The National Council for the Recovery of Ukraine from the Consequences of the War

Draft Ukraine Recovery Plan

Materials of the "Energy security" working group

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UKRAINE RECOVERY PLAN: ENERGY

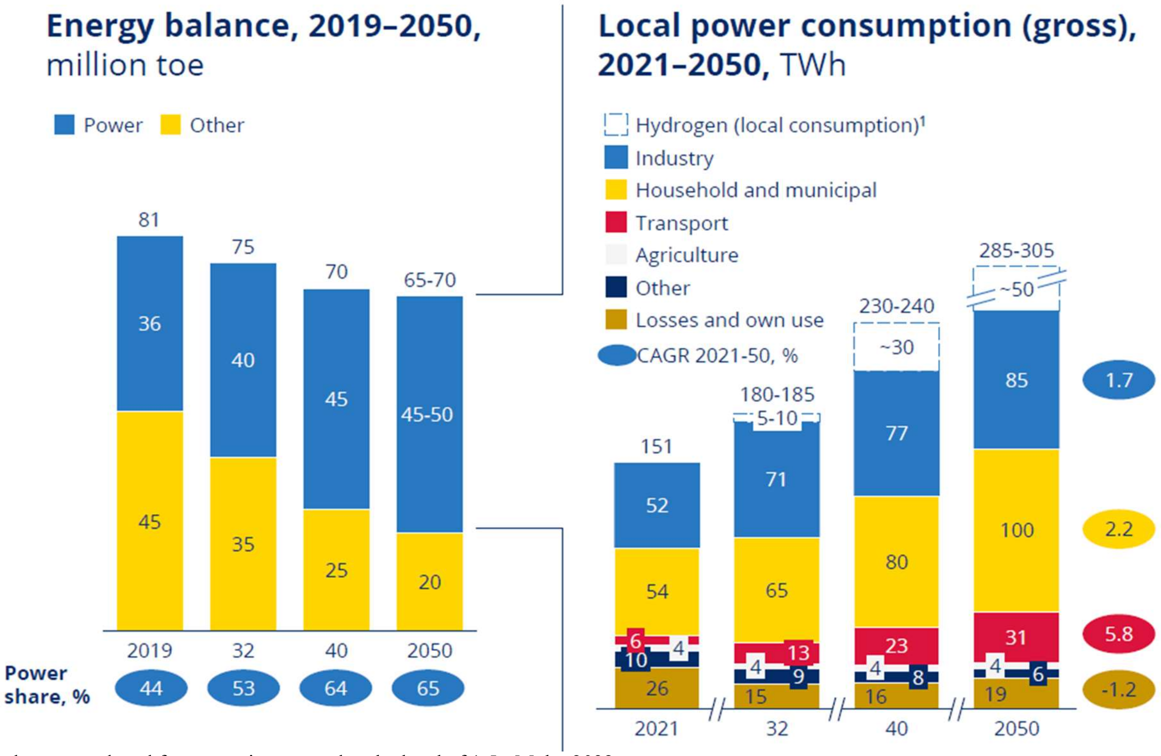
Executive summary: what kind of energy sector are we building in Ukraine? 3
1 Recovery and development of Ukraine's energy sector: objectives, challenges, opportunities 7
1.1 Current state of the sector and impact of the war 7
1.2 Key challenges for the Ukrainian energy sector: 12
1.3 Key opportunities for Ukraine's energy sector 13
1.4 Key assumptions / framework of the plan 14
2 Electricity Sector 16
2.1 Analysis of the state of generating capacities of the IPS of Ukraine 16
Nuclear power 17
Hydro power 18
Thermal power 18
CHP and cogeneration units 20
Renewable energy sources (RES) 20
2.2 Analysis of operating modes of generating capacities in the IPS of Ukraine 22
2.3 Demand development scenarios 27
2.4 Supply development scenarios 33
Nuclear energy 33
Large hydropower 33
Small hydropower 35
Thermal energy 35
Renewable energy sources 41
Technical means to support the integration of RES generating capacities 42
Interconnectors 47
2.5 Assessment of generation adequacy (flexibility) of Ukraine's IPS 54
2.6 Analysis of the external environment: challenges and opportunities 88
2.7 Generation development scenarios 89
3 Gas sector 95
3.1 Ukraine's gas balance before the invasion 95
3.2 Overview of hydrocarbon deposits in Ukraine 96
3.3 Current state of hydrocarbon production and growth potential 99
3.4 Demand structure and production forecast till 2032 100
3.5 RESP: Ukraine's gas transmission and storage infrastructure for European energy security 100
4 Oil and oil products 105
4.1 Structure of the oil products market 105
4.2 Securing fuel supplies for Ukraine during the war 105
4.3 European fuel market restructuring following the Russian aggression and Ukraine's future role 106
5 Power-to-X 108
5.1 Production of hydrogen from RES 108
5.2. Electrification of transport 109
5.3. Electrification of heating 110
6 Recovery and development: detailed plan of measures 111
Objective 1: European integration and efficient operation of energy markets 112
Objective 2: Energy security: diversification of energy supply sources, creating reserves, cyber-security 115
Objective 3: Decarbonisation, optimisation of the energy mix and development of low-carbon generation 119
Objective 4: Modernisation and development of energy transportation, transmission, distribution and storage infrastructure 121
Objective 5: Improvement of energy efficiency and demand-side management 124
7 National projects 127

Executive summary: what kind of energy sector are we building in Ukraine?

This Recovery Plan is ambitious. For Ukraine to achieve its goals in the energy sector, the following pre-conditions are needed:

- Ukraine wins the war within the next 1–2 years, no major parts of the energy sector are lost or severely damaged
- Business environment and macro-financial stability that allow for major investments and healthy returns are restored within 2–4 years, „red tape" and other barriers for swift realization of investment projects are removed
- There is a major funding and investment flow into Ukraine, both public and private

The main trend for the recovery of Ukraine in the energy sector is the rapid electrification of the economy due to the energy transition, as well as a significant increase in energy efficiency.

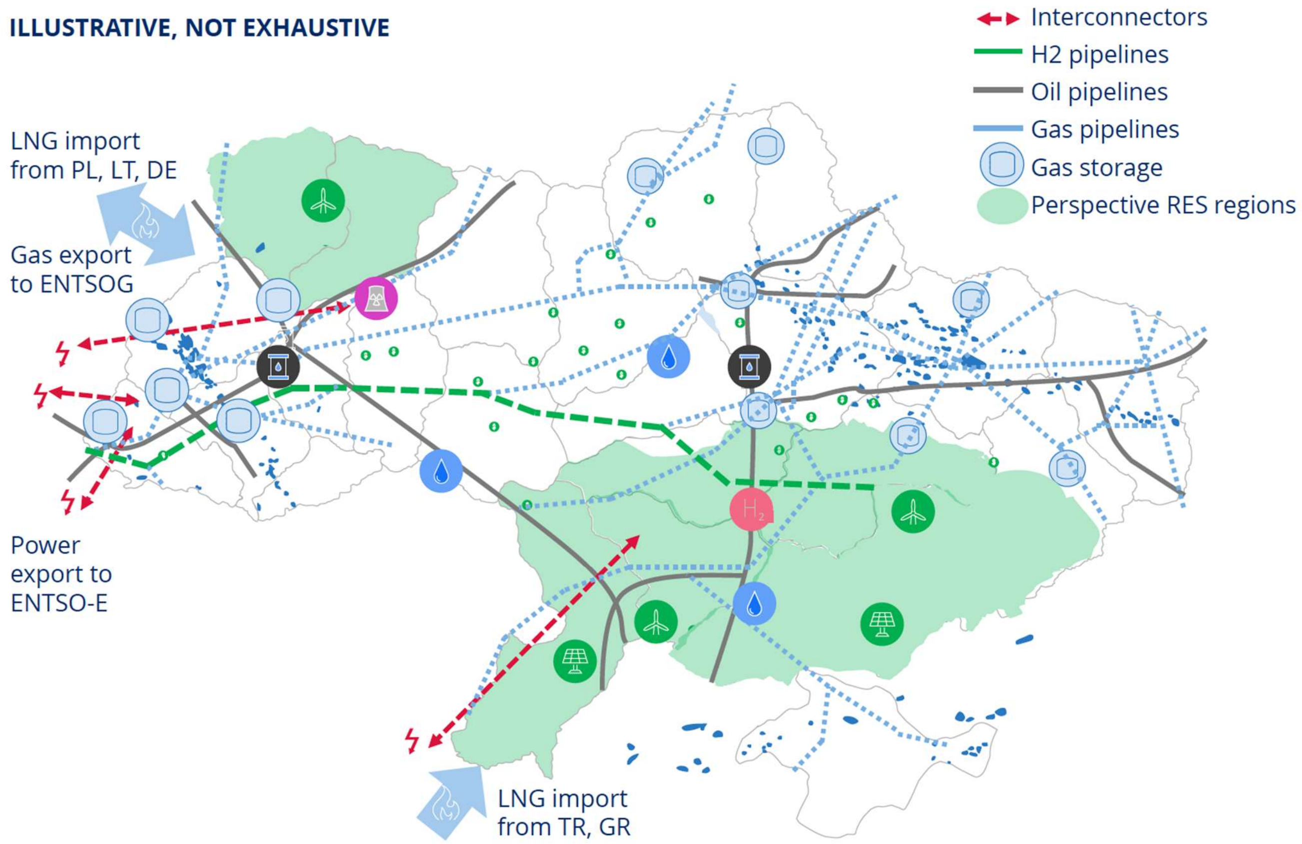


[1]Hydrogen produced for export is expected at the level of 1.5+ Mt by 2032.

Key assumptions by sector

Hydrogen	H2 domestic consumption of ~0.1–0.2 Mt in 2032, ~0.5+ Mt by 2050
Industry	Electrification of core sectors (e.g.metallurgy)
Housing	>50% of buildings thermo modernized by 2032, ~100% by 2050 Partial electrification of heating (electric boilers, heat pumps) ~90% of refugees return by 2024, stable population by 2050 1% CAGR of housing area per person
Transport	Railway transport electrification to 95+% Increase in share of EV cars to ~15% by 2032, ~80% by 2050 Municipal transport electrification/H2 to ~5% by 2032 and ~100% by 2050
Losses	Losses decrease to 8% by 2032 (as per National Economic Strategy)

Ukraine will support Europe's energy security and zero-carbon transition



Key catalytic projects:

- Expanding interconnectors with ENTSO-E to ~6 GW
- Increasing nuclear capacity (2 new units at Khmelnytskyi NPP, safety and prolongation, higher utilization)
- Build 30+ GW wind and solar
- Build ~3.5 GW pumped/reservoir hydro
- Build ~15 GW electrolyzer capacities and develop H2 infrastructure
- Natural gas: increase production from existing fields, develop unconventional gas fields
- EU natural gas hub: strategic stock replenishment and securing connection to EU/Turkish LNG supplies; modernizing gas transmission and distribution network
- Developing biofuels production (bioethanol, biodiesel, biogas/biomethane)
- Expanding oil refining capacity post war (rebuild, build or modernize 2 refinery facilities, build Brody-Adamova Zastava pipeline)

Ukraine will support Europe's energy security and zero-carbon transition

Production | Net Import | Net export | Deep-dive further

Key developments included in National Program

	Energy supply, 2019[1], million toe[5]	Energy supply, 2032, million toe	Current challenges	Short-term	Long-term
Nuclear[2]	21.8 (27%)	30.2 (36%)	• **Lifetime extension** required for 8 units by 2030 • **Decreasing capacity factor** (КВВП) of units • **Dependence on Russian** fuel and waste processing		• **Extend lifetime** (60y), **increase availability** of existing units • **Build 2 new units**[3] at Khmelnytskyy NPP till 2032 (more – in case long-term export agreements/low-cost financing secured) • Build **fuel fabrication** and expand **waste storages** to stop reliance on Russia
RES, incl. hydro	1.0 (1%) Growth to ~1.8 in 2021	4.7 (5%)	• **Fast growing sector with vast capital needs** and not-fully-resolved feed-in tariff and debts • Increasing **balancing needs** for the energy system		• **Increasing RES capacity** (5-10 GW) as power source with the lowest LCOE based on market conditions (no green tariff for new build)
RES for H2		8.6 (10%)	• To avoid need for balancing, this part may be not connected to energy system, but **directly to electrolyzers;** electrolyzers provide additional balancing services to the energy system taking peak RES outputs		• **Vast buildup of RES** (up to 30 GW) **and integration in EU's low-carbon H_2** value chain (pilot and then build-up up to 15 GW of electrolyzers) – volume may be adjusted depending on EU "appetite" for H2, supply chain ability, export feasibility
Energy coal	12.0 | 2.9 — 14.8 (18%)	1.9 (2%)	• **~46% imported,** both thermal and coking coal • Ukraine made a commitment to gradually **phase out coal power generation**		• **Thermal:** phase out coal generation after the war ends and once extra capacity is secured from nuclear and/or gas/biomethane ramp up. Closure of unprofitable mines taking into account the just transition of coal regions (MinRegion)
Natural gas	16.3 | 9.5 — 25.8 (32%)	18.3 | 3.4 — 21.7 (26%)	• **Import accounts for ~30%** of gas consumption • Low energy efficiency in mostly gas-based **house heating** • **Depletion** of largest gas fields **exceeds 80%**	• Roll-out **energy efficiency** at scale • Replenish **natural gas stock in storages**	• **Ramp up gas production** from existing fields and PSAs, develop unconventional gas fields (e.g. in Poltava region)[4] • **Expand gas interconnector with EU LNG terminals** • **Energy efficiency** and **district heating** modernization
Oil	10.9 — 13.4 (17%)	5.9 | 3.1 — 9.1 (11%)	• Significant **imports from Russia and Belarus** • **Refineries damaged** during the war • Most oil fields are **80+% depleted**	• **Expand oil product interconnector** w/ EU • Build **strategic oil product reserve**	• **Expand refining capacities** (rebuilding Kremenchuk refinery and building/modernizing additional refinery) • **Decrease reliance** on oil due to push towards transport electrification, H2 and biofuels (below)
Biofuels	4.2 (5%)	8.5 (10%)	• **Large resources, but lack of systemic push** for various kinds of biofuel production (biomethane, biomass, bioethanol, biomethanol, biodiesel)	• **Expand biomass and biogas use** in district and individual heating	• **Development of biofuels production and use:** • Biomethane/biogas/waste gas (2 bcm – but higher potential exists with up to 5 bcm) and biomass for district heating and industrial use; bioethanol and biodiesel from agri produce
Power export	0.3	1.7		• STATCOM 4x50 MVA • Reconfigure stabilizers at TPPs and HPPs, excitation of NPP units	• Expanding **interconnector with ENTSO-E** (up to ~7 GW) to potentially reach export of **~20-25 TWh**
Power stability & security			• **Fast growing RES require balancing capacities** to maintain security and stability of the system		• Build up **hydro / pumped hydro** power plants (3.5 GW) • Development of **peaker capacities** (1.5-2 GW) **/ batteries** (0.7-1 GW) to balance additional RES capacities • **Localize production of storage capacities** (e.g., lithium batteries) based on local resources • Modernizing and expanding **transmission and distributions networks, incl. smart grids**
H2 export	-	~1.5 Mt			

1. Base year is 2019, in order to conduct analysis without consideration of COVID lock-down disruptions
2. Nuclear energy is produced domestically; however, nuclear fuel is imported. Power output is 33% of input fuel
3. Extra units (up to 7) require additional cost-benefit consideration due to significant CAPEX, limited baseload requirements, and potential new units in CE countries
4. Extra upside (not included in base scenario): Black Sea shelf development
5. Conversion: 1 million toe = 11.6 TWh = 1.1 bcm of natural gas

Source: Ukrenergo, Ukrstat, Powering Past Coal, Ukrgasvydobuvannya, A-95

List of strategic projects*

			CapEx, USD bln	Expected project start
Low-carbon energy	Nuclear	Increasing nuclear capacity (prolongation, higher utilization of existing capacities, and 2 GW new units at Khmelnytskyi NPP)	~14	2023-25
		Localizing nuclear value chain (uranium mining, plant for fuel production, waste storage)	1.3	2023-25
	RES	Build out 5-10+ GW RES (depends on the export capacity)	~11.5	2026-32
	Balancing	Build out of 3.5 GW hydro and pumped hydro capacities	~3.5	2023-32
		Build 1.5–2 GW peaker and 0.7–1 GW of storage	~2.8	2023-25
	Supporting supply chain	Localize RES equipment production (towers, transformers, cables, solar panels, electrolyzers, Li batteries, etc.)	~2+	2026-32
	Biofuels	Developing biofuels (bioethanol, biodiesel, biomethane, biomass) production from agroproduce, residues and waste	~4.2	2022-25
	Infrastructure	Expanding interconnectors with ENTSO-E to ~6 GW (multiple projects)	0.6	2022
		Smart grids	~5-10	2026-32
		Re-build damaged / destroyed energy objects (CHPs, networks)	~0.4	2022-25
H2	RES	Build 30+ GW RES for H2 production	~38	2026-32
	Infrastructure	Build out ~15 GW electrolyzer capacities	~7	2026-32
		Test and develop H2 transport infrastructure	~2	2026-32
Gas	Production	Increase gas production from existing fields, develop unconventional gas fields (not including Black Sea shelf development~$11 bn)	~18	2023-32
	Infrastructure	Modernize gas transmission and distribution networks	~2.5	2023-32
		Securing gas supplies/storage for EU and Ukraine (e.g., extension of Świnoujście/Gdansk LNG and/or interconnect or import from Turkey/Italy/Germany)	0.7	2023-27
	Stock	Natural gas stock replenishment	~5	2022
Oil	Infrastructure	Expanding oil refining capacity post-war (rebuild, build or modernize 2 facilities) + oil pipeline Brody-Adamova Zastava	~2.5	2023-25
		Expanding oil products interconnectors with EU refineries and ports	0.7	2022
	Stock	Oil, oil products emergency stock for 30+ days (protected storages)	1.2+	2022
Total			**>128**	

Full list of submitted projects can be accessed here https://bit.ly/3xQg4KB

* The list and terms of implementation of the projects significantly depends on security, regulatory and financial preconditions

1 Recovery and development of Ukraine's energy sector: objectives, challenges, opportunities

Energy security plays an important role in ensuring the economic functioning and growth of the state. It is also an integral component of the citizens' quality of life and one of the crucial criteria for returning temporarily displaced persons to their homes.

Moreover, in the process of Ukraine's recovery, energy should become one of the key sectors that provides export revenues and supports the state's financial stability.

An intelligent approach to the modernization of Ukraine's energy will allow Ukraine to make a significant contribution to ensuring the strategic autonomy of the EU and reducing the dependence of the bloc on external energy resources. This mutually beneficial approach will speed up Ukraine's integration into the EU.

The Energy Recovery and Development Plan aims to:

(A) identify the overall strategic directions for the renewal and modernization of Ukraine's energy sector, taking into account the country's existing international commitment, as well as new challenges and opportunities that have emerged in the energy markets of Ukraine and the EU as a result of the Russian aggression;

(B) compile the list of reforms, legislative and regulatory initiatives necessary to ensure energy security of Ukrainian consumers and Ukraine's role as a reliable energy partner of the EU;

(C) compile the list of key national projects of greatest importance for achieving the strategic goals of recovery and modernization of Ukraine's energy sector.

Given the security considerations and decisions by the NSDC (National Security and Defense Council of Ukraine), certain urgent actions and decisions, which are implemented by the government and market participants for the preparation for the heating season 2022/23 are not reflected in this plan.

1.1 Current state of the sector and impact of the war

Powerful generation and transport infrastructure

As of February 2022, the Ukrainian energy sector was one of the most powerful in Europe, and remains so now, despite massive damage caused by the Russian invasion. Ukraine has one of the largest electricity generation capacities in Europe; it is also among the top-3 gas producers, and has the largest underground gas storage in Europe.

Extensive and reliable transmission systems of gas, oil, petroleum products and electricity connect Ukraine with neighbouring EU member states and Moldova.

Ukraine has one of the highest parts of the coal-neutral generation in Europe. About 70% of electricity comes from nuclear, hydro, and renewable generation.

Energy security: diversification of certain types of energy and dependence on others

Compared to 2014, Ukraine eliminated its dependence on Russian gas, however, partial or full dependence on imports of most types of fuel persisted.

Before the full-scale invasion in February 2022, Ukraine covered 75% of its demand for coal by domestic production. The rest was imported on competitive terms from a diversified range of suppliers.

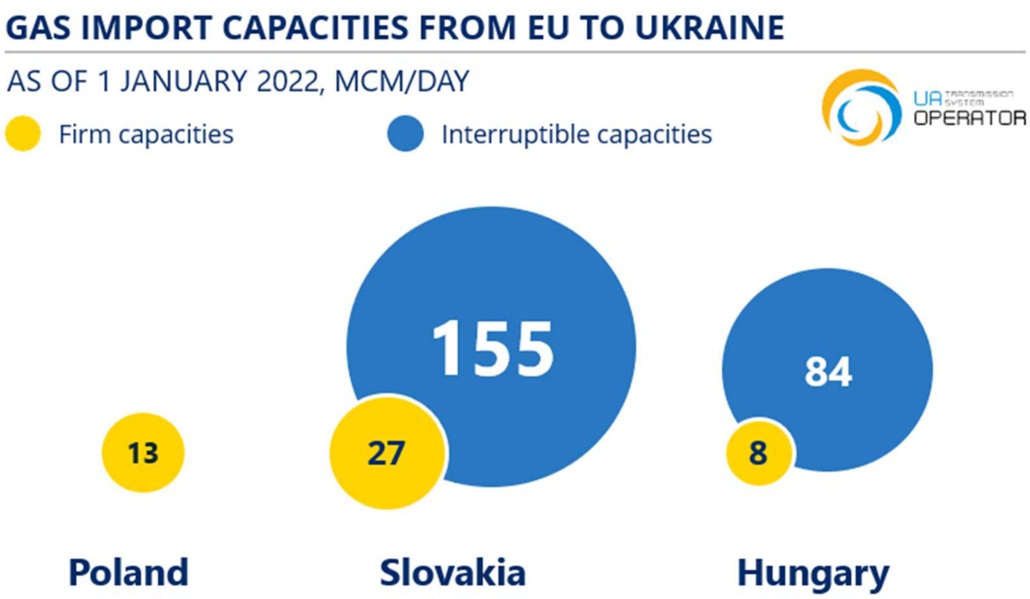
Despite the blockaded supplies of thermal coal by the russian federation, the heating period 2021/2022 went steady, without any restrictions or disconnected consumers. Ukraine diversified its coal supply sources as follows: 1,4 million tons of coal were delivered by sea (18 vessels); along with another 8 vessels expected to deliver 0,6 million tons of coal (50% of all imports). As of 23.02.2022, there were 701 thousand tons of coal in the warehouses - double the volume year on year (330 thousand tons).

In addition, measures have been implemented to save coal by building up domestic coal production and using other fuels (NPP and RES). In 2021, 1.2 GW of new renewable capacities, significantly reducing the demand for coal.

In the gas market, Ukraine covered 67% of its demand with domestic resources, while the rest was imported from the EU from diversified suppliers.

Ukraine's energy security is significantly enhanced by large underground gas storage facilities. As of 23.02.2022, they held 10.2 billion cubic meters of gas – which at that time was sufficient to meet the needs of the Ukrainian market before the end of the heating season, even in absence of imports.

At the same time, the operator of Ukraine's gas transportation system (GTS) provided sufficient capacity for gas imports from the EU.



As of the beginning of the invasion, the Ukrainian energy market largely depended on the imports of Russian and Belarusian oil products. These two countries accounted for the largest volume of imports, and Ukraine provided its own resources by only 30%.

At the beginning of June 2022, Energoatom, the national nuclear generation company, signed agreements to supply nuclear fuel for all of Ukraine's nuclear power plants with the American Westinghouse Electric Company. Previously, fuel for Ukrainian NPPs was supplied from Russia.

Ukraine and Moldova had disconnected from the energy systems of Russia and Belarus shortly before the invasion. In the course of the following few weeks, the Ukrainian and Moldovan power systems were synchronized with the EU networks, and since late June 2022, Ukraine has started commercial electricity trade with the EU.

Progress in the energy sector reform

Ukraine has made significant progress in reforming the energy sector in line with EU legislation. In 2019-2021, Ukraine has successfully completed the unbundling of gas and electricity transmission system operators, which is confirmed by their certification as independent TSOs.

Gas and electricity markets have undergone key structural changes. There is also an ongoing corporate governance reform.

NPC Ukrenergo, Ukraine's TSO for electricity, has been preparing the country's power system for synchronization with ENTSO-E since 2017, when the Agreement on the Conditions for Future Interconnections was signed.

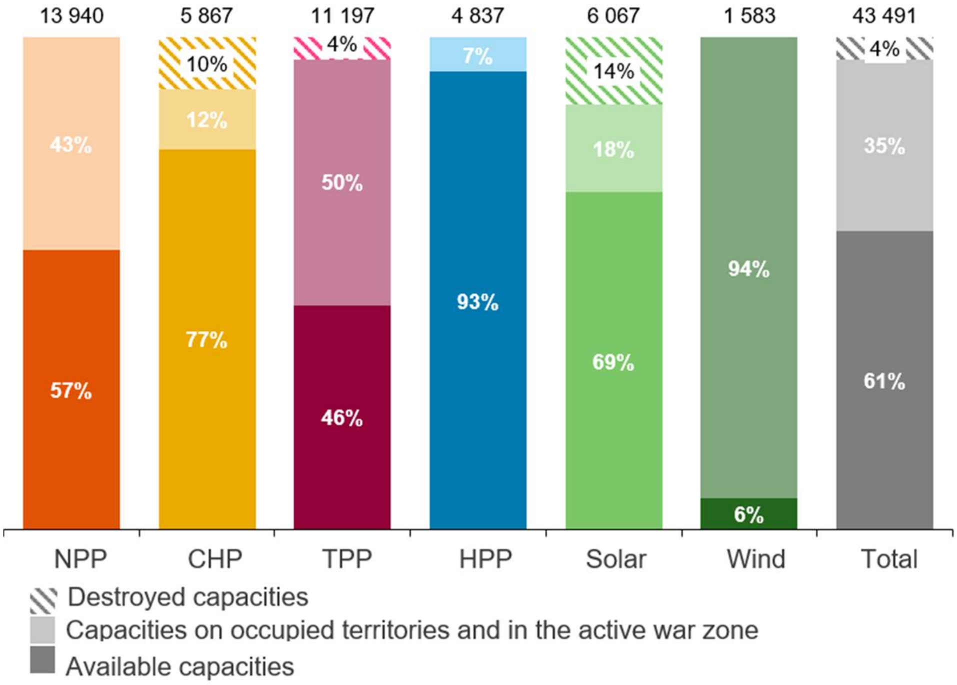
During this time, preparations included testing of the power units of Ukrainian NPPs, TPPs, CHPs and HPPs, and development of a mathematical model of the power systems of Ukraine and Moldova, that then allowed the ENTSO-E Consortium to conduct a study of the static and dynamic stability of the energy systems of Ukraine and Moldova when operating with the network of continental Europe. This study confirmed the feasibility of the synchronization.

Ukraine joined the ENTSO-E Continental Europe Synchronous Area a year earlier than planned. The energy systems of Ukraine and Moldova are now fully synchronized with ENTSO-E networks.

Impact of the war on the sector

Obviously, the war has a massive and devastating impact on Ukraine's energy sector. Because of its economic, humanitarian and geopolitical importance, energy infrastructure is a particularly frequent target of the russian aggression. Nevertheless, the Ukrainian power system keeps exhibiting remarkably stable operation, while energy industry workers show extraordinary bravery and professionalism in ensuring stable operation of the industry even in the conditions of war.

Distribution of operational capacity of power generation, MW



Source: Ukrenergo, working group's analysis

Around 4 percent of generation capacities have been destroyed by the hostilities, and 35 percent of capacities are located in the occupied territories. In particular, the largest in Europe NPP (Zaporizhzhya NPP) operates within the Ukrainian energy system, but it is under continuous pressure from the Russian occupants.

The generation capacity of this plant is 6000 MW, 43% of Ukraine's total nuclear generation capacity.

Overall, over 50 percent of thermal generation, 30 percent of solar generation and 90 percent of wind generation assets either have been destroyed or are under the russian occupation.

Gas production fell by approx. 10-12 percent.

None of oil refineries are in operation (domestic production provided approximately 30 percent of petroleum products); there are logistics difficulties with the supplies of petroleum products.

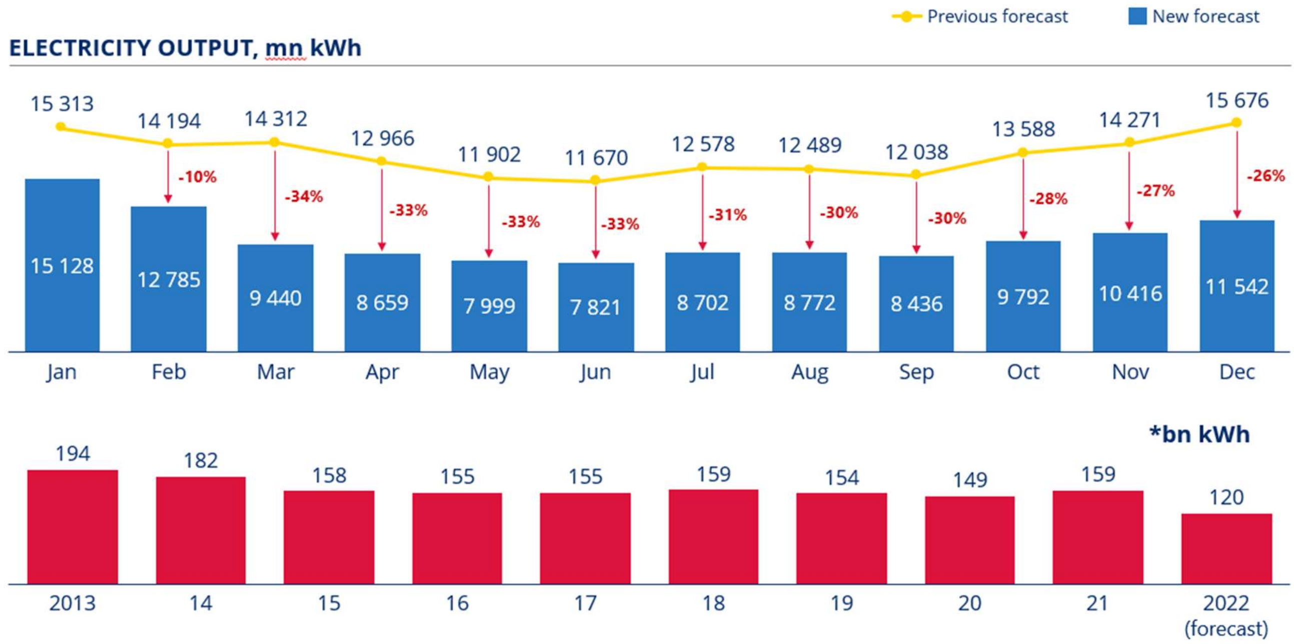
According to preliminary estimates, as of mid-June 2022, direct damages to the infrastructure of the Ukrainian energy, oil and gas sector, amount to 47 billion UAH, or 1.7 billion USD.

Total indirect losses in the electricity sector since the beginning of the war are estimated at 341.8 billion UAH. In gas production, transit and distribution, estimated losses amount to 61 billion UAH. For the oil production and oil refining sector – 66 billion UAH.

Contraction of internal market and payments

As a result of the hostilities, demand decreased significantly (by 30-35 per cent compared to consumption in 2021), and consumption patterns changed significantly due to the *en masse* movement of consumers to the western regions.

As of the end of June 2022, almost 600 thousand consumers are without electricity, and about 180 thousand consumers - without gas.



A significant rise in energy and fuel prices makes it difficult to supply demand and/or prepare for the autumn-winter season.

Energy prices and heat and transmission tariffs for a large part of consumers remain unchanged, increasing financial imbalances in the energy system. Thus, as of June 1, 2022, the expected deficit of funds in the electricity market is about 35 billion UAH. Because of Russian aggression, there is a high level of systemic restrictions on the generation of the RES, with its sources of compensation being currently uncertain.

The fall in the level of calculations and the aggravation of the debt problem, even at fixed prices, indicates a threat to energy poverty.

Loss of labor resources through military actions and departure from the country of the working population has a significant negative impact on the industry.

The impact of the war on the EU market

Russia's military aggression against Ukraine is also accompanied by its aggressive actions against buyers of its energy resources within the EU. Russia's monopoly supplier has already stopped gas supply to Poland, Bulgaria, the Netherlands, Denmark, France and has significantly reduced gas supply to German and Italian counterparties.

In response to energy risks, the EU has developed a RepowerEU plan, whose main goal is to abandon russian energy resources by increasing energy efficiency, diversifying fuel supplies, creating a mechanism for joint gas purchase and accelerating the transition to renewable energy sources. The EU has also imposed sanctions on russian coal and oil.

Some EU countries have announced anti-crisis measures such as resumed coal-fired generation, increased investment in nuclear power, and stimulation of the gas economy. In addition, Germany is discussing the possibility of extending the life of nuclear power units and allowing shale gas production.

These changes abroad have a significant effect on Ukraine's energy security, but also create new opportunities for Ukrainian energy companies in the European market. Ukraine aims to use its significant capabilities in low-carbon electricity generation and extensive infrastructure for transportation and storage of gas to support the EU in reducing its dependence on energy from external sources.

1.2 Key challenges for the Ukrainian energy sector:

Damage/occupation and risk of further destruction or loss of control

- Not clear how long the war may go on
- Prompt repairs of damages to energy infrastructure
- Geographical imbalance regarding production and consumption of energy (especially thermal) as a result of the fighting
- Increased load on grids in certain regions

Current approach to pricing and financing of the industry

- Energy prices in Ukraine do not include all expenditures in connection with state regulation and PSOs, this will have an additional negative impact in the conditions of the armed aggression and loss of some generation assets
- Nuclear power industry incurs losses due to the imperfect PSO model and a number of regulatory obligations to sell electricity at fixed prices below the market level
- the Nuclear Safety Action Plan and the Nuclear Safety Decommissioning Foundation are underfunded; there is shortage of funds for handling spent nuclear fuel and radioactive waste
- changes in the legislation that regulates how the sector works, due to the imposed martial law, are unpredictable, which makes long-term planning a challenge

Difficulty in attracting financial resources and non-payments

- limited financial resources of the state budget and Ukrainian companies
- rising cost of capital
- the problem of accumulating arrears and decreased ability to pay of consumers
- an outstanding issue of repaying debts in Ukraine's wholesale electricity market

Dependence of the power system on coal-fired generation

- flexible thermal generation is critical for the balance of the Ukrainian power system.
- a large portion of TPPs and CHPs have worn-out and obsolete plant (83% of TPPs and CHPs have been in operation for more than 200 thousand hours).
- due to low environmental indicators, primarily, of these assets, Ukraine is among the top 15 countries in the world in terms of SO2 emissions, and accounts for almost 75% of PM10 emissions in Europe.

Technological, technical and resource limitations

- stopping oil and oil imports from aggressor countries and blocked sea routes make it necessary to switch to supplies from other sources, which requires time and resources to expand logistics bottlenecks

- there is no possibility of resuming oil and gas exploration and production fast, due to the significant number of landmines on the territories
- Reduced gas and oil transit, which increases the unit cost
- significant wear of long-term use of electricity and gas distribution networks
- more than 75% exhausted gas deposits.
- new fields are difficult to develop due to significant depth of deposits and complicated geology; access to offshore fields is blocked
- integration of a large number of RES into the energy system, the need for balancing using peak capacities and energy storage systems
- unexplored Ukraine's full infrastructure potential to transport green hydrogen to the EU
- shortage of qualified personnel in the industry
- existing capabilities of energy enterprises and research centers in oil and gas production are not adequate to the challenges facing the industry

1.3 Key opportunities for Ukraine's energy sector

Integration with energy systems of the EU countries

- The possibility of using the underground gas storage system by European companies
- Accelerated integration of the energy sector into European markets and use of the export potential of the electric power industry
- Significant scientific potential in nuclear energy and the possibility of providing scientific services to other countries

Decarbonization

- A significant share of renewable and carbon-neutral energy sources
- The potential for further development of renewable energy sources, with a multiplier effect on the economy by involving the national machine building industry in the production of equipment for renewable generation facilities
- Considerable potential for the development of offshore wind energy in the Black Sea, provided security risks are resolved
- The potential to create a hydrogen ecosystem – from production to storage and transportation of hydrogen produced from renewable energy sources
- Replacement of natural gas with sustainable bioenergy, waste heat and low-potential energy of the external environment
- Developed regulatory framework for further large-scale development of distributed generation based on renewable energy sources
- Replacement of petroleum products with synthetic fuel

Optimizing the energy mix and balancing the power system

- Optimizing the energy mix, taking into account decarbonization and cost minimization
- Powerful nuclear generation with the potential for development and the creation of a multiplier effect on the economy
- The possibility of balancing the energy system through the construction of hybrid RES stations and the development of distributed generation

- Additional opportunities for balancing energy networks in the case of using cogeneration plants based on sustainable bio energy, waste heat and low-potential energy of the external environment
- A significant resource base of the main types of energy resources with the potential to increase, especially in the oil and gas industry and nuclear energy
- Possibility of creating an incomplete fuel cycle (excepting enrichment) in nuclear energy
- Possibility of creating a full production cycle of energy storage systems (due to significant lithium deposits)
- Possibility of production and export of hydrogen

Energy efficiency

- Incentives to domestic enterprises to promote efficient use of energy and production of energy-efficient equipment, metering of energy
- Implementation and provision of continuous improvement of the energy management system at the state and municipal level, as well as at enterprises, in particular in accordance with the requirements of standards and international agreements.
- Stimulating the use of eco-transport (increasing the number of high-speed e-charging stations, increasing the use of biofuel in transport) and ensuring electrification for the development of the use of electric transport at both the national and regional levels, including urban transport.

Other

- Bankable investment projects
- Potential for further privatization and increased competition in the industry
- Possibility of attracting foreign expertise, technologies and financing for exploration and development of difficult-to-recover and offshore hydrocarbons

1.4 Key assumptions / framework of the plan

Security assumptions

- The calculations regarding the medium- and long-term development of the energy system given in this plan are based on data and forecasts that were relevant for the controlled territories as of February 23, 2022.
- Short-term forecasts, as well as demand estimates, consider the existing damage to energy facilities and large industrial consumers, as well as the current situation at the frontline as of the end of June 2022.
- Significant changes in these indicators are possible and may materially affect the given calculations. In case of significant changes, the plan will be revised accordingly.

In addition, this plan is designed with consideration of the following framework assumptions in mind:

- European integration is a strategic priority for the development of Ukraine and its energy industry
- The restoration and modernization of the energy industry will require significant funding, and Ukraine will create favorable conditions for attracting investment
- Ukrainian consumers should be provided with reliable access to energy resources, and vulnerable consumers should be protected from energy poverty

- Ukrainian energy industry should ensure the rapid recovery and development of the existing economy and creation of the new economy
- Ukraine refuses to import any energy resources and components from the russian federation and seeks to increase the use of domestic resources

Accordingly, priority is given to initiatives which:

- speed up Ukraine's European integration and the fulfillment of requirements as a candidate for the EU membership
- meet the requirements of the European Green Deal, contribute to the fulfillment of Ukraine's international energy obligations, increase the share of carbon-neutral energy resources in the energy mix
- improve Ukrainian consumers' access to energy resources and facilitate the return of temporarily displaced citizens, including by creating new jobs
- contribute to reducing the demand for energy resources, do not require non-market approaches to pricing and contribute to reducing the need for budget expenditures to support vulnerable consumers
- are bankable, help attract investment, export of goods and services and increase revenues to the state budget
- allow to replace Russian fuel/components and improve security of supply, increase the share of local energy resources in the energy mix and/or reduce dependence on imports

In terms of supplying various types of fuel to the Ukrainian market, as well as other resource restrictions, the following is also taken into account:

- The priority direction is the improvement of power system balancing capabilities (due to the opening of new flexible capacities, energy storage systems, electricity export to the EU market, measures in demand-side management and incentives for demand-side balancing), which paves the way for increasing renewable generation;
- It is expedient from the point of view of energy security to shift the demand from oil products in transport to gas and electricity, as well as in heating from gas to electricity, which should be accompanied with the network retrofit;
- It is expedient to reduce the need for scarce types of energy resources through improved energy efficiency;
- A maximum priority is given to market-based solutions, with the exception of energy security issues (creation of fuel reserves, spare capacity);
- The choice between alternative market solutions and/or the share of each solution is determined based on economic feasibility and speed of implementation.

2 Electricity Sector

This section of the plan uses analytical data prepared by Ukrenergo, national grid operator, as part of the Report on the Assessment of the Compliance (Sufficiency) of Generating Capacities to Cover the Forecast Demand for Electric Energy and Ensure the Necessary Reserve in 2021. The report is based on data on energy facilities in controlled territories as of the full-scale invasion.

As of the end of June 2022, Zaporizhzhia NPP and TPP, Kakhovka HPP and Kherson TPP are occupied by Russian invaders. In addition, the Luhansk and Kryvorizka TPPs, as well as Severodonetsk, Okhtyrska, Kremenchuk and Chernihiv TPPs suffered significant damage.

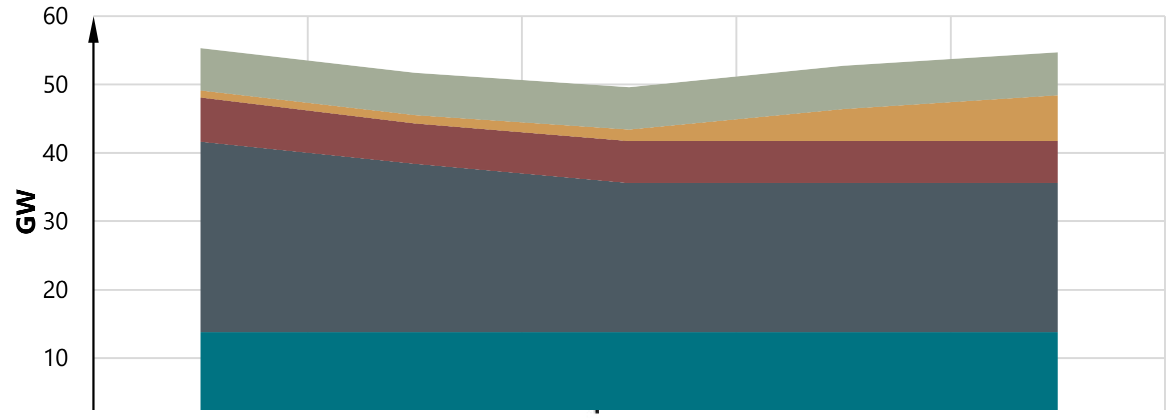
The plan for recovery and development of the energy sector will be regularly updated taking into account the current security situation.

2.1 Analysis of the state of generating capacities of the IPS of Ukraine

Generating capacities in the IPS of Ukraine

Total installed capacity of power plants in the IPS of Ukraine) as of 31.12.2021 (excluding energy generating units of the Crimean power system and temporarily uncontrolled territories of Donetsk and Luhansk regions) is 56.247 GW, of which 49.7% is taken by thermal power plants (in particular, TPPs, CHPs, modular plants), 24.6% – by nuclear power plants, 11.2% – by hydropower and pumped storage power plants, 14.5% – by power plants running on renewable energy sources – WPPs, SPPs, BioPPs.

Dynamics of the installed capacity mix of power plants in the IPS of Ukraine*



	2016	2017	2018	2019	2020	2021
HPP/PSP	6,2	6,2	6,2	6,3	6,3	6,3
RES	1	1,2	1,7	4,7	6,7	8,1
CHP	6,5	5,9	6,1	6,1	6,1	6,1
TPP GC	24,6	24,6	21,8	21,8	21,8	21,8
NPP	13,8	13,8	13,8	13,8	13,8	13,8
Total	52,1	51,7	49,6	52,7	54,7	56,2

*Note. *Excluding TNCT of AR of Crimea, Donetsk and Luhansk regions*

Major generating capacities of the IPS of Ukraine (as of 31.12.2021) are concentrated at:

- four nuclear power plants (15 power units, of which 13 units with capacity of 1,000 MW and 2 units with capacity of 415 MW and 420 MW, respectively);
- 10 hydro power plants on the Dnieper, Dniester and Pivdennyi Buh Rivers, as well as on the Tereblia and Rika Rivers (Tereble-Ritska hydropower plant) with the total installed capacity of about 4,729.5 MW, a total number of 101 units. As well as 3 pumped storage plants having the capacity of 1,487.8 MW and including 11 units (with unit capacity ranging from 33 MW to 324 MW);
- 12 TPPs with units having the unit capacity of 150, 200, 300 and 800 MW (75 power units, including: 150 MW – 6 units, 200 MW – 31 units, 300 MW – 32 units, 800 MW – 6 units) and 3 turbogenerators, as well as 3 large CHPs with 100 (120) MW – 4 units, and 250 (300) MW – 5 units;
- RES plants (including power plants running on bio fuels) with total capacity of 8,148 MW, including the largest in terms of installed capacity Syvaska WPP (245.7 MW but for a number of reasons its actual capacity is much lower), Pokrovska SPP (240 MW), Solar Pharm-1 (200 MW), Botievska WPP phases 1-65 (199,875 MW), Myrnenska WPP phases 1–6 (163 MW), as well as a number of power plants with lower capacity.

Nuclear power

Most NPP power units are equipped with WWER-1000 series reactors (Model B-320), which are similar in technical characteristics to foreign PWR reactors. As of the end of 2021, 12 power units have already used up their 30-year design life, the service life of 11 of them has already been extended for another 10–20 years, with a decision pending about extending the service life of one more power unit. The standard service life of 3 more nuclear power units will expire (ZNPP-6 in 2026, RNPP-4 and KhNPP-2 in 2035) in the medium term.

Service life of NPPs in Ukraine

Power plant	Unit No.	Capacity, MW	Type of reactor unit	Date of commissioning	Expiry date of design service life	Status of unit service life extension
Rivnenska NPP	1	420	B-213	22.12.1980	22.12.2010	Extended to 22.12.2030
	2	415	B-213	22.12.1981	22.12.2011	Extended to 22.12.2031
	3	1,000	B-320	21.12.1986	11.12.2017	Extended to 11.12.2037
	4	1,000	B-320	10.10.2004	07.06.2035	Planned
Yuzhno-Ukrainska NPP	1	1,000	B-302	31.12.1982	02.12.2013	Extended to 02.12.2023
	2	1,000	B-338	09.01.1985	12.05.2015	Extended to 31.12.2025
	3	1,000	B-320	20.09.1989	10.02.2020	Extended to 10.02.2030
Zaporizka NPP	1	1,000	B-320	10.12.1984	23.12.2015	Extended to 23.12.2025
	2	1,000	B-320	22.07.1985	19.02.2016	Extended to 19.02.2026
	3	1,000	B-320	10.12.1986	05.03.2017	Extended to 05.03.2027
	4	1,000	B-320	18.12.1987	04.04.2018	Extended to 04.04.2028
	5	1,000	B-320	14.08.1989	27.05.2020	Extended to 27.05.2030
	6	1,000	B-320	19.10.1995	21.10.2026	Planned
Khmelnytska NPP	1	1,000	B-320	22.12.1987	13.12.2018	Extended to 13.12.2028
	2	1,000	B-320	07.08.2004	07.09.2035	Planned

One of the priority tasks of the NPP operator—NNEGC Energoatom—is to extend the service life of existing power units. The extra service life of NPP units extended by the current licenses issued by the Regulating Agency is from 10 to 20 years and is determined in each case individually based on results of safety reassessment.

Hydro power

Hydropower plays an extremely important role in the functioning of the Ukrainian power system, as HPPs and PSPs are in fact the only source of its peaking capacity, besides, pumped storage power plants make a significant contribution to smoothing the night "gaps" of electricity consumption.

The largest hydropower generating company in Ukraine is PJSC Ukrhydroenergo. The company consists of nine power plants on the Dnieper River – Kyivska HPP (440 MW), Kanivska HPP (500 MW), Kremenchutska HPP (687.4 MW), Seredniodniprovska HPP (388 MW), Dniprovska HPP (1,563.1 MW), Kakhovska HPP (343.2 MW), Kyivska PSP (213.8 MW) and on the Dniester River – Dnistrovska HPP (702 MW) and Dnistrovska PSP (1,296 MW), the first (972 MW) and second (324 MW) phases of which have been commissioned and the third (972 MW) phase is planned for commissioning. Also the IPS of Ukraine includes Tashlytska PSP (302 MW, operated by NNEGC Energoatom). This power plant is under construction (it is expected that the second phase consisting of the third power unit having the capacity of 151 MW will be completed, and the power plant total capacity will reach 906 MW) and belongs to the South-Ukrainian power complex. Other HPPs operating as part of the IPS of Ukraine have a total installed capacity of 193 MW.

Thermal power

The technological basis of generating capacities in thermal power is formed by pulverized coal power units of critical steam parameters (13 Mpa, 545 °C) with a capacity of 150–200 MW and pulverized coal and gas-oil power units of supercritical parameters (24 Mpa, 545 °C) with a capacity of 300 MW and 800 MW at condensing power plants. Most power plants with 150 MW power units were built and put into operation in 1959–1964, units with capacity 200 MW – in 1960–1975, units with capacity 300 MW – in 1963–1988, and units with capacity 800 MW – in 1967–1977.

As of 31.12.2021, TPPs include 75 power units with a total installed capacity of 21,562 MW, of which (see retrospective dynamics of development of generating capacities of Ukraine's TPPs):

68 coal-fired units with a capacity of 16,962 MW, including: 6 mothballed units and 1 unit under reconstruction (below is a breakdown taking into account the conversion of units to GD-brend coal):

23 units firing A-brend and P-brend coal with a capacity of 6,439 MW (5 units with a capacity of 1,280 MW are mothballed);

45 units operating on GD-brend coal with a capacity of 10,523 MW (4 units with a capacity of 935 MW are mothballed);

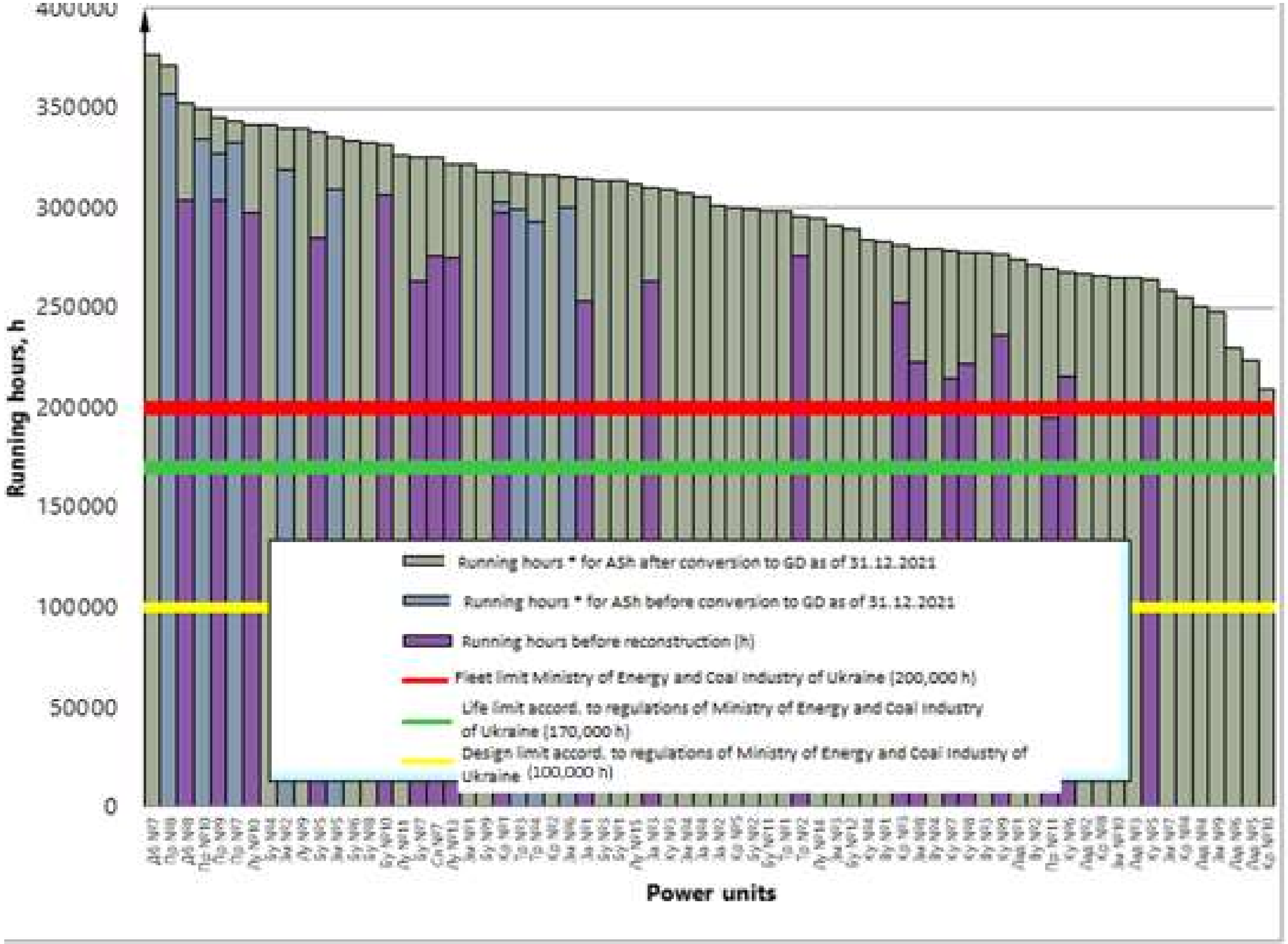
7 gas-oil units with a capacity of 4,600 MW (1 unit of 800 MW is mothballed).

Over the last four years, gas-oil power plants have not been engaged in operation in the IPS of Ukraine (except for one unit of 300 MW at Trypilska TPP).

As of late 2021, about 20% of thermal power plants have been reconstructed, but the issue of bringing their environmental characteristics to modern requirements remains unresolved, and flexibility characteristics though slightly improved still remain inadequate for the current needs of the IPS of Ukraine. The absence of defined financing mechanisms for sustainable modernization set out by the NERP will in the short term lead to a significant reduction in the available capacity of TPPs.

The remainning units are maintained in working condition due to overhauls and current repairs, but their wear is constantly increasing and reaches the threatening limit in terms of the possibility of their further operation without reconstruction.

Running hours of TPP units in Ukraine (as of 31.12.2021)



CHP and cogeneration units

Ukraine's modular CHPs are represented by three power plants (Kyivska CHP-5, Kyivska CHP-6 and Kharkivska CHP-5), which are equipped with power units with cogeneration turbines T-100/120-130, T-110/120-130 and T-250/300-240 with a total capacity of 1,670 MW in the heating mode and 1,980 MW in the condensing mode.

The share of installed capacity of CHPs, 6,070 MW, is significant in Ukraine and most of it comes from CHPs running on natural gas.

Largest CHPs and cogeneration units in the IPS of Ukraine

CHPs and cogeneration units	Type of fuel	Installed capacity*, MW
Kyivska CHP-5	Natural gas	700
Kyivska CHP-6	Natural gas	500
Kharkivska CHP-5	Natural gas	470
Myronivska TPP	Coal ranks Ash and P / G and D	275
Severodonetska CHP	Natural gas	260
Kremenchutska CHP	Natural gas	255
Chernihivska CHP	Coal ranks Ash and P/ Natural gas	210
Cherkaska CHP	Coal ranks G and D/ Natural gas	200
Kaluska CHP	Coal ranks G and D/ Natural gas	200
Darnytska CHP	Coal ranks Ash and P/ Natural gas	160
Kharkivska CHP-2 (ESHAR)	Coal ranks Ash and P/ Natural gas	150
Kramatorska CHP	Coal ranks Ash and P/ Natural gas	150
Bilotserkivska CHP	Natural gas	120
Shostkinska CHP	Natural gas	115
Khersonska CHP	Natural gas	80
Odeska CHP	Natural gas	68
Kharkivska CHP-3	Natural gas	62
Dniprovska CHP	Natural gas	61.6
Novorozdilska CHP	Natural gas	44
Novoyarivska CHP	Natural gas	42.69
Lvivska CHP-1	Natural gas	41.3
Sumska CHP	Coal ranks Ash and P/ Natural gas	40
Mykolayivska CHP	Natural gas	40
Kirovohradska CHP	Natural gas	15
Okhtyrkska CHP	Natural gas	12.75
Lokachi GTI	Natural gas	8.8
CHP of Uman Greenhouse Plant	Natural gas	6
CHP of Cherkasyteplokomunenergo	Natural gas	5.32
CHP of Pervukhinsky Sugar Factory	Natural gas	5

**as of 23 February 2022*

Most CHPs have physically worn out and obsolete equipment. Due to the loss of heat loads, in many cases CHP electricity output is not optimal in terms of the actual needs of consumers in thermal energy, which leads to high fuel costs for the production of electrical and thermal energy in the cogeneration mode.

Renewable energy sources (RES)

In recent years, trends in the development of renewable energy are going upward (the peak of investment in the construction of renewable energy facilities fell on 2019). According to available information, the capacity of power facilities that use renewable energy sources for electricity production in 2019 reached 4,722 GW. During 2020, renewable energy facilities with a capacity of 1.95 GW were additionally put into operation, and in 2021 – another 1.45 GW. However, because of quarantine restrictions due to the spread of COVID-19 pandemic and for a number of economic reasons, not all facilities scheduled for commissioning during the year were put into operation. As expected, renewable energy facilities with a total capacity of about 1.54 GW or more will be additionally put into operation in 2022.

The development of renewable energy shows a stable upward trend. In recent years, there has been a steady increase in the number of commissioned renewable energy facilities. This dynamics of renewable energy development leads to an increase in the forecast electricity output in the IPS of Ukraine from renewable energy sources (in 2019, electricity generation from RES in the overall production mix reached 3.6% or 5.5 billion kWh, and the overall export of electricity to countries of Eastern Europe from the IPS of Ukraine in 2019 made up close to 5.8 billion kWh; in 2020 generation reached 10.1 billion kWh or 6.8%, in 2021 – 12.5 billion kWh or 8%, and it is expected that in 2022 generation will reach about 14 billion kWh, which will make at least 9% of the total electricity output by all power plants in the IPS of Ukraine).

The steadily growing number of renewable energy facilities aggravates the price burden on Ukraine's electricity consumers, as well as exacerbates the problem of ensuring the operational security of Ukraine's IPS.

Dynamics of commissioning of RES generating capacities

RES technology	RES growth compared to the previous year for the period 2016-2021, MW					
	Years					
	2016	2017	2016	2019	2016	2021
WPP	10.9	WPP	10.9	WPP	10.9	WPP
SPP	98.9	SPP	98.9	SPP	98.9	SPP
BioPP	10.2	BioPP	10.2	BioPP	10.2	BioPP
Micro-, mini- and small HPP	n/a	Micro-, mini- and small HPP	n/a	Micro-, mini- and small HPP	n/a	Micro-, mini- and small HPP

As of 31.12.2021, the installed capacity of RES plants in the IPS of Ukraine, which are directly connected to the grid and deliver electricity, is [50]:

- WPP – 1,529 MW;
- SPPs– 6,365.3 MW (including 1,205.3 MW of household SPP);
- BioPP – 254.2 MW;

Micro-, mini- and small HPP – 192.9 MW.

2.2 Analysis of operating modes of generating capacities in the IPS of Ukraine

The electricity production mix during 2016–2021 underwent significant changes.

Electricity production mix and volumes in the IPS of Ukraine* in 2016–2021, billion kWh

Year	Total	NPP	%	TPP	%	CHP and modular plants	%	HPP and PSP	%	WPP, SPP and BioPP	%
2016	154.8	80.9	52.3	49.9	32.2	13.3	8.6	9.1	5.9	1.5	1
2017	155.4	85.6	55.1	45	29	12.4	8	10.6	6.8	1.9	1.2
2018	159.3	84.4	53	47.8	30	12.5	7.8	12	7.5	2.6	1.6
2019	153.96	83	53.9	44.9	29.2	12.6	8.2	7.9	5.1	5.5	3.6
2020	148.85	76.2	51.2	39.6	26.6	14.6	9.8	7.6	5.1	10.9	7.3
2021	156.6	86.2	55.0	37.2	23.8	8.6	5.5	10.45	6.7	12.5	8.0

*Note. *Excluding TNCT of AR of Crimea, Donetsk and Luhansk regions.*

This production mix is predicated on the specifics of generating capacities of Ukraine's energy sector, which is overloaded with baseload capacities (NPPs and most of the thermal generation units) and characterized by an acute shortage of flexible capacities.

As a result, TPP power units designed for operation in baseload modes are used instead for flexibility, and many of them operate in non-design peaking and load following modes.

Under such conditions, the main capacities for load coverage are coal fired TPP units of 150–200–300 MW. Due to the unfavourable capacity structure (low specific weight of flexible capacity, limited regulation range of TPP), the power system practices daily stops of 7–10 units for the period of night offpeaks with their subsequent starts for morning peaks, stops in the daytime zone (to compensate for the increased production by SPPs) and starts during evening peaks. Such modes lead to additional exhaustion of equipment service life, more accidents and higher fuel consumption, which directly affects the adequacy of generating capacities, as well as the increase in fixed and variable costs and, consequently, a higher price bid.

Taking into account the above factors, as well as the base mode of HPPs during floods, more and more TPP units are engaged in daily stops/starts during the spring/summer season.

The total number of starts/stops of TPP power units (unit groups) of 150–300 MW remains at a fairly high level, and for 12 months in 2017 amounted to 1,943, for 12 months in 2018 – 2,255, for 12 months in 2019 – 2,478, for 12 months in 2020 – 2,622, and in 2021 – 2,900 [50].

It should be noted separately that following the events of 2014, when nearly all Ukrainian coalmines that supplied anthracite and lean coal (A-brend and P-brend) ended up in TNCTs, the country's energy sector faced a new problem — a permanent shortage of coal of these brends. To reduce dependence on coal imports, the generating companies converted TPP units running on anthracite coal to gas/steam coal (10 units having a total capacity of 2,060 MW were converted in 2016–2019).

For this reason the use of anthracite coal has decreased significantly in Ukraine over the last years: from 9.2 million tons in 2016 to 1.62 million tons in 2021 (for information: 4.9 million tons in 2017, 4.1 million tons in 2018, 3.4 million tons in 2019, 3.0 million tons in 2020) and was replaced with domestic coal of gas/steam coal. Power units running on coal of G and D brends managed though to maintain fairly high levels of their available operating capacity to cover the electricity load of Ukraine's IPS.

At the same time, the costs borne by TPPs to keep their power units operational are increasing, given further worsening of their operating conditions. In such circumstances, of special importance for TPPs are repairs aimed at retrofitting (improvement) of technical and economic performance of their power units compared to the actual values.

During 2021, as in some preceding years, NPPs experienced balancing curtailments, which caused the reduction of NPP capacities in the daily ELC coverage. Such curtailments were stemming, in particular, from the post-effects of the spread of the COVID-19 pandemic, which caused a reduction in electricity consumption and, as a consequence, other technologies of electricity production forced out certain share of nuclear energy from the daily curve. It all points to the need to engage NPP units to the weekly and daily load control, which in turn would increase the flexibility of the entire power system but requires in-depth studies, tests and modernization, if such option proves to be viable.

Analysis of operating modes of domestic CHPs shows that due to heat load loss most of them have a very low ICUF, which on average in Ukraine in recent years has not exceeded 24% (and shows the downward trend), and maximum capacity during the period of maximum electricity production does not exceed 50% of the installed capacity.

At the same time, electricity produced even by the most efficient gas fired CHPs operating on steam parameters of 13 Mpa and 24 Mpa, given the high cost of natural gas, is uncompetitive relative to electricity produced by TPPs, the same applies to electricity produced by coal fired CHPs with steam parameters of 9 Mpa and less.

Thus, domestic CHPs should be considered primarily as a source of thermal energy, as there is no other alternative to cover heat loads, especially in periods of very low temperatures, when their power output to cover electric load curves can reach 3 GW.

The most mobile peaking producers of electricity are HPPs and PSPs. However, their installed capacity is not covered by hydro resources to control daily load curves to the full extent, especially in recent low-water years. In particular, electricity generation by HPPs in 2020 was the lowest across the study horizon, nevertheless, in 2021, HPP generation returned to the normal average level compared to recent years. This being said, weather conditions in autumn and winter are characterised by abnormally high temperatures and low precipitation affecting the availability of hydro resources and operating modes of HPPs (as observed in late 2019 – early 2020). In addition, the constraints of the existing grid infrastructure affect the normal operation of Dnistrovska PSP (operation of power units in the pumping mode). Constraints are also present in the operation of Tashlytska PSP, which can operate at the downstream water levels of 15.50–16.50 m and upstream water levels of 92–101.50 m in turbine mode with one power unit only for 3 hours 33 minutes or with two power units for 1 hour 47 minutes. And in the pumping mode with one power unit – up to 3 hours 51 minutes or with two power units for 1 hour 56 minutes.

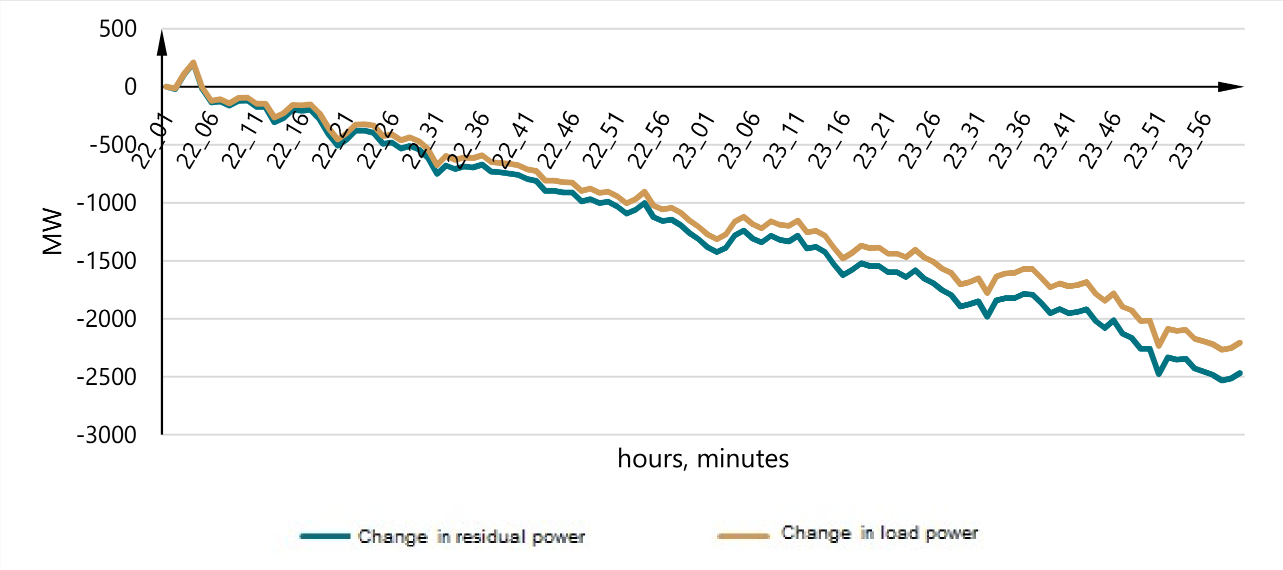
When the downstream water level drops from 15.5 m to 14.5 m (the main factor is the dry microclimate in the vicinity of the basin of the Pivdennyi Buh River) the duration of Tashlytska PSP operation in the pumping and turbine mode will drop by 20%. Operating conditions of the Tashlytska PSP are also affected by upstream water conditions, when at water levels of 93–94.5 m it is partially prohibited to start power units in turbine mode (not more than once a week), and at 94.5-110.5 m it is prohibited to start power units in the pump mode too.

Commissioning the third power unit at Tashlytska PSP under the above listed conditions, indicators and constraints caused by downstream and upstream water levels (there are no new projects presented to increase them) de facto has no influence on the operating modes of the power system.

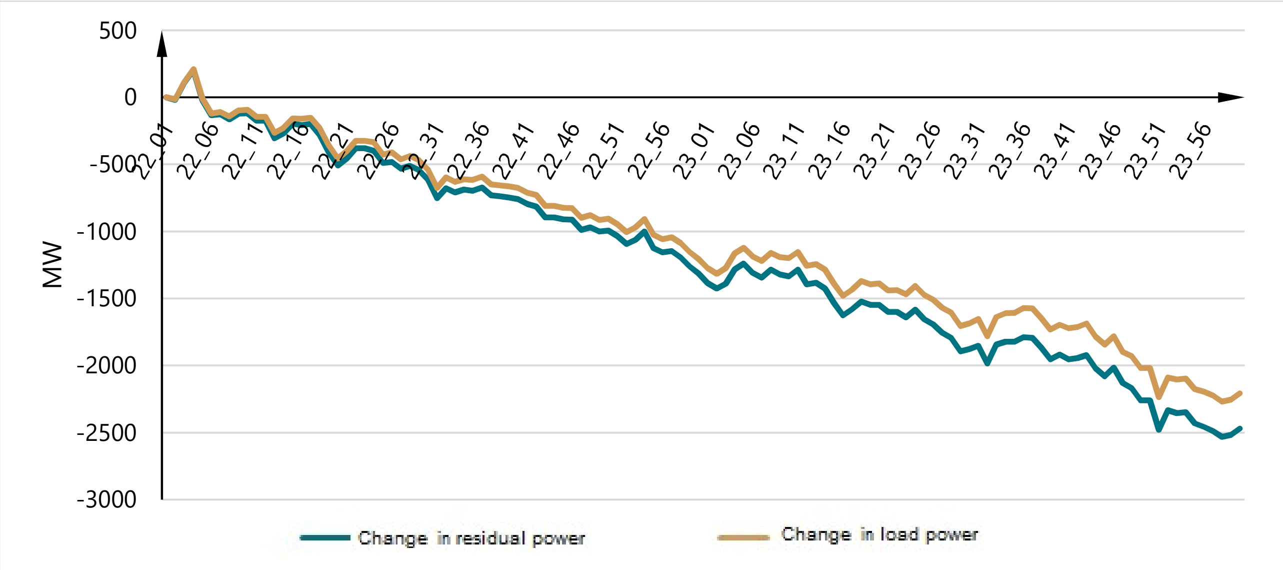
Under such conditions the third power unit will be used as a backup unit when the first and second power units are under repair, which is factored in this Report.

With the start of the new electricity market, the new model practically all the time is experiencing significant discrepancies between trading schedules and physical units commitment schedules (which has almost never happened in the previous model) affecting most the operating modes of HPPs and PSPs. In addition, the operation of most PSPs is focused mainly on the segment of the balancing market. Accordingly, there are more dispatch instructions for HPPs and PSPs to change capacity in order to maintain balance in the power system. At the same time, HPPs continue to participate in automatic and manual load and frequency control, as well as in voltage and reactive power control, ensuring balancing of the IPS of Ukraine, including to compensate for imbalances created by IPPs - Intermittent Power Plant.

Change in the load of consumers excluding the impact of IPP necessitating the change of conventional generation capacity, and including such impact (data for the hour from 16:00 to 17:00 on 16.08.2020)

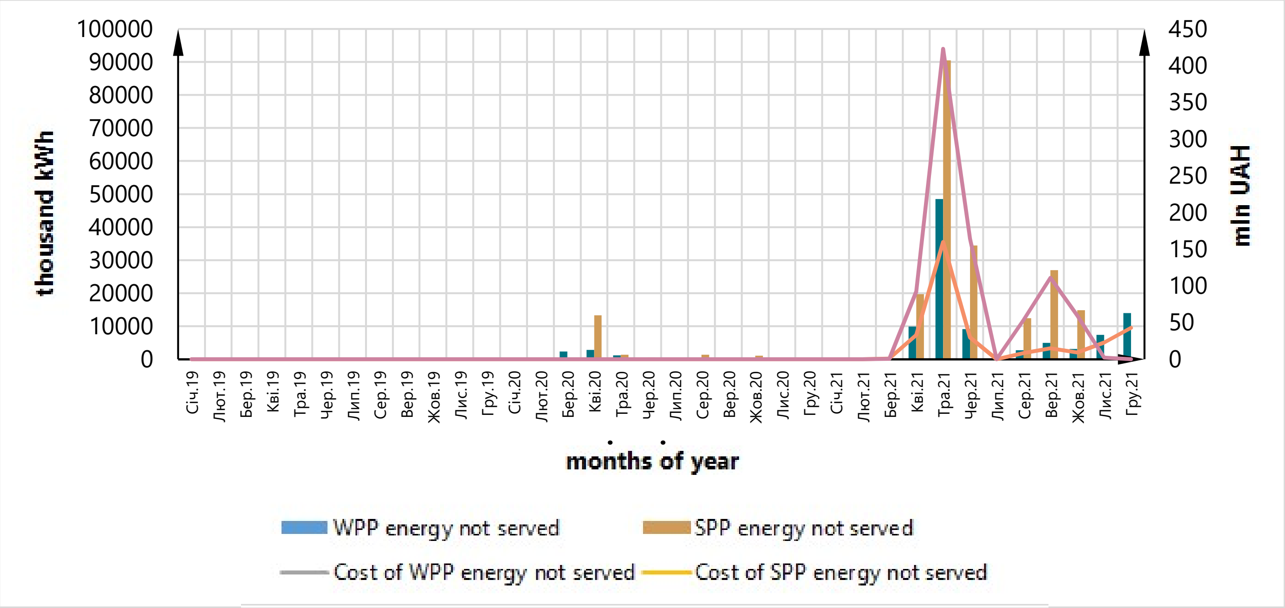


Change in the load of consumers excluding the impact of IPP necessitating the change of conventional generation capacity, and including such impact (data for the hour from 22:00 to 23:00 on 16.08.2020)



Per instructions of NPC Ukrenergo's dispatchers (mainly in periods when generating units running on RES are provided with primary energy sources to the fullest extent), after all balancing options have been exhausted, in 2021 (see Figure 3.7) there were 90 curtailments on RES generation (having the capacity from 365 to 2,385 MW), while in 2020 and 2019 there were 20 curtailments (212 MW to 1,656 MW) and only two curtailments (250–300 MW), respectively. In the coming years, until shortages of flexibility and/or demand-side management are resolved, this tendency will continue.

Dynamics of volumes and cost of curtailments on RES generation in 2019–2021



Analysis of operating modes of the generating capacities indicates that the power system has insufficient level of generating capacities to cover its own peak loads, as a major part of generating capacities cannot be used for intended purposes. For example, during the period of peak loads (based on the results of statistical observations):

- 1-1.5 GW of coal fired generation capacities are unavailable due to scheduled repairs/maintenances;
- 3.5-4 GW of NPP capacities are unavailable due to scheduled repairs/maintenances;
- about 1 GW (and in some periods up to 3 GW) of coal fired generation capacities are unavailable due to unscheduled emergency repairs/outages;
- 2.2 GW of coal fired generation capacities are unavailable because the units are mothballed (pending decommissioning);
- 4.6 GW of gas-oil TPP units are unavailable due to the shortage and/or high cost of natural gas, and power units with a unit capacity of 800 MW have not been put in operation for more than 9 years and have no personnel;
- 3.1-3.6 GW of CHP capacities are unavailable due to lacking heat load;
- a number of capacities at HPPs and RES are unavailable due to the absence of sufficient volumes of primary energy sources (in particular, water resources);
- 2-2.5 GW of coal fired generation capacities are unavailable due to unsatisfactory fuel supply, which has a cyclic nature (which, obviously, requires a change in the fuel accumulation algorithm and enhancing the responsibility for not ensuring the guaranteed coal reserve).

For these reasons, the available operating installed capacity in the IPS of Ukraine is close to the maximum of electric load in the power system, while over the last 5 years in the periods of maximum load:

1) TPP capacity has not exceeded 7.2 GW (at the installed capacity of 21,842 GW at the end of 2021);

2) NPP capacity has rarely reached 12.6 GW and never exceeded it (at the installed capacity of 13,835 GW at the end of 2021);
3) HPP capacity has not exceeded 3.3 GW and is mostly short-term (at the installed capacity of 4,83 GW at the end of 2021);
4) SPP and WPP capacity sometimes dropped to 0 MW and occasionally reached 4.5 GW (at the installed capacity of 8.15 GW at the end of 2021);
5) capacity of CHP and other cogeneration units has not exceed 2.9 GW (at the installed capacity of 6.1 GW at the end of 2021).

A contingency at electricity generation facilities would be threatening to the security of supply during periods when the available operating capacity in the IPS of Ukraine is close to maximum electrical load, which can be avoided, first of all, by maintaining fuel reserves in the required volume because many thermal generating units (TPP)—which could have compensated for the loss of the operating capacity caused by such a contingency—are unavailable due to inadequate fuel supply.

As illustrated by results of the analysis of the state of generating capacities in Ukraine and their operating conditions, the IPS of Ukraine can be characterized as a system, which technically has adequate level of generating capacities (compared to the total load in the power system) but at the same is inflexible (i.e., characterized as a system in shortage of flexible capacities). The prerequisites for such a situation are as follows:

1) many capacities for a variety of reasons are not available during peak load periods;
2) a number of capacities are baseload and not intended for frequent and rapid change of their operating modes;
3) a number of capacities able to change their operating modes (mainly TPPs) have expired fleet resource.

2.3 Demand development scenarios

Demand scenarios in this section have been developed on a number of inputs valid before the full-scale invasion, incl. the territory under control and expected demand from industry and the public sector. The demand forecasts will be revised later, taking into account the incurred damages, economic recovery expectations and the security situation.

Based on the analysis of findings of studies on forecasting the coordinated development of the economy and energy, it was determined that the sustainable economic development with high GDP growth is possible only through the neoprotectionism policy implementation and the energy sector development according to the most effective scenario, which was taken as a basis for SMEE.

At the same time, it reflects the distribution of production as per the theory of globalization of the world economy, which prompted almost all advanced countries to reconsider relocating certain production abroad and manifested itself in the vulnerability of economy during COVID–19 pandemic and in future will only increase competition regarding export opportunities because of return of certain production previously relocated abroad due to the lower cost of production and because of the creation of non-tariff barriers to the possibility of exporting the products that countries can produce themselves, in particular the "tax" on the carbon "footprint" on imports.

So, to achieve the goals set out by the European Green Deal, the Investment Plan provides for attracting at least 1 trillion euros in investment over the next decade, part of which via the Just Transition Mechanism will be allocated to a fair and just "green" transition, which opens up the possibility of attracting at least 100 billion euros of investment in the period from today to the end of 2027 to support workers and residents of the regions most affected by the transition.

The European Green Deal Investment Plan (InvestEU or the Just Transition Fund) also provides individual funding for a wide range of projects, including both small projects (such as improving the energy efficiency of households) and larger ones (such as installing a network of electric car charging stations). Significant funds will also be allocated for the implementation of individual projects of pilot technologies, in particular for the use of surplus "green" energy, development of hydrogen technologies etc.

The scenarios formed for the projected coordinated development of economy and energy are used for the implementation of the "Green Transition" concept in Ukraine. Such scenarios , first of all, envisage economically justified modernization of the domestic economy taking into account its existing potential and the use of targeted refinancing by the National Bank of Ukraine for relevant institutions to support economic development on long-term privileged conditions for large-scale national infrastructure projects (energy, transport, housing and utility services, etc.), as well as programmes for adaptation to climate change, with the priority on participation of domestic producers, and the use of existing industrial potential, creating a system of effective support to mortgaging, support to export-oriented domestic producers, and policies to substitute imports with domestic products.

According to these scenarios SMEE sets out the following main drivers of the economic growth and rising electricity demand in the medium term:

climate change, which causes an increase in electricity consumption for air conditioning and cooling, land reclamation, etc.; utilization of existing production capacities of real sectors of Ukraine's economy through the implementation of targeted state investment programmes for the development of infrastructure sectors of the economy (energy, transport, housing and communal services, etc.), support policy for import substitution, and maximum support for exports; development of automated and robotic productions (in particular, under import substitution projects); development of agro-industrial complex and defence industry; electrification of transport; development of information technologies (in particular DATA-centres).

In the future, with the improvement of the socio-economic situation in the country, major contributors to growing electricity consumption in these scenarios will be:

growth of households income (more household appliances, electric cars, etc.);

accelerated pace of development of the services sector.

Main factors reducing the electricity consumption relative to the current level in this scenario are:

- conducting an active policy to reduce energy intensity and increase energy efficiency in all sectors of the economy through their technological and structural retrofitting;
- formation of appropriate incentives for households in order to implement solutions to minimize and optimize electricity consumption (replacement of household appliances, lighting systems, hot water supply and heating running on electricity with more efficient solutions in terms of electricity consumption);
- minimizing consumption at maximum price levels of the electric load curve, and maximizing consumption at minimum price levels of the electric load curve.

It should be noted that with the existing practice of cross-subsidization and maintaining low prices for households at the expense of other consumers, the households are not motivated to respond to price signals of the electricity market in terms of minimizing and optimizing overall electricity consumption in response to the changing price for electricity.

On the other hand, such payment distribution under conditions of growing prices promotes the implementation of energy saving technologies as well as the introduction of decentralized power supply systems for consumers in real sectors of economy (industrial enterprises, services, etc..), as well as for a certain category of high-income households), which eventually reduces the need for electricity centralized production (for the IPS of Ukraine it is actually a decrease in consumption).

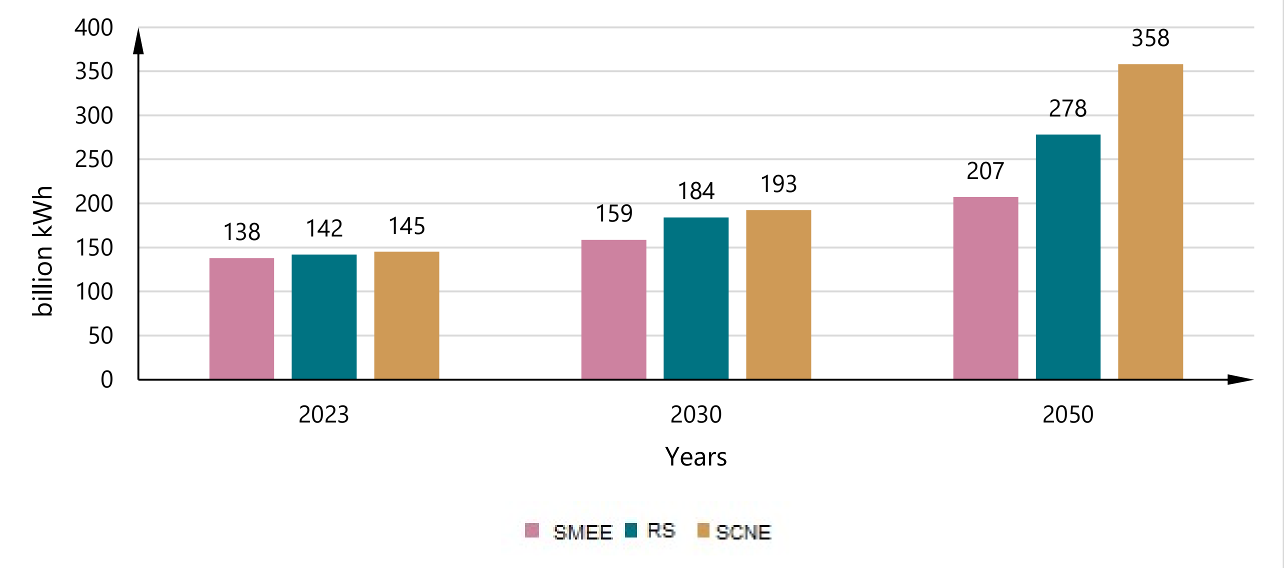
It should also be noted that a higher pace of economic development is accompanied by a higher pace of energy efficiency, which to some extent equalizes the forecast electricity demand.

Also the future demand for electricity is largely affected by its price, which depends on the structure of electricity production and the presence of compensators in the economy in terms of the price impact on the GDP, income of households and the national budget.

The scenarios focused on significant imports of electricity generation technologies, primary energy sources, and technologies ensuring balance reliability and operational security, do not have such compensators, which negatively affects the product demand and services in the domestic market as well as reduces the competitiveness of domestic producers in both domestic and foreign markets. These factors reduce the forecast electricity demand, as they negatively affect the opportunities for economic growth.

Demand under the low-carbon development scenarios is accepted in accordance with the adjusted levels given in the Modelling Report prepared by the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine (hereinafter the IEF Report) under the EBRD project "Support to the Government of Ukraine on updating NDC of Ukraine under the Paris Agreement

Electricity demand forecast in the IPS of Ukraine according to SMEE, RS and SCNE scenarios in 2023, 2030 and 2050



Transformations of daily electric load curves under different strategies of economic development have certain specifics, but all strategies have one common feature: density of the electric load curve is rising due to increasing electricity demand at the minimum price levels of the electric load curve and falling at the maximum price levels of the electric load curve, which is compensated in some way by the demand growth in the services sector and households.

Consumer load peak forecasts according to the scenarios (excluding the capacity of Power to X technologies)

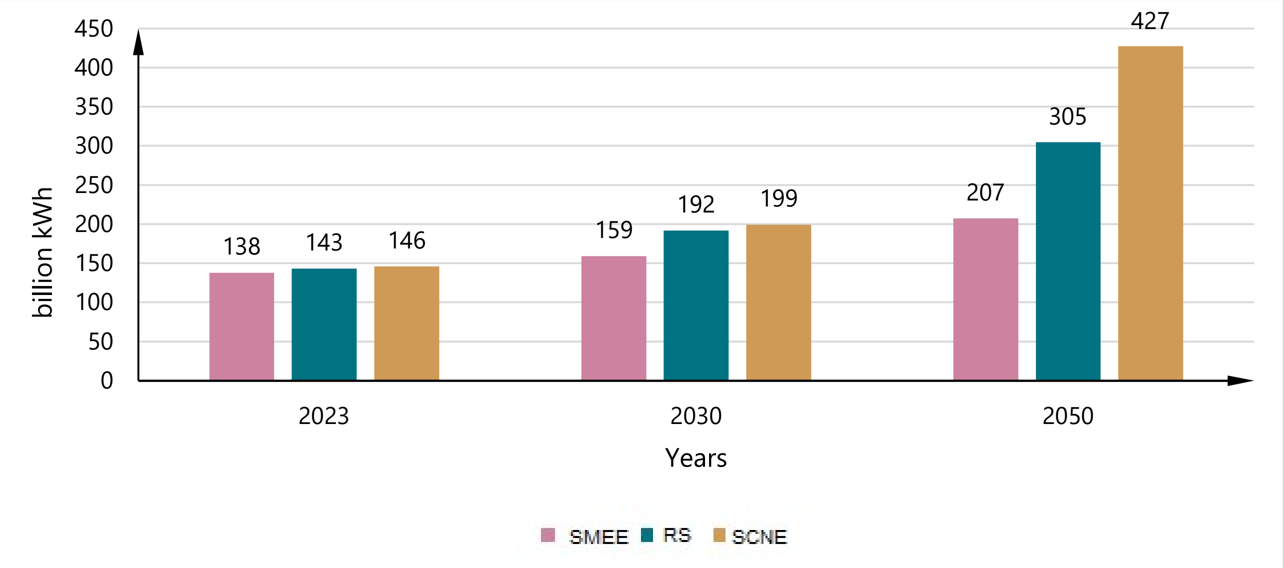
At the same time, one should understand that the growth of IPP capacity to values higher than the demand necessitates the implementation of one of the three options:

1) curtailment of their energy (this possibility is already substantiated at the legislative level);
2) power conversion (occasionally there is a situation it is feasible to use power conversion systems to smooth the electric load curve, i.e. minimise “power fluctuations during a day” within the corresponding electric load curve, and to convert power from the period of its surplus to periods of its shortage);
3) introduction of Power to X technologies for the use of surplus electricity produced by IPPs.

Therefore, if these options are implemented, electricity generation can significantly exceed demand, which is illustrated in detail by the scenarios of low-carbon development.

This is due to the fact that in the preparation of IEF Report the possibility was identified of covering the electricity balances, mainly by power plants operating using RES, primarily WPPs and SPPs, as well as by nuclear power plants operating with high ICUF (85% for existing and at least 90% for new plants). Therefore, based on calculations, the required capacity of WPPs and SPPs is too high due to the fact that they have a low ICUF (36% and 14%, respectively). But this is the ICUF rate averaged for the year, because the profiles of electricity production by wind farms and SPPs, firstly, have very pronounced seasonal features, in particular, the SPP generation in winter is much lower than in summer, and secondly, can vary greatly, even on adjacent days depending on specific weather conditions.

Electricity production forecast according to the scenarios

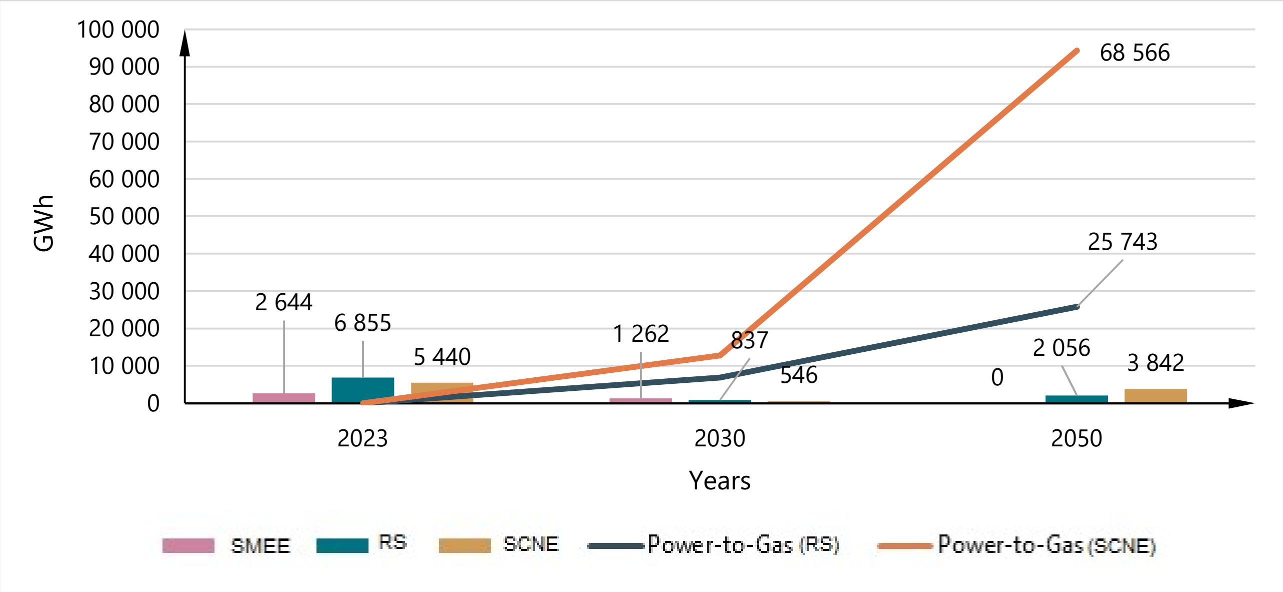


The transition to simulation using power balances to cover daily electric load curves takes into account annual, seasonal, weekly and daily irregularities of electricity consumption, as well as the impact of weather conditions on the possibility of participation of power plants using RES (primarily WPPs and SPPs) in covering the electric load curves.

At high and typical levels of WPP and SPP generation there is a surplus of power at certain levels of electric load curves, but when they reach the installed capacity (the level is comparable to the average maximum load of consumers in daily electric load curves) the surplus will occur at all levels of electric load curves in most days.

This makes it impractical to use Power to Power technologies (technologies such as PSP, Energy Storages and similar), and the only way to eliminate power surpluses is to either curtail RES, or to introduce such technologies as Power to X. Therefore, most of these “surpluses” in these scenarios are used to produce “green” hydrogen, which, according to accepted assumptions, is used to produce electricity.

Calculated volumes of electricity generation by WPPs and SPPs and use of electricity surplus (using Power to Gas technologies) in the scenarios



It should be noted that according to SMEE it will be necessary to curtail WPPs and SPPs because their capacity has increased considerably in recent years, but electricity surpluses in these cases are significantly lower than in RS and SCNE. At the same time, as the simulation results show, the complete elimination of electricity surpluses in RS and SCNE at the level of 2050 in the volumes of 2,056 GWh and 3,842 GWh would not be economically practical because it would necessitate a significant increase in capacities of the technologies of “green” hydrogen production, which will entail their price escalation due to a significant reduction in the ICUF of such technologies.

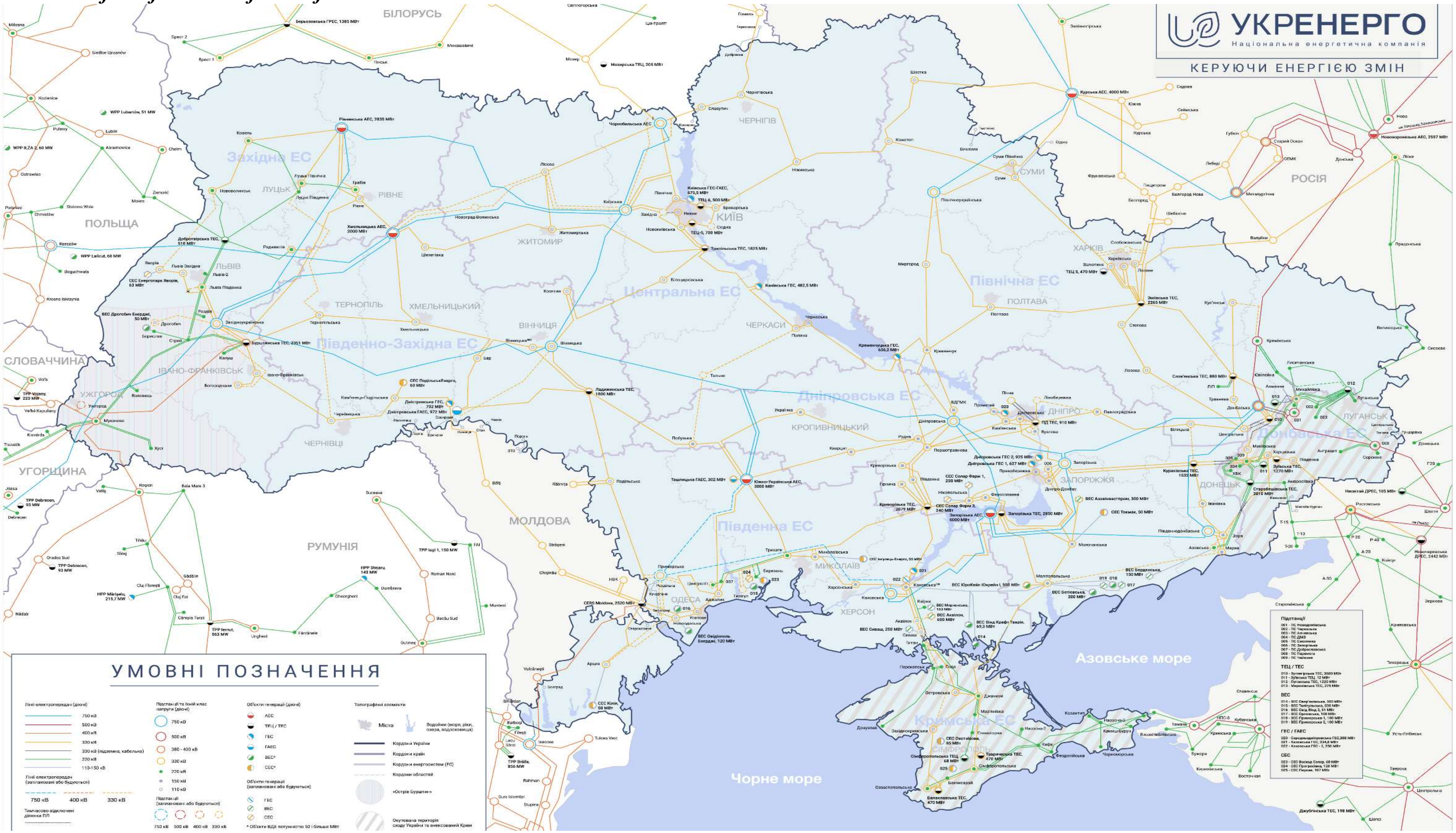
SMEE for the period of 2031–2032 assumes the absence of such surpluses due to the balanced deployment of RES capacities and higher demand.

In RS and SCNE the situation is opposite: surpluses of the capacity are growing. This leads to a situation when with the introduction and operation of Power to X technologies and due to their operation the total maximum capacity of the IPS of Ukraine is shifted to spring, when conditions are most favourable for WPP and SPP but at the same time the electric load curve levels are low.

A specific component of the overall electricity demand is its export. This is the reason why this component is given a lot of attention. Therefore, in accordance with the Transmission Network Development Plan for 2022–2031 approved by the NEURC Resolution (hereinafter TYNDP-UA), this Report sets out the implementation of the following infrastructure projects, which will considerably improve the transfer capacity of domestic and cross-border networks:

- modernization of Mukacheve–Veľké Kapušany (Slovakia) overhead line by retrofitting the existing OHL into a two-circuit line. Construction of a new two-circuit OHL Veľké Kapušany– Mukacheve instead of the existing one-circuit line in the current state of the grid will increase the transit capacity of the 400 kV Mukacheve substation, i.e., the power transfer between countries of Eastern Europe. It is assumed that the 400 kV OHL will be made of AC-400/51 wire and suspension of three wires in phase. As the result, the transfer capacity of each circuit under normal conditions will be 2,500 A;
- construction of the 400 kV “wing” at the 750/400 kV Prymorska substation with a 400 kV Prymorska-Isaccea (Romania) two-circuit line and the installation of a 750/400 kV AT. Implementation of the project will increase the capacity of the interconnector with Romania to 1,000-1,200 MW after 2026.

- *Location of the facilities of IPS of Ukraine*



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2.4 Supply development scenarios

Nuclear energy

The nuclear energy development is perceived in many countries today as an essential element of the decarbonization policy. Ukraine also considers the further development of nuclear generation to be an important component of the Fuel and Energy Balance (FEB) formation without the use of fossil fuel.

Today, SE NNEGC Energoatom has very ambitious plans of own development by 2040:

- extend the service life of existing power units to 60 years for most units, with the only exception that 1 unit with WWER-1000 at YUNPP and 2 units with WWER-400 at RNPP may be decommissioned by 2035;
- build 6 new power units having the total capacity of 6.5 GW (1 unit with WWER-1000 and 5 units with AP-1000 reactor).

The company is also considering the possibility of building new capacities at NPPs with 8 power units (having the total capacity of 12 GW) after 2035.

In view of the above, the upper bound restriction was formed in terms of the development and operation of nuclear energy as illustrated in Table 4.8.

The nuclear energy in Ukraine can maintain its position in the electricity market of Ukraine by extending the service life of existing power units and building new power units in the mid-term.

As of today, SE NNEGC Energoatom expects to extend the service life of existing power units at NPPs. Given the possible terms of the service life extension of the power units, this Report reviews two options: the term of 20 years and the term of 25–30 years (considering the experience gained in extending the term of operation).

The mid-term plans (by 2032) include the completion of construction of two power units at Khmelnytska NPP (with WWER-100 reactor at KhNPP Unit 3 and AP-1000 reactor at KhNPP Unit 4).

Given the above, the nuclear energy development was considered under two scenarios:

- optimistic scenario of nuclear energy development assuming that the service life of existing power units will be extended and new power units will be built;
- pessimistic scenario assuming that the service life of existing power units will be extended once they exhaust their extended service life.

In studies on the formation of coordinated forecasts of economy and energy development, the optimistic scenario forms the upper limit of the nuclear energy development and the pessimistic scenario forms the lower limit.

Development options of NPP generating capacities according to the scenarios, GW

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic	13.8	13.8	13.8	13.8	13.8	13.8
Optimistic	13.8	13.8	≥14.8	≥17	≥20.3	≥20.3
- new capacities*	0	0	≥ 1	≥ 3.2	≥ 6.5	not limited

*Note. * Cumulatively for the period starting from 2023.*

Large hydropower

Hydropower plays a key role today in the context of ensuring the operational security of IPS of Ukraine's compensating for variable and difficult to predict fluctuations in electricity consumption and generation using RES, so its further development is extremely important, especially given the quick pace of deployment of generating capacities using RES. But when a certain level of capacity at power plants running on RES is exceeded, the reservoir capacity of domestic PSPs (as a technology of power conversion from ELC periods with surplus to ELC periods with shortage) becomes insufficient because big capacities of these RES plants and with their long operation during a year, the surplus volumes (caused by RES generation) will far exceed the possible pumping volumes at PSPs.

Also, when considering the development of hydropower, it was taken into account that the sources of planned investments have not been identified yet and there is significant opposition from the public and environmental organizations to the development of hydropower in Ukraine.

In view of the above, the following two scenarios of hydropower development have been formed:

1) pessimistic scenario (minimum development of hydropower);
2) optimistic scenario (maximum development of hydropower).

According to the optimistic scenario of hydropower development, the supply of electricity generated by large HPPs and PSPs is based on the results of the meeting [60] with adjusted terms of the implementation of capacities at HPPs and PSPs in accordance with the Hydropower Development Programme up to 2026 (given the existing plans and timelines for the necessary development of networks on the basis of proposals and taking into account the progress of the Programme implementation, as noted by PJSC Ukrhydroenergo), as well as the completion of construction of Tashlytska PSP.

According to the baseline scenario of hydropower development, it is assumed that the following projects for its development will be implemented:

1) completing the rehabilitation of HPPs of the Dnieper cascade;
2) increasing the capacity of Dnistrovska PSP due to commissioning of the 4th and 5th units (without constraints on generation and pumping modes);
3) increasing the capacity of Tashlytska PSP due to commissioning of the 3rd unit.

In addition to the above-listed projects, in the longer term (by 2050) it is planned to finish the construction of the third phase at Dnistrovska PSP, build and commission Kanivska PSP, which will increase significantly the installed capacity of PSPs in Ukraine. These assumptions give grounds to form the optimistic scenario of PSP development.

Development options of generating capacities of large hydropower according to scenarios, GW

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic, including:	6.75	6.85	6.85	7.25	7.25	7.25
- HPP	4.8	4.9	4.9	5.0	5.0	5.0
- PSP	1.99	1.99	1.99	2.25	2.25	2.25
Optimistic, including:	6.75	7.15	8.6	9.82	10.24	10.37
- HPP	4.8	4.9	5.2	5.45	5.87	6.0
- PSP	1.99	2.25	3.4	4.37	4.37	4.37

The optimistic scenario was considered as maximum possible volumes of capacities deployment in the hydropower sector in the studies on the formation of coordinated forecasts of economy and energy development (upper bound), and the baseline scenario – as the scenario in which hydropower capacity will definitely change (lower bound).

Under all scenarios, the HPP development (with different volumes and timelines) requires the construction of Kakhovska HPP-2 and modernization of many existing capacities. PSP development, given the readiness for operation of the 4th unit at Dnistrovska PSP and the 3rd unit at Tashlytska PSP and the plans to commence the third construction phase at Dnistrovska PSP, is based only on the existing power plants, as it has been assumed in these scenarios.

Thus, the hydropower development according to RS and SCNE is very close to the pessimistic scenario of hydropower development (including for PSP). In addition, many scenarios assume that existing HPPs at the Dnieper River and the Dniester River operating since 2024 as part of hybrid systems having the total install power of 212 MW and the electric capacity of 212 MWh serve primarily for expanding the regulation range of existing HPP capacities and rapid response during operation in all segments of the market.

Small hydropower

The development of small hydropower, under conditions of reduced water resources and high investment costs, makes it unlikely that it will have a significant increase in capacity. For this reason, in SMEE and SCNE the scenario of its development is close to optimistic and in RS it is less optimistic and close to pessimistic.

Small hydropower development options according to scenarios, GW

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic	198	202	212	217	227	237
Optimistic	198	207	227	247	257	297

Thermal energy

The development of electricity supply offer in the market by the existing TPPs will be predicated on the availability, levels and mechanisms of support to the implementation of NERP, the feasibility of keeping in operation the power plants with low ICUF, as well as state energy policy, in particular, mechanisms for limiting GHG emission and their severity, including emission fees, etc.

In this context, the NERP implementation through decommissioning of power units in absence of new peaking and load-following generation will make it impossible to meet the requirements of flexibility, which will entail consumer constraints due to rapidly deteriorating TPP capacities.

In view of the above, the optimal required capacity of TPPs and CHPs was determined by modelling, where maximum levels of their capacity were determined as follows.

RS and SCNE scenarios were based on the following data.

1. Possibility to use some of these capacities in RS during the entire period of modelling. It means that the assumption was that the NERP would be implemented through decommissioning of power units and replacing some of their capacities with new load-following capacities running of natural gas in the volumes sufficient to meet adequacy requirements.
2. SCNE assumed that (due to the NERP fulfilment through power units decommissioning and due to the non-compliance of these power units with ecological standards) most coal fired generation will be decommissioned by 2035 and all coal fired generation will be fully decommissioned by 2050.

SCNE reviewed potential keeping of existing TPP capacities in operation in accordance with proposals on the NERP revision issued by the working group of the Ministry of Energy of Ukraine. Such revision is necessitated by the following factors.

The current version of the NERP provides for major eco-modernization in the period up to 2025 (Annex 3 of the NERP). However, in the absence of funding sources and taking into account the time required for such effort (given that the installation of electrostatic precipitators requires at least 4 years, and sulphur oxide abatement systems – 6 years), implementation of these measures in a timely manner is unrealistic.

Taking into account these factors and the time required for projects preparation, the eco-modernization will not begin before 2024–2025.

Therefore, if the NERP timelines are not revised and reliable sources of funding for eco-modernization are not identified, already in 2025 the capacity of coal-fired power units may drop to a level at which the generation in the IPS of Ukraine will be unable to meet adequacy requirements, i.e., to cover the electrical demand in the reliable and uninterrupted manner.

Since the NERP includes multiple measures, postponed start will lead to postponed completion. At the same time, postponed start of the NERP implementation until 2025 without NERP extension to 2038 with a corresponding change in the slope of the curves for reducing emissions of pollutants into the air, would not resolve the problem of ensuring overall limits on their emissions while keeping the NERP existing deadline. This primarily applies to emissions of sulphur oxides and dust, which in line with Directive 2010/75/EU shall be reduced according to the current version of the NERP by 2028. It means that these limits will be significantly exceeded already in 2025.

Given that the construction of new generation or the introduction of sulphur oxide gas treatment systems requires at least 6–7 years, if the NERP timelines are not adjusted, the security of supply and operational security will have to be ensured through the use of existing TPPs running on natural gas.

That is, practically the only option to be able to fulfil these limits is replacing coal with natural gas, and in this case the volume of electricity production using natural gas will grow quickly. However, given that the cost of electricity generated by steam turbine power units running on natural gas will increase significantly – by at least twice – and the ICUF will be reduced due to non-competitiveness of electricity produced by steam turbine power units relative to its import, which despite the profile constraints has an impact on the price of electricity, the profitability will be unrealistic, and owners will not be interested in keeping these facilities in operation under such conditions.

Without the introduction of mechanisms to finance eco-modernization measures and ensure the profitable operation of power units after such modernization, the development of thermal generation in the optimistic scenario is practically impossible.

In view of the above, the TPP development in SMEE is predicated on the following:

1. Major ecological modernization activities for a number of power units start in 2024–2025 and should be completed no later than by the end of 2033. It is also foreseen that some existing power units will maintain the sufficient capacity level in the power system by running on natural gas, which will be a prerequisite for ecological modernization considering that the implementation of emission treatment system will take from 4 to 7 years.
2. Emission permits are set by the new version of the NERP in accordance with the new deadlines for the implementation of measures to reduce emissions of pollutants into the air and the list of power units that must operate for a limited period of time.
3. Restrictions on air pollutant emissions are revised according to changes in the NERP timelines.
4. The expediency of ecological modernization, in relation to alternative options (reconstruction or new construction on the existing places), is determined for each power unit on the basis of the corresponding feasibility study.

Potential use of TPP capacities according to the scenarios, GW

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic*, including:	16.6	≥15.13	≥12.73	≥13	≥13	≥13
- available load-following	16.6	11.3	5.6	2.87	0	0
- new load-following	0	≥2.83	≥6.13	≥9.13	≥12	≥12
- highly maneuverable with quick start	≥0	≥1	≥1	≥1	≥1	≥1
Optimistic*, including:	17.6	≥17	≥15.1	≥15.1	≥13	≥13
- available load-following	17.6	≥13.17	≥4.57	≥2.1	≥0	≥0

- available reconstructed or new load-following	0	≥2.83	≥9.53	≥12	≥12	≥12
- highly maneuverable with quick start	≥0	≥1	≥1	≥1	≥1	≥1

*Note. * In the context of the coal fired generation development, the pessimistic scenario assumes rapid exit from coal, while the optimistic scenario assumes that the level of thermal generation will be maintained by keeping coal fired generation at the level not exceeding their capabilities as set out in the NERP through decommissioning of power units without their reconstruction and through developing the technologies that run on natural gas*

It should be noted that the scenarios, where one of key assumptions was the NERP implementation through decommissioning of power units, took into account the accelerated depletion of useful life of TPPs, which in the coming years may reach the limit of 20 and 40 thousand hours and will be decommissioned, and the reduced total actual capacity of the units over the years (see the Substantiating Materials).

The optimistic scenario corresponds to SCNE and partly SMEE, where the TPP capacity is approximately by 2 GW lower than in the optimistic scenario at the level of year 2050. The pessimistic scenario corresponds to SCNE where coal generation is quickly decommissioned and replaced with flexible power plants running on gaseous fuel.

CHPs are in special focus when forming long-term development scenarios for thermal power. As noted, CHPs are primarily heat supply facilities, and only the possibility of efficient operation in the cogeneration mode makes it practical to build and keep them in operation for economic reasons.

In this context, the operation of many existing CHPs is inefficient, which necessitates their reconstruction on the basis of highly efficient technologies of combined heat and power with the implementation of measures to ensure their participation in balancing of the IPS of Ukraine, in particular implementation of heat storages or generating capacities enabling quick start-up/shut-down of CHP equipment, the feasibility of which is predicated on the continued policy of stimulating the development of IPPs in Ukraine. Of course, decisions on the construction of new CHPs should be similar.

The feasibility of such vector of the country’s energy sector development is predicated on a number of factors, in particular:

- Promoting the development of high-efficiency cogeneration and the creation of energy efficient patterns of district heat supply, one of the elements of which is the combined production of heat and electricity, which is Ukraine’s commitment under the Association Agreement with the EU.
- Attracting International Funding Institutions (IFI) loans only for the projects implementing high-efficiency cogeneration and creating energy efficient schemes of district heat supply.
- Introducing high-efficiency cogeneration and creating energy efficient schemes of district heat supply is an important factor of decarbonizing the economy and reducing pollutant emissions into the air.

To date, certain preconditions have been created for the development of CHPs in Ukraine, in particular, regarding the possibility of providing state support for their reconstruction and modernization. Many such projects have been developed and approved in accordance with current legislation by the authorized commission, but the Government has not adopted the decision to provide state support to the reconstruction and modernization of CHPs.

The central executive body responsible for the development of district heat supply in the country (the Ministry of Development of Communities and Territories of Ukraine) supports the development of district heat supply based on the creation of energy efficient schemes, as well as projects for the reconstruction of existing schemes. For the development of high-efficiency cogeneration, the Verkhovna Rada adopted the draft Law on Amendments to the Law of Ukraine "On Combined Heat and Power (Cogeneration) and Use of Waste Energy Potential" for the Development of High-Efficiency Cogeneration).

Although, maintaining the "excess" capacities at the CHPs under the new model of the electricity market is impractical, and it is likely that such capacities will be phased out.

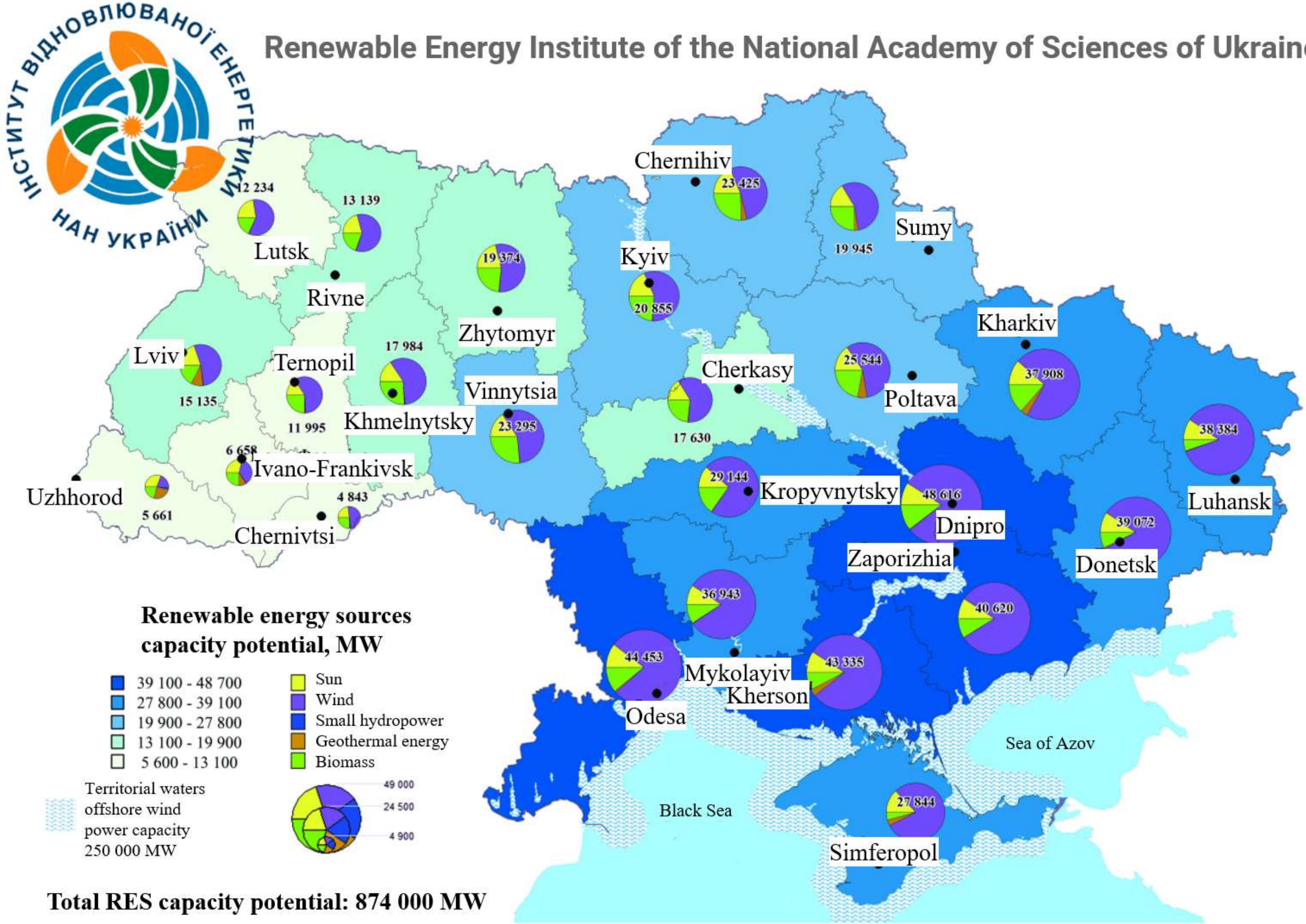
Given the above, SMEE envisages the optimization of the existing capacities at CHPs, their gradual reconstruction based on the latest gaseous fuel technologies and eco-modernization of coal-fired CHPs in accordance with the updated NERP.

According to SCNE, most existing coal-fired CHPs will be decommissioned by 2035. Some gas-oil power plants will be converted to biomethane and/or its equivalents by 2050. According to RS coal-fired CHPs will be gradually decommissioned with full decommissioning (except power plants converted to biomass) at a later date, i.e., by 2050. By 2050, gas-oil CHPs, similarly to SCNE, will be either decommissioned or converted to biomethane and/or its equivalents.

It should be noted when implementing the NERP through decommissioning of CHP power units, the CHPs included in it will also be decommissioned, which will further exacerbate the problem of insufficient capacity in the IPS of Ukraine, as well as in the absence of alternative heat sources will cause a shortage of heat. In this situation, the forced transition of consumers to the use of electricity for heat production will further aggravate the shortage of generating capacities.

Dynamics of CHP development according to scenarios, GW

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic:	6.04	4.89	2.84	2.09	1.74	0.49
- existing	5.8	4.6	2.5	1.7	1.3	0
- new and existing converted to biofuel	0.24	0.29	0.34	0.39	0.44	0.49
Optimistic:	6.14	4.89	3.89	3.79	3.73	5.23
- existing	5.9	4.6	3.1	2.5	2	2.6
- new and existing converted to biofuel	0.24	0.29	0.79	1.29	1.73	2.63


Renewable Energy Institute of the National Academy of Sciences of Ukraine
ІНСТИТУТ ВІДНОВЛЮВАНОЇ ЕНЕРГЕТИКИ
НАН УКРАЇНИ
Chernihiv
23 425
19 945
Sumy
12 234
13 139
Lutsk
Rivne
19 374
Zhytomyr
Kyiv
20 855
Kharkiv
37 908
Lviv
15 135
Ternopil
11 995
17 984
Khmelnytsky
Vinnytsia
23 295
Cherkasy
17 630
25 544
Poltava
38 384
Luhansk
6 658
Ivano-Frankivsk
Uzhhorod
5 661
4 843
Chernivtsi
29 144
Kropyvnytsky
48 616
Dnipro
39 072
Donetsk
Zaporizhia
36 943
40 620
44 453
Odesa
Mykolayiv
43 335
Kherson
Sea of Azov
Black Sea
27 844
Simferopol
Renewable energy sources
capacity potential, MW
39 100 - 48 700
27 800 - 39 100
19 900 - 27 800
13 100 - 19 900
5 600 - 13 100
Sun
Wind
Small hydropower
Geothermal energy
Biomass
Territorial waters
offshore wind
power capacity
250 000 MW
49 000
24 500
4 900
Total RES capacity potential: 874 000 MW

Renewable energy sources

The development of renewable energy is of key importance in terms of forming a promising mix of generating capacities of the IPS of Ukraine. At the same time, IPPs in Ukraine should be developed taking into account the economic potential of the country, the creation of technological prerequisites for the IPP integration, and natural and climatic resources.

Natural and climatic conditions of Ukraine exclude the practical possibility of implementing strategies to meet the needs of the country through nuclear and renewable energy, as the latter is characterized by unstable production of electricity: days of high generation from RES rarely coincide with days of high consumption, daily peaks of SPP production do not coincide with daily peaks of consumption, during peak hours only wind farms generation partially covers it. But in the conditions of Ukraine, in the days of maximum loads the capacity of wind farms will be minimal, because maximum loads occur in days of heavy frost accompanying anticyclones bringing a windless weather. Of course, in certain years winters will not be accompanied by heavy frosts and the capacity of wind farms during peak periods may reach 10–20% of their available capacity, but in the context of generation adequacy the assessment of load-following generation shall factor in the low capacity of wind farms during the assessment period (up to 2% of the installed capacity).

Therefore, the WPP and SPP development in Ukraine has minor influence on the required available capacity of load-following generation, and increasing the capacity of IPPs would not significantly minimize the need to maintain the available capacity of load-following power plants. At the same time, the low ICUF of conventional energy technologies (given that they are progressively replaced by IPPs in coverage of the electric load curve) causes a high cost of their electricity production, which is paid for by consumers, in order to meet the requirements for sufficiency of generating capacities in Ukraine and ensure reliable electricity supply.

Growing RES capacities lead to more investment needs and higher additional operating costs to meet consumer demand for electricity due to the need to introduce new balancing capacities and transform accordingly the existing structure of generating capacities.

At the same time, the technologies of electricity generation from RES, by the assessment of many international organizations studying this subject, are already quite competitive compared to the conventional generating power plants.

In consideration of the foregoing, the further state support to the development of power plants that use renewable energy sources is not practical. It is more practical if these power plants develop operating in the market environment. In this context, the Law of Ukraine “On the Electricity Market” needs to be amended in terms that only those electricity producers from RES who have obtained the state support should be entitled to priority dispatching.

In RS and SCNE the volume of RES penetration was determined based on the results of the Project modelling (see Annex A to the substantiating materials to the Report). In SMEE it was done at the level of the requirements of the National Economic Strategy up to 2030 (with data on the volume of electricity production).

The development of these energy sources provides for a slight increase in the capacity of IPPs in SMEE, mainly due to their deployment in individual power supply systems or adding them to centralized power supply systems.

Note that depending on the ICUF and power consumption levels the required capacity of SPPs and WPPs is in the range shown in Table, to ensure the volume of their electricity production in accordance with the NEcS-2030.

Renewable energy development options according to the scenarios, GW*

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic:						
- SPP	6.8	7.2	8.2	8.2	9.2	13
- WPP	2.8	3.3	4.3	4.7	4.4	7
- BioPP	0.25	0.3	0.35	0.4	0.45	0.5
Optimistic:						
- SPP	8.25	9.2	12	18.5	35.3	58.6
- WPP	3.5	5.2	8	11.7	20	32
- BioPP	0.3	0.9	2.4	3.9	5.2	7.9

*Note. * Scenarios of potential development of small hydropower, which also belongs to renewables, are provided in next paragraphs of this section.*

It should be noted that data in Table is not intended for the purposes of auctions for the allocation of support quotas within the meaning of the Law of Ukraine "On Alternative Energy Sources" until the removal of restrictions of the daily irregularity in the structure of electricity output created by RES.

Along with this, one of the most pressing problems facing the IPS of Ukraine today, in the context of ensuring real-time balancing, is the need to significantly increase the flexibility of the power system, which has long been described as insufficient. And under the current conditions of operation of the IPS of Ukraine, with the reduction of electricity consumption, the growing non-uniformity of electric load curves and the rapid penetration of renewables (without the introduction of technologies to support their integration), this problem is only aggravated.

The development of bioenergy in the long run will be largely determined by economic factors, as well as the adequacy of biomass that will be used for production to sustainability criteria. At the same time, low efficiency of biomass power plants in the condensing mode makes it potentially feasible to build only CHPs on biomass and operate at maximum ICUF, i.e., in the presence of a sufficient level of heat load during the year. Therefore, it is assumed that their capacities can potentially replace or supplement existing heat sources in regions with available biomass resources and with heat demand, in particular, through the use of organic waste in large cities and in production of the agro-industrial complex.

At the same time, the TPPs running on biogas are less promising in Ukraine compared to the power plants running on biomass because biogas has a wider range of application (it is practically equivalent to natural gas and has the same field of application) and therefore is more competitive, which will affect accordingly the price of this energy carrier, especially considering its insufficiency and high demand. For this reason, from the standpoint of economic feasibility biogas for electricity generation only slightly differs from natural gas. Therefore, the pessimistic scenarios (even notwithstanding amendments to the Law of Ukraine "On Alternative Fuels" for the development of production) consider the BioTPP deployment at a moderate pace and optimistic scenarios – at an accelerated pace, which brings the development of such power plants close to the maximum limit given the scarcity of necessary bioresources.

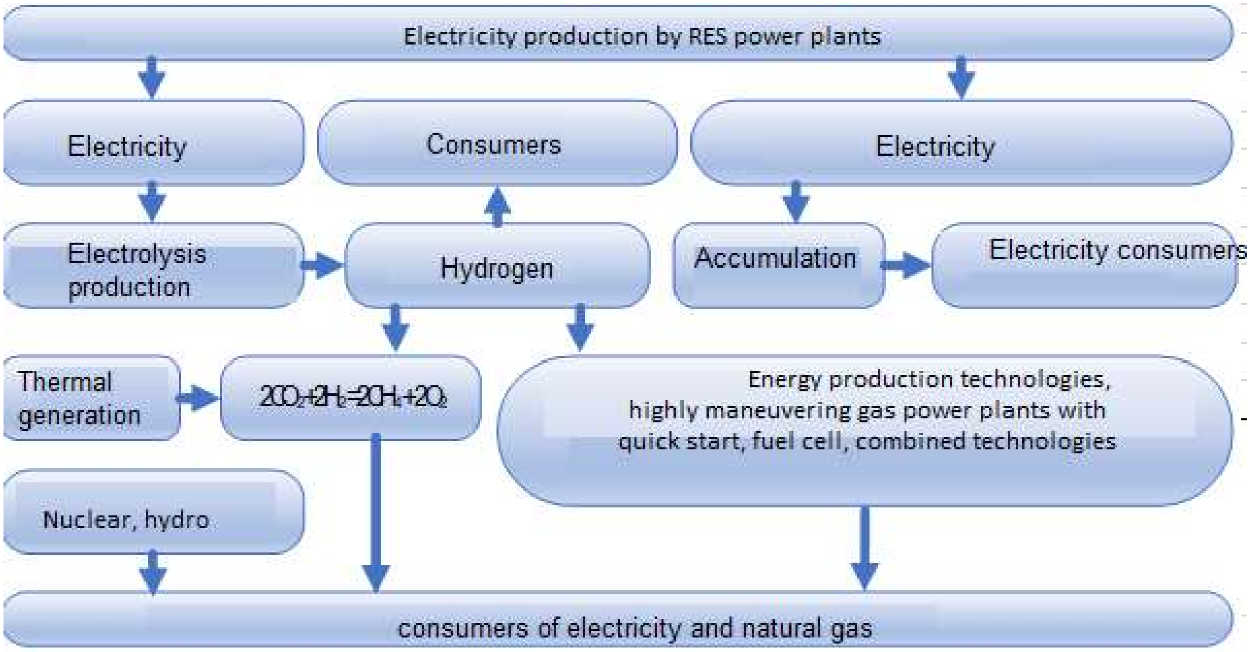
Technical means to support the integration of RES generating capacities

As noted, one of the most important tasks facing the country's energy sector today is to increase the flexibility of the IPS of Ukraine. The today's world offers a number of technologies providing the flexibility to the power system (including balancing) and enabling further integration of renewables into power systems. Such technologies include:

- highly flexible thermal generation (such as gas turbines or gas piston engines) with quick start-up possibility providing wide opportunities for power regulation and starts-up/shuts-down during a day, season and year;

- highly flexible PSPs and HPPs;
- energy storages for frequency control and containment (ES);
- consumer-controllers based on technologies of thermal energy accumulation;
- small modular nuclear reactors;
- technologies for elimination of surpluses in the power system (Power to X), which in Ukraine today are considered, first of all, as enterprises producing hydrogen on the basis of electrolysis (Power to Gas);
- energy storages for power conversion from surplus to shortage periods ("Power to Power"), which in essence are energy storage power plants;
- mechanical energy storages that use gravitation forces and a number of other less common technologies.

Concept of electricity generation without GHG emissions



The implementation of these technologies creates prerequisites for virtually unlimited development of the power plants running on RES and able to fully cover energy demand subject to the equal development of fuel and energy consumption technologies, i.e., hydrogen, but the cost of energy supplied by these technologies will be very high.

Such a level of energy supply systems can be afforded only by the most advanced countries that use their own research and production enterprises (machine building and instrument engineering) to develop hydrogen production and consumption.

As any other technology, energy storages have limited service life of batteries, which need regular replacement, and their operation requires a lot of energy and is accompanied by energy losses. For this reason, especially taking into account rather high capital expenditures, the use of power conversion is possible only up to a certain capacity of power plants running on RES.

Special focus is on systems that use solar and wind energy for electrolysis production and implement the Power to Gas concept, which provides an opportunity to move to the electricity production that is not accompanied by GHG emissions.

These technologies, with a significant increase in the capacity of wind farms and SPPs, provide an opportunity to solve the issue of limited use of Power to Power technologies, in particular, PSPs and energy storages, when total electricity production on a certain day exceeds its consumption at all levels of the electric load curve.In addition, energy storages require large capacity batteries that have a limited service life and are quite expensive, which makes them inefficient in terms of power conversion tasks, especially in relation to PSPs.

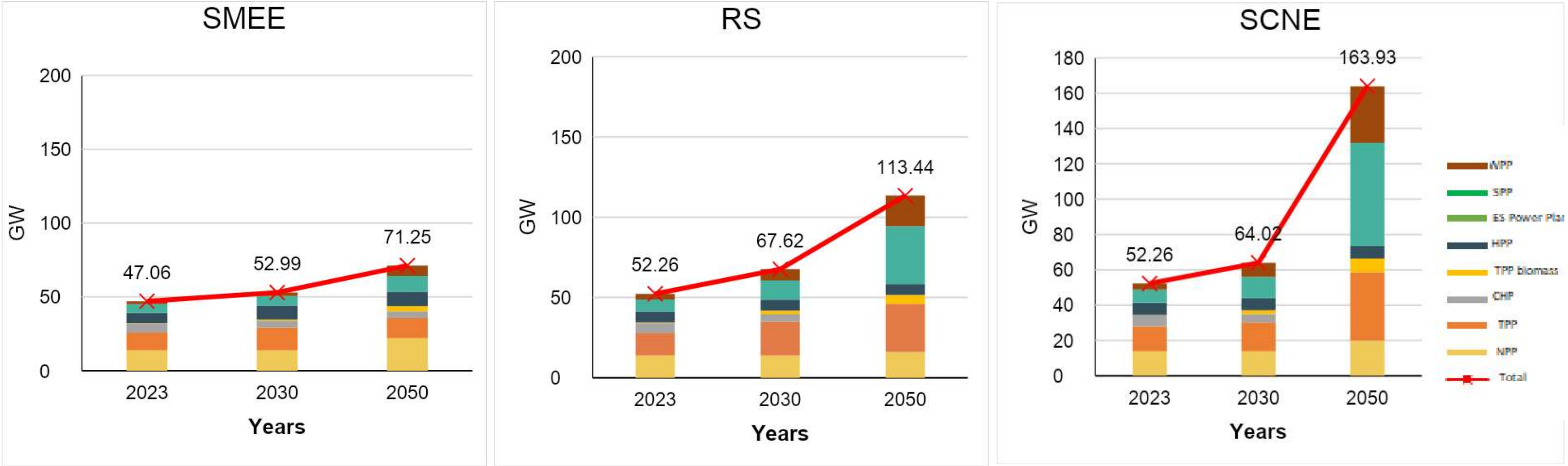
However, Power to Gas technologies have a number of demerits, in particular: the high cost of electrolysis product, which strongly depends on the level of load and electricity prices (in Ukraine, according to TSO, even at the price of electricity produced by wind farms and SPPs at the level of 5–5.5 eurocents and ICUF of electrolyzers at the level of 45%, which corresponds to the dedicated construction of electrolysis plants in parallel with the construction of wind farms exclusively for hydrogen production with utilization of surplus electricity produced using RES in the presence of free capacity of electrolyzers, the cost of hydrogen will be at least 5 euros per kg, which is equal to about 1 thousand euros per ton of fuel equivalent). They have a technical minimum of at least 20% of the rated power for expensive cells, and about 40% for cheaper cells, which to some extent limits their potential use, especially in the wintertime in Ukraine.

In view of the above, increasing the flexibility of Ukraine’s power system has a limited influence on the possibility of integrating IPPs into the IPS of Ukraine, except for Power to X technologies, as IPP capacity growth is higher than demand at a certain level of the electric load curve, considering that its demand is covered by other types of power plants, in particular, CHPs operating on a district heating schedule and under a “feed-in” tariff, HPPs with water pumping into the lower pool, non-flexible NPPs incapable of fast ramping, etc., necessitates the implementation of one of the following options in the short term (4–5 years) and, most likely, in the medium term (up to 10 years):

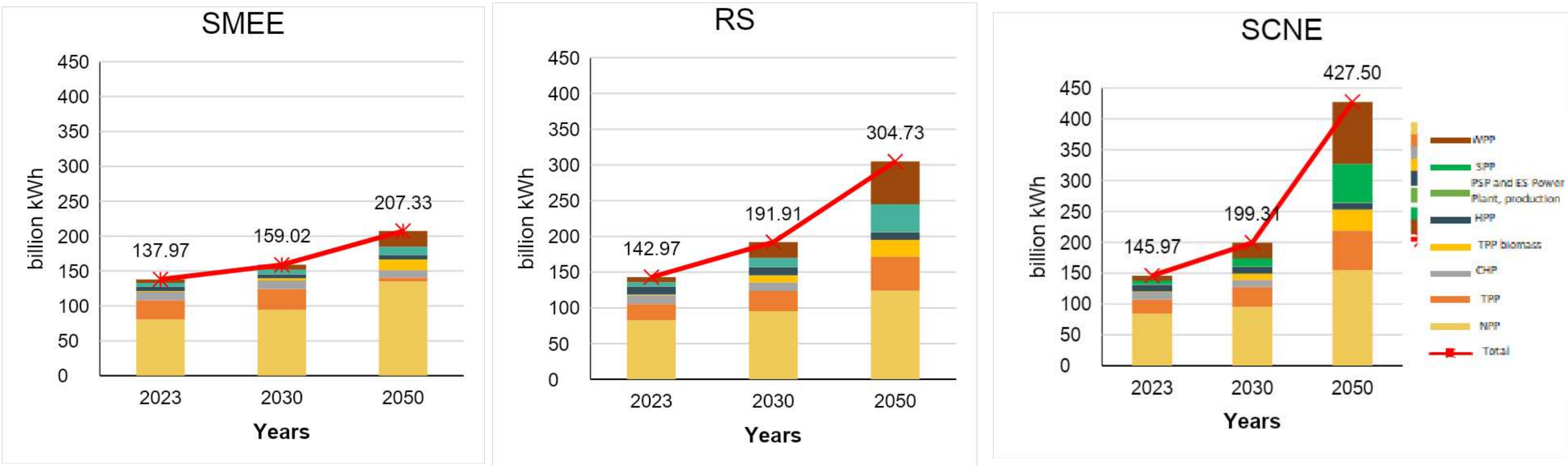
- Limit NPP capacity for a long-term (at least 24 hours) period in advance. Such decision is one of very few balancing instruments available to the TSO. But this decision is not always economically feasible because it entails payments for NPP load shedding as a balancing service and, on the other hand, it is not sustainable because in periods with no surplus instead of NPP energy without pollutants and GHG emissions the electricity demand is covered by thermal power plants running on fossil fuel.
- Introduction of Power to X technologies for the use of excess electricity produced by IPPs. With power surplus at all levels of the electric load curve, a situation may arise when it is practical to use power conversion systems to “level” the electric load curve, i.e., minimize “power fluctuations” within the corresponding electric load curve, as well as to reduce the power demand of Power to X technologies and increase the level of utilization of “excess” electricity, which is especially important for hydrogen production technologies.
- Power conversion from surplus zones of the electric load curve to zones with shortage. But such a possibility may sometimes be unavailable because with IPP significant capacities there is no such option – at all zones of the electric load curve there is a surplus, and at low levels there may be a reverse situation when there is no need for power conversion.

Therefore, electricity generated under options 2 and 3 above can highly exceed the demand for electricity.

Modelling results were used to determine basic indicators of supply development scenarios for SMEE, RS and SCNE as shown in Figures.



Change in the generation mix according to scenarios by 2050



Dynamics of electricity output according to scenarios during the period up to 2050

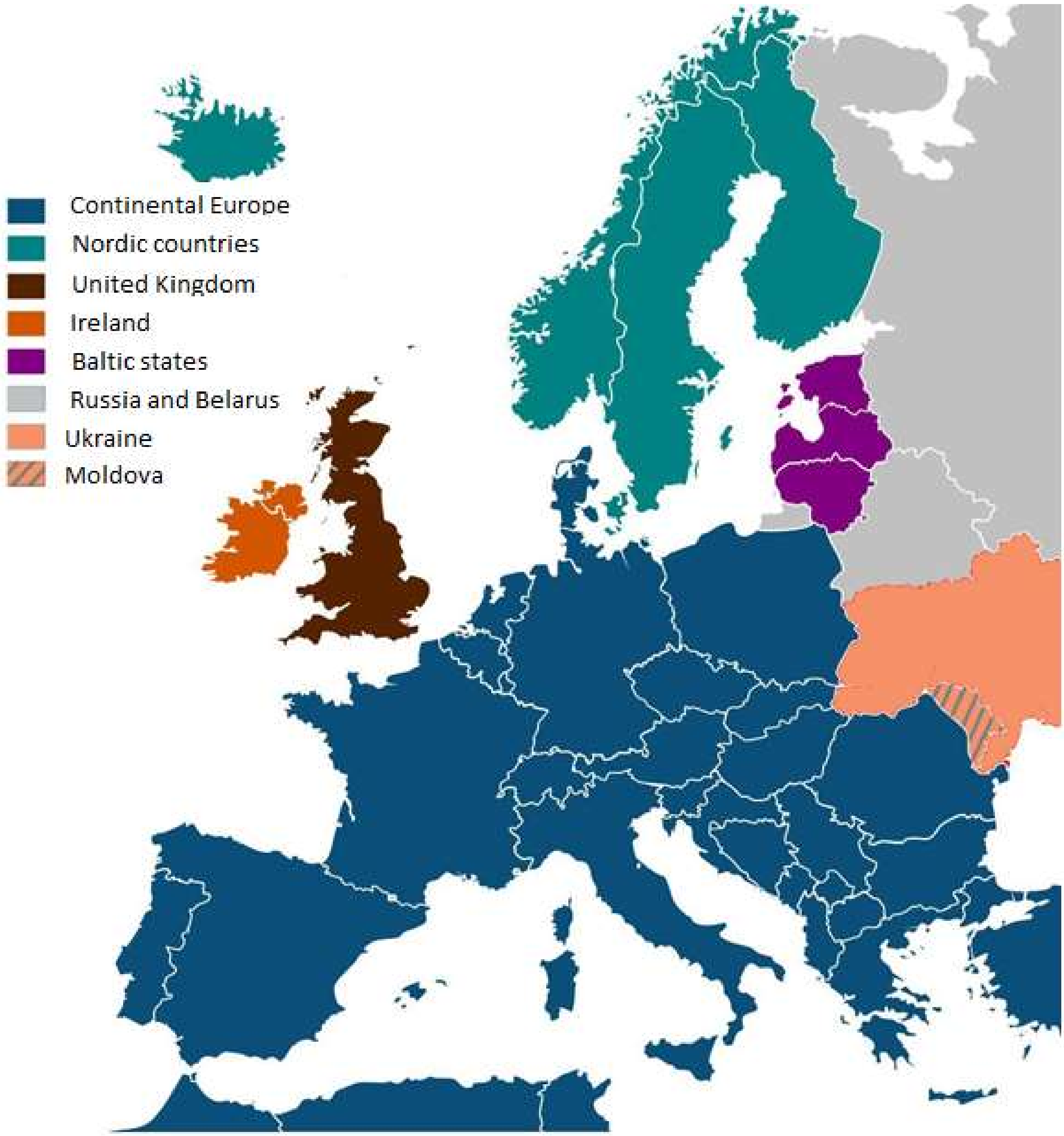
Interconnectors

Given Ukraine's geographical location in the middle of the European continent, on the border with two major power systems (Continental Europe and the CIS), its scale and volume of flows, the model of the IPS of Ukraine includes a number of other power systems.

Model boundaries in this Report compared to its previous version are not limited to Moldova, Slovakia, Hungary and Poland, instead this Report models the interconnected operation mode of the IPS of Ukraine with the entire *ENTSO-E* system of 36 countries, which are modelled here explicitly. Therefore, power systems of many European countries are modelled simultaneously.

It provides an opportunity to correctly model the synchronous operation of power systems of different countries and assess the possibilities of imports as one of the means of ensuring adequacy of generating capacities in the IPS of Ukraine and exports/imports as one of the means of ensuring the flexibility of generating capacities in the IPS of Ukraine.

Geographical boundaries of modelling



Thus, the adequacy and flexibility of generating capacities was assessed taking into account the possibility of exchanging electricity flows with neighbouring countries, defined as a difference between the total operating capacity (equal to the total installed capacity less balance flows, reserves and capacities under repair and in mothballing, or subjected to other constraints) and the corresponding load curves for each country as well as constraints at interconnectors. This Report, as distinct from its previous version, uses the NTC (net transfer capacity) approach, which despite some demerits (it ignores the effect of two Kirchhoff Laws and the presence of process flows) enables a relatively simple, coordinated and bilateral planning of commercial flows.

For illustration purposes Figure shows a graphic method of determining the available operating capacity in one power system. In models built using stochastic methods, such graphs are formed dynamically for each neighbouring power system, and therefore they will differ depending on the time horizon. Given the above and taking into account constraints on the available transfer capacity of interconnectors, every time horizon will be characterized by a different value of the available transfer capacity in each direction.

Note that all scenarios of supply and demand development demonstrate a gradual increase in the transfer capacity of interconnectors through the modernization and restoration of many existing lines in the direction to Europe, which in the mid-term (by late 2032) will increase the transfer capacity in all directions to/from the IPS of Ukraine to the level of 3.6 GW of the total transfer capacity. At the same time, considering the development of generating capacities (primarily at nuclear power plants, high single-unit power) in Ukraine according to the optimistic scenario, it is necessary to envisage the development of domestic grids in order to remove internal constraints at interconnectors and unload already overloaded overhead lines.

Interconnector development options (TTC), GW

Scenario	2023	2025	2030	2035	2040	2050
Pessimistic	2.4	2.4	3.6	3.6	3.7	4.0
Optimistic	3.6**	3.6	4.8**	4.9	6.2	8.0

Notes:
*** the growth under the optimistic scenario in 2023 is stemming from the line rehabilitation in the direction to Rzeszów substation and in 2030 – the line rehabilitation in the direction to Isaccea substation (start of operation is scheduled for early 2027).*

Graphic method for determining the available operating capacity in the power system

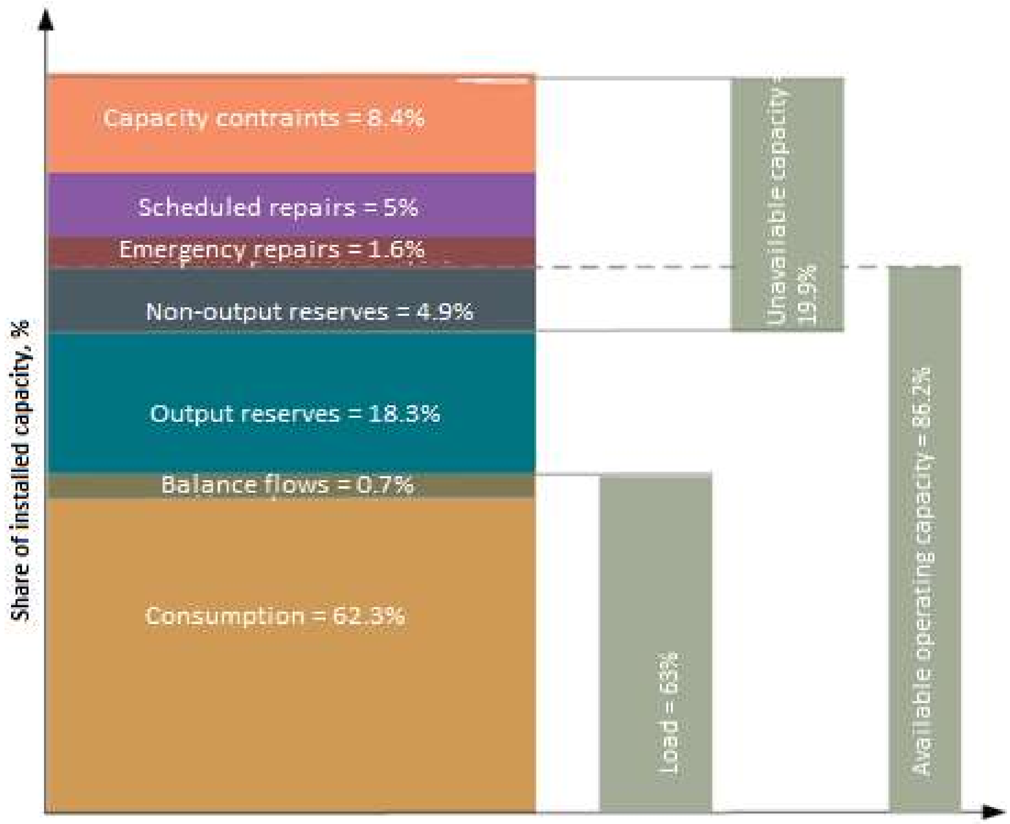


Figure provides summarised data for the year. Based on the analysed data presented in the relevant reports of adjacent power systems and partly provided in the context of future cooperation, Figure below illustrates the daily profile (on the example of a typical day) of electricity import/export options from each adjacent power system, taking into account the available capacity and the constraints on the available transfer capacity at interconnectors.

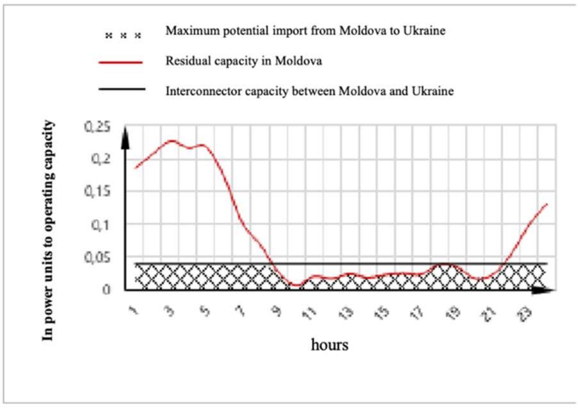
So, from Figure it follows that each neighbouring country is characterized by relatively different electric load curves, different degrees of utilization of their own capacities, and also shifts of consumption peaks/offpeaks.

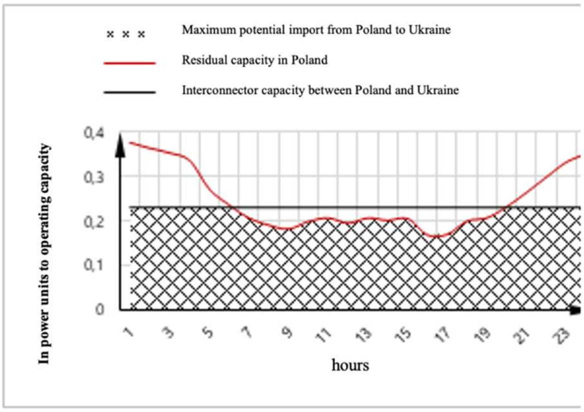
The maximum potential volume of imports to the IPS of Ukraine from neighbouring countries was determined in this way. It should be noted that during periods of maximum daily load in the IPS of Ukraine (i.e., during periods of probable shortage of capacity and reserves) there is a decrease in the maximum potential imports from neighbouring countries.

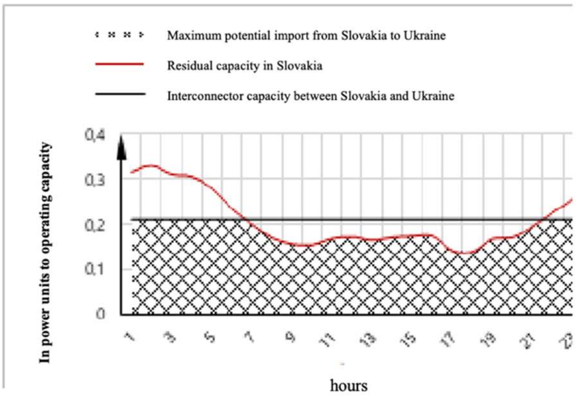
In this context, the formation of a long-term strategy reliably meeting the needs of electricity consumers in Ukraine, focusing on the possibility of importing electricity and reserves, primarily to cover combined maximum loads in the IPS of Ukraine and balancing the power system under normal operation, can jeopardize the fulfilment of energy security requirements of the country.

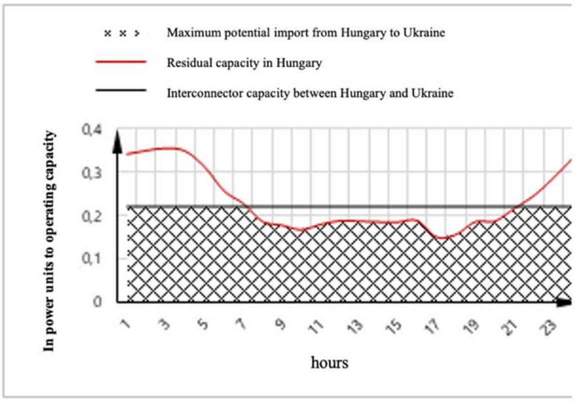
In the absence of sufficient capacities to cover electricity demand on the bilateral contracts market and the day-ahead market and with the insufficient flexibility of the country's power system, the decision to import electricity and reserves becomes a single-option decision.

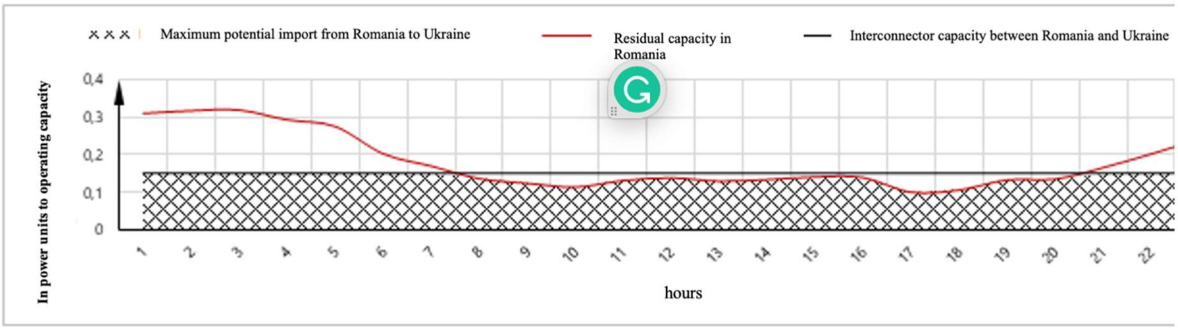
Maximum potential volumes of import to the IPS of Ukraine taking into account the transfer capacity of interconnectors in neighbouring countries











These scenarios of demand and supply development were formed in a balanced way in terms of the ability to fully ensure the flexibility and adequacy of generating capacities, as well as demand-side management (by 2050 in all scenarios), since it was assumed that conditions will be created in the future when all the actions required for assuring supply security and operation security will be implemented in full and on time.

Key indicators of demand and supply scenarios are outlined in the following table.

Key indicators of demand and supply scenarios

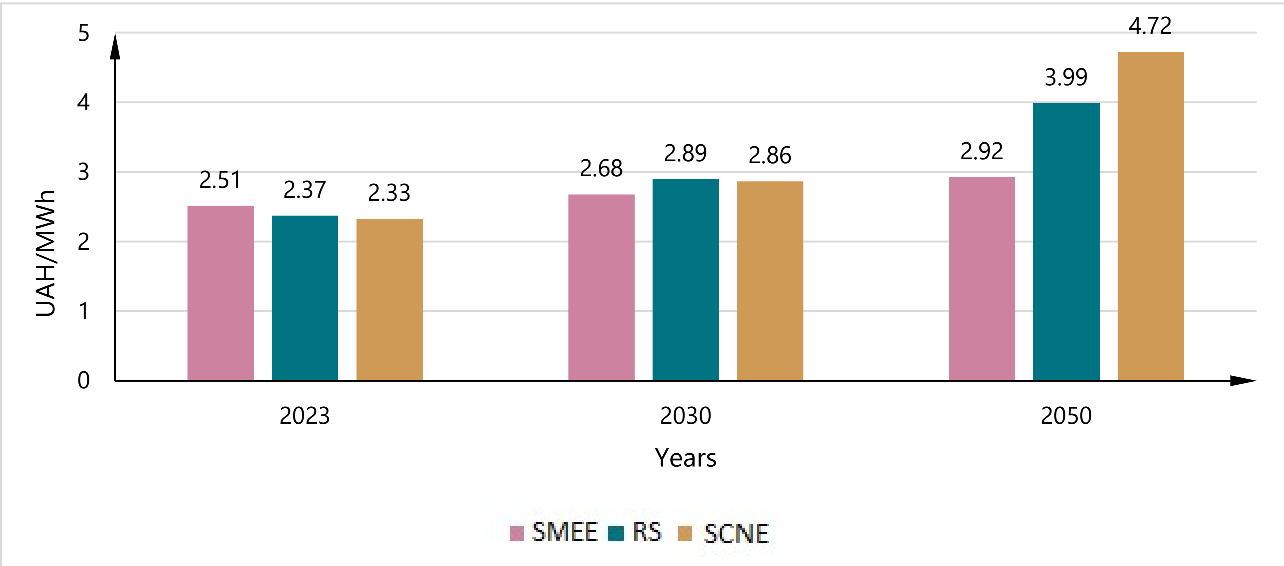
Indicator	Unit	Scenarios								
		SMEE			RS			SCNE		
		2023	2030	2050	2023	2030	2050	2023	2030	2050
Output to grid	bln kWh	138	159	207	142	184	278	145	193	358
Electricity generation	bln kWh	138	159	207	143	192	305	146	199	427
NPP capacity	GW	13.84	13.84	22.10	13.84	13.84	16.00	13.84	13.84	20.00
Capacity of TPP on fossil fuel	GW	12.3	17.55	15.3	14.4	23.15	30.1	14.4	18.45	38.54

Capacity of CHP on fossil fuel	GW	5.80	2.50	2.75	5.9	2.5	0	5.9	2.5	0
Capacity of TPP and CHP on non-fossil fuel*	GW	0.28	0.75	3.60	0.28	2.26	5.46	0.28	2.36	7.91
Capacity of HPP and PSP	GW	6.85	9.55	9.55	6.85	6.88	6.88	6.85	6.88	6.88
WPP capacity	GW	2.00	2.40	7.10	3.50	7.00	19.00	3.50	8.00	32.00
SPP capacity	GW	6.00	6.40	10.60	7.50	12.00	36.00	7.50	12.00	58.60
Energy storage capacity	GW	1.10	1.10	2.00	1.10	1.90	5.50	1.10	1.90	9.10
Capacity of electrolysis technology inverters	GW	0.00	0.00	0.00	0.00	4.71	25.33	0.00	5.23	46.56
Volume of investments in cumulative total (at the level of the corresponding year)	UAH, billion	124	501	4523	229	1369	7320	229	1512	10993
Average price of electricity supply excl. carbon tax	UAH/ kW	2.49	2.68	2.92	2.37	2.89	3.99	2.33	2.86	4.72
Average price of electricity supply incl. carbon tax	UAH/ kW	2.64	2.94	3.00	2.47	3.09	4.18	2.41	3.09	4.85
Fuel consumption, incl.:	mln toe	9.62	9.76	7.45	6.73	9.29	17.68	8.26	12.31	22.59
non-fossil fuel**	mln toe	0.33	0.90	4.34	0.33	3.19	8.32	0.33	3.24	14.16

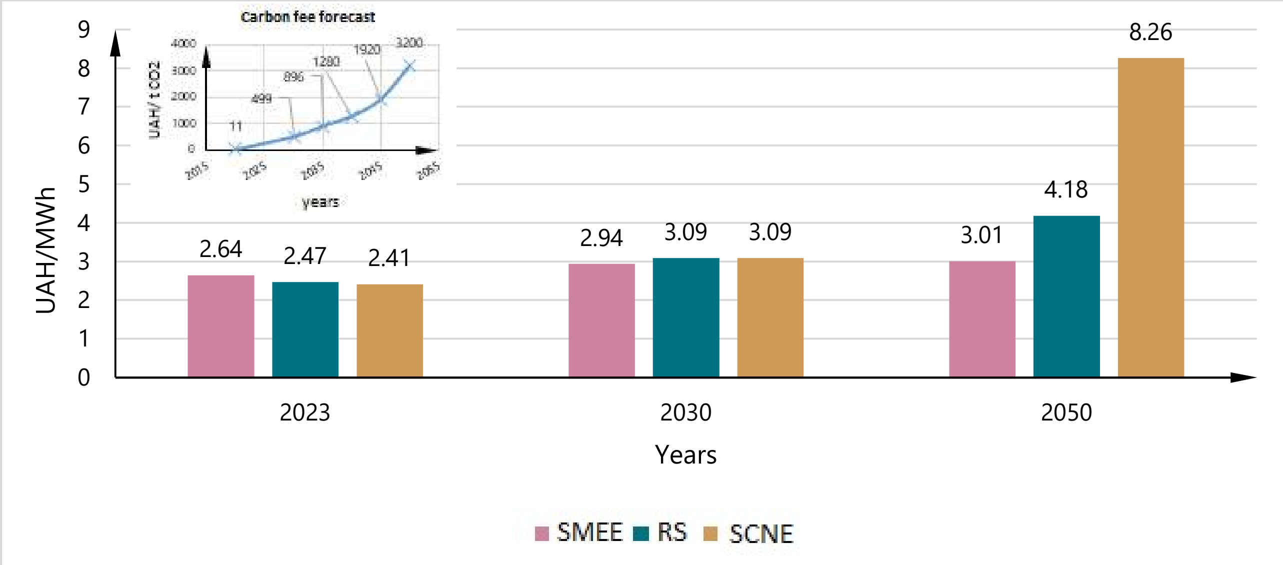
Note. Running on biomass, water and other types of "green" fuel*
*** Biomass, hydrogen and other types of "green" fuel.*

It should be noted that the relatively small increase in the cost of electricity under SCNE and RS in 2030 stems from significantly higher volumes of electricity output than under SMEE, which reduces the share of investment and fixed costs in the cost price of electricity.

Price of electricity output according to the scenarios excl. carbon tax



Price of electricity output according to the scenarios incl. payments for GHG* emissions and the use of produced hydrogen for electricity generation under RS and SCNE scenarios, which under these scenarios reduces payments of carbon tax

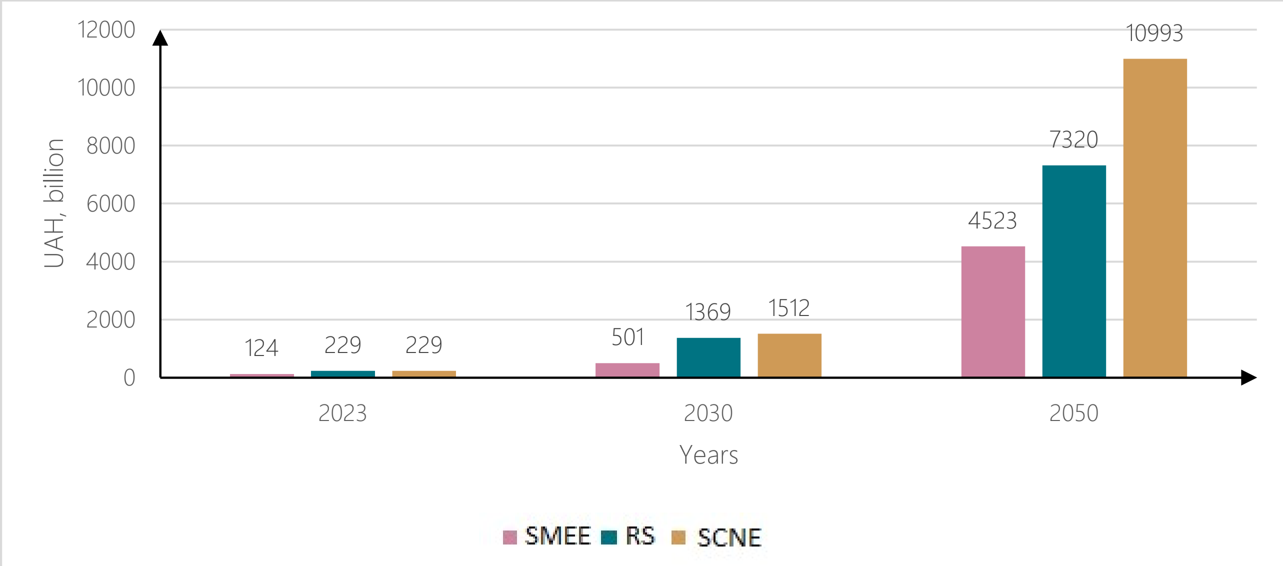


Note. * According to forecast data about carbon tax, see IEF Report

In SCNE and RS, investment needs are much higher than in other scenarios due to higher installed capacity of generation and the need to implement balancing technologies based on energy storages (including investments to replace the capacity of wind farms and SPPs, which have exhausted their useful technical life).

The much higher cost of electricity and the need for larger investments lead to such results that the implementation of SCNE and RS, as well as similar scenarios, will not make economic sense in Ukraine for consumers and investors, because the deployment of SPP and WPP capacities in maximum volumes entails the need to curtail their capacity.

Amount of required investments according to the scenarios (cumulative total at the level of the corresponding year)



Taking into account these factors, the most effective from the TSO view point, in the context of minimizing risks to the reliability of electricity supply, is pursuing the scenarios for the development of generating capacities of the IPS of Ukraine in the long run, which implement the following strategy:

– maintaining and maximizing the use of existing NPP capacities in Ukraine (at least at the today's level and the further development of the nuclear energy by commissioning of new capacities (in the long run) as the most effective means of reducing GHG emissions at prices affordable for consumers (compared to other technologies that provide forecast supply). This provides for the commercial development of new types of power units with sufficiently high flexible characteristics, which are at least comparable to conventional power units running on fossil fuel;

– constructing new and reconstructing the existing power units at thermal power plants running on organic fuel with improvement of their technical and economic indicators, in particular, flexible capability, bringing ecological indicators to normative requirements and extension of service life to minimum 20 years. By estimates, to cover the combined load curve the available firm capacity of such power units shall be at least 8.5 GW in the long run, provided the above scenario of nuclear energy development is implemented. At the same time, using as fuel the domestic energy resources should be considered as an important aspect of ensuring the energy and economy security of the country, which is one of the key factors of ensuring the national security;

– further development of the country's hydropower in accordance with existing plans, in particular, completing the rehabilitation of HPPs at the Dnieper cascade and implementing new power units at PSPs, which is feasible only under condition of increasing the total volumes of water reservoirs. Because its curbing significantly complicates fulfilling the requirements of adequacy (flexibility) of generating capacities and leads to escalating electricity prices;

– supporting the development of RES in volumes that will not exceed the technological capabilities of the IPS of Ukraine for their full integration (without curtailments on RES power plants), in particular, taking into account the operating capabilities of the power system for their balancing;

– developing the country's heat supply system by increasing the capacity of biomass CHPs and reconstructing existing CHPs to implement technologies for the most efficient use of fossil fuel in the combined production of heat and electricity, as well as utilization of waste heat using heat pumps;

– implementing measures to increase the flexibility of the IPS of Ukraine, in particular:

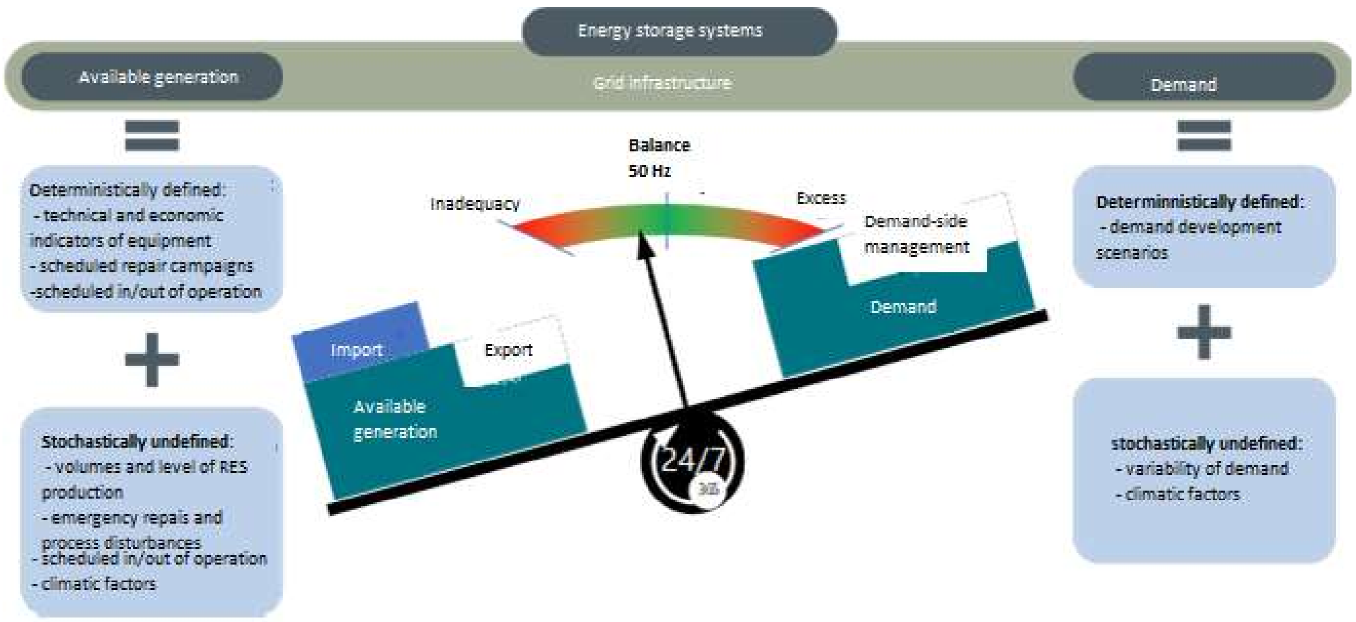
- introducing the minimum necessary volumes of highly flexible generating capacities (with quick start-up capability) and energy storages. At the same time, under equal conditions, it is advisable to give preference to "rapid" generation due to the much longer service life and the absence of restrictions on the capacity of storage systems;
- replacing NPP power units being decommissioned with flexible power units, in particular, with small modular reactors;
- increasing the flexibility of thermal power capacities during the reconstruction (modernization) of existing power units and during new construction.

2.5 Assessment of generation adequacy (flexibility) of Ukraine's IPS

Results of generation adequacy (flexibility) assessment under the baseline scenario of supply and demand development in the IPS of Ukraine demonstrate many problems in terms of adequacy and flexibility, which means that starting from 2025 own generation will not be sufficient to reliably cover the demand on electricity.

To meet the needs of Ukrainian consumers in electricity according to this scenario, it will be necessary to keep increasing electricity imports but it is evident that building up the transfer capacity at interconnectors between the IPS of Ukraine and power systems of neighbouring countries serve as a reliable source of electricity supply.

Graphic representation of the mechanism for achieving generation adequacy (flexibility) of the power system



In the situation of shortage of generating capacities, i.e., non-fulfilment of generation adequacy requirements and insufficient implementation of measures to increase the flexibility of IPS of Ukraine, under the baseline scenario the flexibility requirements can be fulfilled only through the import of reserves, which stipulates further requirements to increase the capacity of interconnectors between the IPS of Ukraine and the power systems of neighbouring countries.

Probabilistic criteria for adequacy assessment showed the following. Considering that on the legislative level in accordance with the latest methodologies of ACER (work is in progress) Ukraine has not yet determined the target values of the power system adequacy as per LOLE and/or LOLP, while in most countries that use these criteria such values differ, the Report establishes as acceptable the LOLP value that does not exceed 0.03%, and LOLE value that does not exceed 3 hours a year (matching the security requirements of European power systems that are equal in size, such as in Poland, France and a number of other countries.

Electric power balance forecast in the IPS of Ukraine according to the baseline scenario for the day of total maximum load during interconnected operational mode with power systems of neighbouring countries, MW

Components of the balance		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Consumption (gross)		24350	24700	25000	25300	25600	26000	26400	26850	27300	27800
Coverage/generation		24350	25200	24300	21790	20940	19490	19640	19590	19540	20810
TPP		7290	7540	6360	3850	3050	1650	850	800	800	800
CHP and modular plants		2150	2250	2100	2000	1900	1800	1700	1600	1450	1350
Biofuel power plants		150	150	200	250	250	250	250	300	350	350
HPP, including:		1800	1800	1800	1800	1800	1800	1800	1800	1800	1800
- micro-, mini- and small HPP		20	20	20	20	20	20	25	25	25	25
PSP generation		1360	1360	1690	1690	1690	1690	1690	1690	1690	2010
SPP		0	0	0	0	0	0	0	0	0	0
WPP		600	700	750	800	850	900	950	1000	1050	1100
NPP		11000	11400	11400	11400	11400	11400	12400	12400	12400	13400
Export		0	500	0	0	0	0	0	0	0	0
Import		0	0	700	1000	1000	1000	2000	2000	2000	2000
"-" SHORTAGE/ "+" SURPLUS		0	0	0	-2510	-3660	-5510	-4760	-5260	-5760	-4990
Frequency containment reserve	at existing equipment	40	130	130	130	130	130	130	130	130	
	shortage	90	0	0	0	0	0	0	0	0	
Frequency restoration reserve (upward)	at existing equipment	1000	300	0	0	0	0	0	0	0	
	shortage	0	700	1000	1000	1000	1000	1000	1000	1000	
Frequency restoration reserve (downward)	at existing equipment	500	500	500	500	500	500	500	500	500	
	shortage	0	0	0	0	0	0	0	0	0	

Electrical energy balance forecast in the IPS of Ukraine for the period up to 2032 according to the baseline scenario, bln MWh

Components	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1. Electricity generation, total	157.0	159.1	153.8	144.7	145.0	141.3	141.6	143.8	144.8	145.6
including:										
1.1. TPP:	33.8	32.4	26.0	15.5	14.6	10.0	5.5	5.0	5.0	5.0
TPP share, %	21.5	20.4	16.9	10.7	10.1	7.1	3.9	3.5	3.5	3.4
1.1.1. Maneuverable with quick start-up/shut-down capability	—	0.1	0.2	0.4	0.5	0.5	0.5	0.5	0.5	0.5
1.2. CHP, cogeneration and modular plants	8.7	8.6	8.4	8.2	8.0	7.8	7.5	7.2	6.9	6.6
1.3. HPP	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
including:										
HPP on Dnieper River, Dniester River	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Other HPP	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1.4. PSP	1.8	1.9	2.1	2.3	2.3	2.3	2.3	2.3	2.4	2.4
1.5. NPP	87.5	89.0	89.0	89.0	89.0	89.0	93.0	95.0	95.0	95.0
NPP share, %	55.73	55.94	57.87	61.51	61.38	62.99	65.68	66.06	65.61	65.25
NPP capacity/load factor	0.72	0.73	0.73	0.73	0.73	0.73	0.71	0.73	0.73	0.73
1.6. Alternative sources in balance	18.1	20.0	21.0	22.2	23.5	24.6	25.7	26.7	27.9	29.0
RES share,%	11.53	12.57	13.65	15.34	16.21	17.41	18.15	18.57	19.27	19.92
Grow compared to last year, %	24.6	9.0	8.6	12.4	5.7	7.4	4.3	2.3	3.8	3.4
including:										
- WPP	8.8	10.0	10.6	11.2	11.9	12.5	13.1	13.7	14.4	15.0
- SPP	9.0	9.3	9.5	9.8	10.0	10.3	10.6	10.8	11.1	11.4
- other	1.3	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3.0	3.2
RES share including HPP, %	16.1	17.0	18.3	20.2	21.1	22.4	23.2	23.5	24.2	24.8
1.7. Energy storage*	—	—	—	—	—	—	—	—	—	—
2. Electricity import	0	1.5	6.0	10.0	10.0	10.0	11.0	12.0	12.5	13.5
3. Electricity export	0	2.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4. Electricity consumption (gross)	154.5	155.5	156	156.5	157	158	159.5	161	162.5	164
Grow compared to the last year, %	0.32	0.65	0.32	0.32	0.32	0.64	0.95	0.94	0.93	0.92
5. PSP electricity consumption in pumping mode	2.4	2.6	2.8	3.0	3.0	3.0	3.0	3.0	3.2	3.2
6. ES electricity consumption in charging mode*	—	—	—	—	—	—	—	—	—	—
7. RES regulation / curtailment (production limitation)**	1.0	1.0	1.0	0.9	0.7	0.6	0.6	0.6	0.6	0.6
8. SHORTAGE	0	0.0	0.4	4.8	5.0	9.7	9.9	8.2	8.4	8.1

*Note. *According to the Methodology (see Section 7 dedicated to formation of electricity load curves with economic dispatching) the balances are formed on an hourly basis. For this reason the energy of energy storages that do not have the capacity to continue operation for one hour is not provided here;*
*** Used in the context of providing the corresponding service of load shedding*

Electric power balance forecast in the IPS of Ukraine for 2023 according to the TSO baseline scenario, MW

Components of the balance		**heating season**			**flood season (weekday)**			**flood season (weekend)**			**summer season**			**non-heating season (weekday)**			**non-heating season (weekend)**		
		at 03:00	at 13:00	at 18:00	at 03:00	at 13:00	at 19:00	at 03:00	at 13:00	at 19:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00
Consumption (gross)		17300	22400	23400	12900	16200	17200	12400	14900	16200	13200	17400	17400	12700	16700	17700	12400	15500	16900
Coverage		18900	22400	23400	13530	17180	17200	12610	15880	16200	13830	17820	17400	13680	17540	17700	13030	16050	16900
Load-following TPP		3900	5150	5430	1480	1180	1880	1060	730	1430	2330	2020	3220	1630	1740	2820	980	750	1870
New highly flexible TPP with quick start-up/shut-down capability		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHP and modular plants		1540	1690	1780	530	470	490	570	560	580	340	330	250	390	380	350	420	410	430
Biofuel power plants		210	260	320	120	130	160	80	90	120	110	120	150	110	120	150	80	90	120
HPP, including;		250	650	1400	700	1000	2600	700	1000	2600	250	650	1200	250	500	1200	250	500	1400
- mini-, micro- and small HPP		20	25	25	35	35	40	35	35	40	15	20	20	15	15	15	20	20	20
PSP generation		0	0	1370	0	0	1370	0	0	1370	0	0	1680	0	0	1680	0	0	1680
SPP		0	1750	0	0	4500	0	0	4500	0	0	4600	0	0	4200	0	0	4200	0
WPP		1300	1200	1300	1100	900	1000	1100	900	1000	700	700	700	1200	1200	1300	1200	1200	1300
RES curtailment		0	0	0	0	700	0	0	1000	0	0	700	0	0	700	0	0	1200	0
NPP		11400	11400	11400	9500	9500	9500	9000	9000	9000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Export		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Import		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSP pumping		1600	0	0	630	980	0	210	980	0	630	420	0	980	840	0	630	550	0
"-" SHORTAGE/ "+" SURPLUS		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency containment reserve	at existing equipment	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (upward)	at existing equipment	1000	1000	700	1000	1000	1000	1000	1000	1000	1000	1000	500	1000	1000	500	1000	1000	300
	shortage	0	0	300	0	0	0	0	0	0	0	0	500	0	0	500	0	0	700
Frequency restoration	at existing equipment	500	500	500	500	200	500	500	200	500	300	200	500	300	101	500	200	0	500

reserve (downward)	RES curtailment	0	0	0	200	300	0	200	300	0	200	300	0	200	300	0	300	500	0

Electric power balance forecast in the IPS of Ukraine for 2027 according to the TSO baseline scenario, MW

Components of the balance		heating season			flood season (weekday)			flood season (weekend)			summer season			non-heating season (weekday)			non-heating season (weekend)		
		at 03:00	at 13:00	at 18:00	at 03:00	at 13:00	at 19:00	at 03:00	at 13:00	at 19:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00
Consumption (gross)		18100	23500	24500	13300	16600	17800	12800	15400	16800	13300	18100	18300	13000	17300	18600	12700	16100	17700
Coverage		18050	20600	21540	13510	17990	17300	13010	16380	16500	12430	18520	16840	13630	18280	17760	13330	17080	16900
Load-following TPP		3000	3000	2900	960	740	1260	960	230	1010	680	1070	2200	880	980	2070	580	280	1060
New highly flexible TPP with quick start-up/shut-down capability		0	0	150	0	0	0	0	0	0	0	0	150	0	0	150	0	0	100
CHP and modular plants		1090	1340	1230	380	370	340	420	410	430	240	230	200	240	230	250	270	260	280
Biofuel power plants		310	360	470	170	180	210	130	140	170	160	170	200	160	170	200	130	140	170
HPP, including;		250	650	1400	700	1000	2600	700	1000	2600	250	650	1200	250	500	1200	250	500	1400
- mini-, micro- and small HPP		20	25	25	35	35	40	35	35	40	15	20	20	15	15	15	20	20	20
PSP generation		0	0	1690	0	0	1690	0	0	1690	0	0	1690	0	0	1690	0	0	1690
SPP		0	1950	0	0	5000	0	0	5000	0	0	5200	0	0	4500	0	0	4500	0
WPP		1600	1500	1700	1600	1300	1400	1600	1300	1400	900	1000	1000	1500	1600	1600	1500	1600	1600
RES curtailment		0	0	0	0	300	0	0	900	0	0	0	0	0	300	0	0	800	0
NPP		11400	11400	11400	9500	9500	9500	9000	9000	9000	10000	10000	10000	10400	10400	10400	10400	10400	10400
Export		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Import		1700	1700	1000	0	0	500	0	0	300	1500	0	1000	0	0	840	0	0	800
PSP pumping		2030	0	0	210	1390	0	210	980	0	630	420	0	630	980	0	630	980	0
"-" SHORTAGE/ "+" SURPLUS		-380	-1200	-1960	0	0	0	0	0	0	0	0	-460	0	0	0	0	0	0
Frequency containment reserve	at existing equipment	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (upward)	at existing equipment	0	0	0	500	850	500	500	850	500	400	300	200	300	200	100	500	400	200
	at new equipment	150	150	0	150	150	150	150	150	150	150	150	0	150	150	0	150	150	50
	shortage	850	850	1000	350	0	350	350	0	350	350	550	700	550	650	900	350	450	750
Frequency restoration	at new equipment	300	200	500	200	200	500	300	100	500	300	200	500	200	300	500	100	200	500

reserve (downward)	RES curtailment	200	300	0	300	300	0	200	400	0	200	300	0	300	200	0	400	300	0

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Electric power balance forecast in the IPS of Ukraine for 2032 according to the TSO baseline scenario, MW

Components of the balance		heating season			flood season (weekday)			flood season (weekend)			summer season			non-heating season (weekday)			non-heating season (weekend)		
		at 03:00	at 13:00	at 18:00	at 03:00	at 13:00	at 19:00	at 03:00	at 13:00	at 19:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00
Consumption (gross)		19500	25400	26600	13800	17200	18600	13300	16200	17600	13500	18900	19100	13400	18200	19600	13000	17200	18900
Coverage		17150	19750	20660	13430	18180	17600	12940	17180	17100	12980	19320	17100	13990	18620	17600	13630	18040	17400
Load-following TPP		900	850	800	30	80	290	40	20	440	380	620	1240	290	70	590	50	10	290
New highly flexible TPP with quick start-up/shut-down capability		0	0	150	0	0	100	0	0	0	0	0	150	0	0	150	0	0	100
CHP and modular plants		990	940	780	430	420	340	470	440	480	190	180	50	290	280	200	300	310	330
Biofuel power plants		310	410	520	170	180	260	130	140	170	160	170	250	160	170	250	110	130	170
HPP, including;		250	650	1400	700	1000	2600	700	1000	2600	250	650	1200	250	500	1200	230	500	1400
- mini-, micro- and small HPP		20	40	40	40	40	60	40	40	60	20	20	20	20	20	20	20	20	20
PSP generation		0	0	2010	0	0	2010	0	0	2010	0	0	2010	0	0	2010	0	0	2010
SPP		0	2200	0	0	5700	0	0	5700	0	0	5900	0	0	5200	0	0	5200	0
WPP		2100	2000	2200	2000	1600	1800	2000	1600	1800	900	1000	1000	1900	2000	2000	1900	2000	2000
RES curtailment		0	0	0	0	900	0	0	1300	0	0	300	0	0	700	0	0	1200	0
NPP		12400	12400	12400	10000	10000	10000	9500	9500	9500	11000	11000	11000	11000	11000	11000	11000	11000	11000
Export		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Import		2500	2000	2000	1000	0	1000	1000	0	500	1500	0	2000	500	0	2000	0	0	1500
PSP pumping		2020	0	0	630	980	0	640	980	0	980	420	0	1090	420	0	630	840	0
“-” SHORTAGE/ “+” SURPLUS		-1870	-3650	-3940	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency containment reserve	at existing equipment	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130	130
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (upward)	at existing equipment	0	0	0	300	200	500	300	200	500	200	300	200	100	200	100	100	200	100
	at new equipment	150	150	0	150	150	50	150	150	150	150	150	0	150	150	0	150	150	50
	shortage	850	850	1000	550	650	350	550	650	350	650	550	800	750	650	900	750	650	850
Frequency restoration	at existing equipment	100	100	500	100	100	500	300	100	500	200	200	500	200	100	500	0	100	500

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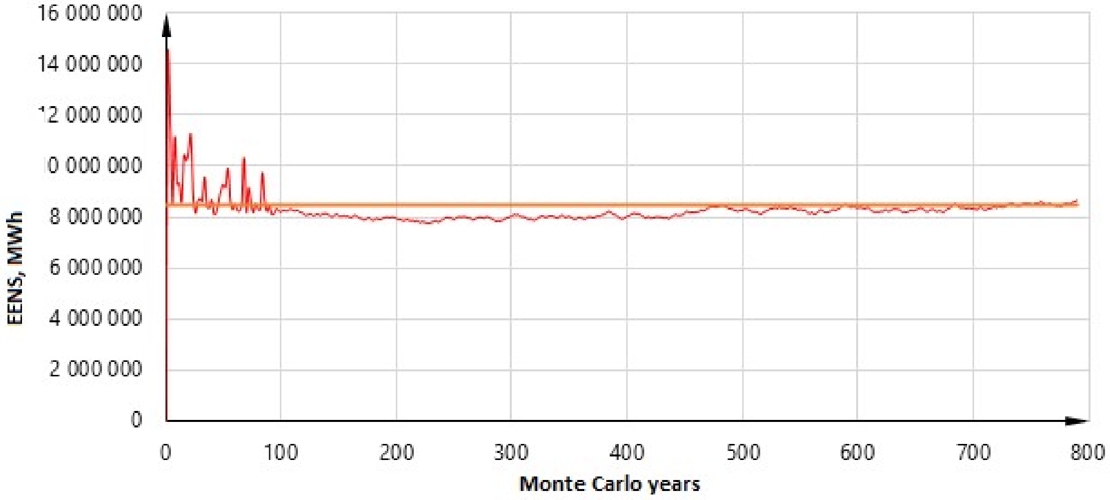
reserve (downward)	RES curtailment	400	400	0	400	400	0	200	400	0	300	300	0	300	400	0	500	400	0

Adequacy indicators were calculated using stochastic modelling methods in combination with the Monte Carlo method. Thus, according to the Methodology, for each year of the 2023–2032 period, a number of Monte Carlo years were modelled (this way baseline scenario indicators factored in different probabilities of changes in the projected demand and supply, changes in weather conditions, unplanned shutdown of elements of the IPS of Ukraine, intermittent generation by WPP, SPP and HPP, etc.), which made it possible to achieve the convergence of results or the sufficient convergence in accordance with the probability theory.

Since other probabilistic indicators and criteria are derived or obtained by multiplying/dividing by the indicators of the EENS criterion, they are not shown, because they repeat the change frequency and form of the latter (see the Methodology).

Graphic representation of the convergence of results of stochastic modelling using the Monte Carlo method (on the example of the EENS indicator for 2032)



Results of the adequacy assessment according to the baseline scenario, taking into account the possibility of electricity imports/exports, are presented in Table (in addition, it should be emphasized that when assessing the adequacy of generating capacities it was taken into account that a number of coal-fired TPPs and CHPs in the Polish power system will be gradually decommissioned operating under conditions of the recently introduced mechanism of the capacity adequacy assurance. For this reason, using such capacities for market import/export operations (including for purposes of providing Ukrainian consumers with electric energy) is controversial.

Results of adequacy assessment of the IPS of Ukraine in the period of 2023–2032 according to the baseline scenario

Years	Indicators		
	EENS, MWh	*LOLE*, h	*LOLP*, %
2023	289	0,61	0,010
2024	2 753	2,36	0,027
2025	422 055	286	6.3
2026	4 830 297	608	13.6
2027	5 036 935	1 831	40.6
2028	9 658 503	2 726	63.6
2029	10 108 895	2 733	66.6
2030	8 094 306	2 597	55.1
2031	8 278 358	2 361	64.5
2032	8 332 253	2 720	69.1

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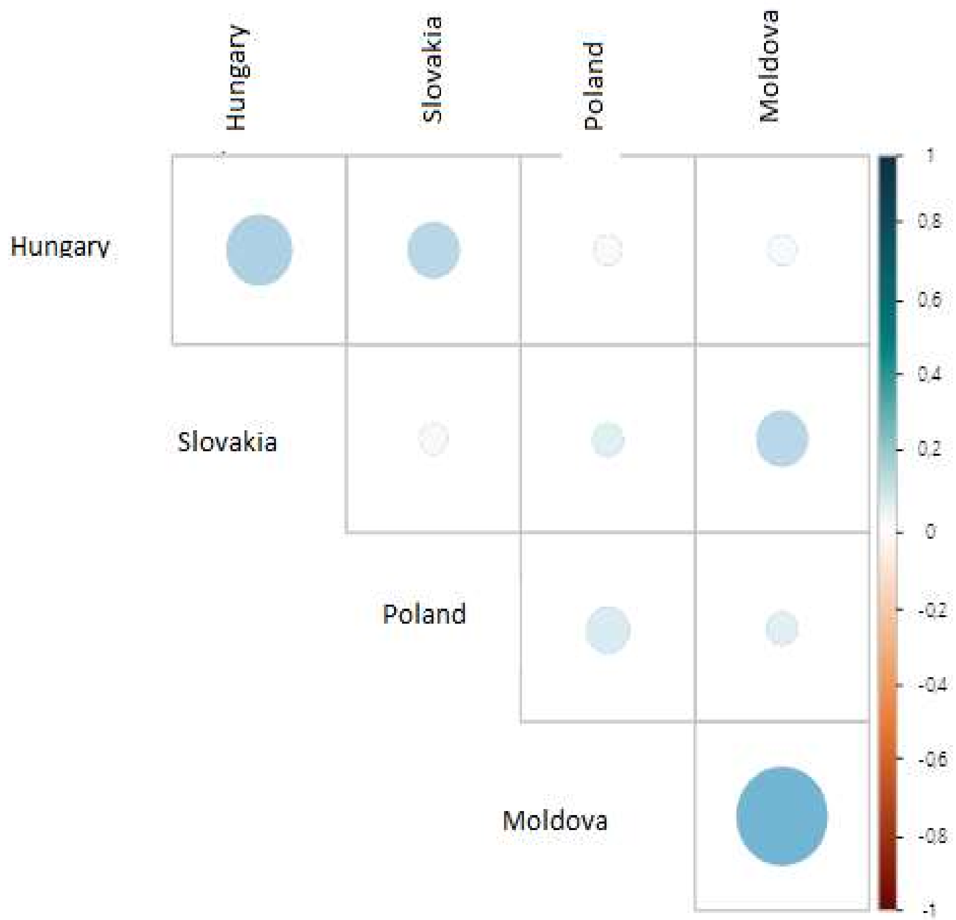
It should be noted that there is a close correlation (Figure 6.3) between the generation adequacy of the IPS of Ukraine and the neighboring power systems, where the latter act not only as the facilities with own generating capacities but also as the facilities transiting to other countries operating within the unified electricity market of Europe.

This indicates that in the event of a power shortage in Ukraine's IPS, a similar situation is very likely to occur in the power systems of neighbouring countries, especially in Moldova, as part of IPS of Ukraine's consumers are energized through Moldova's power system. This actually transforms the latter into a satellite of the IPS of Ukraine in the context of ensuring the generation adequacy. In the longer term, after the implementation of existing network development plans between the power systems of Moldova and Romania, the correlation between the adequacy of generating capacities in the power systems of Ukraine and Moldova will weaken and at the same time will strengthen between the power systems of Ukraine and Romania.

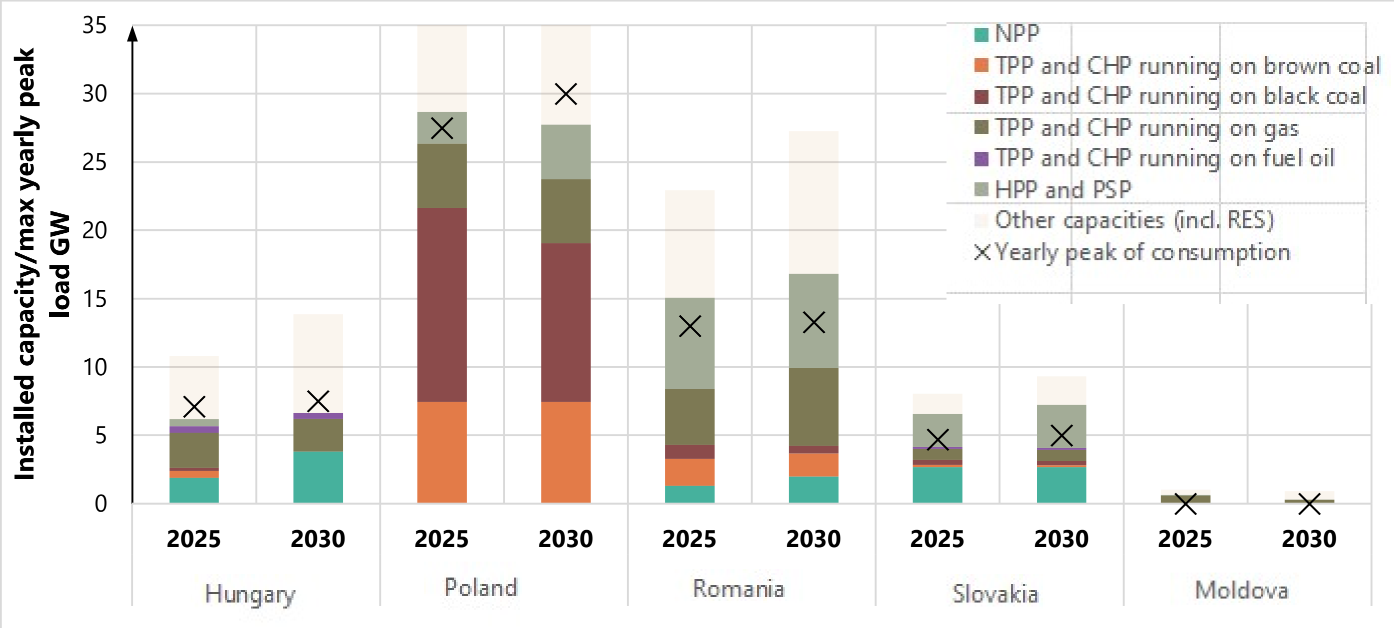
Correlation dependence (through the Pearson correlation factor) of the shortage of generating capacities between the IPS of Ukraine and neighbouring power systems (illustrated by year 2026)



As illustrated in Figure, power systems of such countries as Hungary are unable to cover their own yearly maximum consumption with their own generating capacities because they have in their generation mix many power plants with interruptible power. In this case, given that Figure shows the total installed capacity but not the available capacity to cover the maximum power consumption, the situation becomes even more pragmatic.

It should also be stressed that nowadays almost all neighbouring countries (except Poland) are net importers, which in the event of power shortage in the IPS of Ukraine limits the use of imported capacities (it should be noted that only Poland's power system is commensurate with Ukraine's power system) and foreign transit transmission lines (most of their transfer capacity is used to cover domestic demand) to ensure adequacy in Ukraine.

Generation mix and yearly maximum consumption in interfacing countries – ENTSO-E members, illustrated by years 2025 and 2030



The above data demonstrates that Ukraine's power system in the 2025–2032 horizon according to the scenario assumptions given above is characterized by the generation inadequacy. In other years of the study, IPS of Ukraine's is not facing the adequacy issues because as expected it will keep its baseload, load-following and peaking capacities in sufficient volumes. Subsequently, starting from 2025, a rapid reduction of capacity at existing TPPs and insufficient commissioning of new peaking capacities will entail a significant deterioration of indicators that characterize the generation adequacy and do not meet the adequacy criterion.

In terms of the flexibility assessment, it should be noted that in the context of the rapid deployment of generating capacities using RES and their effective integration (using such technologies such as flexible energy storages, demand-side management systems, etc.), some TSOs of Europe and ENTSO-E in particular alongside with the adequacy assess the flexibility of power systems. Approaches most frequently used for this purpose are:

1) rapid analysis (based on technical data of demand-side management systems, capacity of conventional generation, and flow control);

2) analysis of residual imbalance (based on results of statistical analysis of data on the error of consumption/generation forecasts and their fluctuations);

3) modelling.

The report for the purposes of the generation flexibility assessment used modelling and the analysis of residual imbalance (approaches 2 and 3).

Since the flexibility may be required at different times and for different periods, it is proposed to conditionally divide it into the following types:

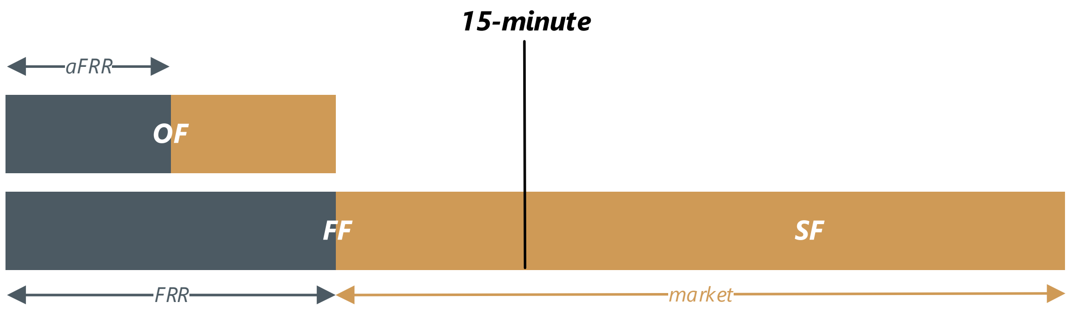
1) slow flexibility – SF, which is a capability to compensate for imbalances that have arisen due to the adjustment of demand/generation forecasts, which precedes opening of the trading gate in the day-ahead market. In addition, this flexibility applies to the scheduled or contingency loss of

capacity (including transmission lines), which is reported before closing of the trading gate in the intraday market. This flexibility can be provided by most of the installed capacity, as there is time to ramp power of the engaged generating equipment, or even to start-up/shut-down it;

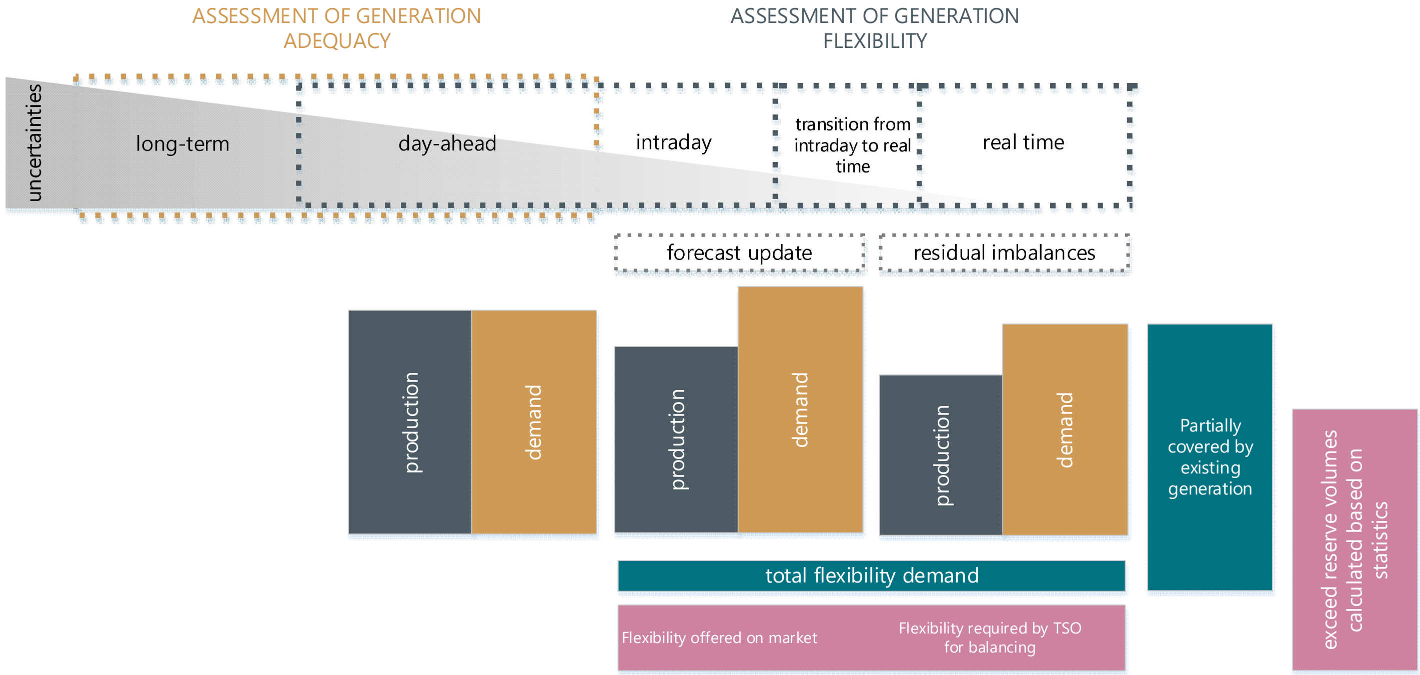
2) fast flexibility – FF, which is a capability to compensate for imbalances stemming from unexpected changes in generation/consumption in real time or during the time for which the last forecast arrives before closing the trading gate in the balancing market;

3) operational flexibility – OF, which is the capability to compensate for imbalances stemming from unexpected changes in generation/consumption in real time, but as distinct from the fast flexibility the time interval of this flexibility is within the 1–15 minute period (expressed in MW/minute). The flexibility of this type can be ensured by frequency containment reserves (solely by load-following technologies, such as running generation units, some HPPs/PSPs, energy storages and controlled flexible demand-side response systems), and its activation releases fast and slow flexibility.

Interrelation between flexibility and reserve capacities



As shown in Figure, the analysis of flexibility means the assessment of the required flexibility of the equipment with which the IPS of Ukraine will operate with no residual imbalance (during the period from the start of gate closure in the intraday market until the occurrence of events in real time). In general, the capability to remove residual imbalances in a conditionally long term (one day and more) is also the flexibility, but such flexibility is covered by the assessment of adequacy because it is factored in modelling using the Monte Carlo method, resulting in preliminary hourly coverage of electric load curves. Boundaries of generation adequacy and flexibility assessment



The residual imbalance in this Report is determined as the electricity demand minus energy served (including from RES) in the market segments preceding the balancing market and based on the forecast (not actual) supply/demand data.

Therefore, based on the assessment of the residual imbalance, the future share of the flexibility demand to be provided by the TSO should be estimated, as such flexibility share depends on the flexibility, which the market can provide to the system. Then the required volumes of reserves and their characteristics are determined (taking into account the probability of imbalance as a result of actual fluctuations in supply/demand and incorrect demand/consumption forecasts).

Thus, because of the insufficient flexibility, flexible or reserve capacities, from time to time there occur or may occur situations when with a too quick change in load or change in generation (including RES generation considering that there are many renewables) the dispatched capacities are unable to respond quickly and fully to such change (having relatively low speed of load gaining/shedding if compared to the speed of load change in the system or RES generation as shown in Figure), which eventually leads to partial non-coverage of the electric load curve.

In turn, the presence of uncovered areas in the electric load curve (i.e., EENS) requires either an accelerated load gaining/shedding (including the speed of activation) of dispatched generating capacities (i.e., bringing existing generating capacities to the requirements of TNC), or early activation of generating equipment in the period preceding the expected peak load. It is difficult to implement the first option because it is necessary to upgrade existing generating equipment or to build a new equipment.

It is difficult to implement the second option because there are no technical means in the IPS of Ukraine (such as energy storage, batteries or other technologies such as Power to X) that will be able absorb temporary aperiodic shortages/surpluses of electric energy.

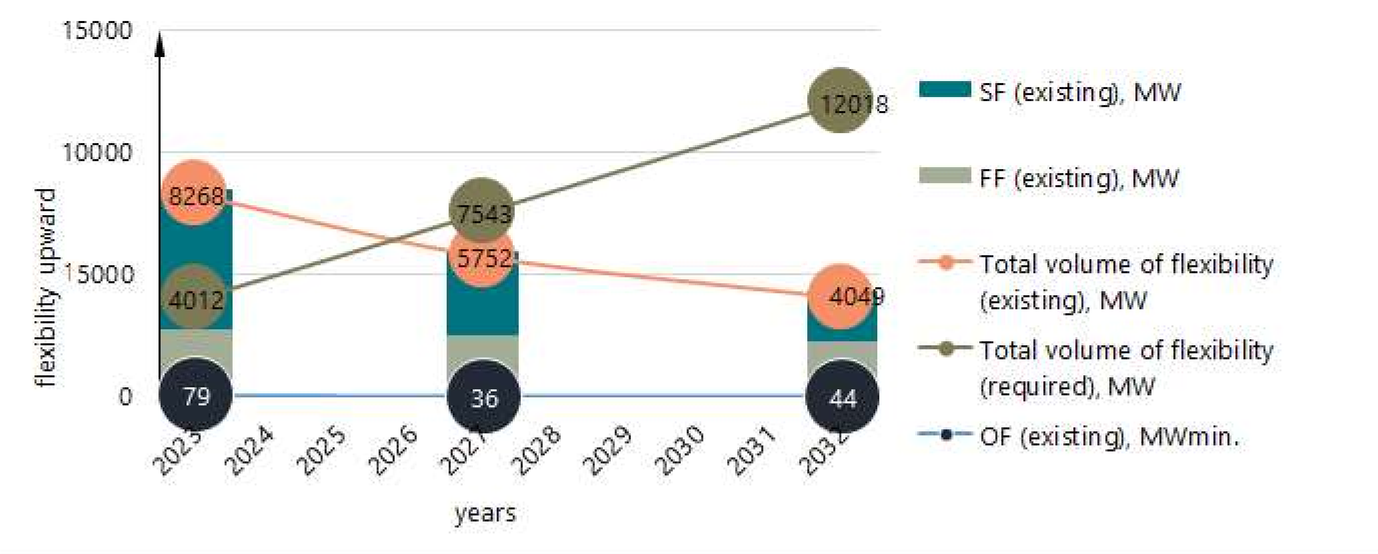
In accordance with ENTSO-E clarifications, the approach is changed to the formation of the coverage curve, according to which emergency reserves (FCR, FRR, RR) can be used only for their intended purpose (i.e., to provide reserves in accordance with the N-1 criterion), and cannot be used to ensure the adequacy of generating capacities, which, in turn, leads to the situation when in the absence of at least one type of reserve at a given hour (even when the load curve is fully covered), the system is characterized by the generation inadequacy (inflexibility).

Given the above and the growing impact of RES generation technologies that are difficult to forecast, the volumes of reserve capacities should grow too (except for constant volumes of reserves for contingency according to N–1 criterion), which is confirmed by modelling results (probability of occurrence of various situations in case of simultaneous activation of balancing capacities to compensate for unforeseen fluctuations of demand/supply, errors of forecasts of demand/supply, etc.), where the volume of currently required reserve capacity is determined, which will provide the required operational flexibility (OF) of the IPS of Ukraine.

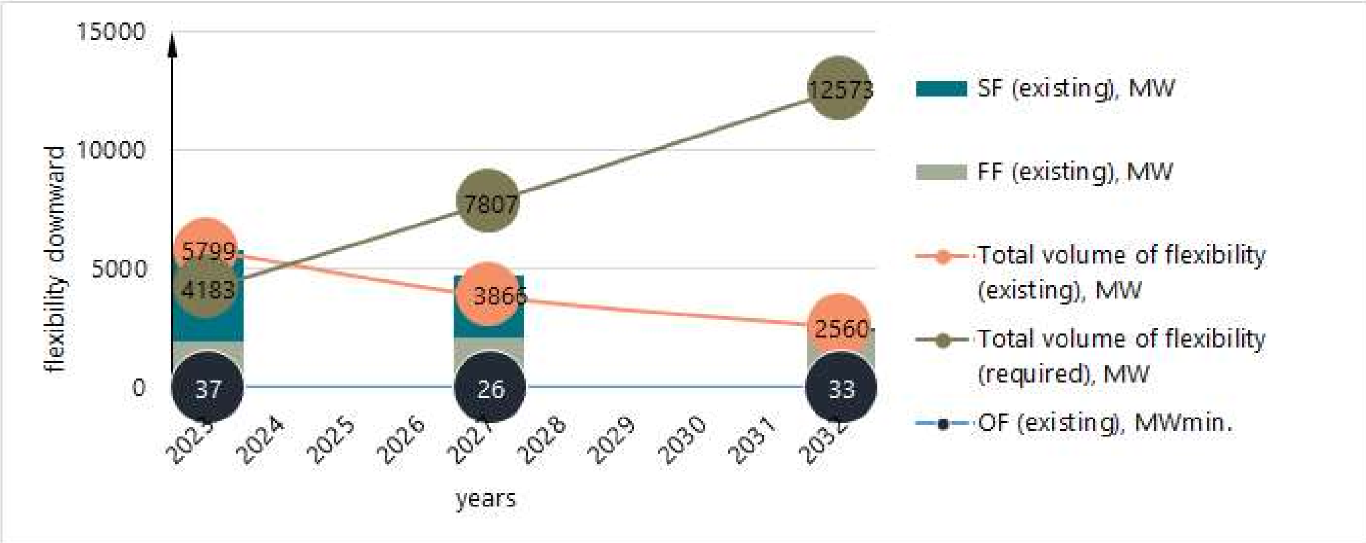
It is worth noting that with the improvement of the quality of supply/demand forecasts, the development of competition in all market segments, the deployment of RES generating capacities, as well as the introduction of new technologies, the share of necessary flexibility (especially operational flexibility) will gradually decrease.

Figures below illustrate the supply of IPS of Ukraine's with flexibility under the baseline scenario, which shows that the situation in the period 2023–2032 is steadily deteriorating.

IPS of Ukraine's supply with flexibility for upward loading according to the baseline scenario



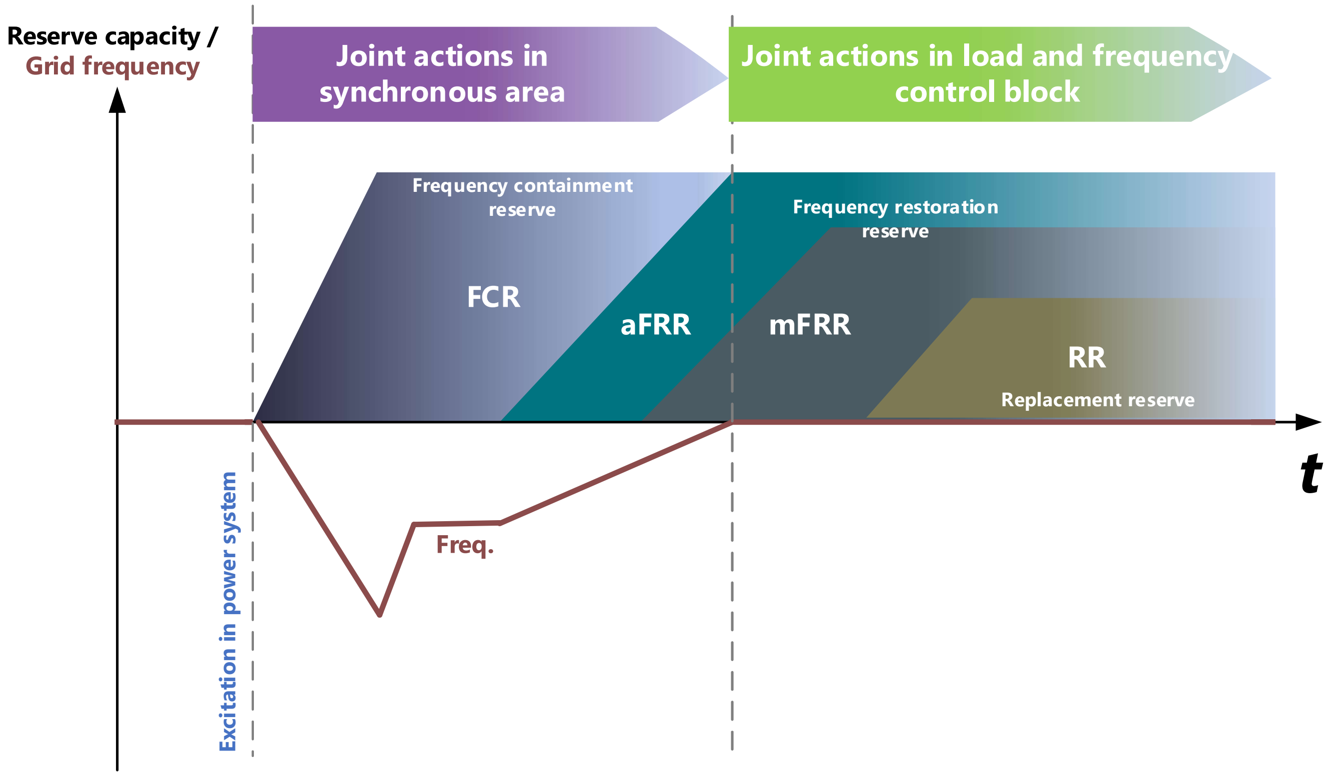
IPS of Ukraine's supply with flexibility for downward loading according to the baseline scenario



Flexibility assessment under the baseline scenario for the parallel operation with power systems of neighbouring countries includes potential imports of electricity and reserves. Flexibility assessment results are provided in the table below.

The calculations show that according to the baseline scenario it is impossible to ensure the generation adequacy nor flexibility in the IPS of Ukraine (it should be noted that the above values of the calculated indicators are averaged, and the range of these values is quite wide).

Graphic representation of the approach of shared capacity reservation by interfacing countries applied in the Report



Maximum shortage of reserve capacities and the total number of hours of such shortage according to the baseline scenario (generalized for all Monte Carlo years in stochastic simulation)

Years	Indicators					
	Reserve for upward loading, MW	Average maximum shortage of reserves for upward loading, MW	Total number of hours of shortage of reserves for upward loading per year, h	Reserve for downward loading, MW	Average maximum shortage of reserves for downward loading, MW	Total number of hours of shortage of reserves for downward loading per year, h
2023	1,000	360	552	500	301	409
2024	1,000	411	504	500	266	630
2025	1,000	419	557	500	310	259
2026	1,000	472	663	500	288	432
2027	1,000	589	650	500	315	425
2028	1,000	461	560	500	336	369
2029	1,000	539	636	500	369	558
2030	1,000	449	474	500	329	537
2031	1,000	348	604	500	368	616
2032	1,100	486	549	500	300	467

The curves of electric load coverage for weekdays and weekends of the typical periods of 2023, 2026, 2032 and yearly balances of power and capacity were calculated using modelling tools for this scenario. Balances reflect average values of SPP and WPP generation for the respective periods, hydro resources of low water year, NPP generation optimal for the IPS of Ukraine by months, PSP generation modes (generation/ pumping) optimal for IPS of Ukraine, curves of electric load coverage and curves of available reserves – probable values of generation and consumption. In addition, it should be noted that the above balances indicate averaged values of RES generation meaning that their generation in the given hours of the respective days can be both lower and higher than these values (by preliminary assessments the deviation can be ± 20%).

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Electrical energy balance forecast in the IPS of Ukraine until 2032 according to the target scenario, bln MWh

Components of the balance	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1. Electricity generation, total	159.7	164.0	164.3	163.2	163.9	165.4	167.3	174.5	177.9	181.4
including:										
1.1. TPP:	37.2	35.1	33.2	25.4	26.4	23.5	24.3	23.6	24.1	18.7
TPP share, %	23.3	21.4	20.2	15.6	16.1	14.2	14.5	13.5	13.5	10.3
including:										
1.1.1. Highly flexible with quick start	—	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.4	1.8
For reference: ICUF of highly flexible TPP	—	8	8	8	8	9	9	10	11	12
1.1.2. Existing mid-merit	37	34.5	26.2	24.7	25.6	22.6	21.5	19.2	17.5	8.2
For reference: ICUF of existing load-following TPP	24	24	19	23	23	26	36	38	43	28
1.1.3. New mid-merit	—	—	—	—	—	—	1.7	3.2	5.1	8.7
For reference: ICUF of new load-following TPP	—	—	—	—	—	—	39	40	39	40
1.2. CHP, cogeneration, modular plants	8.7	8.6	8.4	8.2	8	7.8	7.5	7.2	6.9	6.6
1.3. HPP	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
including:										
HPP on Dnieper, Dniester Rivers	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
other HPP	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1.4. PSP	1.7	1.8	1.9	2.1	2.2	2.3	2.3	2.3	2.3	2.3
1.5. NPP	85.2	88.4	87.9	91.8	89.3	90.4	89.7	94.7	95.8	102.4
NPP share, %	53	54	54	56	54	55	54	54	54	56
NPP ICUF	0.70	0.73	0.73	0.76	0.74	0.75	0.74	0.73	0.74	0.74
1.6. Alternative sources in balance	19.1	21.9	24.3	26.7	29.0	32.1	34.2	37.2	39.1	41.3
RES share, %	12	13.3	14.8	16.3	17.7	19.4	20.5	21.3	22.0	22.8
Grow compared to last year, %	28.3	11.7	11.1	10.4	8.3	9.6	5.6	4.1	3.1	3.7
including:										
- WPP	7.8	8.9	9.9	11.2	12.4	13.5	14.5	15.8	16.8	17.9
- SPP	9.2	10.2	11.1	11.6	12.0	13.3	13.8	14.7	15.2	15.9
- other (including BioPP)	2.1	2.68	3.3	3.9	4.6	5.28	5.96	6.63	7.1	7.55
HPP RES share, %	16	17.7	19.1	20.7	22.0	23.7	24.7	25.4	26.0	26.7
1.7. Energy storage	0.7	1.2	1.4	1.9	1.9	2.1	2.2	2.4	2.6	3.0
2. Electricity import	0	1.5	1.7	2.0	1.9	2.1	2.1	2.2	2.3	2.6
3. Electricity export	0	4.5	4.1	2.3	2.0	2.3	2.5	7.7	9.6	11.6
4. Consumption (gross)	154.5	155.5	156.0	156.5	157.0	158.0	159.5	161.0	162.5	164.0
Grow compared to last year, %	0.3	0.7	0.3	0.3	0.3	0.7	1.0	0.9	0.9	0.9
5. PSP consumption in pumping mode	2.4	2.5	2.6	2.9	3.1	3.2	3.2	3.2	3.2	3.2
6. ES consumption in charging mode	0.8	1.3	1.6	1.9	2.1	2.3	2.4	2.7	2.9	3.1
7. RES regulation / curtailment (production limitation)*	—	—	—	—	—	—	—	—	—	—
8. SHORTAGE	—	—	—	—	—	—	—	—	—	—

Note. * Used in the context of provision of the corresponding load shedding service

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Electric power balance forecast in the IPS of Ukraine for 2023 according to the target scenario, MW

Components of the balance		heating season			flood season (weekday)			flood season (weekend)			summer season			non-heating season (weekday)			non-heating season (weekend)		
		at 03:00	at 13:00	at 18:00	at 03:00	at 13:00	at 20:00	at 03:00	at 13:00	at 20:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00
Consumption (gross)		17208	22460	23159	12928	16428	17580	12169	14672	16463	13430	17363	17777	12622	16844	17913	12167	15239	16347
Coverage		19007	22550	23159	13344	17676	17580	12521	16688	16463	13587	17498	17777	13138	17612	17913	12167	17038	16347
Load-following TPP		3929	5338	5744	921	936	1956	691	735	1047	1730	1252	3785	1720	1101	3557	698	855	2221
Highly flexible TPP		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TPP and modular plants		1459	1453	1272	509	506	466	541	536	530	301	322	345	398	392	414	338	356	294
BioTPP		210	260	320	120	130	160	80	90	120	110	120	150	110	120	150	80	90	120
HPP, including:		314	444	959	622	629	2607	406	437	2140	364	191	1316	158	217	1459	330	346	1553
- mini-, micro- and small HPP		20	25	25	35	35	40	35	35	40	15	20	20	15	15	15	20	20	20
PSP generation		0	0	1521	0	0	1436	0	0	1587	0	0	1223	0	0	1587	0	0	1587
ES generation		0	0	0	0	0	0	0	0	136	0	0	0	0	0	158	0	0	97
SPP		0	2127	0	0	4359	0	0	4007	0	0	4864	0	0	4994	0	0	4790	0
WPP		1406	1275	1485	1213	1197	1084	903	925	1082	1137	844	974	754	878	767	840	671	673
RES curtailment		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPP		11489	11454	11558	9859	9820	9771	9800	9859	9722	9845	9805	9884	9898	9810	9722	9780	9829	9702
Export		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Import		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSP pumping		1799	90	0	416	1248	0	352	2016	0	135	135	0	416	768	0	0	1799	0
ES charging		0	0	0	0	0	0	0	0	0	22	0	0	100	0	0	0	0	0
Frequency containment reserve	at existing equipment	136	135	136	137	131	135	133	137	132	136	131	136	135	132	134	131	131	136
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (upward)	at existing equipment	717	704	719	714	747	713	707	707	706	714	706	733	738	709	722	732	715	723
	at new equipment	312	314	299	299	307	300	295	310	310	315	304	315	302	303	304	307	305	310
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (downward)	at existing equipment	290	310	303	506	195	210	210	305	197	294	211	212	304	96	102	293	103	618
	at new equipment	212	205	201	193	0	315	0	0	317	209	0	310	207	0	306	197	0	0
	RES curtailment	0	0	0	0	312	0	299	196	0	0	312	0	0	403	0	0	401	484

Electric power balance forecast in the IPS of Ukraine for 2027 according to the TSO target scenario, MW

Components of the balance		heating season			flood season (weekday)			flood season (weekend)			summer season			non-heating season (weekday)			non-heating season (weekend)		
		at 03:00	at 13:00	at 18:00	at 03:00	at 13:00	at 20:00	at 03:00	at 13:00	at 20:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00
Consumption (gross)		18690	24070	24964	13876	17898	18989	13206	15962	18037	14452	19131	18997	13596	18005	19356	13181	16541	17860
Coverage		20173	24377	24558	15019	19601	19889	13996	19339	19437	15682	21551	19620	14996	21054	19811	14859	19821	18478
Load-following TPP		4982	5569	6388	2220	1042	1943	1298	820	1806	2202	1756	3782	2410	1783	4092	1943	710	2882
Highly flexible TPP		0	200	300	0	0	827	0	0	611	0	0	717	0	0	625	0	0	950
TPP and modular plants		1440	1240	1080	330	320	240	470	410	330	120	110	110	190	180	100	250	190	150
BioTPP		460	610	720	270	280	360	180	190	270	260	270	260	260	270	350	180	190	270
HPP, including:		238	855	1626	648	654	2804	597	614	2770	1251	1296	1285	1126	1536	1536	1496	1513	1508
- micro-, mini- and small HPP		20	25	25	35	35	40	35	35	40	15	20	20	15	15	15	20	20	20
PSP generation		0	0	1046	0	0	1698	0	0	1698	0	0	1568	0	0	1624	0	0	1698
ES generation		0	230	38	0	0	446	0	0	481	0	0	156	0	0	348	0	0	120
SPP		0	2600	0	0	5781	0	0	5781	0	0	6533	0	0	6116	0	0	6318	0
WPP		1818	1738	1925	1551	1524	1471	1551	1524	1471	1449	1186	1242	1010	1169	1036	1090	900	900
RES curtailment		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPP		10835	10835	10835	9800	9800	9800	9800	9800	9800	10200	10200	10200	9800	9800	9800	9800	9800	9800
Export		0	150	0	797	0	900	768	1352	1400	1140	4	623	1400	543	455	1320	1399	618
Import		380	720	406	0	668	0	0	0	0	0	0	0	0	0	0	0	0	0
PSP pumping		1383	877	0	324	1971	0	0	1743	0	0	2016	0	0	2016	0	135	1881	0
ES charging		480	0	0	22	400	0	22	282	0	90	400	0	0	490	0	223	0	0
Frequency containment reserve	at existing equipment	137	135	131	135	133	130	131	136	133	137	133	132	133	134	134	134	132	135
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (upward)	at existing equipment	520	499	953	51	51	400	51	52	501	53	50	211	50	52	51	51	51	53
	at new equipment	519	495	53	990	1001	641	956	972	505	984	948	814	974	982	969	970	998	990
	shortage	0	6	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Frequency restoration reserve (downward)	at existing equipment	106	384	97	103	300	0	106	302	488	102	308	0	105	48	0	98	0	0
	at new equipment	393	102	402	421	92	497	394	0	0	397	0	519	0	459	480	0	482	492

	RES curtailment	0	0	0	0	109	0	0	206	0	0	194	0	406	0	0	408	0	0

Electric power balance forecast in the IPS of Ukraine for 2032 according to the TSO target scenario, MW

Components of the balance		heating season			flood season (weekday)			flood season (weekend)			summer season			non-heating season (weekday)			non-heating season (weekend)		
		at 03:00	at 13:00	at 18:00	at 03:00	at 13:00	at 20:00	at 03:00	at 13:00	at 20:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00	at 03:00	at 13:00	at 21:00
Consumption (gross)		20628	26684	27910	15299	19524	20943	14590	17642	19660	15983	21252	21035	14905	20284	21552	14623	18501	19526
Coverage		20860	27644	27304	16840	22957	23095	15982	22304	21637	17389	24893	22890	16876	23812	23466	16616	22660	21574
Load-following TPP		1877	3497	3500	1117	188	1155	404	288	1194	1260	423	2701	2011	1094	3503	1146	316	2328
Highly flexible TPP		0	1338	1236	0	0	1218	0	0	39	0	0	1292	0	0	1038	0	0	1432
TPP and modular plants		1789	1841	2090	677	681	734	712	729	750	457	492	516	543	526	593	482	475	508
BioTPP		809	1189	1289	474	371	578	295	282	483	440	397	750	523	472	839	377	285	609
HPP, including:		232	584	1553	640	623	2798	584	596	2692	981	1261	1311	940	188	1593	1544	546	1463
- mini-, micro- and small HPP		20	40	40	40	40	60	40	40	60	20	20	20	20	20	20	20	20	20
PSP generation		0	0	899	0	0	2022	0	0	2022	0	0	1929	0	0	2022	0	0	2022
ES generation		0	0	267	0	0	683	0	0	713	0	0	370	0	0	604	0	0	177
SPP		0	3131	0	0	7226	0	0	7517	0	0	8470	0	0	7999	0	0	8239	0
WPP		2653	2442	2848	2168	2068	2083	2243	2068	2075	2100	1675	1724	1379	1733	1498	1598	1306	1342
RES curtailment		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NPP		13500	13622	13622	11765	11800	11824	11743	10824	11668	12151	12176	12298	11480	11800	11776	11469	11492	11694
Export		0	157	0	694	1923	2353	647	2230	2092	1406	1503	1854	1806	1448	2025	1573	2034	2048
Import		624	580	606	0	0	201	0	0	115	0	77	0	0	0	112	0	0	0
PSP pumping		135	1383	0	135	1510	0	0	2432	0	0	2215	0	135	2080	0	135	2125	0
ES charging		720	0	0	711	0	0	744	0	0	0	0	0	29	0	0	286	0	0
Frequency containment reserve	at existing equipment	136	131	134	137	132	131	130	135	133	132	133	134	136	132	131	133	131	137
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (upward)	at existing equipment	164	557	528	227	83	850	468	71	386	403	474	1017	336	408	740	409	475	694
	at new equipment	983	564	630	878	1241	282	874	1301	873	1269	1278	398	1207	1233	392	1104	1229	432
	shortage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Frequency restoration reserve (downward)	at existing equipment	0	274	0	0	309	0	305	275	491	104	312	0	0	306	0	0	162	0
	at new equipment	518	244	486	527	0	520	0	242	0	404	0	503	511	40	513	478	347	521
	RES curtailment	0	0	0	0	208	0	192	0	0	0	207	0	0	155	0	0	0	0

Calculations (according to the TSO target scenario for the stochastically simulated Monte Carlo years) that fully reflect the situation with the shortage of capacity and reserves for the next 10 years are summarized in the table below.

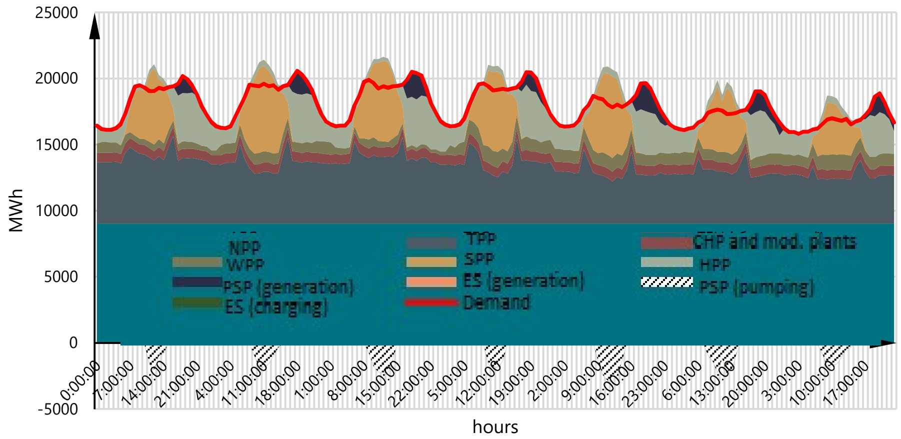
Results of adequacy assessment of the IPS of Ukraine for 2023–2032 according to the TSO target scenario

Years	Indicators		
	EENS, MWh	*LOLE*, h	*LOLP*, %
2023	104	0.09	0.003
2024	152	0.12	0.003
2025	226	0.17	0.004
2026	443	0.38	0.006
2027	287	0.25	0.009
2028	92	0.09	0.010
2029	649	0.67	0.011
2030	287	0.25	0.016
2031	920	0.81	0.023
2032	1117	0.85	0.025

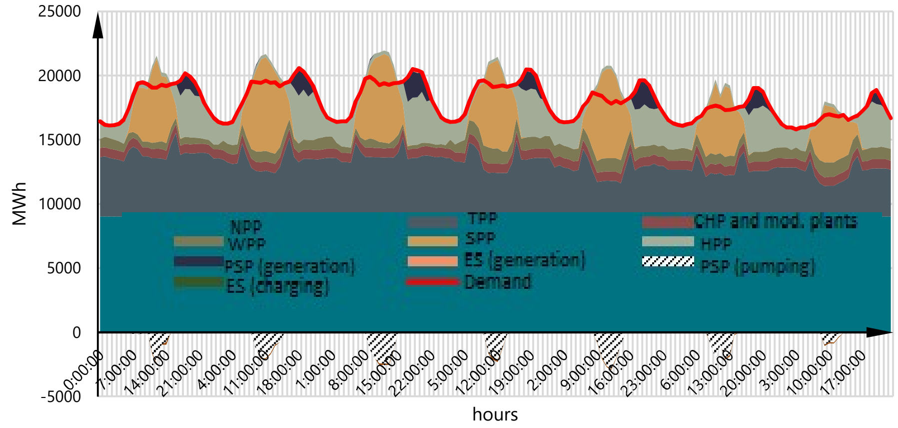
Maximum shortage of reserve capacities and total number of hours of such shortage according to the TSO target scenario (generalized for all Monte Carlo years in stochastic simulation)

Years	Indicators					
	Reserve for upward loading, MW	Average maximum shortage of reserves for upward loading, MW	Total number of hours of shortage of reserves for upward loading per year, h	Reserve for downward loading, MW	Average maximum shortage of reserves for downward loading, MW	Total number of hours of shortage of reserves for downward loading per year, h
2023	1,000	33	3	500	3	12
2024	1,000	9	6	500	10	3
2025	1,000	2	14	500	8	13
2026	1,000	15	14	500	4	10
2027	1,000	19	8	500	4	10
2028	1,000	37	9	500	9	6
2029	1,000	22	13	500	18	6
2030	1,000	26	8	500	4	8
2031	1,000	16	7	500	16	10
2032	1,100	19	9	500	9	9

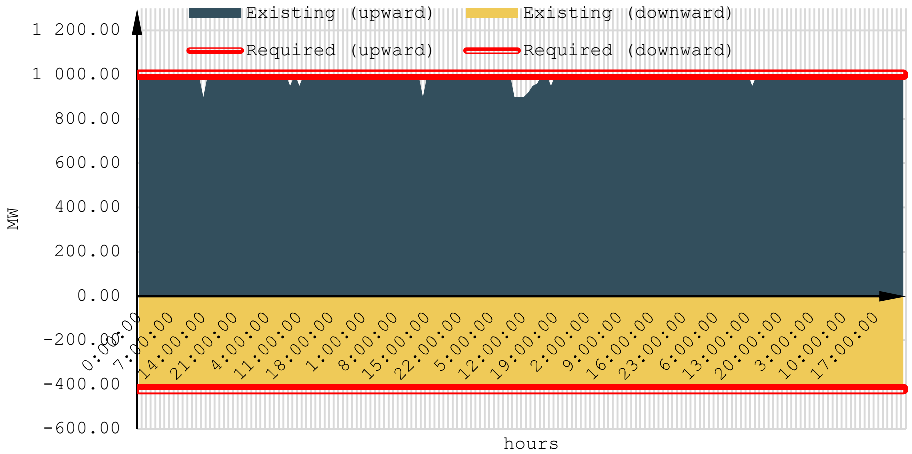
Data in Tables supports the conclusion that according to the TSO target scenario it will be possible to meet the generation adequacy and flexibility requirements throughout the entire period of 2023–2032.
As an example, see the results of simulated coverage of the electric load curve in the IPS of Ukraine according to the baseline and target scenarios for the most typical days (yearly load peaks/off-peaks and spring flood) of 2023, 2026 and 2032 shown in Figures (example of a probable load curve and RES generation, which is randomly selected from all Monte Carlo years in stochastic modelling), which illustrate the calculation results shown above.



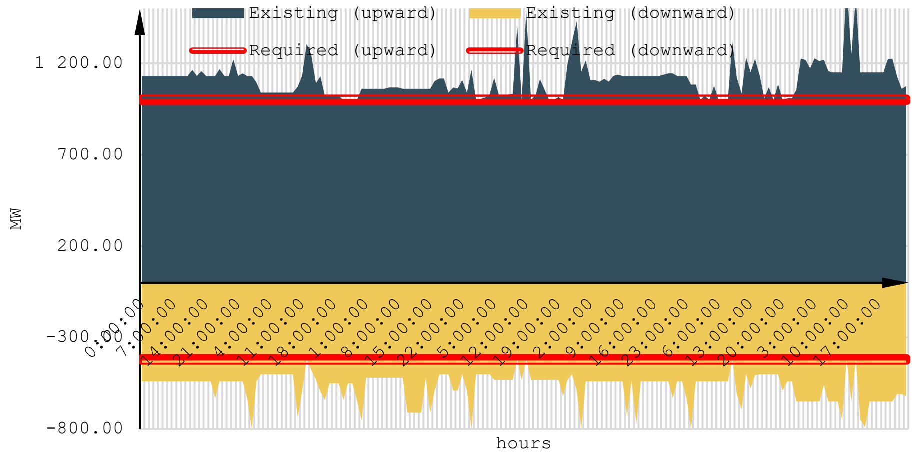
Probable coverage of load curve during flood period in 2023 in the IPS of Ukraine in baseline scenario



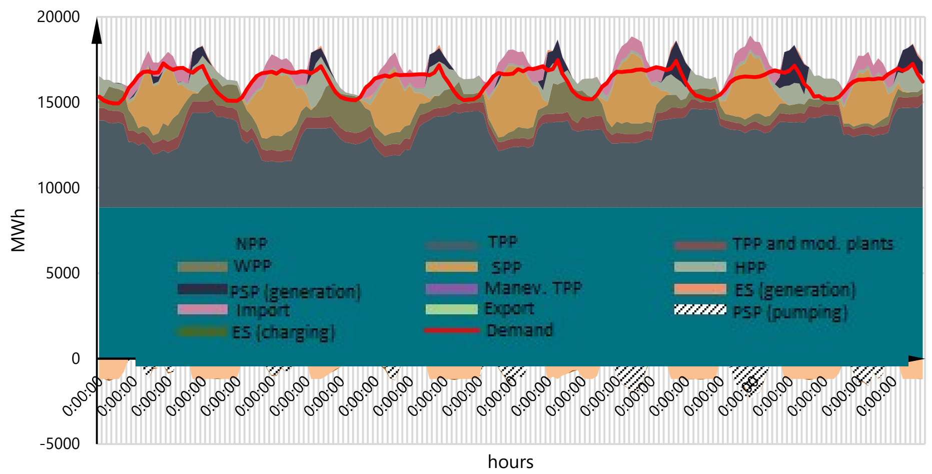
Probable coverage of load curve during flood period in 2023 in the IPS of Ukraine in TSO target scenario



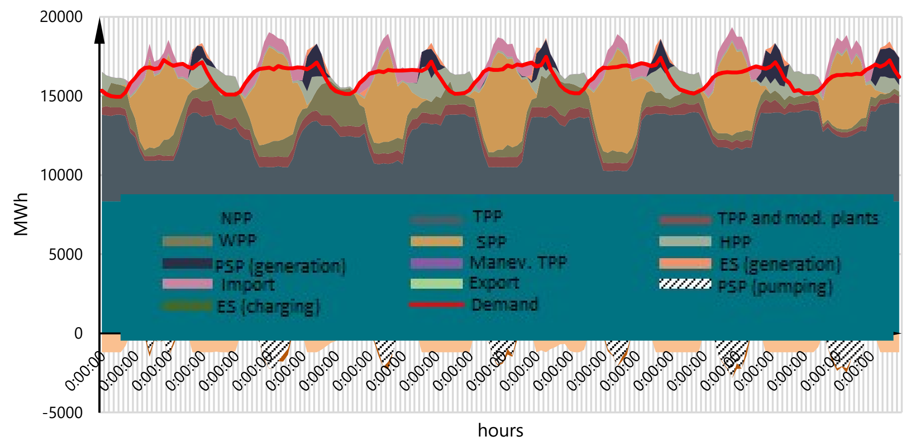
Supply of IPS of Ukraine with reserves in flood period according to the probable load schedule of 2023 in baseline scenario



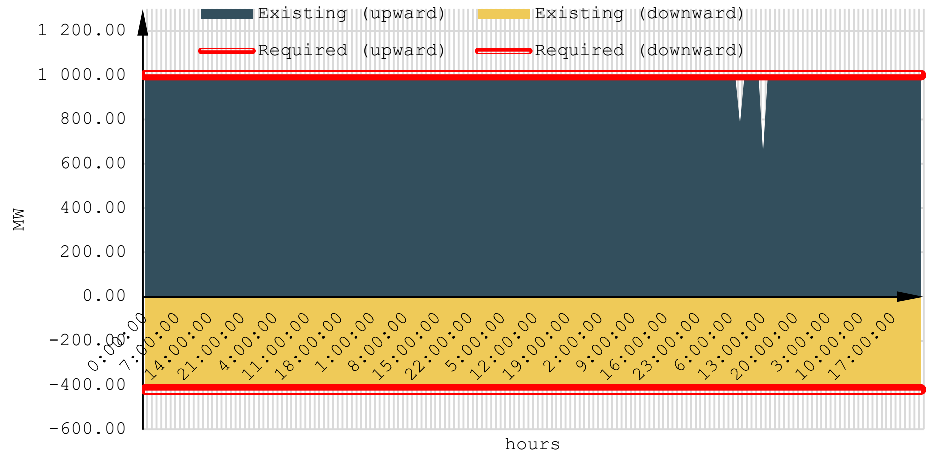
Supply of IPS of Ukraine with reserves in flood period according to the probable load schedule of 2023 in TSO target scenario



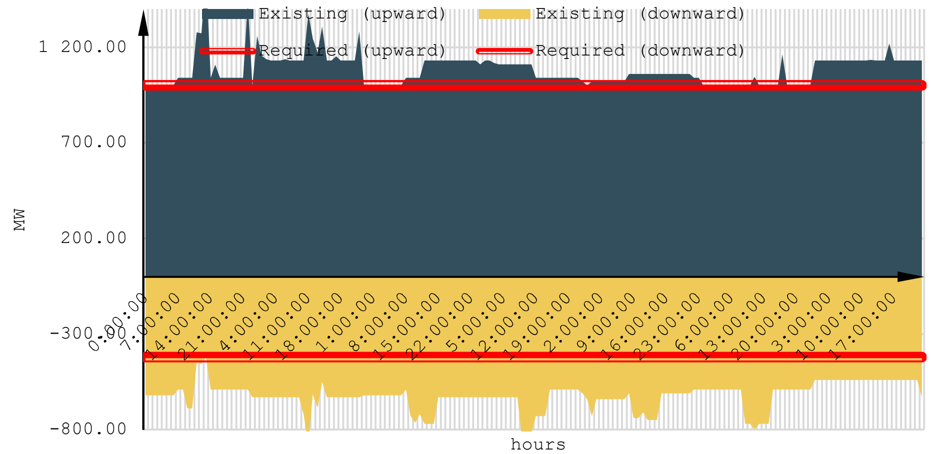
Probable coverage of load curve during summer period in 2027 in the IPS of Ukraine in baseline scenario



Probable coverage of load curve during summer period in 2027 in the IPS of Ukraine in TSO target scenario



Supply of IPS of Ukraine with reserves in summer period according to the probable load schedule of 2027 in baseline scenario



Supply of IPS of Ukraine with reserves in summer period according to the probable load schedule of 2027 in TSO target scenario

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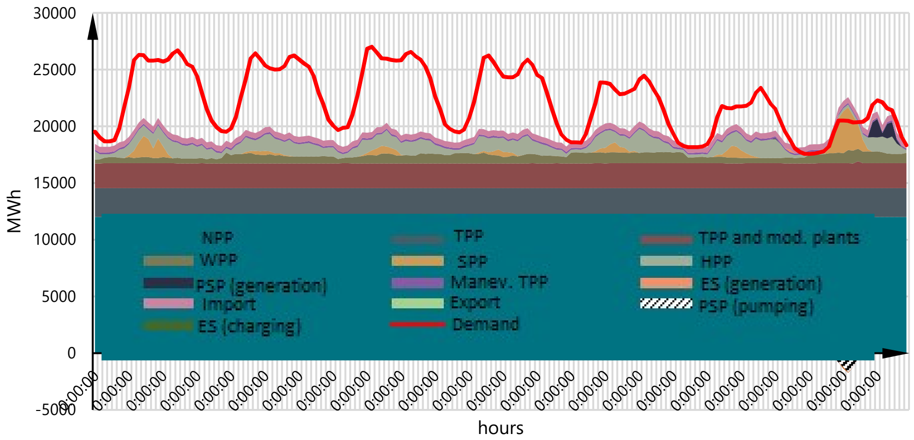
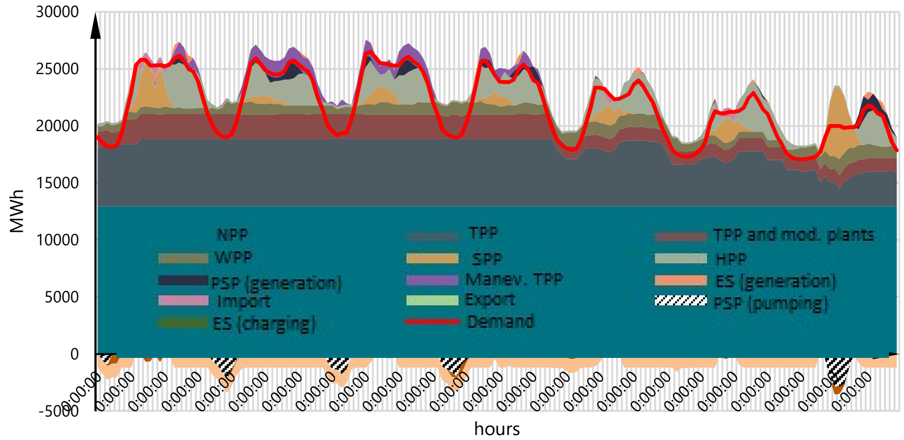
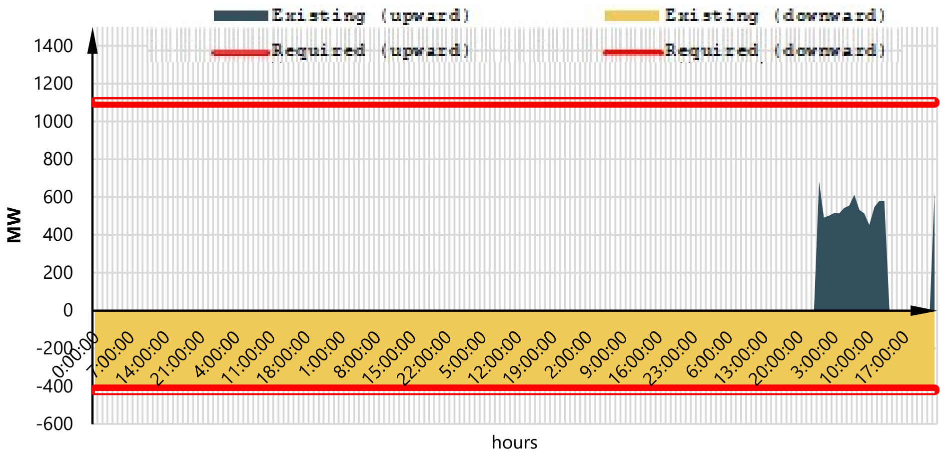


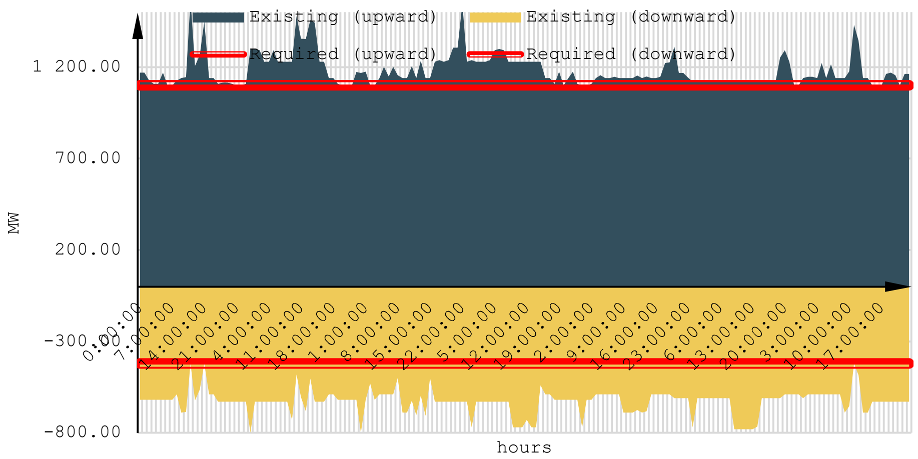
Probable coverage of load curve during winter period in 2032 in the IPS of Ukraine in baseline scenario



Probable coverage of load curve during winter period in 2032 in the IPS of Ukraine in TSO target scenario



Supply of IPS of Ukraine with reserves in winter period according to the probable load schedule of 2032 in baseline scenario



Supply of IPS of Ukraine with reserves in winter period according to the probable load schedule of 2032 in TSO target scenario

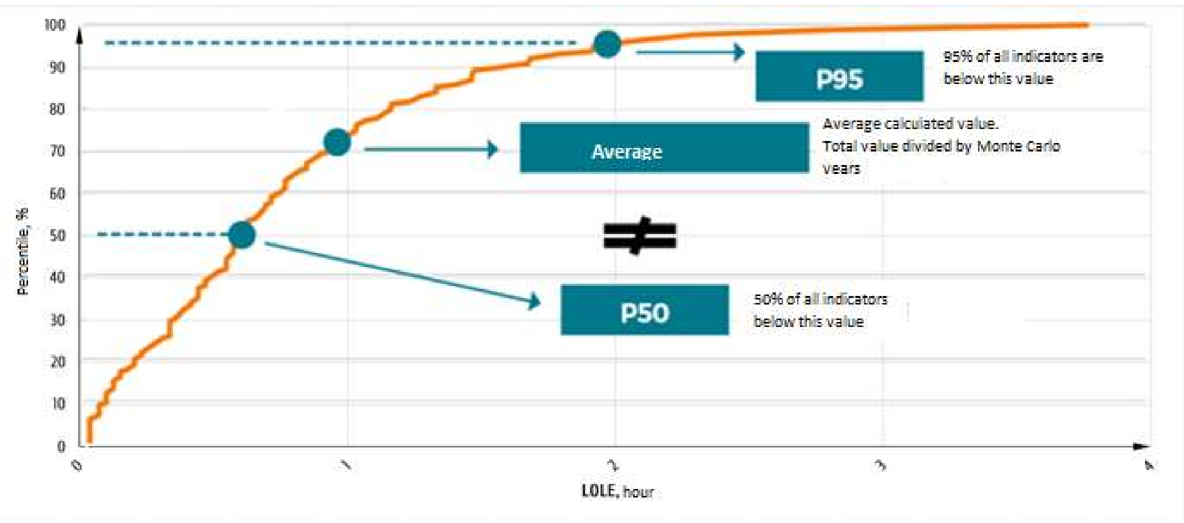
As illustrated above the baseline scenario provides a difficult situation regarding the future availability of generating capacities and reserves in the IPS of Ukraine (primarily the reserves for upward loading). However, as shown in Figures by means of supporting the RES integration (according to the TSO target scenario), problems of the shortage of reserves for downward loading, on one hand, can be avoided through the implementation of projects for construction of energy storages, which in addition would make it possible to partly resolve the balancing issues in the power system.

On the other hand, the introduction of new balancing capacities with a wide range of control and the possibility of quick start-up/shut-down will make it possible to avoid problems with the power shortage and the shortage of reserves for upward loading and, as in the case of the construction of storage systems, will help resolve the balancing problems in the power system, providing additional flexibility to the IPS of Ukraine. In addition, these measures will provide surplus reserves in certain periods, which in turn will raise the power system flexibility to a new level in terms of quality, and will enable active commercial exports of reserves/capacity, i.e., *reserve sharing* according to the European terminology.

Mechanisms to ensure the generation adequacy

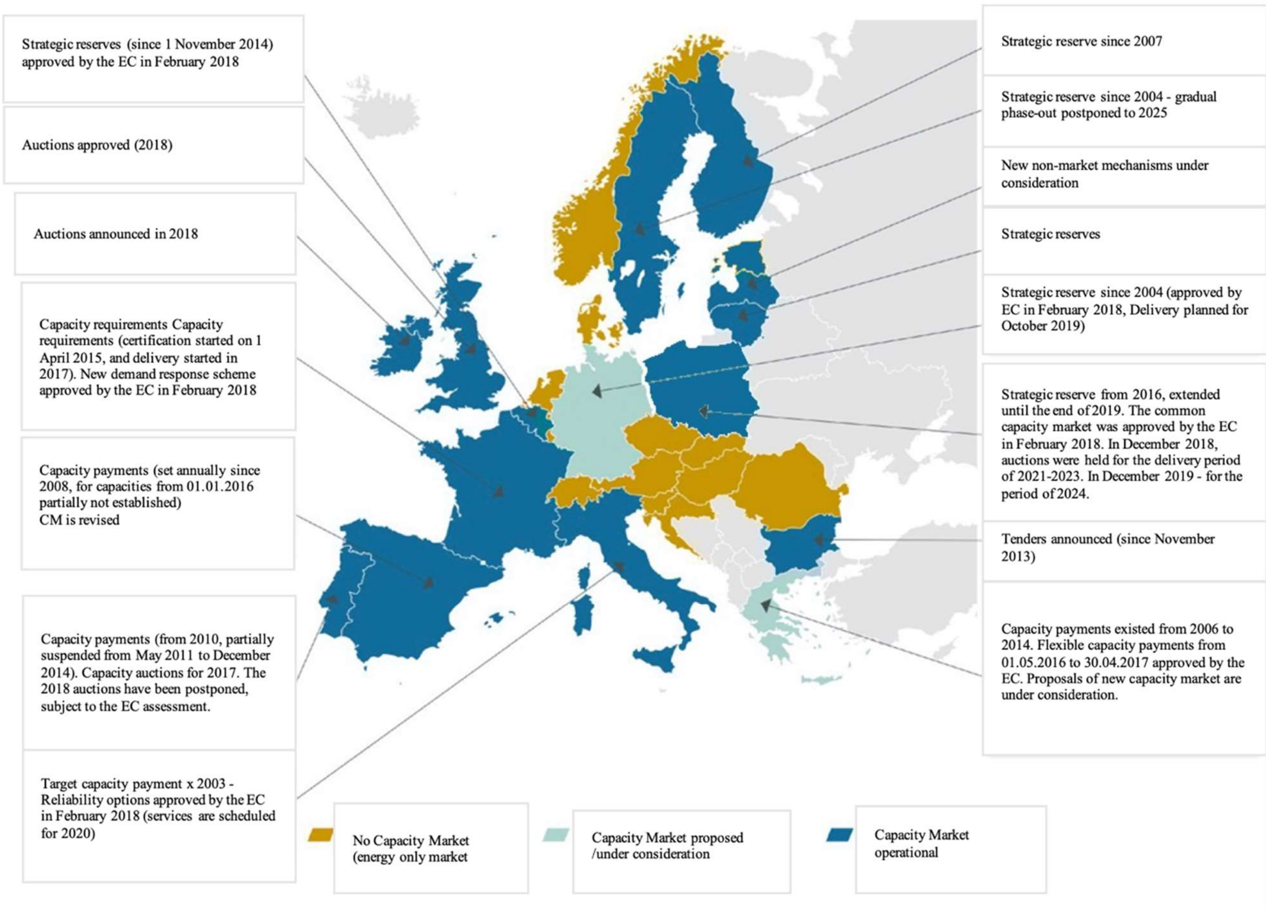
Since Tables provide average values of all criteria, not their statistic distribution, it should be borne in mind that there are different probabilities of occurrence of such shortages of generating capacities, which will significantly exceed the values in Tables. For example, 5% (once in 20 years) and 10% probability (once in 10 years) probability. Such probabilities are determined with LOLE P95 and LOLE P90 indicators (as recommended by ENTSO-E), their difference from the average indicator is illustrated below.

Percentile graph of the distribution of the LOLE criterion



For this reason, to ensure the adequacy of generating capacities, which will be used only in extreme conditions, more and more European countries are implementing various market and non-market mechanisms to ensure the generation adequacy. Such mechanisms and algorithms of their operation vary from country to country. However, they all have one thing in common – these mechanisms are not financed only with revenues from the sale of electricity in the electricity market.

ACER in its annual Market Monitoring Report) provides an overview of capacity mechanisms designed to ensure generation adequacy across Europe. The map below illustrates countries and mechanisms the use.



In addition, the possibility of developing the generation adequacy mechanisms (in case of failure of market mechanisms), in particular, through the use of strategic reserves and cross-border flows is provided for in the "Clean Energy for all Europeans Package”, which Ukraine has acceded as a party of the Energy Community having committed to implement by 31 December 2023 Directive (EU) 2019/944 and Regulation (EU) 2091/941 in accordance with the decision of the Ministerial Council of the Energy Community No. 2021/13/MC-EnC.

At present, Ukraine does not have the legislative framework for such market or non-market mechanisms to ensure the generation adequacy in the future, which would provide for the introduction and use of capacity payments.

On the other hand, for very rare cases (i.e., cases of LOLE P95) when there is a need in generating capacities (which in other cases are not engaged in electricity generation or ancillary services) it would be practical to introduce in the country the demand-side response measures. So, Figure 6.24 illustrates for year 2032 the dependency of the cost of electricity production (with all costs including fixed costs) on the hours in operation during the year.

Dependency of the cost of electricity production on the hours of operation, illustrated by year 2032

Based on the above, the operating time of the power units with highest production cost (over 12 thousand UAH/MWh) with a 5% probability (according to Monte Carlo method) will be from 31 to 229 hours per year, and in the remaining 95% they will be in operation for 0 hours, but their maintenance costs shall be compensated regardless of the operating time. Capacity of such power units in 2032 is 750 MW, therefore it would be more feasible (considering such values of the cost) to use demand-side management measures in those rare cases. It creates prerequisites for the demand-side management function on the industrial scale.

Nevertheless, the terms of demand-side management services on one hand and the readiness of consumers to buy electricity at prices above market average on the other hand should make adjustments to scopes of such services. At present, the introduction of the European Methodology for calculating the value of lost load, the cost of new entry and the reliability standard in accordance with Article 23(6) of Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity should provide some clarity. The purpose of the *Methodology* is to determine for consumers in the country the price threshold above which the consumers could refuse from electricity for a short time for various reasons. Results of the Methodology introduction in Ukraine are expected in 2022.

Nevertheless, based on the expert evaluation, the minimum price of 12 thousand UAH/MWh is the justified threshold subject to the introduction of demand-side response on an industrial scale. On the other hand, in the longer term, correct modelling of demand-side management measures will require a number of studies (according to the current Methodology) of their technical and economic indicators (in particular, maximum capacity of activation at each step, duration and cost of such activation, activation curves, seasonal and daily availability, cost dependency on duration and activation period, etc.).

The development of demand-side management measures in sufficient volumes (depending on the type and cost) in short and medium terms will potentially provide the possibility to partly reduce the need in a number of peaking and load-following capacities (specifically, including those capacities that require non-market mechanisms of generation adequacy assurance as they can compete directly in non-market segments).

As shown in this section, the IPS of Ukraine during the entire period studied in the baseline scenario will be characterized by generation inflexibility, and from 2025 – by generation inadequacy. The proposed TSO target scenario would make it possible to fully avoid this in future until 2032 (see Section 5) through the construction and soonest commissioning of up to 0.74 GW of energy storages and highly flexible quick start-up/shut-down generation (up to 1.45 GW), introduction of requirements for owners of new IPPs to provide energy storages, assurance of the optimal pace of renewables penetration, and a number of other actions.

The introduction of these capacities to ensure flexibility will guarantee:

1. Availability of rapid automatic reserve for upward/downward loading due to the introduction of energy storage systems, which makes it possible to quickly compensate for imbalances within ±740 MW, reduces the need to maintain corresponding reserves at conventional power plants because such reserves accelerate depletion of their fleet life and increase the likelihood of emergency failures. At the same time, it provides more possibilities to use RES to cover the electric load curve because, unlike conventional generation, energy storages do not have a technical minimum load (i.e., the minimum capacity they can work with).

2. Availability of firm capacity reserves for upward/downward loading in the volume of 1.45 GW due to the introduction of highly flexible with quick start-up/shut-down generation in accordance with the requirements of the current TNC.

3. Opportunity, even in low-water periods of the year, to compensate for the decreasing capacity of SPPs when the load is rising, and to reduce the need for TPP power units to cover the electric load curve because of maintaining the reserves for upward loading and the introduction of 1.45 GW of highly flexible with quick start-up/shut-down generation.

The need to build and commission energy storages (up to 0.5 GW) and highly flexible generation with quick start-up/shut-down (up to 1 GW) was stressed in the Report approved by NEURC Resolution No. 975 of 16 June 2021, but in view of the National Economic Strategy up to 2030 approved by the Cabinet of Ministers of Ukraine on 3 March 2021 and its declared target of increasing the renewables share in the total generation mix at the level of 25%, as well as a number of other less weighty but not least important factors, this Report calls for bigger volumes of flexible technologies (up to 1.45 GW of highly flexible generation and up to 0.74 GW of Energy Storages) to balance much higher capacities of renewables

2.6 Analysis of the external environment: challenges and opportunities

In the short term, the key challenges for Ukraine are the consequences of the Russian military aggression, both economic and social. Instead, integration into the EU markets is an opportunity to strengthen Ukraine's energy security. However, it will require significant additional efforts, particularly in the legal field.

Lowering the cost of technologies will promote the development of RES and hydrogen, which will be reinforced by environmental factors and requirements.

Political factors

- Corporate governance reform in the energy sector with the aim of bringing state-owned companies to international business standards, improving profitability and investment attractiveness
- Acceleration of Ukraine's integration into the EU, in particular, obtaining the status of a candidate for EU membership
- Deepening Ukraine's participation in international organizations (possibility of joining the International Energy Association, strengthening cooperation under the EU program)
- Deepening of the political isolation of the Russian Federation and strengthening of sanctions, in particular in the energy sector (for example, refusal of Russian energy carriers)

Economic factors

- Consequences of military aggression of the Russian Federation (more details in Section 1.1)
- Reduction in production volumes / fall in GDP
- Decrease in the purchasing power of the population and inflation
- Destruction of logistics chains (blockage of ports, supply of oil products)
- Occupation and destruction of energy facilities
- Increase in prices for primary energy resources (natural gas, coal, oil)
- Exchange rate fluctuations

Social factors

- Internal and external population migration and, as a result, loss of labor resources and reduction of energy consumption
- Increase in the level of unemployment and poverty of the population

Technological factors

- Development and cheapening of RES, SES, smart grids and demand response technologies, small modular reactors and hydrogen production
- A sharp increase in the share of renewable generation with a stochastic production schedule
- Strengthening the role of the consumer, who is both a producer and consumer of energy (Prosumer)
- Tendencies to increase energy efficiency

Environmental factors

- Increasing payment for greenhouse gas emissions, implementation of CBAM (Carbon Border Adjustment Mechanism)
- Commitment of Ukraine to abandon coal generation by 2035
- Strengthening the demands of investors on environmental issues
- Probable temporary inhibition of global decarbonization trends due to abandonment of Russian energy resources
- An environmental emergency caused by the military aggression of the Russian Federation

Legal factors

- Liberalization of energy markets and changes in the PSO model
- Accumulated debts on the market of gas, electricity, heat and water supply
- The need for further harmonization with EU legislation
- Settlement of legal issues of occupied/damaged energy facilities

2.7 Generation development scenarios

Based on the analysis of the demand and supply development scenarios across the 10-year horizon, the volume of electricity consumption by country's users will be within the range presented in Table below

Minimum and maximum assessment of electricity demand (gross), billion kWh

Indicator	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Electricity consumption (minimum assessment)	153	153.8	154.3	154.7	155.2	156.3	157.7	159.3	160.8	161.7
Electricity consumption (maximum assessment)	156	157.2	157.7	158.3	158.8	159.7	161.3	162.7	164.2	166.3

At the same time, the combined maximum load of the IPS of Ukraine in this period could vary from 24.5 GW to 27.8 GW

The baseline—the most probable—scenario addresses the risks discussed in subsection 4.4. Taking these risks into account, the baseline scenario envisages the following transformation of the generation mix in the period 2023–2032:

- maintaining the current level of NPP capacity during the entire period up to 2032 and commissioning new capacities: in particular, 1,000 MW in 2030 and 1,100 MW in 2032 on Units 3 and 4 at Khmelnytska NPP, which is provided for by all scenarios of NPP development up to 2032. According to information provided by NNEGC Energoatom, KhNPP Unit 3 will use WWER-1000 type reactor with characteristics similar to those already used in Ukraine (except that it has more fuel loading/unloading cycles), and Unit 4 will use the reactor of *AP-1000* type, which as distinct from the previous reactor can be engaged in the daily power regulation and is more flexible (50% stepwise regulation range and up to 300 cycles of fuel unloading/loading per year, rump-up/down 1-3% of the installed capacity per minute);
- reducing the TPP capacity to implement the NERP through decommissioning of power units after they reach the limit of running hours (see the Substantiating Materials for the detailed description of TPP units decommissioning), not feasible for owners to keep some generating capacities in working order due to low ICUF, lack of newly commissioned thermal generation and reconstruction of existing power units due to high risks of such projects for investors, which corresponds to the pessimistic scenario of their development;
- developing hydropower is envisaged according to the pessimistic scenario as described above, i.e., taking into account the capacity build-up by commissioning of Units 4 and 5 at Dnistrovska PSP (both units able to operate in pumping and generation modes) and Unit 3 at Tashlytska plant;
- developing the RES generation is envisaged in volumes ensuring the firm electricity production using renewable energy sources (including HPPs) in accordance with target indicators of the National Economic Strategy up to 2030 (NEcS-2030), among which the key indicator is to ensure the 25% share of renewables in the electricity generation, and the New Energy Strategy of Ukraine up to 2035: Security, Energy Efficiency, Competitiveness (NEnS-2035);

- developing of supporting RES penetration technologies in the IPS of Ukraine is envisaged according to the pessimistic scenario (see paragraph 4.2), where the capacities commissioned by late 2021 will be further operated (as of the end of 2021 there is one 1 MW facility of 1 MWh capacity) and new energy storages to be commissioned in the upcoming years (it is expected that energy storages having the total power of 1 MW and 1 MWh capacity will be commissioned in 2022, and starting from 2024 – additional 212 MW power of energy storages having 212 MWh capacity as part of hybrid systems deployed at existing HPPs at the Dnieper and Dniester Rivers designed to expand the regulation range of existing HPP capacities and their rapid response during operation in all segments of the market.

Generation mix in this scenario is illustrated in Tables. It is clear that the development of generating capacities in this scenario does not ensure the fulfilment of generation flexibility requirements after 2023 and adequacy requirements during the entire period of 2025–2032 (as described in detail in Section 6 and demonstrated by calculations of generation adequacy (flexibility) indicators), which is not acceptable from the standpoint of the energy security, balance reliability and operational security of Ukraine. Therefore, the TSO has formed the scenario of the power system development which will be most economically effective in ensuring the fulfilment of generation adequacy (flexibility) requirements and should, in the TSO opinion, be the target scenario (hereinafter referred to as the TSO target scenario). Nevertheless, even the TSO target scenario will require prompt closing out of risk mitigation actions described in subsection 4.4.

The TSO target scenario for the development of conventional generation was formed taking into account the results of assessing the generation adequacy (flexibility) for the baseline scenario and the results of the formation of long-term demand and supply scenarios. Its main economic indicators (investment needs and electricity prices) are based on SMEE indicators, as well as the forecast of the development of conventional generation. The TSO target scenario provides:

- keeping in operation the existing capacities at nuclear power plants and commissioning new 1,000 MW at Unit 3 and 1,110 MW at Unit 4 of Khmelnytska NPP, which is provided for by all scenarios of NPP development for the period up to 2032 (which as a result will increase the volumes of necessary upward loading reserves to 1,100 MW as per the existing TNC and Regulation (EU) 2017/1485 of 2 August 2017 "Establishing a guideline on electricity transmission system operation");
- maintaining the available operating capacity of load-following TPPs at the level required to meet the adequacy requirements (not less than 7.3 GW in the period up to 2032 excl. demand-side management and flexible generation with quick start-up/shut-down capability), which corresponds to the optimistic scenario of their development;
- developing the hydropower under the scenario that is close to the pessimistic scenario (see paragraph 4.2), i.e., taking into account the total capacity build-up by commissioning Units 4 and 5 at Dnistrovska PSP (with both power units operating in the pumping and generation modes) and Unit 3 at Tashlytska plant;
- developing generation from renewable energy sources in the volumes ensuring the firm production of electricity from renewable energy sources (including HPPs) in accordance with target indicators of NEcS-2030 (25% share in generation mix by 2030) and NEnS-2035 similarly to the baseline scenario, with the exception that RES producers will be actively involved in the power system balancing under general market conditions (this way these producers can provide ancillary services, in particular, frequency restoration reserves for downward);
- system-wide measures to increase the flexibility of the IPS of Ukraine should be implemented as soon as possible, but realistic timeline – starting in 2023, and provide for the introduction of at

least 1.45 GW of highly flexible with quick start-up capacities and up to 0.74 GW of *Energy Storages* in the period until 2032;

Figures below reflect the feasibility of projects of energy storages and highly flexible generation. It should be noted that the electricity surplus according to the target scenario in the long run decreases due to the introduction and use of quick-start reserves, new capacities at HPPs (including the operation of hybrid systems) and rising electricity consumption in the IPS of Ukraine (compared to RES deployment pace), but in order to be able to fully avoid RES curtailments under balance conditions, at least 2 GW of frequency containment and control systems and highly flexible generation need to be introduced.

The assessment of PSP capacities does not include commissioning of units at Kanivska PSP as such commissioning is ineffective and unlikely because first of all the ICUF of such power plant will be atypically low (it will use technologies of low flexibility), will require major capital investments and construction to ensure the normal operation of the grid for it to be able to reliably intake/offtake power in the turbine and pumping modes. To enable the normal operation of 5 power units of Dnistrovska PSP in pumping and generation modes, the Transmission Network Development Plan sets out the following actions for grid development:

- commissioning of the 330 kV OHL Zakhidnoukrainska–Bohorodchany;
- commissioning of the 330 kV OHL Ternopilska–Chernivetska;
- commissioning of the 330 kV OHL Dnistrovska PSP–Vinnytska 750;
- installation of the second AT 750/330 with a capacity of 1,000 MVA (3 × 333) at the 750/330 kV Vinnytska substation.

Based on the above, the operation of Unit 4 of Dnistrovska PSP in the generation mode will be taken into account starting from the beginning of the modelling horizon (2023), and the simultaneous operation of all four units in the pumping mode – starting from 2024 according to the latest approved TYNDP-UA. Commissioning of Unit 5 at Dnistrovska PSP is expected in 2032. Also, given the high probability of Tashlytska PSP construction completion, it is assumed that the third unit will be commissioned in 2022 and will start operation in early 2023.

WPP, SPP, Frequency Containment and Control Systems development according to the baseline scenario

Indicator	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
WPP installed capacity by the end of the year, MW	3100	3300	3500	3700	3900	4100	4300	4500	4700	4900
WPP capacity build-up over the year, MW	580	200	200	200	200	200	200	200	200	200
WPP ICUF, p.u.	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36
Industrial SPP installed capacity by the end of the year, MW	5480	5530	5580	5630	5780	5900	6000	6100	6200	6300
Industrial SPP capacity build-up over the year, MW	80	50	50	50	150	120	100	100	100	100
Household SPP installed capacity by the end of the year, MW	1620	1770	1920	2070	2120	2200	2300	2400	2500	2600
Household SPP capacity build-up over the year, MW	200	150	150	150	50	80	100	100	100	100
SPP installed capacity by the end of the year (total), MW	7100	7300	7500	7700	7900	8100	8300	8500	8700	8900
SPP capacity build-up over the year (total), MW	280	200	200	200	200	200	200	200	200	200
SPP ICUF, p.u.	0,147	0,147	0,147	0,147	0,147	0,147	0,147	0,147	0,147	0,147
ES installed capacity by the end of the year, MW	2	214	214	214	214	214	214	214	214	214

Installed capacity of conventional generation according to the baseline scenario, MW

Power plants	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
Existing TPP	15200	14050	13520	11990	10850	9130	5850	4820	3920	3130
New highly flexible TPP with quick start-up capability	0	50	50	150	150	150	150	150	150	150
BioPP	370	420	470	520	570	620	670	720	770	820
CHP	5500	5200	4900	4600	4300	4000	3700	3400	3200	3000
HPP	4884	4896	4899	4908	4923	4932	4932	4940	4940	4952
PSP	1963**	1963	1963	1963	1963	1963	1963	1963	1963	2287
NPP	13835	13835	13835	13835	13835	13835	14835*	14835	15935*	15935

*Note: *Since the exact data of capacities commissioning in 2029 and 2031 is unknown, it is assumed that the industrial operation will start in early 2030 and 2032, respectively*

***Due to existing network constraints on operation of four units at Dnistrovska PSP, the PSP maximum capacity in 2023 is limited to 1,639 MW.*

WPP, SPP and Energy Storage development according to the TSO target scenario

Indicator	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
WPP installed capacity by the end of the year, MW	1111,2	1529	2520	2920	3320	3720	4120	4470	4820	5120
WPP capacity build-up over the year, MW	86,2	417,8	972	400	400	400	400	350	350	300
WPP ICUF, p.u.	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36	0,36
Industrial SPP installed capacity by the end of the year, MW	45858	5160	5365	5558	5979	6400	6870	7341	7812	8283
Industrial SPP capacity build-up over the year, MW	-	575	418	193	421	421	470	471	471	471
Household SPP installed capacity by the end of the year, MW	777	1205	1335	1692	1871	2050	2230	2409	2588	2767
Household SPP capacity build-up over the year, MW	-	427,2	215	357	179	179	180	179	179	179
SPP installed capacity by the end of the year (total), MW	5363	6365	6700	7250	7850	8450	9100	9750	10400	11050
SPP capacity build-up over the year, MW	1807	1002	633	550	600	600	650	650	650	650
SPP ICUF, p.u.	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
ES installed capacity by the end of the year, MW	0	1	100	200	300	380	440	490	540	590

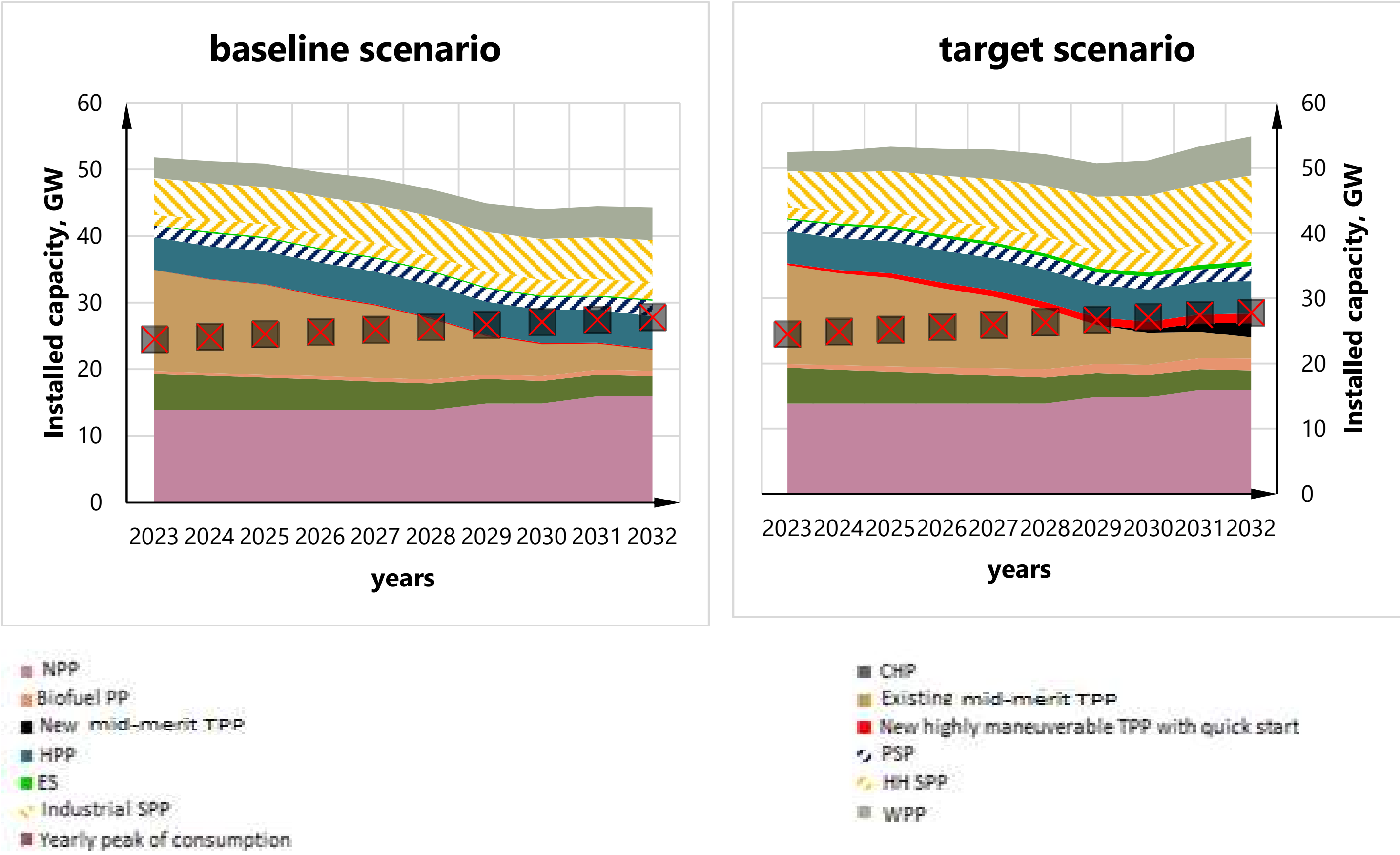
Installed capacity of conventional generation according to the TSO target scenario, MW

Power plants	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
TPP minimum required level, incl.	16040	15288	15105	13973	13080	11608	8979	8553	8395	8747
- new highly flexible TPP with quick start-up capability	300	500	700	850	950	1050	1150	1250	1350	1450
- new load-following TPP	-	-	-	-	-	-	440	800	1300	2200
- existing load-following TPP	15200	14100	13570	12140	11000	9280	6000	4970	4070	3280
- BioPP	540	688	835	983	1130	1278	1389	1533	1675	1817
CHP	5500	5200	4900	4600	4300	4000	3700	3400	3200	3000
HPP	4884	4896	4899	4908	4923	4932	4932	4940	4940	4952
PSP	1963**	1963	1963	1963	1963	1963	1963	1963	1963	2287
NPP	13835	13835	13835	13835	13835	13835	14835*	14835	15935*	15935

*Note. * Since the exact data of capacities commissioning in 2029 and 2031 is unknown, it is assumed that the industrial operation will start in early 2030 and 2032, respectively*

*** Due to existing network constraints on operation of four units at Dnistrovska PSP, the PSP maximum capacity in 2023 is limited to 1,639 MW.*

Change in the generation mix according to scenarios, 2023–2032



Target electricity energy balance 2032

Components of the balance	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
1. Electricity generation, total	159.7	164.0	164.3	163.2	163.9	165.4	167.3	174.5	177.9	181.4
including:										
1.1. TPP:	37.2	35.1	33.2	25.4	26.4	23.5	24.3	23.6	24.1	18.7
TPP share, %	23.3	21.4	20.2	15.6	16.1	14.2	14.5	13.5	13.5	10.3
including:										
1.1.1. Highly flexible with quick start	—	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.4	1.8
For reference: ICUF of highly flexible TPP	—	8	8	8	8	9	9	10	11	12
1.1.2. Existing mid-merit	37	34.5	26.2	24.7	25.6	22.6	21.5	19.2	17.5	8.2
For reference: ICUF of existing load-following TPP	24	24	19	23	23	26	36	38	43	28
1.1.3. New mid-merit	—	—	—	—	—	—	1.7	3.2	5.1	8.7
For reference: ICUF of new load-following TPP	—	—	—	—	—	—	39	40	39	40
1.2. CHP, cogeneration, modular plants	8.7	8.6	8.4	8.2	8	7.8	7.5	7.2	6.9	6.6
1.3. HPP	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
including:										
HPP on Dnieper, Dniester Rivers	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
other HPP	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
1.4. PSP	1.7	1.8	1.9	2.1	2.2	2.3	2.3	2.3	2.3	2.3
1.5. NPP	85.2	88.4	87.9	91.8	89.3	90.4	89.7	94.7	95.8	102.4
NPP share, %	53	54	54	56	54	55	54	54	54	56
NPP ICUF	0.70	0.73	0.73	0.76	0.74	0.75	0.74	0.73	0.74	0.74
1.6. Alternative sources in balance	19.1	21.9	24.3	26.7	29.0	32.1	34.2	37.2	39.1	41.3
RES share, %	12	13.3	14.8	16.3	17.7	19.4	20.5	21.3	22.0	22.8
Grow compared to last year, %	28.3	11.7	11.1	10.4	8.3	9.6	5.6	4.1	3.1	3.7
including:										
- WPP	7.8	8.9	9.9	11.2	12.4	13.5	14.5	15.8	16.8	17.9
- SPP	9.2	10.2	11.1	11.6	12.0	13.3	13.8	14.7	15.2	15.9
- other (including BioPP)	2.1	2.68	3.3	3.9	4.6	5.28	5.96	6.63	7.1	7.55
HPP RES share, %	16	17.7	19.1	20.7	22.0	23.7	24.7	25.4	26.0	26.7
1.7. Energy storage	0.7	1.2	1.4	1.9	1.9	2.1	2.2	2.4	2.6	3.0
2. Electricity import	0	1.5	1.7	2.0	1.9	2.1	2.1	2.2	2.3	2.6
3. Electricity export	0	4.5	4.1	2.3	2.0	2.3	2.5	7.7	9.6	11.6
4. Consumption (gross)	154.5	155.5	156.0	156.5	157.0	158.0	159.5	161.0	162.5	164.0
Grow compared to last year, %	0.3	0.7	0.3	0.3	0.3	0.7	1.0	0.9	0.9	0.9
5. PSP consumption in pumping mode	2.4	2.5	2.6	2.9	3.1	3.2	3.2	3.2	3.2	3.2
6. ES consumption in charging mode	0.8	1.3	1.6	1.9	2.1	2.3	2.4	2.7	2.9	3.1
7. RES regulation / curtailment (production limitation)*	—	—	—	—	—	—	—	—	—	—
8. SHORTAGE	—	—	—	—	—	—	—	—	—	—

3 Gas sector

3.1 Ukraine's gas balance before the invasion

Before the start of full-scale Russian aggression, Ukraine invested in gas production, had sufficient volumes of gas in PSG for a stable heating season, imported and transported gas to EU countries and Moldova.

In 2021, Ukraine consumed 26.8 billion cubic meters (bcm) of gas, including:

- Households – 8.6 bcm (5% increase over 2020), 31.9% of the total consumption;
- District heating – 6.3 bcm (24% decrease compared to 2020), 23.5% of the total consumption;
- Industry, public sector and other non-household consumers – 11.9 bcm (3% less than in 2020), 44.6% of the total consumption.

Production related and technical losses amounted to 1.8 bcm.

Consumption was partially covered by domestic production, which amounted to 19.78 bcm in 2021, 2.2% less than in 2020. The main reason for the reduction in production volumes was low investment activity in 2020 due to the COVID-19 pandemic, which resulted in market prices hitting record low.

Despite this, according to the Association of Gas Producers of Ukraine (AGPU), the year 2021 ended with a stabilization of the production of the state JSC "Ukrgazvydobuvannya" in November-December, as well as a significant increase in the gas production of PJSC "Ukrnafta" and private producers. As a result, private gas producers managed to extract a record 5 bcm of gas, amounting to 25% of the total volume of gas production in Ukraine.

In 2021, 41.6 bcm were transported to Europe through the territory of Ukraine, a 25% reduction compared to 2020. The average daily transit volume was 114 million cubic meters (mcm) of gas per day, in some periods it decreased to 67 mcm per day.

The volume of gas transportation from Europe to Ukraine during the same period amounted to almost 2.6 bcm or six times less than in 2020. The volume of re-export to the EU was also about 2.6 bcm.

At the beginning of 2022, enterprises of all forms of ownership increased gas production. Thus, in January 2022, Ukraine produced 2.3% more gas than in the same period of 2021. Private companies increased production by 4.1%, PJSC "Ukrnafta" by 3.3%, and JSC " Ukrgazvydobuvannya" by 1.6%.

Gas reserves in Ukraine's underground gas storages (UGS) as of January 1, 2022 amounted to 13.5 bcm, of which:

- Residents stored in customs warehouse mode 0.53 bcm;
- Non-residents stored in customs warehouse mode 0.54 bcm.

Gas reserves in UGS as of February 1, 2022 amounted to 11.1 bcm, including:

- Residents storing in customs warehouse mode – 0.42 bcm
- Non-residents storing in customs warehouse mode – 0.2 bcm

Transit through the territory of Ukraine amounted to 1.66 bcm in January 2022. It is 57% lower than the in the same period in 2021. Gas transportation in the Balkan direction has resumed, but deliveries to Slovakia and Poland have significantly decreased. In February 2022, transit amounted to 2.07 bcm.

Imports in January 2022 amounted to 44.8 mcm from the EU, which is 90% lower than in January 2021, but three times more than in December 2021. Export and re-export amounted to 178 mcm, which is 25% less than in January 2021.

Ukraine's consumption in January 2022 amounted to 3.7 bcm, in February – 2.8 bcm. The volume of gas for production and technical losses for two months from the beginning of the year amounted to 318 mcms.

3.2 Overview of hydrocarbon deposits in Ukraine

Gas deposits

A significant share of Ukrainian hydrocarbon reserves is concentrated in three main regions:

- Dnipro-Donetsk basin (Eastern region) – 93% of production, 77% of reserves;
- Carpathian basin (Western region) – 7% of production, 14% of reserves;
- Northern Black Sea basin (Southern region) – less than 1% of production, 9% of reserves;

Prior to the full-scale invasion, Ukraine covered 2/3 of its gas consumption with its own gas. Ukraine has a significant potential for increasing gas production and can achieve self-sufficiency in gas.

As of January 1, 2021, there are 467 listed objects in Ukraine (natural gas deposits and prospective gas fields). Most of them are combined: 65 oil, 111 gas, 18 oil and gas and gas oil, 155 gas condensate, 3 gas condensate non-oil.

There are 285 industrially developed fields with balance (extractable) natural gas reserves of 619 bcm. 22 objects with balance (production) gas reserves of 26 bcm have been prepared for industrial development. Other deposits (areas) are subject to additional geological study, including exploratory, with the aim of preparing them for industrial development.

86% of the booked gas reserves are now used for industrial development. The gas reserves are depleted by 75%. In total, current potential resources amount to 5 506 bcm, of which 719 bcm are currently available for extraction, and the remaining 4 478 bcm need additional geological studies.

Oil and condensate deposits

Oil and condensate deposits are located in three geographical and geological regions on the territory of 10 administrative regions:

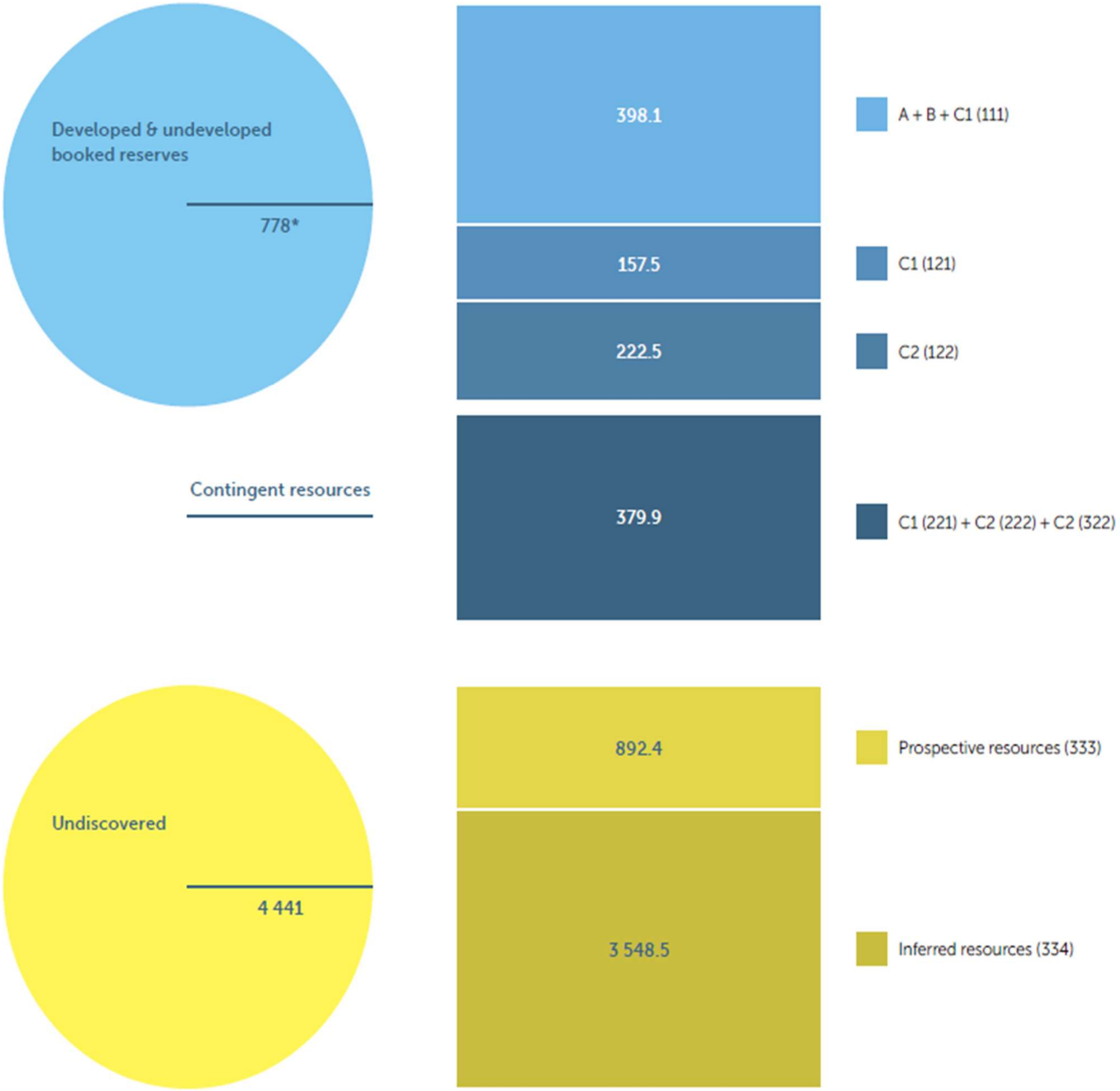
- Carpathian flexure, or Western region (Ivano-Frankivsk, Lviv, Chernivtsi regions);
- Dnipro-Donetsk basin, or Eastern region (Chernihiv, Sumy, Poltava, Kharkiv, Dnipropetrovsk regions);
- Black Sea-Crimean, or Southern region (Odesa region and Crimean AR).

The state mineral balance of Ukraine books 216 oil and 269 gas condensate objects. The main reserves and production of oil are located in the Eastern region, where 51% of the explored reserves are concentrated and 1,125 thousand tons of oil are produced per year (67% of the total production of Ukraine).

Deposits of the Southern region account for 13% of explored reserves and 0% of production. The total booked (extractable) oil reserves of fields under industrial development amount to 69,949 thousand tons (82% of Ukraine's reserves); condensate – 27,430 thousand tons (87%). There are 145 oil and 191 condensate facilities under industrial development.

In 2020, oil production amounted to 1,671 thousand tons, and condensate production reached 758 thousand tons. Booked production reserves of oil are depleted by 80% and condensate by 53%

INFORMATION ON GAS RESERVES AND RESOURCES IN UKRAINE, BCM



*Notes: *including gas of the central-basin type of the Sviatohirsky field*
Source: Association of Gas Producers of Ukraine

Unconventional gas deposits

Technically extractable reserves of unconventional hydrocarbons in Ukraine, in particular tight gas, are estimated at 1.2 trillion cubic meters. These reserves are currently not being developed. In particular, according to the State Mineral Balance Sheet, within the eastern hydrocarbons-bearing region of Ukraine gas reserves of tight collectors amount to about 100 bcm. Almost half of these reserves lie at a depth of more than 5,000 m.

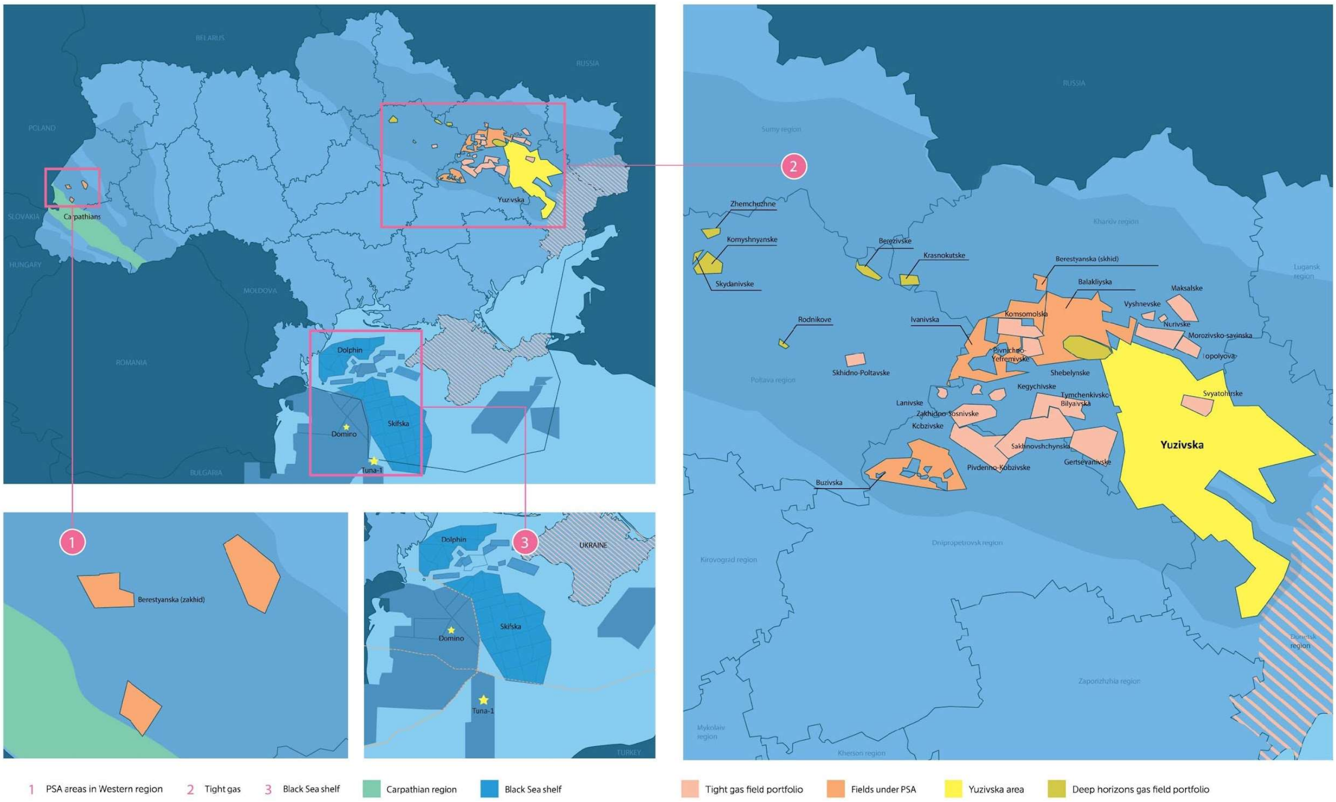
Currently, there are no special incentives for gas extraction from tight gas reservoirs in Ukraine, in terms of the methodology for determining, booking and stimulating taxation for natural gas from tight gas reservoirs. Implementation of these steps is essential for attracting investment in the production of such natural gas and is recommended by this plan.

Shelf

The Ukrainian shelf of the Black and Azov Seas, having 133.7 thousand sq. km of area, has a potential to fully meet Ukraine's needs for gas and partly for oil.

According to the State Mineral Balance of Ukraine, as of 1 January 2021, there were 6 objects at the Black Sea shelf, 3 of which are being developed, and 9 objects in the Sea of Azov, 3 of which are being developed. In total, booked reserves at the Black Sea shelf amount to 37,506 mcm of gas, including those that are developed - 12,139 mcm. The booked (production) reserves on the shelf of the Sea of Azov amount to 9,332 bcm, including those under development – 2,396 mcm. In 2020, 8 mcm of gas were extracted on the shelf of the Sea of Azov.

According to the State Geology and Subsoil Service of Ukraine, the potential reserves of hydrocarbons on the Ukrainian shelf of the Black Sea are estimated at 2.3 billion tons of standard fuel (equivalent to 2.3 trillion cubic meters), which is about 40% of all energy reserves of Ukraine. These reserves are distributed as follows: North-western shelf – 604.1 million tons of oil equivalent (toe); the deep-sea basin of the Black Sea – 346.0 million toe; Kerch shelf – 257.0 million toe; the water area of the Sea of Azov – 324.8 million toe.



Remaining smaller reserves are discovered in other parts of the Ukrainian shelf of the Black and Azov Seas. Significant reserves of energy resources have been discovered in the Kilima area (250–485 bcm of gas), the Skifskaya field (35 bcm of gas and 25–60 mt of oil), the Nakhimov structure (29 bcm of gas), the Kornilov structure (35 bcmof gas), the Akhib structure (6.7 mt of oil).

Eight gas and gas condensate fields have been discovered in the area of the northwestern shelf of the Black Sea - Golitsynske, Yuzhno-Holytsynske, Shtormov, Arkhangelske, Schmidt, Krymske, Odesske, Bezimenne. The named fields have been explored at depths of up to 120 m, but the vast majority of hydrocarbon reserves lie in the deep-water part of the Black Sea shelf, starting at depths of more than 800 meters.

According to experts, only 4-5% of the energy reserves on the Ukrainian part of the Black Sea shelf have been explored. Full exploration of at least a third of hydrocarbon deposits in the Black Sea will require 5-7 years and sufficient investments.

This plan includes production of traditional gas, tight gas and the development of the Black Sea shelf in the list of nationwide priority projects. Preconditions for the implementation of these projects are the stabilization of the security situation, attracting sufficient funding and creation of a favorable regulatory and fiscal regime.

3.3 Current state of hydrocarbon production and growth potential

The occupation forces of Russia advanced from the north, east and south, the main regions of oil and gas production and reserves in Ukraine. Active hostilities and proximity to the contact line led to a reduction in production volumes for objective reasons. So, subsoil users were forced to conserve wells and conduct work only on objects where it was physically possible.

Compared to 23 February 2022, on the following day production dropped by 8%, and on 11 April 2022 – by 12%. In the following months, thanks to retreat of the Russian forces and the localization of active hostilities, gas production rate has stabilized.

In the short term, the volume of gas production depends, first of all, on the security situation and damage to oil and gas infrastructure facilities directly at the production areas. This is especially relevant due to the approach of the heating season and the expected intentions of the occupier to disrupt it, not only in Ukraine, but also in the EU.

The industry requires constant capital investments. In Ukraine, developed oil and gas deposits are depleted by more than 80%. With the natural decline rate of 10-15% per year, drilling of new wells is necessary to cover the decrease in production volumes from the old fund and ensure growth.

The following steps are recommended for increasing gas production in Ukraine:

1. **Development of oil and gas projects.** Ukraine has the potential to become a gas exporter if its reserves are duly developed. The most promising projects are 13 Production Sharing Agreements (PSA), development of Black Sea deposits (especially considering the recent discoveries in Turkey and Romania), Carpathians, development of gas production of tight reservoirs, PEC contracts, projects of deep horizons, etc.
2. **Preservation of incentives.** Preservation of tax incentives and ensuring predictability of the regulatory regime is critical for increasing the volume of gas production in Ukraine.
3. **Conducting public e-auctions.** Since 2019, Ukraine has used transparent electronic online auctions, through which the subsoil use right was sold for 25 oil and gas plots with an area of more than 4,000 square km.
4. **Attracting sufficient capital.** The post-war investment needs of the industry are estimated at more than 25 billion dollars. To attract this capital, Ukraine needs to ensure favorable conditions, including simplification of bureaucratic procedures, preservation of a stimulating and predictable regulatory regime.
5. **Adoption of necessary legislative changes.** Recovery of the extraction industry requires a number of deregulation steps and stimula. In particular, such measures include launch of the license market, simplification of the environmental assessment procedure, aimed at reducing the duration of this procedure from 120 days to 50 days.

3.4 Demand structure and production forecast till 2032

Taking into account the decrease in gas consumption by industry, heat generation and the households, the increase in consumption is possible only in the post-war period and with the mass recovery of Ukraine's economy.

Several major industrial facilities are damaged, destroyed or located in the occupied territory. Several million Ukrainian consumers have left the country. Russia continues shelling civilian, industrial and industry infrastructure. Accordingly, consumption forecasts are based on certain assumptions about the duration of hostilities, the extent of damage and the pace of economic recovery.

According to the AGPU's estimates, provided that active hostilities stop by the end of the current year, a total of 21.4 bcm of gas will be consumed in Ukraine this year (a 20% reduction compared to 2021). In the following years, the energy sector recovery will be focused on electrification, energy efficiency programs and minimization of fossil fuels in the energy mix. Accordingly, the association forecasts the following level of demand for the coming years, bcm:

2023 – 21.8	2028 – 22.4
2024 – 22.2	2029 – 22.1
2025 – 22.6	2030 – 21.4
2026 – 23.0	2031 – 21.9
2027 – 22.7	2032 – 22.0

Decarbonization is the main strategic priority in energy for both Ukraine and the EU. Accordingly, gas will remain an important transitional fuel but its consumption will gradually decrease.

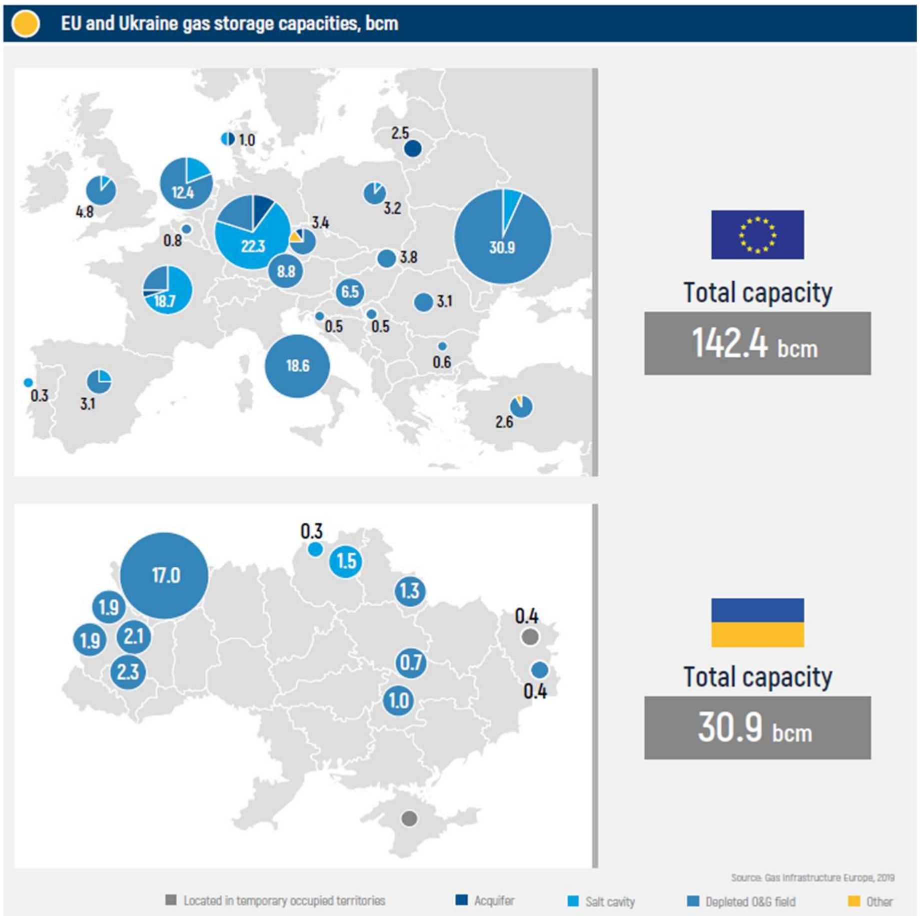
3.5 RESP: Ukraine's gas transmission and storage infrastructure for European energy security

Ukrainian gas trasnmission and storage infrastructure

Ukraine manages underground gas storage facilities with a total capacity of more than 30 bcm, which is the third highest level in the world. The Bilche-Volitsko-Ugerske storage is the largest in Europe with a capacity of nearly 17 bcm.

Approximately 80% of Ukraine's gas storage capacity is located at the western border. The convenient logistics make storing natural gas attractive both for Ukrainian companies working with the EU and for foreign gas traders.

Over 100 foreign companies from 27 countries have already used Ukrainian underground gas storages. In 2020, at the beginning of the heating season, a record 28.3 bcm of gas were stored in Ukrainian storages. Of this volume, non-residents kept approximately 10 bcm.



Source: Naftogaz of Ukraine

Ukraine's gas transportation system is one of the largest in Europe. The maximum technical capacity at entry points is 281 bcm per year, and at the exit points – 146 bcm per year. It is connected to neighboring countries at the state interconnection points, and is thus integrated into the pan-European gas network.

EU gas transmission network limitations and dependence on gas from Russia

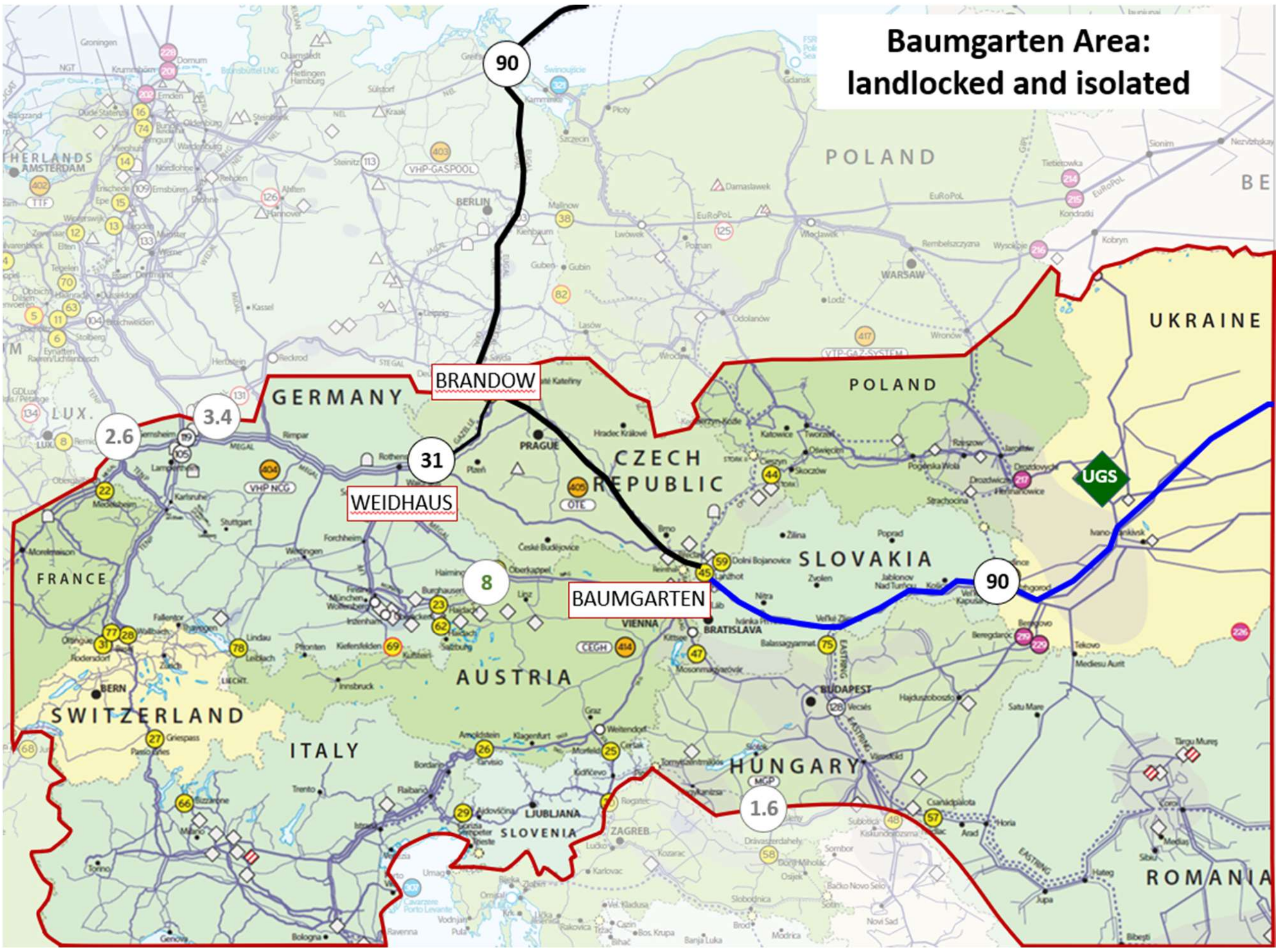
During the previous 12 years, the European Union implemented a number of steps to create an interconnected gas transport network and a liberalized gas market in Europe. These actions have significantly strengthened energy security and boosted competition in this market.

However, not all countries were able to ensure diversification of gas supplies. A significant part of the gas market, in particular, the land locked areas, remains dependent on supply of physical supplies of gas from Gazprom. Consumers in this region, with the center in the Austrian hub of Baumgarten, are virtually isolated from alternative gas suppliers.

Historically, the European gas network was built to transport gas from east to west, supplying Central European markets as gas transits them towards Western Europe. The capacity of the traditional transport corridors diminishes accordingly the farther west they reach. Due to this design, it is difficult to ensure the transportation of significant volumes of gas in the reverse direction (from west to east) or from the sea to the central part of the continent.

Aside of the Baltic Pipe that ensured Poland's access to Norwegian gas, the largest gas pipeline projects in Europe in recent years were carried out by Gazprom (Nord Stream, Turkish Stream). The purpose of these projects financed by Russia was to bypass the restrictions of the Third EU Energy Package in order to preserve the fragmentation of the European market and its dependence on Russian gas.

Region of the European network that has limited access to alternative gas suppliers



To achieve this goal, Russia invested dozens of billions of dollars in the construction of redundant gas pipelines, which allowed Gazprom to bypass the countries of Eastern and Central Europe and supply Russian gas to most European countries independently from each other. At the same time, Gazprom avoided connecting new gas pipelines it built to the existing European network and sought to deliver its gas as close as possible to end consumers, without opening competitors' access to these markets.

This policy has formed a fairly isolated landlocked region of the European gas network with the center in Baumgarten. The region consumes approximately 90 bcm of gas per year, which corresponds to 2/3 of Russian gas supplies to Europe. In addition to constructing pipelines to which it retained exclusive access, Gazprom acquired the major gas storage facilities in the region, thus limiting the ability to accumulate gas from alternative sources during the injection period.

Russia's energy aggression against the EU has demonstrated the flaws of this approach. With the launch of alternative gas pipelines, Russia received the opportunity to limit the supply of gas to certain EU countries and blackmail others by reducing supplies. Having exclusive access to gas pipelines and underground storages serving this market, Gazprom did not ensure the accumulation of normal volumes of gas in storages during the summer of 2021, which resulted in a significant and unjustified increase of gas prices in the European market.

RESP: diversifying gas supply in the Baumgarten area

This part of the European gas transport network has two entry points with significant capacity: the traditional route through Ukraine and Slovakia and the new one through Nord Stream, Germany and the Czech Republic.

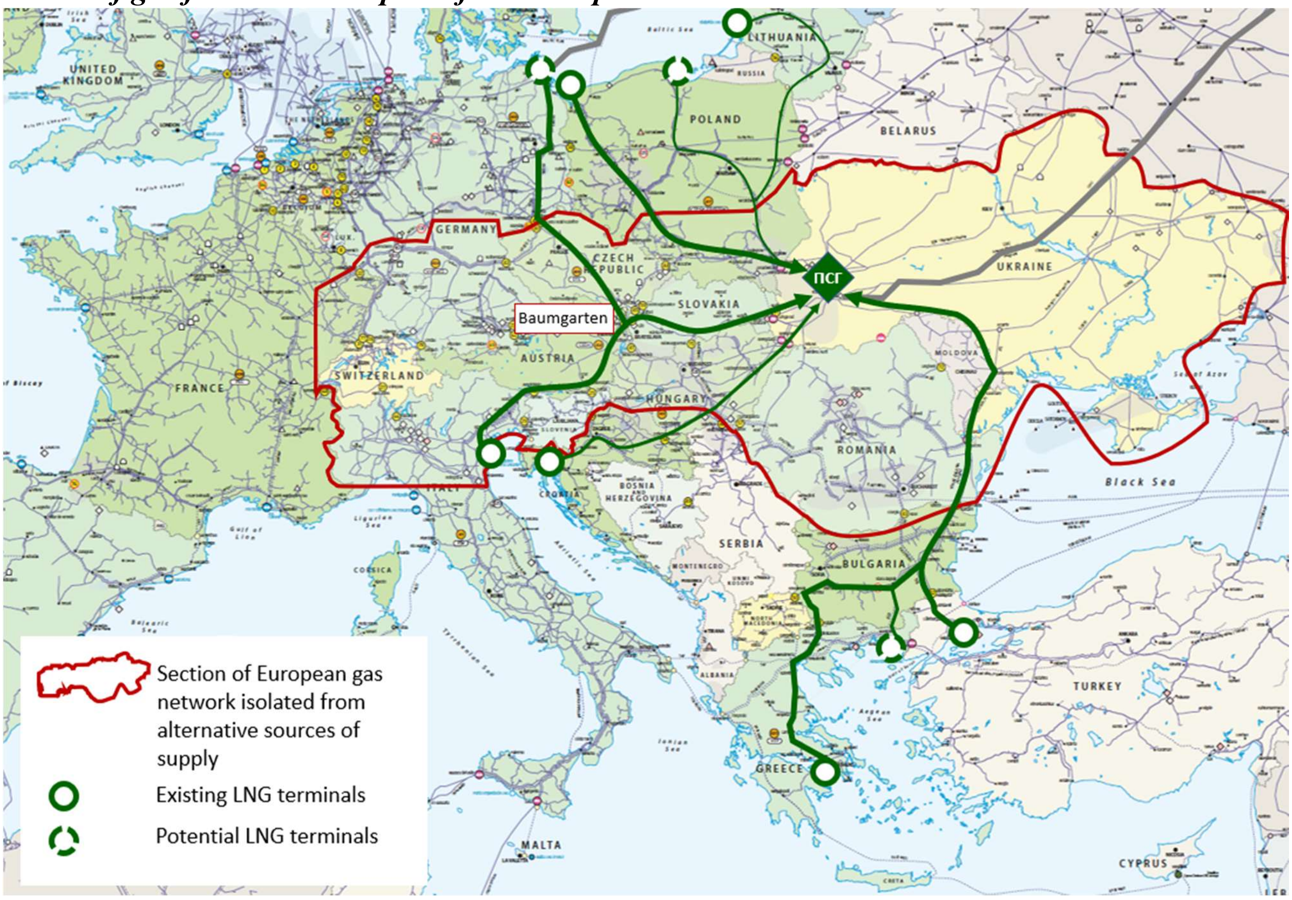
Provision of alternative sources of gas supply by the new route requires the connection of the OPAL and EUGAL onshore gas pipelines to a new LNG terminal instead of the Nord Stream gas pipeline.

The German government has already taken over Gazprom Germania, which controls a significant stake in the OPAL and EUGAL gas pipelines, as well as gas storage facilities in the area. However, ensuring access of alternative gas suppliers access to this infrastructure requires time and investment.

Instead, the traditional route in combination with Ukraine's powerful underground storage allows diversifying gas supplies for this market and strengthening its energy security already now.

Building on its powerful underground gas storages and an extensive system of gas pipelines, Ukraine has proposed the concept of a Regional Energy Security Partnership (RESP) to the European Commission in November 2021.

Use of Ukrainian underground gas storage facilities to store LNG and provide an alternative source of gas for the central part of the European market



The RESP concept includes a number of components:

A. Short-term steps: use available transmission capacity to access to LNG terminals in Poland, Italy, Croatia, Turkey and Greece to accumulate gas reserves in Ukraine's underground storages during the summer when the consumption is low and the European LNG terminals have spare capacity. Reserves accumulated during the summer period should be used to meet the needs of the region in the winter period.

B. Medium-term steps: ensure financing to create a joint gas reserve for the countries of the Baumgarten area in the Ukrainian storages, which will act as an security reserve for the countries of the region and will be used by the participating countries under predetermined conditions in the event of gas shortages or significant fluctuations in wholesale gas prices due to sudden cold spells, technological issues or other emergency situations.

C. Long-term steps: expand interconnector capacity between European LNG terminals and Ukrainian storages, create special bundled tariff products for gas transportation from terminals to storages and from storages to consumers. The implementation of this part of the RESP will allow the EU to significantly reduce its dependence on Russian gas supplies, diversify its pool of suppliers. This structure can also ensure optimal prices and supply terms which are determined by competition, not political considerations.

Gas reserves for the EU which would use the Ukrainian storages and the EU gas pipelines would significantly improve energy security of the region. This project is therefore included in the list of nationwide projects recommended by this recovery plan. The development of the security situation in Ukraine has a significant impact on the implementation of this project.

4 Oil and oil products

4.1 Structure of the oil products market

Before the start of the full-scale aggression, the Ukrainian market consumed about 7.4 million tons of diesel, 2.1 million tons of gasoline, and almost 2 million tons of automobile gas and LPG per year. Approximately 30% of this demand was covered by the import of oil products.

At the same time, Ukraine had a significant dependence on the supply of oil products from Russia and Belarus. More than a third of oil product imports came from these two countries. This choice of Ukrainian suppliers was determined by the taxation policy of Russia and Belarus, as a result of which there were favorable regulatory conditions for the export of petroleum products, thanks to the export of crude oil.

Despite repeated threats of fuel supply interruptions by Russian and Belarusian authorities, Ukrainian market participants continued to rely on these sources of fuel due to the lower price and convenient logistics.

According to Naftogaz of Ukraine, before the full-scale aggression, Ukraine produced about 2.4 million tons and imported about 1.2 million tons of crude oil per year. The largest domestic enterprises engaged in the processing of oil and gas condensate were the Kremenchug Refinery and the Shebelinka Refinery. These facilities produced motor fuel of the Euro-5 standard. The activities of oil refineries in Lysychansk, Odesa, Nadvirnaya, Drohobych and Kherson had been stopped several years ago.

4.2 Securing fuel supplies for Ukraine during the war

As a result of the Russian armed aggression, an absolute majority of the Ukrainian oil refining capacities were put out of operation. The Russians also destroyed nearly 20 oil depots.

As of June 2022, the only working oil refining facilities in Ukraine are the so-called mini-refineries, which are estimated to be able to produce about 0.4 million tons of fuel per year. As an emergency measure, the government has allowed the production and sale of motor fuels of the Euro-3 and Euro-4 environmental standards. In addition, in order to stabilize the market, the government reduced the VAT from 20% to 7% and removed the excise tax on fuel. The government regulation of fuel prices was also lifted.

The import of oil products from the aggressor countries has halted. In addition, Belarus blocked the transit of oil products from Lithuania, which was the third largest country by supply of fuels to the Ukrainian market.

Due to Russia's blockade of Ukrainian ports, the only ways of supplying oil products to Ukraine are currently road and rail transport from EU. Due to limitations in the railway infrastructure and the number of tanks, the maximum capacity of rail imports from the four EU countries neighboring Ukraine is estimated at less than 2 million tons per year.

Another potential way to deliver fuel to Ukraine is the launch of the "Samara-Western Border" oil pipeline in the reverse mode from Hungary to Ukraine. According to experts, it is possible to supply up to 150,000 tons of oil products per month via this route. To implement this scenario, it is necessary to ensure the necessary volumes of oil products on the side of Hungary.

Demand for oil products, according to various industry estimates, has decreased by 30-50% compared to the pre-war level. However, due to the destruction of local production and the significant limitation of import sources and routes, providing the Ukrainian market with oil products remains a difficult task and an urgent issue of energy security.

The fuel shortage is particularly critical for the Ukrainian agricultural industry. Securing sufficient fuel supply for the Ukrainian market is an important step to preventing the global food crisis, which is being instigated by the Russian Federation.

4.3 European fuel market restructuring following the Russian aggression and Ukraine's future role

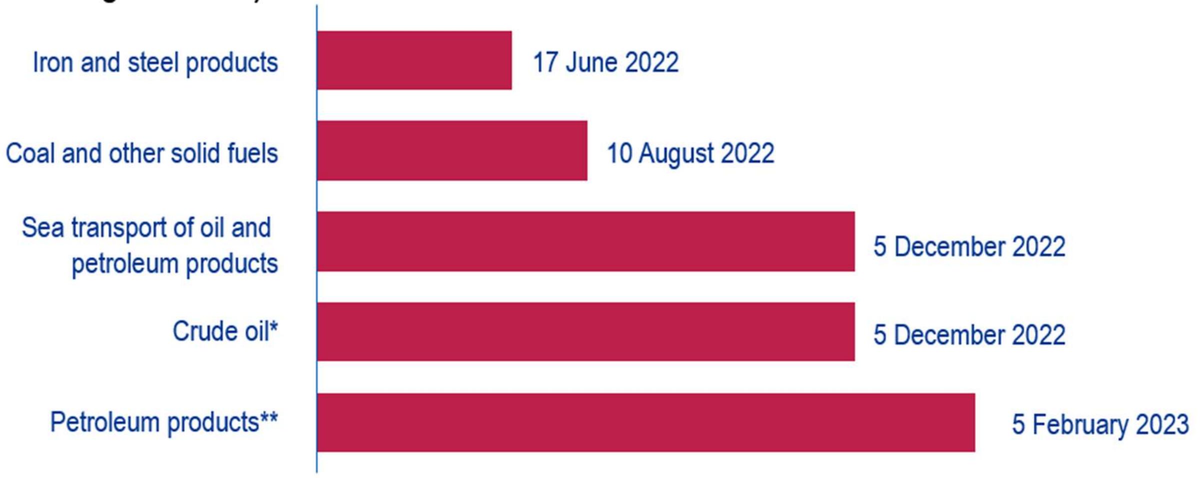
In the REpowerEU document, the European Union announced its intention to abandon Russian energy carriers as soon as possible. This strategy envisages significant changes in the entire European market of oil supply and processing, as well as the supply of petroleum products.

Existing and planned oil pipelines

In the sixth package of sanctions adopted by the EU in early June 2022, a ban was announced on the import of Russian oil, except for pipeline oil, from December 5, 2022, as well as on import of Russian petroleum products from February 5, 2023.

The main consumers of Russian oil in the EU were the Netherlands, Germany and Poland. Germany and Poland, which receive Russian oil through pipelines, have announced that they plan to voluntarily join the restrictions within the same time frame.

Since February, the EU has introduced a set of restrictions on supplies from Russia (date coming into effect):



* Bulgaria exempt till 31.12.2024; pipeline oil exempt for own use, resale prohibited

** Bulgaria exempt till 31.12.2024; Czechia allowed to import petroleum products made of RU oil till 5.12.2023; Croatia allowed to import VGO till 31.12.2023

At the same time, Slovakia, Hungary and the Czech Republic will continue to import Russian oil for their oil refining facilities via the territory of Ukraine. According to Platts, in 2021 Ukraine transited 11.9 million tons of Russian oil: 5.2 million tons for Slovakia, 3.4 million tons for Hungary and 3.4 million tons for the Czech Republic.

Ukraine remains an important partner of the EU in supplying the European market with oil and can support the EU's strategy to abandon Russian oil and oil products. The prospects for the restoration of oil refining in Ukraine depend significantly on the security situation.

Based on the results of the expert discussion and analysis, the following steps are proposed in this plan regarding the market of oil and oil products of Ukraine:

- Expansion of interconnectors between Ukraine and European oil refineries for delivery of petroleum products to the Ukrainian market;
- Creation of stocks of oil and oil products in protected depots;
- Completion of the Brody (Ukraine) - Adamova Zastava (Poland) oil pipeline for bidirectional operation. This project will allow Ukraine to gain access to Baltic ports, and Poland, in its turn, to Ukrainian ports on the Black Sea. Planned project characteristics: capacity of 10 million tons of oil/year with the possibility of expansion to 20 million tons; pipeline lengths: 400 km (including 270 km on the territory of Poland); implementation period: up to 2 years, estimated cost: up to 400 million dollars
- During the post-war period:
    - restoration of oil refining capacity in Ukraine on the basis of one of the existing refineries and/or at new locations where it will be most economically justified.
    - restoration and expansion of LPG production capacity up to 200,000 tons/year and condensate up to 40,000 tons/year.
    - construction of a plant for the production of methanol from natural gas with the capacity of up to 30,000 tons/year.

5 Power-to-X

5.1 Production of hydrogen from RES

Hydrogen produced by electrolysis using low-carbon energy has one of the highest decarbonization potentials in the economy compared to other decarbonization tools. The potential for replacing natural gas is particularly significant, including usage in heavy industry processes (metallurgy, ammonia production, etc.).

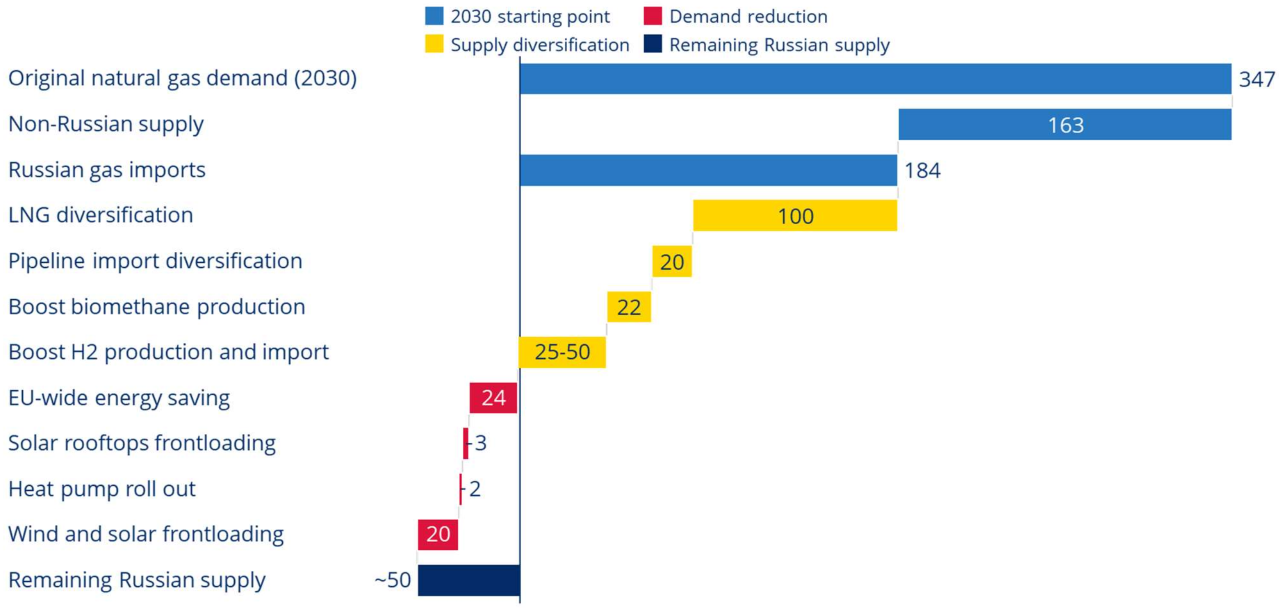
This "fuel of the future" is a key component of "green" strategies in Europe and around the world. The candidate status for EU membership opens up opportunities for Ukraine's integration into European decarbonization processes.

The Green Deal was defined as one of the main strategic priorities of the EU. The ambitious Fit for 55 program was introduced in July 2021 with the aim of reducing carbon emissions by 55% by 2030. On June 29, 2022, the Council of the EU reached an agreement on the outline of the program and its implementation targets.

One of the key mechanisms presented in the program is the Carbon Border Adjustment Mechanism (CBAM). This mechanism will impose tariffs on imports to the EU, the production of which is associated with carbon emissions. The Council decided to gradually tighten CBAM rules over a 10-year period between 2026 and 2035.

Russia's attack on Ukraine has made the problem of the European states' energy dependence on traditional energy imports even more acute. In response to this escalation, the RePowerEU green program has been revamped, taking the ambitious Green Deal and Fit for 55 goals to the next level. The central goal of the program is to replace gas imports from russia.

Potential tools to meet EU gas demand in case of refusal to import gas from Russia until 2030, bcm



RePowerEU provides for the production and import of hydrogen from renewable energy sources in the amount of at least 20 Mt per year. At the same time, it is expected that EU countries will be able to cover only half of this goal through their own hydrogen production.

Ukraine has a significant potential for the production and export of hydrogen. By 2032, Ukraine can produce ~1.6-1.7 Mt of hydrogen, which will require up to 15 GW of electrolyzer capacity. The competitiveness of Ukrainian renewable energy offers a relatively low cost of electricity production (the LCOE of wind farms is about $40/MWh), which represents a significant share of the final price of hydrogen produced. The existing gas infrastructure can potentially be upgraded to export hydrogen to Europe.

However, direct export is not the only promising way to use the hydrogen potential of Ukraine. The development of “green” hydrogen-based metallurgy and potentially the production of “green” hydrogen-based ammonia and fertilizers are also promising options in terms of added value.

A "hydrogen cluster" can potentially be built in Zaporizhzhia and Dnipro Regions. The region has an optimal location in terms of access to natural resources (water, iron ore deposits, attractive renewable energy potential) for the development of hydrogen production and its use for the production of "green" DRI and steel.

Hydrogen can also be used as a means of storing excess electricity generated from renewable sources when its production exceeds demand. However, this use of hydrogen is unlikely to be cost-effective until at least 2030 due to the low efficiency of the process.

5.2. Electrification of transport

Reducing carbon emissions from transport is one of the key priorities of the EU's "green" programs. According to the agreed version of the Fit for 55 program, the goal is 55% reduction in emissions by new cars and 50% reduction in emissions by new trucks by 2030. The goal for 2035 is a 100% reduction in emissions from new vehicles.

In general, two alternative goals have been set for the transport sector: a 13% reduction in sector emissions by 2030 or a 29% share of renewable energy in the sector's energy consumption by 2030. These ambitious goals can only be achieved through a massive shift to alternative types of automobile fuels, including electrification of transport.

The number of cars in Ukraine is quite low compared to the developed European countries and amounts to 245 cars per 1000 people. In the EU, the given indicator reaches 560 cars per 1000 people. This demonstrates a significant growth potential of the Ukrainian automobile fleet soon.

Additionally, the need to reorient export and import flow from maritime to land transport in the short term can lead to a significant increase in the freight transport fleet (both railway and road).

This trend may pose a threat both in terms of carbon emissions and consumption of motor fuel based on petroleum products that are historically mainly imported from Russia and Belarus.

Transport electrification can prevent this. Ukrzaliznytsia is already one of the largest electricity consumers. The company's consumption amounted to 4 TWh in 2020. Large-scale electrification of railroad transportation (95% of total transportation) will increase electricity consumption by the transport sector and reduce diesel fuel consumption.

Also, the number of electric cars is increasing in Ukraine. In 2021, the number of registrations of electric cars reached 8,541, which is 14.2% of the total. By 2032, the share of electric cars may reach 10-12%.

In the longer term, it is possible to increase the share of hydrogen-powered vehicles. This option is especially attractive for freight transport.

5.3. Electrification of heating

Residential heating has a significant weight in the total energy consumption in the domestic household sector and accounts for 53%.

About 85% of the buildings in Ukraine were constructed before Ukraine's independence and have very low energy efficiency indicators. The average energy consumption per m^2 in Ukraine is much higher than in some European countries (for example Germany).

A large-scale program for thermal modernization of buildings (about 70% of buildings) has the potential to significantly reduce energy consumption for premises heating. However, without the simultaneous modernization of the district heating infrastructure and individual heating, the effect of such a program will be limited.

Modernization of heating infrastructure consists of several parts. Repair, modernization, or replacement of heating networks will significantly reduce heat losses during transportation. Modernization or replacement of existing boilers will reduce energy consumption by increasing efficiency output.

The transition from traditional gas boilers to alternative district and individual heating systems will have a significant additional effect on energy consumption (especially natural gas). The most promising areas of such transition are the use of biomass and electrification of heating.

The use of electricity from renewable sources in the domestic household sector is one of the main focuses of the EU's "green" programs. The European Council's version of the Fit for 55 program sets out targets for increasing the share of renewable electricity in domestic heating and cooling energy consumption: a gradual increase of at least 0.8% a year until 2026 and 1.1% a year from 2026 to 2030. There is a specific target to achieve 49% renewable energy share in the energy consumption of buildings by 2030.

One of the most promising ways to electrify heat supply is heat pump installation. Heat pumps can be used both for individual and district heating systems. The main advantage of heat pumps is their high efficiency (about 300%). However, heat pumps (especially large capacity systems used in district heating) are a relatively "immature" technology and require significant capital investment. The target share of heat pumps in heat production can be 2-5%.

In comparison, the other option, electric boilers, is less expensive in the short term. They can be installed relatively fast, which makes them one of the best options for replacing boilers that are in critical condition or have been damaged by war.

The cost-effectiveness of heat supply electrification depends substantially on the price of electricity. Relatively cheap energy from renewable sources is an important factor in the development of electricity-based heating systems.

6 Recovery and development: detailed plan of measures

The main goal of recovery is a stable, modern and investment-attractive energy industry that provides Ukrainian consumers with clean, affordable and reliable energy, relies on the responsible development of domestic energy production, and also supports the EU in achieving its strategic autonomy.

The proposed recovery measures are outlined in the Plan for three time periods (short-term, mid-term and long-term) and are grouped under the following five objectives:

- Objective 1: European integration and efficient operation of energy markets
- Objective 2: Energy security: diversification of energy supply sources, creating reserves, cyber-security
- Objective 3: Decarbonisation, optimisation of the energy mix and development of low-carbon generation
- Objective 4: Modernisation and development of infrastructure for energy transportation, transmission, distribution and storage
- Objective 5: Improvement of energy efficiency and demand-side management

Objective 1: European integration and efficient operation of energy markets

	Stage 1: 06/2022 – 12/2022	***Stage 2: 2023 – 2025***	***Stage 3: 2026 – 2032***
Measures to achieve the objective	1.1: Commercial flows with ENTSO-E are implemented to reduce the EU's energy deficit and support Ukraine in the crisis 1.2: Analysis of Ukraine's current international commitments regarding energy reforms and creating a roadmap of reforms for negotiations on the EU membership 1.3: Development of mechanisms for solving the problem of accumulated debts between participants of the gas, heat, water supply, and electricity markets 1.4: Launching the Energy Security Fund to meet urgent recovery needs 1.5: Ensuring the stable operation of the government bodies in the energy sector 1.6: Analysis of the situation and implementation of an action plan to simplify access to power grids – *cross-sectoral with the Ministry of Digital Transformation* 1.7: Digitalization of utility services for speed and transparency – *cross-sectoral with the Ministry of Digital Transformation*	1.1: Complete market coupling of the energy markets in Ukraine and the EU through proper regulatory changes in Ukraine and the EU 1.2: Liberalization of electricity and gas markets, settlement of accumulated debts, improvement of the support system for vulnerable consumers 1.3. Development of mechanisms for solving the problem of accumulated debts between participants of the gas, heat, water supply, and electricity markets 1.4: Restoration/development of the infrastructure of exchange trading of energy resources 1.5: Completing the corporate governance reform in state-owned energy companies, preparation for placement of credit instruments, establishing partnerships and/or privatization of state-owned companies in the energy sector, taking into account energy security 1.5: Reform of public administration bodies in the energy sector	1.1: Ensuring Ukraine's contribution to the strategic autonomy of the EU through the export of excess energy resources 1.2: Increased competition in the electricity and gas markets 1.3: Partnership/ coupling of energy trading platforms between Ukraine and the EU 1.4: Attracting strategic and/or financial investors into companies in Ukraine's energy sector (while preserving the influence of the state on natural monopolies for reasons of energy security, with partial or full privatization of other companies) 1.5: Bringing functions and powers of state management bodies in the energy sector in line with the EU standards 1.6: Ensuring convenient access to energy infrastructure for business – *cross-sectoral with the Ministry of Digital Transformation*

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
		1.6: Improvement of the procedure to apply for grid connection – *cross-sectoral with the Ministry of Digital Transformation* 1.7: Development of a system that allows the state to provide subsidies/compensations for public utility services to the population quickly and according to flexible criteria – *cross-sectoral with the Ministry of Digital Transformation*	
Measurable indicators of objective achievement	- A possibility of commercial flows of electricity from the EU of at least 1.5GW - An audit of international commitments was conducted, negotiations were initiated regarding their revision in connection with the military situation, if necessary - The Energy Security Fund is operating, at least $50 million of donor funds have been raised to finance the urgent repair of damages - Improved the procedure and scope of imposing fines on DSOs in case of	- An opportunity has been provided for Ukrainian energy companies to compete on the EU markets on an equal footing with European companies, the capacity of commercial flows has been increased to 3 GW - Timely calculations on the energy markets are ensured, with the exception of normal commercial debt - At least 5% of gas volume is traded on the stock exchange - All state-owned energy companies have established supervisory boards and	- - Ukrainian companies are increasing their share in the EU markets (additional research required for more detail), the capacity of commercial flows has been increased to 6 GW - The Herfindahl–Hirschman Index (concentration) values in the gas and electricity market are below 0.18 - At least 15% of gas volumes are traded on the exchange - Involved international partners in gas and oil production and other sectors of the energy industry

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
	violations of the requirements of the law when connecting to networks - An online map of business locations with available grid connections has been developed, 50% of the territory has been digitized - The Unified register of consumers of energy supply services was created, the service of changing the supplier in the "Diya" mobile app was developed	internal control systems, are independently audited, charters and ownership policies are brought in line with OECD standards - Operators of distribution systems and gas distribution networks are obliged to purchase network connection services through transparent competitive procedures - - A simplified procedure for the construction of electric and gas networks for the supply of remote customers, including at the expense of industrial consumers, while fairly reflecting related costs in the tariff, has been developed and is in place - - An online map of business locations with available connections has been developed, 100% of the territory has been digitized - The comprehensive e-Support service has been expanded due to the possibility of submitting an application for assistance, based on the criteria of either vulnerability or	- The EC confirmed compliance of the powers of the state management bodies of the energy sector with EU standards - Implemented a simplified procedure for the construction of electric and gas grids for the supply of remote customers, including at the expense of industrial consumers, while fairly reflecting related costs in the tariff

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
		participation in national energy efficiency projects	

Objective 2: Energy security: diversification of energy supply sources, creating reserves, cyber-security

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
Measures to achieve the objective	2.1: Ensuring the supply of petroleum products 2.2: Accumulation of reserves of energy resources for preparation for the autumn-winter season (financing of measures to create reserves; creation of reserves of gas, coal, oil products in accordance with the government plan) 2.3: Ensuring the operation and urgent restoration of damaged facilities of the energy sector 2.4: Assessment of losses and preparation for claims for damages in the energy sector – *cross-sectoral with the Ministry of Justice* 2.5: Creation of the Industry Cyber Security Center of the Energy Sector of Ukraine (Energy CSOC) and the	2.1: Creation of an oil refining cluster based on one of the existing refineries and/or new locations in Ukraine 2.2: Creation of strategic reserves of petroleum products (30+ days) protected from military action 2.3: Restoration of energy supply and operation of energy sector facilities in the de-occupied territories - *cross-sectoral with the Ministry of Regional Development* 2.4: Collection and systematization of the evidence base for submitting claims for compensation of damages - *cross-sectoral with the Ministry of Justice* 2.5: Construction of the sectoral system of protection of critical infrastructure of the	2.1: Development of the oil refining business in Ukraine considering the needs of the EU market 2.2: Creation of strategic reserves of oil and oil products in accordance with EU requirements 2.3: Optimizing the operation of energy sector facilities in the de-occupied territories - *cross-sectoral with the Ministry of Regional Development* 2.4: Submission of claims for compensation of damages - *cross-sectoral with the Ministry of Justice* 2.5: Expanding the cooperation of the sectoral system of protection of the critical infrastructure of the energy sector with similar systems in the EU - *cross-sectoral*

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
	Interdepartmental Operational Headquarters (IOS) – *cross-sectoral with the Ministry of Digital Transformation*	energy sector - *cross-sectoral with the Ministry of Digital Transformation* 2.6: Liberalization of the process of issuing licenses for gas exploration and production; optimization of gas and oil production from existing fields using modern technologies 2.6.a Digitalization of the procedure for issuing decisions on environmental impact assessment - *cross-sectoral with the Ministry of Digital Transformation* 2.7: Construction of a nuclear fuel production plant and nuclear fuel storage facilities in Ukraine to eliminate dependence on Russia, development of uranium mining 2.8: Coal and coal generation: provision of flexible generation, preparation for withdrawal of specified objects 2.9: Development of the construction project of 1.5-2 GW of flexible capacities to replace coal generation, including using idle compressor stations of the GTS	*with the Ministry of Digital Transformation* 2.6 Start of gas exploration and production on the Black Sea shelf; development of non-traditional types of gas and oil deposits (primarily in the Poltava region) 2.7: Development of nuclear fuel production business considering the needs of the EU market 2.8: Coal and coal-fired power generation: withdrawal of specified objects, implementation of programs for the transformation of coal regions - *cross-sectoral with the Ministry of Regions* 2.9: Construction and launch of 1.5-2 GW of flexible capacities to replace coal generation, including using idle compressor stations of the GTS
Measurable indicators of	- Needs and sources of supply, sources of financing were identified, diplomatic support and	- A project for the creation of an oil refining cluster was developed, a study of the optimal placement of the	- Investments were attracted for the oil refining cluster, diplomatic and regulatory

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
objective achievement	regulatory support for the import of 400,000 tons of oil products per month was provided - The attraction of donor funds to the Energy Security Fund in the amount of at least 10 million dollars was ensured, the urgent needs for the restoration of key energy infrastructure were financed to the amount of funds raised - The damage assessment methodology was developed and approved, the collection of data on actual damages and losses was organized, the legal path for filing claims for damages was determined - The concept of the Cyber Security Center has been approved - A project for the color marking of the amount of consumption in the corresponding colors in energy bills - (Consumption traffic light)	object/objects was carried out, investors and executors were identified - The volumes, placement options, organizational model and sources of financing for the purchase of strategic reserves of petroleum products for 30 days have been determined - Organized and systematized work on the preparation of lawsuits for damages from companies whose assets were damaged - 100% of critical energy infrastructure facilities are connected to the cyber security center - Issuance of an environmental assessment conclusion in electronic form and automation of post-project monitoring have been introduced, a single information module of EIA has been created, creation of a conclusion evaluation module, creation of EIA post-project monitoring systems - Identified sources of financing, provided organizational resources, diplomatic and regulatory support for the incomplete cycle of nuclear fuel production	assistance was provided for unhindered access to EU markets - The volumes, placement options, organizational model, and sources of financing for the purchase of strategic stocks of petroleum products were determined in accordance with the requirements of EU legislation - Support for filing lawsuits for damages by companies whose assets have been damaged is provided - Full cooperation of the cyber security center with similar centers of the EU and the USA has been established - Provided organizational and financial resources, diplomatic and regulatory support for the incomplete cycle of nuclear fuel production - Programs for the transformation of coal regions have been implemented - Provided organizational and financial resources, diplomatic and regulatory support for the construction of flexible capabilities

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
		- Identified sources of funding, provided organizational resources, diplomatic and regulatory support for the construction of flexible capacities	

Objective 3: Decarbonisation, optimisation of the energy mix and development of low-carbon generation

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
Measures to achieve the objective	3.1: Determining an optimal long-term generation mix taking account of international commitments, technical constraints of the system, minimisation of the cost for consumers and the requirements for stable system operation	3.1: Updating the estimation of the optimal generation structure, taking into account the state after the end of hostilities 3.2: Nuclear generation: Modernization and optimization of the use of installed nuclear capacities (increasing the net capacity factor), extension of the operating life of existing units, development of new capacities at the Khmelnytskyi NPP 3.3: Hydropower: Completion of the construction of a new hydropower plant (Kakhovska-2 HPP, Kanivska HPP, Dnistrovsk HPP - completion) 3.4: Solar and wind energy: restoration of capacities taking into account new conditions and opportunities due to integration with ENTSO-E 3.5: Increasing the production of biomethane (up to 1 billion cubic meters per year) and connecting the installations to the GDS/GTS 3.6: Hydrogen: analysis of demand, production possibilities and financing sources	3.1: Updating the assessment of the optimal generation structure taking into account the needs of the EU market 3.2: Nuclear generation: completion of construction of new capacities at the Khmelnytskyi NPP (2 GW) 3.3 Hydropower: Kakhovska-2 HPP, Kanivska HPP - completion 3.4: Solar and wind energy: Capacity building, including for hydrogen production 3.5: Biofuel: production of biomethane up to 2 billion cubic meters. m per year 3.6: Hydrogen: Launch of pilot projects for 1–2 GW with the prospect of building up to 15 GW in combination with RES (mostly at the expense of private investors)

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
Measurable indicators of objective achievement	- Updated Energy Strategy of Ukraine, the Generation Adequacy Report, the Development Plan of the United Energy System of Ukraine and DSOs, the Development Plan of the GTS and GDS, other strategic documents as of 2022 - Negotiations were held with donors, potential investors and market participants regarding attracting financing and creating favorable conditions for the construction of low-carbon generation facilities and energy infrastructure	- Updated Energy Strategy of Ukraine, the Generation Adequacy Report, the Development Plan of the United Energy System of Ukraine and the DSOs, the Development Plan of the GTS and GDS, other strategic documents as of the time end of hostilities - Funding sources were determined, organizational resources, diplomatic and regulatory support were provided for the implementation of the investment strategy of Energoatom NNEGC - The strategic and regulatory basis for the development of the hydrogen economy has been implemented	- Updated Energy Strategy of Ukraine, the Generation Adequacy Report, the Development Plan for the Integrated Power System of Ukraine and the DSOs, the Development Plan for GTS and GDS, other strategic documents taking into account obligations of EU candidate countries - Funding sources were determined, organizational resources, diplomatic and regulatory support were provided for the implementation of the investment strategy of Energoatom NNEGC - Production of biomethane up to 2 billion cubic meters. m per year

Objective 4: Modernisation and development of energy transportation, transmission, distribution and storage infrastructure

	Stage 1: 06/2022 – 12/2022	***Stage 2: 2023 – 2025***	***Stage 3: 2026 – 2032***
Measures to achieve the objective	4.1: Start-up of the 400-kV Khmelnytskyi NPP - Rzeszów power export line, providing capacity for exporting up to 1.5 GW of electricity to the EU 4.2: Ensuring the capacity of gas networks in the direction from Ukraine to the EU in volumes of at least 42 million cubic meters. m/day	4.1: Completion of new high-voltage transmission lines to connect new capacities (stations for the production of energy from renewable sources, hydroelectric power plants and nuclear power plants) and provide capacity for exporting up to 3 GW of electricity to the EU 4.2: Optimizing the operation of the gas transportation system (GTS), facilitating the creation of gas import routes from LNG terminals in Poland, Lithuania, Italy, Croatia and/or Turkey 4.2a: Optimizing the operation of gas distribution networks (GDN) 4.3: Construction of pilot energy storage projects with a capacity of 50-200 MW to ensure balancing of the system and fulfillment of climate obligations 4.4: Modernization and completion of oil pipelines (Brody – Adamova zastava, etc.) and product pipelines taking into account the needs of the Ukrainian market	4.1.: Expansion of transmission capacity from ENTSO-E to 6 GW, modernization of internal power grids taking into account the needs of the Ukrainian economy (smart grids) 4.2: Optimizing the operation of the gas transportation system (GTS) in accordance with the needs of the Ukrainian economy and the EU, potentially ensuring the transportation of hydrogen, promoting the creation of gas import routes from LNG terminals in Germany and other countries 4.2a: Optimizing the operation of gas distribution networks (GDN) ensuring the accounting of gas use at the level of the EU average 4.3: Increasing the capacity of energy storage systems to 750 MW – 1 GW to ensure balancing of the system and fulfillment of climate obligations 4.4: Modernization and completion of oil pipelines and product pipelines taking into account the needs of the Ukrainian and EU markets

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
Measurable indicators of objective achievement	- Launch of the 400 kV line Khmelnytskyi NPP-Rzeszów - Approval of export capacity at the level of 1.5 GW by ENTSO-E - Availability of agreements between GTSOU and related operators regarding the creation of guaranteed capacities in the direction of Ukraine	- Launch of the modernized overhead line 400 kV Mukacheve – Velké Kapusany (Slovakia) with the conversion of the existing PL into a two-wheeler - Design and construction of the 400 kV substation of -Isaccia (Romania) powerline - The creation of routes from European LNG terminals to Ukrainian underground gas storage is ensured through active participation in the relevant EU negotiation groups (Gas Coordination Group, Energy Security Group, etc.), as well as negotiations with transit countries and gas suppliers - Identified sources of funding, provided organizational resources, diplomatic and regulatory support for the construction of pilot projects of energy storage systems - Funding sources were identified, organizational resources, diplomatic and regulatory support were provided for the completion	- The expansion and creation of additional routes from European LNG terminals to Ukrainian underground gas storage has been ensured through active participation in the relevant negotiating groups of the EU (Gas Coordination Group, Energy Security Group, etc.), as well as negotiations with transit countries and gas suppliers; placement of part of the gas reserves of the EU countries in underground storage facilities of Ukraine is ensured - Funding sources were identified, organizational resources, diplomatic and regulatory support were provided for the construction of additional projects of energy storage systems - Funding sources were identified, organizational resources, diplomatic and regulatory support were provided for the modernization or construction of oil pipelines and oil product

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
		of the oil pipeline along the route Adamova Zastava - Brody	pipelines necessary for trade with EU countries

Objective 5: Improvement of energy efficiency and demand-side management

	Stage 1: 06/2022 – 12/2022	***Stage 2: 2023 – 2025***	***Stage 3: 2026 – 2032***
Measures to achieve the objective	5.1: Identifying strategies for the demand-side management and energy efficiency improvement – *cross-sectoral with the Ministry of Regions and the Ministry of Infrastructure* 5.2: Development and implementation of secondary legislation in pursuance of the Law of Ukraine "On Energy Efficiency"	5.1: Updating the demand-side management strategy and increasing energy efficiency, taking into account the situation after the end of hostilities – *cross-sectoral with the Ministry of Regions and the Ministry of Infrastructure* 5.2: Development and implementation of by-laws for the implementation of the strategy and requirements within the framework of negotiations on EU membership 5.3: Ensuring the needs of the transport industry in access to power grids and electricity for the transfer of transport (railway, municipal, private) to electricity - *cross-sectoral with the Ministry of Infrastructure* 5.4: Provision of heat generation needs in access to power grids and electricity for switching heating (centralized or individual) to electricity where it is economically feasible - *cross-sectoral with the Ministry of Regions* 5.5: Promotion of energy modernization projects of district heating and household	5.1: Updating the demand-side management strategy and increasing energy efficiency, taking into account the current state of the economy, the availability of technologies and financing - *cross-sectoral with the Ministry of Regions and the Ministry of Infrastructure* 5.2: Development and implementation of by-laws to fulfill the requirements for EU membership 5.3: Ensuring the needs of the transport industry in access to power grids and electricity for the transfer of transport (railway, municipal, private) to electricity - *cross-sectoral with the Ministry of Infrastructure* 5.4: Provision of heat generation needs in access to power grids and electricity for switching heating (district or individual) to electricity where it is economically feasible - *cross-sectoral with the Ministry of Regions* 5.5: Promotion of energy modernization projects of district heating and household

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
		consumers - *cross-sectoral with the Ministry of Regions*	consumers - *cross-sectoral with the Ministry of Regions*
Measurable indicators of objective achievement	- A plan for preparing legislature to meet the requirements of Annex XXVII to the Association Agreement in terms of energy efficiency and eco-design has been developed - Increasing energy efficiency in buildings by 5% (by implementing low-cost measures in existing buildings and rebuilding destroyed buildings to a high energy efficiency class) - regulatory and diplomatic assistance in achieving the goal	- The legislature was developed and approved to meet the requirements of Annex XXVII to the Association Agreement in terms of energy efficiency and eco-design - Implementation and provision of continuous improvement of the energy management system at the state and municipal level, as well as at enterprises, in particular in accordance with the requirements of standards and international agreements - Increasing energy efficiency in buildings by 13% (by rebuilding destroyed buildings to the NZEB level and thermal modernization of the most energy-consuming buildings) - regulatory and diplomatic assistance in achieving the goal - Conditions have been created for connecting heat generation facilities to power grids in accordance with the request of	- The legislature has been implemented to fulfill the requirements of Annex XXVII to the Association Agreement in terms of energy efficiency and eco-design, the development and implementation of the NPA continues in connection with the negotiations on the acquisition of membership in the EU - Increasing energy efficiency in buildings by 35% (through mass thermal modernization of buildings and construction of buildings with close to zero energy consumption - NZEB) - regulatory and diplomatic assistance in achieving the goal - Conditions have been created for connecting heat generation facilities to power grids in accordance with the request of local self-government bodies and taking into account the economic

	Stage 1: 06/2022 – 12/2022	*Stage 2: 2023 – 2025*	*Stage 3: 2026 – 2032*
		local self-government bodies and taking into account the economic feasibility of switching heating to electricity - Conditions have been created for connecting fast electric charging stations to the power grid in accordance with the request of the transport industry	feasibility of switching heating to electricity - Conditions have been created for connecting fast electric charging stations to the power grid in accordance with the request of the transport industry

7 National projects

Key principles of project and initiative selection

Priority is given to projects and initiatives that correspond to the greatest extent and the greatest number of the following principles:

№	Principle	Description	Approximate criteria for measurement
1	Strengthening energy security	The measure contributes to ensuring access of Ukrainian consumers to energy resources, provides for the rejection of Russian fuel, diversification of suppliers and reduction of import needs	- % coverage of energy resource needs - 0% from Russia - Increase in the number of suppliers/ decrease in the average share of one supplier - % of substituted imports in total demand - % of local resources and components
2	Economic validity	The measure is economically feasible without state aid, promotes GDP growth, lowers the average cost of energy, increases exports, has a proven attractiveness for investments	- Expected indicators of IRR, NPV - The need for special conditions from the state - Lower LCOE - Increase in export volumes - Availability of financing/partner
3	European integration and achievement of climate goals	The measure contributes to the fulfillment of Ukraine's European integration obligations and requirements for the candidate country, including the fulfillment of climate goals	- List of obligations to be fulfilled - %/volume reduction of emissions of harmful substances - % reduction of energy losses - % increase in carbon-neutral types of energy in the energy mix
4	Marketability and promotion of competition	The measure contributes to increasing competition in energy markets and does not provide for special pricing conditions (with the exception of natural monopolies)	- Increase in the number of suppliers/ decrease in the average share of one supplier - Refusal of non-market restrictions and special pricing conditions

5	Socio-economic justice	The measure contributes to the reduction of energy poverty, the return of temporarily displaced persons, the creation of jobs and favorable living conditions	- Increase of the number of citizens who have access to the necessary energy resources - Expected number of temporarily displaced persons who will return - Expected number of new jobs - Expected number of consumers who will have access/more reliable access to energy resources
6	Technological availability and development	The measure involves the use of technological solutions that are available for purchase and can be delivered in time to meet the goal	- Waiting time for the delivery of the necessary technological solution % of substituted imports in the total demand - Involvement of the latest technology in Ukraine/localization of new production

List of strategic projects*

			CapEx, USD bln	Expected project start
Low-carbon energy	Nuclear	Increasing nuclear capacity (prolongation, higher utilization of existing capacities, and 2 GW new units at Khmelnytskyi NPP)	~14	2023-25
		Localizing nuclear value chain (uranium mining, plant for fuel production, waste storage)	1.3	2023-25
	RES	Build out 5-10+ GW RES (depends on the export capacity)	~11.5	2026-32
	Balancing	Build out of 3.5 GW hydro and pumped hydro capacities	~3.5	2023-32
		Build 1.5–2 GW peaker and 0.7–1 GW of storage	~2.8	2023-25
	Supporting supply chain	Localize RES equipment production (towers, transformers, cables, solar panels, electrolyzers, Li batteries, etc.)	~2+	2026-32
	Biofuels	Developing biofuels (bioethanol, biodiesel, biomethane, biomass) production from agroproduce, residues and waste	~4.2	2022-25
	Infrastructure	Expanding interconnectors with ENTSO-E to ~6 GW (multiple projects)	0.6	2022
		Smart grids	~5-10	2026-32
		Re-build damaged / destroyed energy objects (CHPs, networks)	~0.4	2022-25
H2	RES	Build 30+ GW RES for H2 production	~38	2026-32
	Infrastructure	Build out ~15 GW electrolyzer capacities	~7	2026-32
		Test and develop H2 transport infrastructure	~2	2026-32
Gas	Production	Increase gas production from existing fields, develop unconventional gas fields (not including Black Sea shelf development~$11 bn)	~18	2023-32
	Infrastructure	Modernize gas transmission and distribution networks	~2.5	2023-32
		Securing gas supplies/storage for EU and Ukraine (e.g., extension of Świnoujście/Gdansk LNG and/or interconnect or import from Turkey/Italy/Germany)	0.7	2023-27
	Stock	Natural gas stock replenishment	~5	2022
Oil	Infrastructure	Expanding oil refining capacity post-war (rebuild, build or modernize 2 facilities) + oil pipeline Brody-Adamova Zastava	~2.5	2023-25
		Expanding oil products interconnectors with EU refineries and ports	0.7	2022
	Stock	Oil, oil products emergency stock for 30+ days (protected storages)	1.2+	2022
Total			**>128**	

Full list of submitted projects can be accessed here https://bit.ly/3xQg4KB

* The list and terms of implementation of the projects significantly depends on security, regulatory and financial preconditions\