European Resource Adequacy Assessment

2023 Edition

entsoe

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the **association for the cooperation of the European transmission system operators (TSOs)**. The 39 member TSOs, representing 35 countries, are responsible for the **secure and coordinated operation** of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E **brings together the unique expertise of TSOs for the benefit of European citizens** by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the **security of the interconnected power system in all time frames at pan-European level** and the **optimal functioning and development of the European interconnected electricity markets**, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first **climate-neutral continent by 2050** by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires **sector integration** and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources.

ENTSO-E acts to ensure that this energy system **keeps consumers at its centre** and is operated and developed with **climate objectives** and **social welfare** in mind.

ENTSO-E is committed to using its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in **solidarity** as a community of TSOs united by a shared **responsibility.**

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by **optimising social welfare** in its dimensions of safety, economy, environment and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and **innovative responses to prepare for the future** and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with **transparency** and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its legally mandated tasks, ENTSO-E's key responsibilities include the following:

- Development and implementation of standards, Network Codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;
- Assessment of the adequacy of the system in different timeframes;
- Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);
- Coordination of research, development and innovation activities of TSOs;
- Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the **implementation and monitoring** of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

Disclaimer

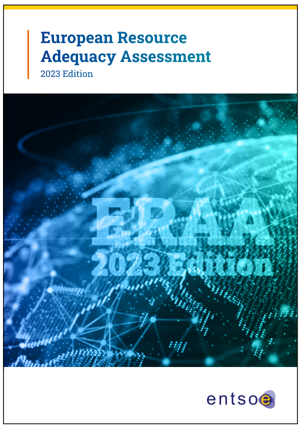
ENTSO-E and the participating TSOs have followed accepted industry practice in the collection and analysis of available data. While all reasonable care has been taken in the preparation of this data, ENTSO-E and the TSOs are not responsible for any loss that may be attributed to the use of this information. The interested parties should not solely rely upon data and information contained in this report in taking business decisions.

Information in this document does not amount to a recommendation in respect of any possible investment. This document does not intend to contain all the information that a prospective investor or market participant may need. ENTSO-E emphasises that ENTSO-E and the TSOs involved in this study are not responsible in the event that the hypotheses presented in this report or the estimations based on these hypotheses are not realised in the future.

European Resource Adequacy Assessment (ERAA) 2023

Navigating the package

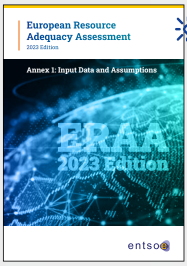
The ERAA 2023 is divided into six parts (Executive Report and Annexes) to help readers identify relevant information.



Executive Report

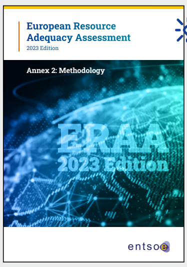
Description of the ERAA 2023 motivation, followed by adequacy results of the scenarios, focusing on the years 2025, 2028, 2030 and 2033, based on the National Trends Scenario and updated through the application of the Economic Viability Assessment (EVA*).

* EVA is a risk assessment of what could happen regarding economic investment or decommissioning.



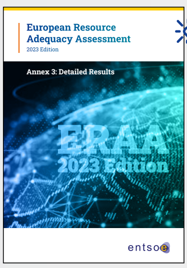
Annex 1: Input Data and Assumptions

Presentation of the ERAA 2023 scenarios and assumptions.



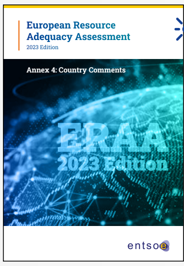
Annex 2: Methodology

Description of the main ERAA 2023 methodology.



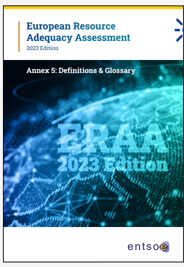
Annex 3: Detailed Results

Presentation of the ERAA 2023 detailed results for the central reference scenario.



Annex 4: Country Comments

Specific comments, optionally provided by TSOs on the ERAA 2023 input data and results.



Annex 5: Definitions & Glossary

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1 Highlights

The ERAA 2023 shows that in the given scenario and methodology framework, high volumes of fossil-fuelled capacity are at risk of becoming economically non-viable in the next five years. In that context, the right incentives and/or targeted intervention will be necessary to avoid adequacy risks.

Adequacy issues in one country are highly dependent on assumptions in neighbouring countries – and, reciprocally, any capacity investment in one country can greatly influence its neighbours. This highlights the importance of **regional coordination in decision-making**.

Growing variability in supply requires the implementation of new **flexibility tools** that facilitate the management of demand (ramps and peaks). It further necessitates capacity that can quickly respond to sudden variation of demand and supply, for example to meet demand spikes in the evening with decreasing photovoltaic (PV) supply.

In the short and midterm (Target Years [TYs] 2025 and 2028), the economic viability assessment points to significant capacities at risk of being decommissioned. At the same time, no significant investments are foreseen in such a short timeframe. This decommissioned capacity decreases notably the available margins and leads to adequacy risks in some countries, also in the European continent. It most importantly highlights the criticality of maintaining the pace of integrating new renewable energy sources (RES) capacities as depicted in the input data to the scenarios studied. In the mid-term, adequacy risks appear in central and north Europe, as well as in island states. Note that adequacy risks reported in the report refer to an average across many climatic years while extreme climatic conditions would lead to major adequacy risks.

In the longer term (i. e. Target Year 2030 and 2033), the economic viability analysis still shows important risks for the assumed thermal generation fleet and simultaneously significant potential new investments (mostly natural gas power plants), triggered by high market prices that occur in some hours. In 2033, significant adequacy risks are observed in many European countries. The countries with the largest amount of capacity at risk are Great Britain, Poland, Italy, Czech Republic, Cyprus, Germany, Luxembourg, Hungary, Denmark, Serbia, France, Belgium.

Despite slightly lower gas prices compared to the ERAA 2022 edition, the **merit order between gas and coal** put more pressure on gas technologies compared to coal in the short term (2025), and the trend is inverted from 2028, bringing gas before coal in the merit order.

2 Main findings of the ERAA 2023

This section presents the main findings of the assessment, whereas more detailed results are available in Annex 3. Assessing the adequacy situation in the ERAA takes place over two steps: 1) the economic viability of the capacity resources is assessed solving a long-term planning optimisation problem, and 2) the adequacy situation is evaluated on viable scenarios conducting a Monte-Carlo[1] analysis of the economic dispatch problem.

Two complementary scenarios derived from the same input data have been addressed in the ERAA 2023:

- **Scenario A (Central Reference):** the climate year representation in the economic viability analysis is calibrated based on the Loss of Load Expectation (LOLE) of the ERAA 2022 adequacy results aiming at the consistency of this indicator throughout the economic viability and adequacy analyses. This scenario results in substantial investment reaction to price spikes.
- **Scenario B (Sensitivity):** the climate year representation in the economic viability analysis is calculated according to the ERAA 2022 methodology, aiming at the consistency of the total system costs throughout the Economic Viability Assessment. This scenario results in comparably measured investment reaction to price spikes.

Both central reference scenario and sensitivity shall be read in conjunction. They are the outcome of an economic viability assessment implemented on the same three climate years but with different weights assigned to each of them. The selected weights serve the different purpose of each scenario described above.

Simulating investment decisions is an inherently difficult task and the ERAA methodology is still under development in that aspect. While Scenario A aims to alleviate the inherent modelisation bias between the Economic Viability and Economic Dispatch studies, it creates another bias on that a single extreme climatic year becomes dominant in the investment/decommissioning decisions. The results of this approach therefore cannot be interpreted in isolation for the identification of adequacy concerns in Europe and needs to be complemented with a sensitivity that maintains consistency on the investment driver (revenues) and thus relies more moderately on a single climate year. Both scenarios together can therefore provide a more robust picture of the risks.

For more information on the scenario selection methodology see Annex 2. Note that both scenarios account for capacity mechanisms that already hold a capacity mechanism contract granted in any previous auction of any existing or approved capacity mechanism at the time of the assessment.

The ERAA is characterised by a significant degree of uncertainty and computational constraints. Thus, modelling decisions and assumptions, in addition to the probabilistic nature of the assessment, must be considered when interpreting the results. All modelling assumptions and decisions are described in Annex 2 of this report, together with the uncertainty characterising the assessment stemming from the climate variables and forced outages on thermal generators and cross-border interconnectors.

The ERAA is still in the implementation phase, and the 2023 edition features considerable improvements over the previous one. In addition, the assumption for a same given target year can evolve fast from one edition to another, due to the ongoing accelerating energy transition. Consequently, successive edition results must be compared with specific care and in view of all the updates and differences between the two products; these include updates and changes in the assumptions and scenarios, but also modelling improvements with significant impact on the adequacy results.

1 Conducted over 15 scenarios of unplanned outages

Overview of EVA methodology

The EVA step assesses the viability of capacity resources[2] participating in the energy-only market and is applicable to both scenarios. The EVA is a risk assessment of what could happen; it is not a prediction of what will happen. Units with an awarded capacity mechanism (CM) contract are excluded from the EVA for the duration of their contracts and the viability of resource capacities participating in the energy-only market are assessed using a long-term planning model, with the objective of minimising the total system costs.[3]

The key decision variables of that long-term model aim to identify the economic-optimal (least-cost) evolution of resource capacity over the modelled horizon. This assessment therefore delivers insight, per each bidding zone and over the TYs, on the resource capacities that are likely to be (i) decommissioned, (ii) invested in, (iii) (de)mothballed or (iv) extended in lifetime. More details on the assumptions behind the EVA can be found in Annex 1, while the detailed methodology is found in Annex 2.

2.1 Scenario A (Central Reference)

2.1.1 Significant volumes of fossil fuel capacity are at risk of economic decommissioning

Decision Variable	Technology	2025	2028	2030	2033	Most affected study zones
New Entry	Battery	0.1	0.1	0.1	1.3	GR00, MT00
	DSR	0.5	2.0	3.5	4.8	AT00, CZ00, DE00, DKE1, DKW1, FI00, HR00, HU00, NL00, PT00, SI00, SK00
	Gas CCGT	0	1.7	17.0	27.3	DE00, HU00, PL00, UK00
	Gas OCGT	0	0	0.5	3.7	BE00
Life Extension	Gas CCGT	0.3	1.6	1.8	1.8	BE00, DKE1, HU00
	Gas OCGT	0.05	0.2	0.4	0.4	BE00, DKW1, HU00
Mothballed	Gas CCGT	− 6.8	− 2.0	− 0.8	0	AT00, DE00, DKE1, ES00, NL00
	Gas OCGT	− 1.5	0	0	0	AT00, DE00, DKW1
	Oil	− 1.4	0	0	0	DE00
	Coal	− 0.2	0	0	0	FI00
Decommissioning	Gas CCGT	− 15.2	− 21.3	− 21.4	− 24.0	ES00, FI00, GR00, IE00, ITCA, ITCN, ITCS, ITN1, ITS1, UK00
	Gas OCGT	− 6.1	− 3.1	− 3.2	− 2.7	BG00, HR00, ITCS, ITN1, ITS1, UK00
	Oil	− 3.2	− 1.8	− 1.6	− 0.6	EE00, GR03, HR00, IE00, UK00, UKNI
	Lignite	− 8.5	− 12.8	− 11.3	− 5.3	BA00, BG00, CZ00, GR00, ME00, PL00, RO00, RS00
	Coal	− 4.5	− 7.6	− 4.2	− 0.9	CZ00, ES00, FI00, HR00, NL00, PL00, RO00
Total		**− 46.4**	**− 43.1**	**− 19.1**	**5.8**	**CZ00, ITCS, ITN1, UK00**

Table 1: Capacity change proposed by the EVA compared to the National Trends scenario [GW] – Non-cumulative (Scenario A – Central Reference)

2 Capacity resources include storage units (i.e. grid-scale batteries).

3 Article 6.2 of the ERAA methodology acknowledges the use of overall system cost minimisation for the EVA, albeit as a simplification and assuming perfect competition.

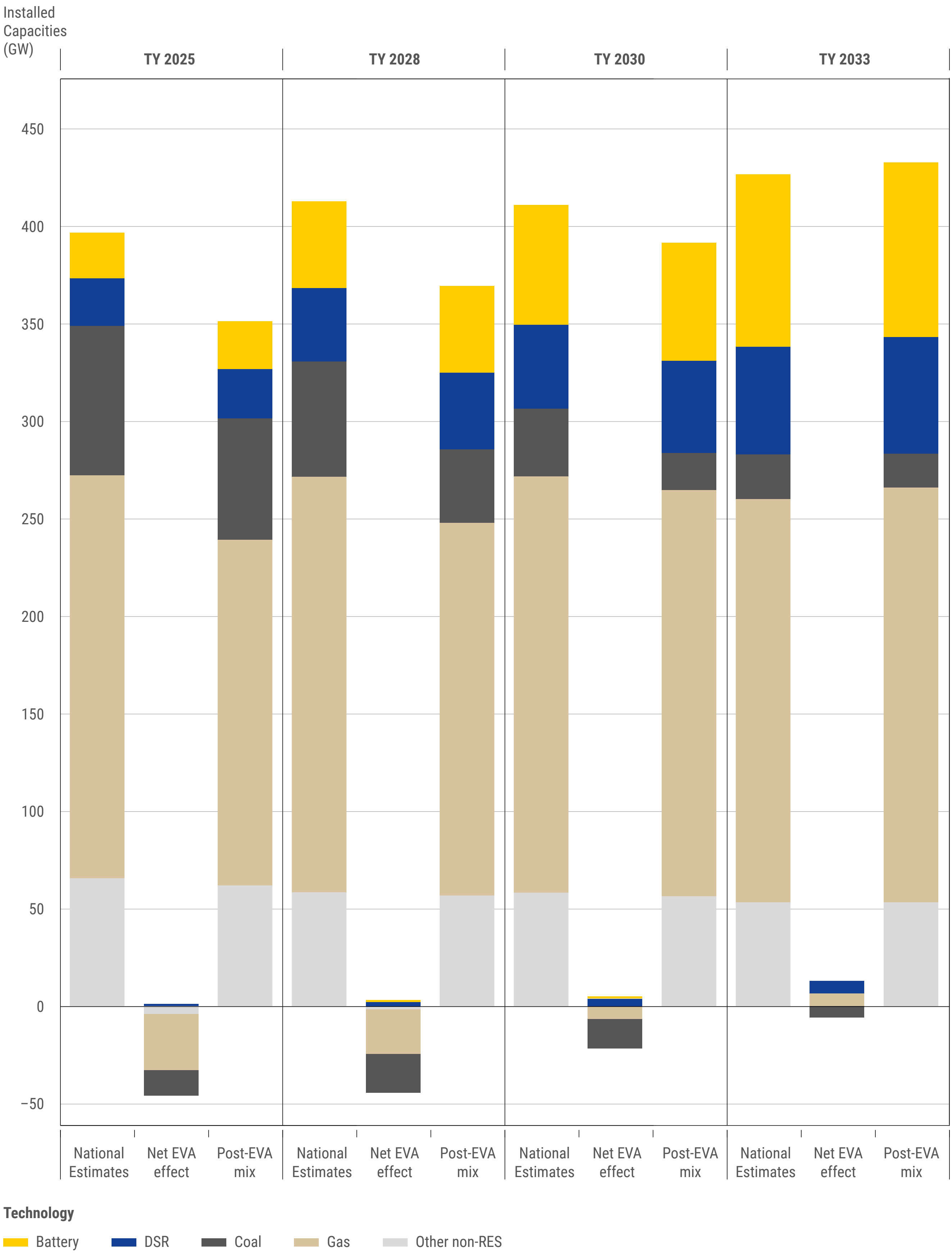


Figure 1: Net effect of the EVA on the European Perimeter – focus on technologies assessed (Scenario A – Central Reference)

2.1.2 Adequacy risks appear in few European countries and margins are tight

Overall, and under the assumptions of the commissioning/decommissioning of capacities subject to EVA and the evolution of transmission capacities, the scarcity issues tend to shift from the peripheral areas of Europe in 2025 to the central parts of the continent by 2033. Figure 2 to Figure 5 illustrate the LOLE per region target years 2025, 2028, 2030 and 2033.

The LOLE values are represented by circles, with a larger radius for larger LOLE values. A region's LOLE is calculated by averaging the Loss of Load Duration (LLD), i.e. hours with unserved energy, resulting from all the simulated Monte Carlo Years using the reference tool.

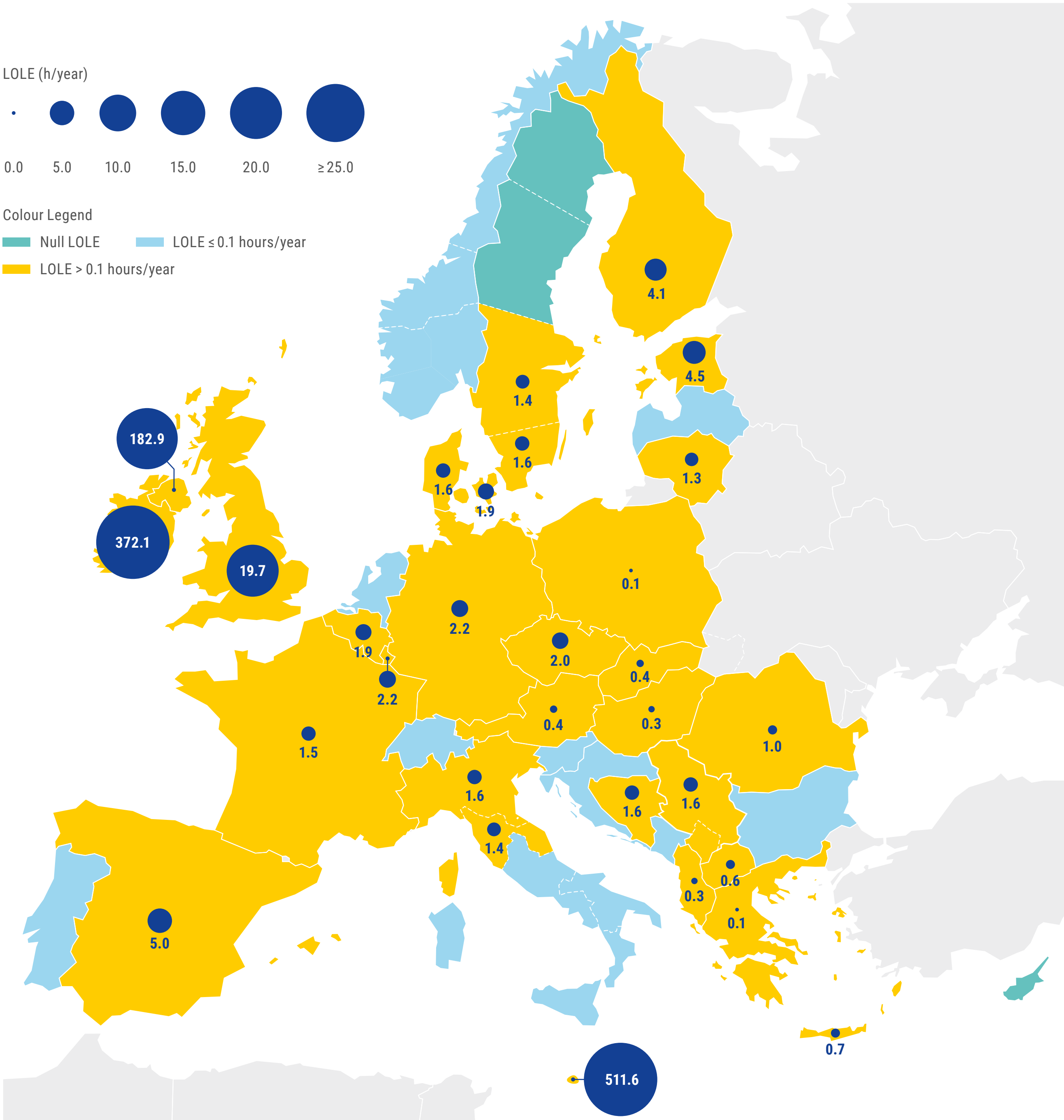


Figure 2: LOLE values in 2025* (Scenario A – Central Reference)

* Both scenarios account for capacity mechanisms that already hold a capacity mechanism contract granted in any previous auction of any existing or approved capacity mechanism at the time of the assessment, including Demand-Side Response (DSR), which is relevant for Poland in target year 2025. In Malta, an additional 215 MW of non-market resource in the form of emergency gasoil-fired back-up plants are available for dispatch at any time and would largely mitigate the risk of scarcity.

More detailed results, including Expected Energy Not Served (EENS) per region, can be found in Annex 3. For the methodology and probabilistic indicators, please see Annex 2. Moreover, there are cases in which the results depend on the specificities of each country or study zone. Annex 4 contains country-specific comments that enable more detailed conclusions.

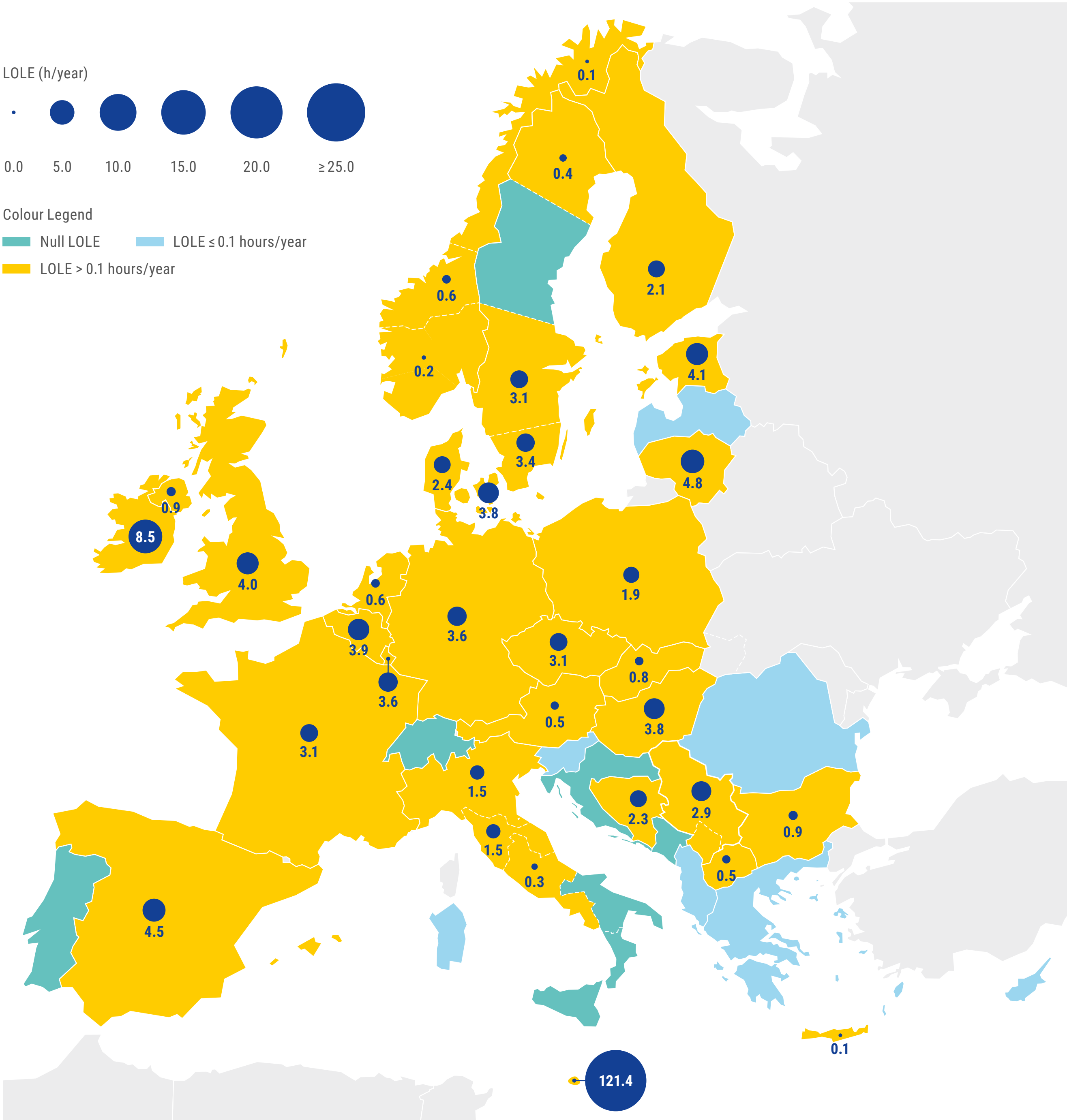


Figure 3: LOLE values in 2028 (Scenario A – Central Reference)

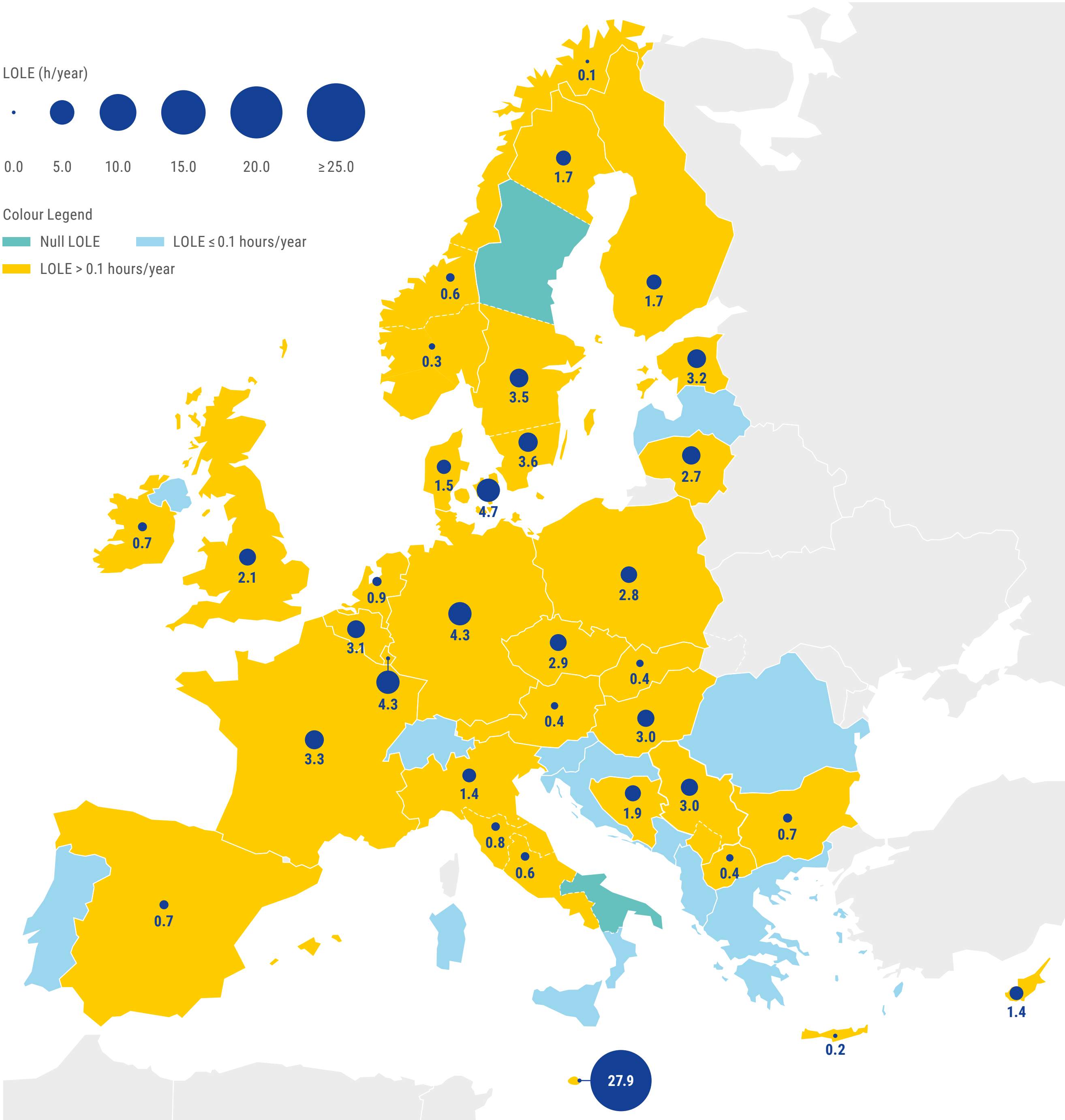


Figure 4: LOLE values in 2030 (Scenario A – Central Reference)

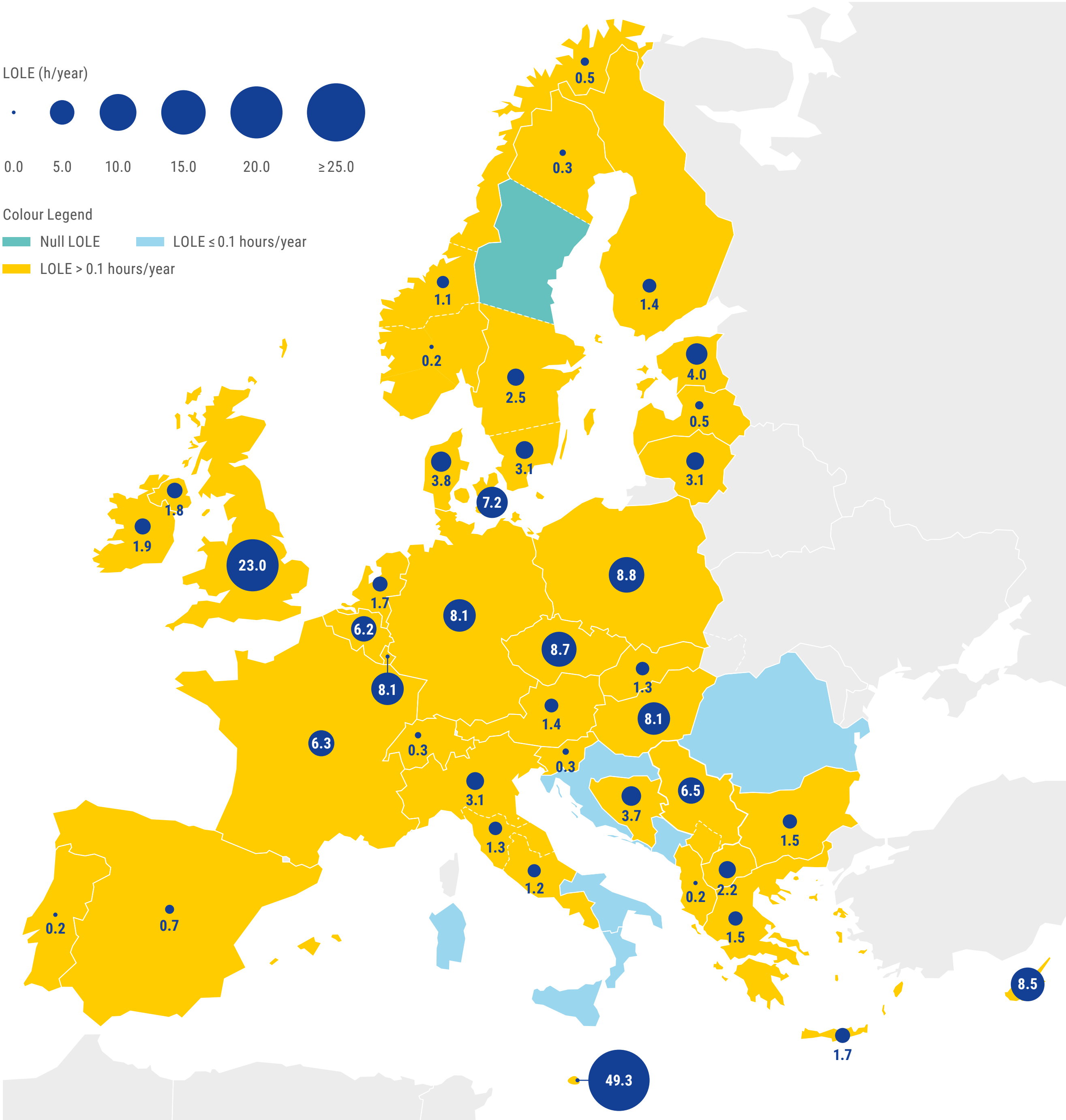


Figure 5: LOLE values in 2033 (Scenario A – Central Reference)

2.2 Scenario B (Sensitivity)

2.2.1 EVA indicates the risk of higher economic decommissioning

The results of the EVA indicate that significant volumes of fossil fuel capacity in Europe are at risk of economic decommissioning. Figure 6 shows the installed capacities assumed in the National Trends Scenario[4] and the resulting post-EVA mix. The net effect for all four target years is that, under the given scenario and methodology framework, a rather significant volume of gas capacity is found at risk of economic decommissioning, especially in the shorter to mid-term horizon, followed by a comparatively smaller capacity of coal.

Table 2 provides further details on the EVA effects in addition to the study zones where the capacity change is highest, notably the case of Czech Republic, Spain, Italy and the UK. The assumptions on gas prices had a clear impact on the results. Especially in the short term (2025), gas prices lead to prioritising coal in the merit order. Contrary to the previous scenario the higher decommissioning of generation units and less investment is expected in the later years.

Decision Variable	Technology	2025	2028	2030	2033	Most affected study zones
New Entry	Battery	0.1	0.1	0.1	1.3	GR00, MT00
	DSR	0.5	1.9	2.5	4.5	DE00, FI00, NL00, PT00
	Gas CCGT	0	2.3	11.4	19.8	DE00, PL00
Life Extension	Gas CCGT	0.3	1.6	1.8	1.8	BE00, DKE1, HU00
	Gas OCGT	0	0.08	0.3	0.3	DKW1, HU00
Mothballed	Gas CCGT	−10.3	−6.2	−1.3	0	AT00, DE00, ES00, NL00, SK00
	Gas OCGT	−4.5	0	0	0	AT00, DE00, DKW1,
	Oil	−2.4	−1.4	0	0	DE00, FR00
	Coal	−0.2	0	0	0	FI00
Decommissioning	Gas CCGT	−17.8	−23.8	−22.5	−26.3	ES00, GR00, IE00, ITCA, ITCN, ITCS, ITN1, ITSI, UK00
	Gas OCGT	−6.7	−6.7	−3.9	−2.9	BG00, HR00, ITCS, ITN1, ITS1, RO00, UK00
	Oil	−4.2	−1.9	−1.6	−0.6	GR03, HR00, IE00, UK00, UKNI
	Lignite	−8.9	−15.9	−14.4	−7.5	BA00, BG00, CZ00, ME00, PL00, RO00, RS00
	Coal	−3.9	−7.6	−4.2	−0.9	CZ00, FI00, HR00, NL00, PL00
Total		**−58.0**	**−57.4**	**−31.9**	**−10.5**	**CZ00, ES00, ITCS, ITN1, UK00**

Table 2: Capacity change proposed by the EVA compared to the National Trends scenario [GW] – Non-cumulative (Scenario B – Sensitivity)

4 The National Trends Scenario is the bottom-up scenario based on TSO's best estimates for the target years of the ERAA 2023. After the EVA is performed on this scenario, the result is a new 'post-EVA' mix, which constitutes the Central Scenario.

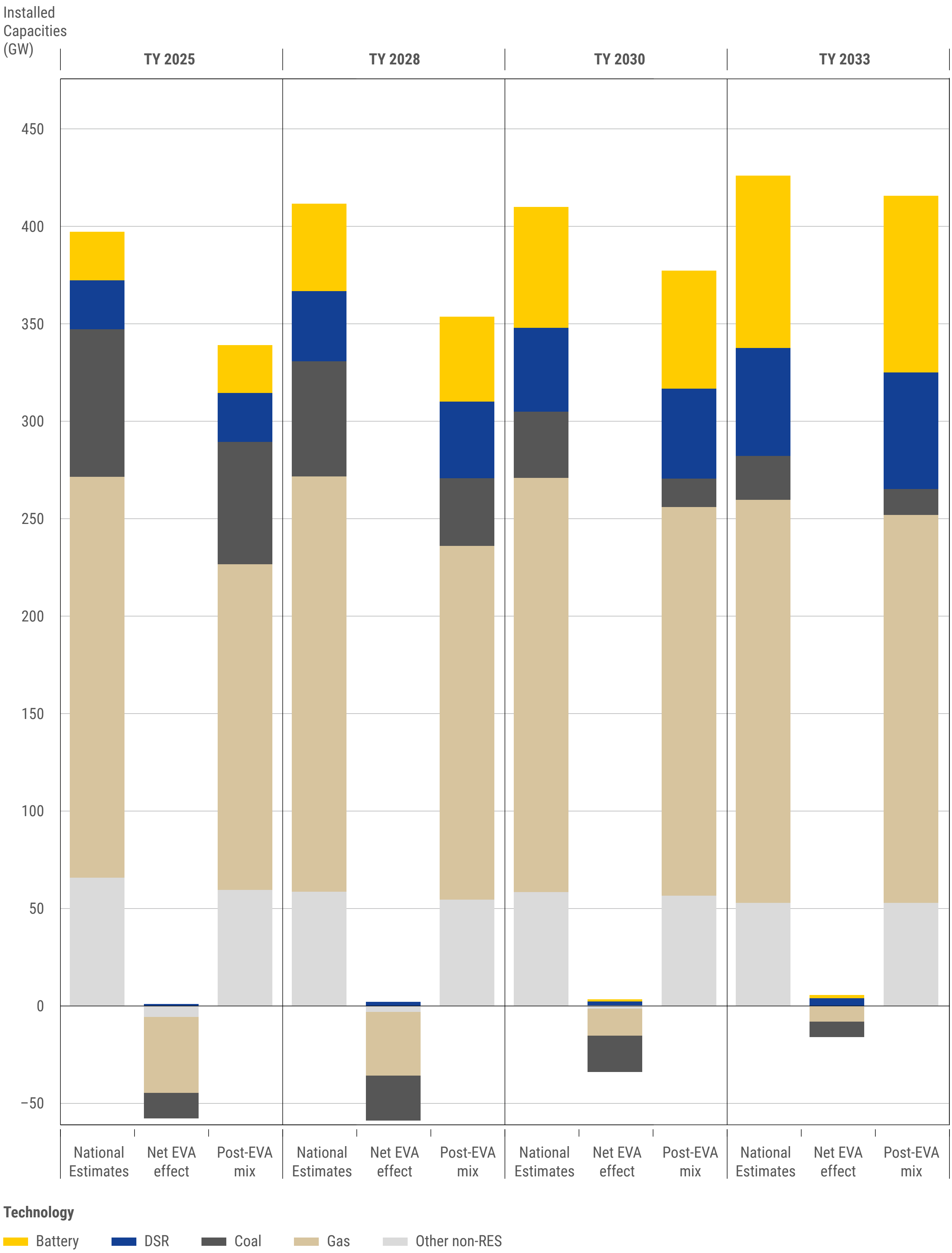


Figure 6: Net effect of the EVA on the European Perimeter – focus on technologies assessed (Scenario B – Sensitivity)

2.2.2 High adequacy risks across Europe

Figure 7 to Figure 10 illustrate the LOLE per region target years 2025, 2028, 20230 and 2033, under scenario B. As before, the LOLE values are represented by circles, with a larger radius for larger LOLE values. It is observed that higher risks of scarcity appear under Scenario B and increase as we move from the short to mid-term. In 2033, LOLE increases significantly in all the geographical perimeter, but mostly in the central and north of Europe.

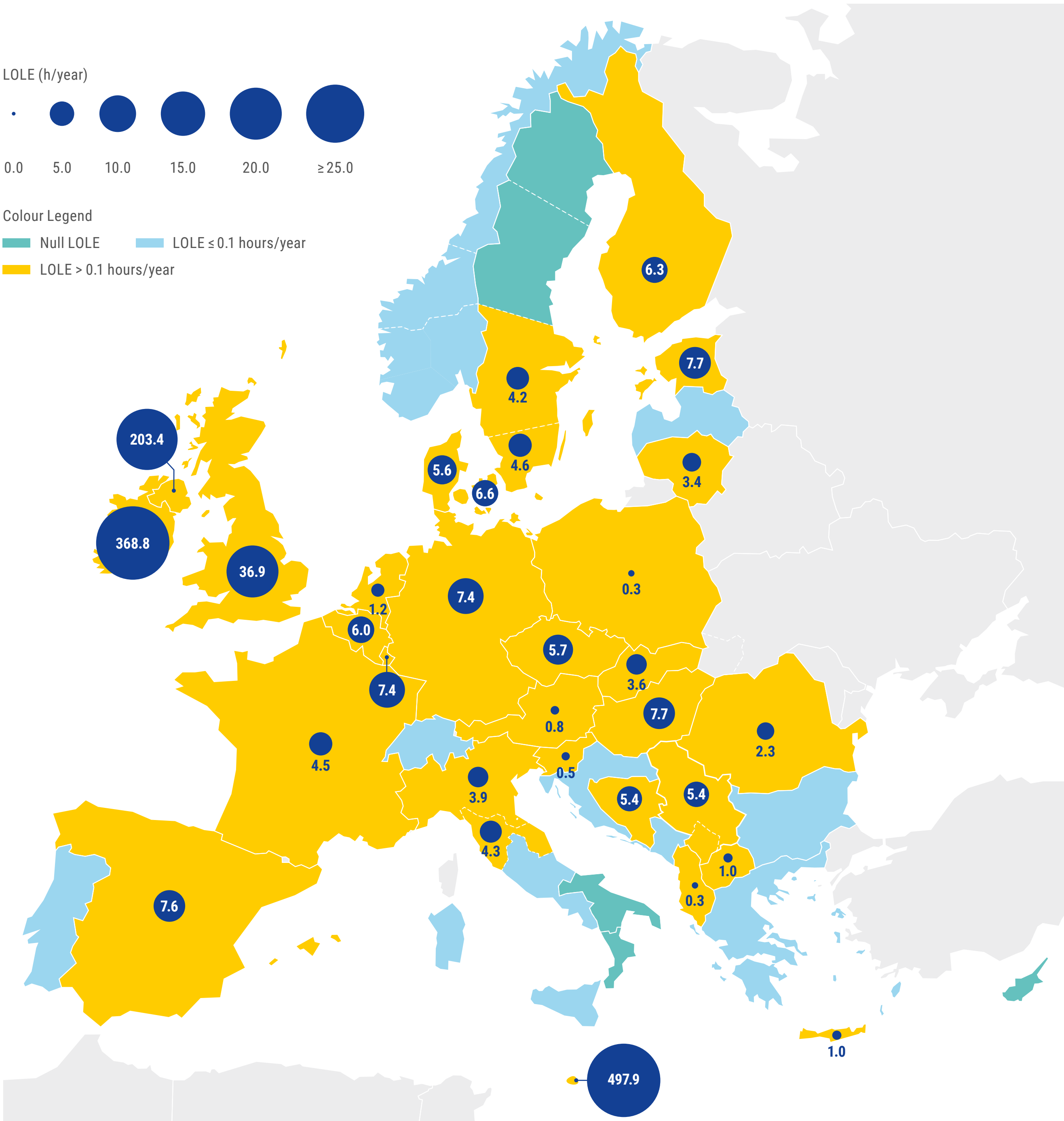


Figure 7: LOLE values in 2025* (Scenario B – Sensitivity)

* Both scenarios account for capacity mechanisms that already hold a capacity mechanism contract granted in any previous auction of any existing or approved capacity mechanism at the time of the assessment, including DSR, which is relevant for Poland in target year 2025.

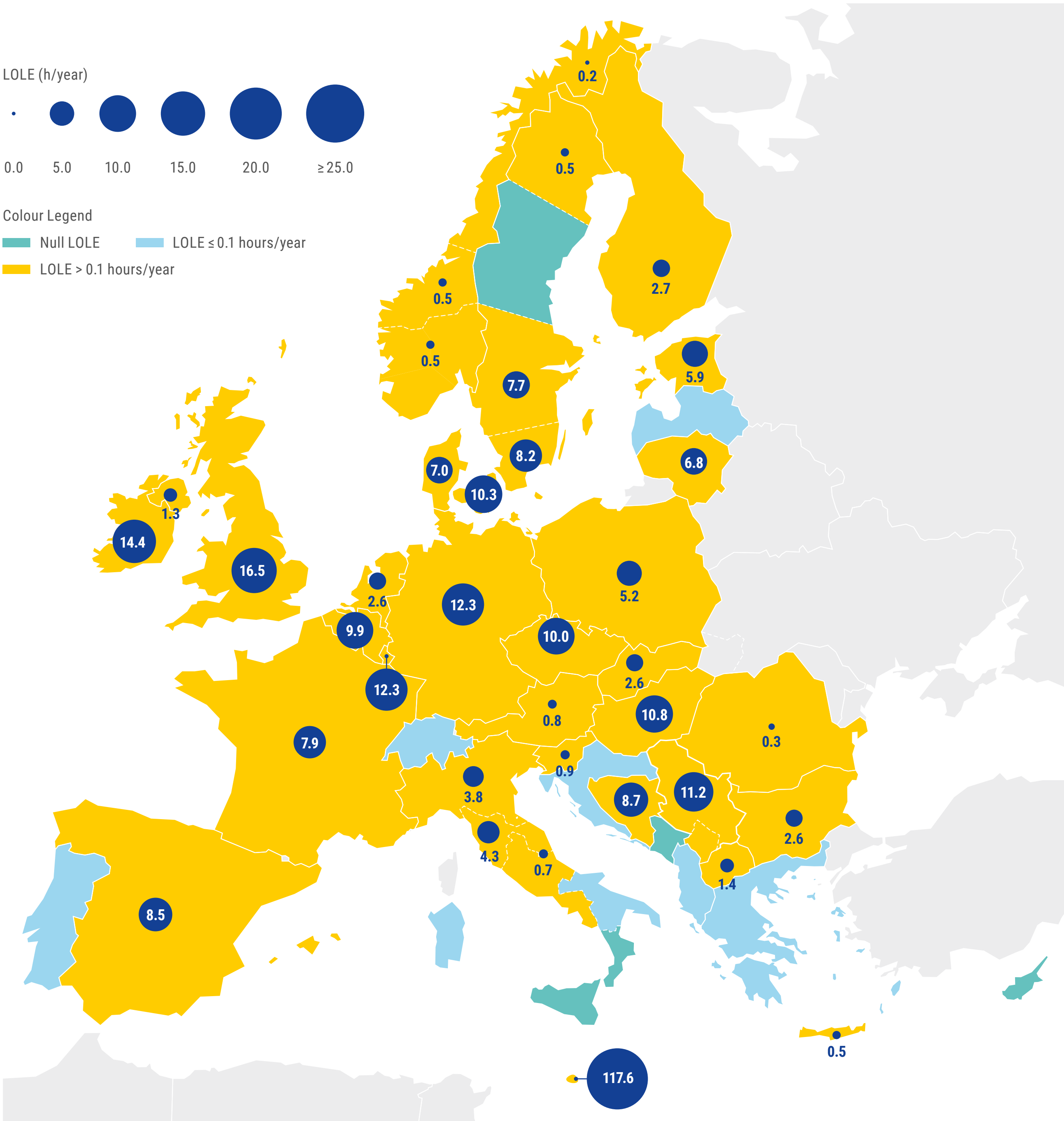


Figure 8: LOLE values in 2028 (Scenario B – Sensitivity)

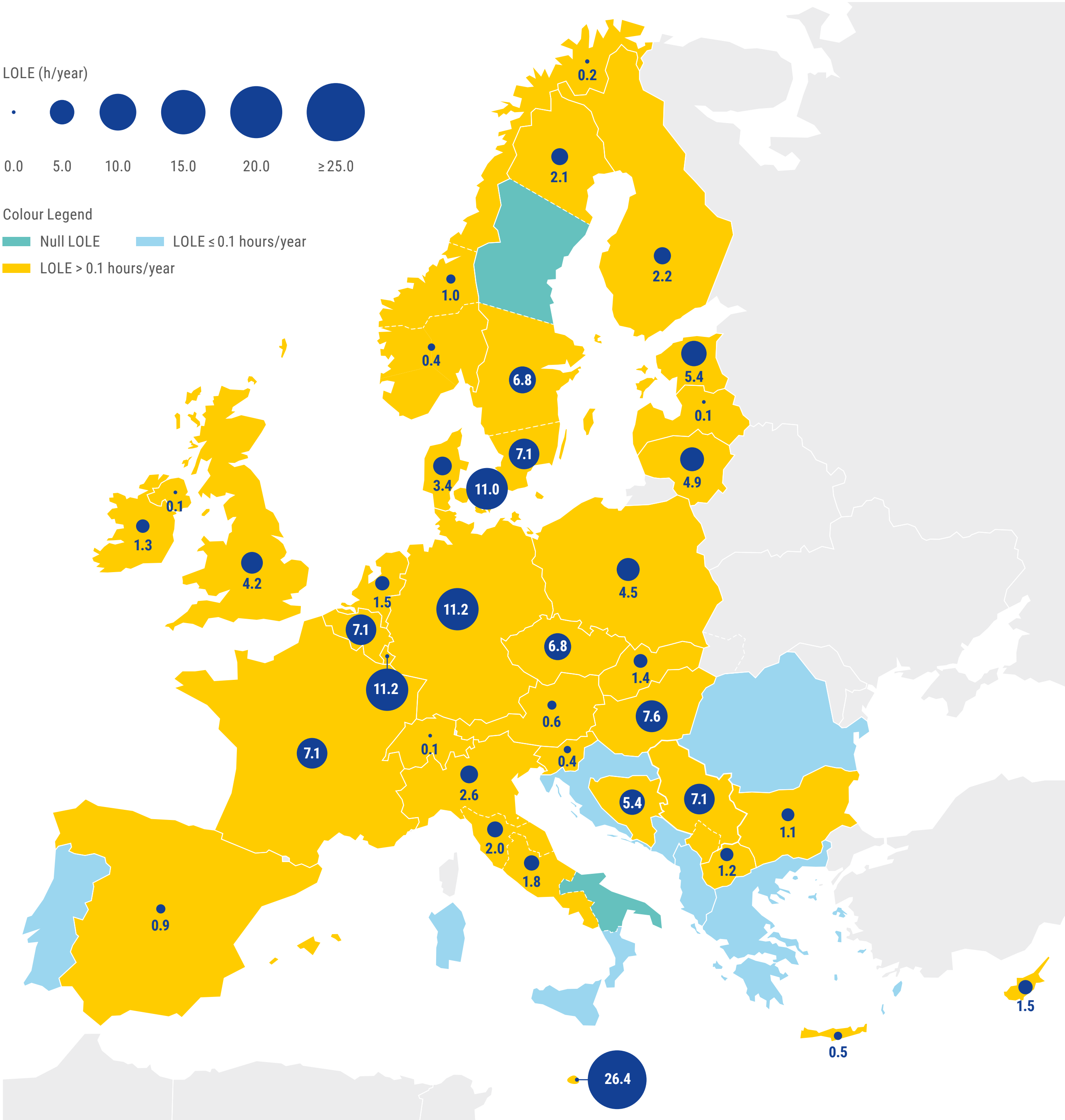


Figure 9: LOLE values in 2030 (Scenario B – Sensitivity)

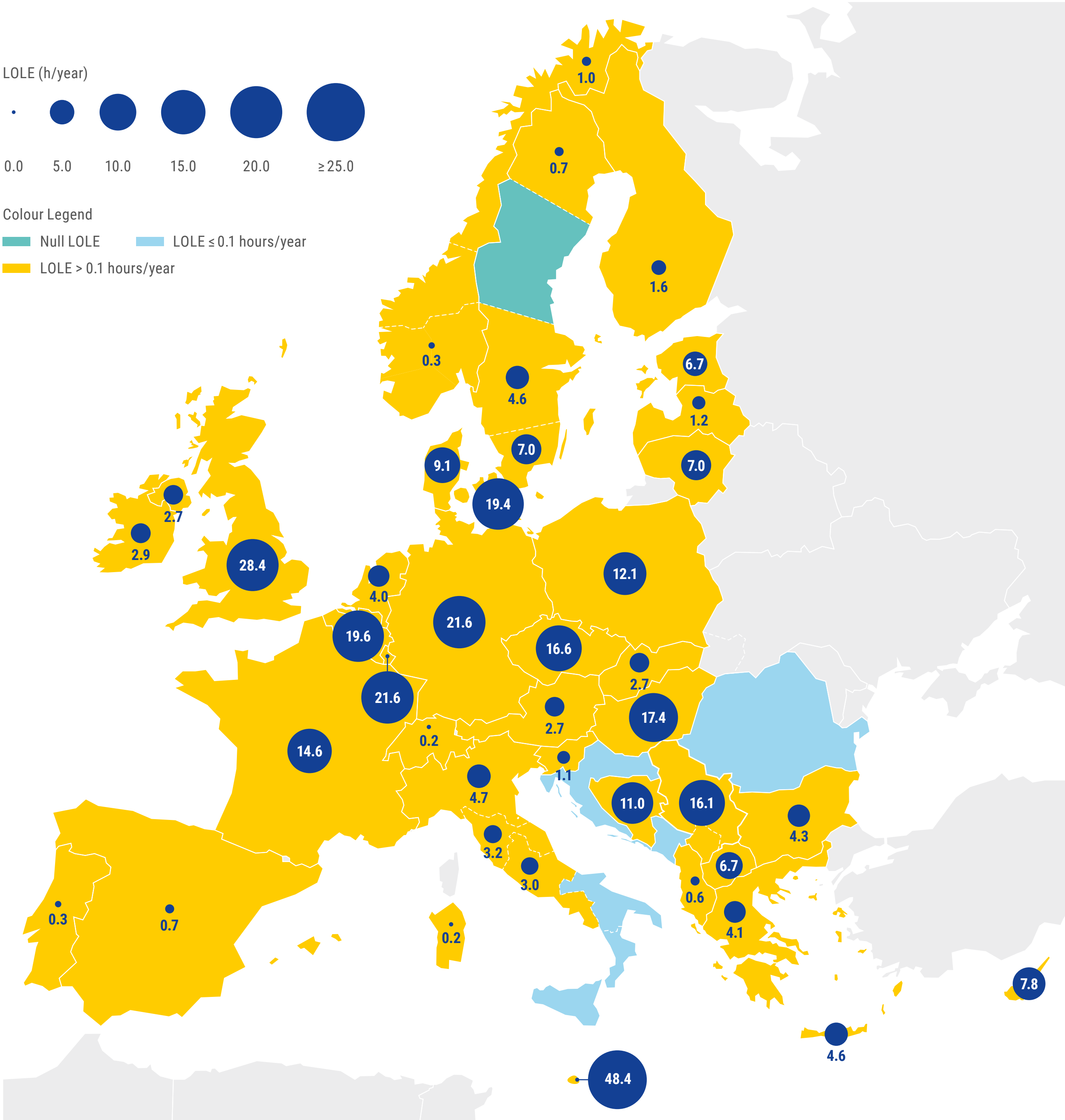


Figure 10: LOLE values in 2033 (Scenario B – Sensitivity)

3 Purpose and Motivation of the ERAA

3.1 General context

What is the purpose of the ERAA?

The ERAA is a pan-European monitoring assessment of power system resource adequacy as far as ten years ahead. Based on state-of-the-art methodologies and probabilistic assessments, it aims to model and analyse possible events that could adversely impact the balance between supply and demand of electric power. The ERAA is an important element for supporting qualified decisions by policymakers on strategic matters in order to maintain power system security.

The European electricity system is undergoing significant changes motivated by the EU's ambition to achieve climate neutrality (cf. Fit for 55 legislative package) in addition to independence from Russian fossil fuel (cf. REPowerEU plan and Wind Power package). These ambitions are driving the integration of greater volumes of variable renewables, an increase in decentralisation, the emergence of new market players, innovation and digitalisation, and the phase-out of thermal generation units. These changes are occurring at unprecedented speed, and the power system must adapt swiftly in response to new challenges. Amid this rapid transition, system operators must safeguard security of supply and maintain the balance between supply and demand across the interconnected system at all times throughout the year.

In this context, a pan-European analysis of resource adequacy – complemented by insights from national and regional analyses – is more important than ever. Cooperation across Europe is necessary to accelerate the development of common methodological standards, and a common 'language' is necessary to perform these studies. Regulation (EU) 943/2019 (hereinafter 'Electricity Regulation') and Regulation (EU) 941/2019 (hereinafter 'Risk Preparedness Regulation'), adopted as part of the Clean Energy Package (CEP), recognise this need.

Assessments of electrical grid resource adequacy (such as the ERAA) are increasingly prominent studies that use advanced methodologies to model and analyse possible events with potentially adverse consequences for the supply of electric power. Such assessments continuously assess the balance between net available generation and net load levels in the European power system, as illustrated in Figure 11. The ERAA should not be interpreted as an effort to predict the system's security of supply, but rather as a measure of the future power system's ability to maintain security of supply under a very high number of possible future system states attributable to various plausible weather conditions in addition to random outages of conventional power plants and relevant network elements. In summary, the ERAA does not predict the future; rather, it identifies potential shortcomings in the system that can be addressed proactively.

To identify these potential shortcomings, the ERAA relies on national standards for system reliability. Individual EU Member States apply reliability standards to assess their national resource adequacy; an overview is presented in Table 3. Loss of Load Expectation (LOLE) is the most common reliability indicator used by EU Member States, with targets typically in the range of 3 – 9 hours per year. Setting such reliability standards is a complex issue because it involves economic in addition to technical considerations. These standards are determined in accordance with the 'Methodology for calculating the value of lost load, the cost of new entry, and the reliability standard'.[5]

5 ACER Decision on the Methodology for calculating the value of lost load, the cost of new entry, and the reliability standard: Annex I

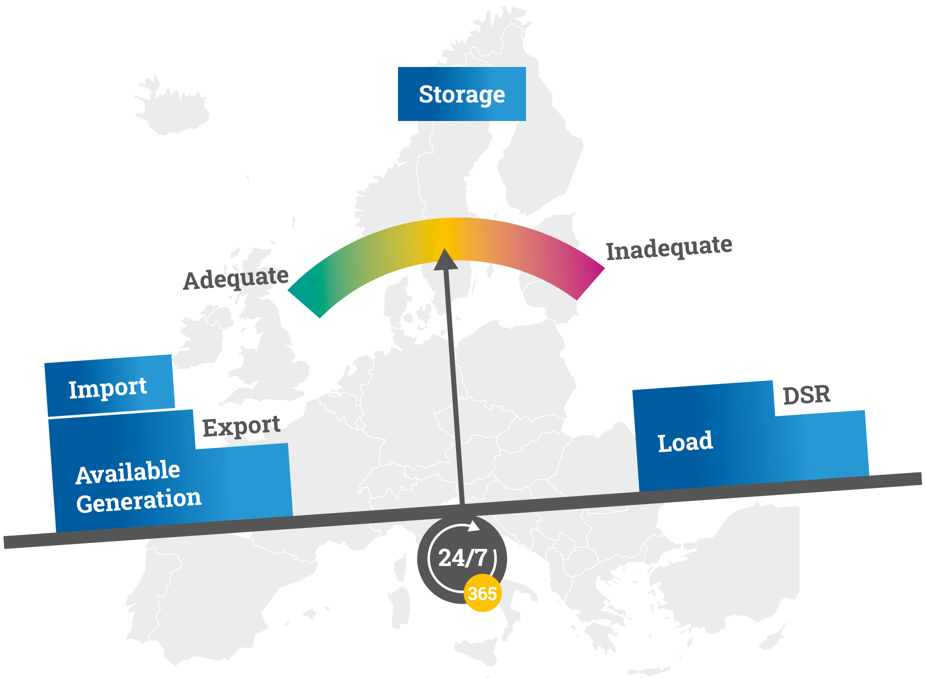


Figure 11: Resource adequacy: Balance between net available generation and net load

Member state	Type of reliability standard	Value
Belgium[a]	LOLE (hours/year)	3.00
Cyprus[b]	LOLE (hours/year)	3.00
Czech Republic	LOLE (hours/year)	15.00
Estonia[c]	LOLE (hours/year)	9.00
Finland[d]	LOLE (hours/year)	2.10
France	LOLE (hours/year)	2.00
Germany[e]	LOLE (hours/year)	2.77
Greece	LOLE (hours/year)	3.00
Ireland (SEM)[f]	LOLE (hours/year)	8.00
Italy	LOLE (hours/year)	3.00
Luxembourg[g]	LOLE (hours/year)	2.77
The Netherlands	LOLE (hours/year)	4.00
Poland[h]	LOLE (hours/year)	3.00
Portugal	LOLE (hours/year)	5.00
Sweden	LOLE (hours/year)	0.99

Table 3: National reliability standards applied by EU Member States as of June 2023 (Source: ACER's Security of EU electricity supply, October 2023)

Sources: ACER based on information from NRAs and for Estonia the relevant study to establish a reliability standard.

Notes 1: a: calculations for VOLL, CONE and the reliability standard updated in 2022
b: In Cyprus, three adequacy metrics are set: LOLE of 3 hours per year, reserve margin of 189 MW and expected energy not served at 0.001 % of annual demand;
c: In Estonia, expected energy not served equal to 4,500 MWh/year and a capacity margin equal to 10 % are also used;
d: In Finland an additional reliability standard expressed as expected energy not served equal to 1,100 MWh/year is in place;
e: In Germany the reliability standard is calculated as the average of annual reliability standards for a five year period.;
f: Ireland is currently re-calculating the VOLL and the reliability standard;
g: Luxembourg uses the same adequacy metrics as Germany;
h: National reliability standard has been calculated, but not based on the regulation.

Notes 2: In Spain, a 10 % reserve margin for mainland and a LOLE of 2.4 hours per year for non-mainland is used.
In Denmark a 7 'outage minutes' (OM) per year metric is used, estimated on the basis of the demand and the expected unserved energy (EUE) as OM = 8,760 × 60 × EUE / Demand.

The ERAA considers a perfect market and aims to provide stakeholders and policymakers with the data and insights necessary to make informed, qualified decisions and promote the development of the European power system in a reliable, sustainable and connected manner. Resource adequacy assessments, such as the ERAA and those undertaken by national system operators, have contributed to the spatial harmonisation of adequacy methodologies across European Transmission System Operators (TSOs). The ERAA is also coordinated and consistent with other timeframe studies, such as the ENTSO-E Ten-Year Network Development Plan (TYNDP) and Seasonal Outlooks. Continuous developments in forecasting methodologies have improved the strength of these assessments, and ERAA represents a substantial step forward.

Each year, stakeholders can expect an even more useful and valuable tool with analyses that better account for the realities and complexities of the single electricity market – an unparalleled data set – in addition to an improved economic viability assessment.

The ERAA 2021 was the first step towards the implementation of the ERAA methodology. The ERAA 2022 and ERAA 2023, while developed over a period during which Europe experienced a deep energy crisis and an overhaul of many energy policies, delivered a study with complex approaches and significant methodological improvements.

ENTSO-E is committed to delivering a yearly ERAA edition that meets the objective of the Electricity Market Regulation and is fit for purpose, especially when decision makers seek guidance on risks and measures for the pan-European electricity system over the next decade. ENTSO-E's work on subsequent ERAAs will again be based on the best available input received from extensive stakeholder engagement and more recent projections from European and national policies.

ENTSO-E asks any reader to note the assumptions on price levels and market response, in addition to the Regulation's provisions that national assessments can provide additional complementary local context when necessary.

3.2 ERAA's role compared to the ENTSO-E's power system Outlooks and TYNDP

The ERAA, the Seasonal Outlook and the TYNDP aim to model and analyse possible events that could adversely impact the balance between supply and demand of electric power in different time horizons ahead. The ERAA focuses on the medium-term horizon of 2 to 10 years ahead, while seasonal adequacy assessments, such as the Winter Outlook, assess the situation in the short-term for the upcoming season (weeks to months ahead). The TYNDP evaluates the long-term horizon, between 10 and 30 years ahead, from a different perspective than resource adequacy assessment, primarily transmission infrastructure system needs for market and RES integration.

The ERAA, Seasonal Outlook, and TYNDP are not forecasts or predictions of the future. Instead, these assessments provide a measure/view of the future power system's ability to maintain security of supply under a very high number of possible future states depending on various factors that impact adequacy (e.g. weather conditions, outages, generation availability) and identify potential shortcomings in the system that could be addressed proactively.

Although all power system assessments are based on state-of-the-art methodologies and probabilistic assessments, they do have their differences. The purpose of the ERAA is to identify adequacy assessment concerns and serve as an action guidance, with a moderate uncertainty up to 5 years ahead, increasing to higher uncertainty beyond the 5 years. It indicates the impact on adequacy in the longer run through the economic viability assessment (estimation of resource capacity at risk), which is subject to specific assumptions for the next 10 years. The Seasonal Outlooks aim to identify risks in the security of supply of the upcoming months, with a low level of uncertainty as they assess a shorter time horizon and are based on data/assumptions/information that much more accurately reflect the real situation ahead of each season assessed. The purpose of the TYNDP is to identify the transmission infrastructure needs under several scenarios spanning the timeframe until 2050, which means a very high level of uncertainty.

The ERAA's economic viability assessment provides a mid-term view in addition to a risk assessment to identify which capacities might lack sufficient revenue to cover their operating costs. This mid-term horizon view is a very important indicator to inform policymaker decisions on potential incentives to support mid-term adequacy.

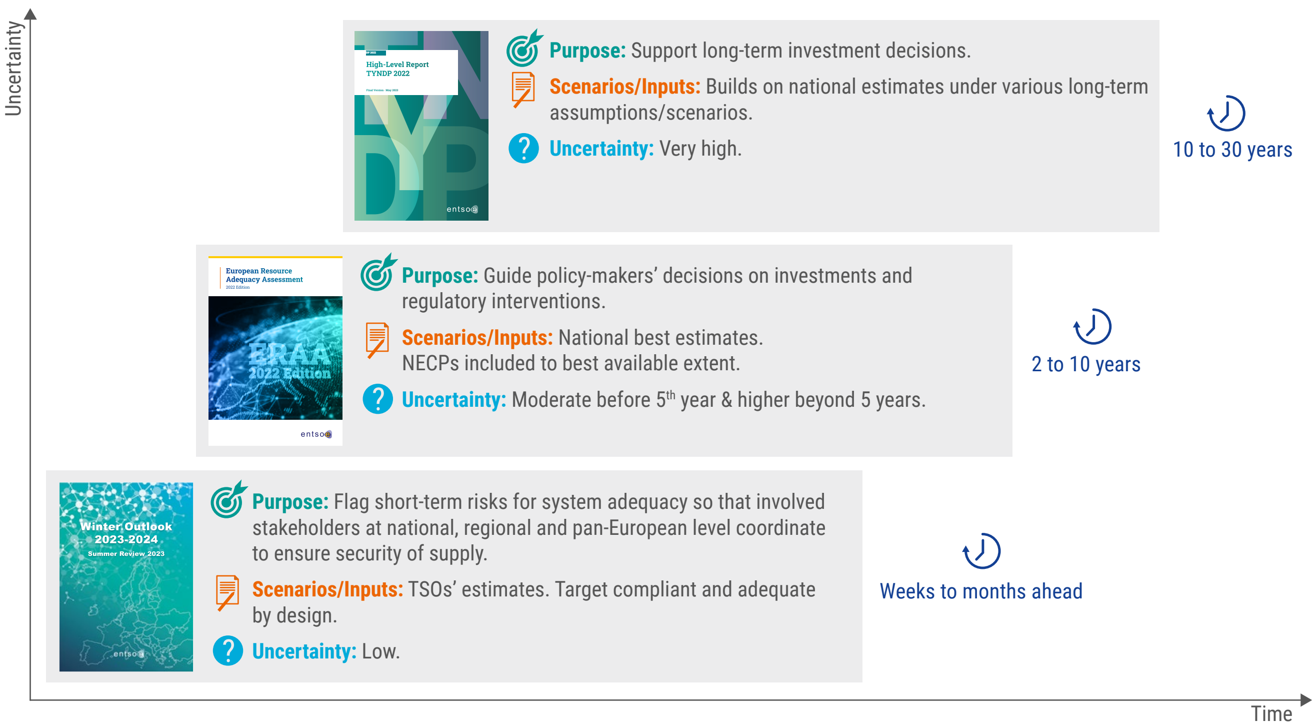


Figure 12: A comparison between the ERAA, the Seasonal Outlook, and the TYNDP.

4 Reference Scenarios and Main Assumptions

4.1 Input data and scenario

The ERAA 2023, as a third edition, builds on the lessons learnt and improvements of the two past editions, and seeks for continuous methodological improvement to ensure high usefulness for policy makers and market actors. The ERAA contains innovative approaches that seek to understand the economic forces impacting capacity in Europe (the EVA) and consider the impact of the physical network on the possible commercial energy exchanges between different bidding zones. The ERAA 2023 was built using the latest available data, especially considering EU's fit for 55 package and REPowerEU in addition to the latest updates in Europe's climate and energy objectives translated into national Trends. A draft data package was published in April 2023, asking for stakeholder feedback before the updated package was used in the models.

The EVA brings together multiple aspects and interdependencies to provide a comprehensive economic analysis of Europe's generation assets. The incorporation of EVA into the ENTSO-E resource adequacy assessments poses a significant challenge that requires a number of assumptions regarding input data, strong computational resources and pragmatic simplifications to achieve trustworthy results. The ERAA 2023 also considers climate change in the input scenarios, though in a simplified manner using a transitionary solution, while ENTSO-E is preparing an enhanced and forward-looking Pan-European Climate Database for future ERAA editions in collaboration with Copernicus Climate Change Service.

The 2023 assessment is carried out for four target years, namely 2025, 2028, 2030 and 2033. Target year 2025 was chosen because it has been a pivotal year from a previous assessment. Target year 2028 is five years ahead and is therefore an important year for decisions related to capacity mechanisms. Target years 2030 and 2033 allow for the evaluation of the adequacy situation further ahead, in a longer-term horizon. The ERAA 2023 is based on national best estimates on the development of the energy supply sector over in the next decades while respecting the relevant EU energy policy targets and objectives. The national trends is updated through the application of the Economic Viability Assessment (EVA). It *accounts for capacity mechanisms that already hold a capacity mechanism contract* granted in any previous auction of any existing or approved capacity mechanism at the time of the assessment. It does not comprise any other future capacity mechanisms.

Figure 13 illustrates the changes in commodity prices over time utilised in the simulation. Typically, a decline in prices is anticipated, with the exception of CO_2. The high oil, gas and coal prices in 2025 are a result of the high prices observed in Europe between end of 2022 and beginning of 2023, which were used as left point for the interpolation. Specifically for the gas blend, there is a noticeable upswing from 2030 to 2033 due to the increased proportion of biomethane and synthetic methane in the blend. However, it is worth noting that when examined independently, the prices of natural gas, biomethane and synthetic methane generally exhibit a downward trend.

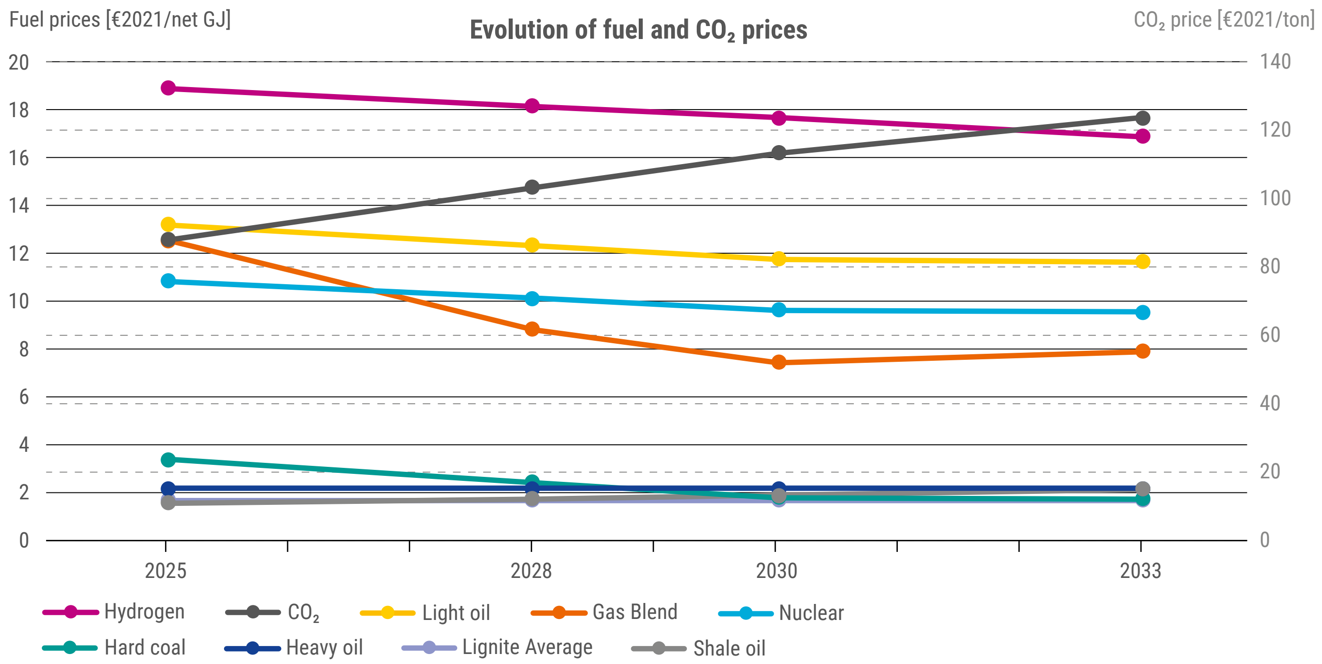


Figure 13: Evolution of fuel and CO_2 prices.

* Sources: cf. Annex 1, chapter 6.1

4.2 Scope and methodology

The geographical scope of the ERAA 2023 covers 39 countries, encompassing all EU members and the a large part of the European continent.[6] For more information regarding the modelled countries, please refer to Annex 1. Figure 14 below illustrates the geographical scope of the ERAA 2023, distinguishing between countries that have been explicitly modelled, neighbouring countries that have been modelled implicitly through fixed exchanges, and non-modelled countries.

The considerable geographical scope of the ERAA 2023 generates highly complex and computationally heavy models, and a pan-European study such as the ERAA must avoid diving into the specificities of each modelled country. For these reasons, only the most relevant and impactful factors[7] for assessing the European adequacy situation were identified and considered in the ERAA, while national and regional assessments are meant to provide complementary and deeper analyses of local constraints. The latter, more localised assessments – which rely on the same methodology and reference scenarios – can assess additional sensitivities related to both infrastructure and operational considerations.[8] For instance, national or regional studies can include considerations regarding internal grid constraints or operational security, which are beyond the scope of the ERAA.

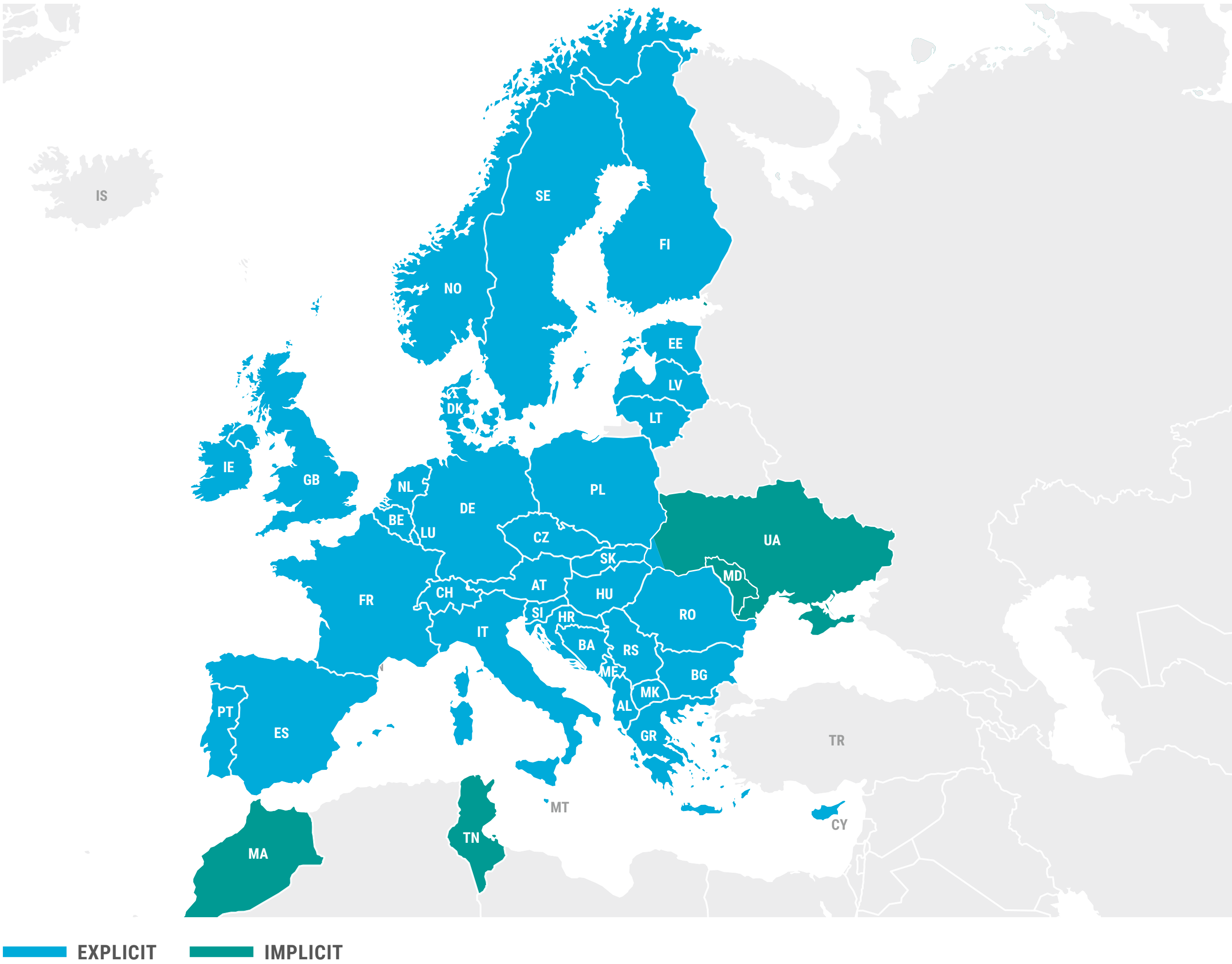


Figure 14: The ERAA 2023 geographical scope

6 This excludes Iceland, which is not connected to the pan-European grid and thus has no effect on the assessment. Ukraine and Moldova are observer members of ENTSO-E and are implicitly modelled. The GB TSOs are no longer ENTSO-E members as of 2022, but due to their impact on the wider region, they are still explicitly modelled. ERAA results are provided only for interconnected ENTSO-E member countries and Malta.

7 Mainly Loss of Load Expectation and Expected Energy Not Served

8 Regulation (EU) 2019/943 of the European Parliament and of the Council on the internal market for electricity, Chapter IV, Art. 20.1.

The ERAA model is a simplified representation of the pan-European power system that – like any model – is based on a set of assumptions. The main assumptions in the ERAA 2023 are:

1. **Cost driven dispatch decision:** Resource allocation for each time horizon is based on their marginal cost of production and other plant parameters.

2. **Perfect foresight:** Available energy sources, DSR and grid capacities (including outages) are assumed to be known in advance with perfect accuracy (i.e. there are no deviations between forecast and realisation).

3. **Focus on energy markets only:** The analyses do not consider non-market resources, such as strategic reserves, voltage reductions, eco gestures, Frequency Restoration Reserves or Frequency Containment Reserves.

4. **Climate-dependent RES production:** Solar, wind and hydro power generation are modelled based on climate conditions.

5. **Planned maintenance of thermal units is optimised:** Planned maintenance for thermal units occurs during periods when there is expected to be an excess of supply rather than a shortage. Country-specific restrictions (e.g. maximum number of units simultaneously under maintenance) and the impact of climate conditions are considered.

6. **Flow-Based modelling for the CORE area:** In the adequacy model, grid limitations within the CORE area (AT, BE, HR, CZ, FR, DE, HU, LU, NL, PL, RO, SK and SI) are modelled using the FB approach. This modelling approach mimics multilateral cross-border exchange restrictions. All other regions are modelled based on bilateral NTC exchange limitations.

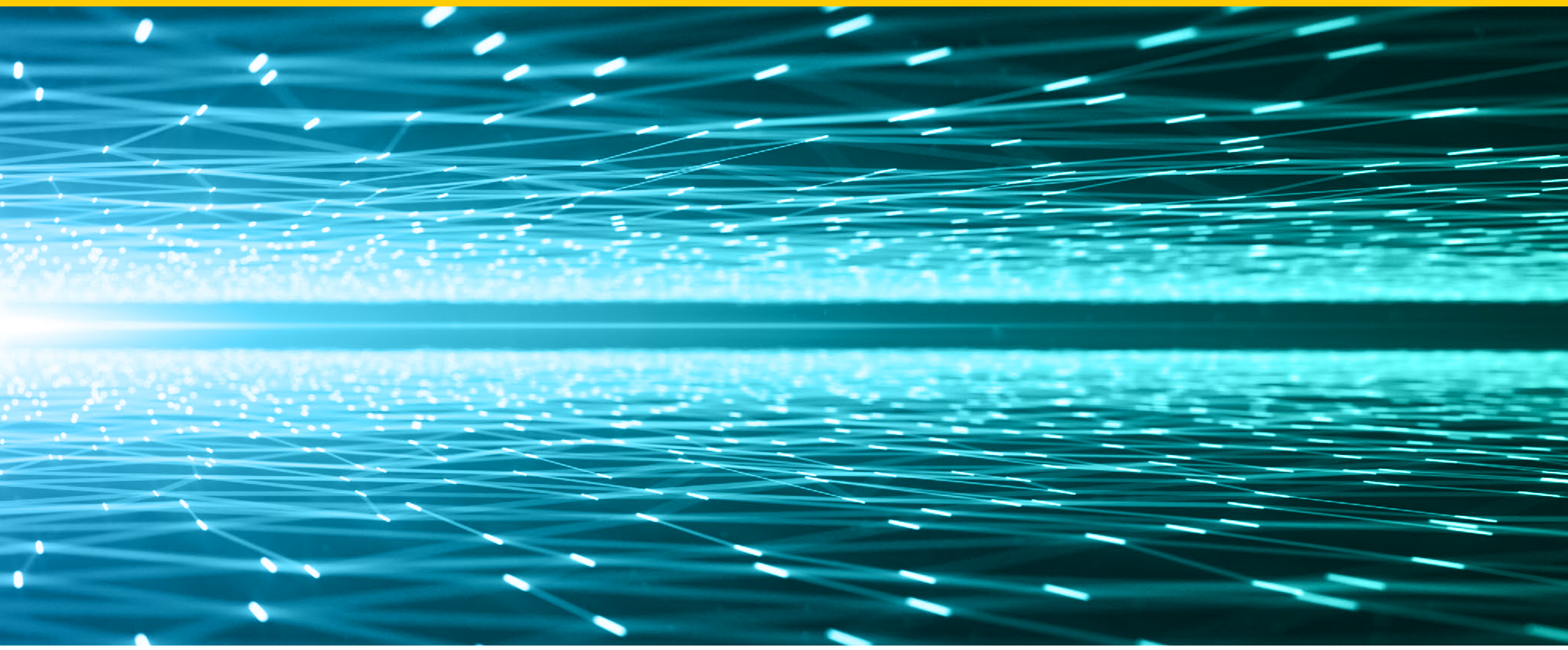
Further details on ERAA modelling assumptions can be found in Annex 2 (Section 1.3).

5 Stakeholder Engagement

Developing the ERAA relies on the contributions of many stakeholders to best understand how the system will develop. Gathering the views of policymakers, regulators and Member States, in addition to electricity market participants, is crucial to frame the ERAA's continuous improvement. ENTSO-E has sought to involve a wide range of stakeholders from the start of the ERAA process, with substantial consultation during the development of our underlying methodologies. The Electricity Coordination Group, comprising experts from EU Member States, was further instrumental in informing the production of the ERAA.

As part of the development of the ERAA 2023, ENTSO-E hosted four webinars on all aspects of the study: input data, methodological insights, results and stakeholder feedback. ENTSO-E's work on the ERAA 2023 has sought best available data and assumptions throughout the development of this study. In April 2023, a public consultation was held on scenarios and key data, which provided valuable stakeholder feedback. Some stakeholders submitted quantifiable recommendations that were evaluated for implementation, mainly for Germany, Greece, and Switzerland.

The data updates included interconnection capacity updates, and thermal power plants decommissioning plans. The assessment is based on best available assumptions, while methodological improvements focus on meeting the legal requirements for the ERAA as given in the Electricity Market Regulation. To make this information accessible and transparent for stakeholders, ENTSO-E created a dedicated webpage where webinar recordings, responses to stakeholder questions and other key information regarding the ERAA implementation process is published.



6 Beyond the ERAA 2023

6.1 Keeping the ERAA fit for purpose in a new context

Adopted in 2019 as part of the CEP, the Electricity Regulation tasked ENTSO-E with the development of the ERAA, which adopts a pan-European approach that can be complemented by regional or national analyses. Through this, ERAA aims to support an efficient and interconnected energy system by measuring the system's ability to maintain security of supply, accounting for climate change and the rapid increase in renewables' installed capacities.

This measurement will increasingly be used to determine which interventions, including capacity mechanisms, are required to ensure the security of supply of Europe's electricity system in the long run. This, in turn, will support Europe's energy transition, proactively addressing the challenges while delivering secure and affordable energy to citizens and industries.

ENTSO-E firmly believes in the power of this analysis and has built on the significant knowledge base of its member TSOs to develop the approaches required for a comprehensive analysis. The European energy context has changed drastically since the Clean Energy Package was released. Due to the current war in Ukraine and deep energy crisis, uncertainty is at an all-time high. Although the conflict has been a catalyst for accelerating the energy transition and reducing EU dependence on fossil fuels, it also likely ends an era of energy insouciance with comfortable margins and moderate prices. ENTSO-E is convinced that the ERAA role goes far beyond being a tool for capacity mechanisms decisions. The ERAA can support policymakers in building their mid-term strategy. ERAA can also depict 'what if' scenarios to shed light on possible futures. Policy discussions are ongoing, especially on possible refurbishing of current market designs. In addition, high prices and scarcity periods may occur more frequently than in past decades.

With the integration of Europe's electricity markets, in addition to the integration of large quantities of renewable capacity and shifting demand patterns, resource adequacy will be a major focus for decades to come. The ERAA will ensure that decision makers have the best available information for approaching these challenges, and, although the report itself will not recommend specific actions, its data will inform decisions regarding capacity mechanisms and other state policy interventions. The ERAA contains pioneering methodologies and tools to analyse future adequacy with an unprecedented combination of scope and detail, and it can be referred to when considering the overall future of Europe's electrical grids. The ERAA provides an effective tool to identify system needs complementing the TYNDP, and future development through methodological innovation, pilot programmes, consultation with stakeholders and refinement of scope will continue to strengthen the ERAA's usefulness. Meanwhile, whereas ENTSO-E remains committed to the multi-year planning, data delivery, scenarios and methodologies required to fulfil the ERAA's potential.

6.2 ERAA implementation roadmap

The stepwise approach endorsed by ACER on 2 October 2020 has served as the basis for the ERAA's evolution and implementation. Of particular focus has been the development of the EVA and FB analysis, to increase robustness to the findings of the report. In each ERAA edition, hundreds of man-hours and thousands of computing hours have been devoted to the development of these tools.

ENTSO-E considers that the ERAA 2023 has reached maturity thanks to iterative upgrades since 2021 and plans that further editions should focus on specific improvements for increasing data quality and robustness, while keeping the generic features of the ERAA 2023.

WORK STREAMS	ERAA 2021	ERAA 2022	ERAA 2023	ERAA 2024
TARGET YEARS	\ \	\ \ \	\ \ \ \	\ \ \ \
ECONOMIC VIABILITY ASSESSMENT	Deterministic for CYs	Stochastic in steps	Single-step multiyear stochastic with perpetuity	Enhanced CYs, FB implementation
FLOW-BASED MARKET COUPLING	Proof of concept	FB for CORE in the reference scenario	FB for CORE + kick-off for Nordics	Nordics included
LOCAL MATCHING & CURTAILMENT SHARING		First implementation	Robust methodology & implementation	
CLIMATE CHANGE IMPACT	Original PECD	Temperature detrended PECD		PECD V 4.0

Figure 15: ERAA implementation roadmap

Glossary

CEP	Clean Energy Package
CONE	Cost of New Entry
DSR	Demand-Side Response
EENS	Expected Energy Not Served
ENTSO-E	European Network of Transmission System Operators for Electricity
ERAA	European Resource Adequacy Assessment
EUE	Expected Unserved Energy
EVA	Economic Viability Assessment
LLD	Loss of Load Duration
LOLE	Loss of Load Expectation
OM	Outage Minutes
PV	Photovoltaic
RES	Renewable Energy Sources
TSO	Transmission System Operator VOLL Value of Lost Load
TY	Target Year
TYNDP	Ten-Year Network Development Plan

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