
# Towards climate-neutral and resilient energy networks across Europe

advice on draft scenarios under the EU regulation on trans-European energy networks

European Scientific Advisory Board on Climate Change

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# About the European Scientific Advisory Board on Climate Change

The European Scientific Advisory Board on Climate Change (ESABCC, hereafter 'the Advisory Board') is an independent scientific advisory body that provides the EU with scientific knowledge, expertise and advice relating to climate change. The Advisory Board identifies actions and opportunities to achieve the EU's climate neutrality target by 2050. The Advisory Board was established by the European Climate Law of 2021, with a mandate to serve as a point of reference for the EU on scientific knowledge relating to climate change by virtue of its independence and scientific and technical expertise.

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# Summary and recommendations

The EU is committed to reducing its greenhouse gas (GHG) emissions to net zero by 2050 at the latest and to aiming to achieve net negative emissions thereafter. Achieving these objectives requires adapting and developing the EU's energy infrastructure in a way that supports rapid electrification, coupled with fossil fuel phase-out and adequate carbon dioxide ($CO_2$) value chains, and the scale-up of renewable electricity generation and energy system integration.

The EU's trans-European networks for energy (TEN-E) policy helps reach that goal by setting out a process to identify and select energy and $CO_2$ infrastructure projects that could benefit from financial and regulatory support. The identification of infrastructure needs and the selection of cross-border projects of high EU relevance rely on the 10-year network development plan (TYNDP) process. At the heart of this process are the EU-wide energy scenarios that are developed jointly by the European Network of Transmission System Operators for Gas (ENTSOG) and the European Network of Transmission System Operators for Electricity (ENTSO-E) every 2 years. The joint scenarios create investment landscapes in which the value of new cross-border infrastructure projects is assessed.

To ensure that the infrastructure projects effectively contribute to achieving the EU's climate neutrality objectives, the TEN-E regulation invites the European Scientific Advisory Board on Climate Change (ESABCC, hereafter "the Advisory Board") to deliver opinions at different stages of the TYNDP process (EU, 2022).

In this report, the Advisory Board presents its findings and recommendations from the assessment of the draft joint scenarios published by ENTSO-E and ENTSOG in May 2024. This advice builds on the Advisory Board's 2022 recommendations on scenario guidelines for TEN-E that it gave to the European Union Agency for the Cooperation of Energy Regulators (ACER) (ESABCC, 2022), its 2023 recommendations on methodologies for a harmonised EU-level cost–benefit analysis (ESABCC, 2023a) and its 2024 recommendations for the more effective implementation and design of the EU climate policy framework (ESABCC, 2024).

**Key recommendation 1 – The European associations of gas and electricity transmission system operators should improve their draft scenarios to make them more in line with the achievement of the EU climate objectives for 2030 and 2050 and the 'energy efficiency first' principle.**

**Using these scenarios in their current form could result in inadequate energy infrastructure planning and development, presenting several risks for the EU, such as an overshoot of the EU's GHG budget, energy and cost inefficiency, and import dependency. (see Chapters 2–4).**

The Advisory Board has found that the draft joint scenarios are not fully in line with the requirements set out in the TEN-E regulation (EU, 2022), with the ACER guidelines (ACER, 2023) and with its own previous recommendations (ESABCC, 2023a, 2022).

Some indicators featured in the draft joint scenarios appear to be aligned with the ranges set out by the European Commission's modelling results (scenario S3) and the collection of scenarios used by the Advisory Board to determine fair and feasible climate neutrality pathways for the EU (hereinafter 'the benchmark scenarios') ([1]). This is, for example, the case for final energy consumption levels and renewable energy shares until 2030, which appear to be in line with the EU's binding targets, and

([1]) In line with the advisory board's recommended GHG budget for 2030–2050, these include six filtered scenarios that achieve at least a 90 % reduction in net GHG emissions by 2040 and that do not exceed the environmental risk thresholds identified by the ESABCC (2023b).

installed wind and solar capacities, which are aligned with the benchmark scenario ranges. However, the following interlinked indicators deviate from these benchmark scenario ranges, particularly beyond 2030:

- At 15.9 Gt of carbon dioxide equivalent ($CO_2e$), the GHG budget presented for the distributed energy (DE) scenario exceeds the Advisory Board's recommended GHG budget of 11–14 Gt $CO_2e$ for 2030–2050 (even after accounting for differences in maritime scope), while remaining slightly below the European Commission's recommended maximum of 16 Gt $CO_2e$. Similarly, if inconsistent carbon capture and storage (CCS) assumptions are brought in line with the source data, the GHG budget for the global ambition (GA) scenario lies outside the Advisory Board's recommended range, sitting at approximately 15 Gt $CO_2e$. The exclusion of some industrial process emissions, mainly from cement, suggests a further underestimation of gross emissions by up to 2 Gt $CO_2e$ in the GA and DE scenarios.
- Capacities for combined CCS and carbon capture and use (CCU) in the GA scenario exceed the maximum feasibility thresholds identified in the benchmark scenarios. This is probably due to inconsistencies between the assumed scale of CCS in the draft joint scenarios and that in the European Commission's strategy, which is referred to as the original data source for the CCS potential.
- Hydrogen consumption, supply and import levels are substantially higher in the draft joint scenarios, particularly in the 2030 baseline (NT+) shared by all the draft joint scenarios, than in the benchmark scenarios. In the scenarios, hydrogen demand (483 TWh) and electrolyser capacity (103 GW) are two to three times higher than the benchmarks. All draft joint scenarios show a very high reliance on hydrogen imports in 2030–2050 compared with the benchmark scenarios, where imports feature minimally. For example, the GA scenario shows hydrogen imports of 670 and 737 TWh in 2040 and 2050 respectively, compared with just 15 and 42 TWh in scenario S3 for the same respective time points.
- Final energy consumption and electrification deviate from the benchmark scenarios in 2040 and 2050, especially in the GA scenario, which has higher final energy consumption and lower electrification rates than all the benchmark scenarios.

Methodological issues and questions presented additional challenges in assessing alignment with EU climate and energy objectives.

- The draft joint scenarios for up to 2030 are based on largely outdated national data and do not build on the draft updated national energy and climate plans published by EU Member States in 2023. This necessitates 'gap filling' by ENTSO-E and ENTSOG to achieve target compliance, which affects the robustness, coherence and relevance of scenario outcomes.
- There are several points of concern regarding the GHG budget methodology. Notably, the draft joint scenarios (i) seem to overestimate CCS potential in two scenarios, given their inconsistencies with the source values, (ii) fail to distinguish between CCS, CCU and carbon removals, (iii) do not clearly distinguish between external inputs and modelling results and (iv) seem to exclude $CO_2$ emissions from some industrial processes.
- Modelling fossil gas jointly with biomethane and synthetic gas obscures the effect of the potential decommissioning as well as the overall CCS capacities.
- The core assumptions used for the DE and GA scenarios are not sufficiently differentiated to provide useful insights on the range of potential pathways to climate neutrality.
- Several core assumptions and definitions appear internally inconsistent and misaligned with the stated sources or rely on uncommon practices that are insufficiently justified. This is particularly the

case for CCS and CCU definitions and costs, carbon prices, the cost of hydrogen and the differentiation of technology costs for renewable energy between storylines.

The Advisory Board therefore recommends that ENTSO-E and ENTSOG improve their draft joint scenarios by carrying out the following adjustments:

- updating **core assumptions, including carbon capture (CCU/CCS) deployment, definitions and costs**, based on the latest scientific and institutional scenarios;
- improving the **GHG budget calculation** to give a more accurate picture of the net carbon emissions resulting from the scenarios – including updating assumptions and distinguishing between CCU, CCS and carbon removals and their sources – and explicitly including and disaggregating energy and industrial process $CO_2$ emissions;
- using the most **up-to-date plans and projections** for joint scenario preparation;
- further **differentiating scenarios** to capture a broader spectrum of possible climate neutrality pathways.

**Key recommendation 2 – The European associations of gas and electricity transmission system operators should factor climate risks into their scenarios to enhance the resilience of EU energy infrastructure against the adverse effects of climate change (see Chapter 5).**

The TEN-E regulation (EU, 2022) outlines the need to increase the EU energy infrastructure's resilience, disaster prevention capacity and preparedness. This point was also raised by the Advisory Board in its recommendations in 2022. Yet the Advisory Board found that considerations regarding climate resilience and adaptation efforts have not been incorporated into the draft joint scenarios:

- the scenarios do not sufficiently consider major climate risks to infrastructure, such as droughts and floods;
- the climate scenarios are based on outdated climate data and do not consider future climatic trends;
- the scenarios consider the negative effects of weather conditions only on wind and solar energy, rather than on the entire energy infrastructure.

The Advisory Board therefore recommends that ENTSO-E and ENTSOG adequately **account for climate risks** and incorporate the necessary adaptation activities and costs for existing and new infrastructure.

**Key recommendation 3 – The transparency, timeliness and participatory nature of the scenario-building process should be further enhanced (see Chapter 6).**

The transparency and documentation of the draft joint scenarios of the 2024 TYNDP cycle have substantially improved compared with those in the previous TYNDP cycles. Methodologies and assumptions are generally well described, informative and understandable, albeit data sources are not always provided.

Nevertheless, the scenario-building process does not yet fully build on timely consultations of stakeholders and external experts. The process remains complex and rigid, and hence insufficiently participatory and insufficiently reflective of the latest climate mitigation and resilience needs, as highlighted by the newly established Stakeholder Reference Group (SRG, 2024). Owing to the delay in ENTSO-E and ENTSOG submitting the draft joint scenarios to ACER and the tight sequence of steps under the TYNDP process (ACER, 2023), the consultation and correction mechanisms of the draft scenarios embedded in the TEN-E regulation did not work as intended. Moreover, having a cut-off date of early 2023 for scenario input data collection (ENTSO-E and ENTSOG, 2024a) increases the risk that the selection of projects of common interest / projects of mutual interest in 2025 will be based on largely outdated data.

The Advisory Board therefore recommends that:

- ENTSO-E and ENTSOG deliver draft joint scenarios in a timely manner and allow sufficient **time for stakeholders** (including the Stakeholder Reference Group, ACER and the European Commission) to provide input at an appropriate stage in the process, so that modelling and decisions can adequately reflect the feedback received within the same TYNDP cycle;
- all stakeholders consider how to improve the agility of the **scenario-building process** to enable faster incorporation of new assumptions, climate plans and targets, and to facilitate the analysis of relevant scenario sensitivities.

Unless the draft joint scenarios are considerably improved, the Advisory Board notes that using the current joint scenarios for the selection of energy and $CO_2$ infrastructure projects eligible for favourable regulatory treatment and financial support, or for any other decision affecting the European energy system, may result in the following **risks for the EU**:

- an **overshoot** of the EU's GHG gas budget,
- the avoidable **climate vulnerability** of energy infrastructure,
- insufficient pace of **fossil fuel phase-out** and **direct electrification**,
- unnecessarily **high costs** of the energy transition,
- high **energy import dependency**.

# 1. Introduction

## 1.1. Context and aim

Energy infrastructure lies at the heart of the EU's energy security and climate neutrality. The EU has adopted policies setting it on a course to reduce greenhouse gas (GHG) emissions by at least 55 % by 2030 compared with levels in 1990 and to reach climate neutrality by 2050 and negative emissions thereafter (EU, 2021). As energy supply and use are responsible for 75 % of the EU's total GHG emissions (EEA, 2024a), the EU's transition towards net zero requires a major transformation of the energy sector, including energy savings, a massive scale-up of renewables, increased electrification, fossil fuel phase-out and establishment of adequate carbon dioxide ($CO_2$) value chains (ESABCC, 2024). This requires a well-functioning internal energy market ([2]), extensive cross-border collaboration and a focus on climate-resilient energy. The EU energy system is already affected by climate impacts and exposed to multiple climate risks (EEA, 2024b). The Russian invasion of Ukraine in 2022 exposed further vulnerabilities and reminded Europe that climate change mitigation and resilience go hand in hand with energy security and competitiveness (Letta, 2024).

The 2050 vision of the EU energy industry depends largely on joint European Network of Transmission System Operators for Electricity (ENTSO-E) and European Network of Transmission System Operators for Gas (ENTSOG) scenarios showing possible futures of the European energy system. Regulation (EU) 2022/869 (the trans-European networks for energy (TEN-E) regulation) requires ENTSOG and ENTSO-E to jointly develop scenarios projecting the long-term energy demand and supply and the resulting infrastructure use in the European energy system (EU, 2022). These joint scenarios must be fully in line with the 'energy efficiency first' principle, the EU's 2030 targets for energy and climate and the EU's 2050 climate neutrality objective. The networks must consider the most recent available European Commission scenarios and the national energy and climate plans (NECPs) (EU, 2022). The scenarios provide a quantitative basis for infrastructure investment planning and development under the 10-year network development plan (TYNDP) process, including the identification of projects that are key to achieving net zero do not yet exist, and the possibility of preferential regulatory treatment – for example, sped-up issuing of permits, regulatory financial incentives and EU funding for European projects of common interest (PCIs) and projects of mutual interest (PMIs). The TYNDP also plays a role in the development of EU $CO_2$ networks, carbon capture and use (CCU) and carbon capture and storage (CCS), hydrogen infrastructure, and digital and smart solutions enabling active demand management.

To ensure that this process and these projects effectively contribute to achieving the EU's climate neutrality objectives, the TEN-E regulation invites the European Scientific Advisory Board on Climate Change (ESABCC, hereafter "the Advisory Board") to deliver opinions at different stages of the TYNDP process. The Advisory Board has already observed that, so far, this process has not been sufficiently addressing the transformational changes and rapid reductions in GHG emissions necessary to achieve the EU's climate neutrality and climate resilience targets by 2050. This observation pertains to the entire TYNDP process, in particular scenario development (ESABCC, 2022), system needs assessment, cost–benefit analysis and the subsequent selection of PCIs/PMIs (ESABCC, 2023a).

([2]) The welfare gains delivered by cross-border trade in electricity were around EUR 34 billion in 2021 and are likely to have been even higher during the 2022 energy crisis (ACER, 2022).

The scenarios have previously supported the case for further fossil fuel investment, which is incompatible with climate neutrality pathways ([3]), and underestimated the need for investment in direct electrification, grids expansion and demand response (ACER, 2022). Furthermore, in the conclusions of their Council meeting of May 2024, EU energy ministers reflect the Advisory Board's concern regarding the EU's energy infrastructure planning and development by calling for more transparency and independent oversight of the 'whole transmission planning and development process' (Council of the European Union, 2024). The Council also calls for the development of a forecasting tool for grid needs and the linked investment needs on the path to climate neutrality at the EU level by 2050 and calls for an assessment of gaps in and development of measures to improve 'the planning, selection and implementation of cross-border infrastructure, especially within the TYNDP process and taking into account ACER's opinions' (Council of the European Union, 2024).

With this report, the Advisory Board presents its findings and recommendations from the assessment of the draft joint scenarios published by ENTSO-E and ENTSOG in May 2024, building on the Advisory Board's 2022 recommendations on scenario guidelines for TEN-E that it gave to the European Union Agency for the Cooperation of Energy Regulators (ACER) (ESABCC, 2022), its 2023 recommendations on methodologies for a harmonised EU-level cost–benefit analysis (ESABCC, 2023a) and its 2024 recommendations for the more effective implementation and design of the EU climate policy framework (ESABCC, 2024). The advice report also highlights opportunities to better align the 2024 TYNDP draft joint scenarios with the EU's climate neutrality objectives.

## 1.2. Analytical approach

The Advisory Board's analysis of the draft joint scenario data builds on insights from its previous reports and on the European Commission's modelling and stakeholders' insights. To deliver its advice, the Advisory Board took the following steps:

1. the draft joint scenario data published by ENTSO-E and ENTSOG in May 2024 (ENTSO-E and ENTSOG, 2024b) was compared with the European Commission's scenario underpinning the 2040 target communication (EC, 2024a) and the Advisory Board's scenarios behind its 2040 target recommendation (ESABCC, 2023b);
2. the draft scenarios' report and the results of the comparison made in step 1 were assessed in the light of the Advisory Board's recommendations laid out in its previous reports (ESABCC, 2024, 2023a, c, 2022) and the first output of the TYNDP Stakeholder Reference Group (SRG) (SRG, 2024);
3. on the basis of the work carried out in steps 1 and 2, the Advisory Board formulated a set of recommendations.

In its advice on the TYNDP scenario guidelines (ESABCC, 2022) the Advisory Board included six overarching recommendations and 22 specific action points aiming to align the joint scenarios with the EU climate and energy objectives. Of the 22 specific action points, 17 were also included in ACER's guidelines on the scenario-building process in the 2024 TYNDP (ACER, 2023).

The Advisory Board has reviewed to what extent its previous six recommendations were followed in the context of the 2024 TYNDP draft joint scenarios published in May 2024. The new findings are presented in the same six areas:

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([3]) For example, under ENTSOG's 2022 hydrogen and natural gas TYNDP, out of 358 investments, 215 are in new or repurposed infrastructure to carry or further integrate hydrogen or biomethane (ENTSOG, 2023), while the remaining 143 projects are in traditional fossil gas activities, such as gas transmission pipelines, compression facilities and liquefied natural gas terminals. Furthermore, 11 out of 26 national electricity transmission plans are based on outdated wind and solar targets, and grids are being designed using scenarios underestimating the wind and solar capacity additions needed (EMBER, 2024).

- consistency with the EU's climate and energy goals,
- soundness of the assumptions,
- contrasting range of pathways,
- building block approach,
- incorporation of projected climate impacts,
- quality of the scenario-building process.

The assessment has been guided by the need for the EU to reach climate neutrality by 2050 while minimising the costs of the transition, including the costs of locked-in fossil fuel infrastructure (see Box 1). It assumes that, to meet that need, the EU must act as one, reinforcing its internal energy market through energy-efficient solutions. **The assessment is not comprehensive**, as it does not cover all of the draft joint scenarios' assumptions and results. No consultations with external stakeholders were carried out regarding this advice.

#### Box 1: The EU's energy and $CO_2$ infrastructure in science-led pathways to climate neutrality by 2050

Science-led pathways to climate neutrality by 2050 assume that the electricity supply in the EU is free of GHG emissions and dominated by renewables and that fossil gas will have only a marginal role by 2040 (ESABCC, 2023b). The extent to which fossil fuels will be replaced by renewables depends on the share of directly electrified uses in the overall energy demand, including residential heating, industry and transport (ESABCC, 2024). Electrification hinges on the right infrastructure – not only renewable energy generation assets, such as solar photovoltaics and wind turbines, but also transmission and distribution grids enabling system integration and the flexibility provided, for example, by batteries and demand-side management. Investment in electricity grids in the EU (~ EUR 40 billion per year) has to at least double for the EU to meet its climate and energy targets (ESABCC, 2024). This means overcoming investment barriers: high capital costs, permit-issuing and supply chain problems, and regulatory uncertainty. Renewables and electricity grid projects develop in parallel with the declining fossil fuel industry, which is nevertheless building on its strengths acquired over decades of market access, price and income formation and its strategic position in delivering energy security. Even if the fossil fuel investment outlook deteriorates – for example, as a result of the expected rise in EU emissions trading system price signals – the fossil fuel infrastructure developed today will still be operational for decades and could lead to massive stranded costs (ESABCC, 2023a). Continued use of fossil fuel in energy supply perpetuates high import bills, fugitive emissions and the EU's reliance on external suppliers (ESABCC, 2024, 2023c). It may also cause competition for permanent carbon storage with uses that have no viable decarbonisation alternative to CCS (ESABCC, 2024).

## Overview of the draft joint scenarios

The storyline headlines, data baselines and sources for the three draft joint scenarios, as described by ENTSO-E and ENTSOG in the draft scenarios report and the storyline report (ENTSO-E and ENTSOG, 2024a, 2023a), are presented in Table 1.

**Table 1: Overview of the draft joint scenarios**

| Data | NT+ | Deviation scenarios | |
|---|---|---|---|
| | | Distributed energy | Global ambition |
| Storyline | The aggregation of national pathways to reach EU targets | Higher European autonomy with renewable and decentralised focus | Global economy with centralised low-carbon and renewable energy source options |
| Baseline | 2019 | 2030 NT+ | |
| 2030 | Collected from gas and electricity TSOs by March 2023, except for offshore energy data collected in August 2023. Based on national policies, including NECPs and other national strategies, and TSOs 'best estimate' of the updated NECPs. The ambition gap between the national data and the EU targets (Fit for 55 package and REPowerEU plan) was filled by ENTSO-E and ENTSOG using a gap-filling methodology. The 'NT+ energy mix gap filling methodology' (ENTSO-E and ENTSOG, 2023b) consists of final energy demand reduction through reduced demand for oil and coal in selected sectors | | |
| 2040 | Based on national data | Modelled by ENTSO-E and ENTSOG, based on their own data and assumptions | |
| 2050 | Not available | Modelled by ENTSO-E and ENTSOG, based on their own data and assumptions | |

NB: NT+, national trends plus; TSO, transmission system operator.

*Source:* Advisory Board, based on ENTSO-E and ENTSOG (2024a, 2023a).

# 2. Consistency with the European Union's climate and energy goals

## Key findings

In its 2022 recommendations on scenario guidelines, the Advisory Board recommended that scenarios be adjusted as necessary to remain compatible with the EU's climate and energy targets and be modelled until at least 2050 (ESABCC, 2022).

In its assessment of the 2024 draft joint scenarios, the Advisory Board found that the draft joint scenarios align with the EU's binding 2030 targets for final energy consumption and the renewables share of the primary energy mix, largely as a result of the aforementioned gap-filling methodology. However, a broader benchmarking exercise highlighted that:

- the projected greenhouse gas budgets for 2030-2050 underestimate $CO_2$ emissions in both the distributed energy (DE) and global ambition (GA) scenarios.
- Two sources of underestimation of emissions are: 1) CCU should not have been deducted as negative emissions; 2) chemical process emissions from cement and lime production should not have been excluded from the overall emission budget.
- the projected carbon capture capacity (in GA) and hydrogen demand exceed the ranges set out by the European Commission's modelling results and the Advisory Board's collection of feasible scenarios;
- final energy consumption and electrification rates are lower than benchmark scenarios in 2040 and 2050, especially in the GA scenario, which has higher final energy consumption and lower electrification rates than all the benchmark scenarios;
- only two (DE and GA) out of three scenarios are modelled until 2050, and none goes beyond that time horizon.

This means that the EU risks overshooting its share of the global GHG budget and being slow in phasing out fossil fuels – for example, by continuing its use of fossil gas if renewable hydrogen production and imports do not meet these high expectations. The scenarios also imply higher costs for the energy transition due to prioritising large-scale hydrogen deployment across many sectors, while not maximising electrification or final energy reductions to the same extent as in the benchmark scenarios. Continued reliance on gaseous fuels risks also crowding out more efficient decarbonisation pathways (e.g. slowing the pace of direct electrification and heating/cooling decarbonisation).

ENTSO-E and ENTSOG are bound to follow ACER's guidelines (ACER, 2023) by Article 12(2) of the TEN-E regulation (EU, 2022); this includes following the requirement for the scenarios to be fully in line with the 'energy efficiency first' principle, the EU's 2030 climate and energy targets and its 2050 climate neutrality objective. They 'shall take into account the latest available Commission scenarios, as well as, when relevant, the national energy and climate plans' (EU, 2022).

The draft joint scenarios report provides an assessment of the alignment of the draft joint scenarios with the climate and energy targets set out in EU law, including the:

- European Climate Law targets of a reduction of net GHG emissions by at least 55 % by 2030 relative to levels in 1990 and of climate neutrality by 2050 (EU, 2021);
- renewable energy directive target of a 42.5 % share of renewable energy in the final energy mix (EU, 2023a);

- energy efficiency directive target of a reduction in FEC to 763 million tonnes of oil equivalent (Mtoe) (~ 8 874 TWh[4]) (EU, 2023b).

The Advisory Board assessed the national trends plus (NT+) scenario's alignment with these targets based on the information provided in the draft joint scenarios report. The NT+ scenario also lays the basis for the DE and GA scenarios.

In addition to these legal targets, the Advisory Board carried out a high-level benchmarking exercise to assess how the draft joint scenarios compare with other climate-neutral scenario pathways. Namely, this builds on the benchmarking exercise already conducted in the draft scenarios report – in which selected indicators were compared with the European Commission's scenario S3 from the 2040 impact assessment (EC, 2024b) – to create a broader assessment that also brings in the scenarios underpinning the Advisory Board's advice on a 2040 reduction objective (ESABCC, 2023b). For consistency with the Advisory Board's recommendation regarding a fair and feasible 2040 climate target, these scenarios include only those that achieve at least a 90 % reduction in net GHGs by 2040 while remaining within the key environmental risk thresholds identified by the Advisory Board (ESABCC, 2023b). The purpose of this broader benchmarking exercise was to identify significant trends or assumptions that diverge from these climate neutrality pathways, and therefore to identify key risks or opportunities for further improvement. This exercise was based on the methodology used for the Advisory Board's assessment of climate and policy progress, gaps and opportunities (ESABCC, 2024), and compared selected indicators in the draft joint scenarios with those from the collection of scenarios used by the Advisory Board to determine fair and feasible climate neutrality pathways for the EU (hereinafter 'the benchmark scenarios'). This comparison was based on either relative changes (mainly for energy and efficiency progress indicators) or absolute values (for capacity and hydrogen indicators), and the results of the assessment. Detailed data, analysis and results are contained in the Excel file annexed to this report.

## 2.1. Alignment with the updated national energy and climate plans

According to the draft joint scenarios report, the NT+ scenario relies on national data collected by the end of March 2023, except for offshore energy data, which was collected by August 2023. The draft joint scenarios do not reflect the draft updated NECPs due by June 2023. They do not explicitly build on the draft NECP progress reports due in March 2023, which contain the most up-to-date GHG projections for up to 15 years from when projections are made.

## 2.2. Energy use and energy efficiency

An overview of the draft joint scenarios' alignment with the Advisory Board's and the European Commission's scenarios for selected energy use and energy efficiency indicators is presented in Table 2.

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(4) A factor of 11.63 is applied to convert Mtoe to TWh as in the International Energy Agency's unit converter (IEA, n.d.).

**Table 2: Alignment of the draft joint scenarios with the benchmark scenarios for selected energy use and energy efficiency indicators**

| Year<br>*Benchmark scenario* | 2030<br>*ESABCC* | <br>*Commission* | 2040<br>*ESABCC* | <br>*Commission* | 2050<br>*ESABCC* | <br>*Commission* |
|---|---|---|---|---|---|---|
| **NT+** | | | | | | |
| Primary energy | Aligned | Aligned | Aligned | Aligned | No benchmark data | No benchmark data |
| • non-biomass renewables | Mostly aligned | Aligned | Mostly aligned | Mostly aligned | No benchmark data | No benchmark data |
| • fossil | Aligned | Aligned | Mostly aligned | Mostly aligned | No benchmark data | No benchmark data |
| Final energy | Mostly aligned | Aligned | Deviates somewhat | Mostly aligned | No benchmark data | No benchmark data |
| Electrification rate | Mostly aligned | Aligned | Deviates somewhat | Mostly aligned | No benchmark data | No benchmark data |
| **DE** | | | | | | |
| Primary energy | *Assumed to be the same as for NT+* | | Aligned | Aligned | Aligned | Aligned |
| • non-biomass renewables | | | Aligned | Aligned | Aligned | Aligned |
| • fossil | | | Aligned | Aligned | Aligned | Aligned |
| Final energy | | | Deviates somewhat | Mostly aligned | Mostly aligned | Mostly aligned |
| Electrification rate | | | Deviates somewhat | Mostly aligned | Mostly aligned | Aligned |
| **GA** | | | | | | |
| Primary energy | *Assumed to be the same as for NT+* | | Aligned | Aligned | Aligned | Aligned |
| • non-biomass renewables | | | Aligned | Aligned | Aligned | Aligned |
| • fossil | | | Mostly aligned | Mostly aligned | Aligned | Aligned |
| Final energy | | | Deviates significantly | Deviates somewhat | Deviates somewhat | Mostly aligned |
| Electrification rate | | | Deviates significantly | Deviates somewhat | Deviates significantly | Mostly aligned |

● Aligned with the benchmark scenario
● Mostly aligned with the benchmark scenario
● Deviates somewhat from the benchmark scenario
● Deviates significantly from the benchmark scenario
● Going in wrong direction compared with or exceeding feasibility thresholds of the benchmark scenario
● No benchmarkdata available

NB: Assessment progress based on values from the *TYNDP 2024 Draft Scenarios Report* and accompanying Excel file, with benchmarks based on the value ranges from the filtered scenarios underpinning the Advisory Board's advice on the EU-wide 2040 climate target and GHG budget, and scenario S3 from the European Commission's 2040 target impact assessment. Owing to minor differences in energy definition scopes between the three scenarios, the relative change method was used to measure alignment, alongside the target assessment provided in the draft scenarios report.

*Sources:* 2024 TYNDP draft joint scenarios benchmarking data and analysis (see the Annex), with source data from ENTSO-E and ENTSOG (2024a, 2024b), the advisory board's 2040 scenario database (ESABCC, 2023b) and the European Commission (2024b).

**The final energy consumption (FEC)** of 8 818 TWh in the NT+ 2030 baseline (Figure 41 ENTSO-E and ENTSOG, 2024b) is in line with the EU's 2030 target of 763 Mtoe (~ 8 874 TWh) set out in the recast energy efficiency directive (EU, 2023b). This alignment is a result of the gap-filling methodology, as the national data aggregation indicated an 8 % ambition gap (ENTSO-E and ENTSOG, 2024a, p. 52). Beyond

2030, reductions in FEC and final energy demand (FED) ([5]) deviate from and are less ambitious than the benchmark scenarios. In 2040, FED decreases by only 18–24 % from 2019 in the draft joint scenarios, compared with 38–40 % in the Advisory Board's scenarios, and similarly FEC decreases by 25–31 %, compared with 38 % in the European Commission's scenario S3. In 2050, FED decreases by 27–33 % compared with 42–46 % in the Advisory Board's scenarios, and FEC decreases by 35–40 %, compared with 43 % in the European Commission's scenario S3. In each case, the GA scenario achieves the smallest reduction in final energy use, with the DE scenario achieving the greatest.

In terms of **primary energy supply** (or gross available energy), the NT+ scenario shows lower primary energy supply than the benchmark scenarios. In 2040 and 2050, reductions in primary energy supply appear to exceed the trends in these other scenarios, with the DE scenario showing greater reductions in primary energy supply than the GA scenario. It is difficult, however, to assess alignment with the EU's indicative energy efficiency target for **primary energy consumption** of no more than 992.5 Mtoe (~ 11 543 TWh) in 2030 (EU, 2023b) owing to differences in scope, as the primary energy consumption target excludes international maritime bunkers, non-energy use and ambient energy, while the primary energy supply (Figure 19 of the scenario data figures) includes these categories. Primary energy supply in the NT+ scenario is 11 792 TWh in 2030, while the EU's indicative primary energy consumption target is 11 543 TWh in 2030.

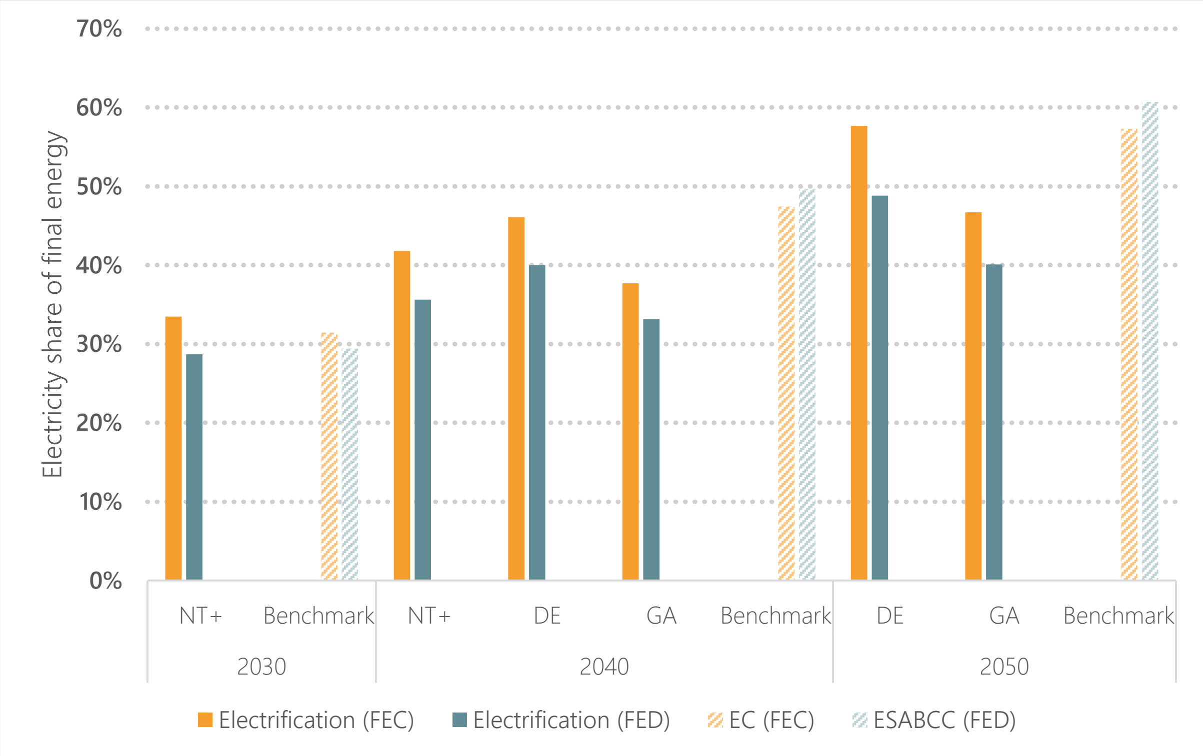
The **renewable energy** share of the EU's FEC in the NT+ scenario (45.4 %), is in line with the target of at least 42.5 % for 2030 set out in the renewable energy directive (EU, 2023a) as a result of the aforementioned gap-filling methodology. In addition, the primary energy supply from non-biomass renewables and fossil fuels is generally aligned with the ranges seen in the benchmark scenarios up to 2050.

In 2030, the **electrification rates** (electricity share of FEC and FED) are similar between the NT+ and the benchmark scenarios as a result of the aforementioned gap-filling methodology. However, as Figure 1 shows, electrification in 2040 and 2050 is much lower in the GA and NT+ scenarios (for 2040) than in the benchmark scenarios. As deep direct electrification of FED is described as a key distinctive feature of the DE scenario, it features electrification rates in 2040 and 2050 that are higher than those in the GA and NT+ scenarios and comparable to the European Commission's benchmark rates depending on which benchmark for electrification is used from the impact assessment[6]. However, these are still below the lower bound of the electrification rates within the Advisory Board's benchmark range from the filtered scenarios.

([5]) The scenario data figures distinguish between FED (Figure 5), which includes final energy associated with the energy sector, non-energy use and international transport, and FEC (Figure 41), which excludes the energy branch, international shipping, ambient heat and non-energy use. FEC is used as the scope for the European Commission benchmark (Figure 41), while FED is used as the indicator for the advisory board's benchmark because of its more comparable scope.

([6]) The European Commission's impact assessment provides two sets of values for electrification in the S3 scenario. Table 10 (Summary of Key Energy Indicators) provides higher electrification rates than those calculated from Figure 32 in Annex 8, which shows final energy consumption by fuel. The latter figures are used for the Draft Scenario Report's assessment of FEC target compliance (Table 1), and are the values referenced above. If the higher values are used, this would also result in DE having lower electrification rates than all benchmark scenarios.

**Figure 1: Rate of electrification in FEC and FED (%)**




*NB:* The ESABCC value refers to the *lower bound* of the range of electrification values from the filtered scenarios, making the gap larger for other filtered scenarios.

*Sources:* 2024 TYNDP draft joint scenarios benchmarking data and analysis (see the Annex), with source data from ENTSO-E and ENTSOG (2024a, 2024b), the Advisory Board's 2040 scenario database (ESABCC, 2023b) and the European Commission (2024b).

## 2.3. Installed capacities and hydrogen demand

Table 3 presents an overview of the draft joint scenarios' alignment with the benchmark scenarios for selected capacity and hydrogen indicators.

**Table 3: Alignment of the draft joint scenarios with the benchmark scenarios for selected capacity and hydrogen indicators**

| Year | 2030 | | 2040 | | 2050 | |
|---|---|---|---|---|---|---|
| *Benchmark scenario* | *ESABCC* | *Commission* | *ESABCC* | *Commission* | *ESABCC* | *Commission* |
| NT+ | | | | | | |
| Installed capacity | | | | | | |
| • wind and solar | | | | | | |
| • green hydrogen | | | | | | |
| CCU/CCS | | | | | | |
| Hydrogen demand | | | | | | |
| DE | | | | | | |
| Installed capacity | *Assumed to be the same as for NT+* | | | | | |
| • wind and solar | | | | | | |
| • green hydrogen | | | | | | |
| CCU/CCS | | | | | | |
| Hydrogen demand | | | | | | |
| GA | | | | | | |
| Installed capacity | *Assumed to be the same as for NT+* | | | | | |
| • wind and solar | | | | | | |
| • green hydrogen | | | | | | |
| CCU/CCS | | | | | | |
| Hydrogen demand | | | | | | |

- Aligned with the benchmark scenario
- Mostly aligned with the benchmark scenario
- Deviates somewhat from the benchmark scenario
- Deviates significantly from the benchmark scenario
- Going in wrong direction compared with or exceeding feasibility thresholds of the benchmark scenario
- No benchmark data available

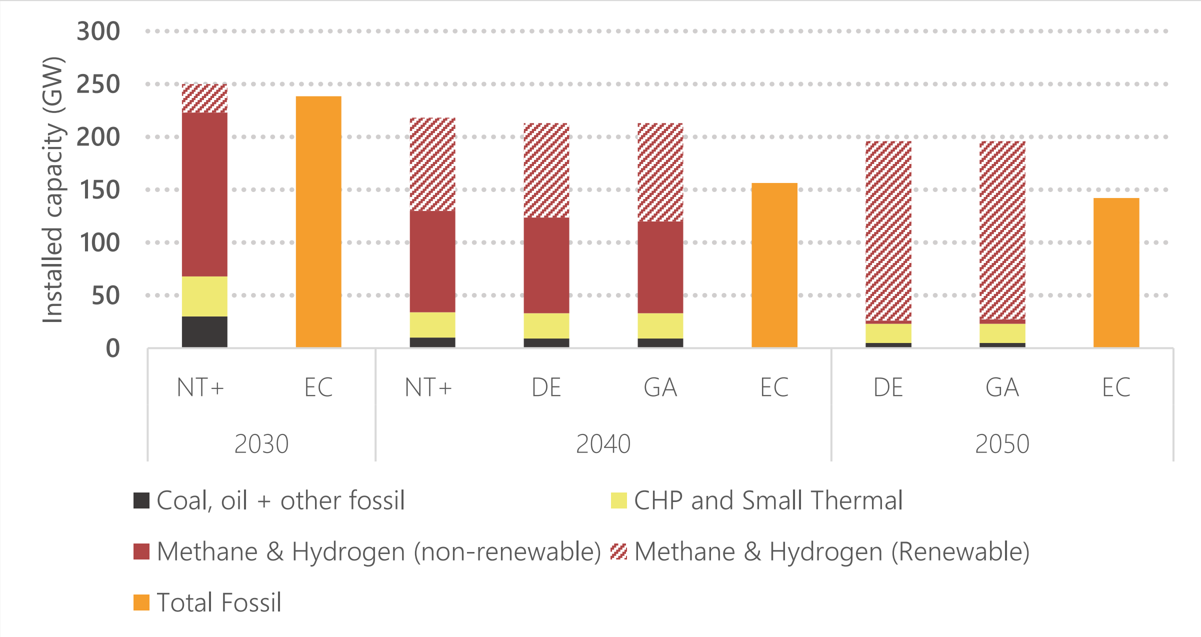
NB: Assessment progress based on values from the *TYNDP 2024 Draft Scenarios Report* and accompanying Excel file, with benchmarks based on the value ranges from the filtered scenarios underpinning the Advisory Board's advice on 2040 reduction objectives, and scenario S3 from the European Commission's 2040 target impact assessment. The absolute value benchmarking method was used to assess alignment, alongside feasibility thresholds from the Advisory Board's 2040 advice.

*Sources:* 2024 TYNDP draft joint scenarios benchmarking data and analysis (see the Annex), with source data from ENTSO-E and ENTSOG (2024a, 2024b), the Advisory Board's 2040 scenario database (ESABCC, 2023b) and the European Commission (2024b).

In terms of the electricity system, the **installed capacities of wind and solar** generally align with the targets and trends seen in the benchmark scenarios. In 2030, the draft joint scenarios' 1 127 GW of installed wind and solar capacity is above the RePowerEU plan's combined target of 1 110 GW (600 GW of solar photovoltaics, 510 GW of wind capacity), although slightly less than the levels set out in the Advisory Board's scenarios (1 267–1 370 GW). In 2040 and 2050, the installed wind and solar capacity generally align with the Advisory Board scenarios (disaggregated wind and solar capacities were not available from the European Commission).

The decrease in **installed fossil fuel capacity** in the draft joint scenarios relies on assumptions of the fuel blend split between renewable and non-renewable methane and hydrogen, rather than significant decommissioning of gas infrastructure. As Figure 2 shows, the overall level of gas power capacity (methane and hydrogen) will largely remain static between 2030 and 2050 compared with the European Commission scenario (disaggregated data was not available in the Advisory Board's scenarios). This trend relies on the availability of renewable hydrogen and methane, with little differentiation between the NT+, DE and GA scenarios.

**Figure 2: Installed fossil fuel and gas power capacity**




Sources: 2024 TYNDP draft joint scenarios benchmarking data and analysis (see the Annex), with source data from ENTSO-E and ENTSOG (2024a, 2024b) and the European Commission (2024b).

Notes: The dashed bars show the share of gas capacity that is assumed to operate on renewable methane or hydrogen.

In addition, the **fossil gas supply** of 2 987 TWh in 2030 in the draft joint scenarios (Figure 32 of the scenario data figures) is much higher than the ~ 1 835 TWh in the European Commission's modelling (Figure 14, EC, 2024). This is in part due to the gap-filling methodology underpinning the NT+ scenario (see Section 1.3 'Overview of the draft joint scenarios'), in which only demand for energy from oil and coal is considered, not that from fossil gas. As a result, 'the gap closing methodology does not require adaptation on the electricity and gas figures, [and therefore] the modeling [*sic*] simulation results are not affected with this adaptation' (ENTSO-E and ENTSOG, 2024a, p. 53). The justification for the chosen gap-filling methodology is only generally outlined in the draft joint scenarios documentation and remains somewhat unclear.

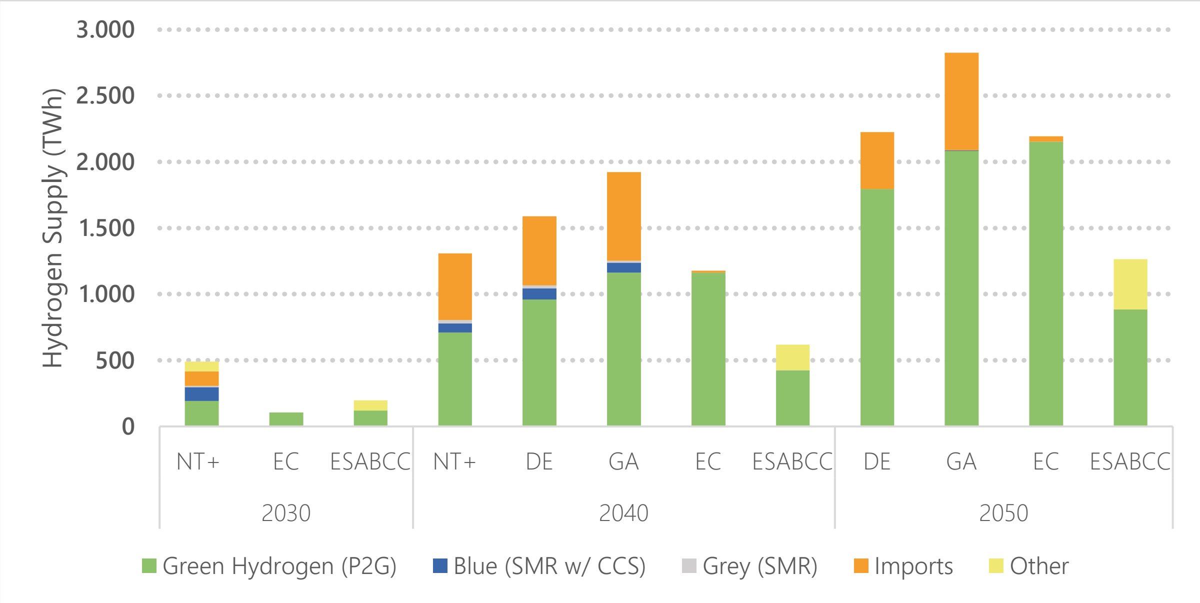
The **domestic green hydrogen production capacity** for 2030 is considerably higher in the draft joint scenarios than in the benchmark scenarios. The NT+ scenario's 2030 baseline is 103 GW of electrolysis capacity (Figure 34, ENTSO-E and ENTSOG, 2024b), compared with just 50–56 GW in the Advisory Board's scenarios and 30 GW in the European Commission's S3 scenario. This significantly exceeds the value of 50 GW in 2030 above which implementation is expected to become technologically challenging that was identified in the Advisory Board's 2040 advice, although it is less than the highest feasibility threshold of 150 GW.

Similarly, **hydrogen demand** levels (including demand for conversion) are significantly higher in the draft joint scenarios than in the benchmark scenarios. The hydrogen demand of 483 TWh in 2030

(Figure 10 ENTSO-E and ENTSOG, 2024b) is more than double the upper limit of the range set out in the Advisory Board's scenarios (175–196 TWh) (hydrogen demand for 2030 was not available in the European Commission's impact assessment). In 2040–2050, the hydrogen demand in the draft joint scenarios remains higher than in the benchmark scenarios. The GA scenario stands out in this respect, with hydrogen demand of 2 189 TWh in 2040 (approximately 2–5 times higher than in the benchmark scenarios) and 3 114 TWh in 2050 (1.5–4 times higher than the benchmarks).

To meet this increased demand, all draft joint scenarios rely on significantly higher **hydrogen supply** than the benchmark scenarios; this supply is met mainly by increased green hydrogen production and imports. The level of imports is notable in both the GA and DE scenarios, compared with minimal hydrogen imports in the benchmark scenarios (Figure 3). In addition, in 2050 domestic hydrogen production through electrolysis is expected to take up nearly one third of the total electricity demand in the DE and GA scenarios (ENTSO-E and ENTSOG, 2024a).

**Figure 3: Hydrogen supply by source**




NB: P2G, power to gas; SMR, steam methane reforming. 'Green hydrogen' refers to hydrogen produced through electrolysis in the different scenarios. Ammonia imports, which are provided as an additional source of hydrogen supply (beyond the level shown above in draft scenarios) have not been included in this graph for comparability with the other benchmarks. The Advisory Board scenario values refer to the *maximum* of the filtered scenario range, making the difference larger for other scenarios. Due to more limited granularity, 'Other' in the Advisory Board's scenarios refers to the difference between the total hydrogen supply and green hydrogen supply, and mostly consists of hydrogen produced from biomass, as well as some grey/blue hydrogen in earlier years.

*Sources:* 2024 TYNDP draft joint scenarios benchmarking data and analysis (see the Annex), with source data from ENTSO-E and ENTSOG (2024a, 2024b), the Advisory Board's 2040 scenario database (ESABCC, 2023b) and the European Commission (2024b).

## 2.4. Carbon capture and the greenhouse gas budget

All scenarios rely to some extent on **carbon capture, utilisation, and storage (CCU/CCS)**, including CCS applied to fossil fuel emissions and CCU for the production of synthetic fuels. This reliance is much greater in the GA and NT+ scenarios than in the DE scenario. The GA and NT+ scenarios use 344 Mt of carbon dioxide equivalent ($CO_2e$) of CCS capacity in 2040 and 452 Mt $CO_2e$ in 2050 (Figure 45 in the draft scenario data figures, although this is subsequently capped at 400 Mt $CO_2e$), the values for which are described as being based on estimates found in the European Commission's 2040 impact assessment (scenario S3) and the industrial carbon management strategy (EC, 2024c). (EC, 2024). A small volume of CCS resulting from hydrogen-CCS processes is subtracted from these exogenous totals, with the remainder undefined (i.e. between BECCS, DACCS, fossil CCS). Furthermore, 100–144 Mt $CO_2e$ in 2040 and 148–222 Mt $CO_2e$ in 2050 of carbon capture capacity that "are additional to the amounts of $CO_2$ captured and stored" is expected for the production of synthetic fuels (Figure 39 ENTSO-E and ENTSOG, 2024b), namely for e-Diesel, e-Kerosene and synthetic methane. As a result, this implies combined CCS/CCU capacity in the GA scenario of 548-622 Mt $CO_2e$ by 2050, which is significantly above the high feasibility threshold of 425 Mt $CO_2e$ per year by 2050 identified in the Advisory Board's 2040 advice and the 500 Mt $CO_2e$ per year that the European Commission identified as the maximum feasibility threshold from the scientific literature (EC, 2024).

Moreover, the CCS volumes in the GA and NT+ scenarios are inconsistent with the referenced source values in the European Commission's 2040 impact assessment. Figure 10 in the European Commission impact assessment ([7]) shows that the value of 452 Mt $CO_2e$ refers to the total volumes of $CO_2$ captured by 2050, a figure that includes both $CO_2$ that is captured and used for synthetic fuel production (CCU) and captured and stored (CCS). Out of the 452 Mt $CO_2e$ of captured carbon in 2050 (European Commission's scenario S3), only 247 Mt $CO_2e$ stored underground or 59 Mt $CO_2e$ stored in products could be considered CCS, with the remaining 147 Mt $CO_2e$ used for the production of synthetic fuels (i.e. as CCU). The same discrepancy can be observed for the CCS volumes used in 2040 for GA and NT+, in which some carbon capture values from the European Commission impact assessment appear to have been mislabelled as CCS.

This also indicates that, in the 2030–2050 **GHG budget** assessment for the GA scenario (Figure 4), the impact of CCS on net emissions has been overestimated, and therefore the overall GHG budget has been underestimated. In these calculations, the annual CCS volumes are subtracted from $CO_2$, non-$CO_2$, and land use, land use change and forestry emissions to derive net emissions. However, as the total CCS volumes for the GA scenario are based on the total capture volumes from the European Commission's 2040 impact assessment (subject to this cap of 400 Mt being applied in the final years of the 2030-2050 period), these figures are likely to erroneously include CCU volumes, which – as $CO_2$ captured and used eventually re-enters the atmosphere – should not be subtracted from the GHG budget calculations. Therefore, taking the correct CCS estimates from the European Commission assessment (i.e. excluding the CCU for synthetic fuels component of this overall capture estimate from the European Commission, and including storage in materials) would reduce the cumulative CCS capacity to approximately 4.4 Gt $CO_2e$ between 2030 and 2050 in the GA scenario (compared with the 5.8 Gt $CO_2e$ shown in Figure 47 in the draft scenario data figures), and as a result, raise the overall carbon budget for the GA scenario to

([7]) Although the text in the draft scenarios report does not specify the figure from which these estimates were taken, these values clearly match the 2040 and 2050 carbon capture levels shown in Annex 8, Figure 10 of the European Commission's impact assessment, which show volumes of 344 Mt $CO_2e$ and 452 Mt $CO_2e$ for 2040 and 2050 respectively. This figure is also the source of the industrial carbon management strategy's estimate of approximately 450 Mt $CO_2e$ captured by 2050. It should be noted that the industrial carbon management strategy references a separate estimate of 400 Mt $CO_2e$ of carbon removals, which refers to approximately 300 Mt $CO_2e$ of net land use, land use change and forestry removals (counted separately in the GHG budget) and just 100 Mt $CO_2e$ of industrial (bioenergy CCS and direct air CCS) removals.

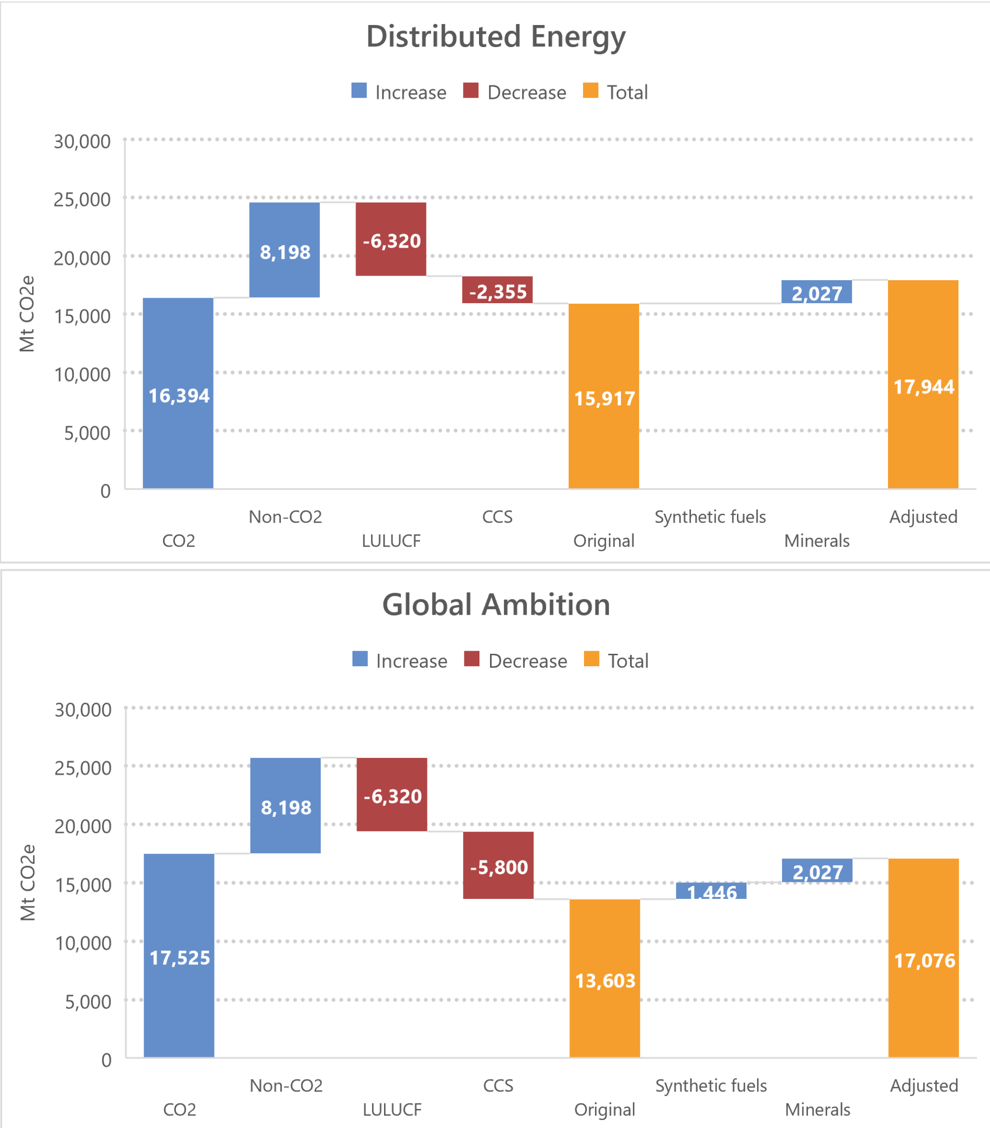
approximately 15 Gt $CO_2$e, rather than the 13.6 Gt $CO_2$e initially estimated. This would therefore exceed the Advisory Board's recommended range of 11–14 Gt $CO_2$e over the same period (or approximately 11.3–14.4 Gt $CO_2$e when adopting a similar scope to the European Commission and TYNDP scenarios) ([8], [9]), although it would still be within the maximum budget of 16 Gt $CO_2$e identified by the European Commission. The DE scenario's 2030–2050 GHG budget was estimated at 15.9 Gt $CO_2$e, which also lies above the upper limit of the Advisory Board's recommended range. Its CCS volumes, while lower than those in the GA scenario, are also mostly exogenously derived, but there is no clear data source provided to assess whether this also includes some CCU capacity.

Furthermore, the methodology for calculating gross $CO_2$ emissions in the GHG budget appears to overlook some **non-energy-related $CO_2$ emissions (i.e. from industrial processes)** (Figure 4). Gross $CO_2$ emissions are calculated based on the primary energy content of fuels, which would include some non-energy uses of energy products (e.g. the use of fossil gas as feedstock for hydrogen or ammonia). However, $CO_2$ emissions related to industrial processes that are not directly derived from the use of energy products – such as emissions from the calcination process during cement and lime production – seem to be excluded by this methodology, while also seemingly being overlooked in the other exogenous inputs to the GHG budget calculation. This could omit as much as 2 Gt $CO_2$e over 2030-2050 (e.g. based on the gross non-energy $CO_2$ emissions from mineral products contained in the European Commission's 2040 impact assessment), resulting in a higher GHG budget than indicated in the draft joint scenarios.

([8]) The Advisory Board's recommended range excludes 50 % of the extra-EU maritime emissions that fall within the scope used by the European Commission and TYNDP to estimate the GHG budget.

([9]) Both the GHG emission budget and data from the European Commission scenarios are stated in CO2-equivalents (CO2e) using Global Warming Potential values over a time horizon of 100 years (GWP100) from the IPCC Fourth Assessment Report published in 2006. If GWP values were be updated to values from more recent IPCC reports, adjustments to the calculations have to be made to ensure consistency.

Figure 4: Comparison between greenhouse gas budget estimates, 2030-2050




NB: The figure shows a comparison between the greenhouse gas budget estimates, as presented in the draft scenarios report, and the adjusted estimates when accounting for 1) the component of the European Commission's carbon capture estimates that relate to use for synthetic fuel production, and 2) the gross *non-energy* (process) $CO_2$ emissions (i.e. net emissions plus CCS as reported in the European Commission's impact assessment) from the mineral products sector. This sector includes cement & lime production, alongside other process uses of carbonates, although a specific sub-sectoral breakdown is not provided. 'CO2' refers to gross CO2 emissions from the use of coal, gas (including a small component for hydrogen production) and oil. 'Non-CO2' includes CH4, N2O and F-gases LULUCF refers to the net CO2 removals from the LULUCF sector.

*Source:* Benchmarking data (see the Annex), with source data from ENTSO-E and ENTSOG (2024a, 2024b) for gross CO2 emissions, and

In summary, the Advisory Board has concerns about the target compliance and feasibility of the draft joint scenarios in several areas, particularly projected carbon budgets, carbon capture capacity and hydrogen demand/supply values that are not within the ranges set out by the European Commission's and the Advisory Board's benchmark scenario pathways.

# 3. Soundness of the assumptions

## Key findings

In its 2022 recommendations on scenario guidelines, the Advisory Board recommended that assumptions be based on up-to-date, scientifically sound and forward-looking information (ESABCC, 2022).

In its assessment of the 2024 draft joint scenarios, the Advisory Board found that the scenario assumptions, including climate impacts, are not always based on up-to-date, comprehensive and scientifically sound information prepared in an unbiased manner. The draft joint scenarios do not demonstrate sufficient granularity and still rely mainly on average and Europe-wide assumptions for many input factors. For example, the soundness of the following assumptions has not been sufficiently demonstrated: the cost of hydrogen, the cost of renewable energy technologies, the cost of $CO_2$, the cost of CCS, the shares of fossil gas in gas blends, the countries applying CCS to existing facilities by 2030 and the gas demand in the residential sector.

Scenarios rely heavily on assumptions. Choices made regarding inputs can considerably change the outcomes of scenarios. It is therefore of utmost importance for the usefulness and credibility of scenarios that they have a reliable and sound basis for their data. The Advisory Board has previously called for adequately integrating expected changes in technology costs, innovations and commodity prices into the scenarios, with sufficient levels of granularity – including changes related to regional differences, which are especially pronounced for energy prices (and import), utilisation rates and financing costs, for example (ESABCC, 2022). Although not having assessed all the scenario assumptions, the Advisory Board identified the following scenario assumptions as meriting revisiting.

## 3.1. Cost of hydrogen

The assumption behind the price-setting mechanism for hydrogen is one of the most important parameters for the draft joint scenarios. The assumed capital investment costs of electrolysers appear low (e.g. EUR 565/kW in 2025 and EUR 366/kW in 2030 (ENTSO-E and ENTSOG, 2024c, p. 51) in the draft joint scenarios when compared with the European Commission (2024b) and International Energy Agency (IEA, 2023) assumptions. Moreover, the expansion model is set to optimise the electrolysers' operations, the electricity price, the expected electricity price and the current storage level. 'This means that low price hours with a large penetration of RES [renewable energy sources] will be preferred' (ENTSO-E and ENTSOG, 2024c p. 55). The draft scenarios methodology does not explain, however, how this optimisation meets the criteria for the temporal and geographic correlation required for renewable hydrogen (EC, 2023). For hydrogen imports, constant prices in low and high ranges are assumed. For example, the GA and DE scenarios both assume large-scale imports of hydrogen (232 TWh) from Ukraine in 2040 at a price range of between EUR 32.5 and EUR 73.3 per MWh (ENTSO-E and ENTSOG, 2024c, p. 79). The specific source of this price assumption in the draft joint scenarios is unclear.

## 3.2. Cost of renewable energy technologies

The investment and operational cost assumptions in the draft joint scenarios are generally based on a source from one Member State (the Danish Energy Agency, Denmark). The DE and GA scenarios feature a differentiation of the renewable energy cost of between ± 15 % and ± 20 % from the baseline (ENTSO-E and ENTSOG, 2024c, p. 35), which is neither documented nor explained. The implications of these assumptions and deviations from the source should be investigated and, if necessary, the assumptions should be revisited to include the best and most up-to-date scientific information available on future costs and cost trends.

## 3.3. Cost of carbon dioxide

In the draft joint scenarios, the assumed $CO_2$ prices affect the final commodity price based on the fuel's emission factor. The $CO_2$ price is assumed to be equal in all draft joint scenarios and ranges from EUR 114/t in 2030 and EUR 147/t in 2040 to EUR 168/t in 2050, referring to both the U.S. Energy Information Agency (ENTSO-E and ENTSOG, 2024c, p. 32) and the International Energy Agency (ENTSO-E and ENTSOG, 2024a, p. 73). In its advice on TYNDP project cost–benefit analysis, the Advisory Board recommended basing the cost of GHG emissions on an opportunity cost approach for the entire EU climate policy – that is, one that considers options both within and outside the EU emissions trading system – and referred, as an example, to the value applied by the European Investment Bank, a value that increases from EUR 250/t $CO_2e$ in 2030 to EUR 800/t $CO_2e$ in 2050 (ESABCC, 2023a).

## 3.4. Cost of carbon capture and storage

The cost of CCS is not considered by the investment model (ENTSO-E and ENTSOG, 2024d, p. 11), as 'no economic viability assessments have been conducted for these modifications, which may not have led to the adoption of CCS technology or decommissioning' (ENTSO-E and ENTSOG, 2024c, p. 88). This is a significant omission considering that ENTSO-E and ENTSOG assume that many Member States will have CCS in all existing fossil gas facilities by 2030. They also recognise that the 'cost for producing hydrogen … is hugely dependent on the natural gas price as well as the CCS costs and the $CO_2$ price for the residual $CO_2$ emissions' (ENTSO-E and ENTSOG, 2024c, p. 52) and identify all hydrogen produced with CCS as 'decarbonized hydrogen' (ENTSO-E and ENTSOG, 2024c, p. 51). Moreover, the overall cost of CCS will be driven up by the assumption that an overall average $CO_2$ capture potential rate of 90 % is used for all CCS facilities, which may not be achievable for all CCS technology types – some are described as having capture rates of 60–90 % (ENTSO-E and ENTSOG, 2024c, p. 51).

## 3.5. Coverage of carbon capture and storage on existing installations

It is assumed that if 'a country has a published CCS strategy, … the current [steam-methane-reforming and autothermal reforming] facilities without CCS will be retrofitted with CCS by 2030'. (ENTSO-E and ENTSOG, 2024c, p. 51). It is unclear how many countries were considered to have a CCS strategy or were included for other reasons, owing to discrepancies between the text and the table (ENTSO-E and ENTSOG, 2024c, pp. 51–52). Based on the text, the 'countries considered having a CCS strategy are Bulgaria, Croatia, Czech Republic, Denmark, France, Greece, Hungary, Italy, The Netherlands, Norway, and UK. Besides these countries Germany and Belgium are considered as well because they will connect to projects in the North Sea' (ENTSO-E and ENTSOG, 2024c, pp. 51–52). In Table 14 (p. 52), Austria, Estonia, Spain, Finland, Lithuania, Poland, Portugal, Romania, Sweden and Slovakia are also considered to have a CCS strategy, while most of the countries mentioned in the text are not. If combined, as many as 21 Member States are considered to have CCS strategies or meet other conditions leading to the assumption that all of their existing fossil gas hydrogen production plants will be retrofitted with CCS within the next 6 years. This assumption appears to be limited to hydrogen supply, while CCS assumptions for other sectors are not sufficiently explained. Hence it is unclear if CCS is targeted towards activities with no or limited mitigation options, as recommended by the Advisory Board (ESABCC, 2024).

## 3.6. Methane blend

The gas blend described in the joint scenarios methodology and input data includes increasing shares of biomethane, synthetic methane and hydrogen, based on the following assumptions regarding the fossil gas shares in the blend: 90 % in 2030, 61–76 % in 2040, and 5–21 % in 2050, depending on the draft joint scenario (ENTSO-E and ENTSOG, 2024c, p. 74). This assumption has been revised in the scenario modelling to 100 % of renewable methane and hydrogen, however, without sufficient justification. Overall, methane supply in 2050 (Figures 8 and 33, ENTSO-E and ENTSOG, 2024a) is expected to reach 938 TWh (DE scenario) or 1 094 TWh (GA scenario) and it is assumed to be all renewable – that is, mostly (68 % in DE scenario and 74 % in GA scenario) **biomethane**, with some synthetic methane. Biomethane supply in the draft joint scenarios is 379 TWh in 2030, rising to 635 TWh in the DE scenario and 811 TWh in the GA scenario in 2050. This means slightly overshooting the ~ 375 TWh (35 billion cubic metres) target for 2030 set out in the REPowerEU Plan (EC, 2022) and roughly doubling the 2030 volumes by 2050. The modelled scale-up of biomethane supply is massive, considering that the EU's biomethane supply stood at around 37.5 TWh in 2021 (BIP Europe, 2023). Apart from feasibility concerns regarding such high reliance on biomethane, the promotion of biomethane as a replacement of fossil gas risks extending the use of fossil gas, delaying electrification and leading to higher fugitive emissions (ESABCC, 2024).

## 3.7. Methane and hydrogen demand in the residential and tertiary sectors

Regarding **methane** demand in the residential and tertiary sectors in 2040, the draft joint scenarios assume 599 TWh (NT+ scenario), 504 TWh (DE scenario) and 601 TWh (GA scenario) (Figure 8 (ENTSO-E and ENTSOG, 2024a, which are much higher than the corresponding volume of ~ 287 TWh in 2040 – including fossil gas, biogas and biomethane – in the European Commission's scenario S3 (EC, 2024, Figure 30).

All draft joint scenarios set out a role for **hydrogen** for heating in the tertiary and residential sectors (ENTSO-E and ENTSOG, 2024c, p. 70). As brought up by the Advisory Board recently (ESABCC, 2024), the Intergovernmental Panel on Climate Change warns against this because:

> *the delivered cost of heat from hydrogen would be much higher than the cost of delivering heat from heat pumps, which could also be used for cooling. Repurposing gas grids for pure hydrogen networks will also require system modifications such as replacement of piping and replacement of gas boilers and cooking appliances, a factor cost to be considered when developing hydrogen roadmaps for buildings. There are also safety and performance concerns with domestic hydrogen appliances … scenarios assessed show a very modest role for hydrogen in buildings by 2050.*

(IPCC, 2022)

The Advisory Board recommended targeting hydrogen deployment and prioritising well-defined uses that cannot be directly electrified, notably in industrial processes and fuels for some modes of transport (ESABCC, 2024).

# 4. Contrasting range of pathways and integrated building blocks

## Key findings

In its 2022 recommendations on scenario guidelines, the Advisory Board recommended that scenarios capture a range of climate neutrality pathways reflecting the varying impacts of key infrastructure development drivers. It also recommended that scenarios:

> *be constructed using an integrated building-block approach, including at least the following, partly interdependent building blocks:*
>
> *a) Flexibility (including demand response, storage, mass transit, sector coupling, and cross-sector flexibility);*
>
> *b) Electrification (including transport, residential heating/cooling, industry);*
>
> *c) Hydrogen and e-fuels;*
>
> *d) Offshore grids;*
>
> *e) Carbon Dioxide Removal (CDR).*
>
> (ESABCC, 2022)

In its assessment of the 2024 draft joint scenarios, the Advisory Board found that the draft joint scenarios:

- do not capture sufficiently contrasting climate neutrality pathways;
- do sufficiently reflect the integrated building block approach, despite including additional modules – it is still unclear how the separate modules are connected and how data and assumptions interact dynamically.

## 4.1. Range of pathways

There are two transition pathways described by the DE and GA scenarios. While they differ in some respects, they also have close similarities, as exemplified in Table 4.

All scenarios assume relatively high imports of methane and installed fossil gas capacity for electricity in 2040. Fossil gas has not been explicitly modelled and the joint scenarios always describe it in combination with other (e.g. synthetically produced) gases for fuel use. There is therefore little insight from the scenarios regarding the decommissioning of fossil fuel assets. The 2030 and 2040 capacity levels of these assets are based on transmission system operator data and the values in between; that is, 2030–2040 and 2040–2050 are interpolated.

The two scenarios reaching 2050 (DE and GA scenarios) rely heavily on hydrogen, including hydrogen from fossil gas with CCS, in FED (see also Chapters 1 and 3). The DE and GA scenarios expect similar electrolysis capacities. Although their values are differentiated in scale, both expect hydrogen use in the residential and tertiary sectors, notably through hybrid heat pumps (ENTSO-E and ENTSOG, 2024c).

In effect, the scenarios fail to cover a sufficiently wide range of potential climate neutrality pathways aligned with the assessments that form the basis of EU decision processes, including technological progress and lifestyle changes. In addition, they do not sufficiently capture diverse options to decrease

Europe's dependency on fossil fuel infrastructure and imports. The Advisory Board also notes that the GA and DE scenarios are only differentiated from the NT+ scenario after 2030, which limits the breadth of the pathways time-wise.

Table 4: Selected indicators in the draft joint scenarios

| Indicator | 2040 | 2050 | Scenario | Source |
|---|---|---|---|---|
| **Fossil fuel installed capacity for electricity** (GW) | 130 | n/a | NT+ | fig. 55-56 |
| | 124 | 26 | DE | |
| | 120 | 27 | GA | |
| **Methane imports** (TWh) | 1402 | n/a | NT+ | fig. 40 |
| | 1026 | 18 | DE | |
| | 1126 | 15 | GA | |
| **Final hydrogen demand** (TWh) | 633 | n/a | NT+ | fig. 51 |
| | 592 | 824 | DE | |
| | 1195 | 1605 | GA | |
| **Hydrogen with CCS** (TWh) | 248 | n/a | NT+ | fig. 33 |
| | 220 | 111 | DE | |
| | 271 | 196 | GA | |
| **Hydrogen demand in residential and tertiary** (TWh) | 72 | n/a | NT+ | fig. 54 |
| | 75 | 109 | DE | |
| | 347 | 391 | GA | |
| **Electrolysis capacity** (GW) | 306 | n/a | NT+ | fig. 34 |
| | 278 | 517 | DE | |
| | 290 | 528 | GA | |
| **Biomethane** (TWh) | 767 | n/a | NT+ | fig. 32 |
| | 537 | 635 | DE | |
| | 690 | 811 | GA | |

NB: n/a, not available

*Source:* Advisory Board, based on ENTSO-E and ENTSOG (2024).

## 4.2. Building blocks

The scenario-building process has been updated since the previous cycles, and additional modules and building blocks, such as the Energy Transition Model (see Chapter 6) and offshore grids, have been added. Still, the integrated building block approach is not very prominent in the draft joint scenario preparation. For example, it is unclear how the separate modules are connected and how the data and assumptions interact dynamically.

Exploring correlations and interdependencies between input parameters and variables is crucial to establishing linkages between, for example, interrelated prices and volumes and to constructing meaningful sets of assumptions. Apart from the clear demarcation of four storyline drivers in the storyline report (ENTSO-E and ENTSOG, 2023a), there is little evidence that the storylines apply the drivers as the building blocks, given that the scenarios are not sufficiently contrasting as described in Section 4.1 'Range of pathways'.

# 5. Incorporation of projected climate impacts

## Key findings

In its 2022 recommendations on scenario guidelines, the Advisory Board recommended that scenario development incorporate future climate projections and their impact on energy infrastructure resilience (ESABCC, 2022).

In its assessment of the 2024 draft joint scenarios, the Advisory Board found that the draft joint scenarios build on outdated climatic information and do not reflect climate projections that are expected with high levels of confidence. This means that the EU's energy infrastructure risks being highly vulnerable to climate impacts, instead of increasing its resilience and minimising climate risks.

Scenarios' dispatch modelling considered 1995, 2008 and 2009 – selected by ENTSO-E and ENTSOG as the most representative climate years – with the following weights: 23 %, 37 % and 40 % respectively (ENTSO-E and ENTSOG, 2024c, p. 30). The expansion model in the DE and GA scenarios considers only 2009 owing to the long computational time required to run the model (ENTSO-E and ENTSOG, 2024c, p. 30). Hydrogen demand in buildings is the only variable that is modelled based on annual demand decomposed into hourly profiles in the last 30 climate years (ENTSO-E and ENTSOG, 2024c, pp. 70–71). The scenarios' assumptions reflect the impact of global warming, but only narrowly in terms of wind's and solar photovoltaics' exposures to weather variability during *Dunkelflaute* (2-week cold period / cold spell with low wind load factors and solar radiation). As a result, the DE scenario is considered the most vulnerable because it assumes the highest rate of heating electrification and maximum wind and solar development. Scenarios do not pay sufficient attention to other climate extremes and factors, such as droughts, floods, peak load shifts from winter to summer, heat waves and water shortage. These are expected to become more pronounced and could affect hydro and thermal power plants (including nuclear ones), especially in southern Europe, reducing usable cooling water capacity at power plants and affecting the operational efficacy of grid infrastructure and the general operational patterns of the system (EEA, 2024b).

In effect, the scenarios fail to incorporate future climate projections, even those regarding changes in average climate conditions that are expected with high confidence, and do not consider the projections' implications for infrastructure requirements. Future adaptation needs of existing and new energy infrastructure therefore remain unaccounted for.

# 6. Quality of the scenario-building process

## Key findings

In its 2022 recommendations on scenario guidelines, the Advisory Board recommended that the process be more transparent and be built on timely consultations of stakeholders and external experts (ESABCC, 2022).

In its assessment of the 2024 draft joint scenarios, the Advisory Board found that:

- the scenario-building process has become more transparent but does not yet fully build on timely consultations of stakeholders and external experts;
- methodologies and assumptions are generally well described, informative and understandable, but data sources are not always provided (see Section 3 'Soundness of the assumptions').

The various models and data tools, shown in Table 5, contribute to the complexity and high computing needs of the scenario-building process and do not fully comply with the 'findable, accessible, interoperable and reusable' principle. Access to the Plexos model and the demand forecasting toolbox seems restricted – for example, paid, confidential and/or not published. The break-down of FEC gap filling (NT+) per sector and per country are not published. Other tools and inputs are published, and, while the Energy Transition Model is open access, its complexity means that in practice it is difficult to recreate the results of the scenario modelling (SRG, 2024).

Table 5: Overview of tools and models applied in the 2024 TYNDP scenario-building process

| Tool/input | Function | Transparency |
|---|---|---|
| **Plexos** | Is an investment (expansion) model that determines supply and flexibility capacities | Restricted access |
| **Demand forecasting toolbox (DFT)** | Determines electrical load profiles | Restricted access |
| **Results of NT+ gap filling** | Shows results of the 2030 ambition gap filling through reduction of FEC per sector / per country | Not published |
| **Energy Transition Model** | Quantifies demand and is used in the TYNDP for the first time in the 2024 cycle | Open access |
| **Supply tool** | Determines domestic gas supply and gas imports in Excel file | Published |
| **Pan-European market modelling database** | Provides figures collected by the transmission system operators | Published |
| **Pan-European climate database** | Reflects changes in wind load factors | Published |
| **Electricity and Hydrogen Reference Grid & Investment Candidates after Public Consultation** | Provides ENTSO-E and ENTSOG's perspectives on the network's state in 2030 and 2035 | Published |

| | | |
|---|---|---|
| **Other inputs** | Include commodity prices, specific modelling inputs and emissions factors | Published |

**Public consultation** on the draft inputs to the 2024 TYNDP scenarios occurred between 4 July and 8 August 2023, attracting input from 30 stakeholders. The following documents and tools were consulted:

- draft supply inputs,
- draft supply tool (EU level),
- modelling methodologies and draft assumptions,
- draft line data inputs,
- draft demand scenarios,
- draft carbon budget methodology,
- draft hydrogen steel tank methodology,
- NT+ scenario energy mix gap-filling methodology.

A consultation summary report summarises how ENTSO-E and ENTSOG considered the inputs and discarded some of them – for example, the need to revise the assumption of continued imports of fossil gas from Russia (ENTSO-E and ENTSOG, 2024d).

The public consultation informed the **Scenario-Building Working Group**, which consists of ENTSO-E and ENTSOG delegates. The group is engaged in a collective decision process that affects the scenario results but is not always transparent and justified in sufficient detail.

**Stakeholder engagement** started in the first quarter of 2023, and draft joint scenarios were published on 22 May 2024. For the joint scenarios to be useful in the PCI/PMI selection process, they have to be approved by the European Commission in time to enable the subsequent TYNDP steps before the next PCI/PMI list is established in 2025. This suggests that any potential amendments to the draft joint scenarios report requested by the European Commission, as stipulated in Article 12 of the TEN-E regulation, would put the timeliness of the PCI/PMI cycle at risk.

The **Stakeholder Reference Group (SRG)** was established in autumn 2023, with the aim of contributing to the 2026 TYNDP cycle. It consists of 22 members, of which 6 represent civil society and/or independent think tanks (ENTSO-E and ENTSOG, n.d.). The SRG has been given access to preliminary joint scenario data within the 2024 cycle (i.e. in January 2024), and its comments were considered by ENTSO-E and ENTSOG in the preparation of the draft joint scenarios published on 22 May 2024. In its published input, the SRG noted that the data it was given was 'plentiful and very detailed' and appreciated the workshop at which ENTSO-E and ENTSOG explained the modelling approach. The SRG also noted that the modelling is 'highly complex and contains many different assumptions that are used in different tools', and the group found several inconsistencies and errors (SRG, 2024). The SRG asked ENTSO-E and ENTSOG to allow the group sufficient time to review the model files in the next TYNDP cycle.

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# Abbreviations

| | |
|---|---|
| ACER | European Union Agency for the Cooperation of Energy Regulators |
| CCS | carbon capture and storage |
| CCU | carbon capture and use |
| $CO_2$ | carbon dioxide |
| $CO_2e$ | carbon dioxide equivalent |
| DE | distributed energy |
| ENTSO-E | European Network of Transmission System Operators for Electricity |
| ENTSOG | European Network of Transmission System Operators for Gas |
| FEC | final energy consumption |
| FED | final energy demand |
| GA | global ambition |
| GHG | greenhouse gas |
| Mtoe | million tonnes of oil equivalent |
| NECP | national energy and climate plan |
| NT+ | national trends plus |
| PCI | project of common interest |
| PMI | project of mutual interest |
| SRG | Stakeholder Reference Group |
| TEN-E | trans-European networks for energy |
| TYNDP | 10-year network development plan |

## Annex: data and calculations

The Annex containing the underlying data and calculations is available for download on the Advisory Board's website