.
- They also summarise and relay outage schedule information from the DSOs back to the TSO.

Distribution system operators (DSOs):

- **Oblenergos** – one per Oblast, in active coordination with the RDCs – determine the actual hourly outage schedules (when and where) based on the limits provided by their RDC and are responsible for turning on and off different power lines.

State Inspection of Energy Supervision:

- **Derzhenergonaglyad** monitors the application of HOS, in particular for consumer facilities that receive power directly from the TSO network, and controls the establishment of new consumer restrictions.

Consumers include

- households,
- industry, and
- critical infrastructure

HOS = hourly outage schedules

TSO = transmission system operator

DSO = distribution system operator



Evolution of hourly outage schedules rules since 2022

Before November 2022

Initial hourly outages implementation with schedules indicating possible time slots for shutdowns. Maximum consumption reduction set at 250 MW, with emergency shutdowns occurring if consumption reduction needs exceeded this threshold.

May 2024

Government approves resolution for more balanced distribution of electricity during outages. Regional military administrations required to prepare lists of critical facilities for priority supply. Resolution effective from June 24, 2024.

December 2022

Ministry of Energy approves amendments to the hourly power outages instructions. Schedules required to cover up to 100% but not less than 75% of maximum power consumption between 8:00 and 22:00. Schedules divided into 6 equal queues maintained at minimum 12.5% of current electricity consumption.

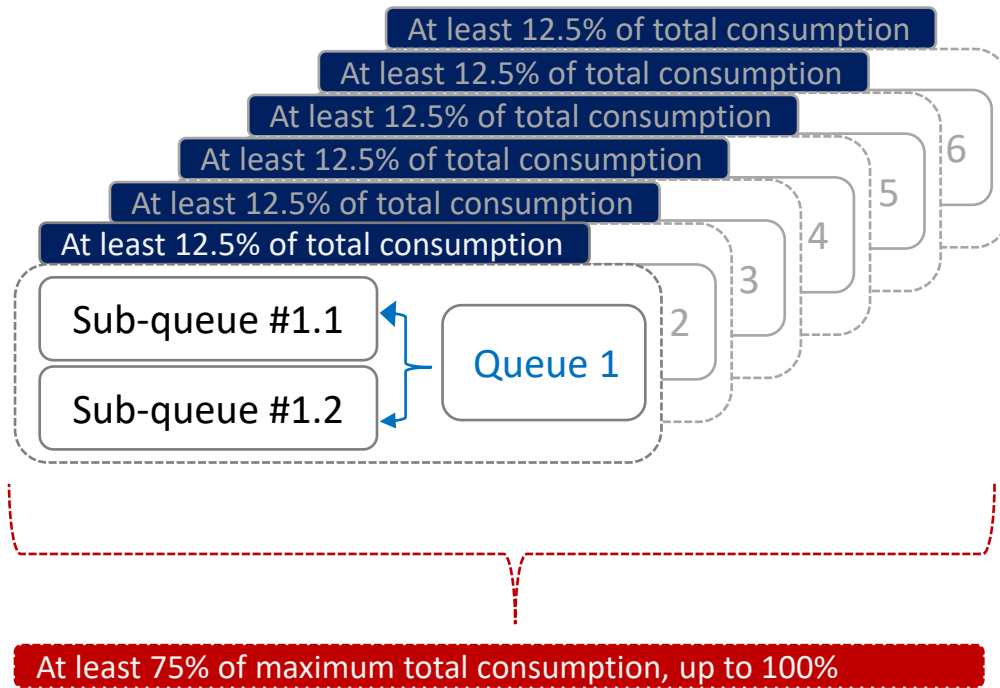
November 2024

Ministry of Energy amends the instructions on drawing up and applying hourly power outage schedules in order to ensure an equitable and balanced order of distribution of the use of available capacity and electricity between consumers.



November 2024 rules: grouping of consumers into queues

Consumer are divided into 6 queues

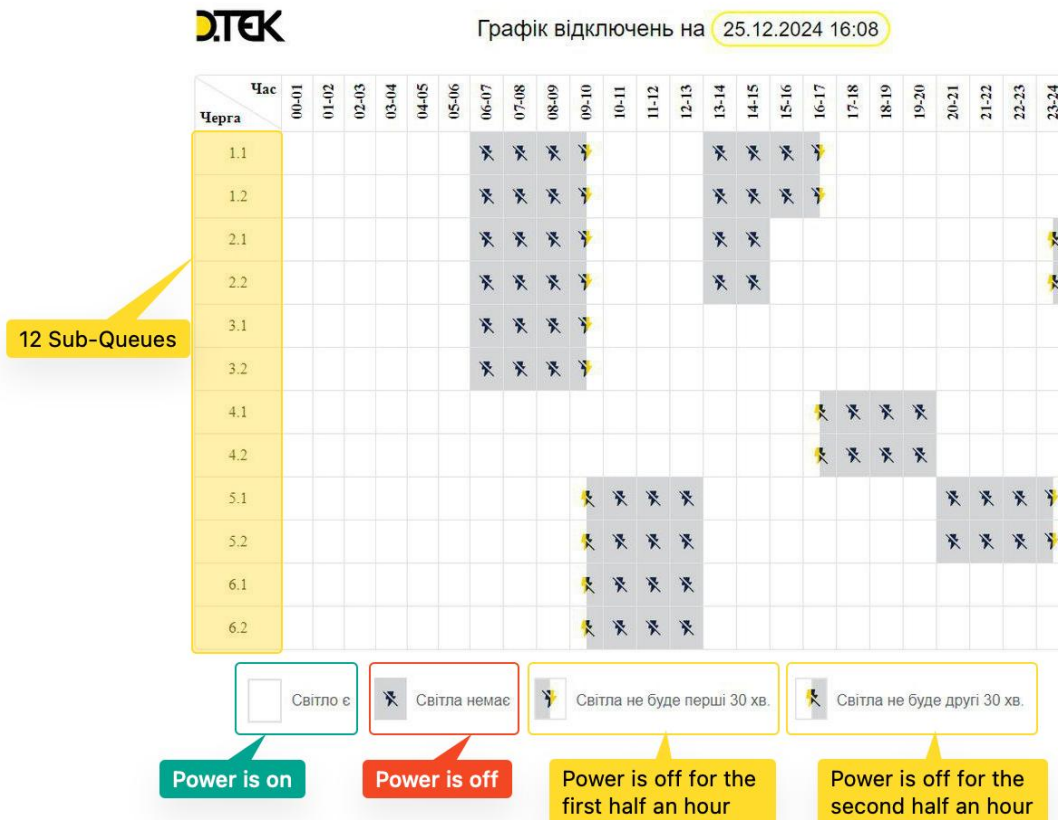


- Hourly outage schedules (HOS) designed to cover 75%-100% of the maximum power consumption between 08:00 and 22:00 on the measurement day of each Distribution System Operator.
- HOS divided into **6 queues** each covering at least 12.5% of the total consumption of the last measurement day's metering.
- **Sub-queues** representing half of a queue's consumption each allowing for addressing consumer groups more accurately.
- **Queue:** a group of household consumers and businesses that typically consume a certain amount of power.



November 2024 rules: maximum duration, exceptions and critical infrastructure

Hourly Outage Schedule for Kyiv, 25 December 2024



Normally, a single interruption should **not exceed 4 hours**.

Exceptions:

- If **temperatures** fall below -10°C , interruptions should not exceed 2 hours.
- During martial law (and up to 12 months after), hourly outage schedules should **not exceed 6 hours** (+1-hour deviation), with at least 2 hours of restored power between interruptions. Switching between queues should not exceed 30 minutes.

Outage durations are balanced on a weekly basis between queues.

Critical infrastructure facilities are excluded from scheduled outages and get priority power supply. The list of such facilities is approved by the regional and Kyiv city military administrations.

The goal of the November 2024 amendment was to establish the same principles for applying hourly outages schedules **in all regions**.



Reliable power supply for business and industry customers

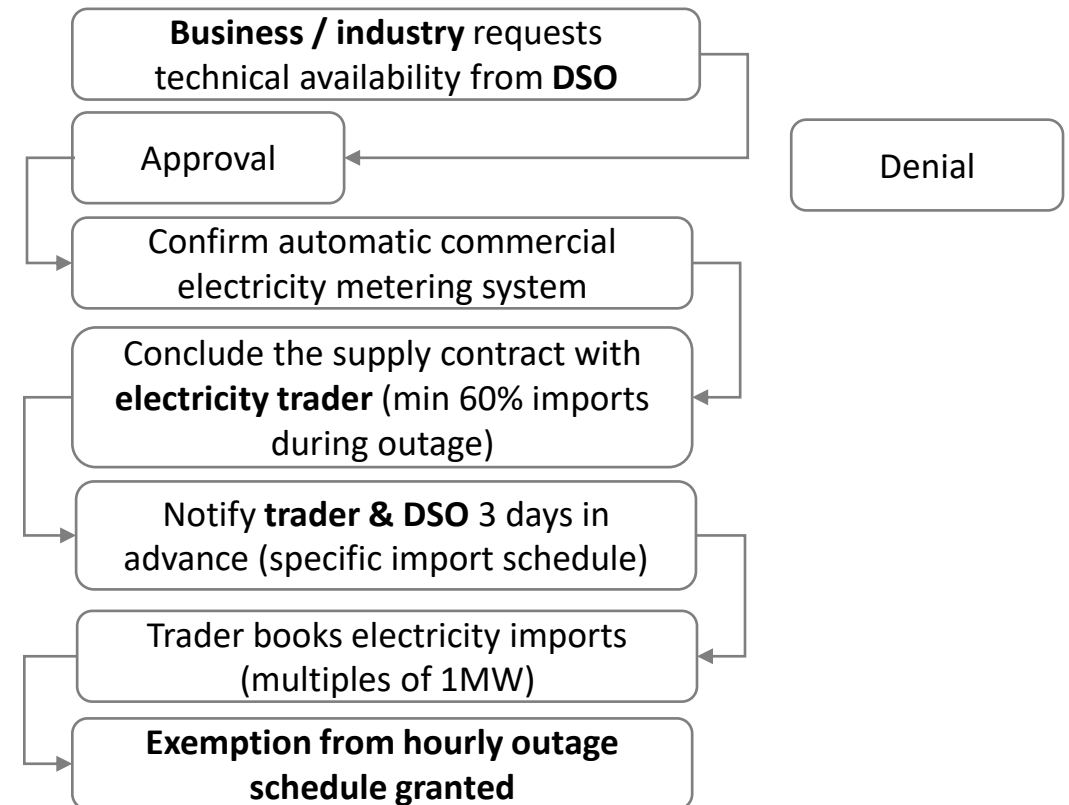
Current rules for large customers to opt out from scheduled outages

- Consumption of **at least 60%** of electricity from **imports and/or self-generation** in each of the hours of the import schedules.
- Import schedule: pre-defined hourly schedule indicating volumes of electricity to be imported during times with possible outages, i.e. generally matching HOS as a counter measure.
- **However:** emergency outage schedules still apply to prevent grid failures, and HOS still apply if import quotas aren't met or payments are overdue.

Previous rules

- 2022: Opting out from HOS through voluntary power consumption reduction (minimum of 50% during peak hours and 25% during mid-peak hours).
- 2023: Shift to imports as the primary way for opting out. Variations of quotas and further rules.

Exemptions from HOS for non-household consumers via imports





Practical obstacles to collect comprehensive data on planned and actual outages

Planned outages

No comprehensive overview over HOS available[TORGSOFT: 5 & DIXI: 6]:*

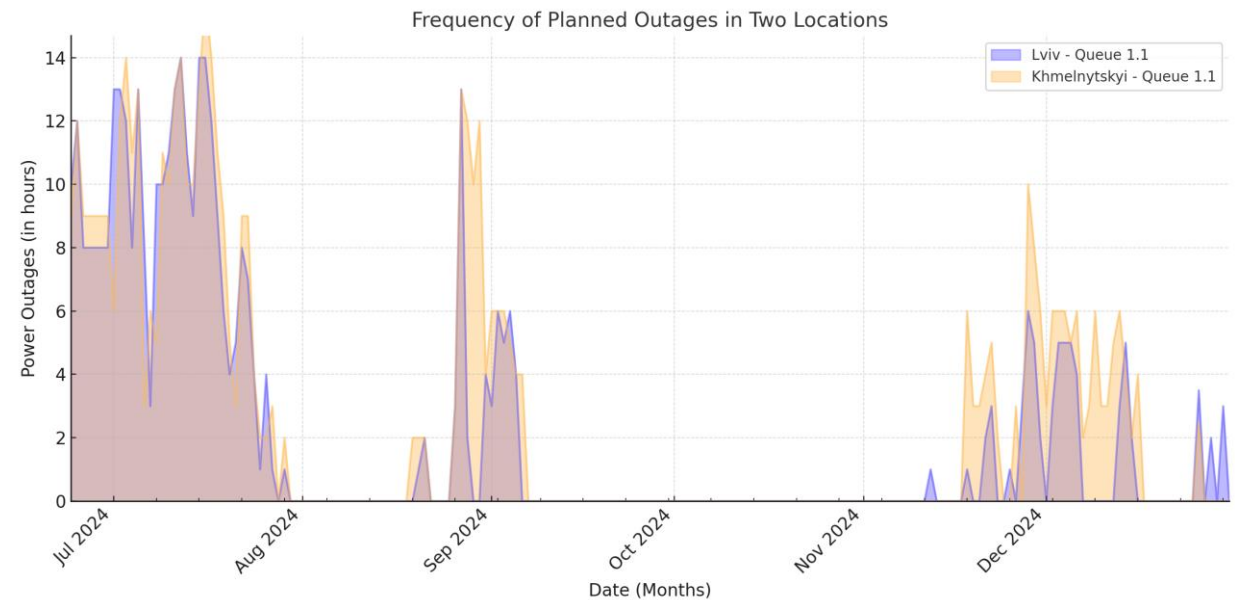
- Publication formats vary across regions.
- Schedules change on short notice.
- Past schedules are often not available or stored without time-stamps.

Actual outages

- Include emergency and unplanned outages.
- No official releases due to military considerations.
- Social media sources incomplete and unreliable.

* Only available summary of scheduled outages roughly aggregated to the national level for

Frequency of planned outages in two locations, July-December 2024





Signalling willingness-to-pay through imports and self-generation

	Household retail price	Weighted average DAM price Excl. distr. fees	Import retail price Relative to applicable domestic price	Self-generation (diesel)
UAH/kWh	4.32	5.34	+10-50%	+100-200%
€ct/kWh	9.6 ¹	11.9 ¹		
Notes	Regulated price since 6/2024	Wholesale price incl transmission but excl distribution fees as of May 2025 ²	Sources: Media ³ , own research. Including network costs.	Fuel costs only amount to 13 €ct/kWh, assuming fuel consumption of 10 l/100 kWh and fuel price of 1.33 EUR/l. excl. instalment and maintenance.

¹ based on a 45 UAH/EUR exchange rate.

² Weighted average price on the Day-Ahead Market (DAM) in May 2025, based on [Energy Map: 8]

³ RBC Ukraine [9]



Recommendations – households

Short run: Enable demand response by increasing price for consumption above 80% compared to pre-war period¹

- Our simulation shows that doubling the tariff only for consumption above the 80% threshold will substantially decrease load shedding. Implementation is possible using existing infrastructure. Smart meters are not needed.
- In a first step, set up pilot project in conjunction with reimbursing vulnerable households with lump-sum payments.

Long run: Liberalize retail market by erasing price cap

- If prices reflect marginal costs, demand can adjust such that load shedding is only needed in emergencies.
- This will also create an incentive to invest in additional capacity and support the integrated power system.

Implementation

- Message of higher prices even for a small part of consumption is politically highly sensitive as social hardships intensify.
- As conventional supply management shows its limits, introducing elements of demand management could mean less power interruptions and less bureaucracy.

¹For details see appendix and GDU Analysis [GDU: 10]



Recommendations – business and industry

Long run: fully liberalize wholesale markets and align with EU regulation

- If prices reflect marginal costs, demand can adjust, and resources can be allocated efficiently.

Short run: simplify import rules and raise import capacity

- Gradually lift upper price cap at wholesale markets.
- Further raise import capacity.

Political implementation

- Emphasize advantages of further liberalization.
- Stress previous successes to more openness and flexibility:
 - Raising of import capacity to 2.1 GW.
 - Lowering of import threshold need to to opt out from scheduled outages to 60% including self-generation.



Summary

Challenges of war for Ukraine's power system

- Due to the destruction of generation and transmission capacity, balancing Ukraine's power system has become ever more difficult.
- Regulation including price caps on retail and wholesale markets creates the need for administrative load shedding as demand cannot respond to price signals reflecting marginal costs. Managing the shortages has evolved into a system of complex rules.

Rules for scheduled outages

- Scheduled outages follow complicated rules, are subject to change and information is costly to obtain.
- Non-household consumers can opt out of scheduled outages by ensuring enough imported power and/or self-generation.
- Premiums paid on imported electricity and self-generation show high willingness to pay for uninterrupted delivery, which reflects the costs of restricting energy while capping prices.

Recommendations

- In the short and the long run, introducing market-based elements will allow for demand to respond more accurately to price signals and create incentives for investing in further capacity.



Recommendations

Exploit marginal price signals by liberalizing electricity markets

- **Households**
 - Long term: Integrate Ukrainian market into European power system including removal of retail price caps.
 - Short term: Strengthen demand-side management by increasing tariff on consumption exceeding 80% threshold of pre-war household demand in a pilot project.
 - Couple pilot-project with lump-sum reimbursements for vulnerable households.
- **Business and industry**
 - Long term: Fully liberalize wholesale electricity markets and harmonize regulation with EU standards.
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Appendix

Modelling of 80%-block tariff impact on load shedding in PyPSA

- The model used is GDU's in-house [PyPSA](#) (Python for Power Systems Analysis) model.
- PyPSA is an economic dispatch model that optimises the dispatch of electricity given
 - a specific hourly demand trajectory and
 - a set of installed generation capacities and transmission lines.
- Simulation of load shedding in the residential sector:
 - Line 1: Base simulation
 - Line 2: Constant, equal demand reduction in each hour (10% of total demand / 8760 hours)
 - Line 3: 10% reduction in each hour's prior demand (00:00 – 24:00)
 - Line 4: 10% reduction in each peak hour's prior demand (08:00 – 23:00)
- For further details regarding PyPSA, see <https://arxiv.org/abs/1707.09913>.
- For further details about GDU's PyPSA model, please refer to <https://greendealukraina.org/products/data-modelling>



Sources

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Modelled impacts of 10% HH demand reduction on load-shedding

	Total demand (GWh)	Demand reduction (GWh)	Total load shedding (GWh)	Load shedding reduction (GWh)	Load shedding reduction (%)
Estimated annual household demand (2025)	29,923	-	6,961	-	-
Constant, equal demand reduction in each hour (10% of total demand / 8760 hours)	26,931	-2,992	5,374	-1,587	-23%
10% reduction in each hour's prior demand (00:00 – 24:00)	26,931	-2,992	5,657	-1,304	-19%
10% reduction in each peak hour's prior demand (08:00 - 23:00)	27,291	-2,132	5,801	-1,159	-17%

Based on **PyPSA** (Python for Power System Analysis) model.