European Scientific Advisory Board on Climate Change

European Scientific Advisory Board on Climate Change
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Potsdam, 15 March 2023

Subject: Recommendations on a harmonised EU energy system-wide cost-benefit analysis

Dear colleagues,

In the framework of Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure ('TEN-E Regulation'), the European Scientific Advisory Board on Climate Change (the 'Advisory Board') would hereby like to provide an advice on methodologies for a harmonised energy system-wide cost-benefit analysis (CBA) at EU level.

The role of the Advisory Board is to give independent scientific advice on how to ensure coherence between the EU measures and the EU climate policy objectives. As energy supply and use represent 77 % of the EU's total greenhouse gas emissions, it is critical that the EU's energy network development support and drive the transition towards renewable-based and efficient energy systems while avoiding further lock-ins into fossil infrastructure. It should also safeguard the resilience of the EU's energy infrastructure to the unavoidable impacts of climate change.

To prepare its recommendations, the Advisory Board met with, and analysed publications from, ACER, ENTSO-E, ENTSO-G, the European Commission, and the scientific community. It analysed in particular the draft 4th ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects, published on 15 December 2022. ENTSO-G's preliminary draft single-sector Cost-Benefit Analysis methodology could not be specifically considered as it was only published on 28 February.

The Advisory Board found that the ten-year network development plan (TYNDP) process does not sufficiently address the transformational changes and rapid reductions in greenhouse gas emissions that are necessary to achieve the EU's climate neutrality and climate resilience targets by 2050. This observation pertains to the entire TYNDP process, in particular the scenario development, system needs assessment and cost-benefit analysis (CBA), as well as the subsequent selection of Projects of Common Interest (PCI) and Projects of Mutual Interest (PMI).

To address this weakness, the Advisory Board recommends that priority be systematically given to full decarbonisation, energy efficiency, and infrastructure resilience, in particular through **rapid and wide-spread electrification combined with demand-side flexibility**. This requires ENTSO-E, ENTSO-G, DG Energy, and ACER to enhance:

1. **integration** of their work within and across TYNDP cycles,
2. **consistency** between the CBA methodologies,
3. **transparency** of tools and processes,
4. respective **capacities and capabilities**.

As regards CBA methodologies for energy infrastructure projects, the Advisory Board recommends that these:

1. adequately account for **all** relevant **greenhouse gas emissions**,
2. assess **climate adaptation** costs, benefits, and measures,
3. apply appropriate **scenarios and sensitivities**,
4. ensure granular **net-present value** assessment,
5. take into account project **implementation feasibility and social aspects**,
6. capture expected benefits of **renewable energy** integration, and
7. adequately assess **multi-sectorial dynamics** to identify the **most beneficial solutions**.

You will find our detailed recommendations in the attached document. We prompt you to consider these recommendations in your ongoing and future work relevant to the TYNDP/PCI-PMI processes, including the CBA methodologies.

We look forward to meeting with your teams 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 decarbonised and climate-resilient EU energy infrastructure:

recommendations on a harmonised EU energy system-wide cost–benefit analysis

15 March 2023

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Abbreviations

ACER	European Union Agency for the Cooperation of Energy Regulators
BCR	Benefit–cost ratio
CBA	Cost–benefit analysis
CO_2	Carbon dioxide
$CO_{2\ eq.}$	Carbon dioxide equivalent
DSO	Distribution System Operator
EEA	European Environment Agency
EIB	European Investment Bank
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
ETS	Emission Trading System
EU	European Union
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre
NECPs	National energy and climate plans
NPV	Net-present value
NRA	National Regulatory Authority
PCI	Projects of Common Interest
PMI	Projects of Mutual Interest
RES	renewable energy sources
RGI	Renewables Grid Initiative
TEN-E	Trans-European networks for energy
TSO	Transmission System Operator
TYNDP	Ten-year network development plan

About the European Scientific Advisory Board on Climate Change

The European Scientific Advisory Board on Climate Change (the Advisory Board) is an independent scientific advisory body providing 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.

The members of the Advisory Board are:

- Ottmar Edenhofer (Chair)
- Jette Bredahl Jacobsen (Vice-Chair)
- Laura Díaz Anadón (Vice-Chair)
- Maarten van Aalst
- Constantinos Cartalis
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- Joeri Rogelj
- Nicolaas Schrijver
- Jean-François Soussana

Executive summary

Energy networks are a core component of the European energy system. As energy supply and use cause 77 % of the EU's total greenhouse gas emissions, the design and development of the EU's energy networks define the EU's transition towards a decarbonised and resilient energy system. The EU's success in reaching its 2050 climate neutrality target depends on energy infrastructure investment decisions of today.

Achievement of EU climate goals depends on further renewable energy-based electrification, which, in turn, relies on the availability, resilience and innovativeness of electricity grids.

The revised regulation on trans-European networks for energy (TEN-E) sets out provisions aiming to ensure the timely development of interoperable EU energy networks, including electricity grids, smart electricity grids, smart gas grids, energy storage, hydrogen technologies, electrolysers and CO_2 networks. It stipulates that this development will contribute to ensuring climate change mitigation, in particular achieving the EU's 2030 targets for energy and climate and 2050 climate neutrality objective. It also aims to enhance the resilience of energy infrastructure to the unavoidable impacts of climate change.

The TEN-E regulation outlines a revised process for planning the development of the EU's gas and electricity networks with a 10-year horizon, the 10-year network development plan (TYNDP). This plan then forms the basis for selecting Projects of Common Interest (PCI) and Projects of Mutual Interest (PMI), which are eligible for access to EU funding and accelerated permitting procedures. The TYNDP process includes three key phases: scenario development, infrastructure gaps identification and cost–benefit analysis (CBA). Gaps identification and CBA inform decision-makers when selecting PCI and PMI.

In accordance with the new requirements set out in the TEN-E regulation, the European Network of Transmission System Operators for Electricity and for Gas (ENTSO-E and ENTSO-G) will submit draft CBA methodologies to the European Union Agency for the Cooperation of Energy Regulators (ACER) and Member States by 24 April 2023. ACER will then provide its opinion on the draft guidelines, allowing ENTSO-E and ENTSO-G to take it into account before submitting the CBA methodologies to the European Commission for final approval. In order to provide timely advice on the CBA process set out in the TEN-E regulation, we focused on the draft 4th ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects (ENTSO-E, 2022), published on 15 December 2022. ENTSO-G published its preliminary draft on 28 February 2023 (ENTSO-G, 2023), when the analyses conducted for the purposes of this document were already complete. Nevertheless, we note the relevance of our recommendations to ENTSO-G. We also note that the European Commission CBA methodologies for electrolysers, smart gas grids, smart electricity grids, CO_2 networks and energy storage (JRC, 2022a, 2022b, 2022c, 2022d, 2022e, 2022f) will be compatible with the CBA methodologies developed by ENTSO-E and ENTSO-G, in accordance with Article 11(8) of the TEN-E regulation.

The European Scientific Advisory Board on Climate Change (the Advisory Board) has been mandated to provide objective, science-based advice, helping the EU to successfully achieve its climate targets. This includes the following three inputs to the TYNDP process:

1. a first set of recommendations, published in November 2022, to ACER on the draft scenario guidelines (European Scientific Advisory Board on Climate Change, 2022);
2. the present input to the preliminary draft of CBA methodologies, developed by ENTSO-E and ENTSO-G, pursuant to Article 11 of the TEN-E Regulation;

3. a forthcoming input on the scenarios for TYNDP, under Article 12 of the TEN-E regulation.

In its first set of recommendations on the draft scenario guidelines, the Advisory Board recommended that scenarios should reflect the EU's most up-to-date climate and energy targets, should be target compliant and should allow for dynamic decarbonisation and resilience-building of the energy system. This includes adjustments to scenarios as soon as intermediary climate targets are adopted, their modelling until at least 2050, and capturing a range of different pathways to climate neutrality. Scenarios should acknowledge and consider projected climate-related impacts on energy infrastructure, use a flexible building-blocks approach across sectors (including flexibility, electrification, hydrogen, offshore grids and carbon dioxide removal) and be based on up-to-date, scientifically sound and forward-looking information. The assumptions, methods and results of scenarios should be published in detail, and independent experts should be consulted early in the process. Given the role that the joint scenarios have as the backdrop to the CBA as part of the energy infrastructure assessment from an integrated system perspective, the Advisory Board calls for the timely improvement of the scenario-building process in line with the Advisory Board recommendations of November 2022.

By providing this second set of recommendations within the framework of the TEN-E regulation, the Advisory Board aims to:

- contribute to the development of CBA methodologies that are applied mainly in the selection of PCI and PMI, and
- provide scientific insights relating to the ongoing and future planning and development of energy infrastructure projects.

Cost–benefit analysis can be a useful tool to support and inform decision-making and is an essential part of PCI selection. It has some inherent limitations, including its focus on quantifiable indicators, and therefore in decision-making needs to be systematically complemented by additional considerations. CBA results rely heavily on delimitation and assumptions made. The Advisory Board focuses in particular on some of the methodological and empirical assumptions made, as well as addressing some of the tool's limitations.

To prepare its recommendations, the Advisory Board conducted a review of relevant scientific literature and other research outputs, as well as the existing institutional guidelines and EU legislation. It complemented these findings with consultations with experts and stakeholders organised between November 2022 and February 2023.

Based on this work, the Advisory Board hereby provides recommendations addressing both the overall TYNDP process and the CBA methodology. These recommendations are primarily addressed to ENTSO-E, ENTSO-G and ACER. They are also relevant to the European Commission and its Joint Research Centre.

Recommendations regarding the ten-year network development plan process

On the overall TYNDP process, the Advisory Board observes that it is not yet sufficiently driven by climate neutrality and resilience imperatives. In particular, the current approach to system needs assessment, aimed at identifying long-term infrastructure gaps and bottlenecks, does not reflect the needed transformation of the energy sector. The Advisory Board expresses concern that the TYNDP process does not take adequate account of the EU's transformational changes that lie ahead and the necessary acceleration of reducing greenhouse gas (GHG) emissions to meet existing (2030 and 2050) and expected (2040) climate targets for the EU.

The Advisory Board therefore recommends the following:

- All key steps of the TYNDP/PCI-PMI processes, including scenario development, system needs assessment and CBA, as well as all intermediate steps, should be guided by and comply with EU climate targets.
- Climate mitigation and resilience aspects cutting across all steps and investment categories of the TYNDP and PCI/PMI processes should be handled consistently and in an integrative way that facilitates joint institutional learning and new knowledge collection and use.
- Coordination between ENTSO-E and ENTSO-G, as well as between the European Commission and both ENTSO-E and ENTSO-G, should be made more transparent.
- ENTSO-E, ENTSO-G, the Directorate-General for Energy of the European Commission, and ACER should deploy the necessary capacities and capabilities required to conduct the process, as well as to develop new activities in response to the transformational changes ahead.
- ENTSO-E, ENTSO-G, and the European Commission should systematically and proactively involve key stakeholders, including non-incumbent actors such as the EU Distribution System Operators (DSO) Entity.

Recommendations regarding the cost–benefit analysis methodology

On the CBA, the Advisory Board makes the following recommendations:

1. Account adequately for all relevant greenhouse gas emissions

- The CBA methodologies should adopt a consistent approach to GHG emissions accounting, including methane, and express emissions in CO_2 equivalents. This would involve using uniform approaches to the counterfactual, emission factors and efficiency coefficients, as well as their monetisation.
- The cost of GHG emissions should be based on an opportunity cost approach for the entire EU climate policy, i.e. one that considers options both within and outside the EU Emissions Trading Scheme.
- The CBA methodology should use a single source for inputs regarding the cost of GHG emissions, and the inputs should evolve over time. The source could be, for example, the most recent document developed by the European Commission.
- The cost of GHG emissions should include more granular inputs with respect to time development, e.g. annual values.

2. Assess climate adaptation costs, benefits and measures

- The CBA methodology should give guidance on how to provide project-specific descriptions and cost estimates of adaptation measures relating to climate variables and climate-related hazards.
- The CBA methodology should include quantifiable indicators on climate adaptation costs, monetised where possible. The CBA methodology should reflect the expected impacts of current and future site-specific climate conditions on costs, including insurance and asset lifetime considerations. The climate-sensitive design threshold of specific technologies should be analysed.
- The CBA methodology should include a quantified indicator, or benefit–cost ratios (BCRs), to reflect the benefits of climate resilience.
- Building on institutional learning and new knowledge integration within the TYNDP processes, the CBA methodology should link to relevant empirical adaptation data, enabling the tracking of the

costs of extreme weather event management to help quantify the avoided damages with respect to subsequent updates and improvements of the quantitative CBA indicators.

3. Apply appropriate scenarios and sensitivities

- The CBA methodology should specify that indicators be determined based on target-compliant scenarios only.
- The CBA methodology should ensure that all information from the climate target-compliant scenarios is used for the quantification of indicators until the time horizon in which targets are achieved.
- Sensitivity analysis should integrate recent climate years in the historic time series and modelled projections for future climate years and patterns, including future extreme weather events.
- Sensitivity analysis should also take into consideration compound climate events and cascading risks.
- The choice of climate years should draw on the latest scientific evidence on climate change trends and on climate change projections up to 2050.
- Climate years and related projections should feed into climate vulnerability and risk assessment, e.g. as recommended in the European Commission guidelines (EC, 2021a).
- ENTSO-E and ENTSO-G should ensure that the choice of applied sensitivity parameters, the projects to which they apply and their assessment framework is transparent and driven by the latest science.
- The market and network models used by ENTSO-E and ENTSO-G to calculate projects' relative costs and benefits should be made as accessible as possible based on existing good practice across the world and in line with the FAIR (findable, accessible, interoperable and reusable) principles. The models could be uniformly applied by ENTSO-E and ENTSO-G and made available to non-TSO project promoters for the CBA calculations.

4. Ensure adequately granular net present value assessment

- The CBA methodology should require assessment periods that reflect realistic project lifetimes.
- The CBA methodology should specify that study years include short-term, mid-term – and long-term – horizons.
- ENTSO-E, ENTSO-G, and the European Commission should investigate the impact of more granular quantification of indicators in NPV and BCR calculations. This investigation should include study years at 5-year intervals and annual values for crucial exogenous input factors, such as the cost of carbon.
- The European Commission, ENTSO-E, and ENTSO-G should jointly reflect on the need to update the applicable discount rate.

5. Consider project implementation feasibility

- Decision-makers should consider commissioning years submitted by the project promoters as part of the CBA results.
- ENTSO-E should further expand the commissioning dates assessment to capture the likelihood of timely project implementation, together with net impacts of delays in the form of a new quantified indicator.
- The CBA methodology should encourage project promoters to mitigate negative project impacts and the risk of delays by considering public concern linked to environmental and social impacts at the project CBA stage. An assessment of the project's importance, impact level and mitigation

options based on the latest best practice could be provided as part of the environmental and social impacts information in the CBA.

6. Adequately capture renewable energy integration benefits

- The CBA methodology should more adequately capture benefits linked to additional renewable energy source (RES) capacities that are enabled by the project under assessment (indicators B1 and B3), going beyond the connection of RES capacities already accounted for in the reference grid and avoiding curtailment of electricity produced from these sources.
- The definition of RES applied in CBA methodologies developed under Article 11 of the TEN-E regulation should be aligned with the definition of RES set out in Article 2 of the EU Renewable Energy Directive.

7. Adequately assess multisectoral dynamics to identify the most beneficial solutions

- The CBA methodology should further elaborate on ways to account for the impacts of sector coupling and make it non-optional.

Ten-year network development plan for a decarbonised and resilient energy system

Ten-year network development plan at the heart of energy transition

The EU energy sector is responsible for 77 % of the EU's total greenhouse gas (GHG) emissions (EEA, 2022) and is increasingly vulnerable to external shocks (IEA, 2021). The design and development of the EU's energy networks is key to enabling and shaping the EU's transition towards a decarbonised and resilient energy system. This transition will in the coming decades be dominated by the further phasing out of fossil fuels and by renewable energy-based electrification (Allard et al., 2020; Golombek et al., 2022; Klaaßen and Steffen, 2023). The European Network of Transmission System Operators for Electricity and for Gas (ENTSO-E and ENTSO-G) develop 10-year network development plans (TYNDPs). These European electricity and gas grid infrastructure investment roadmaps link, support and complement national grid development plans and are connected to the national energy and climate action plans. The TYNDPs and the way that they inform today's energy infrastructure investment decisions play a pivotal role in the EU's path to its 2050 climate neutrality target.

Climate change at the heart of the 10-year network development plan process

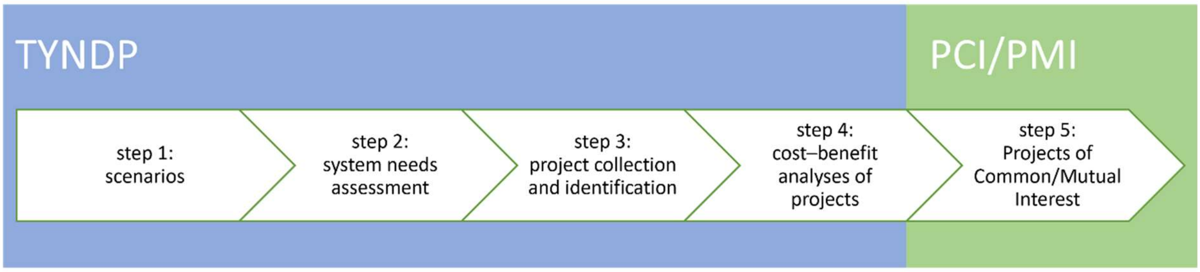
Because the EU's achievement of climate targets depends on the development of energy infrastructure through the TYNDP process, it is crucial that the EU's climate neutrality objective is put at the core of analysis in each step of the TYNDP and Project of Common Interest / Project of Mutual Interest (PCI/PMI) processes. It is, however, not always visible throughout the process how far the achievement of climate targets is used as the guiding principle in these processes. For instance, not all scenarios are demonstrated to be target compliant, which in turn affects the system needs assessment (infrastructure gap identification) and the cost–benefit analysis (CBA). Moreover, climate resilience is strikingly underrepresented throughout the TYNDP and PCI/PMI processes, despite its overwhelming importance in future long-term infrastructure investments and its prominent place in the revised TEN-E regulation.

As stakeholders are involved in a variety of ways in the different steps of the TYNDP process, there is a risk that cross-cutting aspects, such as climate resilience, are not integrated early and consistently enough in the process. To address this challenge, joint working groups on topics that require similar integration at different steps of the process (e.g. scenarios, system needs, CBA) and between TYNDP cycles could mitigate this risk. A possible solution for climate resilience could be, for example, for the European Commission's Directorate-General for Energy (DG Energy) to establish a 'resilience of electricity grid infrastructure' working group. It could consist of TSOs and distribution system operators (DSOs), project promoters, national regulatory authorities and other stakeholders. The aim of the working group could be to identify, through transparent institutional learning that captures relevant data and projections, climate risks, their likely impacts on the power grid and energy system, the options offering the most resilience under different climate change scenarios and possible risk mitigation / adaptation measures.

Crucial climate considerations in all steps of the 10-year network development plan and Project of Common Interest/Project of Mutual Interest processes

The TYNDP and PCI/PMI processes are conducted in biennial cycles in consecutive steps. The scenario development is followed by the identification of system needs and collection of project proposals. Proposed projects then undergo CBA, and some projects may be listed as a PCI/PMI (see Figure 1).

Figure 1 Ten-year network development plan and Project of Common Interest/Project of Mutual Interest processes



Source: European Scientific Advisory Board on Climate Change, adapted from ENTSO-E (2023)

The scenario development (step 1), jointly undertaken by ENTSO-E and ENTSO-G, is a key step in the process, as it has an impact on the results of all subsequent steps of the TYNDP process. The Advisory Board provided its input to the scenario development guidelines in November 2022 and commented on several issues in relation to compatibility with EU climate objectives (European Scientific Advisory Board on Climate Change, 2022).

The system needs assessment (step 2) is equally crucial, as this step identifies the infrastructure gaps that will be addressed by the subsequent step of project identification. The TEN-E regulation requires ENTSO-E and ENTSO-G to base the system needs assessment on the scenarios and, in particular, to 'focus on those infrastructure gaps potentially affecting the fulfilment of the Union's 2030 climate and energy targets and its 2050 climate neutrality objective' (Article 13 of the TEN-E regulation). In the 2022 TYNDP cycle, the ENTSO-E system needs study was, however, based on the 'National Trends' scenario, which is not compliant with the EU's 2030 climate and energy targets, and does not take account of the 2050 climate neutrality objective. This is problematic from a climate policy perspective because project identification (step 3) is carried out while taking into account the infrastructure needs identified in step 2, which should be systematically guided by long-term climate neutrality and resilience considerations.

In the CBA assessment of projects (step 4), a series of CBA indicators is determined for each submitted project. At the start of the PCI/PMI status process (step 5), decision-makers consider both a project's CBA results and whether the project addresses a need identified in the system needs study (ENTSO-E, 2023a). The first EU list of PCI/PMI (6th Union list), scheduled to be adopted in autumn 2023, will cover electricity transmission, electricity storage, smart electricity grids, smart gas grids, electrolysers, hydrogen, and CO_2 networks. Although the PCI/PMI selection process based on the 2022 TYNDP process is already under way, there is still a window of opportunity for candidate PCI/PMI to better reflect the benefits and costs of climate mitigation and resilience. The Advisory Board recommendations provided here can inform such efforts.

Electricity and gas interplay in the 10-year network development plan

ENTSO-E and ENTSO-G are mandated to work jointly and develop 'a consistent and progressively integrated model that will provide consistency between single sector (CBA) methodologies based on common assumptions including electricity, gas and hydrogen transmission infrastructure, as well as storage facilities, liquefied natural gas and electrolysers' (Article 11 of the TEN-E regulation). The fundamental challenge that the two associations face in the coming decades is no longer 'keeping the lights on', but 'getting to net-zero' in a changing climate. The EU energy policy framework calls for the acceleration and wide roll-out of electrification, renewable energy deployment and energy demand solutions as the main policy direction (EU, 2022). For this reason, projects must be evaluated in line with their future role, also embracing the energy efficiency first principle and the avoidance of stranded assets caused by decarbonisation efforts. The increasingly transparent and inclusive TYNDP process driven by ENTSO-E could become a reference for EU cross-sectoral and integrative infrastructure planning to ensure the achievement of EU climate targets.

Transparent and integrated efforts

Currently, little information is publicly available regarding the integrated approaches and coordination efforts between the European Commission, the European Union Agency for the Cooperation of Energy Regulators (ACER), ENTSO-E and ENTSO-G in the context of TYNDP and PCI/PMI processes. For instance, the published CBA draft methodologies (ENTSO-E, 2022; JRC, 2022a-g) do not explain the undertaken consistency efforts that they shall be based on according to Article 11 of the TEN-E regulation. Several different entities are currently developing CBA methodologies that differ from each other in scope, indicators and input assumptions. It may be questioned whether this is the best long-term solution for CBA assessment of projects that eventually enter the same list. The current TEN-E regulation requires consistency of CBA methodologies across different energy investment categories to allow for system-wide assessment and objective decision-making. To meet the new requirements stemming from the revised TEN-E regulation, all involved entities will have to cooperate extensively, while deploying adequate capacities, which will in some cases require the development of new skills (e.g. related to understanding and managing complex dynamics across different energy carriers) and additional resource allocations.

Non-incumbent stakeholders will have to be well integrated into the TYNDP and PCI/PMI processes. For example, the role of the EU DSO Entity may gain importance in driving electrification and consumer-led flexibility of EU energy systems; its contributing role is explicitly mentioned in Articles 11, 12, and 13 of the TEN-E regulation. In general, key stakeholders and non-governmental organisations should be enabled to keep track of – and contribute to – integration and consistency efforts in EU-level project planning and development across the TEN-E asset categories.

The Advisory Board therefore recommends the following:

- All key steps of the TYNDP and PCI/PMI processes, including scenario development, system needs assessment and CBA, as well as all intermediate steps, should be guided by and comply with EU climate targets.
- Climate mitigation and resilience aspects cutting across all steps and investment categories of the TYNDP and PCI/PMI processes should be handled consistently and in an integrative way that facilitates joint institutional learning and new knowledge collection and use.
- Coordination between the ENTSO-E and ENTSO-G, as well as between the European Commission and both ENTSO-E and ENTSO-G, should be made more transparent.
- ENTSO-E, ENTSO-G, DG Energy, and ACER should deploy the necessary capacities and capabilities required to conduct the process, as well as to develop new activities in response to transformational changes ahead.
- ENTSO-E, ENTSO-G, and the European Commission should systematically and proactively involve key stakeholders, including non-incumbent actors such as the EU DSO Entity.

Recommendations on cost–benefit analysis

CBA can be a useful tool to support and inform decision-making and is an essential part of the multi-criteria assessment informing PCI selection. As a decision-making tool it has some inherent limitations, including its focus on quantifiable indicators, and should in decision-making always be complemented by other considerations. This can be done, for example, for the non-monetised indicators within the multi-criteria approach. CBA results rely heavily on delimitation and the assumptions made. Therefore, transparency in approach and inputs, as well as carefully executed sensitivity analysis, is generally crucial for CBA to serve as an appropriate tool for decision-making. The main quantified result of CBA is typically value provided in terms of increased socioeconomic welfare. In this context, CBA assesses only whether a project would provide value to society as a whole. It does not account for distributional impacts, i.e. it does not distinguish where, when and for whom costs and benefits would occur. In some instances, it can be relevant to demonstrate and assess the distributional impacts instead of considering aggregated socioeconomic welfare alone, as recommended by the Organisation for Economic Co-operation and Development in its CBA guidelines (OECD, 2018). We note that such disaggregation is not included in the draft CBA methodology 4.0. This is despite the fact that 'there may be pragmatic reasons for knowing which groups win and which groups lose from implementing the project' (OECD, 2018), considering the fundamental role of the CBA in cross-border cost allocation (ACER, 2023).

The following recommendations were developed primarily based on the draft CBA guidelines published by ENTSO-E on 15 December 2022. The Advisory Board does not define whether they are applicable to the CBA guidelines, its future Implementation Guidelines, or both.

1. Account adequately for all relevant greenhouse gas emissions

1.1. Account for all greenhouse gas emissions

The ENTSO-E draft CBA methodology 4.0 differs in terms of GHG emission accounting from the draft methodologies developed by the Joint Research Centre and from those currently in use by ENTSO-G. Notably, the way in which the benefit of avoided GHG emissions (indicator B2) in the ENTSO-E draft CBA methodology 4.0 is calculated **and** monetised does not capture non-CO_2 emissions, including methane, attributed to the project resulting from changes to the generation plan (substitution effect) and losses. This could be addressed by applying CO_2 equivalents to the relevant non-CO_2 emissions, calculated using global warming potential (GWP) values consistent with the Paris Agreement's enhanced transparency framework (IPCC AR5 values over a 100-year period). In order to capture climate impacts and make them easier to compare across energy infrastructure categories, GHG accounting methodologies should be as closely aligned to the different CBA methodologies as possible.

The Advisory Board therefore recommends the following:

- The CBA methodologies should adopt a consistent approach to GHG emissions accounting, including methane, and express emissions in CO_2 equivalents. This would involve using uniform approaches to the counterfactual, emission factors and efficiency coefficients, as well as their monetisation.

1.2. Apply credible annual emission costs

The societal cost of carbon attributes a value to public and private decarbonisation projects and enables investments to be assessed and selected on the basis of their socioeconomic, and not just financial, value (France Stratégie, 2019). In principle, this cost can be based on either an assessment of the climate damage from emissions or, when climate policies are in place, an estimate of the emission abatement cost (Tol, 2019). Given that the EU has a set of climate targets, we suggest using an opportunity cost approach for the entire EU climate policy, i.e. one that considers options both within and outside the EU Emissions Trading System (ETS). The ENTSO-E draft CBA methodology 4.0 leaves the choice of which societal cost to apply to the project appraiser, also suggesting that they use the most recent values published by the European Commission. Currently, the 'Technical guidance on the climate proofing of infrastructure during 2021–2027' (EC, 2021a) uses the shadow cost of carbon published in the 'EIB Group Climate Bank Roadmap 2021–2025' (EIB, 2020). This value represents the full cost of saving a tonne of carbon in the European economy. It increases from EUR 250/t $CO_{2\,eq.}$ in 2030 to EUR 800/t $CO_{2\,eq.}$ in 2050. Monetary values of GHG emissions proposed by the European Commission are among the many other monetary carbon values available for impact assessment tools. Such estimates are inherently uncertain, with the technologies continuing to develop. The choice of monetary values of GHG emissions may need to be reviewed regularly (Isacs et al., 2016). The key common data used for CBA, such as costs of carbon (indicators B2 and B4), should come from an up-to-date, credible single source to ensure comparability and robustness of the calculations.

The cost of $CO_{2\,eq.}$ is available on an annual basis. Applying such annual costs as accurately as possible in the cost and benefit calculation will provide decision-makers with the most realistic account of project benefits. However, in the TYNPD 2022 implementation guidelines (ENTSO-E, 2023b), only two values were given for the social cost of carbon (2030 and 2040), which corresponded to the study years for the market indicators. While we acknowledge that emission volumes (in tonnes) can be calculated only for study years (i.e. the years for which the market indicators are determined), we see an opportunity for CBA to take a more granular approach, for example annually varying values for externally sourced inputs, such as ETS prices or the social cost of carbon (in EUR/tonne), when calculating net present value (NPV) and benefit–cost ratio (BCR).

The Advisory Board therefore recommends the following:

- The cost of GHG emissions should be based on an opportunity cost approach for the entire EU climate policy, i.e. one that considers options both within and outside the EU ETS.
- The CBA methodologies should use a single source for inputs regarding the cost of GHG emissions, and the inputs should evolve over time. A source could be, for example, the most recent document developed by the European Commission.
- The cost of GHG emissions should include more granular inputs with respect to time development, e.g. annual values.

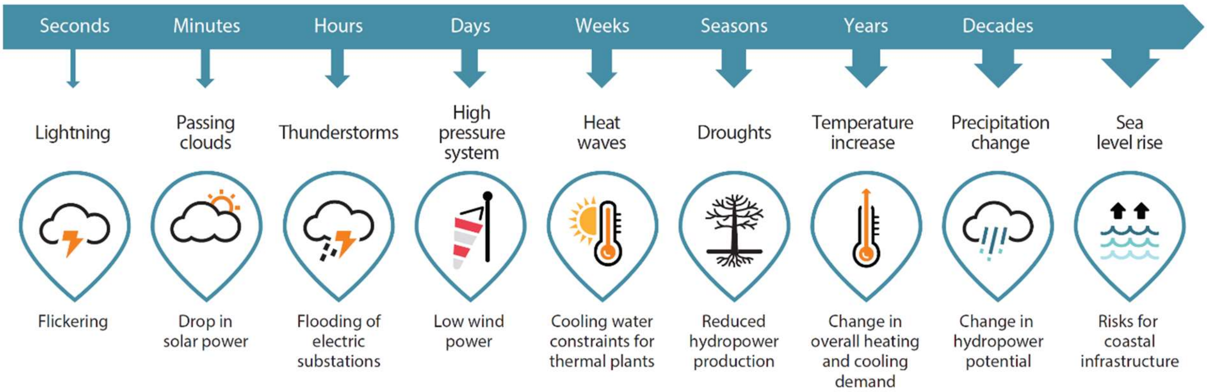
2. Assess climate adaptation costs, benefits and measures

In its advice on TYNDP scenario development from November 2022 (European Scientific Advisory Board on Climate Change, 2022), the Advisory Board recommended that the scenario (1) integrate up-to-date information on observed changes in regional climate and on projected future climate impacts; and (2) reflect the need for energy infrastructure to adapt to climate change (including the impacts of high temperatures, floods, extreme weather events and water scarcity). These elements of analysis have significant financial and security implications and should therefore be detailed in the CBA.

2.1. Assess the costs of climate adaptation measures

The changing climate has significant impacts on energy infrastructure, such as the heat-induced reduction of available transmission capacity, restricted water-cooling for thermal power, flood risk at hydropower plants in northern and eastern Europe, reduced wind speeds, and a possible peak-load shift from winter to summer, with demand peaks during heat waves (EEA, 2019; IPCC, 2022a; JRC, 2022g). Some of these effects will occur even with the EU continuing on its pathway to climate neutrality. Resilience considerations are therefore not optional. Resilience in the context of power grid planning can be understood as (1) minimising the vulnerability of the grid infrastructure to extreme weather events (see Figure 2) and (2) accounting for power grid capacity to alleviate weather-induced system stress (McKinsey, 2021; Millstein et al., 2023).

Figure 2 Weather and climate impact on the energy system on all time scales



Source: EEA, adapted from Troccoli (2018)

The revised TEN-E regulation includes new requirements for the CBA to 'address costs in the broader sense, including externalities' and to 'ensure that the climate adaptation measures taken for each project are assessed' (Annex V).

ENTSO-E's draft CBA methodology 4.0 includes, in the supplemental methodologies (6.6 'Climate adaptation measures'), a requirement for project promoters to 'state which climate adaptation measures have been taken', including 'all adaptations to an investment in order to cope with possible (predicted) future extreme weather events'. However, the ENTSO-E draft CBA does not specify how to integrate adaptation measures in the quantification of costs and benefits. There are no proposed indicators reflecting climate adaptation and resilience in the context of key climate variables and climate-related hazards for infrastructure projects (see examples in Table 1).

Climate change risks will affect both the project and the counterfactual, i.e. the backdrop scenario against which the project is evaluated. The implications for both should be considered and assessed at the very outset of the project, e.g. in the first feasibility study (ESMAP, 2022). Climate adaptation measures and disaster management have significant financial implications, including an increase in operating expenditure, the need for additional capital expenditure, asset value deterioration and reduced life, loss of income, increased litigation risks, changes in market prices and increased insurance costs (EC, 2016a). The evaluation of costs related to climate adaptation measures requires the following steps [adapted from the European Commission's 'Guidelines for project managers: making vulnerable investments climate resilient' (EC, 2016a)]:

1. identification of climate sensitivities and evaluation of exposure to future climate;
2. assessment of vulnerability;
3. risk assessment;
4. identification of and appraisal of adaptation options, and integration of action plan into the project.

We consider it crucial that the CBA methodology includes guidance on how to draw up project-specific descriptions and cost estimates of adaptation measures, including key climate variables to consider. Climate adaptation should be also reflected in key assumptions in CBAs within the TYNDP process.

Table 1 Climate variables and climate-related hazards for infrastructure projects

Key climate variables	**Climate-related hazards for infrastructure projects**
1. Annual/seasonal/monthly average (air) temperature 2. Extreme (air) temperature (frequency and magnitude) 3. Annual/seasonal/monthly average rainfall 4. Extreme rainfall (frequency and magnitude) 5. Average wind speed 6. Maximum wind speed 7. Humidity 8. Solar radiation	9. Sea level rise (plus local land movements) 10. Sea/water temperatures 11. Water availability 12. Storm (tracks and intensity), including storm surge 13. Flood 14. Ocean pH 15. Dust storms 16. Coastal erosion 17. Soil erosion 18. Soil salinity 19. Wild fire 20. Air quality 21. Ground instability / landslides / avalanches 22. Urban heat island effect 23. Growing season length

Source: European Commission guidelines (EC, 2016a)

The Advisory Board therefore recommends the following:

- The CBA methodology should give guidance on how to provide project-specific descriptions and cost estimates of adaptation measures relating to climate variables and climate-related hazards [see Table 1 and risk identification checklist in Annex IV of the European Commission guidelines (EC, 2016a)].
- The CBA methodology should include quantifiable indicators on climate adaptation costs, monetised where possible. The CBA should reflect the expected impacts of current and future site-specific climate conditions on costs, including insurance and asset lifetime. The climate-sensitive design thresholds of specific technologies should be analysed.

Further guidance on climate adaptation measures for infrastructure projects can be found on the CLIMATE-ADAPT Platform (Adaptation case studies) and through the Energy Sector Management

Assistance Program, e.g. the Hands-On Energy Adaptation Toolkit (ESMAP, 2022) and 'Economic analysis of power projects: integration of climate change and disaster resilience' (ESMAP, 2022). Moreover, Eurocodes, as well as standards developed by CENELEC and the International Organization for Standardization, could be helpful in guiding climate adaptation and resilience measures for infrastructure projects (CEN/CENELEC, 2022; EC, 2021a).

2.2. Assess the benefits of climate-resilient infrastructure

The revised TEN-E regulation states that the modelling in the CBA 'shall allow for a full assessment of economic benefits, including market integration, security of supply and competition, as well as lifting energy isolation, social and environmental and climate impacts, including the cross-sectorial impacts' (Annex V). In terms of benefits for the security of supply, the ENTSO-E draft CBA methodology 4.0 includes 'variability of climate effects' and 'loss of load' from extreme events in the B6 indicator, 'adequacy to meet demand benefit'. It also includes the B8 indicator, 'System stability benefit'; however, this indicator is considered by ENTSO-E as a 'non-mature' indicator and is computed by project promoters individually.

Climate change affects the availability of primary energy sources and energy transformation, transmission, distribution, storage and demand (EEA, 2019). As a result, grid operators across the world face the urgent task of weatherising energy transmission and distribution systems (McKinsey, 2021). The benefits of adaptation are commonly assessed by calculating avoided losses, i.e. considering the avoided direct and indirect damage to infrastructure and assets and the avoided deaths and well-being losses (EEA, 2023a). There is growing evidence that cross-border electricity interconnections can bring substantial benefits during extreme grid conditions (Figueiredo et al., 2021; Millstein et al., 2023). Building climate-resilient infrastructure presents benefits in terms of energy security and avoided damage costs, and those should be reflected in the CBA.

The Advisory Board therefore recommends the following:

- The CBA methodology should include a quantified indicator, or BCRs, to reflect the benefits of climate resilience.

2.3. Enable institutional learning and new knowledge on climate adaptation

Despite the increasing and direct pressure from climate change on every part of the electricity system (IEA, 2021), climate adaptation and resilience considerations are not yet adequately reflected in the TYNDP process. In the context of the CBA specifically, the Advisory Board notes that quantifying climate adaptation costs and benefits is currently difficult owing to a lack of relevant data. In this respect, recent joint ENTSO-E and Renewables Grid Initiative action reflecting on the adaptation and resilience aspects of the electricity infrastructure is very welcome (ENTSO-E and RGI, 2023; RGI, 2021). It could be a good starting point for reflecting on how relevant data on climate impacts and adaptation measures could be systematically collected, analysed and used, e.g. to inform the CBA. Availability of such data is a prerequisite for the future development of monetised indicators to identify cost-effective resilience measures at the planning stage (IEA, 2021).

In order to ensure the development, continuous improvement and regular updating of such indicators, a process should be designed that enables institutional learning and the integration of new knowledge. This may include the collection of empirical data related to adaptation measures and investments in ongoing projects and the systematic circling back of such information into the TYNDP process. The process could also benefit from systematic analysis of submitted CBAs and their estimated adaptation measures and costs, and documentation and publication of these in an aggregated form to inform future project sponsors, ensuring institutional learning and facilitating knowledge building across stakeholders.

Such institutional learning and new knowledge integration could be the focus of joint efforts by the relevant entities, in line with the Advisory Board recommendation on climate resilience in the TYNDP and PCI/PMI processes in the first chapter of this document.

The Advisory Board therefore recommends the following:

- Building on institutional learning and new knowledge integration within the TYNDP processes, CBA methodology should link to relevant empirical adaptation data, enabling the tracking of the costs of extreme weather event management to help quantify the avoided damages with respect to subsequent updates and improvements of the quantitative CBA indicators.

3. Apply appropriate scenarios and sensitivities

3.1. Use target-compliant scenarios for indicator quantification

The draft CBA methodology 4.0 does not specify under which scenarios the indicators are to be quantified. It is our understanding that, in the ongoing 2022 TYNDP process, indicators are mostly quantified for the 'National Trends' scenario. We consider it of the utmost importance that projects are assessed based on climate target-compliant scenarios to avoid any misrepresentation of costs and benefits and potential lock-in of carbon-intensive infrastructure. The applied scenarios must reflect the dynamics of the changing energy systems until climate target compliance is achieved.

The Advisory Board therefore recommends the following:

- The CBA methodology should specify that indicators be determined based on target-compliant scenarios only.
- The CBA methodology should ensure that all information from the climate-target compliant scenarios is used for the quantification of indicators until the time horizon in which targets are achieved.

3.2. Perform systematic sensitivity analysis on recent and projected climate years

ENTSO-E's draft CBA methodology 4.0 includes a sensitivity analysis on climate years. The B6 indicator, 'adequacy to meet demand benefit', is calculated based on 'several hundreds of Monte Carlo years' using 'several climate years combined with plant (and if possible, grid) outage patterns'. The methodology indicates that the number of climate years will be determined in the 'Implementation Guidelines' (issued at each TYNDP cycle, every 2 years).

The resilience of the energy infrastructure projects needs to be tested over the full range of potential future climate scenarios over their lifetimes, as recommended in the European Commission's guidelines (EC, 2021a). The analysis must also take account of compound events. Compound events can lead to extreme impacts on infrastructure and systems that are much larger than the sum of the impacts of individual events alone, especially in the occurrence of positive feedback mechanisms. This is because multiple climate drivers can affect the resilience of a system faster. Compound events can be classified as follows (Seneviratne et al., 2021): (i) two or more extreme events occurring simultaneously or successively, (ii) combinations of extreme events with underlying conditions that amplify the impact of the events, or (iii) combinations of events that are not themselves extreme but lead to an extreme event or impact when combined. Examples of compound events include the co-occurrence of a heat wave and drought, the co-occurrence of extreme precipitation and extreme winds, and coastal flooding coupled with wind hazards associated with a storm.

The frequency of compound events has increased as a result of human-induced climate change and will probably continue to increase with further global warming (Ridder et al., 2022; Seneviratne et al., 2021). For instance, concurrent heat waves and droughts (as occurred in western Europe in summer 2022) have become more frequent, and this trend will continue with increasing global warming (IPCC, 2022a).

Traditional risk assessment methods typically consider only one event at a time, potentially leading to underestimation of risk (Zscheischler et al., 2018). Such compound risk analysis within the TYNDP will also need to take account of the risk of cascading impacts triggered by compound events (Niggli et al., 2022). Recent examples of such a scenario include (a) the series of violent thunderstorms (Derecho event) in that occurred Corsica and parts of north Italy and Austria following a compound event consisting of a marine heat wave and a persistent atmospheric blocking pattern (summer 2022) and (b) the destructive forest fires in Greece that followed a compound event of a heat wave coupled with a drought (summer 2021). The more local and specific the data are, the more accurate the assessment; it can be informed by, among other things, national and local disaster risk reduction strategies (EC, 2021a).

The Advisory Board therefore recommends the following:

- Sensitivity analysis should integrate recent climate years in the historic time series, as well as modelled projections for future climate years and patterns, including extreme weather events.
- Sensitivity analysis should also take into consideration compound climate events and cascading risks.
- The choice of climate years should draw on the latest scientific evidence on climate change trends as well as on climate change projections up to 2050.
- Climate years and related projections should feed into climate vulnerability and risk assessment, e.g. as recommended in the European Commission's guidelines (EC, 2021a).

Further guidance on future climate projections can be found on the CLIMATE-ADAPT Platform (e.g. Adaptation case studies) developed by the European Commission and the European Environment Agency.

3.3. Ensure that the choice of sensitivity parameters is transparent and driven by the latest science

The sensitivity parameters applied in the CBA have potentially major implications for emission intensity and resilience of the energy system. Sensitivity parameters include fuel and CO_2 price, the long-term societal cost of CO_2 emissions, climate year, load, conventional thermal power plants' must-run conditions, installed generation capacity, flexibility of demand and generation, storage availability and projects' commissioning years. The sensitivity parameters and the projects that they are to be applied to will be defined in the Implementation Guidelines (ENTSO-E, 2022). Sensitivity analyses may become a defining factor in the overall CBA results, with a risk of creating a systematic bias against certain investment categories and projects, should the choice and scope of applied sensitivities be left ungoverned and subject to arbitrary decision-making.

The Advisory Board therefore recommends the following:

- ENTSO-E and ENTSO-G should ensure that the choice of applied sensitivity parameters, the projects to which they apply and their assessment framework is transparent and driven only by the latest science.

3.4. Make counterfactual calculations more transparent

The ENTSO-E CBA methodology 4.0 describes the counterfactual, i.e. the backdrop against which the projects are evaluated, as defined by market and network simulations that are performed based on a project's inclusion in, or removal from, the reference grid. The market model and assumptions are relatively transparent; the network model is, however, much more closed owing to various public safety and commercial sensitivity concerns.

Transparency of market and network models and calculations is key to ensuring public scrutiny of political investment decisions based on the TYNDP outputs and is successfully encouraged in some American and European jurisdictions (National Grid, 2023; RMI, 2020). The traditionally closed and proprietary nature of energy system planning at national levels is no longer fit for purpose, given the interconnected market fundamentals and the need for rapid reductions in GHG emissions and integration of wind, solar and storage technologies (Morrison, 2018; Pfenninger et al., 2018). The FAIR (findable, accessible, interoperable and reusable) principles for data management, endorsed by among others the European Commission in the Horizon Europe programme, could inspire reflection on how to make the models and calculations more transparent (CSEI, 2022; EC, 2016b; Wilkinson et al., 2016).

The Advisory Board therefore recommends the following:

- The market and network models used by ENTSO-E and ENTSO-G to calculate projects' relative costs and benefits should be made as accessible as possible based on existing good practice across the world in line with the FAIR (findable, accessible, interoperable and reusable) principles. The models could be uniformly applied by ENTSO-E and ENTSO-G and made available to non-TSO project promoters for the CBA calculations.

4. Ensure an adequately granular net present value assessment

The CBA methodology 4.0 describes how to calculate the NPV and BCR of a project based on annual cash flow accounts of costs and monetised benefits. The guidelines do not advise how the different indicators should be prioritised or considered in decision-making. In general, NPV and BCR demonstrate the viability of the investment and facilitate a comparison of competing investments where consistent assumptions are applied. It is therefore crucial that NPV and BCR calculations are sufficiently defined and adequately governed.

4.1. Duly consider project long-term benefits through assessment period and benefit-to-cost ratio

The draft CBA methodology 4.0 defines the assessment period across all available technologies as 25 years, and demands that the terminal value after that period is zero.

Applying the same expected useful life for all available technologies sets long-lived technologies (e.g. submarine power cables) on a par with shorter-lived technologies, as well as transitory ones (e.g. fossil gas projects). Some projects may have considerable long-term benefits that are neglected.

We acknowledge that it becomes more difficult to compare values of projects with differing lifetimes (especially based on non-normalised NPV). However, we find that the disadvantages of an approach using the same lifetimes for all projects across all categories outweigh its benefits.

For differing project lifetimes across project types, a consistently applied guideline on the expected useful life of each technology is needed in order to incentivise investments in assets that are aligned with the 2050 targets. Explicit reference to the expected economic life of each available technology can ensure a fair comparison between technologies, a better capture of full benefits and costs and more transparency for project selection.

The Advisory Board therefore recommends the following:

- The CBA methodology should apply assessment periods that reflect realistic project lifetimes. As a consequence of using differing project lifetimes, PCI/PMI selection decision-making should focus more on normalised BCR than on (non-normalised) NPVs.

4.2. Allow for granular net present value and benefit–cost ratio calculations

Since the CBA methodology is a more stable document than the Implementation Guidelines, with a longer lifespan, it does not refer to specific years by which full quantification of indicators is required. Instead, it refers to the 'mid term' (typically 5–10 years), the 'long term' (typically 10–20 years) and the 'very long term' (typically 30–40 years). These terms are further specified in the Implementation Guidelines, in which, we understand, fixed study years are also defined. In the ongoing 2022 TYNDP process, two study years have been defined by which full quantification of indicators is required: 2030 and 2040.

Net present value and BCR calculations require annual values for the whole project lifetime that go beyond the study years. The draft CBA methodology 4.0 describes the following approach. Before the first study year (e.g. 2030), the same values as from the first study year should be applied. Between study years, values should be interpolated linearly. After the last study year (e.g. 2040), values of the last study year should be repeated. This relatively rigid and static approach is applied to projects with different commissioning and decommissioning dates, which creates some issues. We may see a systematic bias against certain types of projects; notably, early benefits from quickly implementable projects in systems with relatively high emission factors can be underestimated. Moreover, benefits and costs that occur primarily in the long term are potentially misrepresented, despite the availability of scenario data points.

The Advisory Board sees benefit in the quantification of indicators for the short term (i.e. a study year that corresponds to the year of commissioning), the mid term and the long term. This will reduce the need for repeating values. In addition, the draft CBA methodology 4.0 already mentions that scenarios must be provided that are representative of at least two study years in the mid-term horizon ($n + 5$ and $n + 10$), which means that scenario data will be available for a more granular quantification of indicators in the mid term. As mentioned, the draft CBA methodology 4.0 does not define the study years for which full quantification of indicators is required (to be defined in the Implementation Guidelines). Acknowledging this, and with reference to the previously applied study years, we express concern about the limited extent and granularity to which indicators are quantified. This could be mitigated, for instance by following ACER's opinion that 'the use of fixed years (rounded to full five years) could facilitate data availability, comparability and consistency checks over time' (ACER, 2020). In addition to that, annually varying values should be used for crucial exogenous input factors, such as the cost of carbon.

The Advisory Board therefore recommends the following:

- The CBA methodology should specify that study years will include short-term, mid-term – and long-term – horizons.
- ENTSO-E, ENTSO-G and the European Commission should investigate the impact of using a more granular quantification of indicators in NPV and BCR calculations. This investigation should include study years at 5-year intervals and annual values for crucial exogenous input factors, such as the cost of carbon.

4.3. Consider the choice of discount rate

The draft CBA methodology 4.0 requires that all NPV calculations use a common discount rate in real terms, which is set at 4 %. The choice of discount rate is a highly important assumption in CBA (EC, 2021b). Even marginal changes in the discount rate can influence the evaluation of a proposal considerably, as they result in substantial changes in the NPV of future costs and benefits. The higher the discount rate, the less value is put on future values, including on the social cost of future carbon emissions in today's terms (OECD, 2018; Stern, 2007). Many EU countries choose discount rates lower than 4 %. Furthermore, recent findings in the scientific literature point to declining discount rates as suitable choices for long-term assessments, valuing impacts on the next generations more adequately (see, for example, Bula and Foltyn-Zarychta, 2023). The European Commission most recently recommended a 3 % (in real terms) social discount rate for EU policy analysis (EC, 2021c).

The Advisory Board therefore recommends the following:

- The European Commission, ENTSO-E and ENTSO-G should jointly reflect on the need to update the applicable discount rate.

5. Consider project implementation feasibility

Transformational changes ahead for EU energy systems require the implementation of energy infrastructure projects at an unprecedented scale and speed. The projects undergoing CBA have different levels of maturity and potential for timely implementation (feasibility). Around 40 % of monitored PCI have their commissioning dates postponed every year as a result of delays and/or rescheduling (ACER, 2022). Such delays are problematic from a climate perspective, as they result in these projects failing to deliver emission reductions by the expected time and may delay the overall energy transition. Environmental and social aspects are often key factors that slow down project implementation (EC et al., 2021). Delays may be due to a range of external and internal factors, not all of which can be easily foreseen and prevented.

Other issues related to the feasibility of project implementation are equally worth exploring. The range of factors that feasibility depends on includes geophysical, environmental–ecological, technological, economic, socio–cultural and institutional factors. Notably, large infrastructure projects often have considerable impact on local communities and citizens; their concerns must be taken seriously. Feasibility may change over time, for instance when the enabling conditions are strengthened (IPCC, WGIII, 2022). Decision-makers should have access to information about feasibility, as well about the environmental and social impacts of projects, to enable more informed decisions. Such information can also help mitigate the risks of project delays by requiring project promoters to systematically anticipate delaying factors and calculating more realistic commissioning dates on this basis.

5.1. Include information on implementation feasibility in decision-making

The draft CBA methodology 4.0 includes a new feature: assessment of commissioning dates, aimed at indicating project maturity and reported as additional information. The assessment, starting from the study year, takes into account project duration linked to the permitting process, the construction phase and complexity. Project complexity is considered in terms of technology, set-up, offshore or onshore location, new or updated project, and environmental and social aspects. The new feature is a welcome starting point for informing about project feasibility and delay probabilities. The development of a quantitative project feasibility indicator could help decision-makers select projects with the highest likelihood of timely completion and the lowest social and environmental impacts.

The Advisory Board therefore recommends the following:

- Decision-makers should duly consider commissioning years submitted by the project promoters as part of the CBA results.
- ENTSO-E should further expand the commissioning dates assessment to capture likelihood levels of timely project implementation, together with net impacts of delays, in the form of a new quantified indicator.

5.2. Mitigate project negative impacts and delays

The draft CBA methodology 4.0 asks for an estimation of project expenditure linked to mitigating negative environmental and social impacts and a description of the remaining environmental and social aspects of the project (residual impacts S1 and S2). No monetisation of the residual impacts is required, while it is indeed standard practice to include public preferences and the monetisation of related economic loss in CBAs (OECD, 2018). At the very least, project promoters should reflect on ways to reduce negative societal and environmental impacts in the form of a mitigation plan, and address citizen engagement aspects. Such reflection on and anticipation of acceptance aspects at the CBA stage can improve project design and may lead to a win–win situation for the project and for society (EC et al., 2021). Moreover, the socio-environmental costs and benefits, such as impact on air pollution, may play an important role when determining cross-border cost allocation of PCI (Sun et al., 2020) in line with Article 16(5) of the TEN-E regulation. Such cost-sharing agreements may facilitate the implementation of PCI (EC, 2021a).

The Advisory Board therefore recommends the following:

- The CBA methodology should encourage project promoters to mitigate negative project impacts and the risk of delays by considering public concern linked to environmental and social impacts at the project CBA stage. An assessment of the project's importance, impact level and mitigation options based on the latest best practice could be provided as part of the environmental and social impacts information in the CBA.

6. Adequately capture renewable energy integration benefits

Energy efficiency and widespread electrification based on RES could enable full decarbonisation of the EU energy system by 2050 (see, for example, Rosenow and Eyre, 2022). Integrating renewable power generation at scale to reach national and EU targets will require substantial investment in onshore and offshore grids, for both cross-border interconnections and internal national grids (ENTSO-E, 2023c). It will also require more investment in options to provide system services (e.g. frequency control) and flexibility (e.g. provided by demand side response, batteries, pumped hydro storage and renewable gas storage). Furthermore, TEN-E regulation, in Annex V (6), stipulates that the CBA methodologies developed by ENTSO-E and ENTSO-G 'shall explain that the development and deployment of renewable energy will not be hampered by the project'. According to our understanding, based on consultations related to the draft CBA methodology 4.0, this principle is not yet fully reflected, as no consensus has been reached on its appropriate implementation (ENTSO-E, 2023d).

6.1. Capture project ability to enable additional renewable energy source capacities

The current approach based on incremental changes compared with a predetermined reference grid captures benefits related to the direct connection of RES and to avoided curtailment thanks to reduced congestion (benefit indicator B3). We find that, because of the static nature of the counterfactual calculation, the relevant benefit indicators insufficiently capture the potential benefits of projects related to unlocking of additional investment in RES and hence increased RES integration related to capacities that are not included in the reference grid, especially if this occurs through cross-sectoral integration dynamics.

The Advisory Board therefore recommends the following:

- The CBA methodology should more adequately capture benefits linked to additional RES capacities that are enabled by the project under assessment (indicators B1 and B3), going beyond the connection of RES capacities already accounted for in the reference grid and avoiding curtailment of electricity produced from these sources.

6.2. Use the common EU legal definition of renewable energy

The draft CBA methodology 4.0 defines RES as 'any non-conventional energy sources to be defined within the study specific Implementation Guidelines'. This is an unnecessary ambiguity given that today renewable energy is well defined and part of what can be called conventional energy. In fact, renewable energy is dominant in capacity-increasing investments in Europe and worldwide (IRENA, 2022). Renewable energy is comprehensively defined under the EU Renewable Energy Directive (EU, 2018).

A uniform definition applied in the EU context increases the transparency and efficiency of EU law and policy implementation. The CBA methodology developed under Article 11 of the TEN-E regulation contributes to that implementation.

The Advisory Board therefore recommends the following:

- The definition of RES applied in CBA methodologies developed under Article 11 of the TEN-E regulation should be aligned with the definition of RES set out in Article 2 of the EU Renewable Energy Directive.

7. Adequately assess multisectoral dynamics to identify the most beneficial solutions

The revision of the TEN-E regulation was aimed at strengthening the multisectoral consistency of the CBA methodologies, as well as reflecting the energy efficiency first principle and its contribution to EU climate neutrality objectives in all steps of the TYNDP process. However, operational and market solutions, efficiency measures and cross-sectoral projects could still be at a disadvantage in the current TYNDP and PCI/PMI processes, owing to persistent systemic biases stemming from the rather static nature of the system assessment, the implementation of CBA methodologies and the governance of the processes.

This can be an issue, as the European Commission has recently highlighted the importance of better use of existing infrastructure by operational and market mechanisms as well as the use of energy-efficient technologies (EC, 2021d). It is well recognised that flexibility tools that facilitate management of demand (ramps and peaks) play a key role in achieving the EU climate neutrality targets, especially if they are based on demand-side response by consumers, with the potential to reduce the need for new energy infrastructure (EC, 2021d; IRENA, 2019). Demand-side solutions are often outside the control of TSOs and DSOs, and their implementation depends on relatively new actors such as energy-saving companies. The EC thus recognises that 'it is important to find ways to ensure comparability between short-term measures and long-term investments, as well as developing mechanisms that could guarantee reliability of contracted measures in the longer-time perspective' (EC, 2021d). However, these project types and actors seem underrepresented in the current TYNDP process ("Conclusions of 8th Energy Infrastructure Forum, 2-3 June, Copenhagen," 2022).

Similarly, electrification of energy demand, notably in the heating sector (EEA, 2023b; Thomaßen et al., 2021), as well as in the transport and industry sectors, has considerable potential in terms of EU energy system decarbonisation and resilience in line with the energy efficiency first principle (EC, 2020). Electrification of transport, heating/cooling and industry may generate substantial new electricity demands, but also offers considerable new demand flexibility (IPCC, 2022b). Projects with primarily cross-sectoral benefits that have a dynamic impact on demand and production patterns and that may shift investment needs also seem to be underrepresented and under-evaluated in the current TYNDP process and the CBA methodology.

Multisectoral integration that enables the capturing of transactions between different parts of the energy system is new and not yet mature in the draft CBA methodology developed by ENTSO-E. In the ENTSO-E draft CBA methodology 4.0 the sector-coupling impacts are captured mostly through cross-sector rents as part of the socioeconomic welfare (benefit indicator B1). They are calculated from the price difference between two coupled sectors, the energy conversion efficiency and the additional power that is required for the energy conversion from energy carrier A to energy carrier B. Their calculation is optional.

The Advisory Board therefore recommends the following:

- The CBA methodology should further elaborate on ways to account for the impacts of sector coupling and make it non-optional. This could be guided by the European Commission recommendation C(2021) 7014 on 'Energy Efficiency First: from principles to practice' (EC, 2021d).

Conclusions

Overall governance of the TYNDP and PCI/PMI processes

The Advisory Board recommends that:

- All key steps of the TYNDP/PCI-PMI processes, including scenario development, system needs assessment and CBA, as well as all intermediate steps, be guided by and comply with EU climate targets.
- Climate mitigation and resilience aspects cutting across all steps and investment categories of the TYNDP and PCI/PMI processes should be handled consistently and in an integrative way that facilitates joint institutional learning and new knowledge collection and use.
- Coordination between ENTSO-E and ENTSO-G, as well as between the European Commission and both ENTSO-E and ENTSO-G, should be made more transparent.
- ENTSO-E, ENTSO-G, the DG Energy, and ACER should deploy the necessary capacities and capabilities required to conduct the process, as well as to develop new activities in response to transformational changes ahead.
- ENTSO-E, ENTSO-G, and the European Commission should systematically and proactively involve key stakeholders, including non-incumbent actors such as the EU Distribution System Operators (DSO) Entity.

Specific aspects of the CBA

The Advisory Board recommendations can be split into categories related to the proposed indicators, assumptions, calculations and practices outlined in the ENTSO-E draft CBA methodology 4.0.

New indicators
• The CBA methodology should include quantifiable indicators on climate adaptation costs, monetised where possible. The CBA methodology should reflect the expected impacts of current and future site-specific climate conditions on costs, including insurance and asset lifetime considerations. The climate-sensitive design threshold of specific technologies should be analysed.
• The CBA methodology should include a quantified indicator, or benefit–cost ratios (BCRs), to reflect the benefits of climate resilience.
• ENTSO-E should further expand the commissioning dates assessment to capture the likelihood of timely project implementation, together with net impacts of delays in the form of a new quantified indicator.
• The CBA methodology should further elaborate on ways to account for the impacts of sector coupling and make it non-optional.
Adjusted indicators
• The CBA methodologies should adopt a consistent approach to GHG emissions accounting, including methane, and express emissions in CO_2 equivalents. This would involve using uniform approaches to the counterfactual, emission factors and efficiency coefficients, as well as their monetisation.

- The CBA methodology should give guidance on how to provide project-specific descriptions and cost estimates of adaptation measures relating to climate variables and climate-related hazards.
- The CBA methodology should encourage project promoters to mitigate negative project impacts and the risk of delays by considering public concern linked to environmental and social impacts at the project CBA stage. An assessment of the project's importance, impact level and mitigation options based on the latest best practice could be provided as part of the environmental and social impacts information in the CBA.
- The CBA methodology should more adequately capture benefits linked to additional renewable energy source (RES) capacities that are enabled by the project under assessment (indicators B1 and B3), going beyond the connection of RES capacities already accounted for in the reference grid and avoiding curtailment of electricity produced from these sources.

Adjusted calculations/assumptions

- The CBA methodology should use a single source for inputs regarding the cost of GHG emissions, and the inputs should evolve over time. The source could be, for example, the most recent document developed by the European Commission.
- The cost of GHG emissions should be based on an opportunity cost approach for the entire EU climate policy, i.e. one that considers options both within and outside the EU Emissions Trading Scheme.
- The cost of GHG emissions should include more granular inputs with respect to time development, e.g. annual values.
- The CBA methodology should specify that indicators be determined based on target-compliant scenarios only.
- The CBA methodology should ensure that all information from the climate target-compliant scenarios is used for the quantification of indicators until the time horizon in which targets are achieved.
- Sensitivity analysis should integrate recent climate years in the historic time series and modelled projections for future climate years and patterns, including future extreme weather events.
- Sensitivity analysis should also take into consideration compound climate events and cascading risks.
- The choice of climate years should draw on the latest scientific evidence on climate change trends and on climate change projections up to 2050.
- Climate years and related projections should feed into climate vulnerability and risk assessment, e.g. as recommended in the European Commission guidelines (EC, 2021a).
- The CBA methodology should require assessment periods that reflect realistic project lifetimes.
- The CBA methodology should specify that study years include short-term, mid-term – and long-term – horizons.
- ENTSO-E, ENTSO-G, and the European Commission should investigate the impact of more granular quantification of indicators in NPV and BCR calculations. This investigation should include study years at 5-year intervals and annual values for crucial exogenous input factors, such as the cost of carbon..
- The European Commission, ENTSO-E, and ENTSO-G should jointly reflect on the need to update the applicable discount rate.

- The definition of RES applied in CBA methodologies developed under Article 11 of the TEN-E regulation should be aligned with the definition of RES set out in Article 2 of the EU Renewable Energy Directive.

Adjusted practices for the CBA methodology

- Building on institutional learning and new knowledge integration within the TYNDP processes, the CBA methodology should link to relevant empirical adaptation data, enabling the tracking of the costs of extreme weather event management to help quantify the avoided damages with respect to subsequent updates and improvements of the quantitative CBA indicators.

- ENTSO-E and ENTSO-G should ensure that the choice of applied sensitivity parameters, the projects to which they apply and their assessment framework is transparent and driven only by the latest science.

- The market and network models used by ENTSO-E and ENTSO-G to calculate projects' relative costs and benefits should be made as accessible as possible based on existing good practice across the world and in line with the FAIR (findable, accessible, interoperable and reusable) principles. The models could be uniformly applied by ENTSO-E and ENTSO-G and made available to non-TSO project promoters for the CBA calculations.

Adjusted practices for using CBA results

- Decision-makers should consider commissioning years submitted by the project promoters as part of the CBA results.

References

ACER, 2023. Public consultation on the update of ACER's Recommendation on good practices for the treatment of the investment requests, including cross-border cost allocation requests for projects of common interest.

ACER, 2022. Consolidated report on the progress of electricity and gas Projects of Common Interest. European Union Agency for the Cooperation of Energy Regulators, Ljubljana, Slovenia.

ACER, 2020. Opinion No 03/2020 of the European Union Agency for the Cooperation of Energy Regulators of 6 May 2020 on the ENTSO-E draft 3rd guideline for cost benefit analysis of grid development projects. European Union Agency for the Cooperation of Energy Regulators, Ljubljana, Slovenia.

Allard, S., Mima, S., Debusschere, V., 2020. European transmission grid expansion as a flexibility option in a scenario of large scale variable renewable energies integration. Energy Economics 87. https://doi.org/10.1016/j.eneco.2020.104733

Bula, R., Foltyn-Zarychta, M., 2023. Declining Discount Rates for Energy Policy Investments in CEE EU Member Countries. Energies 16, 1–27. https://doi.org/10.3390/en16010321

CEN/CENELEC, 2022. Tailored guidance for standardization technical committees: how to include adaption to climate change (ACC) in European infrastructure standards.

Conclusions of 8 the Energy Infrastructure Forum, 2-3 June, Copenhagen, 2022. . Presented at the Energy Infrastructure Forum, Copenhagen, Denmark.

CSEI, 2022. Draft methodology for integrated network planning in Europe a deliverable of the STEERS-project. Copenhagen, Denmark.

EC, 2021a. Commission Notice - Technical guidance on climate proofing of infrastructure in the period 2021-2027 (C/2021/5430), OJ C 373, 16.9.2021, p. 1–92.

EC, 2021b. TYNDP 2020 joint scenarios methodology : a CSEI assessment. Luxembourg.

EC, 2021c. 'Better regulation' toolbox – November 2021 edition. European Commission, Brussels, Belgium.

EC, 2021d. Commission Recommendation (EU) 2021/1749 of 28 September 2021 on Energy Efficiency First: from principles to practice — Guidelines and examples for its implementation in decision-making in the energy sector and beyond, C/2021/7014.

EC, 2020. Powering a climate-neutral economy: An EU Strategy for Energy System Integration, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

EC, 2016a. Guidelines for Project Managers: Making vulnerable investments climate resilient. European Commission.

EC, 2016b. Guidelines on FAIR Data Management in Horizon 2020. European Commission, Brussels, Belgium.

EC, ENTSO-E, Intrasoft International, Navigant, Planet, Valeu Consulting, White Research, 2021. Innovative actions and strategies to boost public awareness, trust and acceptance of trans-European energy infrastructure projects. European Commission, Brussels, Belgium.

EEA, 2023a. Assessing the costs and benefits of climate change adaptation (briefing). European Environment Agency, Copenhagen, Denmark.

EEA, 2023b. Decarbonising heating and cooling — a climate imperative (briefing). European Environment Agency, Copenhagen, Denmark.

EEA, 2022. Trends and projections in Europe 2022 (Publication No. 10/2022). European Environment Agency, Copenhagen.

EEA, 2019. Adaptation challenges and opportunities for the European energy system, (No. 1/2019). European Environment Agency, Copenhagen, Denmark.

EIB, 2020. EIB Group Climate Bank Roadmap 2021-2025.

ENTSO-E, 2023a. Stakeholders Engagement Report. European Network of Transmission System Operators for Electricity, Brussels, Belgium.
ENTSO-E, 2023b. Implementation Guidelines for TYNDP 2022 based on 3rd ENTSO-E guideline for cost benefit analysis of grid development projects. European Network of Transmission System Operators for Electricity.
ENTSO-E, 2023c. High-Level Report TYNDP 2022. European Network of Transmission System Operators for Electricity, Brussels, Belgium.
ENTSO-E, 2023d. Slides for the public workshop on 4th ENTSO-E Guideline for CBA of grid development projects, slide 8.
ENTSO-E, 2022. 4 th ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects, Draft version 4.0 for public consultation.
ENTSO-E, RGI, 2023. Joint ENTSO-E & RGI Conference on Adaptation & Resilience - Ensuring the energy transition is built on resilient infrastructure [WWW Document]. URL https://www.entsoe.eu/events/2023/03/14/save-the-date-joint-entso-e-rgi-conference-on-adaptation-resilience-ensuring-the-energy-transition-is-built-on-resilient-infrastructure/ (accessed 2.28.23).
ENTSO-G, 2023. ENTSOG Single-Sector Cost-Benefit Analysis (CBA) Methodology Preliminary Draft. European Network of Transmission System Operators for Gas, Brussels, Belgium.
ESMAP, 2022. ECONOMIC ANALYSIS OF POWER PROJECTS: INTEGRATION OF CLIMATE CHANGE AND DISASTER RESILIENCE. International Bank for Reconstruction and Development / The World Bank, Washington DC, US.
EU, 2022. Regulation (EU) 2022/869 of the European Parliament and of the Council of 30 May 2022 on guidelines for trans-European energy infrastructure, OJ L 152, 3.6.2022, p. 45–102.
EU, 2018. Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast), OJ L 328, 21.12.2018, p. 82–209.
European Scientific Advisory Board on Climate Change, 2022. Advice on scenario guidelines for trans-European networks for energy. Copenhagen, Denmark.
Figueiredo, R., Nunes, P., Brito, M.C., 2021. The resilience of a decarbonized power system to climate variability: Portuguese case study. Energy 224. https://doi.org/10.1016/j.energy.2021.120125
France Stratégie, 2019. The value for climate action a shadow price of carbon for evaluation of investments and public policies. Paris, France.
Golombek, R., Lind, A., Ringkjøb, H.-K., 2022. The role of transmission and energy storage in European decarbonization towards 2050. Energy 239. https://doi.org/10.1016/j.energy.2021.122159
IEA, 2021. Climate Resilience. Electricity Security 2021. International Energy Agency, Paris, France.
IPCC, 2022a. Climate Change 2022: Impacts, Adaptation and Vulnerability, Working Group II Contribution to the Sixth Assessment Report. The Intergovernmental Panel on Climate Change, Geneva, Switzerland.
IPCC, 2022b. Working Group III contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change -Summary for Policy Makers.
IPCC, WGIII, 2022. Climate Change 2022, Mitigation of Climate Change Summary for Policymakers.
IRENA, 2022. Renewable Energy Statistics 2022. The International Renewable Energy Agency, Abu Dhabi, UAE.
IRENA, 2019. Demand-side flexibility for power sector transformation. The International Renewable Energy Agency, Abu Dhabi, UAE.
Isacs, L., Finnveden, G., Dahllöf, L., 2016. Choosing a monetary value of greenhouse gases in assessment tools: A comprehensive review. Journal of Cleaner Production 127, 37–48. https://doi.org/10.1016/j.jclepro.2016.03.163
JRC, 2022a. Harmonised system-wide cost-benefit analysis for candidate hydrogen projects. Joint Research Centre, Petten, the Netherlands.

JRC, 2022b. Harmonised system-wide cost-benefit analysis for candidate electrolyser projects. Joint Research Centre, Petten, the Netherlands.
JRC, 2022c. Harmonised system-wide cost-benefit analysis for candidate smart gas grid projects. Joint Research Centre, Petten, the Netherlands.
JRC, 2022d. Harmonised system-wide cost-benefit analysis for candidate smart electricity grid projects. Joint Research Centre, Petten, the Netherlands.
JRC, 2022e. Harmonised system-wide cost-benefit analysis for candidate carbon-dioxide transport network projects. Joint Research Centre, Petten, the Netherlands.
JRC, 2022f. Harmonised system-wide cost-benefit analysis for candidate energy storage projects. Joint Research Centre, Petten, the Netherlands.
JRC, 2022g. Drought in Europe. Joint Research Centre, Ispra, Italy.
Klaaßen, L., Steffen, B., 2023. Meta-analysis on necessary investment shifts to reach net zero pathways in Europe. Nature Climate Change 13.
McKinsey, 2021. How to increase grid resilience through targeted investments.
Millstein, D., Wiser, R., Jeong, S., 2023. The Latest Market Data Show that the Potential Savings of New Electric Transmission was Higher Last Year than at Any Point in the Last Decade. Lawrence Berkeley National Laboratory.
Morrison, R., 2018. Energy system modeling: Publicvtransparency, scientific reproducibility, and open development. Energy Strategy Reviews 20, 49–63. https://doi.org/10.1016/j.esr.2017.12.010
National Grid, 2023. National Grid ESO Data Portal [WWW Document]. URL https://data.nationalgrideso.com/ (accessed 2.27.23).
Niggli, L., Huggel, C., Muccione, V., 2022. Towards improved understanding of cascading and interconnected risks from concurrent weather extremes: Analysis of historical heat and drought extreme events. PLOS Climate. https://doi.org/10.1371/journal.pclm.0000057
OECD, 2018. Cost-Benefit Analysis and the Environment: Further Developments and Policy Use. Paris, France.
Pfenninger, S., Hirth, L., Schlecht, I., Schmid, E., Wiese, F., Brown, T., 2018. Opening the black box of energy modelling: Strategies and lessons learned. Energy Strategy Reviews 19, 63–71. https://doi.org/10.1016/j.esr.2017.12.002
RGI, 2021. How can we increase the climate resiliency of the electricity system?
Ridder, N., Ukkola, A., Pittman, 2022. Increased occurrence of high impact compound events under climate change. npj climate and atmospheric science 5. https://doi.org/10.1038/s41612-021-00224-4
RMI, 2020. How to Build Clean Energy Portfolios: A Practical Guide to Next-Generation Procurement Practices. Rocky Mountain Institute.
Rosenow, J., Eyre, N., 2022. Reinventing energy efficiency for net zero. Energy Research & Social Science 90. https://doi.org/10.1016/j.erss.2022.102602
Seneviratne, S.I., X. Zhang, M., Adnan, M., 2021. 2021: Weather and Climate Extreme Events in a Changing Climate. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change, Cambridge, UK.
Stern, N.H. (Ed.), 2007. The economics of climate change: The Stern review. Cambridge University Press, Cambridge, UK.
Sun, D., Olmos, L., Rivier, M., 2020. Considering Local Air Pollution in the Benefit Assessment and Cost Allocation of Cross Border Transmission Projects. Energies. https://doi.org/10.3390/en13061426
Thomaßen, G., Kavvadias, K., Jiménez Navarro, J.P., 2021. The decarbonisation of the EU heating sector through electrification: parametric analysis. Energy Policy 148. https://doi.org/10.1016/j.enpol.2020.111929
Tol, R.SJ., 2019. Climate economics: economic analysis of climate, climate change and climate policy. Edward Elgar Publishing.

Wilkinson, M., Dumontier, M., Aalbersberg, I., 2016. The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data 3. https://doi.org/10.1038/sdata.2016.18

Zscheischler, J., Westra, S., Van Den Hurk, B., 2018. Future climate risk from compound events. Nature Climate Change 8, 469–477.

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