European Scientific Advisory Board on Climate Change
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Christian Zinglersen
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Potsdam, 11 November 2022

Subject: Input to framework guidelines on scenarios for network development planning

Dear Mr Zinglersen,

As per the regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure (Article 12), the European Scientific Advisory Board on Climate Change (the 'Advisory Board') would hereby like to provide input to your agency for the framework guidelines on scenarios for the ten-year network development plans. Please find attached our recommendations.

The role of the Advisory Board is to provide independent scientific advice on how to ensure the compliance of network planning scenarios with the climate targets of the European Union (EU). As energy supply and use are responsible for 77% of the EU's total greenhouse gas emissions, it is of the utmost importance that the network planning process drives the transition towards renewable-based and efficient energy systems, and avoids creating further lock-ins into fossil infrastructure. Moreover, it is critical for network planning to ensure the resilience of the EU's energy infrastructure to the impacts of climate change, such as extreme temperatures, water shortages and flooding risks.

In order to prepare its recommendations, the Advisory Board has analysed ACER's draft guidelines and previous assessments. The Advisory Board also met with, and analysed publications from, ENTSOs, the European Commission, and the scientific community.

Our key recommendations, which you will find explained in detail in the attached advice document, can be summarised as follows:

- **Comply with climate targets at all times:** Scenarios should be adjusted as soon as intermediary climate targets are adopted, be modelled until at least 2050, and capture a range of different pathways to climate neutrality.
- **Adapt to a complex and constantly changing world:** Scenarios should incorporate projected climate impacts on the energy infrastructure, use a building-blocks approach (including flexibility, electrification, hydrogen, offshore grids and carbon dioxide removals), and be based on up-to-date, scientifically sound and forward-looking information.

- **Conduct a transparent and inclusive process:** The assumptions, methods and results from scenarios should be published in detail, and independent experts should be consulted early in the process.

The Advisory Board urges ACER to emphasise the long-term perspective of infrastructure planning and climate impacts, in order to avoid stranded assets, as well as the need to bridge the gap between current plans and the goal of climate neutrality. To do so in a robust manner, energy system scenarios need to cover a wide range of the uncertainties impacting infrastructure needs, such as market trends, geopolitical developments, technology maturity, consumers' demand and risks of climate disasters. The thoroughness of the analysis should not be compromised by resources constraints.

We prompt you to integrate these attached recommendations into your scenario guidelines. We look forward to meeting with your team to present our recommendations and remain at your disposal to answer any question that might arise.

Best regards,

Professor Dr. Ottmar Edenhofer
Chair of the European Scientific Advisory Board on Climate Change

European Scientific Advisory Board on Climate Change

Towards a climate-neutral and climate-resilient EU energy infrastructure:

Advice on scenario guidelines for trans-European networks for energy

14 November 2022

Contents

Glossary

ACER	European Union Agency for the Cooperation of Energy Regulators
BECCS	Bioenergy with carbon capture and storage
CBA	Cost-benefit analysis
CCU	Carbon capture and utilisation
CCS	Carbon capture and storage
CDR	Carbon dioxide removal
DACS	Direct air carbon capture and storage
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
ENTSOs	ENTSO-E and ENTSO-G
EU	European Union
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land use change and forestry
NECPs	National energy and climate plans
NECPRs	National energy and climate progress reports
PCI	Projects of common interest
TEN-E	Trans-European networks for energy
TSO	Transmission System Operator
TYNDP	Ten-year network development plan

Executive summary

Energy networks, such as gas pipelines, electricity grids and interconnections, are a core component of the energy system of the European Union (EU). They play a significant role in determining to what extent different energy sources can be transmitted and used across the EU, and, in the case of fossil energy sources, how much greenhouse gas emissions they generate. As energy supply and use are still responsible for 77% of the EU's total greenhouse gas emissions, the design and development of the EU's energy networks play a key role in driving the EU's transition towards a fossil-free energy infrastructure. Strategic, long-term planning for the development of cross-border energy infrastructure is particularly critical to reach the EU's 2050 climate neutrality target set out in the 2021 European Climate Law[1].

The 2013 EU Regulation on Trans-European Networks for Energy (TEN-E)[2] provided a legal framework to support the development of cross-border energy infrastructure at the EU level and deliver an integrated and shock-resilient EU energy system. It mainly focused on improving energy network connection across the EU, and promoting cross-border interconnections and the integration of renewable energy in the system. To improve the coordination between these different objectives, the TEN-E Regulation was revised in 2022[3]. In particular, the revised Regulation sets out new provisions aiming to ensure a development of the EU's gas and electricity networks that is in line with the objectives of the European Climate Law, as well as the energy efficiency first principle and the EU's 2030 targets for energy and climate. The revised Regulation also aims to enhance the resilience of the EU's energy infrastructure to the unavoidable impacts of climate change in Europe.

To do so, the Regulation outlines a revised process for planning the development of the EU's gas and electricity networks with a ten-year horizon, the Ten-Year Network Development Plan (TYNDP). This plan then forms the basis for selecting Projects of Common Interest (PCI), which are eligible for EU funding (5.84 billion euros between 2021 and 2027) and accelerated permitting procedures.

The development of scenarios of future energy supply and demand is at the core of this planning process, as it enables the identification of infrastructure gaps. The European Networks of Transmission System Operators for Electricity and for Gas (ENTSO-E and ENTSO-G, respectively — hereafter 'ENTSOs') are responsible for developing such scenarios. These energy system scenarios are subsequently used to inform the cost-benefit analysis which is used for the selection of infrastructure development projects. The TEN-E Regulation requires the EU Agency for the Cooperation of Energy Regulators (ACER) to develop framework guidelines on scenarios for network development planning (hereafter Scenario Guidelines).

The Scenario Guidelines *shall establish criteria for a transparent, non-discriminatory and robust development of scenarios* in the context of energy networks development. Moreover, the Scenario Guidelines are to ensure that the Scenarios are *fully in line with the energy efficiency first principle and with the Union's 2030 targets for energy and climate and its 2050 climate neutrality objective* (Article 12 of the TEN-E Regulation).

The revised TEN-E Regulation also invites the European Scientific Advisory Board on Climate Change (the 'Advisory Board') to contribute to the planning process by providing objective, science-based input to help ensure that scenarios comply with these targets and objectives, as well as input to the draft Scenarios and on the cost-benefit analysis methodology. The Advisory Board is an independent scientific advisory body established by the European Climate Law to serve as a point of reference on scientific knowledge relating to climate change.

On 6 October 2022, ACER launched a public consultation inviting stakeholders to submit their views on the draft Scenario Guidelines[4]. Following evaluation and consideration of the feedback received, ACER's Scenario Guidelines will be adopted by 24 January 2023.

With this input, the Advisory Board aims to contribute to this consultation by providing independent scientific advice on the Scenario Guidelines, based on its assessment of the current scenario development process. By doing so, the Advisory Board aims to help the EU deliver on the ambition of the revised TEN-E Regulation and on the objectives of the European Climate Law, supporting an accelerated transition of the EU energy system towards one based on renewable energy, without carbon lock-ins, and with infrastructure that is more resilient to the impacts of climate change.

To prepare this input, the Advisory Board analysed previous TYNDP publications from ENTSOs, previous TYNDP assessments from ACER and from the European Commission, reports from stakeholder consultations run by ENTSOs and ACER, and the draft Scenario Guidelines from ACER. The Advisory Board consulted key stakeholders, including ENTSOs, ACER, the European Commission, and members of the research community. These consultations revealed potential resource constraints that may hinder thorough modelling, analysis, and an inclusive stakeholder and expert engagement process. The Advisory Board urges ENTSOs and ACER to enhance their efforts to ensure high quality scenarios. The Advisory Board also reviewed scientific literature, synthesised best practices and assessed the consistency of the current process with the findings from recent research and from the Intergovernmental Panel on Climate Change (IPCC).

Based on this analysis, the Advisory Board formulates six key recommendations to be considered by ACER for inclusion in the Scenario Guidelines. These recommendations, presented below, are further described in the following sections.

Comply with climate targets at all times

1. Scenarios should be adjusted as necessary to remain compatible with EU's climate and energy targets, and be modelled until at least 2050.
2. Scenarios should capture a range of climate neutrality pathways reflecting the varying impacts of key infrastructure development drivers.

Adapt to a complex and constantly changing world

3. Scenario development should incorporate future climate projections and their impact on energy infrastructure resilience.
4. Scenarios should 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).
5. Assumptions should be based on up-to-date, scientifically sound and forward-looking information.

Conduct a transparent and inclusive process

6. The process should be more transparent and built on timely consultations of stakeholders and external experts.

Recommendation 1: Scenarios should be adjusted as necessary to remain compatible with EU's climate and energy targets, and be modelled until at least 2050

1.1 Scenarios must be regularly updated to comply with new or revised EU climate and energy targets, achieving target levels within the specified time frame.

The TEN-E Regulation requires scenarios to be fully in line with the energy efficiency first principle and the EU's 2030 and 2050 climate and energy targets (Article 12). These targets continue to be shaped by ongoing and future developments of EU energy and climate policy, such as the Fit-for-55 package[5], the REPowerEU plan[6], and the future adoption of an EU-wide 2040 greenhouse gas emission target, based *inter alia* on a projected indicative EU greenhouse gas budget for the 2030-2050 period. The Advisory Board recommends that the Scenario Guidelines require the scenarios to comply not only with the current 2030 and 2050 climate targets, but to be updated as necessary to comply with new or revised EU climate targets.

In the latest ENTSO Scenario Report[7], The 'National Trends' scenario served as a mid-term 'current policy' scenario and was constructed bottom-up from national policies (National Energy and Climate Plans, NECPs). However, the aggregation of current national policies is not necessarily sufficient to ensure full compliance with EU energy and climate targets for 2030, as shown by the European Commission in its 2020 assessment of NECPs[8]. The Advisory Board acknowledges that the revised TEN-E Regulation requires scenarios to be target compliant at EU level, and to take into account NECPs when relevant (Article 12). The Advisory Board notes the benefit of an additional baseline projection in order to represent the expected effects of current policies until 2050.

According to the ENTSOs, the 'Distributed Energy' and 'Global Ambition' scenarios of the previous planning cycle achieved net zero greenhouse gas emissions. However, neither this statement nor the underlying analysis seemed to demonstrate that net zero emissions would be reached by 2050. The Advisory Board recommends that the Scenario Guidelines require demonstrating the compliance of scenarios with EU targets within the correct timeframe, i.e. by 2050 at the latest in the case of net-zero GHG emissions.

1.2 To credibly demonstrate climate target compliance, scenarios must be modelled until at least 2050.

Previous scenarios in the 2022 TYNDP process included 'Best Estimate', 'National Trends', 'Distributed Energy' and 'Global Ambition' scenarios[9] , with varying time horizons, as depicted in Figure 1.

Compatibility with climate targets can only be demonstrated if the full period until 2050 is analysed. In line with TEN-E Regulation that states that *the joint scenarios shall also include a long-term perspective until 2050 and include intermediary steps as appropriate*, the Advisory Board recommends that the Scenario Guidelines require all scenarios to be modelled until at least 2050.

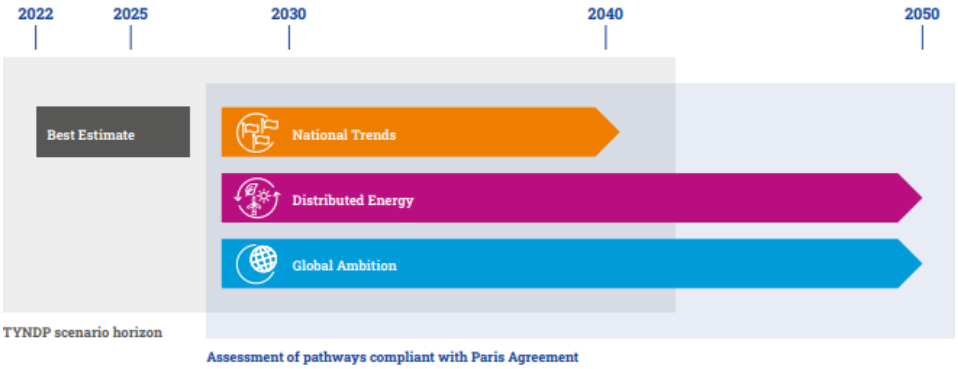

Figure 1 - Extract from ENTSOs' TYNDP 2022 Scenario Report

1.3 Scenarios should reflect all relevant policy objectives adopted at EU level, including non-binding ones, up to a cut-off date agreed upon with the European Commission.

For the scenario building, the TEN-E Regulation requires that the scenarios *take into account the latest available Commission scenarios, as well as, when relevant, the national energy and climate plans* (Article 12). The Advisory Board agrees that it is important that scenarios integrate the most recently adopted policies at both EU and national levels. To capture the most up-to-date information and ensure alignment with EU policies, the Advisory Board further recommends that the Scenario Guidelines also require all relevant non-binding agreements at EU level to be considered in the scenarios.

As a process to integrate the most up-to-date information on EU and national policies in the scenarios, the Advisory Board recommends that during scenario planning, ENTSOs, ACER and the European Commission agree on an appropriate date until which adopted policies and targets should be taken into account. This date should be specified in the comprehensive process timeline developed at the start of each scenarios-building cycle. This date should be as late as possible, in order to minimise out-of-date information by the time scenarios are published, and with the view to achieving the EU's long-term climate targets.

1.4 Where relevant, policy assumptions from National Energy and Climate Plans (NECPs) should be updated, and complemented in order to ensure compliance with climate and energy targets.

The first National Energy and Climate Plans were submitted in 2019 and should be updated every five years. They do not necessarily represent the most up-to-date and relevant source of information in relation to the TYNDP, which is updated every two years. In addition, there is no guarantee that the full implementation of all NECPs would lead the EU to achieve all its climate and energy targets. Therefore, NECPs should be complemented with updated sources of information where relevant. The Advisory Board recommends that a process is established to ensure further updating of policy inputs, to supplement the NECPs where needed. This could for example include the biennial national energy and climate progress reports (NECPR), the European Commission's assessments of NECPs[10] and national long-term strategies[11]. The Advisory Board recommends updating national policies information through the consultation of Member States and involving a dedicated stakeholder consultation. The Scenario Guidelines should require ENTSOs to outline a process and methodology for updating policy assumptions from NECPs and other assumptions to achieve the 2030 target at the EU level during the scenario

planning. This methodology should be discussed, adapted if necessary, and subsequently agreed upon between ENTSOs, ACER and the European Commission.

Recommendation 2: Scenarios should capture a range of climate neutrality pathways reflecting the varying impacts of key infrastructure development drivers

2.1 Scenarios should cover a sufficiently wide spectrum of climate neutrality pathways, aligned with the assessments that form the basis of EU decision processes, and strive to decrease Europe's dependency on fossil fuel infrastructure and imports.

The EU has not committed to a particular pathway for achieving its climate objectives. A wide range of options for meeting the EU's climate-neutrality objective is possible, including, at a minimum, the ranges analysed by the European Commission in its Impact Assessments. The climate neutrality objective was originally informed by the Commission's "Clean Planet for All"[12] analysis from 2018, which considered a wide range of options, summarised in the "1.5LIFE" and "1.5TECH" scenarios, including technological progress as well as lifestyle changes. More recently, the Commission's proposals for a revised 2030 target ("Climate Target Plan"[13]), the legislation to deliver it ("Fit for 55"[14]) and the response to the global energy market disruption caused by Russia's invasion of Ukraine ("REPowerEU"[15]) have been informed by iterations of a collection of scenarios run using the PRIMES, GAINS & GLOBIOM models[16].

ENTSOs' TYNDP 2022 Scenario Report[17] provides benchmarking of the 'Distributed Energy' and 'Global Ambition' scenarios against 2050 modelling from the European Commission's Climate Target Plan. This shows that some of the variables considered in the TYNDP scenarios are outside of the range considered in the European Commission's analysis. In particular, both scenarios feature higher electricity demand and larger quantities of imported hydrogen, while the 'Global Ambition' scenario features considerably higher use of Carbon Capture and Storage (CCS) (e.g. five times higher than in the European Commission's 1.5LIFE scenario). Scenarios have in the past relied heavily on imports, which contribute to Europe's dependency on third countries, meaning that a significant share of energy consumed (and its embodied emissions) originates outside the system being modelled in the scenarios. The Advisory Board recommends that the Scenario Guidelines encourage the development of scenarios that do not preclude climate neutrality pathways that are conceivable, based on adopted EU and national policies. At the same time, they should not rely on findings that suggest infeasible over-reliance on certain mitigation options[18].

2.2 Scenarios should be differentiated at the latest within seven years of the start of the scenario time frame.

The use of scenarios such as the previous 'Distributed Energy' and 'Global Ambition' scenarios from the 2022 TYNDP that follow different decarbonisation pathways is useful to identify 'no regret' options for infrastructure expansion in the short and medium term. To serve this function, scenarios must be sufficiently differentiated at the earliest date reasonable. In light of the long-term nature of infrastructure projects and the specific nature of the adopted policy frameworks at national and EU level for 2030, it would be reasonable for scenarios to be differentiated directly after this time. The Advisory Board hence recommends that the Scenario Guidelines require scenarios to be differentiated as early as is reasonable, and at the latest within 7 years of the start of the scenario time frame (as per definition of 'short term' in ACER's draft guidelines).

2.3 Scenarios should capture contrasting pathways based on differences between the most impactful drivers affecting infrastructure development.

Scenarios are a widely used tool to explore the future. The greatest value lies not in the development of complex, quantitative models to accurately predict an outcome, but in the identification of a range of plausible futures[19]. The scenarios developed for the TYNDP are normative: they must comply with EU climate objectives (be 'objective-driven'). Hence, the development of plausible narratives (or 'storylines') to reach these objectives is crucial. Results will inevitably be shaped by the choice of inputs. Research on scenario building has shown that a set of different scenarios, spanning a wide range of possible outcomes, helps better accounting for the range of potential futures[20]. These storylines should allow for transformative changes, such as decentralisation, digitalisation and electrification, which are deemed by some actors as key to a decarbonised future[21]. In the 2022 TYNDP scenarios, the storylines were built upon four high-level drivers, represented in Figure 2.

Figure 2 - Extract from ENTSOs' TYNDP 2022 Storylines Report

The high-level drivers, and key parameters within each of the high-level drivers, are constantly evolving with new policy and system realities. Therefore, the identification of drivers and parameters to be differentiated should be newly explored in each TYNDP cycle. Economic growth is not a sufficient differentiation factor in energy scenarios, as infrastructure development is significantly determined by choices around level of decentralisation, technology mix, type of energy carriers, level of import dependence — leading to vastly different energy system pathways that may all develop at similar levels of economic growth rates. The Advisory Board recommends that relevant drivers and parameter differentiation across scenarios should be identified in connection with an integrative building-block approach, as detailed in recommendation 4 and be made explicit.

2.4 Benchmarking should include short-term and medium-term outcomes, cover climate-relevant aspects, and include an analysis of deviations.

Benchmarking to the European Commission's Impact Assessments and other Commission modelling outcomes has proved to be highly informative and relevant to improving the understanding and justification of the TYNDP scenarios, including for assessment of target compliance and ranges of decarbonisation pathways. Therefore, scenario outcomes (including demand and supply volumes, greenhouse gas emissions, technology mixes, etc.) should continue to be benchmarked against the latest European Commission modelling analysis used in proposals that inform adopted climate and energy targets and policies. The benchmarking should include comparisons of key variables and justification of deviations. The Advisory Board recommends that the benchmarking is expanded and is made more comprehensive, in order to cover key strategic aspects, in particular those relevant to greenhouse gas emissions, and to further analyse deviations. Moreover, it should include the short-term and medium-term time frames. Providing 2050 benchmarking only for two seemingly extreme scenarios seems of limited use in guiding

network planning. The Advisory Board therefore recommends that the Scenario Guidelines require benchmarking that includes comparisons of key inputs and outputs for the whole scenario time frame. Deviations should be described in detail and explained, as well as their expected implications on scenario outcomes.

Recommendation 3: Scenario development should incorporate future climate projections and their impact on energy infrastructure resilience

3.1 Scenarios should, to the extent possible, draw from up-to-date information on observed changes in regional climate, and on projected future climate impacts.

The energy sector in Europe is already impacted by climate extremes, with increasing occurrence of exceptionally dry and/or hot years[22]. Moreover, average temperatures have changed, with heating-degree days decreasing and cooling-degree days increasing[23]. This means that scenarios should not draw upon regional climatic information that are more than ten years old as they are likely not representative anymore. The IPCC has identified further changes likely to affect the European energy system in the near term under all scenarios, with effects including reduced efficiency of power plants due to increasing temperatures and heat-induced transmission capacity reduction, changing precipitation patterns, increasing flood risks in Northern and Eastern Europe affecting hydropower plants, decreasing onshore wind potential from reduced surface wind speeds, and limited usability of power plants and onshore carbon capture and storage options due to water shortage in some regions[24]. In scenarios with global temperature increases above 2 degrees Celsius, the IPCC identifies a possible shift of peak load from winter to summer in many countries[25]. This has implications on infrastructure planning methodology[26].

It is crucial that scenarios incorporate at least those changes induced by 'committed climate change', i.e. the unavoidable consequences of climate change that Europe is already committed to due to past emissions. Certain parameter changes, such as average temperature increases at continental scale can be incorporated in deterministic models, whereas other effects will increase uncertainties and induce a need for additional scenarios and stress-testing. The IPCC concludes that energy infrastructure planning under climate change must take into account a greater number of scenarios and investigate impacts on particular energy segments[27]. The Advisory Board recommends that scenarios at least incorporate future climate projections regarding changes in average climate conditions that are expected with high confidence, and consider their implications for average infrastructure requirements.

3.2 Scenarios should reflect the need for EU energy infrastructure to adapt to climate change and be climate resilient. This includes vulnerability to high temperatures, floods and other extreme weather events, as well as water scarcity.

Climate change and extreme weather events increasingly affect all parts of the European energy system[28]. Extreme climate events will increase the vulnerability of the infrastructure. The IPCC forecasts that, together with peak load shifts, water-cooling constraints for thermal power may challenge the stability of electricity networks during heatwaves[29]. Investments will be needed for European energy infrastructure to adapt to these new climate realities that include more varied weather situations and extreme events. A synergy could potentially be found in ongoing adaptation analysis done for the EU Taxonomy for sustainable activities[30]. Adaptation investment needs should be captured in the TYNDP process, for example through additional stress-testing based

on future climate projections. The Advisory Board recommends that the assessment should at least cover the performance and longevity of energy infrastructure to capture future adaptation needs of existing energy infrastructure, and to incorporate related results in the scenarios[31]. This work can in the future draw from the forthcoming European Climate Risk Assessment to be published by the European Commission in 2024.

Recommendation 4: Scenarios should be constructed using an integrated building-block approach

4.1 Scenario development should draw from a continuous process of storyline development. The number of scenario variants should be determined by the key factors identified through this process.

An inclusive scenario building procedure is key to ensuring reasonable and coherent sets of assumptions, timely integration of up-to-date knowledge and expertise, effective stakeholder engagement, and to enable quick scenario updates. The Advisory Board therefore advises conducting an iterative storyline development process continuously during TYNDP cycles, with regular storyline updates. The process should involve all relevant stakeholders and independent experts from the beginning (see also recommendation 6) and should aggregate insights from continuous work in groups structured around major building blocks of the scenario modelling. The Advisory Board expects that understanding and insights will emerge from this continuous process, in particular on the relevance of high-level drivers and the differentiation of parameters for storylines. Therefore, the Advisory Board recommends that the Scenario Guidelines should not prescribe the number of scenarios nor the number or type of drivers differentiating the storylines. Moreover, the number of scenario variants, e.g. to test uncertain inputs, should be an outcome of the process.

4.2. The continuous storyline development should build upon analytical work examining major and partly interlinked building blocks, including but not limited to flexibility, electrification, hydrogen and e-fuels, offshore grids and carbon dioxide removal.

Existing model structures and procedures in the TYNDP process are complex and already comprise several soft-link tools that form the basis for the scenario building, including for example the 'Ambition Tool' used in the previous scenario development process[32], and an integrated hydrogen module. These tools and models form, together with simpler data collection efforts, the inputs for the scenarios. They are the 'building blocks' of the scenario development. However, the existing structures do not naturally incorporate a number of future energy system realities, especially those with a predominantly cross-border and cross-sector nature which require enhanced attention in the scenario process. From the latest IPCC assessment[33] and other relevant research in the area, we have identified the further development of the following five building blocks as relevant, in alignment with TEN-E Regulation's 11 priority corridors and priority thematic areas.

a) **Flexibility** of energy demand and production, through demand response, storage, sector integration and interactions between energy carriers, is expected to become a major feature of future energy systems[34]. A dedicated analysis and more detailed modelling of flexibility will allow for the capture of possible trade-offs and synergies between network infrastructure solutions and other, market-based activities to integrate renewable energies for example. The

scenario development should take into account and sufficiently value opportunities for optimisation across sectors, including electricity, heat, transport and industry, even if interdependencies can only be represented in a simplified manner (e.g. via surrogates). This should also include secondary effects on commodity prices, cost and economic activity levels, e.g. from electrification in industry.

b) **Electrification** of transport, heating/cooling and industry may generate substantial new electricity demands but also offers considerable new demand flexibility[35]. The electricity grid will serve as a backbone of future low-carbon energy systems[36]. Future estimations of demand will have to take these new flexible demands into account in a more integrated way. Electrification of segments of the transport and heat sectors could lead to changes in demand patterns that may have implications on network infrastructures and generators. This would create challenges to system operators but could also offer flexibility when properly managed through system integration and advanced information and communication technologies under adequate regulation. Similarly, industrial electrification potentially requires large amounts of electricity but also offers flexible demand. A dedicated analysis and stakeholder-inclusive process around electrification is merited to ensure its adequate representation in the scenarios.

c) **Hydrogen and e-fuel** demand and production can considerably change the structure and function of our energy system and will require vast amounts of additional electricity production and network infrastructure. The scientific community expects hydrogen to play an important role in the decarbonisation of some industries, and a possible role in some other sectors[37], both for on-site applications and integrated within the energy system. The scenarios should take into account relevant national and European level hydrogen strategies. A continuous dedicated analysis and modelling of hydrogen and e-fuels will allow for the identification of direct and secondary effects on a range of inputs. The integration of the latest knowledge on these aspects will be important here. For example, the cost of retrofitting natural gas pipelines is an important factor when assessing the economic viability of the options, and also when identifying the likely amount of imports compared to domestic production. For e-fuels and chemical industry feedstock containing carbon (e.g., methane and methanol), the sourcing of carbon for carbon capture and storage (CCS) is important and linked to biomass resources as well as infrastructure for negative emissions.

d) **Offshore grids** are a complex topic that requires an integrated perspective. The European Commission expects meshed offshore grids to play a large role in the decarbonisation of the energy system[38]. The TEN-E Regulation requires the development of high-level strategic integrated offshore development plans (Article 14). A stakeholder-inclusive process to integrate offshore grids into existing model structures will ensure their best representation in the scenarios.

e) **Carbon Dioxide Removal (CDR)** from land use, land use change and forestry (LULUCF), CCS, bioenergy with CCS (BECCS) and direct air carbon capture and storage (DACS) should be modelled explicitly, rather than simply taken from an exogenous source. Due to the immaturity of the latter technologies, it is highly important to address uncertainties around assumptions and risks related to the technologies, especially regarding leakages, infrastructure needs and costs, as well as social and governance barriers. Technologies and related negative emissions should be analysed and modelled to adequately consider likelihood of implementation and risk from reliance on technologies unproven at scale, to ensure economic viability and realistic technical assumptions if considered, and to ensure consistency between assumptions (for example, the direct dependency between land use and biomass potential). Moreover, at least one of the scenarios should be free from CDR technologies.

The Advisory Board therefore recommends that the amount of analytical work and number of tools are expanded and in time incorporate a number of additional partly interlinked building blocks, including but not limited to the five building blocks mentioned above.

4.3 Coherence of inputs and assumptions should be strived for within scenarios, consistency between scenarios checked, and drivers of differentiation explained.

A building block-based storyline process involves developing separate narratives for each key "block" and using them to test the scenarios' overall coherence. Taking such an approach should facilitate exploration of correlations and interdependencies between input parameters and variables, so that linkages between interrelated prices and volumes can be upheld and meaningful sets of assumptions can be constructed. The consideration of interdependencies is crucial, as effects sometimes amplify each other and sometimes cancel each other out. A more integrated approach allows to adequately value the benefits of, for example, system integration to achieve decarbonisation targets in a cost-efficient way. The Advisory Board acknowledges that fully integrated modelling is likely neither possible nor necessary for all elements, but simplified rules for correlated assumptions can be considered as well as a mandatory cross-check of coherence across inputs. To ensure coherent storylines, it is crucial that inputs are checked for consistency internally within scenarios and between scenarios, and that drivers of differentiation are explained. Dedicated stakeholder and external expert involvement in the storyline development process, on modelling methodology and assumptions, will ensure that key inputs and their interdependencies are based on up-to-date expertise and the most recent scientific knowledge (see recommendation 6). The Advisory Board recommends that the Scenario Guidelines require ENTSOs to undertake and document consistency checks, demonstrate coherence between different relevant inputs, explain deviations that might arise, e.g. due to modelling realities or compromises made, and explain drivers of differentiation.

Recommendation 5: Assumptions should be based on up-to-date, scientifically sound and forward-looking information

5.1 Scenario assumptions should be based on up-to-date, comprehensive and scientifically sound information, both for current assumptions and forecasts, and prepared in an unbiased manner. Regional differences and expected changes in technology costs, innovations and commodity prices should be adequately integrated into the scenarios, with sufficient levels of granularity.

Scenarios rely heavily on assumptions. Choices made regarding inputs can considerably change the outcome of scenarios. It is therefore of utmost importance for the usefulness and credibility of scenarios to have a reliable and sound basis for data.

The Scenario Guidelines should require the use of up-to-date scientifically sound information for all input data. All assumptions should be scrutinised for their compatibility with the energy and climate targets. All scenario assumptions should be scrutinised in an engagement process with stakeholders and independent experts.

Regional specificities should be taken into account in assumptions, including energy prices, utilisation rates, and discount rates. Since the major purpose of the scenarios is to detect projects with cross-border benefits, it is of utmost importance that regional differences are captured adequately. National differences may arise from market conditions and legal frameworks that

affect costs directly, or indirectly from flexibility potential, e.g. for prosumers and electric vehicles. The Advisory Board acknowledges that a country-level approach for assuming energy delivery costs for different energy carriers has already been taken. The Advisory Board recommends to expand this approach in order to encompass import prices of all relevant fossil and non-fossil energy carriers, in particular natural gas, hydrogen and e-fuels.

5.2 The long-term climate effects of the infrastructure under consideration should be considered, and assumptions on the expected useful life of energy infrastructure should be aligned with the transition and net-zero objective.

Special attention should be given to the assumptions on infrastructure and greenhouse gas emissions. In particular, the potential climate impact and risks of various gases and blends should be considered, e.g. with regards to leaks of methane or hydrogen (and indirect greenhouse gas emissions). Carbon lock-ins and long-term effects, e.g. from gas pipelines, should be considered in the assessment of climate target compatibility of the scenarios. In scenarios that comply with climate targets, it is not conceivable that new fossil infrastructure would have a lifetime of 25 years. These will either be retired early or become or stranded assets unless there is a potential for repurposing. Similarly, electricity and hydrogen networks planning should reflect the gaps needed to reach climate neutrality. The Advisory Board recommends that the Scenario Guidelines specifically require assumptions on expected useful life of energy infrastructure to be aligned with the transition pathways and climate neutrality objective.

5.3 Scenarios should be, whenever possible and reasonable, based on data sources and modelling tools that are comparable to those adopted by EU institutions to inform EU policies. In case of deviations, these should be explained and justified.

The TEN-E Regulation states that "relevant input parameters for the modelling such as assumptions on fuel and carbon prices or installation of renewables shall be fully consistent with the European resource adequacy assessment" (Article 27). This could include requiring the referencing of assumptions for e.g. current and projected CAPEX and OPEX for key technologies (e.g., wind, solar photovoltaic and electrolysers) and the investment needs at Member State level from official EU publications[39], as well as Member State documents whenever relevant. Commodity price trajectories, including national gas prices, CO_2 prices, as well as currency exchange rates, etc. should be informed by the latest forward-looking assessments, including those by the European Commission[40]. The Advisory Board recommends making this requirement explicit and instrumental in the Scenario Guidelines.

5.4 Scenario assessment should account for uncertainties relative to input assumptions.

Scenarios depend on several assumptions and uncertain inputs. The Advisory Board is aware that ENTSOs are already testing several sensitivities, especially in relation to determining system adequacy, but have not yet published the full analysis or results. The Advisory Board recommends that the Scenario Guidelines require analysis and documentation of the range of uncertainty around all relevant inputs and a justification for the chosen input value within the uncertainty range. Whenever uncertainty ranges are tested for inputs and their impact on major scenario outcomes is understood, the findings should be documented and published in the scenario report. The scenario report should also identify which general uncertainties are inherent in assumptions (including economic growth, energy price fluctuations, technology maturity, changes in policy and geopolitical situation, supply constraints of raw materials, stretches of high/low temperatures,

drought and low water levels, infrastructure outages from floods) and give a qualitative assessment of how scenarios may be impacted by input values materialising within the uncertainty range. The analysis could be done in a separate process after the scenario building, with the main purpose of identifying the largest drivers for differences, important correlations, and the robustness to certain changes in inputs.

Recommendation 6: The process should be more transparent and built on timely consultations of stakeholders and external experts

6.1 Detailed descriptions of methodologies and models should be published, to the greatest extent possible.

In the course of the scenario development process, a large number of decisions regarding methodological and data choices have to be made. This unavoidably requires value judgements. Governance structures can alleviate the perceived subjectivity by making the process as transparent as possible. Moreover, the TEN-E Regulation requires ENTSOs to *publish the corresponding input and output data in a sufficiently clear and accurate form for a third party to reproduce the results* (Article 12). To do so, detailed information and descriptions of models and methodologies are necessary. The Advisory Board recommends that the Scenario Guidelines require ENTSOs to provide detailed descriptions of methodologies and models used, including input-output relations between models and modules, data linkages and iterations undertaken. ENTSOs should also provide a detailed description of simplifications of reality and choices made to stylise certain relations, methodology for data aggregation and methodology for carbon budget calculations.

6.2 Detailed assumptions should be published for each scenario, including data sources, how data is used, necessary information to assess and reproduce calculations, and including adjustments and corrections of inputs made during the modelling process – according to FAIR principles (Findable, Accessible, Interoperable and Reusable).

In previous TYNDP editions, ENTSOs have made some data available. However, not all inputs and assumptions have been publicly documented, and not all corrections have been explained. ENTSOs' TYNDP 2022 Scenario Guidelines show some assumptions, but they appear incomplete and incomprehensive. For example, some tables lack units. The scenarios were not reproducible in full by external experts and could therefore not be fully scrutinised. The TYNDP therefore had to forego important learning opportunities and potential suggestions for improvements of method and inputs. In line with the above-mentioned requirement of the TEN-E Regulation, and to allow for scrutiny of the scenario development process, ENTSOs should publish further detailed information and descriptions of inputs and results, as well as uncertainties around inputs and results. To enhance transparency and usability of data, the Advisory Board recommends that the Scenario Guidelines require data to be published according to the FAIR[41] principles, i.e., findable, accessible, interoperable and reusable. ENTSOs should provide at least the following documentation:

- Detailed data tables for inputs and outputs of all scenarios and all modelled years, with full unit disclosure, ideally with the provision of all publishable data, including metadata, in a machine-readable way;
- Detailed descriptions of sources, including directions as to which exact information was taken, from which publication, and which version/edition;

- Descriptions of data and their use in the models and scenarios;
- Uncertainty ranges around input data.

6.3 The Scenario report should contain an analysis and a detailed description of all results, including compliance of scenarios with EU climate and energy targets. Scenarios must be informative and made understandable to decision makers and relevant stakeholders.

Informed discussions of scenarios and independent scrutiny of results depend on comprehensive data disclosure (as recommended above), but also on detailed result descriptions and relevant analysis of outcomes. This will ensure that scenarios are informative and made understandable to decision makers, stakeholders and the public.

The Advisory Board recommends that the Scenario Guidelines require certain minimum contents of the scenario report. ENTSOs' scenario report should include a detailed description of results, including any known uncertainties and robustness against changes in input parameters. The analysis should detail how the scenarios comply with the EU's climate targets and explain any deviations to European Commission's scenarios. ENTSOs should also address carbon budgets, carbon leakage and cross-border greenhouse gas effects of all scenarios. The degree of carbon budget utilisation should be described for all scenarios, including the timing of cumulative emissions over the whole scenario period and, where relevant, beyond.

Even though the purpose of the scenarios is not infrastructure assessment or predicting technology mixes, the scenarios do rely on key underlying assumptions for their realisation. These factors, such as security of supply, reliance on import of materials and commodities, as well as costs for consumers, should be transparently described in a scenario evaluation report, to the largest extent possible.

6.4 The Scenario development process should be based on effective consultations and meaningful engagement with stakeholders.

The TEN-E Regulation requires ENTSOs to *invite the organisations representing all relevant stakeholders, including the EU DSO entity, associations involved in electricity, gas and hydrogen markets, heating and cooling, carbon capture and storage and carbon capture and utilisation stakeholders, independent aggregators, demand-response operators, organisations involved in energy efficiency solutions, energy consumer associations, civil society representatives, to participate in the scenarios development process* (Article 12). Open and transparent stakeholder engagement is particularly relevant as the ENTSOs, representing their members (transmission system operators), have their own stake in the process based on their individual business models. From reviewing publications about previous scenario development and consultation processes, stakeholders have in general not been entirely satisfied with the process and there are indications that stakeholders feel that their comments and recommendations have not been sufficiently taken into account.

The Advisory Board welcomes the creation of a 'Stakeholder Reference Group', and recommends that the independence of the group is ensured through the Scenario Guidelines. The Scenario Guidelines should define the composition and appointment process of the members of the Stakeholder Reference Group, describe roles and responsibilities, and detail how its independence is ensured.

In addition, both ENTSOs and modellers involved in scenarios informing European Commission proposals should be involved in scenario comparison and benchmarking exercises. This

involvement should be documented in the scenario report. Better traceability of the benchmarking should be ensured by reporting using comparable units and statistical concepts.

6.5 An expert engagement process should involve independent experts to scrutinise modelling methodology, input assumptions and robustness of results. Independent experts should be consulted early in the process.

The persuasiveness of scenarios derived from storylines is mostly driven by the stories' cause-and-effect dynamics[42]. To utilise expert knowledge on scenario development and modelling methodology, an expert engagement process could be developed to 'unpack the model box'. This process would allow researchers and other experts to re-model scenarios, either with access to the model tools used for the scenarios or based on their own models. Scenario outcomes can then be compared and tested for robustness of results and sensitivity to changes in inputs. The improved understanding can feed into subsequent scenario development processes. The involvement of independent experts should be systematic, and not conditional on outcomes in other parts of the process (for example, lack of consensus in stakeholders' group).

The Advisory Board therefore recommends that the Scenario Guidelines establish an expert engagement process, which is integrated with the overall scenario development, the continuous storyline process and the dedicated work on individual building blocks.

Recommendations for ACER's Scenario Guidelines

The Advisory Board recommends that ACER include the following points in the Scenario Guidelines.

1.1 Scenarios must be regularly updated to comply with new or revised EU climate and energy targets, achieving target levels within the specified time frame.
1.2 To credibly demonstrate climate target compliance, scenarios must be modelled until at least 2050.
1.3 Scenarios should reflect all relevant policy objectives adopted at EU level, including non-binding ones, up to a cut-off date agreed upon with the European Commission.
1.4 Where relevant, policy assumptions from National Energy and Climate Plans (NECPs) should be updated, and complemented in order to ensure compliance with climate and energy targets.

2.1 Scenarios should cover a sufficiently wide spectrum of climate neutrality pathways, aligned with the assessments that form the basis of EU decision processes, and strive to decrease Europe's dependency on fossil fuel infrastructure and imports.
2.2 Scenarios should be differentiated at the latest within seven years of the start of the scenario time frame.
2.3 Scenarios should capture contrasting pathways based on differences between the most impactful drivers affecting infrastructure development.
2.4 Benchmarking should include short-term and medium-term outcomes, cover climate-relevant aspects, and include an analysis of discrepancies.

3.1 Scenarios should, to the extent possible, draw from up-to-date information on observed changes in regional climate, and on projected future climate impacts.
3.2 Scenarios should reflect the need for EU energy infrastructure to adapt to climate change and be climate resilient. This includes vulnerability to high temperatures, floods and other extreme weather events, as well as water scarcity.

4.1 Scenario development should draw from a continuous process on storyline development. The number of scenario variants should be determined by the key factors identified through this process.
4.2 The continuous storyline development should build upon analytical work examining major and partly interlinked building blocks, including but not limited to flexibility, electrification, hydrogen and e-fuels, offshore grids and carbon dioxide removal.
4.3 Coherence of inputs and assumptions should be strived for within scenarios, consistency between scenarios checked, and drivers of differentiation explained.

5.1 Scenario assumptions should be based on up-to-date, comprehensive and scientifically sound information, both for current assumptions and forecasts, and be prepared in an unbiased manner. Regional differences and expected changes in technology costs, innovations, and commodity prices should be adequately integrated into the scenarios, in sufficient granularity.
5.2 The long-term climate effects of infrastructure under consideration should be considered, and assumptions on the expected useful life of energy infrastructure should be aligned with the transition and net-zero objective.

5.3 Scenarios should be, whenever possible and reasonable, based on data sources and modelling tools that are comparable to those adopted by EU institutions to inform EU policies. In case of deviations, these should be explained and justified.
5.4 Scenario assessments should include an account of uncertainties around input assumptions.

6.1 Detailed descriptions of methodologies and models should be published to the greatest extent possible.
6.2 Detailed assumptions should be published for each scenario, including data sources, how data is used, necessary information to assess and reproduce calculations, and adjustments and corrections of inputs made during the modelling process – according to FAIR principles (Findable, Accessible, Interoperable and Reusable).
6.3 The scenario report should contain an analysis and a detailed description of all results, including compliance of scenarios with EU climate and energy targets. Scenarios must be informative and made understandable to decision makers and relevant stakeholders.
6.4 The scenario development process should be based on effective consultations and meaningful engagement with stakeholders.
6.5 An expert engagement process should involve independent experts to scrutinise modelling methodology, input assumptions and robustness of results. Independent experts should be consulted early in the process.

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