Setting climate targets based on scientific evidence and EU values

Initial advice to the European Commission on an EU-wide 2040 climate target and a greenhouse gas budget for the 2030–2050 period

European Scientific Advisory Board on Climate Change

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European Scientific Advisory Board on Climate Change
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel: +45 33 36 71 00
Web: climate-advisory-board.europa.eu
Enquiries: climate-advisory-board.europa.eu/contact

Manuscript completed in January 2023

Luxembourg: Publications Office of the European Union, 2024

PDF ISBN 978-92-9480-658-1 doi:10.2800/83937 TH-02-24-644-EN-N

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About the European Scientific Advisory Board on Climate Change

The European Scientific Advisory Board on Climate Change 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:

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- Joeri Rogelj
- Nicolaas Schrijver
- Jean-Francois Soussana

The Advisory Board is supported in the execution of its tasks by a secretariat, hosted by the European Environment Agency.

1 Executive summary

1.1 Objectives of this initial advice

With this document, the European Scientific Advisory Board on Climate Change (Advisory Board) provides an initial input to the European Commission on key principles to be considered in setting an EU-wide 2040 climate target and a greenhouse gas budget for the 2030–2050 period.

Under the European Climate Law, the European Commission is required to make a proposal for the EU's 2040 greenhouse gas emissions reduction target and to publish a projected indicative 2030-2050 greenhouse gas budget in the first half of 2024[1]. To prepare this proposal, the European Commission is expected to conduct detailed analysis including a public consultation and an impact assessment featuring modelling and scenario analysis.

The Advisory Board has chosen to publish its first advice on this topic in early 2023 in order to provide a constructive and timely input in advance of the European Commission's preparations. Following the publication of this initial guiding input, the Advisory Board intends to publish quantitative advice within the first half of 2023, before the Commission finalises its proposal. This advice will consist of an indicative range of emission pathways for the EU, based on available modelling results selected in accordance with the principles and method described in this initial input, the associated interim target values, and a discussion of the implications of choosing between different pathways.

The Advisory Board's results will provide a basis for analysing and understanding the implications of the European Commission's proposal. While both the European Commission and the Advisory Board will prepare quantitative analyses of post-2030 decarbonisation pathways, their respective outputs will differ in terms of their content, their timing and their legal status, as described below.

- While the Advisory Board will make use of existing modelling results to produce relevant scenarios and pathways for the EU, the European Commission may produce new scenarios based on its own modelling capacity and expertise.
- The publication of the Advisory Board's initial advice in early 2023 and quantitative advice within the first half of 2023 aims to contribute to the public discourse and to leave time for the European Commission to consider the Advisory Board's recommendations in its analysis accompanying its target proposal.
- The Advisory Board's advice on EU emission pathways will not have the same legal status, as the European Commission's proposal. The Commission might also interpret and apply EU values in a different way from the Advisory Board.

1.2 The Paris Agreement context and European Climate Law

To strengthen the global response to climate change, the 2015 Paris Agreement sets a long-term goal of limiting the global temperature increase to well below 2 degrees Celsius while pursuing efforts to limit the increase to 1.5 degrees relative to preindustrial levels.

In pursuit of this temperature goal, the European Climate Law was adopted in 2021 and sets a binding objective for the EU to reach climate neutrality by 2050, with the aim of achieving negative emissions thereafter. The European Climate Law also sets the 2030 emissions reduction target for the EU (to reduce

(1) Regulation 2021/1119 of the European Parliament and of the Council of 30 June 2021, Art. 4. The deadline for the proposal is within 6 months of the conclusion of the Paris Agreement Global Stocktake, which continues until December 2023.

net domestic greenhouse gas emissions by at least 55% compared with 1990 levels) and mandates the European Commission to propose an EU-wide climate target for 2040, together with a projected indicative EU greenhouse gas budget for the 2030-2050 period, at the latest within six months of the conclusion of the first Global Stocktake under the Paris Agreement.

The European Climate Law also established the Advisory Board to ensure that EU climate action remains fully in line with the best available scientific evidence. The purpose of the Advisory Board is to serve as a point of reference for the EU on scientific knowledge relating to climate change by virtue of its independence and expertise. One of its key tasks is to provide scientific advice and issue reports on existing and proposed EU measures, climate targets and indicative greenhouse gas budgets and on their coherence with the objectives of the European Climate Law and the EU's international commitments under the Paris Agreement. In particular, the European Climate Law requires the European Commission to consider the advice of the Advisory Board when proposing the 2040 climate target and submitting the accompanying indicative greenhouse gas budget.

1.3 Recommendations for setting climate targets based on scientific evidence and EU values

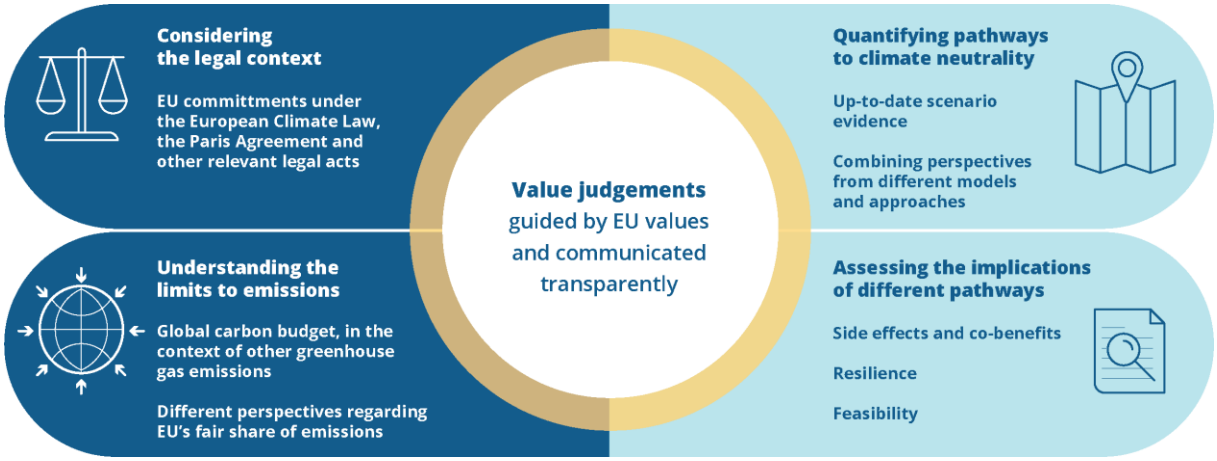
To prepare its proposal of an EU 2040 target and accompanying greenhouse gas budget, the European Commission must examine a considerable number of scientific, legal, technical and ethical issues[2]. This will require both technical analysis and value judgements and is expected to unveil tensions or trade-offs, for example between cost-effectiveness and social impacts.

The Advisory Board recommends that the European Commission follows an approach that is systematic, transparent and guided by EU values in order to ensure that it properly addresses the required combination of issues. To this end, the Advisory Board recommends that the European Commission's analysis considers the five following key areas, also presented in Figure 1:

1. the scientific and legal context;
2. the physical limits to global emissions and the EU's 'fair share';
3. the transformation scenarios towards net zero greenhouse gas emissions by 2050 for the EU;
4. the implications of different pathways in terms of side effects, co-benefits, resilience and feasibility;
5. the use of value judgements, especially when addressing tensions between different issues and principles.

([2]) For example, see Section 7 for an overview of the relevant principles, values and issues documented in EU law.

Figure 1 An evidence-based approach to setting scientifically sound EU climate targets guided by international legal commitments and EU values and principles



The Advisory Board recommends that the European Commission follows an approach that is systematic, transparent and guided by EU values.

For each of the five key areas to be considered by the European Commission in its target-setting exercise, the Advisory Board makes the following detailed recommendations.

Considering the legal context

1. The legal context: EU commitments under the European Climate Law the Paris Agreement and other relevant legal requirements

1.1 As a consequence of the EU's commitments to pursue efforts to limit global warming to 1.5 °C (under the 2015 Paris Agreement, the 2021 Glasgow Climate Pact and the 2022 Sharm el-Sheikh Implementation Plan), an intermediate 2040 target and 2030–2050 greenhouse gas budget should be consistent with these efforts.

Understanding the limits to emissions

2. Physical limits to global emissions and the EU's 'fair share': global carbon budget and perspectives on the EU's fair share of emissions

2.1 Intermediate targets for meeting the EU net zero greenhouse gas emissions target by 2050 should start from a scientifically sound estimate of the global carbon budget (the maximum amount of carbon dioxide consistent with the Paris temperature goal) and limits to other greenhouse gas emissions by making transparent choices in the factors that influence the carbon budget's size and which reflect physical climate and socio-economic uncertainties.

2.2 This estimate of the global budget should be used to determine an appropriate 'fair share' for the EU, using approaches that are consistent with principles based in European and international environmental law.

2.3 The EU should consider its mitigation target in the context of its assessed 'fair share' and as part of a broader set of measures that ensure an overall fair contribution of the EU and its Member States to the collective goals and commitments of the Paris Agreement. The EU's fair share might differ from the emissions implied by other considerations, such as cost-effectiveness.

Quantifying pathways to climate neutrality

3. Quantifying transformation scenarios[3] towards net zero greenhouse gas emissions by 2050 for the EU

3.1 Up-to-date scenario evidence should be used to ensure that aspects of costs, current policies and other global and regional trends are represented in the best possible way, combining perspectives from different models and approaches.

3.2 Issues related to the under- or over-representation of certain mitigation options, to societal choices or to transition dynamics in the scenario literature should be carefully considered and addressed.

Assessing the implications of different pathways

4. Assessing the implications of different pathways in terms of side effects, co-benefits, resilience and feasibility

4.1 Proposals for EU pathways should reflect on trade-offs and synergies in several dimensions, including their feasibility[4], their interactions with sustainable development and their performance in terms of climate resilience. These aspects should be assessed and communicated transparently, focusing both on challenges and on measures to overcome them.

Value judgements

5. Use of value judgements: guided by EU values and communicated transparently

5.1 In its proposal on 2040 greenhouse gas targets for the EU, the European Commission should acknowledge the use of value judgements and communicate them transparently. Value judgements are an unavoidable element of proposing climate targets and should be guided by the foundational values and principles of EU law. They are essential, for example, when determining the EU's fair share, when framing the implications of scenarios beyond greenhouse gas and climate impacts, and when assessing the feasibility of different pathways to net zero by 2050.

([3]) Here the scenario definition of the Intergovernmental Panel on Climate Change (IPCC) is used: 'A plausible description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technological change, prices) and relationships. Note that scenarios are neither predictions nor forecasts, but are used to provide a view of the implications of developments and actions.'

([4]) Feasibility is multi-dimensional, with the IPCC identifying six areas. This also covers institutional and political challenges.

2 Introduction

Under the European Climate Law, the EU is required to set a 2040 emissions reduction target, taking into account the advice of the Advisory Board[5]. The European Climate Law requires the European Commission to make its proposal in the first half of 2024, within 6 months of the conclusion of the first Global Stocktake (GST) under the Paris Agreement and to take into account the advice of the Advisory Board[5].

This input presents the Advisory Board's initial advice to the EU, and particularly to the European Commission, on how to ensure that scientific evidence underpins the setting of these targets in the context of international and EU commitments. The Advisory Board decided to publish this advice in early 2023 so that it can be considered by the European Commission at an early stage of its preparation of a 2040 climate target proposal. The Advisory Board intends to provide further quantitative advice within the first half of 2023. This subsequent advice will derive from an application of the guiding principles presented in this document and consist of a range of pathways, with their relative performance and merits, and associated interim target values for the EU.

When setting targets or advising on them, expert and value judgements are needed. Expert judgements are made based on and supported by the scientific literature, evidence and outcomes of assessments. Value judgements should be guided by the foundational values and principles of the EU. In both cases, the Advisory Board endeavours to use scientific or legal evidence to underpin any value judgements and communicate them transparently. Target proposals by the EU should follow a similar level of transparency.

This initial input discusses each of the five key issues outlined in Figure 1. It begins with an overview of the legal and policy context at EU and international level. It then addresses the issues of physical limits to global emissions and possible approaches to deriving an EU 'fair share' contribution to the Paris temperature goal. This is followed by a discussion of transformation scenarios and the insights that can be gained from different types of literature, followed by a discussion of how to consider the side effects and co-benefits of different pathways, as well as their feasibility and implications for resilience to climate change. This is followed by a discussion of EU values and principles.

The document concludes by providing an example of how the high-level advice of previous sections could be implemented. This is the example that the Advisory Board itself intends to follow in order to provide quantitative advice within the first half of 2023. The European Commission proposal may not follow the exact steps elaborated in this section (even if it follows the high-level advice of the initial input in general), since it will have its own perspective, have access to different experts and modelling tools, and may interpret and apply EU values in a different way.

This advice is provided without prejudice to future advice on the same or other subjects.

(5) European Climate Law 2021, Art. 4.3.

3 International and EU policy context

Addressing the threat of climate change is a global endeavour. The EU is a Party to the United Nations Framework Convention on Climate Change (UNFCCC), the Kyoto Protocol and the 2015 Paris Agreement. Together with subsequent decisions, these set out the context for the EU's international climate policy aims and commitments. The Paris Agreement commits Parties to keeping global warming well below 2 °C and pursuing efforts to limit the increase to 1.5 °C relative to preindustrial levels[6], also known as the Paris Agreement long-term temperature goal. This commitment was reaffirmed during the third and fourth conferences of Parties serving as meetings of the Parties to the Paris Agreement (CMA), (held in Glasgow and Sharm el-Sheikh respectively in 2021 and 2022), where Parties resolved to pursue efforts to limit warming to 1.5 °C[7].

The European Climate Law sets out the legally binding objective of achieving climate neutrality in the EU (meaning net zero greenhouse gas emissions) by 2050, with the aim of achieving net negative greenhouse gas emissions thereafter. To reach this objective, the Commission must propose a 2040 target[5], as well as an indicative greenhouse gas budget for the 2030–2050 period, and consider the advice of the Advisory Board when fulfilling both mandates. The European Climate Law also makes clear that its 2050 climate neutrality objective is set in pursuit of the long-term temperature goal of the Paris Agreement and that advice of the Advisory Board must reflect the EU's international commitments under the Paris Agreement.

The European Climate Law also specifies that the Commission's 2040 proposal is to take account of the outcomes of the first Paris Agreement Global Stocktake (GST)[5], which will conclude at the end of 2023 during the Fifth CMA (to be held in conjunction with 28th UNFCCC Conference of the Parties, or COP28). The first GST has a mandate to assess the world's collective progress towards achieving the purpose of the Agreement and its long-term goals[8] but not to revise the long-term global goal. In a parallel UNFCCC process called the Second Periodic Review of the Long-term Global Goal[9], Parties did review the adequacy of the same long-term temperature goal[10] and the progress towards achieving it[11]. This process was concluded in 2022 at COP27 with reaffirmation of the goal; it was noted that achieving the goal was still possible with immediate, rapid, deep and sustained global emissions reductions, but that current policies, measures and emissions reduction pledges are insufficient[12].

The long-term goals under the Paris Agreement and UNFCCC are therefore not expected to change, implying that current decisions and commitments to pursue efforts to limit warming to 1.5 °C provide a stable starting point for target setting and advice.

As a consequence of the EU's most recent commitment under the 2021 Glasgow Climate Pact to pursue efforts to limit warming to 1.5 °C, advice and proposals for an intermediate 2040 target

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(6) Paris Agreement, 2015, Art. 2.1.

(7) Glasgow Climate Pact, 2021, Decision 1/CMA.3, paragraph 21, falling under the Paris Agreement, and Sharm el-Sheikh Implementation Plan, Decision -/CMA.4 (Advance unedited version), paragraph 8.

(8) Paris Agreement, 2015, Art. 14.

(9) https://unfccc.int/topics/science/workstreams/periodic-review

(10) In relation to the adequacy of the long-term global goal, 'the goal is to hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change' (Decision 10/CP.21, paragraph 4).

(11) The Cancún Agreement, 2010, Decision 1/CP.16, paragraphs 138–140.

(12) Decision -/CP.27 on the Second Periodic Review of the long-term global goal under the Convention and of overall progress towards achieving it.

and a 2030–2050 greenhouse gas budget should be consistent with the goal of limiting global warming to 1.5 °C.

4 Physical limits to emissions

4.1 Global carbon budget

Proposals for interim 2040 targets and a 2030–2050 greenhouse gas budget must start from a solid understanding of the global limits consistent with the long-term temperature goal of the Paris Agreement.

The latest physical science assessment of the Intergovernmental Panel on Climate Change (IPCC) highlights that limiting global warming to a specific level requires global cumulative carbon dioxide (CO_2) emissions to be kept within a global CO_2 emissions budget (henceforth referred to as the 'global carbon budget') together with deep reductions in other greenhouse gas emissions[13]. The corresponding size of this global carbon budget can be estimated after choices have been made about (i) the global limit to which warming should be kept, (ii) the probability with which global warming should be kept to below this limit and (iii) the extent to which warming from non-CO_2 emissions will be capped[13]. For example, the remaining global carbon budget for limiting warming to 1.5 °C equals 500, 400 or 300 billion tonnes of CO_2 ($GtCO_2$) starting from the beginning of 2020, depending on whether one accepts avoiding the 1.5 °C limit with 50%, 67% or 83% probability. These values assume strong accompanying reductions in non-CO_2 emissions, and methane in particular, and the global carbon budget can further increase or decrease by several hundreds of $GtCO_2$ depending on the assumed success of these non-CO_2 reductions[14]. Note that carbon budget estimates by the IPCC are distinct in nature from the EU greenhouse gas budgets (see Box 1).

Intermediate targets for meeting the EU net zero greenhouse gas emissions target by 2050 should start from a scientifically sound estimate of the global carbon budget by making transparent choices about the factors that influence the carbon budget's size and reflect physical climate and socio-economic uncertainties.

(13) IPCC, 2021, Summary for policymakers, 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*. Note that while the IPCC AR6 WGI contribution reports the IPCC assessment of the total and remaining carbon budget, the IPCC WGIII contribution reports cumulative CO_2 emissions as an indicator of specific scenario categories.

(14) IPCC AR6 WGI Chapter 5, Canadell J.G., et al., 2021, Global carbon and other biogeochemical cycles and feedbacks, in IPCC, 2021, *Climate Change 2021: The Physical Science Basis*

Box 1 The difference between IPCC carbon budgets and EU greenhouse gas budgets

Assessments of the physical science of climate change typically calculate a global carbon (CO_2) budget because CO_2 emissions are the main driver of global warming and there exists a near-linear relationship between cumulative CO_2 emissions and increases in global surface temperature[13,14]. Emissions of other greenhouse gases generated by human activities (such as methane and nitrous oxide emissions from agriculture) are also important contributors to global warming. To estimate the global carbon budget consistent with keeping global warming below a specific temperature limit, assumptions need to be made about the warming caused by other greenhouse gases. This contribution is estimated separately by the IPCC.

EU climate policies regulate emissions of all major greenhouse gases, which is why the European Climate Law requests an indicative greenhouse gas budget rather than only a carbon budget as a guide to emissions pathways compatible with its climate neutrality goal. This budget therefore represents the cumulative greenhouse gas emissions in the EU over the 2030–2050 period expressed in CO_2-equivalence when aggregated with the 100-year global warming potential metric.

4.2 Understanding the EU's fair share

Proposals for emissions reduction targets for the EU must translate global emissions reduction requirements into a fair and equitable contribution at the EU level.

The notion of equity and fairness has been a central principle of the UNFCCC[15] since its opening for signature in Rio de Janeiro, Brazil, in 1992. The Paris Agreement re-emphasises this fundamental principle of common but differentiated responsibilities and respective capabilities (CBDR&RC) as one of its guiding principles[16]. Several approaches have been suggested to carrying out the translation of a global carbon budget to national fair shares, applying considerations of equality, capability, needs, responsibility, grandfathering, responsible sovereignty or cost-effectiveness[17]. However, not all these approaches are in accordance with principles of international environmental law or the normative pillars of the climate change regime[18,19]. For example, grandfathering of past and current emissions as an approach to determining fair shares would reward historical wrong-doing[18,19], which goes against the 'polluter pays' principle that should guide the EU following the European Climate Law[20].

Determining a 'fair share' contribution of a specific region or country to meeting the Paris Agreement long-term temperature goal typically leads to a wide range of estimates[21]. Scientific studies show that if all states choose to deliver the minimum implied by these ranges, the international community will collectively fail to deliver on the goals of the Paris Agreement[19,22]. In addition, analyses of fair shares are typically applied to territorial emissions and do not account for trade-related emissions from imported or exported goods. This perspective can result in greenhouse gas-intensive activities being outsourced

(15) UNFCCC, 1992, Art. 3(1).
(16) Paris Agreement, 2015, Preamble, Art. 2(2).
(17) For example, see Ringius et al., 2002, https://doi.org/10.1023/A:1015041613785; van den Berg et al., 2020, https://doi.org/10.1007/s10584-019-02368-y; Chakravarty et al., 2009, https://doi.org/10.1073/pnas.090523210; Pan et al., 2017, https://doi.org/10.1016/j.envsci.2017.04.020
(18) IPCC AR6 WGIII Chapter 14, Patt, A. L., et al., 2022, International cooperation, in IPCC, 2022, *Climate Change 2022: Mitigation of Climate Change*
(19) Rajamani et al., 2021, https://doi.org/10.1080/14693062.2021.1970504
(20) European Climate Law, Regulation (EU) 2021/1119, paragraph 9.
(21) For example, see Pan et al., 2017, https://doi.org/10.1016/j.envsci.2017.04.020; Robiou du Pont et al., 2016, https://doi.org/10.1038/nclimate3186; Rajamani et al., 2021, https://doi.org/10.1080/14693062.2021.1970504
(22) Robiou du Pont & Meinshausen, 2018, https://doi.org/10.1038/s41467-018-07223-9

to other countries[23], which would frustrate the achievement of the global goals of the Paris Agreement. Combining an understanding of a country's territorial, production and consumption-based emissions is therefore valuable, and proposals exist for how to deal with the responsibility for the emissions of imported goods[24].

The fair share of a developed country or region such as the EU can already be strongly depleted or fully exhausted by historical emissions. In this case, no technically possible path for reducing emissions over the next few years and decades would constitute a fair contribution by itself. Such a shortfall in required emissions reductions compared with a region's fair share could, however, be balanced by contributions in other avenues of climate action under the Paris Agreement, for example through providing means of implementation to developing countries[25].

A fair share for the EU should be derived from approaches that are supported by the principles of international environmental law and the fairness principles highlighted in the European Climate Law. Because EU fair shares can differ from the emissions implied by other considerations such as cost-effectiveness, the EU should consider its mitigation target part of a broader set of EU measures that ensure an overall fair EU contribution to the goals and commitments under the Paris Agreement.

(23) Also known as 'carbon leakage'.

(24) For example, see Jakob et al., 2021, https://doi.org/10.1016/j.gloenvcha.2020.102207

(25) Means of implementation typically refers to the provision of finance, technology transfer and capacity building to developing countries, for example the collective pledges made in the Glasgow Climate Pact 2021, including paras. 15, 17, 18, 40, and 43–46.

5 Transformation scenarios towards net zero greenhouse gas emissions

Having laid out the international legal context and EU principles and values, this section describes the scientific evidence and methods that have been identified to support the setting of scientifically sound intermediate 2040 targets and a 2030–2050 greenhouse gas budget for the EU.

5.1 Scenario literature informing the EU

Understanding how greenhouse gas emissions can be reduced to meet the EU's mid-century climate neutrality target requires information about how sectors and global regions may interact and compete over several decades of deep transformation. Integrated scenarios provide some of the relevant information needed, and a vast literature is available[26,27].

IPCC Working Group III (WGIII) compiled a database of integrated scenarios[28] from the literature[27] in support of its assessment[26] for the most recent Sixth Assessment Report of the IPCC (AR6) containing thousands of scenarios[29]. Since then, more scenarios have been developed that try to answer new questions and provide further insights into EU-specific issues[30]. **Drawing on scenario evidence that is as up to date as possible is crucial to ensure that aspects of technology costs[31], current policies and other global and regional trends are represented in the best possible way.**

Scenarios are created to inform specific research questions and might not be very informative for answering others. Apart from differences in the scientific models used to calculate scenarios[29], normative modelling choices (e.g. choices about the acceptability of certain measures, socioeconomic development) are always necessary when creating a scenario. These choices can shape scenario outcomes to a large degree.

Collections such as the IPCC AR6 scenario database include a wide variety of scenarios. However, these can vary in quality or be outdated. It is also possible, and in most cases probable, that the available scenarios do not cover the whole range of possible futures. Scenario databases should therefore be used carefully.

- **Scenarios should be expertly and transparently selected and vetted before insights can be drawn**[32].
- **Insights should include consideration of the extent to which they may have been affected by sampling bias and the under- or over-representation of mitigation options in the scenario literature**[32]. The selection of a small subset of scenarios according to scenario archetypes with

(26) IPCC AR6 WGIII Chapter 3, Riahi, K. R., et al., 2022, Mitigation pathways compatible with long-term goals, In IPCC, 2022, *Climate Change 2022: Mitigation of Climate Change*

(27) Byers et al., 2022, https://doi.org/10.5281/zenodo.5886912

(28) For clarity purposes, this guidance document uses the term 'scenario' when referring to any modelled transformation outcome, for example as included in the IPCC scenario database. The term 'pathway' is used only for the description of specific paths that the Advisory Board considers advisable.

(29) IPCC, 2022, Annex III: Scenarios and modelling methods

(30) Including several research projects funded by the EU's Horizon 2020 (H2020) Research and Innovation Programme, such as ENGAGE, NAVIGATE and PARIS REINFORCE.

(31) For example, see Meng et al., 2021, https://doi.org/10.1073/pnas.1917165118

(32) Huppmann et al. (2018, https://doi.org/10.1038/s41558-018-0317-4) provides a list of do's and don'ts for the use of large scenario ensembles such as those compiled by the IPCC.

distinct characteristics can provide a good starting point for further evaluation[33] but should be complemented by efforts to consider factors[34] or futures that are absent from the entire dataset.

- **Scenario analysis should therefore be enriched with non-scenario insights**, as we discuss in more detail in Section 5.2.

The scientific literature provides scenarios that have an integrated cross-sectoral perspective as well as scenarios that examine individual sectors in greater detail, for example industry, mobility, buildings and agriculture[26,29]. The latter group of scenarios provide additional context regarding the extent and magnitude of feasible emissions reductions in the different economic sectors. Both types of scenarios should be collected and analysed.

5.2 Combining integrated and sectoral perspectives

Different scientific communities use different sets of tools to answer distinct yet often complementary research questions. **Valuable insights can be obtained from combining a diversity of perspectives, and overall scientific confidence in advice or the soundness of proposals can be strengthened.**

Modelling results from scenarios with an integrated perspective, typically created by a class of models known as integrated assessment models (IAMs), are often contrasted with insights from detailed models at the sector level, also known as bottom-up models, as well as with analysis of empirical data[35]. IAMs offer a comprehensive and dynamic view that allows economy-wide mitigation pathways to be explored under various assumptions. These explicitly represent trade-offs across sectors and regions, as well as those resulting from the type and the timing of mitigation efforts. By contrast, bottom-up models are typically grounded in engineering–economic analyses and allow the exploration of mitigation strategies with high technological detail but with a specific sector or sub-sector focus. They lack representation of broader economic or system interactions. Even within each model class, there is heterogeneity of modelling approaches, geographical and sectoral coverage, and detail.

These two model approaches serve different purposes and have foundational differences that make their results at times difficult to reconcile under one internally consistent worldview of societal transformation. Bottom-up approaches identify mitigation opportunities that IAMs do not[29], and consequently the mitigation potential of some IAM scenarios may be underestimated compared with bottom-up scenarios. On the other hand, bottom-up scenarios may be overly optimistic since they do not include system interactions in which multiple sectors might rely on the same limited resources. Precisely because of these differences, the approaches provide complementary insights, and combining them can further strengthen scientific understanding[36] and provide fruitful input for the formulation of emission targets as well as sectoral and cross-sectoral policies (e.g. ranging from carbon pricing to setting product standards) and infrastructure needs (e.g. renewable electricity or hydrogen infrastructure).

([33]) Both the 2018 IPCC Special Report on Global Warming of 1.5 °C and the 2022 IPCC AR6 WGIII Report implemented this approach as one way to clarify differences and trade-offs between scenario choices.

([34]) For example, the very high gas prices experienced today.

([35]) For example, Wilson et al., 2013, https://doi.org/10.1007/s10584-012-0618-y; Jewell & Cherp, 2020, https://doi.org/10.1002/wcc.621

([36]) For example, IAMs can be updated with more detailed and recent assumptions on specific mitigation options or by adjusting input parameters to reflect insights about how end-use demand can change. Conversely, bottom-up approaches can be informed by IAMs concerning the speed and scale needed for mitigation across different sectors or regions to reach specific climate targets. In recent years there have been increasing efforts to link the two approaches, including through EU H2020 projects such as NAVIGATE and REINVENT.

6 Side effects, co-benefits, climate resilience and feasibility

6.1 Trade-offs and synergies of scenario alternatives

A variety of scenarios that describe the transformation to a climate-neutral EU by 2050 can be identified from the literature. These alternatives are meant to reflect distinct policy choices and preferences, and can, despite aiming for the same overarching target, ultimately lead to very different net zero worlds.

The differences between scenarios can be the outcome of **societal preferences** for clusters of different technology options, for example a preference to rely more heavily on the upscaling of supply-side options (such as renewables) or a preference to focus instead on limiting energy and material demands (enabled by placing more emphasis on novel service provisioning systems). Scenarios quantify alternative values and lifestyle decisions that have major implications for the greenhouse gas emissions reduction needs of different sectors (e.g., dietary changes, and people's use of transport). At the same time, some of these decisions may be difficult to implement in terms of broader societal acceptance. Transformation scenarios can also differ in their reliance on less mature and risky measures (such as carbon dioxide removal, CDR) or their acceptance of mitigation options that result in trade-offs with other societal objectives, such as biodiversity, poverty and equity, energy and food security, and other Sustainable Development Goals (SDGs).

Scenarios can also differ in their **climate resilience**. Certain mitigation measures not only help reduce greenhouse gas emissions but also can act to support society in increasing its resilience against climate disturbances. Depending on context, examples of such measures can include sustainable agroforestry, decentralised energy distribution, reforestation and restoring damaged ecosystems, and zero energy buildings, among other options that in each case bring benefits in terms of both mitigation and adaptation. Alternative scenarios can emerge from assumptions about different choices, or combinations of choices regarding the deployment of these or other measures. While many scenarios can provide equivalent outcomes for greenhouse gas emissions or the climate, they might still differ markedly in their implications for society.

Key dimensions for which the consequences of scenarios should be assessed include trade-offs and synergies with the SDGs, policy characteristics and costs, as well as the performance of scenarios in terms of climate resilience. The scientific scenario literature, which is as vast as it is disparate, does not provide a comprehensive and consistent assessment of these dimensions[37]. However, trade-offs and synergies with SDGs can, for example, be assessed by mapping the dominant mitigation options deployed in a given scenario to an interaction matrix as was developed by the IPCC[38] (see Figure 2). The assessment of the climate resilience of alternative mitigation scenarios can follow a similar approach but this time with mapping to resilience dimensions that include synergies and trade-offs between mitigation and adaptation measures.

For the selection of the intermediate EU 2040 target and the 2030–2050 greenhouse gas budget, the implications of the underlying pathway choices in terms of their trade-offs and synergies

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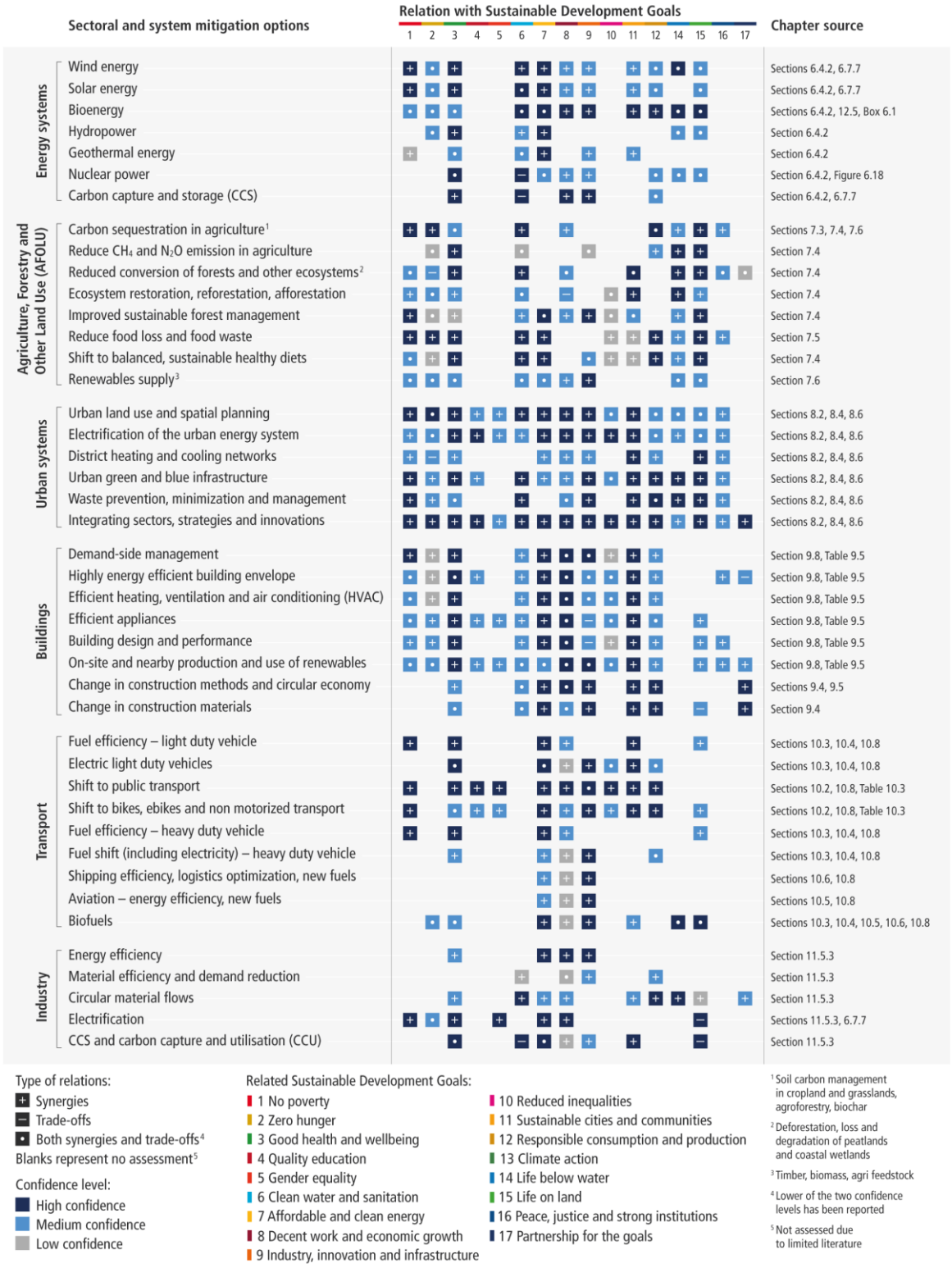
([37]) For example, for a review of the co-benefits literature, see Deng et al., 2017, https://doi.org/10.1088/1748-9326/aa98d2

([38]) For an example, see Section 2.5.3, Section 2.SM.1.5 and Figure 2.28 in Rogelj, J., et al., 2018, Mitigation pathways compatible with 1.5 °C in the context of sustainable development, in *Global Warming of 1.5 °C: An IPCC Special Report on the Impacts of Global Warming of 1.5 °C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, https://doi.org/10.1017/9781009157940.004

across a multitude of dimensions, including their interactions with SDGs and performance in terms of climate resilience, must be assessed and communicated transparently.

Figure 2 Synergies and trade-offs between sectoral and system mitigation options and the SDGs



Source: IPCC 2022: Mitigation of Climate Change (Figure SPM.8).

Notes: This interaction mapping can be used to assess the relative performance of individual scenarios as in Section 2.5.3 and Figure 2.28 of the IPCC Special Report on Global Warming of 1.5 °C.

6.2 Understanding feasibility

A final way to strengthen the assessment of scenarios for the EU transition to climate neutrality is by enriching it with a 'feasibility' assessment. Feasibility is a concept commonly used in the political science literature and distinguishes the feasibility of 'what' (i.e. specific emissions reduction strategy), 'when and where' (i.e. year and geography) and by 'whom' (i.e. the actors involved)[26].

There are multiple dimensions to feasibility, as detailed in a large and established literature. The IPCC AR6 considered the feasibility of both individual climate mitigation options and the resulting pathways along five dimensions: geophysical, technological, economic, socio-cultural and institutional[39,40]. Each of these feasibility dimensions is itself multidimensional.

For a range of measures in energy, urban, buildings, transport, agriculture and other cross-sectoral areas, the IPCC shows the extent to which feasibility dimensions can enable or prohibit a measure's implementation relative to other options. While this provides a powerful framework for understanding the relative challenges of some individual measures, an assessment of other measures is challenging due to limited availability of evidence. In addition, some sectors such as industry are too heterogeneous to be assessed practically using this framework. The feasibility of an option also 'varies depending on context (e.g., region), scale (e.g., small, medium, full scale), speed (e.g., implementation in 2030 versus 2050) and warming level (e.g., 1.5 °C versus 2 °C)'[26]. Crucially, feasibility is dynamic and depends on societal action.

The application of the IPCC feasibility framework crucially relies on a broader literature beyond the scenario literature, including a wide range of disciplines (e.g. economics, geography, political science, law, social anthropology, psychology) relying on different research methods, including case studies, surveys, interviews and ethnographic work. An initial framework that combined different lines of evidence to evaluate the feasibility of mitigation scenarios[41] was used by the IPCC[26]. Overall, the IPCC indicated that most mitigation pathways come with feasibility challenges that are institutional (political) and economic rather than technological or geophysical[26,42]. To assess the implied feasibility concerns and enabling conditions of EU pathways, it is valuable to combine an options-level feasibility assessment with more systemic feasibility approaches to evaluate the pathways. A diligent mapping of feasibility challenges and potential remedies is essential to soundly compare alternative transformation scenarios for the EU. While the complexity of such mapping can seem overwhelming, applying a simple framework for structuring these discussions can already provide valuable insights (see Figure 3).

Proposals for EU targets towards climate neutrality should reflect on the feasibility dimension of different pathways and their underlying mitigation options, highlighting both the challenges and the key decisions or measures to overcome them.

([39]) Pathak, M., et al., 2022, Technical summary, in *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, page TS-137, Figure TS.31

([40]) For individual measures the IPCC also considers an environmental-ecological feasibility dimensions. Although this is an important dimension, it is not explicitly mentioned here as it overlaps with the assessment of trade-offs with SDGs described earlier.

([41]) Brutschin et al., 2021, https://doi.org/10.1088/1748-9326/abf0ce

([42]) While noting that accelerated technological innovation across a range of areas will also be needed to meet climate targets.

Figure 3 Simple framework for structuring considerations of feasibility across five dimensions identified by the IPCC

Feasibility dimensions	Challenges	Enabling factors / measures to overcome challenges
Institutional	[short description]	[short explanation]
Socio-cultural	[short description]	[short explanation]
Technological	[short description]	[short explanation]
Economic	[short description]	[short explanation]
Geophysical	[short description]	[short explanation]

Notes: Challenges and remedies identified to overcome them can be listed alongside each dimension. This framework can be applied to assess the feasibility of alternative individual mitigation options and of integrated transformation scenarios.

7 EU guiding values and principles

Fundamental values and principles of EU law are reflected in EU institutions and decision-making and provide guidance when formulating proposals that need to consider choices and trade-offs.

Several EU treaties and laws define values and principles that are codified expressions of foundational choices shaping the identity of the EU as a union. They provide important context within which the climate commitments of the EU under the UNFCCC, the Paris Agreement or the European Climate Law are to be achieved. Many of these values and principles are expressed in core EU legislation[43] and are therefore integral to formulating advice or proposals on economy and society-wide climate targets for the EU.

The European Climate Law (in its recitals) makes explicit reference to several principles, including the principles of the EU (discussed below) as well as the principles of the Charter on Fundamental Rights of the EU, sustainable development, the precautionary and 'polluter pays' principles, the 'do no harm' principle of the European Green Deal, the 'energy efficiency first' principle of the Energy Union, the principles of proportionality and subsidiarity, and the Commission's commitment to the principles of better law-making.

Furthermore, Article 4.5 of the European Climate Law provides a more specific list of issues that the European Commission is to consider when proposing its 2040 target. These include the best available scientific evidence and a range of issues related to economic and social aspects of a just and fair transition, as well as environmental effectiveness. The consideration of this wide range of issues is expected to unveil tensions or trade-offs, for example between cost-effectiveness and social impacts. These challenges should be acknowledged and require reflection and transparent communication.

From the start, EU legislation has emphasised the *central role of science and evidence in policymaking*[44]. In addition, a wide set of values and principles is relevant when setting targets. Some of these principles frame ambitious climate action in the context of sustainable development, such as:

- Principles of *human dignity*[45] and respect for *human rights*[46] that underpin the fundamental importance of addressing climate change for the benefit of current and future generations. Human rights also encompass the right to information and the right to participation of citizens in decision-making, an aspect that can be crucial in the process of setting EU-wide climate targets.
- Principles linked to *sustainable development*[47] that emphasise the critical importance of the sustainable development of Europe[48] and developing countries, with the aim of eradicating poverty and fostering sustainable development[49], and the importance of the sustainable development of the Earth[50].
- Principles linked to *environmental protection and combating climate change* that mandate a high level of preservation, protection and improvement of the quality of the environment and a

(43) In particular, the Treaty on European Union (TEU) and the Treaty on the Functioning of the European Union (TFEU). See Official Journal of the European Union 2016, C202/01.
(44) TEU, Art. 3(3), and TFEU, Art. 191(3).
(45) TEU, Preamble, Art. 2, 21(1).
(46) TEU, Art. 2, 3(5), 21(2)(b).
(47) UN Sustainable Development Goals are also included as framing concepts in the European Climate Law (2021).
(48) TFEU, Preamble, Art. 3(3).
(49) TEU, Art. 21(2)(d), and TFEU, Art. 208(1).
(50) TEU, Art. 3(5), 21(2)(f).

prudent and rational use of resources[51] and anchor the international fight against climate change as one of the top priorities of the EU. These principles are especially relevant since the EU's stated aims in the area of cooperation on international relations include to 'help develop international measures to preserve and improve the quality of the environment and the sustainable management of global natural resources, in order to ensure sustainable development'[52];

Other principles provide guidance for making choices or formulating advice where evidence indicates that alternative options come with very distinct consequences. For example:

- The *precautionary principle* and the *principle of preventive action*[53] indicate that preference should be given to policy options with the fewest identified potential risks for adverse or harmful consequences. The same EU principle also states that 'the polluter should pay'. Furthermore, various regulations build on the principle of 'do no significant harm'[54].
- Further explicit emphasis is put on *promoting energy efficiency and energy savings, and the deployment of renewable energy*[55].
- Lastly, EU principles also put emphasis on the importance of *international cooperation and global governance*[56] as well as *solidarity*[57]. The former is expressed through decisions to promote multilateral solutions to common problems[58] and a commitment of the EU and its Member States to comply with commitments and objectives under the United Nations[59] such as the current SDGs[60]. The EU's commitment to solidarity carries implications for both inter- and intragenerational equity and fairness of climate action, emphasising loyal cooperation and good neighbourliness[61] and the importance of solidarity between generations and the rights of children as well as solidarity and mutual respect among peoples[62].

Where proposals need to differentiate between alternatives with distinct implications beyond greenhouse gas emissions and climate impacts, value judgements should be based on the consideration of relevant EU values and principles and be communicated transparently.

(51) TFEU, Art. 11, 191(1).
(52) TEU, Art. 21(2)(f).
(53) TFEU, Art. 191(2).
(54) See Regulation 2020/852 on sustainable investments and Regulation 2021/241 on recovery and resilience facility (Art. 5).
(55) TFEU, Art. 194(1)(c).
(56) TEU, Art. 21(2)(h), and TFEU, Art. 191(1), 214.
(57) TEU, Art. 2, 3, 21(1).
(58) TEU, Art. 21(1).
(59) TFEU, Art. 208(2).
(60) European Climate Law, Preamble, paras. 4 and 32.
(61) TEU, Art. 4(3), 8(1).
(62) TEU, Art. 3(3), 3(5).

8 Next steps and practical perspectives

The recommendation to combine various lines of scientific evidence, and the advice to integrate expert and value judgement in a transparent manner, beg the question of how this can be achieved in practice. This section of this guidance document therefore builds on the preceding sections to provide a more practical perspective on the formulation of scientifically sound greenhouse gas emissions targets for the EU. It aims to provide one example of how the high-level advice of previous sections could be implemented, including steps the Advisory Board intends to take in the preparation of its quantitative advice on the EU interim 2040 target and the 2030–2050 greenhouse gas budget, due to be published within the first half of 2023. Figure 4 provides a visual schematic of the proposed steps. The description below is, however, without prejudice to the precise approach that will ultimately be taken by the Advisory Board when formulating its concluding advice or other future products.

8.1 Practical perspectives

The global carbon budget and EU fair shares. Estimating fair shares for the EU can start from an updated global carbon budget estimate in line with limiting warming to 1.5 °C and based on the expert assessment of the latest IPCC assessment report[13]. The value judgements required to identify the likelihood of limiting warming to 1.5 °C can be informed by the EU's precautionary principle. Subsequently, a set of estimates of the EU's fair share of this global budget can be explored, and the inclusion of individual approaches in this set should be transparently motivated by the foundation and alignment of these with international and EU legal principles and values. The analysis of the EU's fair share can provide a framing perspective that conceptually distinguishes between quantified fair shares for the EU, greenhouse gas emissions implied by EU scenarios to climate neutrality in 2050, and other perspectives that affect the overall fairness assessment of the EU climate action package for 2040, such as imported emissions, carbon leakage and international finance[63].

Ensuring up-to-date and relevant scenario information. The scenario database compiled in preparation of the IPCC AR6 WGIII report[26,27,64] can serve as a starting point, but it needs to be updated. To this end, the Advisory Board has launched a call to the European and wider modelling community to submit relevant scenarios to an interactive database hosted in partnership with the International Institute for Applied Systems Analysis (IIASA) and managed by the Advisory Board's Secretariat[65]. The call invites the community to contribute scenarios with a comprehensive and integrated systems perspective that project emissions trajectories at the EU or a more granular level up to at least 2050. Scenarios in which the EU reaches net zero emissions in 2050 are of particular interest, but scenarios that model the implications of current policies, nationally determined contributions, or the fit-for-55 package also provide valuable context for the assessment. In addition, scenarios presenting detailed sectoral perspectives on how to reduce emissions in the areas of, for example, industry, mobility, buildings or agriculture are also welcomed.

This curated compilation of scenario evidence should allow for systematic comparisons of scenarios based on most recent community methods and data standards[32], including their climate outcomes consistent with the latest IPCC assessment[66]. The available scenarios will be re-assessed to identify the

(63) Because of the variety of aspects that can be included in such analysis, no simple framework is yet available.
(64) Accessible online and downloadable at: https://data.ece.iiasa.ac.at/ar6/
(65) European Scientific Advisory Board on Climate Change – Call for scenario data contributions, https://www.eea.europa.eu/about-us/climate-advisory-board/call-for-scenario-data-contributions
(66) Kikstra et al. (open access preprint), https://doi.org/10.5194/egusphere-2022-471

subset that limits global warming to 1.5 °C with no or limited overshoot[67] and is consistent with the EU goal of achieving climate neutrality or net zero greenhouse gas emissions by 2050. Informed by this subset, a small set of iconic scenarios for the EU will be selected that describe distinct societal mitigation choices or strategies. The analysis may also consider scenarios in which the EU's fair share is consistent with 1.5 °C warming but the world as a whole may not be on a pathway consistent with this.

Combining perspectives from diverse lines of evidence to strengthen analysis and understand potential trade-offs and synergies. To integrate insights from diverse lines of evidence and scholarship, the Advisory Board aims to synthesise the insights available from the set of iconic scenarios, and present the implications of scenario characteristics related to the energy system, transport, building, industry, and agricultural system transformation from the various perspectives, including implications and considerations of the following.

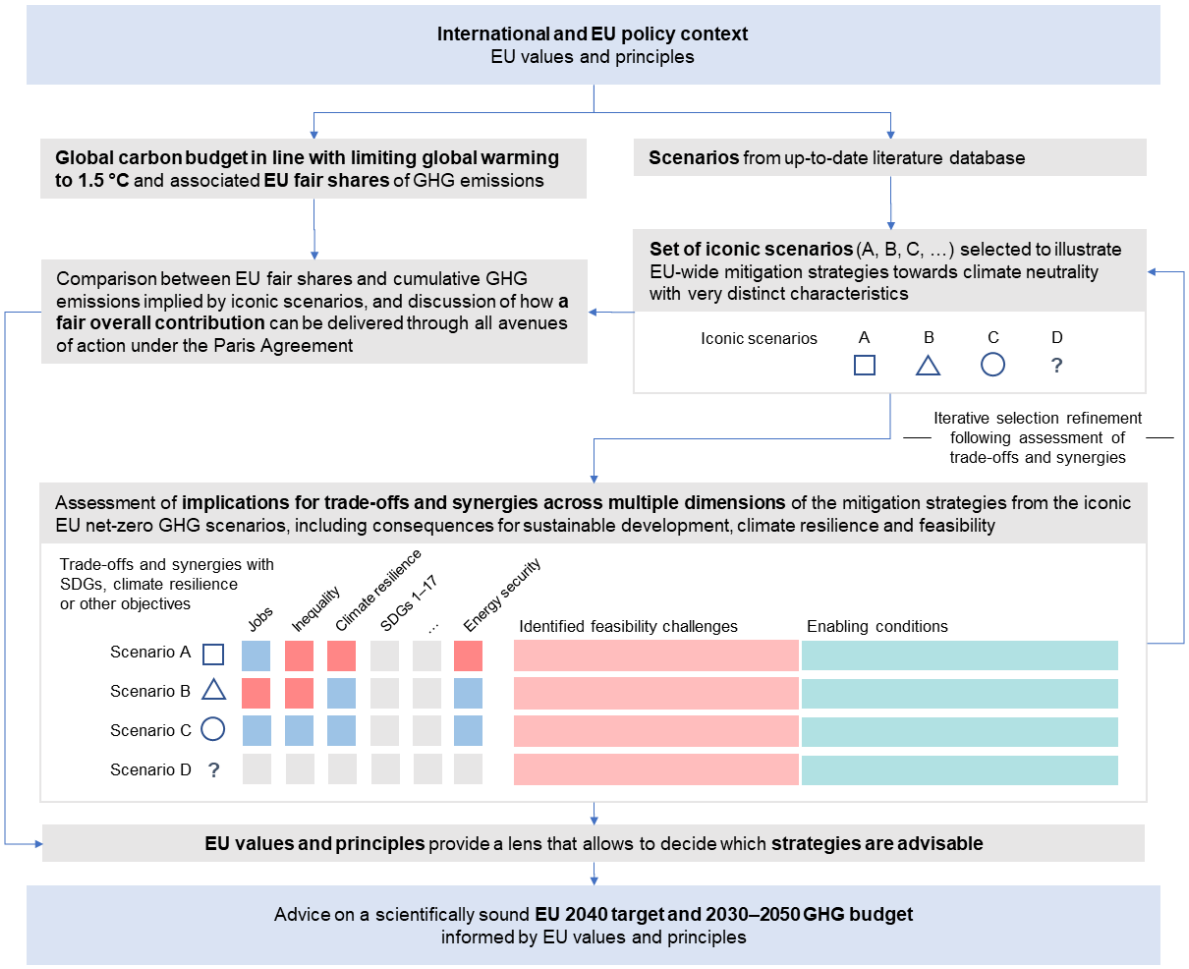
- *Sectoral mitigation potentials*, by comparing the magnitude of mitigation measures and demand-side responses found in comprehensive, integrated scenarios with the technical and sectoral insights of detailed bottom-up models. This can also include an assessment of the readiness of the technologies needed under a specific scenario to meet the proposed 2040 emissions reduction target.
- *Sustainable development*, by mapping greenhouse gas mitigation measures to potential trade-offs and synergies with SDGs or other aspects of interest to society such as labour market impacts or natural resource requirements (see Figure 2) and determine how different scenarios perform based on the relative importance of specific mitigation measures in their overall mitigation strategy following the approach presented in the IPCC's special report on global warming of 1.5 °C[38].
- *Climate resilience*, through a similar exercise that maps mitigation measures with respect to their adaptation co-benefits and their vulnerability to being disturbed or reversed by climate change and climate extremes. As is the case for the assessment of trade-offs or synergies with sustainable development, the performance of scenarios can be assessed based on the relative role and contributions of specific mitigation measures and their respective consequences for climate resilience.
- *Feasibility challenges and enablers*, by assessing the implications of scenario strategies for the feasibility dimensions identified by the IPCC: geophysical, technological, economic, socio-cultural and institutional[39,39]. Because the concept of feasibility is dynamic and depends on societal action, a relatively static assessment such as for mitigation potentials or climate resilience is not possible here. Instead, each iconic scenario will be assessed using a simple template to allow reflection on implied feasibility challenges and necessary enablers (Figure 3). These considerations can cover a broad range of aspects including costs, pace of upscaling of new options, reliance on CDR with low permanence or high technological uncertainty, degree of reliance on changes in societal preferences or behaviour, institutional and governance risks, policy characteristics, or the heterogeneity of implications across countries and associated challenges for an equitable EU-internal transition. Because feasibility dimensions and enabling conditions will also be core components of other future products of the Advisory Board, the 2040 target advice will focus on aspects of gross emissions reductions versus CDR, with other sectors and measures considered elsewhere.

Framing advice based on EU values and principles. A structured approach to identifying and assessing the adequacy, challenges, opportunities and risks of potential pathways for the EU transition to climate neutrality by 2050 can allow a systematic interpretation of the implication of transition pathway choices

(67) Consistent with category C1 of the IPCC AR6 WGIII report.

at the EU level and frame scientifically sound target advice through the lens of foundational EU values and principles.

Figure 4 Proposed steps and assessments to support the formulation of scientifically sound advice on the EU 2040 target and 2030–2050 GHG budget in the context of the Paris Agreement commitments and EU values and principles



Notes: Arrows show connections and steps requiring either scientific expert or value judgements that are informed by EU values and principles. Each step and choice must be documented transparently. Scenarios A, B, C, …, in the set of iconic scenarios for the EU transition to climate neutrality are selected in a way such that they cover very distinct characteristics. Importantly, the assessment of trade-offs and synergies with important societal objectives such as climate resilience and SDGs will determine whether an iconic scenario is advisable or not.

8.2 Outlook

The proposed approach to developing proposals or formulating scientific advice on the interim 2040 target and the associated 2030–2050 greenhouse gas budget for the EU describes a transparent science-based process to synthesise and assess the broad relevant evidence basis available in the literature. By starting from an up-to-date database, it will ensure that the scenario evidence available for understanding appropriate 2040 targets is as recent as possible. Additional literature will allow us to determine whether it is necessary to consider scenarios beyond those directly available. Subsequently, the mitigation potential, sustainability, climate resilience and feasibility implications are first assessed at a coarse level. This process will allow us to narrow the choices to a more limited number of pathways

with balanced underlying assumptions for which a more detailed assessment can be carried out. The outcome of this exercise is expected to show the relative performance and merits of scenarios and associated interim target values for the EU. The various aspects that are assessed for the scenarios can subsequently be used as inputs into political and societal judgements at the EU level.

Applying the described approach will help to systematically identify targets for 2040 and the EU 2030–2050 budget that are ambitious, maximise positive interactions with the SDGs and climate resilience, reduce risks, and adequately identify potential challenges to and enablers of their feasibility.

Acronyms, abbreviations and symbols

AR6	6th Assessment Report of the IPCC
CDR	carbon dioxide removal
CMA	Conference of the Parties serving as the meeting of the Parties to the Paris Agreement
CO_2	carbon dioxide
COP	Conference of the Parties to the United Nations Framework Convention on Climate Change
EU	European Union
GST	Paris Agreement Global Stocktake
$GtCO_2$	gigatonnes (billion tonnes) of carbon dioxide
IAM	integrated assessment model
IPCC	Intergovernmental Panel on Climate Change
SDG	Sustainable Development Goal
UNFCCC	United Nations Framework Convention on Climate Change
WGI, II, III	IPCC Working Group I, II, III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