# European Resource Adequacy Assessment

2024 Edition

## Executive Report


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# 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 **40 member TSOs**, representing 36 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.

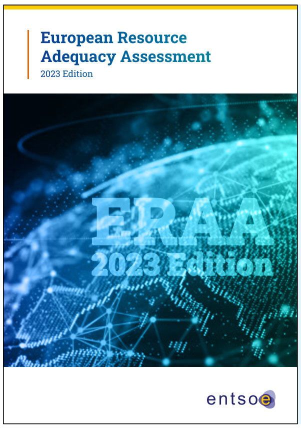
# Disclaimer

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.

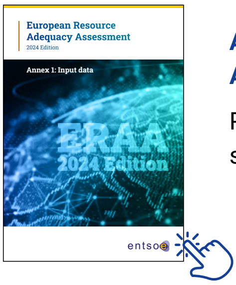
# European Resource Adequacy Assessment (ERAA) 2024: Navigating the package

ERAA 2024 is divided into six parts (Executive Report and Annexes) to help readers identify relevant information:



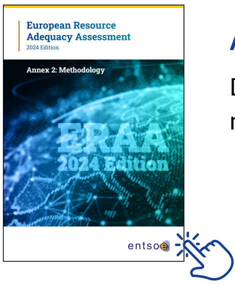

## Executive Report

Overview of the main results followed by a description of the ERAA 2024 purpose and a high-level overview of the scenario, main assumptions and stakeholder engagement.



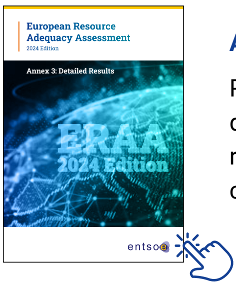

### Annex 1: Input Data and Assumptions

Presentation of the ERAA 2024 scenarios and assumptions.



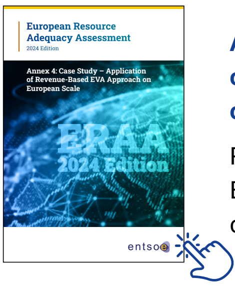

### Annex 2: Methodology

Description of the ERAA 2024 methodology.



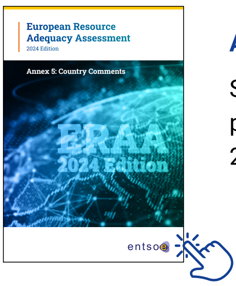

### Annex 3: Detailed Results

Presentation of the ERAA 2024 detailed results for the central reference scenario and EVA comparisons related to CONE.



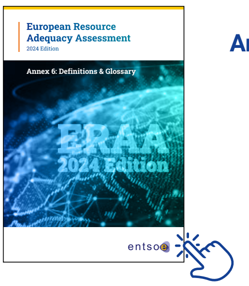

### Annex 4: Case Study – Application of Revenue-Based EVA Approach on European Scale

Revenue-based approach for the EVA, including methodology and case study results.




### Annex 5: Country Comments

Specific comments, optionally provided by TSOs on the ERAA 2024 input data and results.




### Annex 6: Definitions & Glossary

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# 1 Executive summary

The ERAA is a pan-European monitoring assessment of power system resource adequacy up to 10 years ahead, mandated by Regulation (EU) 2019/943. It is based on state-of-the-art methodologies and probabilistic assessments, aiming to model and analyse investment behaviour under perfect market assumptions and potential events that could adversely impact the balance between electric power supply and demand. System modelling features have been gradually improved in each ERAA edition since 2021.

ERAA results inform governments and institutions about resource adequacy concerns at European level, along with possible needs to ensure the security and reliability of their electricity systems. It is an important element for supporting qualified decisions by policy makers on strategic matters such as the introduction of capacity mechanisms (CMs). Together with national resource adequacy assessments that identify adequacy concerns, ERAA 2024 supports Member States in triggering the implementation of CMs to guarantee resource adequacy.

## The transformation of the European power system creates significant adequacy challenges

The European electricity system is undergoing significant changes motivated by the EU's ambition to achieve climate neutrality by 2050 and independence from Russian fossil fuel. The Fit for 55 Package and REPowerEU Plan accelerate the energy transition to 'net zero' at a much larger scale, increasing renewable energy and energy efficiency targets for 2030. These ambitions are driving the integration of greater volumes of variable renewables, increased decentralisation, the emergence of new market players, innovation and digitalisation, and the phase-out of fossil-fuelled thermal generation units. These changes are occurring at unprecedented speed, and the power system must adapt swiftly in response to new challenges. At the same time, the security and adequacy of European energy infrastructure have become more critical than ever due to drastic changes in the geopolitical environment. Amid this rapid transition, system operators must safeguard security of supply and maintain a balance between supply and demand across the interconnected system year-round. The ERAA and NRAAs aim to inform about this balance from both short- and midterm perspectives.

Europe will see a rapid increase in renewable energy sources, a decrease in fossil-fuelled generation and a substantial increase in electrification. EU Member States anticipate an unprecedented rise in electricity demand over the coming decade, creating significant adequacy challenges due to persistent obstacles hindering the necessary investments in generation. These changes will impact how Europe ensures the adequacy of its electricity system in the future. This is also crucial because, alongside achieving carbon neutrality by 2050, industry competitiveness and energy affordability are key policy objectives for the EU in the years ahead.

The European power system is highly interconnected and plays an increasingly crucial role in ensuring security of supply, especially with the growing integration of solar and wind, which have high spatial and temporal variability. Therefore, assumptions made for one country can significantly impact the adequacy results of neighbouring countries. It is therefore crucial that the methodology is based on sound transparent and plausible investment assumptions.

## Action is needed to maintain the security of supply for electricity in Europe

In addition to units approaching the end of their technical lifetime in the next decade, ERAA 2024 finds that significant volumes of fossil-fuelled capacity are likely to become economically non-viable by 2030, as they will capture a smaller market share due to the rise of renewable energy sources.

- In the short- and midterm (years 2026, 2028 and 2030) significant capacities are at risk of being decommissioned
- In the longer term (2035), significant risks of decommissioning remain for the assumed thermal generation fleet in certain regions, while global investments may be anticipated, assuming favourable context not modelled in ERAA (supply chain considerations, energy transmission networks, primary energy availability, etc.).
- The development of the power system must be closely monitored to confirm that investment needs are being realised. Relevant authorities should consider necessary mitigation actions to secure European adequacy. This report assumes that a significant portion of investments will be driven by scarcity prices during periods of high demand or supply constraints, when peak units are expected to operate. However, risk-averse investors may decide to postpone investments if not backed by long-term contracts.
- The equivalent should be monitored for existing power plants to ensure that the decommissioning of the current fleet does not exceed the anticipated levels.
- Renewable generation capacity is expected to expand over the coming years based on national policy targets and TSO estimates (Figure 1). However, due to the intermittency of renewable resources, the capacity will not be sufficient to compensate for the expected decline in dispatchable thermal generation and the growing electrification by 2035.

ERAA modelling suggests that over 50 GW of new investment in fossil gas flexible capacity would be beneficial, given the anticipated high market scarcity prices, although they are expected to occur infrequently in 2035. This investment would help ensure adequacy during peak times or periods of low RES infeed. However, for the EU to reach its climate goals, fossil-fuelled capacity must be reduced and/or replaced over the long term. In addition, market signals based solely on a few scarcity price hours in a year would not justify risk-averse investments in generating capacity. Real-world investors may not rely solely on a few hours of scarcity with exceptionally high price signals, especially when such events are driven by extreme weather that could occur once a decade, with no certainty as to when. Therefore, incorporating the new entry capacity from the Economic Viability Assessment (EVA) results into the adequacy assessment may underestimate the adequacy risk.

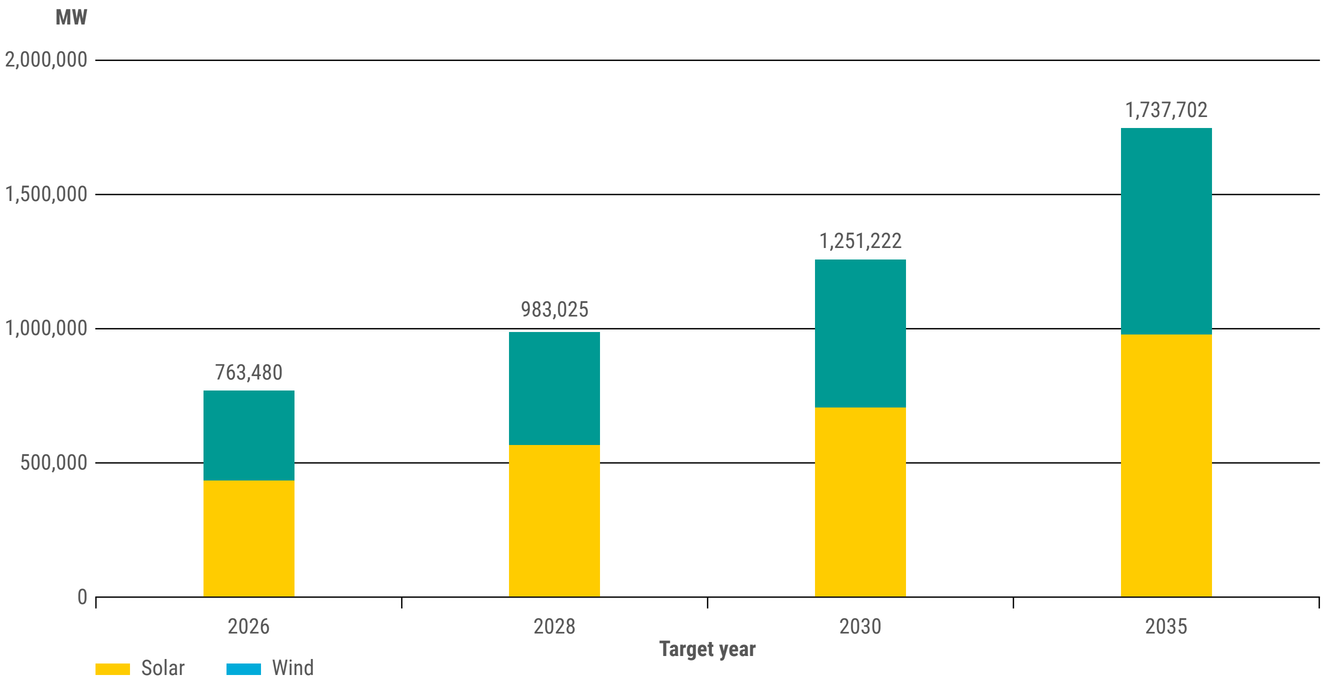


Figure 1: Anticipated wind and solar capacity evolution [MW]

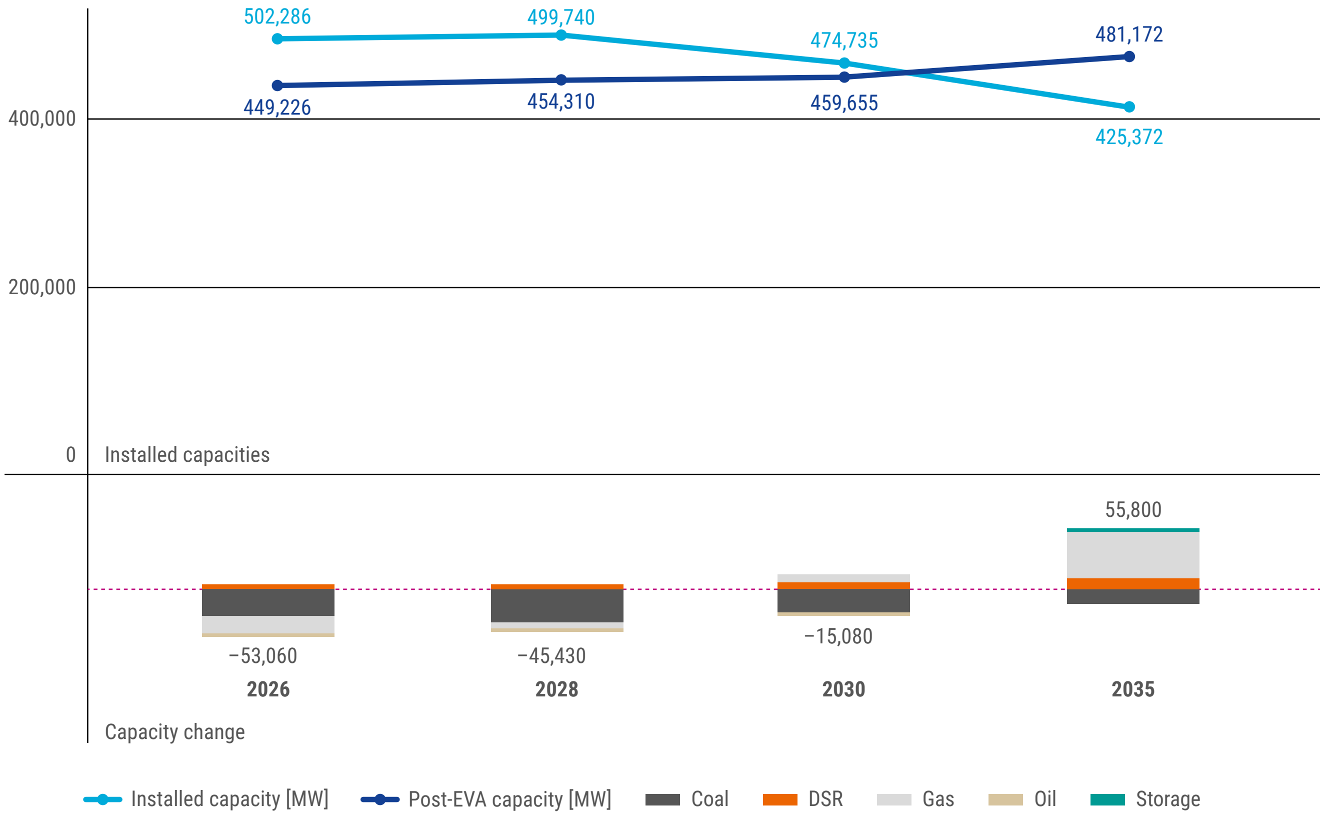


Figure 2: Net effect of the EVA on the European mix – focus on the technologies assessed

Notable adequacy risks are observed across Europe. Risks tend to be low around the Balkan region and a few other specific areas of Europe. Existing non-market resources for addressing adequacy risks have already been accounted for in these assessments. Identified notable adequacy risks may indicate the need for additional resources to mitigate those risks if deemed necessary. Conversely, some non-market resources effectively address adequacy risk in regions where such risks would be significant without them (e. g. Ireland). These results are presented in Figure 3.

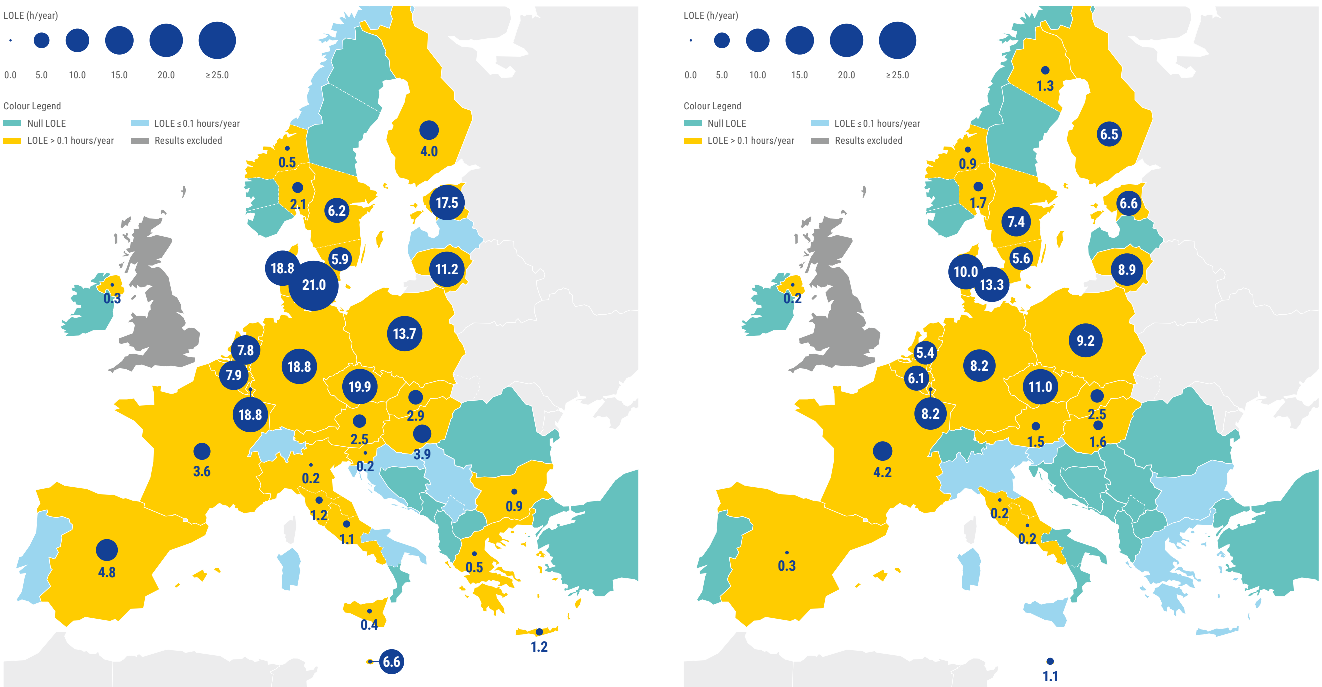


Figure 3: Adequacy risks in 2028 (left) and 2030 (right) – pivotal year for CM establishment

At the European level, the adequacy risk from decommissioning thermal capacity due to economic unviability remains, despite ambitious policy targets to support renewable generation capacity, storage and demand-side response (DSR) expansion and some additional investment opportunities identified in the EVA. In this context, the right incentives and/or targeted intervention, such as long-term market mechanisms, are essential to avoid adequacy risks by providing efficient price signals. These signals would ensure both the retention of existing capacity in the market the timely deployment of new capacity in the right location.

Urgent action is needed: additional supporting mechanisms must be promoted where necessary to enable the transition while maintaining system security. Therefore, the establishment and approval process of CMs must be accelerated.

To ensure electricity security and meet climate objectives, Europe must accelerate the deployment of flexibility solutions and infrastructure, including cross-border electricity transmission network to direct RES electricity where it is most needed, as well as storage and other sources of flexibility, while safeguarding security of supply at all times.

## National adequacy assessments complete the ERAA

Currently, at least 12 Member States complement the ERAA with a national resource adequacy assessment (NRAA). NRAAs can provide a more detailed picture of a Member State's adequacy concerns, taking into account specific local circumstances that may not be reflected in ERAA outcomes given the enormous size and complexity of the EU power system and computational constraints.

While the ERAA is one of the instruments used to inform EU Member States and National Regulatory Authorities (NRAs) about the level of security of supply and serves as the basis for decisions on different market design options by providing a comprehensive pan-European overview of capacity concerns, it should not be the sole basis for identifying resource adequacy concerns. NRAAs are also essential, as they provide a complementary, more detailed picture on national specificities and local sensitivities. The ERAA and NRAAs should therefore be considered in conjunction.

## An evolving tool in a European power system undergoing a fundamental transformation

The methodological approach of ERAA 2024 is unmatched globally. The calculation complexity pushes the limits of computational power given the constraints of preparation, execution, and delivery. The implementation of the ERAA Methodology has steadily advanced since 2021 and will continue to evolve.

ERAA 2024 includes key improvements, such as a new Pan-European Climate Database (PECD), the extension of Flow-Based Market Coupling (FBMC) to the Nordic region, and significant advances in EVA simulations, such as the inclusion of FBMC and representative weather scenarios and forced outage patterns. For the first time, ERAA 2024 also includes a case study on the revenue-based EVA at a Pan-European scale, is expected to improve the robustness of EVA simulations. ENTSO-E plans to refine and adopt this approach in future ERAAs as an alternative to the current cost-minimisation EVA.

With the integration of Europe's electricity markets, along with the integration of large quantities of renewable capacity and shifting demand patterns, resource adequacy will be a major focus for decades to come. ENTSO-E believes that **the primary purpose of the ERAA goes far beyond merely a tool for decisions on CMs**. The ERAA supports policymakers in building midterm strategies. It includes pioneering methodologies and tools to analyse future adequacy with an unmatched level of scope and detail, making it a valuable resource for shaping the future of Europe's electricity grids. ERAA also has the potential to illustrate additional 'what if' scenarios, providing insights into possible future outcomes. Therefore, ENTSO-E believes the **ERAA Methodology should be improved and streamlined to empower policy-makers to make well-informed decisions that support national and EU objectives going forward**. The ERAA serves as an effective tool to identify system needs, complementing the TYNDP. Methodological innovation, pilot programmes, stakeholder consultation and refinement of its scope will continue to strengthen the ERAA's usefulness.

# 2 Main findings of ERAA 2024

This section presents the main findings of the assessment, with more detailed results available in Annex 3. Assessing the adequacy situation in the ERAA takes place over two steps:

1. **Assessing the economic viability of the capacity resources:** This is the EVA, a risk assessment that evaluates potential outcomes related to the decommissioning of existing capacity or the possible new investment of capacity resources in the energy-only market[1].

2 **Evaluate the adequacy situation in an economically viable scenario.** This step measures 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.

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, together with the uncertainty characterising the assessment stemming from the weather variables and forced outages on thermal generators and cross-border interconnectors.

The 2024 ERAA edition features considerable improvements over the previous one. In addition, the assumption for a 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.

## 2.1 Significant volumes of fossil fuel capacity are at risk of economic decommissioning in the midterm horizon

The EVA suggests that substantial generation capacity is at risk of not guaranteeing revenues to sustain its operation and presence in the energy-only market. Meanwhile market opportunities for DSR technology are available across all future years. The decrease in fossil fuel capacity within the system may be steeper than currently anticipated by 2030. Meanwhile the post-EVA capacity graph suggests that market opportunities tend to increase over time, with more capacity expected to be viable in the longer term. This suggests that the expected electrification may not be fully addressed by the current projections for RES and other technology expansion. This is particularly evident in 2035, as substantial fossil fuel capacity will reach the end of its lifetime between 2030 and 2035.

1 Simulating potential investment decisions based on modelled market scarcity price signals with limited occurrence over a 10-year period is a highly complex task that involves uncertainties and could be non-representative for some investors.

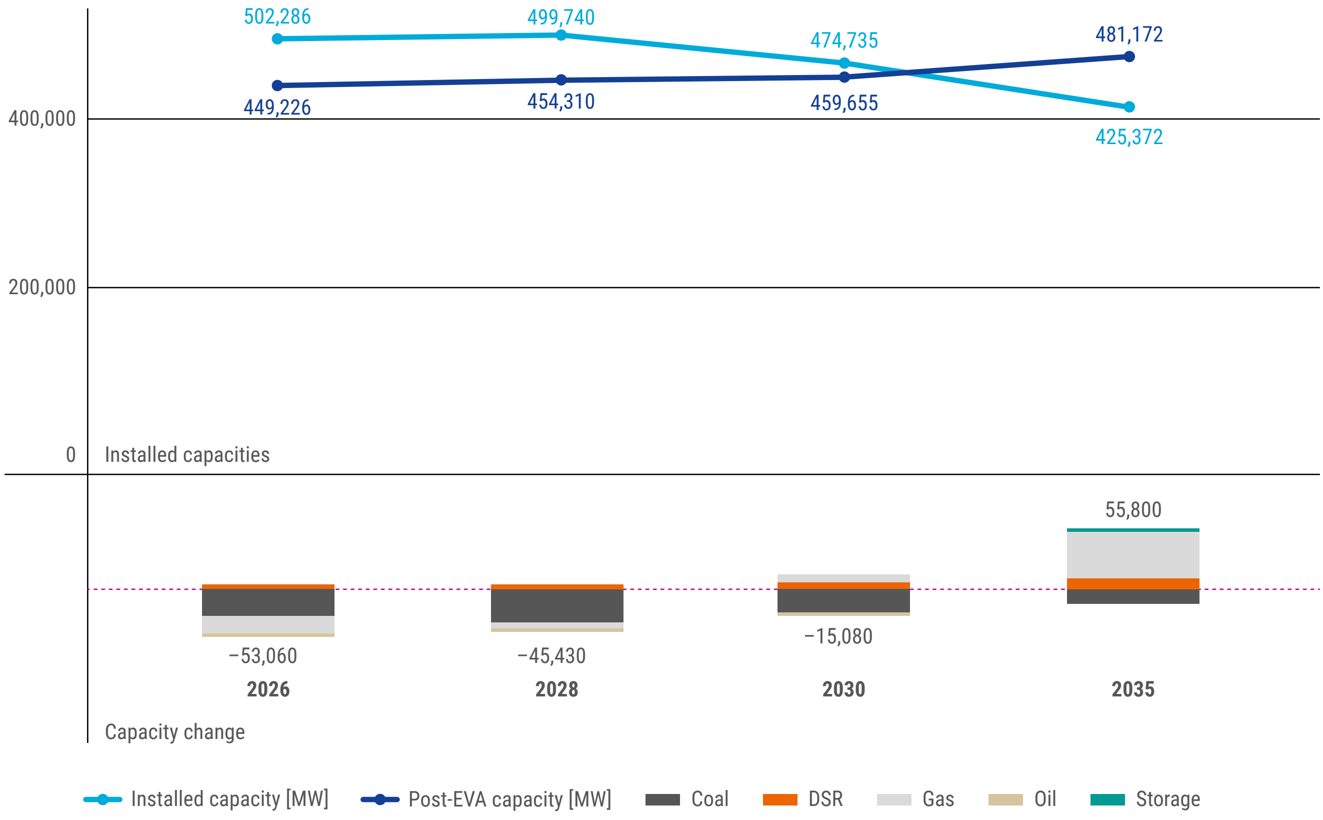


Figure 4: Overview of net effect of the EVA on the European perimeter

| Decision variable | Technology | 2026 | 2028 | 2030 | 2035 | Affected study zones |
|---|---|---|---|---|---|---|
| **New entry** | **Battery** | 0.34 | 0.34 | 0.57 | 1.83 | GR00, ITCN |
| | **DSR** | 4.72 | 6.07 | 8.98 | 12.23 | CZ00, DE00, DKE1, DKW1, FI00, HR00, HU00, LT00, NL00, SE03, SE04, SI00, SK00 |
| | **Gas CCGT** | 0 | 9.42 | 19.98 | 31.62 | CZ00, MT00, PL00, TR00 |
| | **Gas OCGT** | 0 | 0 | 3.00 | 41.56 | AT00, DE00, DKE1, EE00, FI00, SE04, UK00 |
| | **Total** | **5.06** | **15.83** | **32.53** | **87.24** | |
| **Life Extension** | **Gas CCGT** | 1.91 | 4.27 | 4.70 | 8.28 | BE00, DE00, DKE1, HU00, NL00 |
| | **Gas OCGT** | 0.04 | 1.62 | 2.26 | 2.57 | BE00, DE00, HU00 |
| | **Total** | **1.95** | **5.89** | **6.96** | **10.85** | |
| **Decommission-ing** | **Gas CCGT** | -22.71 | -23.14 | -21.59 | -23.82 | AL00, BE00, ES00, GR00, HR00, ITCA, ITCS, ITN1, PT00, RO00, TR00 |
| | **Gas OCGT** | -0.63 | -0.72 | -0.62 | 0 | AT00, DE00, HR00, LT00, RO00, SE01 |
| | **Hard Coal** | -12.13 | -18.03 | -13.80 | -6.07 | BG00, DE00, FI00, FR00, HR00, NL00, PL00, RO00, TR00 |
| | **Lignite** | -21.61 | -23.46 | -16.85 | -12.40 | BA00, BG00, CZ00, DE00, GR00, ME00, PL00, SI00, TR00 |
| | **Oil** | -2.99 | -1.80 | -1.71 | 0 | EE00, FR00, GR03, HR00, SE03, TR00 |
| | **Total** | **-60.07** | **-67.15** | **-54.57** | **-42.29** | |
| **Total** | | **-53.06** | **-45.43** | **-15.08** | **55.80** | |

Table 1: Capacity change proposed by the EVA compared to the National Trends scenario [GW] – Non-cumulative

# 2.2 Considerations regarding the Economic Viability Assessment results

The ERAA 2024 EVA suggests notable investments and lifetime extensions in the coming years. By 2035, a net increase of more than 60 GW of flexible fossil gas capacity (OCGT and CCGT) is projected, with investments driven by scarcity prices that occur infrequently. The running hours of some new gas capacity would likely be under 500 full-load hours. Almost all OCGT units (42 GW) rely on near scarcity revenues. The EVA also suggests that scarcity pricing is prompting significant CCGT investments in 2035 (32 GW), with these units being dispatched for a limited number of hours throughout the year (cf. Annex 3). Such market signals, based on only a few scarcity price hours in a year, may not reflect the behaviour of risk-averse investors in generating capacity. A risk-averse investor is more likely to postpone investments that carry high risks. The EVA result is driven by the methodological approach, which seeks an equilibrium between the average VOLL (Value of Loss Load) and the average CONE (Cost of New Entry). If this new capacity were not fully materialised, adequacy concerns would be significantly higher.

For these reasons, the EVA results are linked to their given assumptions and methodology and, should be considered with caution, as actual decisions made by investors might differ. As a result, adequacy risks should be considered in light of the given assumptions and methodology, with some degree of uncertainty depending on actual investment decisions. More insights and analyses can be found in Section 2.1.2 of Annex 3. Future editions of ERAA will continue to refine the modelling of investment behaviour representation.

## About the EVA methodology

The EVA step assesses the viability of capacity resources[2] participating in the energy-only market. The EVA is a risk assessment of what could happen; it is not a prediction of what will happen. Units with an awarded 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 to minimise 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 study zone and over the **target years (TYs)**, on the resource capacities that could be (i) decommissioned, (ii) invested in, or (iii) 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 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.

## 2.3 Adequacy risks appear in several European countries and margins are tight

Figure 5 to Figure 8 illustrates the Loss of Load Expectation (LOLE) per region in TYs 2026, 2028, 2030 and 2035. LOLE values are represented by circles, with larger radii indicating 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 simulated Monte Carlo years using the reference tool.

Note that 2026 results for Italy are not shown. For this TY, despite a net decrease of more than 50 GW of thermal capacity, the ERAA 2024 results indicate only limited adequacy concerns – only in a few study zones, and not necessarily those where most of the capacity would be decommissioned (10 GW in Italy, 7 GW in Poland, 6 GW in Germany and 3 GW in France) or in those relying on imports to guarantee adequacy (e. g. Italy).

This result is inconsistent with recent events observed in Italy: in early September 2024, the minimum adequacy margin in Italy was less than 2 GW (including import contributions), leaving little to no room for shutting down capacity without creating significant adequacy concerns. The comparison between modelling results and recently observed events indicates that the complexity of the European power system may not be fully captured in the simulations. Consequently adequacy concerns (in particular in the short-term) may be underestimated.[4]

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 where the results depend on the specific characteristics of each country or study zone. Annex 4 provides country-specific comments that enable more detailed conclusions.

4 There could be several reasons for this:
(1) A simplified grid model is applied (bus-bar model based on NTC/partial FB), which does not explicitly reflect infrastructure outages/bottlenecks and voltage control constraints within a bidding zone. These effects can significantly reduce the transport capacity between bidding zones during stress events and would need to be considered in the definition of interzonal transfer capacities. The day-by-day allocation of RCCs illustrates operational grid limits: only for a limited number of hours per year is the available transport capacity equal to its theoretical maximum under ideal conditions. Therefore, the transport capacity allocated in ERAA may exceed the maximum flows that are actually achievable during stress events. Indeed, factors such as the rating values of individual transmission lines, grid maintenance, faults, voltage violations and dynamics constraints significantly impact capacity, and are not comprehensively captured in ERAA, leading to a risk of underestimating adequacy concerns.
(2) In a complex and interconnected electricity system like Europe's, there are several ways EENS could be distributed among the European market nodes. ERAA aims to closely follow the market clearing rules for curtailment (adequacy patch) to represent the EU power system's behaviour when resources and transmission capacity are insufficient to meet demand in all study zones. However, other adequacy issues beyond the scope of ERAA may arise in these shortage situations, both before market clearing and certainly after market clearing and in the operational phase.

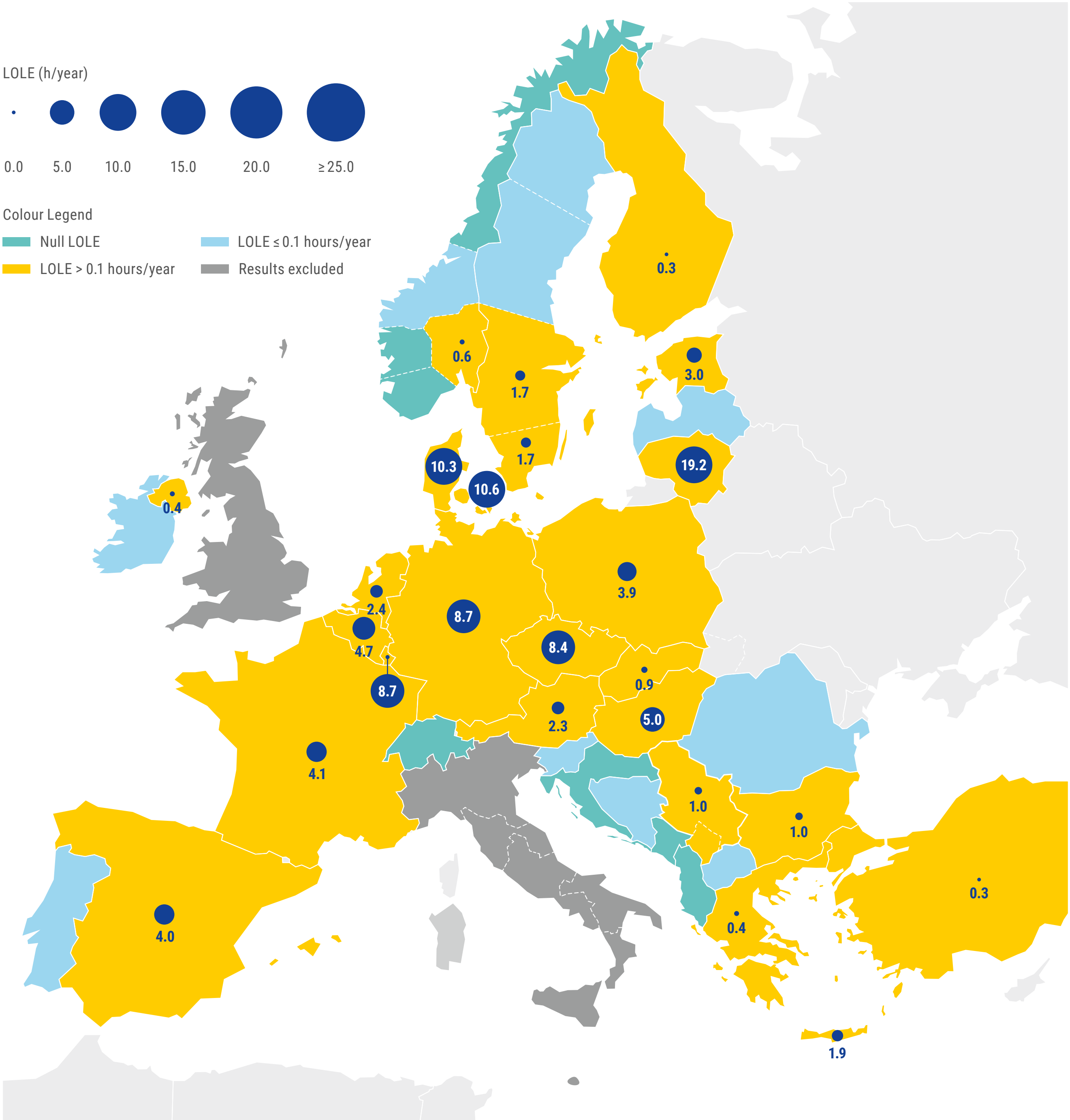


Figure 5: LOLE values in 2026

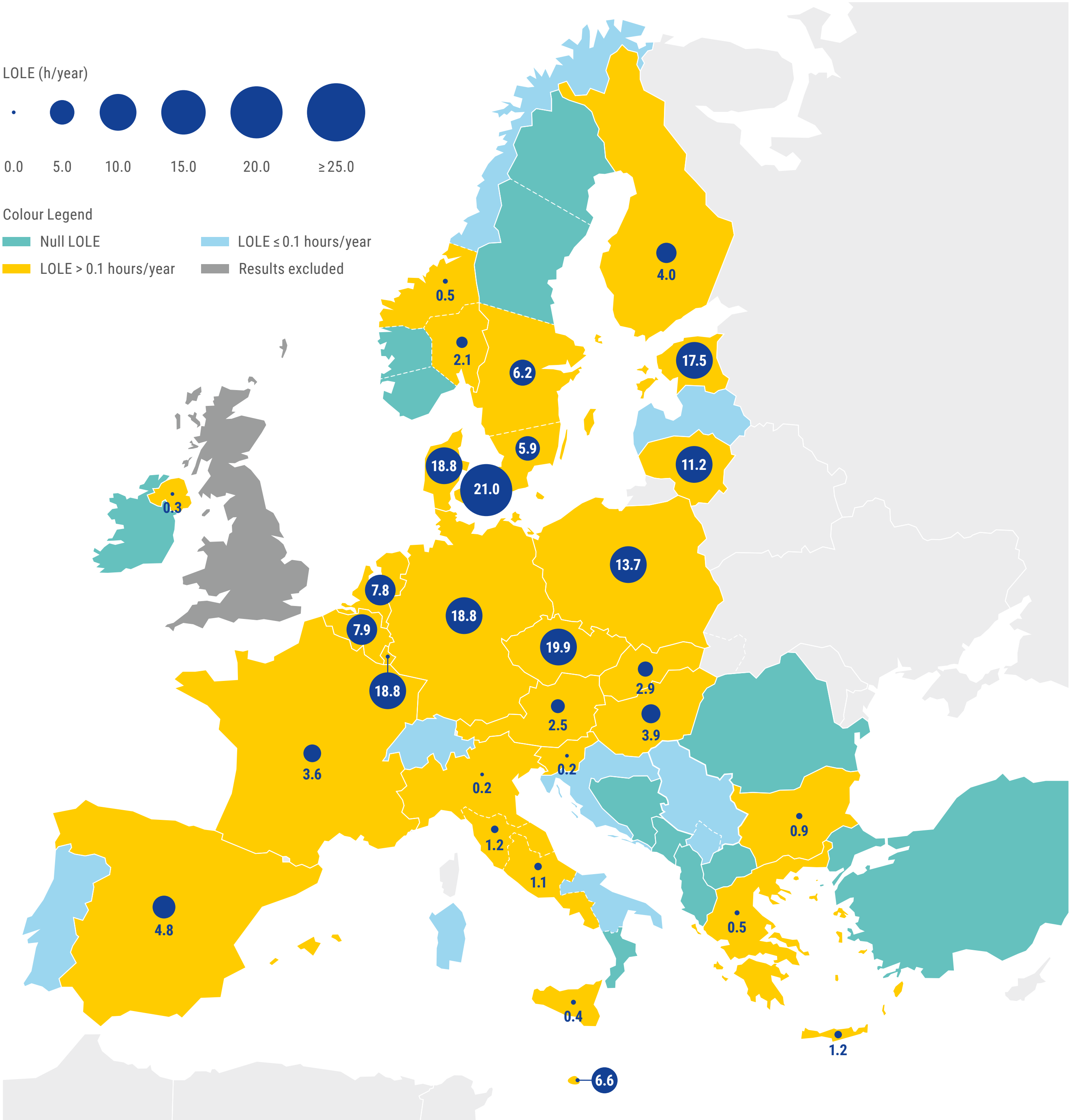


Figure 6: LOLE values in 2028

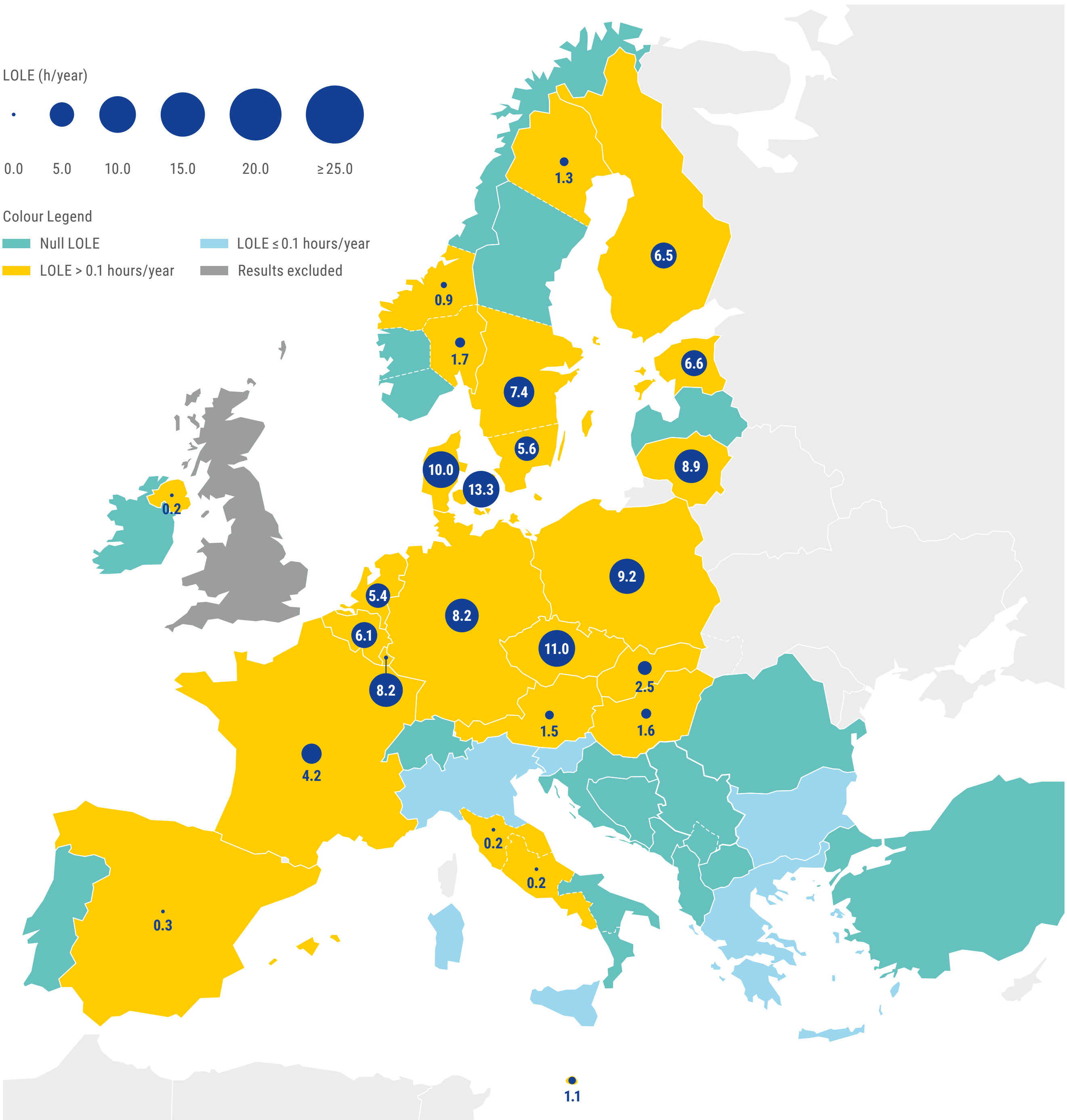


Figure 7: LOLE values in 2030

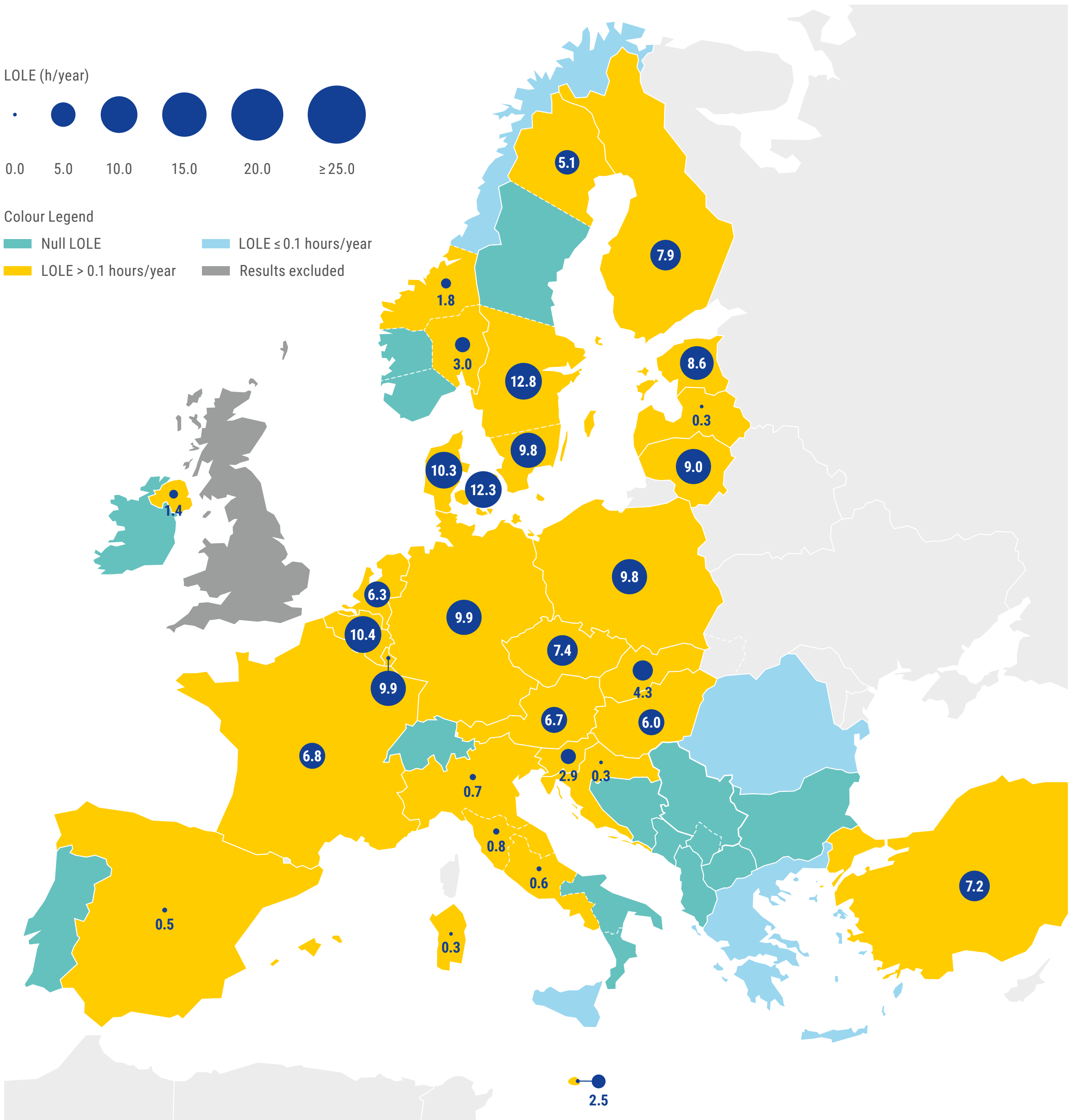


Figure 8: LOLE values in 2035

# 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 up to 10 years ahead. Based on state-of-the-art methodologies and probabilistic assessments, it aims to model and analyse potential events that could adversely impact the balance between electric power supply and demand. The ERAA is a crucial tool for supporting informed decisions by policymakers on strategic matters to ensure 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) and independence from Russian fossil fuel (cf. REPowerEU plan and Wind Power package). These ambitions are driving the integration of greater volumes of variable renewables, increased 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 a balance between supply and demand across the interconnected system year-round.

In this context, a pan-European analysis of resource adequacy – complemented by insights from national 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 system 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 electric power supply. Such assessments continuously assess the balance between net available generation and net load levels in the European power system, as illustrated in Figure 9. The ERAA should not be seen as an effort to predict the system's security of supply, but rather as an assessment of the future power system's ability to maintain security of supply under wide range of potential future system states resulting from various plausible weather conditions, as well as 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 available national standards for system reliability. Individual EU Member States apply reliability standards to assess their national resource adequacy; an overview is presented in Table 2. LOLE, an indicator representing the probabilistic number of hours during which generation is unable to meet demand, is the most common reliability indicator used by EU Member States, with targets typically in the range of one to a few 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 for generation or demand response, and the reliability standard".

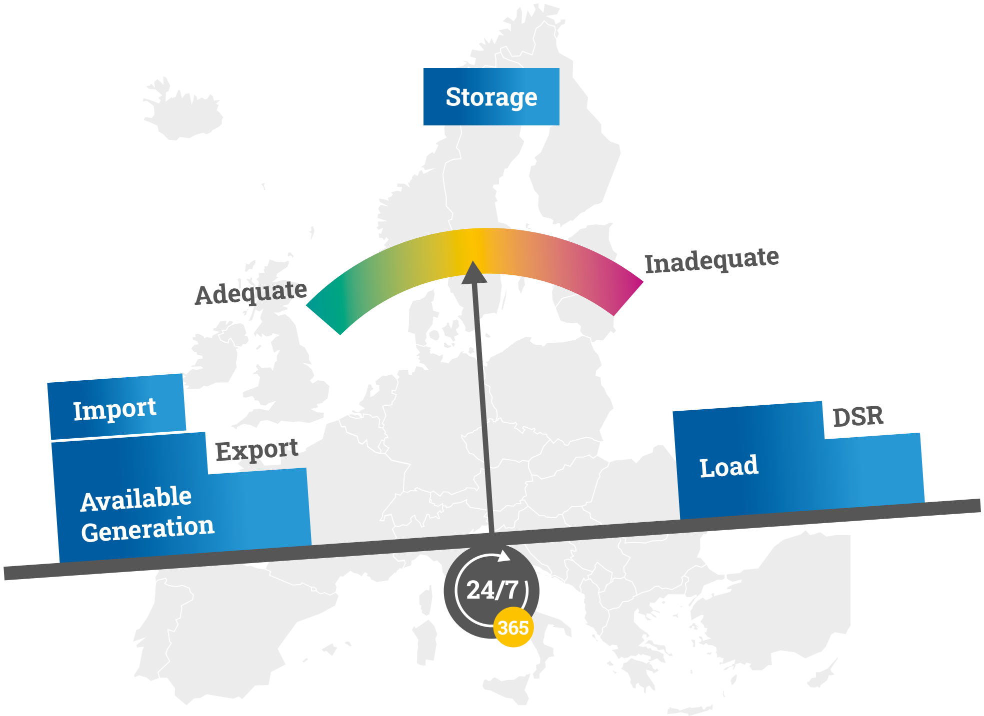


Figure 9: Resource adequacy: Balance between net available generation and net load

| Member state | Type of reliability standard | Value |
|---|---|---|
| Belgium[a] | LOLE (hours/year) | 3.00 |
| Cyprus[b] | LOLE (hours/year) | 15.00 |
| Czech Republic | LOLE (hours/year) | 6.7 |
| Estonia[c] | LOLE (hours/year) | 8.00 |
| 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 | LOLE (hours/year) | 3.00 |

| Member state | Type of reliability standard | Value |
|---|---|---|
| Italy | LOLE (hours/year) | 3.00 |
| Luxembourg[f] | LOLE (hours/year) | 2.77 |
| The Netherlands | LOLE (hours/year) | 4.00 |
| Northern Ireland[g] | LOLE (hours/year) | 4.90 |
| Poland[h] | LOLE (hours/year) | 3.00 |
| Portugal | LOLE (hours/year) | 5.00 |
| Sweden | LOLE (hours/year) | 1 |
| Spain[i] | LOLE (hours/year) | 0.94 – 1.82 |

Table 2: National reliability standards applied by EU Member States as of December 2023 (Source: ACER's Security of EU electricity supply, December 2024, the Estonian recent study, the Spanish recent study)

Notes 1:
- a: calculations for VOLL, CONE and the reliability standard were updated in 2022;
- b: In Cyprus, Reliability Standards were developed by the relevant NRA and used in various national activities including national adequacy studies and in the latest NECP. There are three adequacy metrics: LOLE of 15 hours per year, reserve margin of 189 MW and EENS at 0.01 % of annual demand.;
- c: In Estonia, EENS is equal to 4,500 MWh/year;
- d: In Finland an additional reliability standard expressed as EENS 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: Luxembourg uses the same adequacy metrics as Germany;
- g: The adequacy standard for Northern Ireland is 4.9 hours of LOLE, as set by the Department for the Economy;
- h: A national reliability standard has been calculated, but not based on the regulation;
- i: The Spanish Reliability Standard, expressed as the maximum acceptable LOLE has not yet been approved. A value of 0.94 hours/year was proposed in October 2023, and a new CONE study released in October 2024 suggests a possible range of 1.19 – 1.82 hours/year. Therefore, when analysing the adequacy results, a range of 0.94 – 1.82 hours/year for the reliability standard could be considered.

Note 2: In Denmark, a 5 "outage minutes" (OM) per year metric is used, estimated based on the demand and 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 TSOs. The ERAA is also coordinated and consistent with other timeframe studies, such as the ENTSO-E's Ten-Year Network Development Plan (TYNDP), Seasonal Outlook reports and ENTSO-E's Flexibility Needs study. Continuous developments in forecasting methodologies have improved the strength of these assessments, and ERAA represents a substantial step forward.

Each year, stakeholders can expect a more useful and valuable tool, with analyses that better reflect the realities and complexities of the single electricity market. This includes an unparalleled data set and an improved EVA. ERAA 2021 was the first step towards the implementation of the ERAA methodology. ERAA 2022 and ERAA 2023, while developed over a period when Europe experienced a deep energy crisis and an overhaul of many energy policies, delivered a study with complex approaches and significant methodological improvements. ERAA 2024 features further significant enhancements over previous editions, especially in weather scenarios and cross-border capacity modelling. A new Pan-European Climate Database (PECD) has been used, developed within the EU Copernicus Climate Change Service (C3S) framework in close cooperation with ENTSO-E. More information can be found in Annex 2. Cross-border capacity modelling was improved by considering Nordic FB market coupling. Also, for the first time FB market coupling was represented in EVA simulations. These were two major achievements in ERAA 2024.

ENTSO-E is committed to an ERAA 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.

## 3.2 The ERAA's role within ENTSO-E's outlook studies

### ERAA, the Seasonal Outlook and the TYNDP

The ERAA and the Seasonal Outlook aim to model and analyse potential events that could adversely impact the balance between electric power supply and demand in different future time horizons. The ERAA focuses on the medium-term horizon of two to 10 years ahead, while seasonal adequacy assessments 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 and identify potential shortcomings that could be addressed proactively.

Although all power system assessments are based on state-of-the-art methodologies and probabilistic assessments, they do have differences. The purpose of the ERAA is to identify adequacy assessment concerns and provide action guidance, with moderate uncertainty up to five years ahead, increasing to higher uncertainty beyond that period. It indicates the impact on adequacy in the longer run through the EVA (estimation of resource capacity at risk), which is based on specific assumptions for the next 10 years. The Seasonal Outlook aims to identify security of supply risks for the upcoming months, with  low uncertainty as is assesses a shorter time horizon based on data/assumptions/information that more accurately reflect the real situation ahead of each season assessed. The purpose of the TYNDP is to identify transmission infrastructure needs and no-regret investments under several scenarios, covering the time frame through 2050, which involves a very high level of uncertainty.

The ERAA's EVA provides a midterm 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 crucial to inform policymaker decisions on potential incentives to support midterm adequacy.

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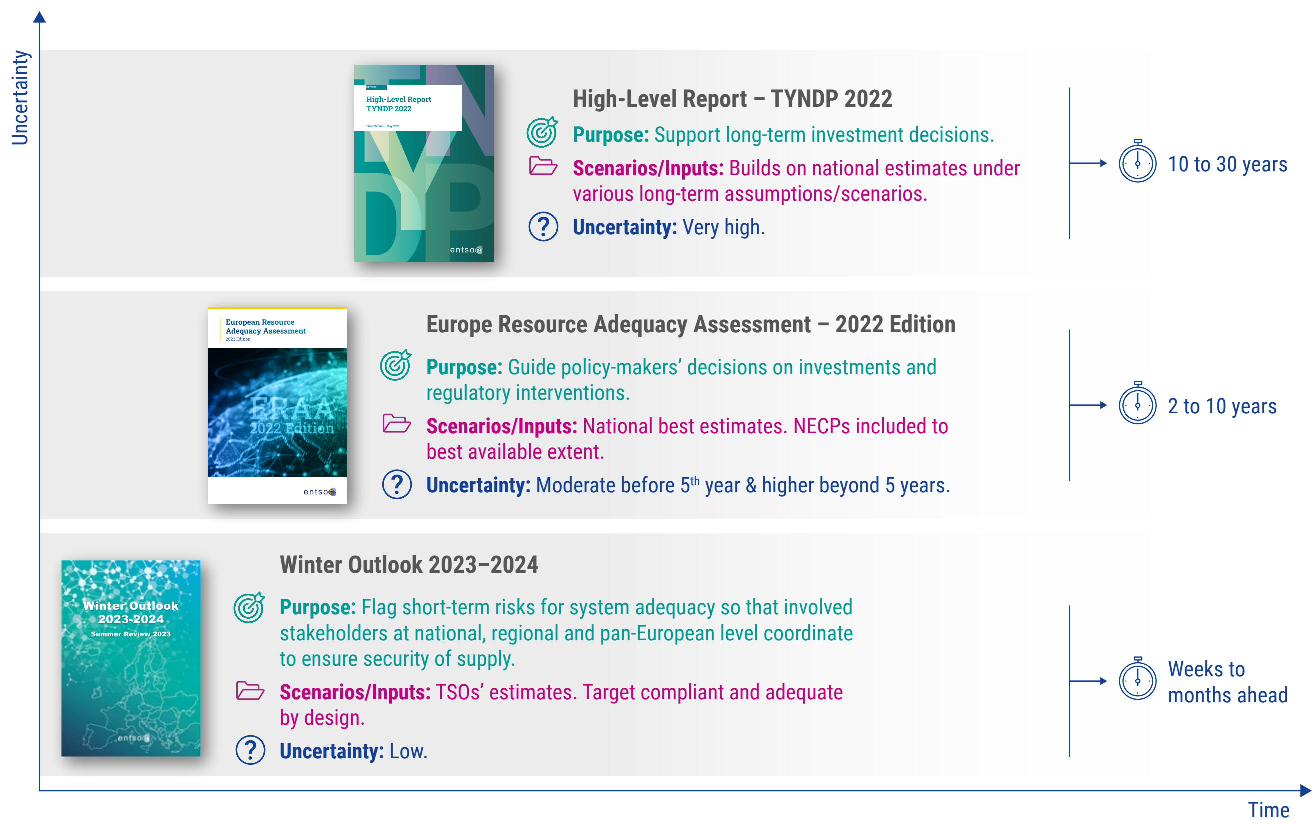


Figure 10: A comparison between the ERAA, the Seasonal Outlook and the TYNDP

# 4 Scenario and main assumptions

## 4.1 Input data and scenario

ERAA 2024, as a fourth edition, builds on the lessons learnt and improvements of the three past editions, and striving for continuous methodological improvement to maximise 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 study zones. ERAA 2024 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 March 2024, 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, requiring numerous assumptions regarding input data, substantial computational resources and pragmatic simplifications to achieve trustworthy results. ERAA 2024 for the first time includes an enhanced and forward-looking PECD for future ERAA editions in collaboration with C3S.

The 2024 assessment is conducted for four TYs; 2026, 2028, 2030 and 2035. TY 2026 allows a short-term view. TY 2028 is an important year for decisions related to CMs, as well as the pivotal TY 2030. TY 2035 provides insights into a longer-term horizon. ERAA 2024 is based on TSOs' national best estimates on the development of the electricity sector in the coming decade while respecting the relevant EU energy policy targets and objectives. The available capacity of this initial scenario is then updated through the application of the EVA. It accounts for CMs already contracted or granted through auctions at the time of the assessment.

## 4.2 Scope and methodology

The geographical scope of ERAA 2024 encompasses a large part of the European continent.[5] For more information regarding the modelled countries, please refer to Annex 1. Figure 11 illustrates the geographical scope of ERAA 2024, 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 ERAA 2024 results in highly complex and computationally intense models. As a pan-European study, the ERAA must avoid delving into the specificities of each modelled country.

For these reasons, only the most relevant and impactful factors[6] for assessing the European adequacy situation were identified and considered in the ERAA, while national assessments are meant to provide complementary and deeper analyses of local constraints. These more localised assessments, based on the same methodology, complement the ERAA by reflecting particularities of national electricity demand and supply, and by using tools and consistent recent data.[7]

5 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. Moldova is implicitly modelled in ERAA 2024. Ukraine, due to high uncertainty and war, is not modelled in ERAA 2024. Cyprus requested a derogation based on Article 64 of the Regulation (EU) 2019/943. 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.

6 Mainly LOLE and EENS

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

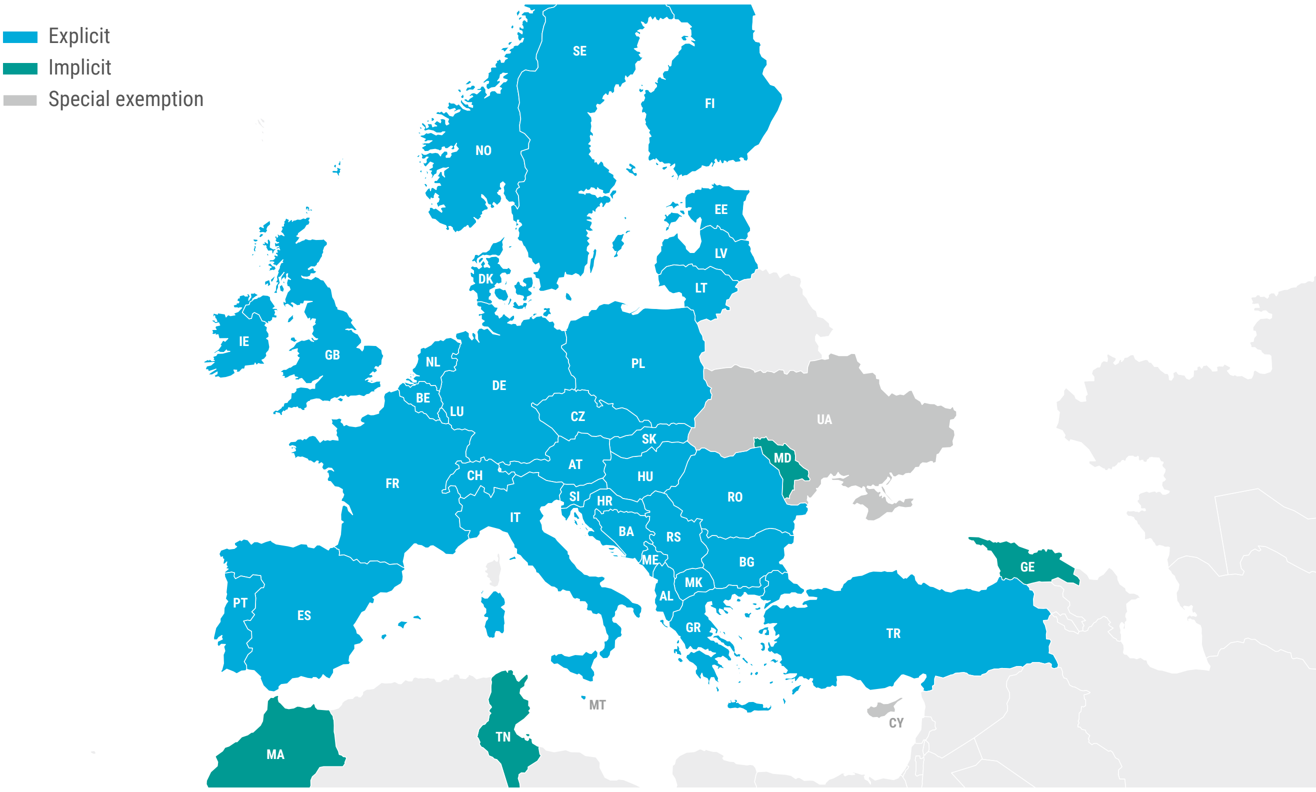


Figure 11: ERAA 2024 geographical scope

## 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 ERAA 2024 are:

1. **Cost-driven dispatch decisions:** 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 consider non-market resources designed for adequacy reasons, such as strategic reserves, but do not consider extraordinary operational measures that TSOs may use to manage system stability such as voltage reductions.

4. **Weather-dependent RES production:** Solar, wind and hydro-power generation are modelled based on selected weather scenarios.

5. **Optimised planned maintenance of thermal units:** Planned maintenance for thermal units occurs in periods with an expected sufficient supply margin. Country-specific restrictions (e. g. maximum number of units simultaneously under maintenance) and the impact of weather conditions are considered.

6. **FB modelling for the CORE and Nordic 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), and Nordic area (DK, FI, NO, SE) are modelled using the FB approach, which mimics multilateral cross-border exchange restrictions. All other regions are modelled based on bilateral NTC exchange capacities.

7. **Compared to ERAA 2023**, which found the probabilistic representation of nuclear availability insufficient to capture the observed variability, ERAA 2024 includes two additional nuclear availability profiles for France in the economic dispatch studies for 2030 and 2035, where this variability is more pronounced. This approach more comprehensively captures the effects of nuclear availability, which has been consistently shown, especially in 2022, to have a potentially detrimental effect on security of supply across Europe. For countries where the impact is significant in characterising adequacy concerns (such as France and Belgium), the results are presented with these additional studies taken into account.

Further details on ERAA modelling assumptions are available in Annex 2 (Section 1.3).

# 5 Stakeholder engagement

Developing the ERAA requires the contributions of numerous 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 each ERAA edition, ENTSO-E hosts at least three webinars at different phases of the study: assumptions and input data; methodological insightsand results and takeaways.

ENTSO-E's work on ERAA 2024 has sought the best available data and assumptions throughout the development of this study. In March 2024, a public consultation was held on scenarios and key data, which provided valuable stakeholder feedback.

The public consultation resulted in some data adjustments, mainly for Germany, Norway, and Ireland, regarding renewable energy capacity, interconnector capacity, and other fuels capacity, respectively. The assessment is based on the best available assumptions, while methodological improvements focus on meeting the legal requirements for ERAA as stated in the Electricity Market Regulation.

To make this information accessible and transparent for stakeholders, ENTSO-E created a dedicated webpage where webinar recordings and stakeholder feedback are published. An update of the dataset following the feedback received during the public consultation was also published with information on how the data had changed. Additionally, in 2024, more detailed results (hourly ENS) will be published, as requested by several stakeholders.

# 6 Beyond ERAA 2024

## 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 complemented by national analyses. Through this, the ERAA aims to support an efficient and interconnected energy system by measuring the system's ability to maintain security of supply while accounting for climate change and the rapid increase in installed renewable capacities. This measurement will increasingly be used to determine which interventions, including CMs, 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 challenges while delivering secure and affordable energy to citizens and industries.

The European energy context has changed drastically since the CEP was released. Due to the war in Ukraine and the 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. In response to the recent energy crisis, the Electricity Market Design Reform (EMDR) was initiated to better prepare Europe's electricity market for future challenges. ENTSO-E is convinced that the role of the ERAA goes far beyond being a tool for decisions on CMs. It can also support policymakers in building their mid-term strategies and illustrate 'what if' scenarios to shed light on possible futures.

With the integration of Europe's electricity markets, as well as 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 does not recommend specific actions, its analysis will inform decisions regarding CMs and other state policy interventions. The ERAA contains pioneering methodologies and tools to analyse future adequacy with an unprecedented combination of scope and detail, serving as a key reference when considering the future of Europe's electricity system.

The ERAA provides an effective tool for identifying system needs complementing the TYNDP. Future development through methodological innovation, pilot programmes, stakeholder consultation and scope refinement will continue to enhance the ERAA's value. Meanwhile, ENTSO-E remains committed to the multi-year planning, data delivery, scenarios and methodologies required to fulfil the ERAA's potential.

### ENTSO-E has outlined the following main recommendations in view of an ERAA methodology revision, expected to be triggered by spring 2025:

1. Within the current legal framework, ERAA shall use as assumptions National Energy and Climate Plans and other projections of Member States, considering the latest political commitments along with existing or anticipated developments and policies. This may lead the ERAA to deliver outcomes based on the strong assumption that energy and climate policy targets will be systematically reached on time and consistently across all Member States. Considering that policies might not be 100 % effective in achieving their intended goals within the expected timeline, future ERAAs could also assess adequacy risks through an additional scenario that accounts for potential future delays in the commissioning of new capacities, such as the deployment of RES and other low-carbon technologies, including storage.
2. The ERAA can serve as a common European reference for investigating the impact of existing and/or planned market reforms, such as CMs, in some of its scenarios. However, the current experiences of Member States reinforce that the ERAA should not be understood as the sole legal basis to initiating CM discussions. Instead both the ERAA and NRAAs (where the ERAA has not identified a resource adequacy concern) should be used complementarily to identify resource adequacy concerns.
3. Some ERAA methodology content will be streamlined to reduce modelling complexity while allowing more time to incorporate insights into the results. This will include, among other things, a focus on a few key TYs, ensuring their relevance for stakeholders.

## 6.2 Case study: EVA with a revenue-based approach

A case study of EVA based on a revenue-based iterative approach was performed at a European scale. The approach complies with the ERAA methodology[8] and has already been used by several TSOs in their national adequacy assessments. This case study was launched to assess the implications of this approach at a pan-European scale and confirm its technical feasibility.

The motivation for preparing for a revenue-based EVA approach is to enhance the anticipation of investors' behaviour and to mitigate the computational burden, supporting a better understanding of investment decisions. Moreover, with less computationally demanding models, a revenue-based EVA could accommodate more weather scenarios, improving consistency between the EVA and ED modules of the ERAA.

While both modelling approaches are viable according to the methodology, ACER pointed out in their approval of ERAA 2023 decision[9] that such modelling refinement (referred to as an "iterative" modelling approach) would be considered an improvement of ERAA robustness.

More details on the approach and results are available in Annex 4. The revenue-based EVA approach must be further matured and consolidated for application within the ERAA framework.

8 ACER's ERAA methodology approved by ACER in Decision 24-2020.

9 ACER Decision 06-2024

# 7 List of data

## Inputs:

- **Dashboard_raw data (folder)**
  - Aggregated Demand
  - Commodity Prices
  - Flow-Based Core KPI
  - Generation Capacities Maintenance Daily – Per Technology
  - Non-Market Batteries
  - Reserves Requirements
  - Storage
  - Hydro Capacities

## Complementary Input Data:

- Common Data
- Demand
- Dispatchable Consumption
- Economic and Technical Investment Parameters
- FB Domains
- iDSR Ratios
- NTCs
- PECD – RES
- PECD – Weather

## Outputs:

- **Dashboard of the results**
  - EVA
  - Case Study of revenue-based EVA
  - Adequacy
- **Hourly ENS time series**

# Glossary

| | |
|---|---|
| **ACER** | European Union Agency for the Cooperation of Energy Regulators |
| **CEP** | Clean Energy Package |
| **CM** | Capacity Mechanism |
| **CONE** | Cost of New Entry |
| **DSR** | Demand-Side Response |
| **EENS** | Expected Energy Not Served |
| **EMDR** | Electricity Market Design Reform |
| **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 |
| **NRA** | National Regulatory Authority |
| **NRAA** | National Resource Adequacy Assessment |
| **OM** | Outage Minute |
| **PECD** | Pan-European Climate Database |
| **RES** | Renewable Energy Sources |
| **TSO** | Transmission System Operator |
| **TY** | Target Year |
| **TYNDP** | Ten-Year Network Development Plan |
| **VoLL** | Volume of Lost Load |

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