



Six Options to boost power transfers from Continental Europe to Ukraine

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List of Abbreviations

AC: Alternating Current
BEMIP: Baltic Energy Market Interconnection Plan
CAPEX: Capital Expenditure
CHP: Combined Heat and Power
DC: Direct Current
DLR: Dynamic Line Rating
DSO: Distribution System Operator
ENTSO-E: European Network of Transmission System Operators
EPC: Engineering, Procurement, and Construction
FACTS: Flexible Alternating Current Transmission System
GW: Gigawatt
HPP: Hydro Power Plant
HVDC: High Voltage Direct Current
IFI: International Financial Institution
kV: Kilovolt
MW: Megawatt
MWh: Megawatt hour
NPP: Nuclear Power Plant
NTC: Net Transfer Capacity
PCI: Project of Common Interest
PECI: Projects of Energy Community Interest
PMI: Project of Mutual Interest
PV Photovoltaic
TPP: Thermal Power Plant
TSO: Transmission System Operator
TYNDP: Ten-Year Network Development Plan
UCTE: Union for the Coordination of Transmission of Electricity

1 Introduction

This paper explores grid solutions that contribute to improving the security of the electricity supply in Ukraine. The focus is on actions that help to meet the power demand of the country in the short and medium term.

A lot has happened since the first edition of this paper: ENTSO-E has increased the allowed net transfer capacity to Ukraine to 2.1 GW per hour, starting on December 1st 2024. ENTSO-E also announced that by March 2025 the methodology of the capacity calculation to Ukraine would be changed.

Also, proposed by the authors measures like using the Zamość-Dobrotvir line (220 kV) line for imports to Ukraine have been taken up by TSOs and policy makers. A powerline from Slovakia to Ukraine, currently at 35 kV, but originally designed for 110kV, will be reused.

While these changes are welcome, the dramatic situation in Ukraine has to be underlined: massive waves of Russian attacks on energy assets and the energy infrastructure continue. The electricity supply for the population and system operation are far from normal. The situation varies from region to region. Especially the city and region of Odesa are very difficult to supply. The West-East transmission capacity has been impacted by the destructions. Imports of electricity from the EU member states to Ukraine are therefore even more important, forming part of a solution that has to be also decentralised supply for enhanced energy security, mobile supply to places like Odesa etc.

Our paper presents the latest state of play and updates policy recommendations.

The identified six grid options can be implemented relatively swiftly if there is political will and a constructive approach of key technical stakeholders, and sound coordination of both.

The authors present the solutions one by one, also highlighting open questions related to each solution, and invite distinguished readers – policymakers, regulators, experts, business and civil society on national, EU and international levels – to comment and take action. While our scope does not include the important aspect of tariffs in Ukraine that requires further reform, we want to stress its importance, as it is the condition for using the available interconnection capacities: while Summer 2024 has seen near to full use of the available capacities, the dramatic situation in Winter 2024 sees at once that they are only used to 1/3, because of the tariffs.

The paper is structured as follows: after setting the scene and describing the state of play both in terms of generation adequacy and networks, we describe the grid options in greater detail concluding with a summary table of potential impact.

Our research is based on available data, and on extensive interviews with technical experts and relevant stakeholders, including Transmission System Operators, engineering firms, Ukrainian and European policymakers, as well as regulators and civil society.

Unless external sources are explicitly provided, all statements in the paper are the authors' best interpretation of the available quantitative and qualitative information.

We would like to thank colleagues from the Green Deal UKRAINA team, in particular Georg Zachmann, Frank Meissner, Vlad Miknych, Maciej Jakubik from Forum Energii; Monika Morawiecka from the Regulatory Assistance Project (RAP) and member of the GDU Advisory Council, as well as Olha Yestivnieieva from the Reform Support Team of Ministry of Energy of Ukraine. We are grateful for the many discussions we could have on the sidelines of the URC and our visits to Kyiv in 2024, and there in particular with Ukrenergo, ministries, the Parliament Rada, the regulator NEURC, and our partners Dixi Group and EcoAction. We would like to thank Anna Piddubna, intern at GDU project and master student at Hertie School Berlin, for her editorial support.

All comments and feedback for this paper are welcome at the Green Deal Ukraine project. Readers are encouraged to contact greendeal.ua@helmholtz-berlin.de.

2 Summary and Recommendations (December 2024)

Four action areas are needed to improve the security of the supply situation for Ukraine in the short and medium term. They are air defence, generation repair and new builds, electricity grids, and, last but not least, demand-side measures and energy efficiency. While there is a hierarchy among these four actions, they need to be taken simultaneously. This paper addresses the actions needed on electricity grids.

Based on our analysis we propose that policymakers at European and national levels, grid operators, suppliers and IFIs mobilise and take swift action to:

1. Further boost grid interconnection with the EU. While we welcome the increase of the net transfer capacity by ENTSO-E to 2.1 GW, and the introduction of a new calculation methodology, much more is needed and possible. We recommend to increase the capacity of exports to Ukraine further to at least 2.4 GW, through all possible measures as below. We suggest to urgently address the current shortfalls in the Hungarian, Slovak, Polish, Romanian, and Ukrainian systems to be able to lift the 2.1GW to at least 2.4 GW in Winter 2025/26. At once, decentralised solutions need to be boosted to diminish local and regional vulnerability.
2. The authors welcome the foreseen use of the 220 kV antenna¹ **line between Poland and Ukraine (Zamość-Dobrotvir)**: options are to build capacities outside of Ukraine in Zamość or to fully connect and use the line as part of the exchanges with ENTSO-E. The line should be upgraded in the next years to 400 kV to allow for even more exchanges.
3. There is an urgency to speed up two major transmission projects: **between Slovakia and Ukraine (Kapušany) and Romania, Moldova and Ukraine (Isaccea)**: both can contribute tremendously to the regional integration of Ukraine; in the case of Isaccea also to support the very vulnerable city of Odesa and to make Moldova independent from Transnistria assets. These projects must be finalised by 2026 at the latest and require strong EU backing, governance, and a PCI label.
4. **Use all available technologies**, such as Dynamic Line Rating (DLR) and power electronics, to maximise flows, in line with the NOVA principle, widely adopted in European grid planning.
5. **Explore using and expanding the abundant in Ukraine 110 kV grids**. Ukraine disposes of five 110 kV interconnectors to Moldova that could be used better, and some more 110 kV interconnections could be built. Options to use the existing line between Slovakia and Ukraine is in assessment, and should be used at the originally foreseen 110 kV, and not at 35 kV. 110 kV grids are much cheaper- and possibly faster- to build than other high-voltage lines and are very suitable for integrating decentralised renewables solutions and increasing the security of supply. Ukrenergo should list the 110 kV lines in their network development plan, in collaboration with the DSOs.
6. To **ensure efficient coordination among Ukraine and the bordering countries**, the successful Baltic Energy Market Integration Plan BEMIP should be taken as a template. A proper Ukraine-Moldova Energy Market Integration Plan (UMEMIP) could be either set up, or the options within existing framework CESEC explored for such a regional collaboration purpose.

The measures taken since our paper was first published amount to +0.75 GW, through the upgrade of the ENTSO-E exports from 1.7 GW to 2.1 GW and the exchange with Moldova after July. Additional transfer capacity can be provided by implementing antenna line Zamość-Dobrotvir (not started yet) or the Slovakia 110 kV line (not started yet).

¹ Antenna line means that the line is not connected or only loosely connected to the overall transmission grid. It is a line from point A to point B. While there usually are grids around to transport electricity further, the tie-lines are usually open and not connecting to those grids.

It is important to push already now for additional export capacities, so as to secure supply in 2025-2026. A proper power market in Ukraine is equally needed as to incentivise imports: in December, power prices in Poland are higher than in Ukraine, thus hampering exports.

For the more medium- and long-term, we suggest setting up an efficient framework for regional energy market integration, using the Baltic Energy Market Integration Plan as a benchmark. BEMIP was crucial for the Baltic and regional security of supply and to drive the integration of the Baltics into the European energy market (European Commission, n.d.). While such a group would work mainly on the mid- and long-term solutions and include all relevant actors, it would also weigh into the short-term measures through its holistic approach. Therefore, this plan should include all grid actions recommended above.

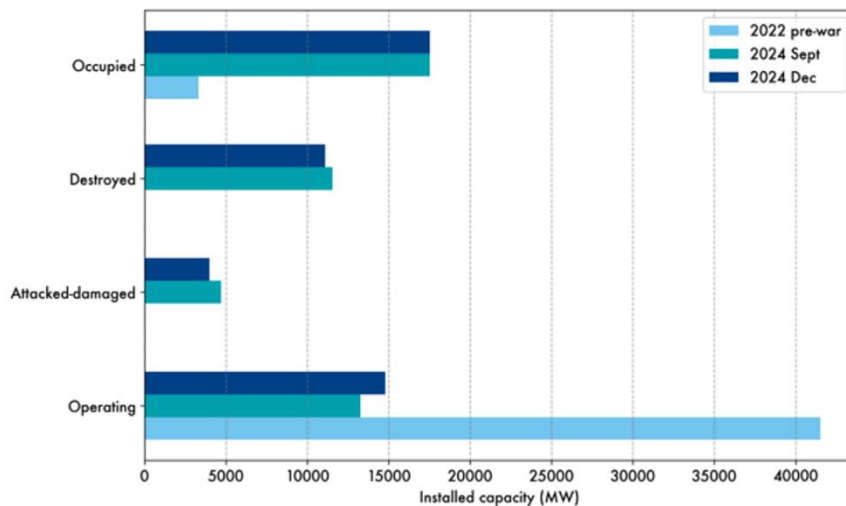
3 Background

2024 has seen a rapidly deteriorating electricity supply situation between March 2024 - massive Russian attacks on energy assets - and July 2024, until when the scheduled maintenance of the nuclear power plants took place. In this period, Ukrainians have been exposed to massive load shedding and demand restrictions of up to 12 hours a day. The situation went back to a “normal” supply-demand match between August and mid-October as a result of the nuclear generation fleet being again available and some repairs having been implemented. Overall, since the start of the full-scale invasion (24th February 2022), over 80 per cent of Ukraine's conventional power plant capacity has been occupied, destroyed, or attacked, translating into a significant supply-demand mismatch that requires daily power cuts to the war-torn population. For example, in the Bucha area, close to Kyiv, daily cuts of 10 hours were reported this summer, obliging the population to rely on small diesel generation, if available altogether.

November saw renewed massive, targeted attacks on the Ukrainian grid infrastructure and power generation assets: as we speak, 12.4 GW in Ukraine remain operational, out of a before-war situation of 30 GW+.² Only on November 17th all seven critical substations connected to the nuclear power plants were targeted, and five were hit. Those close to the western borders of Ukraine have, in addition, a critical role in the exchange with ENTSO-E. Needless to say, the all but conventional operation of these assets in Ukraine let them deteriorate much faster than in normal circumstances.

² GDU project data 2024

Figure 1: Our assessment of the state of generation capacity in Ukraine



Source: Green Deal Ukraïna 2024, based on publicly available information.

Electricity is needed not only to keep the lights on but also to supply water and to keep the heating systems working. Yet available power supply amounts to around 10 to 11 GW of conventional power plants (including nuclear, hydro, coal, and gas) and more than 3.4 GW of installed capacity of renewables. Renewable energies, which in Ukraine are dominated by solar (PV) will not substantially contribute to supply in the next winter, while PV is indeed very valuable in summer. And it can make a difference for smaller consumption, like communication tools charging, or in remote places in such unheard of energy situations as Ukraine is facing. Nuclear power is the decisive contributor, with about two-thirds of the available winter supply, as was forecasted by Ukrenergo. There is an unknown number of repairable units of conventional power plants (data is classified for security reasons) with a total restored capacity estimated at 3 GW.

Since the emergency synchronisation on February 16th, 2022, there have been grid connections with EU member states that allowed for a combined 1.7 GW of import capacity, which was updated to 2.1 GW on December 1st.

There are four action areas for electricity security in Ukraine: Air defence and deterrence against attacks, supply-side measures, transmission grids for imports, and demand-side response plus energy efficiency. Those should be applied simultaneously, not consecutively.

The first priority must always be stronger air defence and deterrence. It is paramount to protect what is still there and shield the ever-scarcer workers at construction sites for repairs or new installations to keep the system running. Defence and deterrence should additionally come as international presence; thus, the presence of IAEA at Zaporizhzhia NPP has proven to be effective and should be replicated in all critical infrastructure around all other NPPs of Ukraine, not only the NPPs themselves (Putte & Burnie, 2024, IAEA 2024).

The second area is to improve the supply side and increase power generation: this includes repairing partly damaged power plants and deploying small cogeneration gas units, renewables and batteries. Flexible and decentralised power solutions are paramount and have been discussed in several reports and publications, which provide good guidance and recommendations, including by Green Deal Ukraïna project through the publication ‘Modelling the electricity deficit in Ukraine’ (Bilek et al., 2024; Kubrushko, 2024; Meissner et al., 2024).

Power grids and electricity interconnections are the third area of solutions that will play into the short, medium-, and long-term. Due to its complexity and the limited availability of data, discussions on these matters are less present in wider society, beyond the narrow expert circles. But as current cross-border

exchanges show, it is already important, and can be even more a crucial ingredient to provide critical electricity supplies.

The fourth area encompasses demand-side measures and energy efficiency, which are necessary to mitigate capacity deficits and ensure the best use of available resources. Measures to optimise consumption and reduce peak demand can play a significant role and should not be missed out on in the overall efforts.

Time is for action. Below, we outline actions that can be taken in the third area, related to transmission grids. Leveraging available opportunities for a better electricity interface between Ukraine and the EU will not only provide massive, short-term benefits, literally saving people's lives, but also paramount medium- and long-term benefits. Well-developed grids have been Europe's pride ever since the UCTE was put together: they contributed and continue to contribute to all three energy policy objectives: security of supply, sustainability and functioning markets generating welfare.

3.1 Ukraine's Power Grid Overview

The high-voltage power system of Ukraine has a total length of 19,000 km and includes 103 substations. Before the synchronisation, the system featured more than 50 cross-border links (Ukrenergo, 2021). From Soviet heritage, Ukraine still operates a very high-voltage 750 kV backbone, typically related to a huge supply (like big nuclear or coal plants) or very high industrial demand, as well as the need for long-distance transmission. The corresponding legacy 750 kV links to Poland, Hungary, and Romania only have a fraction of their previous capacity as the network topography shifted substantially since the 1990s. Only one of those 750 kV links has remained, connecting Ukraine and Hungary. Most of Ukraine's operational domestic and cross-border lines feature more standard voltage levels of 110, 220, 330, and 400 kV.

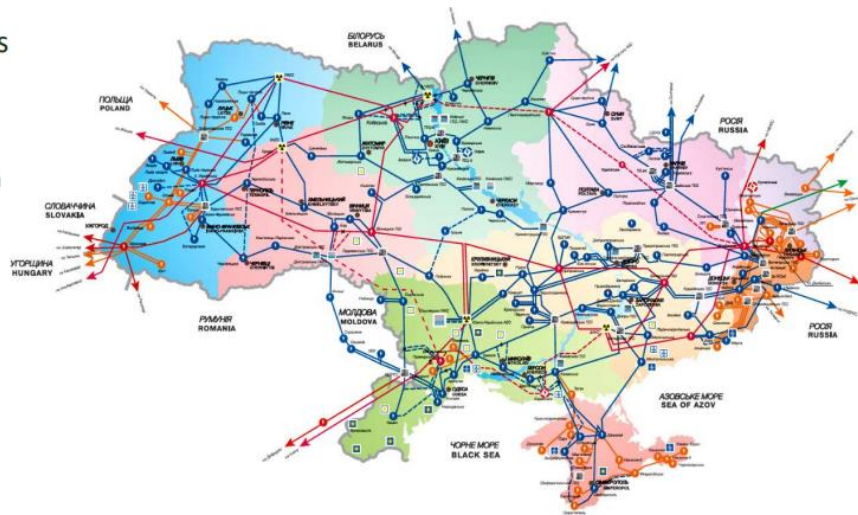
Until 23 February 2024, Ukraine and Moldova were connected through powerful 4.2 GW links with the post-Soviet IPS/UPS energy system. This connection only remains today for some of the occupied territories- and that are not connected currently with the synchronised ENTSO-E western electricity grid. IPS/UPS today includes Russia, as well as the Baltic states, Belarus, Georgia, and other former Soviet bloc countries. On the other hand, since 2002, the western part of Ukraine has had pre-established connections with the grid of continental Europe (UCTE) through the so-called Burshtyn energy island and power lines dedicated for exports from two thermal power plants in Ivano-Frankivsk and Lviv regions. Another example is the Dobrotvir coal power plant some blocks of which were equally used to export to Poland (Zamość) through a 220 kV line.

Ukraine's electric power system was originally designed for much higher consumption and transfer in all directions. This provided some reserves and redundancy that helped to deal with massive damage from Russian attacks, but now it requires a redesign to meet new challenges, including bi-directional trade with EU member states, decentralisation of generation capacities and integration of intermittent renewables.

Figure 2: Interconnectors of Ukraine with seven neighbouring countries in 2018

Interconnectors
with:

- Russian Federation
- Moldova
- Belarus
- Poland
- Slovakia
- Hungary
- Romania



Source: CIGRE (2018)

3.2 March 16th, 2022: Synchronisation with Continental Europe (EU)

Infrastructure links are either economic bridges or captivity chains, with roles altered by changing geopolitical and policy environments. On March 16, 2022, the continental European electricity grid and the grids of Ukraine and Moldova became connected and synchronised. Synchronisation implied connecting the large 50 Hertz alternating current (AC) system of continental Europe with the Ukrainian and Moldovan electricity grids.

In preparation since 2017, this step was made as an emergency synchronisation against the background of Russia’s full-scale invasion of Ukraine. Island mode operation³ was required as a precondition, which started before the war, and stretched into it. Originally, synchronisation was planned for much later, somewhere between 2024 and 2026.

The synchronous European energy system, formally called Regional Group Continental Europe, corresponds to the synchronous subset of the ENTSO-E and now has 28 members, including Ukraine and Moldova (ENTSO-E, 2018).

The expansion of the geographical area and integration of electricity markets is the prerequisite for successful energy transition and maximising the use of renewable sources of energy, particularly solar and wind. This, in turn, requires deepening the collaboration among the transmission system operators that, together, ensure continuity of power supply 24/7.

Next February 2025, after long years of preparation, the Baltic countries will also be synchronised through Poland, adding yet another East-West move of links to the European energy map.⁴ The Baltic Energy Market Interconnection Plan has contributed massively to overcoming political, regulatory and technical hurdles.

³ Island mode means to desynchronise a national system from all neighbours for the time of the test as to prove that the national system can be run also in this mode, in case of emergencies.

⁴ It is important to note that from an energy security point of view, the synchronisation of the Baltics is much more complicated, depending on one single interconnector: Litpolbalt. If this one is lost, the system is at risk; several technological and additional line project measures have therefore been developed. Ukraine, on the other hand, benefitting from the wealth of interconnectors with its neighbours, is – under normal conditions, of course, not during war – on a much safer side.

In the Ukrainian case, synchronisation meant reconnection between Burshtyn island and the rest of the Ukrainian system, plus additionally connecting Moldova to Romania. The Dobrotvir link did not form part of the synchronisation step.

3.3 Slow but gradual increase in cross-border exchanges

Synchronisation started with limited import and export windows to protect the Continental European System and to trial the new link first. Since March 2022, the allowed exports and imports have changed multiple times.

Table 1: Changes to agreed exports/imports based on various ENTSO-E announcements, 2022-2024

Date	Export to Ukraine	Import from Ukraine	Comments
16 March 2022	0 MW	0 MW	Emergency Synchronisation Ukraine-ENTSO-E (Continental Europe) decided by the EU Commission and the ENTSO-E. In the first two stages of synchronisation, there were no commercial exchanges.
26 April 2022	0 MW	0 MW	Ukraine becomes an ENTSO-E observer member. The first phase of synchronisation trialling was successfully finished.
30 June 2022	-	100 MW	Start of commercial trading through Moldova-Romania.
16 February 2023	700 MW	400 MW	Massive Russian attacks on energy infrastructure from September 2022 to Spring 2023 ended exports from Ukraine.
27 March 2023	850 MW	400 MW	Emergency assistance was agreed upon between the EU and Ukraine.
15 April 2023	1050 MW	400 MW	Start of commercial power exchanges through the rehabilitated Rzeszów- Khmelnytskyi line.
20 June 2023	1200 MW	400 MW	
1 December 2023	1700 MW/h	400 MW/h	The ENTSO-E announces that as of 1 January 2024, Ukrenergo will become the 40 th full member of the ENTSO-E.
27 February 2024	1700 MW/h	550 MW/h	

March to December 2024	No change	No change	Massive attacks on Ukraine’s energy system started in 2024 on March 22 nd , with a major attack on May 8 th and in November 2024. More than 9 GW of thermal capacities lost. Russian energy terrorism continues, with now more than 30 attack waves in 2024 alone.
1 December 2024	2100 MW/h	No change	ENTSO-E announces, on October 29 th 2024, to increase the export capacity limit to Ukraine and Moldova to 2.1 GW. In addition, the capacity limit will be reassessed on a monthly basis from March 2025.

Source: Green Deal Ukraine 2024, based on information from Ukrenergo and ENTSO-E.

Connecting a country in war indeed corresponds to additional risks especially when importing to the centre, to continental Europe. Risks are much lower in the case of exports. Every power line has a so-called Net Transfer Capacity (NTC), calculated in hours. TSOs will always avoid using the full NTC, as this disempowers them from applying emergency solutions in case anything unforeseen happens. This is the reason why the ENTSO-E set limits to allow transfers with Ukraine in both directions.

3.4 State of play with power generation capacities and outlook

This paper focuses on grid solutions, yet, for the sake of being complete, refers to recent publications on the supply side (Bilek et al., 2024; Meissner et al., 2024) and briefly summarises the state of play in this section.

The most important challenge Ukraine is facing relates to restoring and building as much generation capacity as possible to ensure the security of supply while Russian attacks on energy infrastructure continue. By next winter season, building decentralised solutions will have a significant impact, yet their implementation must be activated immediately. Interviews indicated that several concrete projects and technologies are discussed - their concrete appraisal does, however, go beyond the scope of this paper.

All necessary resources and spare parts should be provided for long-running repairs of severely damaged units at HPPs and TPPs, potentially contributing another 1 GW of restored capacity by winter 2025/26. Building gas-fired cogeneration at new sites and commissioning de-centralised CHPs can realistically add another 600 MW in a 1.5-year timeframe, according to expert interviews.

Ukrainian energy companies are already mobilising equipment and spare parts for fast repairs of recoverable units at HPPs and TPPs, which can add around 1 GW of additional capacity. Deploying new modular gas-fired cogeneration units at available sites and connecting them to existing infrastructure could add up to another 400 MW, with the commissioning of 200 MW well underway (Ukraine Business News, 2024).

The available winter capacity of variable renewables, namely solar and wind power, is expected to be only around 500 MW, particularly due to the low-capacity factor of solar in the winter. Yet it can potentially be expanded by another 100 MW with fast deployments of additional energy storage at existing sites of utility-scale plants, as well as hybrid solar power plants at critical infrastructure facilities. Batteries can indeed optimise the contribution of solar and wind by expanding balancing reserves and shifting power output to peak demand hours reducing curtailments in summer (ExPro Consulting, 2024).

Additionally, deploying solar and batteries at existing infrastructure of state-owned energy companies (including hydropower plants and pumped hydro storage plants sites) could add 200 MW to the stock.

Private investment in renewable energy and public-private partnerships with municipal utilities could also have a significant impact. This includes fast-tracking the development of utility-scale wind and solar with energy storage (+400 MW) and deploying decentralised RES solutions in municipalities (+200 MW).⁵

4 Challenges short and medium-term

4.1 Challenges short-term

Ukraine's Winter peak power demand of 15-18 GW (in the hour of highest consumption, typically around 17.00) is not a lot per se: a country like Germany has a peak load of up to 80 GW, or France up to 104 GW in cold spell times in winter.

Yet, the estimated available capacity from large conventional power plants that can be operational in the winter is only 12.4 GW, leaving Ukraine with a deficit of up to one-third of the potential winter. It should be noted that GDU's demand estimations already include a decrease of 20 per cent compared to pre-war demand. When factoring in the contribution of renewables (which will be limited due to the high share of solar and low irradiation in the winter) and imported electricity, the deficit in the baseline case could be up to 3.0 GW (see Table 5). All efforts should be undertaken to ensure that critical infrastructure's energy needs are fully and reliably met and that interruptions in supply for businesses and the population are minimised.

Ukraine has solutions to fight back on the energy front and they should be used to the full extent.

4.2. Mid to long-term challenges and the need for a comprehensive regional framework

It is unclear what Ukraine will export in the future, with much uncertainty due to the ongoing full-scale war and uncharted recovery roadmaps: will Ukraine export electrons, molecules, or goods?

In every scenario, high capability for both export and import will be a no-regret solution. Lines that are built are subject to a so-called cost-benefit analysis, for which a guideline exists at the ENTSO-E level, approved by the European Commission in 2024 (ENTSO-E, 2024a).

Cross-border interconnections increase the reliability and resilience of the electricity supply. By pooling and sharing power generation resources across the region, supply shortages can be mitigated, and emergency assistance can be provided in case of unexpected outages.

In normal operation conditions, interconnections enable more efficient electricity markets by allowing electricity to flow where it is needed most. This helps balance supply and demand across regions, leading to more competitive prices and lower costs for consumers.

Grid interconnection contributes to reaching climate targets, enabling the integration of renewable energy sources like wind and solar energy. Surplus renewable energy generated in one country can be exported to another, reducing curtailment and making better use of green energy resources. When pooled from a wider geographic area, solar and wind resources provide a more stable supply, and less balancing is needed.

Finally, electricity Interconnections boost regional development and, thus, cohesion across the EU. Eastern Poland, for example, or Northern Romania, would benefit from such integration. In the context of economic recovery, investing in grid infrastructure can create high-quality jobs and stimulate economic growth. It also attracts investments in renewable energy projects by providing a more stable and integrated market.

Overall, expanding transmission grid interconnections between Ukraine and its neighbours aligns perfectly with the goals of the EU Energy Union, a landmark initiative aimed at creating a unified and secure energy market across all EU member states (European Council/Council of the European Union, 2024). In essence, the Energy Union aims to provide cleaner, cheaper, and more reliable energy to all Europeans across the

⁵ Numbers indicated in this paragraph are based on GDU's own expert estimates

continent. Enhanced grid interconnection can contribute to all its goals: enhancing energy security, market efficiency, renewable energy integration, and economic growth while also supporting climate action and innovation.

The authors suggest, therefore, to enshrine the regional electricity market integration of Ukraine with the neighbouring countries into a comprehensive plan, very much like BEMIP, to be kick-started by the incoming European Commission.

5 Grid solutions for the short and medium-term

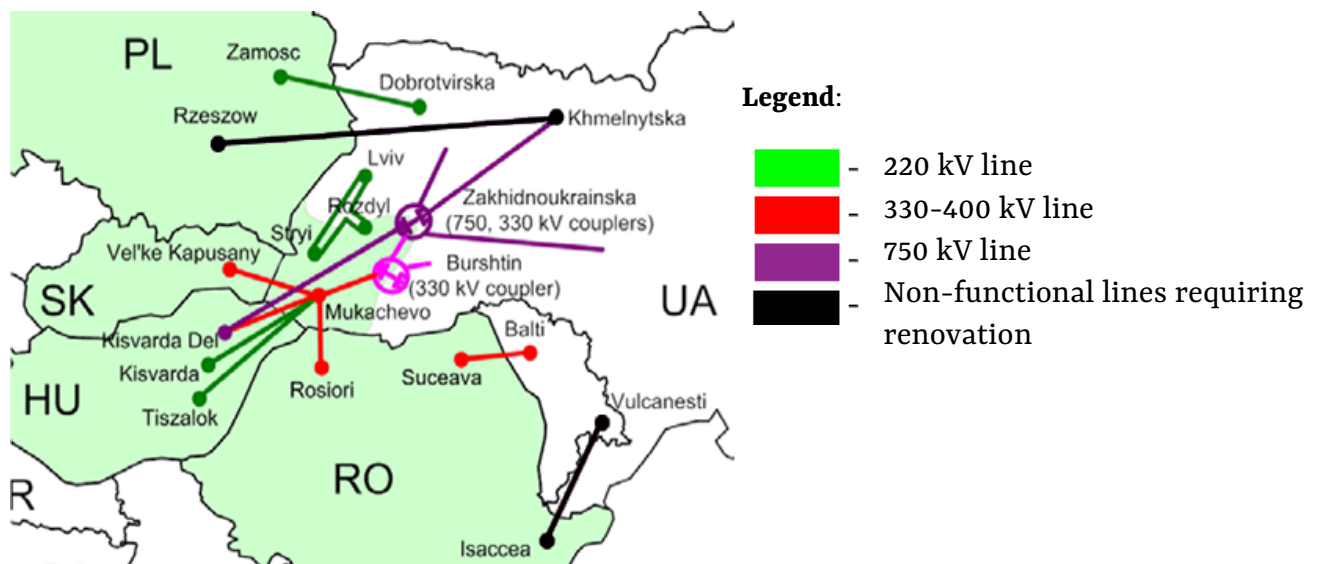
5.1 Increase the transmission capacity between EU Member States and Ukraine: the ENTSO-E

As Table 1 shows, the current export limit to Ukraine is 2.1 GW per hour, and from March 2025 onwards the allowed exports will be assessed on a monthly basis, thanks to the introduction of dynamic calculations through TSC NET, the Regional Coordination Center of TSOs (ENTSO-E, 2004b). 2.1 GW corresponds to about 12-14% of a peak load of 15-18 GW, respectively. To increase the contribution of exports further in light of a dramatic supply-demand mismatch, urgent measures should be taken. They are possible, given the many existing interconnectors between Ukraine and the neighbouring countries. Additional measures would allow ENTSO-E to increase the allowed transfers even further, up to 2.4 GW, for the winter 2025-26.

5.2 Use existing lines that are currently unused: the example of Zamość-Dobrotvir

Before the synchronisation and the full-scale war, the operational power connection between Poland and Ukraine was limited to the 220 kV antenna line connecting several blocks of the Dobrotvir coal power plant in Western Ukraine with a substation in Zamość, Eastern Poland. Figure 3 below shows the map of interconnections as of 2017. Previously, the Dobrotvirska thermal power plant exported power to Poland in substantial volumes. The regional supply situation changed dramatically after the coal power plant in Dobrotvir was targeted by the Russian attacks in May. The existing line, which is currently not in use, is able to transfer up to 400 MW and potentially can be used in the other direction to supply Ukraine with more electricity. In the future it can be upgraded from 220 kV to 400 kV and contribute to further strengthening of energy security in the region. Building a new substation nearby in Zamość area would strengthen the connection further, as PSE experts state.

Figure 3: Grid Interconnections of Ukraine and Moldova with Western neighbours before synchronisation



Source: Zasuń (2017).

Options for using the line for reverse flows now to Ukraine include exporting power through the grid from Poland, thus making the line part of the synchronised system. Alternatively, capacity could be set up swiftly at Zamość: for example, a windfarm, a solar power plant with batteries and/or a modular gas power plant. Yet, the gas plant requires a supply from a pipeline that is not available closer than 30 km from Zamość. At the same time, Ukraine can supply gas from Ustyluh (Volyn Oblast) through a pipeline, unused since 2011 for the reason of a missing business case, to the Polish city of Hrubieszów. From there, gas can be supplied via distribution gas pipelines to Zamość, located approximately 50 km away.

Such fast-to-be-built capacities require political backing, financial guarantees, and a more longer-term business case for private investors, plus the openness of IFIs to provide funding for projects. Such solutions would not only boost the economy and create new jobs in the bordering regions (in Eastern Poland or Northern Romania), but they would also create capacities outside of the Russian reach and would, therefore, be more protected than investments in the Ukrainian territory. Additionally, designating this 220 kV antenna line with a separate status from the Polish national transmission network would eliminate the need to include it in the limit as set by ENTSO-E. As for the more mid- to long-term business case, the following facts need to be shared: with Ukraine joining the European electricity system and the Baltics being synchronised with the continental grid, Poland will take to a much more central place in the region. More broadly, this requires Poland anyways to strengthen its grid in the country's East, in Rzeszów, where most of the industry and logistics are located.

Moreover, future capacity projections for the EU, such as the European Resource Adequacy assessment, also show that Poland and Germany might be 'short' in electricity supply, while Romania and possibly Ukraine might have a surplus in the long term. In this context, enhancing grid connectivity between Germany and Poland, as well as connecting Poland and Romania through Ukraine, makes sense and should form part of the next round of TYNDP discussions among TSOs and the ENTSO-E and the already mentioned needed BEMIP-type approach.

Ukraine's TSO Ukrenergo, on its end, has confirmed that the grid on the other side of the border, in the Lviv area, could be reinforced fast to accommodate power transfers from Poland. Now, in the state of emergency, all solutions should be considered by Polish policymakers and technical experts. Polish TSO PSE, as well as the Energy Community, European Commission and ENTSO-E, should explore the possible use of the

Dobrotvir-Zamość line for the forthcoming winter, indeed exploring at once how it could accommodate the regional flows in the medium- and long-term too.

5.3 Speed up existing – and delayed – interconnection projects between Ukraine and Slovakia, Ukraine and Romania

What is possible beyond the existing lines and their better use? One successful benchmark is indeed provided by the rehabilitation and down-powering of the existing Rzeszów-Khmelnytskyi line. Within about a year - and not the average twelve that grid projects take- this line was re-opened in early 2023 at 400 kV instead of 750 kV, rapidly expanding Ukraine’s synchronous interface with continental Europe (see below in section 6.3.3. for more details).

According to various Network Development Plans of TSOs and the ENTSO-E TYNDPs 2022 and 2024, as well as reflected in the National Energy and Climate Plan of Ukraine,⁶ several projects are currently planned. These include the strategic Romania-Ukraine and Slovakia-Ukraine interactions. Yet, they are late or not progressing. As mentioned in our recommendations, these should form part of the BEMIP-type approach for Ukraine.

Table 2: Interconnections to Ukraine and foreseen dates and capacities (not considering 110kV)

	Country	Net Transfer Capacity, MW					
		2025	2030	2035	2040	2045	2050
Export to	Hungary	429	429	650	650	650	650
	Moldova	264	264	400	400	400	400
	Poland	799	799	1210	1210	1210	1210
	Romania	198	264	264	1400	1400	1400
	Slovakia	264	264	264	1400	1400	1400
	TOTAL EXPORT	1954	2020	2788	5060	5060	5060
Import from	Hungary	297	429	650	650	650	650
	Moldova	264	264	400	400	400	400
	Poland	666	666	1000	1000	1000	1000
	Romania	99	264	1400	1400	1400	1400
	Slovakia	264	264	1400	1400	1400	1400
	TOTAL IMPORT	1590	1887	4850	4850	4850	4850

Source: REKK et al., (2024); based on Ukrenergo NDP 2022 and ENTSO-E TYNDP 2022.

⁶ Cabinet of Ministers of Ukraine approved the National Energy and Climate Plan of Ukraine for 2024-2030 on 25 June 2024.

Table 2 above shows the Net Transfer Capacity between Ukraine and the neighbouring countries as well as estimated NTC expansion and grid expansion until 2050, based on the data from the Ukrenergo Network Development Plan and the ENTSO-E TYNDP. The only currently foreseen change between 2025 and 2030 relates to the imports from Hungary, with a foreseen increase by 133 MW between 2025 and 2030. And as for exports, an increase of 66 MW is foreseen for the same period for Romania. It should also be noted that the table does not include the lower voltage lines, such as the 110kV lines or the line between Slovakia and Ukraine currently operated at 35kV (see description in the section on 110kV).

What is the state of the projects that can lead to significant increases, as per Table 2, after 2030, above the capacities highlighted by the authors in bold in the column 2030? The lines behind the very high NTC increases for Slovakia (+1134 MW in 2035), Romania (+1134 MW equally in 2035), and Poland (+434 MW in 2035) are respectively Kapušany, Isaccea, and Rzeszów–Khmelnitskyi.

Could they be accelerated to maximise the available transfer capacity at the borders and help Ukraine to cope with capacity deficits in the short and medium term? Those three borders will be discussed in the sub-sections below.

5.3.1 Slovakia- Ukraine

The project to rehabilitate an overhead line of a total length of 53 km (42 km on the Slovak side, 11 km on the Ukrainian side) and of 400 kV Mukacheve (Ukraine)—Veľké Kapušany (Slovakia) was already started in 2013 (see Figure 3). According to the Energy Community website, 70 per cent of the work has been done in Ukraine, yet no work started in Slovakia (Energy Community, n.d.). It should be noted that the prime ministers of both countries agreed in January 2024 to speed up the project delivery (Tumanova, 2024). It is also promising that the project was accepted as a late submission to the ENTSO-E TYNDP 2024. This submission is a precondition for it being considered a Project of Common Interest of the EU (PCI). Such PCIs provide either a European label to projects or, in addition, public co-funding, as was done, for example, in the case of Baltic synchronisation. The line's commissioning is foreseen for 2028 but can and should be speeded up. The project can be implemented in two stages, first as a single-circuit line with a second circuit added at a later stage. Such a single circuit would add about 600-800 MW of transfer capacity; Table 2 above assumes an additional 1136 MW for both circuits being built.

5.3.2 Romania-Ukraine

As a late submission to the ENTSO-E TYNDP 2024 was equally accepted the construction of the 400 kV transmission line Pivdenoukrainska NPP (UA)—Isaccea (RO). The originally foreseen commissioning year is 2028.

Ukrenergo is currently working on the line section in the Odesa region. This line would add huge benefits and increase the transfer capacity by more than 1 GW. Potentially it can become operational by 2026 or even before with due efforts by both TSOs. What is more, the Isaccea line would also end Moldova's dependency on Transnistria, a Russian-controlled enclave including the large Transnistrian MGRES thermal power plant operated by Russian state-owned power company InterRAO.

Pivdenoukrainska NPP—Isaccea, as much as the Slovakia-Ukraine line, should be included in the priority list of Projects of Common Interest (PCIs) and supported by the European Commission.

According to the Energy Community, the interconnection projects with Romania and Slovakia have not progressed so far. They were identified by the Energy Community as PMIs (Projects of Mutual Interest) in 2020, again applied as such in 2024 and as candidates for the Projects of Energy Community Interest (PECI). As the Energy Community is no longer responsible for the projects between EnC countries and EU member states, the solution must be found at the European Commission level (Joint Research Centre is leading the analysis for PCIs). This process has been initiated. A necessary precondition for the project to be nominated as PCI is that they are also nominated for being included in TYNDP, prepared by the ENTSO-E.

It should be noted that Romania, Moldova and Ukraine have held trilateral talks on July 5th, 2024, at the Foreign Minister level, and agreed, among other things, to expand their collaboration on energy security. This means a gas-to-power swap, with Moldova receiving gas for generating power that is after exported to Ukraine (Ministry of Foreign Affairs of Romania, 2024).

The joint declaration contains the following paragraph: “We (the foreign ministers) emphasized the paramount importance of the development of regional electricity interconnections, such as the promotion of the project of the second circuit of the 330 kV Over Head Line (OHL) "Bălți-Dnestrovsk Hydroelectric Power Plant", OHL 330 kV "Vulcănești - Artsyz", OHL 400 kV "Isaccea - Vulcănești - Chișinău", OHL 400 kV " Bălți - Suceava", OHL 400 kV " Strășeni - Gutinaș", OHL 400 kV Suceava - Cernăuți and OHL "Yuzhnoukrainsk Nuclear Power Plant - Prymorska - Vulcănești - Isaccea". According to Moldovan sources, 150 MW in addition will be supplied this way to Ukraine, and a further 350 MW were proposed to Ukraine.”

5.3.3 Improving the functioning of the line between Poland and Ukraine

The Rzeszów–Khmelnyskyi power line was set up in 1977, when Europe was still divided into two blocs and operated as a 750 kV line. It links one of four Ukrainian nuclear power plants located in the Khmelnytskyi region to the Eastern Polish city of Rzeszów. It was the only 750 kV line in Poland and was taken out of service in 1995 when Poland joined the then UCPT (former name of the Regional Group Continental Europe, becoming UCTE in 1999). Several plans existed to reactivate the line, for example, with the construction of back-to-back HVDC⁷ stations discussed as the “Energy Bridge” project. Energoatom, the Ukrainian nuclear power plant operator, in 2016 considered disconnecting one unit at the Khmelnytskyi NPP from the Ukrainian grid and using the 750 kV line to connect it directly to Poland for exports. The Ministry of Energy of Ukraine created in 2019 a consortium called Ukraine Power Bridge Company to promote the project, but the project was never agreed on the Polish side.

Given the full-scale war since February 2022, it was decided to rehabilitate the line and repower it as a 400 kV line, which went into service only one year later, in 2023. The Rzeszów–Khmelnyskyi line now has a capacity of 550 MW, yet given technical constraints, particularly impedance issues, limit the actual transfers today, as Table 4 shows. Solutions exist to mitigate this issue: impedance control devices and power electronics, or so-called FACTS (STATCOM, SSSC). Replacing parts of the overhead line with sections of underground cables presents another option for reactive power compensation (Karki et al., 2015). Innovative solutions employing buffer batteries are also available. Given these options, the Polish Transmission System Operator together with ENTSO-E, should find suitable solutions and take action to solve the impedance issues and increase transfer capacity.

⁷ An HVDC back-to-back station can be used to create an asynchronous (DC) interconnection between two AC networks.

Table 3: Current commercial transfers Poland-Ukraine (Day-Ahead-Market)

Hour	Trading day: 2024-12108			
	Ukraine (ZAM-DOB)		Ukraine (RZE-CHA)	
	Export, MW	Import, MW	Export, MW	Import, MW
1	0	0	51	0
2	0	0	56	0
3	0	0	56	0
4	0	0	60	0
5	0	0	60	0
6	0	0	133	0
7	0	0	186	0
8	0	0	41	0
9	0	0	0	0
10	0	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0		0
20	0	0		0
21	0	0		0
22	0	0		0
23	0	0	97	0
24	0	0	90	0

Source: Data from PSE (2024) PSE S.A. (n.d.).

5.4 Use Grid Enhancing Technologies (GETs) to make the most of the existing lines: the example of Dynamic Line Rating and of addressing impedance on the Rzeszów-Khmelnyskyi line

Dynamic Line Rating has been used in many countries for decades now: it improves the use of the existing grid to accommodate higher power flows. Dynamic Line Rating (DLR) refers to the active varying of presumed thermal capacity for overhead power lines in response to environmental and weather conditions. This is done continually in real-time, based on changes in ambient temperature, solar irradiation, wind speed and wind direction, to minimise grid congestion (IRENA, 2020).⁸

While countries like Germany have foreseen the use of DLR in all high-voltage grids since 2023, Ukraine has not yet implemented the technology. According to technology suppliers such as Ampacimon (Belgium) or Operato (Slovenia), the DLR solutions could be deployed within less than six months.⁹ Ukrenergo initially foresaw the installation to start in Summer 2024. The company, by October, did a first assessment for a pilot project to be confirmed in 2025 according to acting CEO Brekht.¹⁰ DLR would be able to raise the Ukrainian grid's transmission capacity by 10-30 per cent, especially in winter, when cold allows for more loading of power transmission lines.

Yet, ENTSO-E would need to allow for the additional capacity on the interconnectors and revise the current cap of 2.1 GW. ENTSO-E and TSOs of neighbouring countries should analyse the options for deployment of DLR on the interconnectors and Ukrenergo within Ukraine for a fast deployment to be guaranteed and funded

⁸ See www.currentheurope.eu for a detailed overview of Grid Enhancing Technologies.

⁹ Discussion with the company by author, May 2024

¹⁰ Meeting with the authors, Kyiv, October 2024

by IFIs. Political pressure might help to increase the speed of deployment. Ukraine started discussions on such measures in 2021, restarted them in 2022, with a concept of implementing smart grids in Ukraine by 2035 (Cabinet of Minister of Ukraine, 2022). The concept lists the application of flexible alternating current transmission systems (FACTS) for dynamic compensation of reactive power based on power electronics, the application of storage installations and the use of DLR. Indeed, 2035 is way too late, and the Green Deal Ukraine project therefore recommends swift and immediate action on some of those foreseen measures.

5.5 Explore using the 110 kV networks, starting from Ukraine-Moldova, and possibly adding more 110 kV bridges

If only some of the existing 110 kV lines would be used for exchanges with Ukraine, including 5 between Moldova and Ukraine, and 1 (uprated from 35 kV) between Slovakia and Ukraine, up to 200 MW of additional transfers could be added by each line, or an estimated additional 1.2 GW of power could be transferred if six of them were used. All those smaller lines together would thus make up for the equivalent of one big high-voltage transmission project and come in addition to the advantage of the distributed generation and decentralised approach. This is even more crucial as the inner-Ukrainian transfers are interrupted regularly by the shelling of the high voltage lines.

While typically owned and managed by distribution system operators (DSOs) within national borders, 110 kV lines are always controlled by TSOs when they are cross-border lines.

Ukraine disposes of a well-developed 110 kV network, including eleven existing 110 kV lines from Ukraine to Moldova (this includes 5 to Republic Moldova and 6 to Transnistria), as Table 4 shows. Those should be used to increase transfer capacity between Ukraine and its neighbours, to start with as antenna lines, not forming part of the ENTSO-E interconnected system. Such cross-border lines can be built or restored as part of new power generation projects in border regions that could export electricity to Ukraine. There are some technical challenges when 110 kV and higher voltage grids intersect (because of variations in phase angle between current and voltage), yet those are different from place to place and can be addressed through special transformers and other phase-shifting devices. There are also political and regulatory challenges, such as that Distribution System Operators typically operate 110 kV grids, so that they need to sit at the table together with the TSOs. Moldovan sources also highlighted to the authors the existence of four 110 kV lines in Moldova that are not used at the border to Romania and potentially could be used as interconnectors.

As a side-thought (out of scope here of this study), using 110 kV more might also encourage an EU-wide rethink. Actually, several studies have been made to investigate the potential of 110 kV lines for improving overall system operation (Hoffrichter et al., 2017).¹¹

There is also a link under scrutiny between Slovakia and Ukraine: the existing link between Slovakia and Ukraine (Visne Nemecke-Uzhgorod) of 35kV shall be uprated to the initially foreseen 110 kV and the DSO VSD¹² on the Slovakian side needs to be associated. The 35 kV line originates from a substation near the Slovak-Ukrainian border in the Košice Region, with the substation Vyšné Nemecké. In Ukraine, the line connects to a substation in the Zakarpattia Oblast, Ukraine. Uzhhorod is the nearest large city, and it is a key energy hub in the region that may host the Ukrainian endpoint.

¹¹ Examples include the pioneering work by RWTH Aachen. The overarching challenge here is that DSOs are usually responsible for 110 kV and that a high-voltage grid development coordination, including also the lowest level of high voltage (precisely 110 kV), is missing.

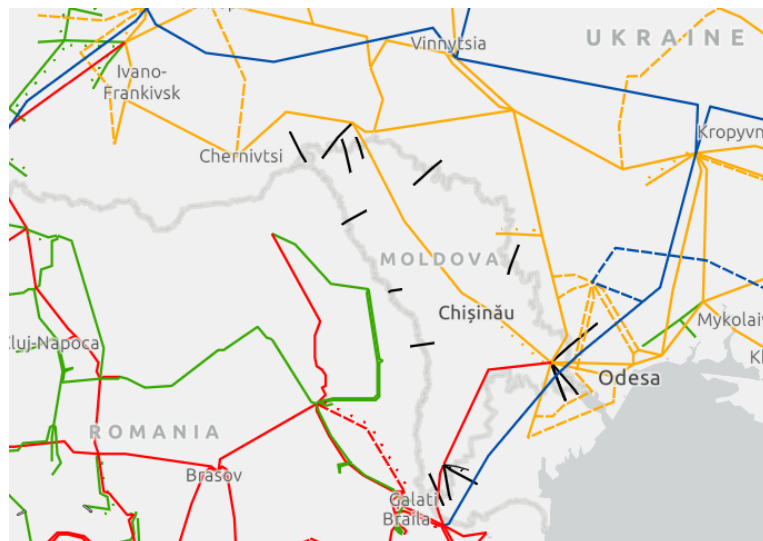
¹² VSD stands for Východoslovenská distribučná, a.s. (VSD)- a DSO that oversees electricity distribution in eastern Slovakia, including regions near the Ukrainian border.

Table 4: Number of cross-border power lines between Ukraine and neighbouring countries by voltage class

Interconnections	Voltage class of transmission lines					
	Country	750 kV	400 kV	330 kV	220 kV	110 kV
Poland	-	1	-	1	-	-
Slovakia	-	1	-	-	(1)	(1)
Hungary	1	-	1	2	-	-
Romania	1	1	-	-	-	-
Moldova	-	-	7	-	11 (5 in Moldova, 6 in Transnistria)	1
TOTAL	2	3	1	3	11 (12)	1 (2)

Sources: Green Deal Ukraine 2024 based on CIGRE (2018); Ukrenergo (2021), own research.

Figure 4: Moldova Grid Connections. 110 kV lines appear in black



Source: ENTSO-E. (n.d.)

5.6 Set up an appropriate governance for regional power exchanges

The authors recommend investigating a regional collaboration framework, that can use the Baltic Energy Market Interconnection Plan (BEMIP) (European Commission, n.d.) as a template. BEMIP has successfully coordinated the regional energy market integration and infrastructure built up between the three Baltic countries and their neighbours. While such a political framework would mainly address the mid-and long-term needs, it should include the listed projects above from the beginning and ensure sound coordination and a common vision.

CESEC stands for Central and South Eastern Europe Energy Connectivity. In our exchanges with several stakeholders, it was often mentioned as a possible host for such a governance framework. CESEC is an initiative launched by the European Commission in 2015 to improve energy security, market integration, and diversification of energy sources and routes in Central and Southeastern Europe. The authors are agnostic about using CESEC or a possible UMEMIP (Ukraine-Moldova Energy Market Integration Plan) as a framework. CESEC focuses on energy security, market integration, infrastructure development, and the transition to clean energy, which indeed is perfectly in line with what would need to be achieved with a

regional integration plan for Ukraine. The Directorate-General for Energy (DG ENER) is the primary body within the Commission responsible for CESEC's leadership, providing strategic direction, funding and coordination. While CESEC foresees regional coordination groups, including TSOs or regulators, no such group has yet been set up for Ukraine/Moldova.

This would be, therefore, a step one if CESEC wants to play a key role in the regional integration of both countries.

6 Overview of the impact of all possible short-term solutions

As our analysis has shown, the successful synchronisation and consecutive steps since 2022 have already played an important role for Ukraine. More can be done, and fast, to increase transmission capacity between the European continental grid and Ukraine. Our analysis has shown for the current winter that with the political will and necessary resources mobilised, and even without taking all the measures, Ukraine can get an additional 0.5 GW of import capacity: as said, the ENTSO-E move alone (from 1.7 GW to 2.1 GW is already making up for 400MW; additional could come from the use of the 220 kV line Poland-Ukraine, and/or the 110 kV interface to Moldova). By the winter 2025/26, electricity exchange can be expanded further by 1.4 GW to reach 3.6 GW, as the summary Table 5 below shows. This would mean that even with the implementation of only some of the measures proposed, the deficit in Ukraine in winter can be reduced to 1.8 GW (of course, with the contribution of both generation and grid-enhancing measures) and would be entirely solved, with a positive reserve of +1 GW in the consecutive winter.

Table 5: Forecasted power needs (winter peak load) in Ukraine and options to reduce capacity deficits in the short-term

Expected peak load	Available installed capacities of large conventional power plants	Forecasted generation capacity* of renewables	Imports from EU member states	Capacity deficits and options on the demand side
15-18 GW *	12.4 GW* (baseline)	0.5 GW**	2.1 GW	Up to -3.0 GW (baseline)
Options to increase available capacities and address deficits in winter 2024/2025	Deploying and connecting new modular gas-fired units to existing infrastructure: +200 MW Decentralised solution for vulnerable cities like Odessa +250 MW ¹³	Adding energy storage to solar and wind plants to expand balancing reserves and reduce curtailments: +50 MW Deploying solar and batteries at critical infrastructure facilities: +50 MW	ENTSO-E raising the export limit to 2.4 GW with optimisation of existing grids and the reverse use of 220 kV Poland-Ukraine line	Options to reduce the need for load shedding: Energy efficiency improvements Investments in equipment for self-supply by businesses and enterprises
	12.85 GW	0.6 GW	2.4 GW	+0.85- -2.15 GW deficits
Options to increase available capacities	Build out flexible generation +2,8 GW Build	Build out RES and energy storage +1 GW	Develop 110kV +600 MW interconnector	Additional self-supply by businesses and enterprises,

¹³ Gluchova, I. (2024, October 3)

and address deficits 2025-27	Storage + 800 MW ¹⁴		Boost Isaccea and Kapușany +2 GW Address shortfalls in Rzeszów-Khmelnyskyi +600 MW	energy efficiency in public buildings and RES for self-supply
Additional supply	+3,6 GW	+1 GW	+3.2 GW	+7.8 GW (total additional supply)

* The winter peak load in Ukraine is expected to range between 15 GW (for ambient temperatures at -3 Celsius) and 18 GW (for temperatures below -10 Celsius and more).

** Calculated by applying typical capacity factors to define contribution to covering peak load by available solar and wind installed capacities (3.4 GW), which are provided with necessary reserves.

Source: Authors (2024).

For the mid-term and long-term regional security of supply, all options need to be boosted and projects for repowering of lines should be implemented. For example, 220 kV Zamość-Dobrotvir line can be converted into a 400 kV line. Further grid development, including a possible HVDC link inside of Ukraine, should also be implemented.

¹⁴ Kubrushko (2024, July 5)

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