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Keywords: Climate change mitigation scenarios, investment, finance, climate alignment assessments, net zero target setting, greenhouse gas emissions.

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Abstract

This paper analyses climate change mitigation scenarios used in the financial sector for setting climate-related targets and assessing alignment with the Paris Agreement. Based on three analytical dimensions reflecting perspectives of different stakeholders, the analysis highlights that: (i) only very few of analysed scenarios fulfil all criteria of the Paris-consistency framework relied on for this study; (ii) current limited geographical and sectoral granularity requires financial sector users to make further assumptions to address gaps; (iii) users do not always have sufficient information on uncertainties relating to scenario assumptions and feasibility. The paper identifies opportunities for improved design and use of climate change mitigation scenarios for target setting and alignment assessments in the financial sector. Scenario providers could improve the sectoral and geographical coverage and granularity of scenarios, more comprehensively disclose climate outcomes of scenarios, and propose harmonised sets of underlying assumptions. Financial sector users should apply a Paris-consistency framework when selecting scenarios and could consider the relevance of relying on more than one scenario. Climate policy makers can contribute to the granularity of global scenarios by developing national sector-specific scenarios, and help reduce scenario uncertainty by providing climate policy certainty and specificity in their jurisdiction.

Keywords: Climate change mitigation scenarios, investment, finance, climate alignment assessments, net-zero target setting, greenhouse gas emissions.

JEL Codes: G23, G24, Q54, Q56.

Résumé

Ce rapport analyse les scénarios d'atténuation du changement climatique utilisés dans le secteur financier pour fixer des objectifs liés au climat et évaluer l'alignement avec l'Accord de Paris. L'analyse est basée sur trois dimensions reflétant les perspectives de différentes parties prenantes, et met en évidence que: (i) très peu des scénarios analysés remplissent l'ensemble des critères de cohérences avec l'Accord de Paris utilisés pour cette étude; (ii) la granularité géographique et sectorielle limitée actuelle oblige les utilisateurs du secteur financier à formuler des hypothèses supplémentaires pour combler les lacunes; (iii) les utilisateurs ne disposent pas toujours d'informations suffisantes sur les incertitudes liées aux hypothèses et à la faisabilité des scénarios. Le rapport identifie des possibilités pour améliorer la conception et l'utilisation des scénarios d'atténuation du changement climatique pour la fixation d'objectifs liés au climat et les évaluations d'alignement dans le secteur financier. Les fournisseurs de scénarios pourraient améliorer la couverture sectorielle et géographique et la granularité des scénarios, divulguer de manière plus complète les résultats climatiques des scénarios et proposer des ensembles harmonisés d'hypothèses sous-jacentes. Les utilisateurs du secteur financier devraient appliquer un cadre de cohérence avec l'Accord de Paris lors de la sélection des scénarios, et pourraient envisager de s'appuyer sur plus d'un scénario. Les responsables de politiques climatiques peuvent contribuer à la granularité des scénarios mondiaux en élaborant des scénarios sectoriels nationaux, et aider à réduire l'incertitude des scénarios en apportant certitude et spécificité en matière de politique climatique au sein de leur juridiction.

Mots-clés: Scénarios d'atténuation du changement climatique, investissement, financement, évaluations de l'alignement sur le climat, fixation d'un objectif net zéro, émissions de gaz à effet de serre.

Codes JEL: G23, G24, Q54, Q56.

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- Oral feedback and written comments from OECD member countries on both an initial scoping note and a complete draft.
- Data inputs, consultations and reviews with the following providers of climate change mitigation scenarios: the International Energy Agency (IEA), the University of Technology of Sydney's Institute for Sustainable Futures (UTS-ISF), the European Commission's Joint Research Centre (JRC), the Network of Central Banks and Supervisors for Greening the Financial System (NGFS).
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Table of contents

Tables

Figures

Boxes

Executive summary

Climate change mitigation scenarios are a key forward-looking input for a range of financial sector climate-related analyses and assessments. These include setting climate-related targets, developing climate transition plans, and designing metrics to assess progress towards alignment with a low greenhouse gas emissions pathway, as called for by Article 2.1c of the Paris Agreement. This in turn can inform assessments of progress towards the goals of the Paris Agreement, including UNFCCC Global Stocktakes. Although not the focus of this study, these scenarios are also used to assess the potential impact of the climate transition on financial activities, i.e. analysis of climate-related transition risks and opportunities, as well as stress testing at both the institution level and from a macroprudential perspective.

Climate change mitigation scenarios were not initially designed for use in the financial sector, but evidence shows that many climate-related metrics and analyses in the financial sector rely on and are highly sensitive to the choice and characteristics of such scenarios. In turn, the inaccurate use of mitigation scenarios can contribute significantly to unintended incentives, environmental integrity concerns, and greenwashing risks in methodologies and metrics used to assess and report the climate change mitigation performance of the financial sector.

This paper aims to inform climate change mitigation scenario providers, financial sector participants and stakeholders, and climate policymakers on how they may contribute to improved use of scenarios in climate-related target setting and alignment assessments in the financial sector. To do so, the analysis takes stock of a selection of climate change mitigation scenarios commonly used for these purposes and qualified as net zero, 1.5°C or below 2°C by scenario providers. The four providers of these scenarios are: the European Commission's Joint Research Centre (JRC), the Sydney University of Technology's Institute for Sustainable Futures (UTS-ISF), the International Energy Agency (IEA), and the Network of Central Banks and Supervisors for Greening the Financial System (NGFS).

The analysis identifies common practices and gaps by investigating the scenarios' consistency with the Paris Agreement, practicality, and underlying assumptions, i.e. degree of consistency with the agreement's long-term temperature goal and emission reduction objective; applicability in the financial sector, notably in terms of sectoral and geographical granularity; characteristics of mitigation strategies and input assumptions, including in relation to feasibility and uncertainty.

None of the scenarios that providers currently qualify as net zero, 1.5°C or below 2°C are assessed as fully consistent with stringent interpretations of all five criteria of the Paris-consistency framework relied on for this study. Following a relatively less stringent interpretation, only very few scenarios are assessed as fully consistent, noting that some providers do not disclose sufficient and comparable data to allow for a full assessment. The five criteria, proposed in the complementary paper "Paris-consistent climate change mitigation scenarios: A framework for emissions pathway classification in line with global mitigation objectives", ensure that temperature increase is limited to 1.5°C, with no or very limited overshoot throughout the century, with rapid peaking of GHG emissions and reaching net-zero GHG emissions in the second half of the century. Evidence from climate science highlights that such level of ambition is needed to reduce future impacts of climate change, including risks of crossing climate tipping points and, as a result, also the scale of financial losses and instability.

Current limitations and gaps in the design, scope and granularity of scenarios, mainly in terms of sector and geography, restrict their applicability in the financial sector, and can have possible unwanted portfolio allocation implications, including risks of carbon lock in. First, a complex mapping is needed to address the mismatch between economic sector classifications used in corporate and financial accounting and broad sector classifications that underpin scenario modelling. Second, pathway modelling or disclosure for several high-emitting subsectors commonly found in financial portfolios are still missing. Third, as sectoral and geographic granularity of scenarios is currently often insufficient for analyses at the level of individual financial assets, asset classes and portfolios, significant assumptions need to be made to downscale available scenario output data. In the absence of international consensus on burden sharing, such assumptions can raise further equity concerns across the jurisdictions that investors and financial institutions may be active in, including developing countries where data is more limited and hence uncertainties larger.

Ambitious scenarios imply rapid scaling-up of different mitigation options, some of which involve trade-offs, uncertainties, and feasibility challenges that the financial sector needs to understand to set targets and design transition plans, but that it cannot address on its own. This relates for instance to phasing out fossil fuels, scaling up renewable energy, and increasing energy efficiency and electrification. Furthermore, mitigation strategies and GHG emission pathways provided by climate change mitigation scenarios are determined by various socio-economic, technology and policy assumptions. For example, global scenarios either assume a uniform carbon price or only make broad differentiations between developed and developing countries, thus failing to provide a realistic proxy for overall climate policy intensity in specific jurisdictions and sectors. However, as multiple scenarios may lead to similar climate outcomes based on different mitigation options and assumptions, financial sector users of scenarios can consider the possibility of using more than one scenario as input, to capture a range of potential options and to reflect inherent uncertainties.

Climate scenario providers, financial market stakeholders and climate policy makers can contribute to the improved design and use of mitigation scenarios for climate-related target setting and alignment assessments in the financial sector. Scenario providers could standardise the formulation of climate outcomes of their scenarios, disclose scenario variables and climate outcomes, develop harmonised sets of input assumptions, and enhance the scope and granularity of their models to the extent possible with available granular data. Users of scenarios in the financial sector should select Paris-consistent scenarios and could consider the relevance of relying on more than one scenario, identify scenarios that provide the sectoral and geographical scope and granularity closest to the characteristics of specific financial assets and asset classes, as well as understand and transparently communicate climate outcomes and uncertainties of the scenarios they select. Climate policymakers can promote standardised disclosure of scenario-based targets and alignment assessments. They can also contribute to the granularity of global scenarios and data by developing national sector-specific scenario and data, as well as help to reduce scenario uncertainty by providing climate policy certainty and specificity within their jurisdiction, which could include sector-specific mitigation targets.

The feasibility of scenario outcomes and of investors' assessments and decisions based on such scenarios ultimately depends on the credibility and effective implementation of ambitious climate policies. The potential actions outlined in this paper are technical in nature but can be viewed within the broader policy and investment environment that can increase or reduce scenario uncertainty. The financial sector can proactively invest in climate solutions and the climate transition, thereby significantly contributing to the viability of more mitigation options and strategies by bringing down technology costs and increasing technology roll-out. At the same time, public policy retains a central role in increasing the overall feasibility and financial viability of the climate transition. Scenarios that keep global warming at 1.5°C (with 50% likelihood by end of century), all assume ambitious and immediate mitigation actions and entail feasibility challenges that need to be addressed with appropriate policies.

1 Introduction

Reaching the Paris Agreement's temperature goal implies rapid and profound transformations in all economic sectors, which in turn requires actions by all economic actors, including in the financial sector (IPCC, 2022[1]). On the one hand, the financial sector needs to manage potential transition risks from such transformations (TCFD, 2017[2]). On the other hand, it has a major role to play in investing in and financing the required transformation and transition of the economy.

In this context, financial sector stakeholders are increasingly relying on climate change mitigation scenarios as a key forward-looking input for different climate-related analyses. There are a range of different use case (Täger and Dikau, 2023[3]), but they can be broadly summarised in two groups:

- Use cases that consider the impact of climate change mitigation-related policies and transformations on the financial sector: Climate change mitigation scenarios are used to conduct climate-related transition risk assessments and stress testing exercises at both institutional and macroprudential levels (ECB, 2022[4]; FSB, 2022[5]; TCFD, 2017[6]; Sustainable Fitch, 2023[7]). While not the primary focus of this study, these use cases play an important role in influencing financial sector investment and portfolio allocation decisions.
- Use cases that consider the role and impact of financial sector activities towards reducing GHG emissions and reaching climate mitigation policy goals: Climate change mitigation scenarios are used to develop and set GHG reduction or net-zero targets (SBTi, 2021[8]) and climate transition plans (OECD, 2022[9]), as well as to assess the extent to which such targets and plans, and progress towards them, are aligned with climate mitigation policy goals, most notably the Paris Agreement temperature goal (Noels and Jachnik, 2022[10]). Such use cases are the focus of this study and can help inform aggregate-level assessments of the contribution of the financial sector to meeting climate policy goals, including in the context of UNFCCC Global Stocktakes.

Previous research found that the selection of a mitigation scenario is a key methodological dimension influencing the results of existing methodologies to assess the alignment of financial assets and portfolios with the Paris Agreement temperature goal (Noels and Jachnik, 2022[10]). However, they were not initially designed with the financial sector in mind. This results in challenges, for instance, in terms of matching scenario and financial data at a granular level and of understanding the implications of the assumptions and uncertainties relating to the design and use of scenarios in finance (Noels and Jachnik, 2022[10]).

Against this backdrop, the aim of this analysis is to contribute to bridging the potential information, co-ordination and knowledge gaps between: the climate science community developing climate change mitigation scenarios; financial market participants using such scenarios; and climate policymakers overseeing the environmental integrity of climate-related assessments of finance. To do so, and with above-mentioned focus on the role of scenarios in informing financial sector target setting and alignment assessments, the analysis covers climate change mitigation scenarios currently commonly used in the financial sector for such purpose. The analytical approach considers the following three main complementary dimensions:

- The extent to which these scenarios can be considered as consistent with the Paris Agreement temperature goal and long term GHG emission objectives. In doing so the analysis applies criteria and an analytical framework developed in a parallel paper (Pouille et al., 2023[11]).

- The applicability of the scenarios for analysing the climate mitigation performance of financial assets and portfolios, which notably implies the availability of scenario data and information for specific sectors and sub-sectors as well as specific geographics.
- The characteristics of the mitigation strategies and input assumptions that underpin the scenarios.

Across these three dimensions, the analysis identifies challenges and opportunities related to the use of climate mitigation scenarios with the aim to inform climate policy makers, climate scenario providers, climate-related assessment methodology providers and financial market stakeholders on how they each and collectively may contribute to improved design and use of mitigation scenarios in financial sector climate-related target setting and alignment assessments.

1.1. Context and concepts

In 2015, amid growing awareness of the role of the financial sector in the climate transition, the Paris Agreement established a goal of "making finance flows consistent with a pathway towards low greenhouse gas (GHG) emissions and climate-resilient development" (UNFCCC, 2015[12]). This formulation contributed to the development of the concept of "climate alignment" (or "misalignment") of investments and financing activities by both public and private institutions, and of transition finance. These concepts form part of broader developments of green and sustainable finance, which respectively consider other environmental priorities beyond climate change, as well as social and human rights aspects.

Since the adoption of the Paris Agreement, an increasing number of national and subnational governments, as well as financial and non-financial corporates and organisations have set goals or targets to align their activities with the Paris Agreement's climate change mitigation objectives (NewClimate Institute, 2022[13]; Jeudy-Hugo, Lo Re and Falduto, 2021[14]; SBTi, 2022[15]). In the financial sector, this is often done through international voluntary coalitions. For example, the UN-convened Net-Zero Asset Owner Alliance (NZAOA) brings together global asset owners who commit to "*transitioning their investment portfolios to net-zero GHG emissions by 2050 consistent with a maximum temperature rise of 1.5°C*" (UNEP FI, 2022[16]). Similar coalitions to contribute to the achievement of the Paris Agreement were launched for banks (UNEP FI, 2022[17]), asset managers, insurers, and other financial market participants. In 2021, the Glasgow Financial Alliance for Net Zero (GFANZ) brought together such existing and new initiatives supporting net-zero emissions in the financial sector (GFANZ, 2022[18]).[1] In the context of macroprudential stress-testing and considerations, some early regulatory efforts are also exploring recommending specific scenarios (Nieto and Papathanassiou, 2023[19]).

1.1.1. Methodologies for climate target setting and alignment assessment in the financial sector

Climate change mitigation scenarios provide reference pathways for target setting methodologies, notably in the context of the Science Based Targets initiative (SBTi), which works with companies to define a path to reduce emissions in line with the Paris Agreement goals. Pathways used by the SBTi are "determined based on a combination of science and principled judgements that aim to steer voluntary climate action and contribute to achieving the aims of the Paris Agreement and the Sustainable Development Goals (SDGs)" (SBTi, 2021[20]). Mitigation scenarios inform the design of targets by setting baselines to define the magnitude and timing of emissions reductions (SBTi, 2020[21]). Climate-related financial coalitions encourage their members, such as banks and asset owners, to use what they refer to (without necessarily clearly defining the terms and their implications) as "science-based" climate change mitigation scenarios

[1] In 2022, this included 500 financial institutions representing around 40% of global private financial assets, who have committed to the goal of net zero by 2050.

to set their long-term and intermediate targets (UNEP FI, 2021[22]; NZAOA, 2021[23]), as well as to help define how corporate strategies may respond to net-zero transformations (GFANZ, 2022[24]).

Once targets are set, actual progress by financial institutions and economic players underlying the assets they own, need to be assessed with respect to their transition towards reaching their target and alignment with the Paris Agreement goals. Assessing the alignment of a financial portfolio or asset requires making a range of methodological assumptions, including to downscale, either explicitly or implicitly, the Paris Agreement's global temperature goal to the level of financial institutions, financial assets, and the economic sectors, actors or countries underlying those assets. Since there is no agreed or unique way of doing so, financial market participants, stakeholders and researchers have developed methodologies for climate-alignment assessment.

Climate-alignment assessment methodologies provide specific indicators to assess the alignment of financial portfolios and assets (e.g. equity, bonds), based on the performance of the underlying real-economy actors and assets (e.g. companies, countries, infrastructure) with the Paris Agreement mitigation objectives (Noels and Jachnik, 2022[10]). They typically calculate the current climate performance level of a given financial portfolio or asset and project it forward using the climate-related target disclosed by the financial firm or underlying economic actor. Such trajectory is then compared to the required performance level of a climate change mitigation scenario pathway, at given points in time or in cumulative.

However, there is evidence that results of climate alignment assessments vary significantly depending on the reference point, i.e. scenario used (Noels and Jachnik, 2022[10]; Jachnik and Dobrinevski, 2021[25]; Dobrinevski and Jachnik, 2020[26]; Dobrinevski and Jachnik, 2020[27]; Schwegler et al., 2022[28]). Different providers of climate-alignment assessment methodologies may choose different climate change mitigation scenarios (each coming with different underlying assumptions), as well as make different methodological assumptions and choices, including on techniques to downscale a scenario to the level of granularity needed for asset level analyses, and the year in which performance is compared. As a result, the selection and application of a given climate change mitigation scenario greatly influences the alignment result.

1.1.2. Climate change mitigation scenarios

Climate change mitigation scenarios translate medium- and long-term temperature and emissions goals (e.g.,1.5°C end-of-century global temperature increase, net-zero global CO_2 emissions by 2050) into GHG reduction pathways. Different scenarios explore how different mitigation policies and strategies allow to reach GHG emissions pathways consistent with climate change mitigation goals, typically compared to so-called "business as usual" scenarios, which assume no climate policies are implemented than those already in place or about to be introduced (Riahi, 2022[29]). Starting with underlying assumptions about the development of socio-economic processes (e.g. GDP and population developments) and of technological change (e.g. solar and wind capacity developments, and their respective costs), climate change mitigation scenarios model different climate policy choices impact changes primarily in energy use, land use and GHG emissions (IPCC, 2022[30]) (see Box 1.1). In doing so, such scenarios may take either an economy-wide approach by looking at interactions and resulting emissions across all sectors of the economy (Riahi, 2022[29]), or a sectoral approach and focus on a subset of the system, for example, the energy sector and energy-related emissions as is the case for the International Energy Agency (IEA, 2021[31]). While many climate change mitigation scenarios have a global coverage, some focus on a specific country or region. Furthermore, national scenarios are regularly produced to explore how a specific country can reach its climate mitigation goals.

Box 1.1. Scenarios, pathways and models

This paper refers to a **climate mitigation scenario** as the coherent set of quantitative projected pathways which are based on an explicit or implicit narrative describing a possible future world and translated as assumptions inputted into models. Depending on their complexity and scope, climate scenarios may include internally consistent pathways for hundreds of different variables, such as for the evolution over time of emissions by gas, energy use, energy supply, land use, economic variables such as GDP, but also water use, waste, sectoral outcomes etc.

This paper defines a **pathway** as the modelled evolution over time of a single variable. With this in mind, a GHG **emissions pathway** is the modelled trajectory of anthropogenic emissions and is therefore part of a scenario. In accordance with these definitions and for greater clarity, this paper will restrict the use of the term pathway. In this way it is considered as part of a scenario, acknowledging, however, that the term is often employed more generally in reference to a complete mitigation trajectory i.e. a mitigation scenario.

Climate change mitigation scenarios considered in this paper are the output of **models**, which are systems of equations characterising how the different elements of the economy, energy system and other systems (e.g. land, water…) interact and result in emissions. **Integrated Assessment Models (IAM)** are a common type of model used to produce climate mitigation scenarios. IAMs describe the coupled energy-land-economy-climate system and "whole system" mitigation trajectories on the long-term. Another common type of models is **energy-economy system models**. These adopt a hybrid approach, combining top-down macro-economic models and detailed bottom-up energy sectoral models.

Note: See Annex A for more definitions of and detail on scenarios, pathways, and models.
Source: (Riahi et al., 2022[32]; IPCC, 2022[30]).

The models used to produce climate change mitigation scenarios cannot possibly capture the full complexity and dynamics of socio-economic systems. Each climate change mitigation scenario is, therefore, underpinned by a wide range of explicit and implicit assumptions. For example, scenarios' outcomes are strongly dependent on projections of future economic and demographic growth and technological development, on the type and scope of models used to produce them, and on the formulation of a normative climate target in their design.

The development of climate change mitigation scenarios has been an on-going process for decades**,** undertaken by climate science academic communities (e.g. through global consortiums of research teams such as EMF, ENGAGE, COMMIT, ADVANCE[2]) and by institutional bodies (e.g. the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA)). When producing scenarios, different actors typically explore specific research or policy questions. Examples of such questions include

[2] The Energy Modeling Forum (EMF) is an international forum of academic, government and corporate bodies which has produced over 30 studies since the 1970s, supported by the production of sets of climate and energy scenarios. ENGAGE is a global consortium of research groups coordinated by the International Institute for Applied Systems Analysis, which explores the feasibility of pathways that can meet the objectives of the Paris Agreement. COMMIT stands for Climate pOlicy assessment and Mitigation Modeling to Integrate national and global Transition pathways. It consisted of a consortium of a large number of national research teams and aimed to improve the modelling of national low-carbon emission pathways and the analysis of country contributions to the global ambition of the Paris Agreement. The ADVANCE project (Advanced model Development and Validation for the improved ANalysis of Costs and impacts of mitigation policies) developed a new generation of IAMs to explore different climate change mitigation pathways in the context of the Paris Agreement.

comparing the policy implications of different temperature goals, understanding the trade-offs of mitigation strategies with other sustainable development goals, exploring the implications of immediate versus delayed action. Scenarios and their underlying models are constantly being refined and updated. This allows to improve modelling limitations, including the usability of scenarios depending on feedback received from users[3], as well as to incorporate latest real-world developments which affect the economy and emissions, such as the COVID-19 pandemic and the 2022 energy crisis.

Amid recent demand by the financial sector for climate change mitigation scenarios, scenarios specifically designed to be used by the financial sector have been developed**.** The Network for Greening the Financial Sector (NGFS) has for instance commissioned the Potsdam Institute for Climate Impact Research (PIK), the International Institute for Applied Systems Analysis (IIASA) and the University of Maryland (UMD) to produce a set of six climate scenarios tailored to the needs of central banks and financial supervisors (NGFS, 2022[33]). The intended use of NGFS scenarios is to understand how physical and transition risks from climate change could evolve over time, but also to allow actors from the private and public sectors to set more granular alignment targets in their transition strategies (NGFS, 2020[34]). Similarly, the United Nations (UN)-convened Net Zero Asset Owners Alliance commissioned the Institute for Sustainable Futures (ISF) to produce a set of sectoral decarbonisation pathways with a high granularity and a sector classification adapted to the needs of financial investors (Teske et al., 2020[35]). Such scenarios are developed to provide a common reference framework for scenario analyses in and by the financial sector.

1.1.3. Need for coordinated understanding in using climate change mitigation scenarios to inform metrics and assessments in the financial sector

Existing studies on the use of climate change mitigation scenarios in the financial sector have mostly focused on its use for financial risk assessment, risk management and stress testing (NGFS, 2020[36]; UNEP FI & CICERO, 2021[37]; FSB, 2022[5]; ECB, 2022[38]; Banque de France, 2022[39]; Bank of Canada, 2021[40]; I4CE, 2022[41]; Colin, Vailles and Hubert, 2019[42]). Only a few studies take stock of climate change mitigation scenarios currently used by the financial sector for the purpose of analysing its possible contribution to reaching climate change mitigation policy goals, and provide some recommendations to climate modellers to support scenario use in the financial sector in this context (UNEP FI & CICERO, 2021[37]; GFANZ, 2022[18]; Noels and Jachnik, 2022[10]). Such studies acknowledge that mitigation scenarios were not originally designed for use by the financial sector and identify resulting issues and limitations.

Previous research identified downscaling as a central challenge to using climate change mitigation scenarios in climate-alignment assessment methodologies for finance (Noels and Jachnik, 2022[10]). On the one hand, assessments of alignment with the Paris Agreement require analyses at the level of individual financial portfolios, assets, and underlying economic actors and activities, which requires some degree of sectoral and geographical granularity (UNEP FI & CICERO, 2021[37]; GFANZ, 2022[18]; Noels and Jachnik, 2022[10]). On the other hand, there is no political or societal consensus on suitable approaches to disaggregate the global goals of the Paris Agreement to such a level of granularity.

More generally, existing studies acknowledge that financial institutions and supervisors need to better understand the characteristics, assumptions, and uncertainties of climate change mitigation scenarios (UNEP FI & CICERO, 2021[37]; Noels and Jachnik, 2022[10]; Trust et al., 2023[43]). Such information also needs to be better communicated to improve the credibility, transparency and comparability of climate target setting and alignment assessments analyses. In this context, there is a need for a common language

[3] Climate mitigation scenario data and methodologies are often opensource, making them easily accessible to potential end-users.

between climate policy makers, climate scenario providers, climate-related assessment methodology providers and financial market stakeholders, which the present paper can contribute to.

1.2. Objectives and scope

Considering the importance and challenges of using climate change mitigation scenarios for climate target setting, transition planning, and alignment assessments in finance, the general objective of the analysis is to contribute to improved use of climate change mitigation scenarios in such contexts, thereby strengthening transparency and credibility. Improved understanding of what the alignment of assets and portfolios with climate objectives means, including underlying targets for such portfolios and individual assets, is critical amidst increasing environmental integrity concerns (CPI, 2021[44]; Rogelj et al., 2019[45]), evidence of potential market integrity and greenwashing risks based on existing metrics and practices (OECD, 2022[46]), and interest in disclosure and metrics using mitigation scenarios (TCFD, 2017[6]; IFRS, 2022s[47]; GFANZ, 2022[24]).

More credible scenario-based metrics and assessments can in turn support the achievement of the Paris Agreement mitigation goals by providing a sound basis for contributing to inform investors' decisions and climate policy. In contrast, inconsistency and lack of transparency and environmental integrity in alignment assessments of finance undermine both the achievement Paris Agreement goals and efficient capital reallocation towards the transition of the economy towards low GHG emissions.

Against this backdrop, this paper provides a detailed snapshot and analysis of climate change mitigation scenarios currently used in financial sector for climate-related target setting and alignment assessment. Based on a comparative analysis of the main characteristics, strengths, limitations and underlying assumptions of these scenarios, the paper pursues the following specific objectives:

- Position such scenarios against aggregate-level criteria that can be used to define consistency with the Paris Agreement ("Paris consistency" thereafter) from a climate mitigation perspective, based on a framework and criteria defined in Pouille et al. (2023[11]).
- Unpack inherent challenges in using climate change mitigation scenarios to assess the climate alignment of individual financial and real economy assets, such as downscaling scenarios to allow for an analysis of individual economic and financial assets or actors, as well as consider areas where such challenges may be overcome, how and by whom.
- Provide enhanced transparency and common understanding of the characteristics, assumptions and uncertainties associated with climate change mitigation scenarios used in the financial sector. In doing so, the analysis does not aim to rank or judge scenarios, but rather, as aforementioned, bridge the information and potential co-ordination gap between different stakeholder and policy communities.
- Identify opportunities for climate policy makers to facilitate providers of climate change mitigation scenarios to design scenarios that are not only consistent with the Paris Agreement temperature goal, but also better suited as inputs to robust and policy-relevant financial sector climate alignment assessments.
- Discuss implications for aggregate-level alignment assessments of finance (e.g. at the level of financial centres, coalitions of investors and financial institutions), including in the context of measuring progress towards the Paris Agreement goal of making finance consistent with a pathway towards low greenhouse gas emissions and climate-resilient development (Article 2.1c), and as highlighted by the UNFCCC Standing Committee on Finance's most recent Biennial Assessment and Overview of Climate Finance Flows (UNFCCC, 2021[48]).

Previous research developed guidance for the use of climate transition scenarios and pathways in the financial sector to answer questions about institutional preparedness for the low-carbon transition (UNEP FI & CICERO, 2021[37]; GFANZ, 2022[18]; Colin, Vailles and Hubert, 2019[42]), This study is, however, the first to consistently consider the use of climate change mitigation scenarios in the financial sector for target setting and alignment assessments against analytical dimensions relevant to the three stakeholder communities, i.e. the climate policy community, financial market participants (including providers of climate-alignment assessment methodologies), and the climate science community (including climate modellers). As such, the analysis contributes to developing a common language and understanding as well as bridging potential information gaps between communities, based on a novel analytical approach.

This paper builds on previous OECD analyses, which identified that climate-alignment assessments may vary depending on the reference point used, whether when considering financial portfolios and assets (Noels and Jachnik, 2022[10]), or real economy investments and underlying sources of finance (Jachnik and Dobrinevski, 2021[25]; Dobrinevski and Jachnik, 2020[27]; Dobrinevski and Jachnik, 2020[26]). Previous analyses specifically highlighted the role and impact of climate change mitigation scenarios in climate-alignment assessments and methodologies (Noels and Jachnik, 2022[10]; Schwegler et al., 2022[28]). Knowledge and information gaps identified in such studies are here analysed more in-depth by going into the characteristics of the climate models, scenarios and pathways, building on latest developments and updates from relevant climate mitigation scenario providers.

The Paris Agreement calls for alignment with both mitigation and resilience policy objectives. Physical risks scenarios of climate impacts can be used to identify adaptation needs in the private and financial sector (NGFS, 2022[49]; TCFD, 2017[6]), but are beyond the scope of this paper. While this paper focusses on mitigation, complementary analysis on the alignment of finance with resilience objectives is explored (Mullan and Ranger, 2022[50]).

The remainder of this paper is structured as follows:

- Chapter 2 takes stock of the climate change mitigation scenarios commonly used for these purposes for financial sector target setting and alignment assessments, with a focus on those qualified as “net zero”, 1.5°C or below 2°C by scenarios providers, and outlines the analytical approach and key dimensions against which scenarios are analysed in the remainder of the paper.
- Chapter 3 analyses the extent to which these scenarios are consistent with the Paris Agreement, based on five concrete criteria for identifying and selecting climate change mitigation scenarios that can be considered as consistent with the Paris Agreement’s temperature goal and long-term emissions objective, as proposed in Pouille et al. (2023[11]).
- Chapter 4 studies the scope and granularity of those same scenarios, with the aim of highlighting their applicability and challenges for their use in the financial sector.
- Chapter 5 explores the characteristics of the mitigation strategies and assumptions that underpin the scenarios.
- Chapter 6 summarises the current challenges, discusses areas for improvements in applying climate change mitigation scenarios for target setting and alignment assessment in finance, and suggests how climate scenario providers, users, as well as climate policy makers may contribute to such improvements.

2 Climate change mitigation scenarios in scope and analytical approach

An OECD stocktake on methodologies to assess the alignment of financial assets and portfolios found that these methodologies follow three approaches when selecting reference points or, more specifically, scenarios as input to their assessments (Noels and Jachnik, 2022[10]). These approaches may also be followed for setting decarbonisation targets (SBTi, 2021[20]).

- Most methodologies select specific scenarios that they use to compare the target and/or trajectory of a financial asset with. In this context, they can use one scenario for one temperature outcome from one scenario source, or may consider multiple scenarios for different temperature outcomes from one scenario source. Alternatively, the methodologies can offer a choice of multiple scenarios from multiple scenario sources, allowing users to compare against different pathways for the same temperature outcome.
- Less frequently, methodologies calculate an average scenario across a set of scenarios selected from the IPCC Sixth Assessment Report (AR6) or SR1.5 scenarios database[4]. For this, methodologies may select a set of scenarios from the database based on a range of criteria, such as early action and no overshoot. The mean of the selected scenarios can then be calculated for each point in time, although such use is not what individual scenarios were designed for (Huppmann et al., 2018[51]).
- A limited number of methodologies use the remaining carbon budget for a given temperature rise calculated by the IPCC, instead of a scenario. They may either build their own proprietary scenarios or develop an approach to allocate the budget to financial assets.

This paper mainly focuses on the climate change mitigation scenarios used as input by methodology providers that select specific scenarios (first approach above and most commonly used). However, the analysis, also includes considerations relevant to the other approaches, notably by positioning the specific scenarios featured in the analysis in the context of the broader AR6 scenario database and so-called scenario envelopes derived from Pouille et al. (2023[11]). With this in mind, this chapter presents the specific climate change mitigation scenarios in scope of the analysis (Section 2.1) and provides an overview of the approach and dimensions used to analyse and characterise these scenarios in the following chapters (Section 2.2).

2.1. Climate change mitigation scenarios used in financial sector climate target setting and alignment assessment

Many institutions worldwide design and provide climate change mitigation scenarios. The latest IPCC Assessment and special reports on mitigation have been accompanied by scenario databases where many

[4] The International Institute for Applied Systems Analysis (IIASA) hosts the scenarios and data used in the IPCC reports (Byers, 2022[52]). This includes the IAMC 1.5°C Scenario Explorer (Huppmann et al., 2018[51]), which covers the pathways used in the Special Report on Global Warming of 1.5°C (IPCC, 2018[146]).

existing scenarios provided by the research community and scientific institutions are collected and used to support the assessments. Over 3,000 of the latest generation of such scenarios were collected and made available in the context of the publication of the IPCC's AR6 (Byers, 2022[52]).

While there are a range of scenario sources that alignment methodology providers can choose from, scenarios used in current climate-alignment assessment of finance are from only four sources, representing a small subset of all existing climate mitigation scenarios. Table 2.1 lists the main climate change mitigation scenarios that have so far been chosen to underpin existing climate-alignment assessments, as identified through literature review and bilateral consultations with providers of climate-alignment methodologies[5] in the recent OECD stocktake (Noels and Jachnik, 2022[10]). Annex A provides a more detailed description of each of these four providers:

- **The International Energy Agency (IEA):** The IEA has developed global and macro-regional pathways for broad sectors, as published through its World Energy Outlook, relying on the IEA Global Energy and Climate Model (GEC) (IEA, 2022[53]).
- **The Network for Greening the Financial System (NGFS):** The NGFS' set of climate scenarios, available in a dedicated database, currently consists of six scenarios classified in three categories: orderly transition, disorderly transition, and hot house world (Bertram et al., 2021[54]). For each of the NGFS scenarios, multiple IAMs are used to provide a range of estimates and better cover the uncertainty space.
- **The European Commission's Joint Research Centre (JRC):** The JRC has developed its so-called POLES model, which simulates technology dynamics and is used to generate scenarios under its Global Energy and Climate Outlook (GECO) (Després et al., 2018[55]; Keramidas et al., 2021[56]).
- **The Institution for Sustainable Futures (ISF):** The ISF has developed the One Earth Climate Model (OECM) scenarios, adapted to produce sectoral pathways that uniquely consider sector classifications used in financial and economic accounting (i.e. GICS) (Teske et al., 2020[35]).

Climate-alignment assessment methodologies may consider scenarios for a range of temperature outcomes, including scenarios that reflect current levels of policy ambition and hence result in above 2°C temperature increase outcomes. However, with the Paris Agreement temperature goal in mind, this paper focusses on below 2°C scenarios. As these scenarios and their underlying frameworks are constantly being refined and updated, this paper focuses on the most recent iteration of each scenario (Table 2.1).

The four scenario providers provide nine different "below 2°C" scenarios, five of which aim for net-zero emissions or 1.5°C, the four other scenarios are less ambitious. The providers use six different models, including the IEA Global Energy and Climate Model (GEC, the JRC's Prospective Outlook on Long-term Energy Systems (POLES-JRC) model, ISF's One Earth Climate Model (OECM) and Integrated Assessment Models (IAMs) such as the Global Change Assessment Model (GCAM).

[5] Climate-alignment assessment methodology providers that were consulted include Arabesque, Carbon Disclosure Project, Carbon Risk Real Estate Monitor, FTSE Russell Beyond Ratings, Carbone 4, MSCI, Paris Agreement Capital Transition Assessment, right. based on science, S&P Sustainble1 (previously Trucost), Transition Pathway Initiative.

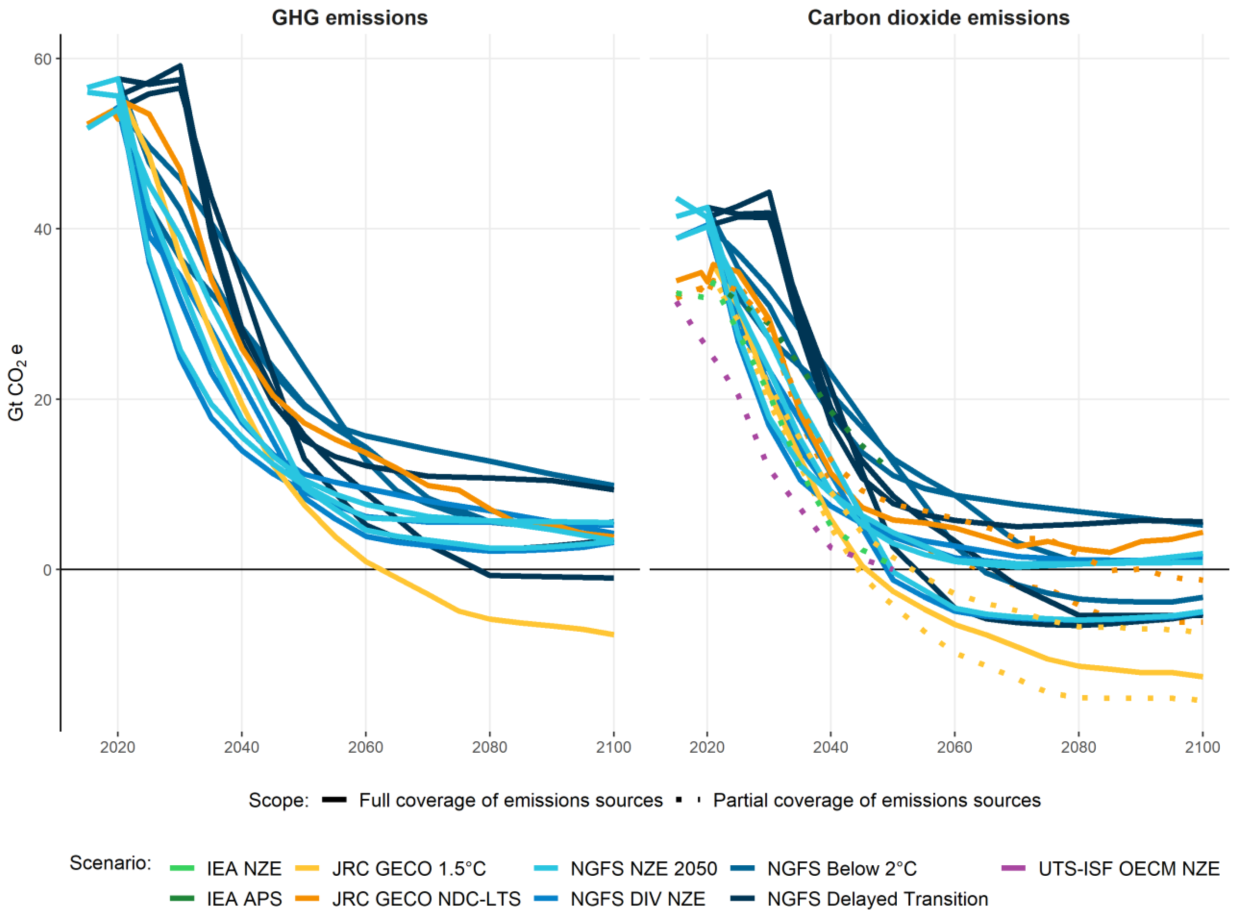
Table 2.1. Main global climate change mitigation scenarios for below 2°C used by climate alignment assessments of finance

Scenario	Acronym used in this paper	Model	Latest publication year	Source	Previous versions
International Energy Agency (IEA)					
Net Zero Emissions by 2050 Scenario	IEA NZE	Global Energy and Climate Model (GEC) 2022	2022	(IEA, 2022[53])	NZE 2021 (World Energy Model)
Announced Pledges Scenario	IEA APS	Global Energy and Climate Model (GEC) 2022	2022	(IEA, 2022[53])	
EU's Joint Research Centre (JRC)					
GECO 1.5°C	JRC GECO 1.5°C	POLES JRC 2022	2022	(Keramidas, 2022[57])	GECO 1.5°C uniform, GECO 1.5°C Differentiated 2021
GECO NDC-LTS	JRC GECO NDC-LTS	POLES JRC 2022	2022	(Keramidas, 2022[57])	GECO NDC-LTC 2021
Network for Greening the Financial System (NGFS)					
NGFS3 Net-Zero 2050 (GCAM, MESSAGE, REMIND versions)	NGFS NZE 2050 G NGFS NZE 2050 M NGFS NZE 2050 R	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 3.0-4.4	2022	(NGFS, 2022[33])	NGFS2 Net-Zero 2050
NGFS3 Divergent Net Zero Policies (GCAM, MESSAGE, REMIND versions)	NGFS DIV NZE G NGFS DIV NZE M NGFS DIV NZE R	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 3.0-4.4	2022	(NGFS, 2022[33])	NGFS2 Divergent Net Zero Policies
NGFS3 Below 2°C (GCAM, MESSAGE, REMIND versions)	NGFS Below 2°C G NGFS Below 2°C M NGFS Below 2°C R	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 3.0-4.4	2022	(NGFS, 2022[33])	NGFS2 Below 2°C
NGFS3 Delayed transition (GCAM, MESSAGE, REMIND versions)	NGFS Delayed G NGFS Delayed M NGFS Delayed R	GCAM 5.3, MESSAGEix-GLOBIOM 1.1, REMIND-MAgPIE 3.0-4.4	2022	(NGFS, 2022[33])	NGFS2 Delayed transition
University of Sydney Institute for Sustainable Futures (UTS-ISF)					
UTS-ISF Net Zero	UTS-ISF OECM NZE	One Earth Climate Model (OECM)	2020	(Teske et al., 2020[35]; Teske et al., 2023[58])	OECM 1.5°C and OECM 2°C 2019

Note: Green highlights the most recent version of scenarios. All scenarios are used by current climate-alignment assessment methodologies. Some methodologies also indicated that these scenario sources may be used in the future, in which case it is unclear which specific scenario will be used.
Source: Authors. List established based on consultations with alignment methodology providers listed in footnote 5. Information source for each scenario is given in the source column.

Figure 2.1 represents GHG or CO_2 emissions pathways under the scenarios highlighted in Table 2.1. While this already indicates the range of possible decarbonisation pathways that can be followed for a relatively similar level of ambition, the scope of these scenario pathways are not consistent (in terms of covered emissions sources etc, see also in Chapters 3 and 4). To address this issue, scenario variables and pathways were collected for this paper, in consultation with the scenario providers (see Acknowledgements), on a consistent basis and scope to obtain comparable data.

Figure 2.1. Main global GHG or CO_2 emissions pathways from scenarios used in climate-alignment assessments of finance with scope differences



Note: Some scenarios do not cover all types of GHG and therefore do not have an aggregated GHG emissions pathways (left panel). The different scenarios have different scopes in terms of CO_2 emissions sources, therefore the pathways displayed here are not directly comparable. NGFS emissions pathways here cover CO_2 emissions from energy use, industrial processes, agriculture and land use, and waste. ISF total CO_2 emissions cover energy-related emissions only. IEA pathways are for emissions from energy use and industrial processes.
Each of the four NGFS scenarios is produced using three different models, there are therefore three different pathways for each of the scenarios. GHG emissions presented here are aggregated by providers using Global Warming Potentials over 100 years (GWP_{100}), as estimated by different IPCC assessments. ISF scenarios use GWP_{100} values estimated by the IPCC AR4. The IEA, NGFS and JRC do not explicitly mention which IPCC assessment is relied on for GWP_{100} values.
Source: Authors.

Because of the very limited number of scenarios produced with finance as the intended use case, alignment methodology providers must mostly rely on scenarios that were built for other use cases and non-financial audiences. Annex A, which presents in more detail the listed scenarios and their respective main objectives, shows that most of the scenarios currently used for alignment assessments were not specifically produced for this use case:

- JRC produces scenarios to explore specific international mitigation issues with a climate policy perspective.
- IEA scenarios aim at proposing trajectories to decarbonise the energy sector globally and are intended to inform energy and climate policymaking.

- NGFS scenarios, while produced to be used by the financial sector, are designed for the purpose of climate-related transition risk analysis rather than alignment assessments.
- The UTS-ISF's OECM scenarios are based on country-specific energy scenarios to inform policy makers and the energy industry. They have been further developed for GHG target setting in the financial sector and for other uses that require practical pathways to achieve the Paris climate goals.

The only exception is the recent ISF Net Zero sectoral pathways, commissioned by the UN-convened NZAOA, an international group of over 30 institutional investors who have committed to transition their investment portfolios to net-zero GHG emissions by 2050 (Teske et al., 2020[35]). The ISF Net Zero scenario constitutes the first to rely on a sector classification commonly used for financial sector analysis (as further explained in Section 4.2), with the aim of describing 1.5°C-consistent sectoral pathways that can be more easily interpreted by financial market participants for net-zero analyses.

The original research questions and intended use cases influence scenarios' key design choices, including the formulation of the targeted climate outcome, the choice of modelling framework, the time horizon, the geographical and sectoral scopes, as well as socio-economic, technology and policy assumption inputs. Such design choices need to be transparent so scenarios can be applied in the most appropriate way. The fact that most scenarios are not designed for use in finance makes such need even more acute as additional assumptions and implementation choices need to be made.

2.2. Analytical perspectives and dimensions

Challenges to the use of climate change mitigation scenarios in the financial sector, and their implementation in financial sector climate target setting and alignment assessments, can be considered from the perspectives of three communities that interact with each other, namely climate policy makers, the financial sector stakeholders, and climate scenario modellers and providers. These three communities have different yet partly overlapping perspectives, which. this paper captures based on three complementary analytical dimensions:

- The scenarios selected for climate-related analyses in the financial sector need to have environmental integrity. In the context of international climate policy particularly, this relates to the Paris **consistency** of mitigation scenarios, as scenarios are used for target setting and alignment assessments of finance. Climate policy makers may also consider the alignment of their domestic financial market and consistency with national climate policy objectives. Climate policy researchers may further analyse the implications and interpretations of such policies.
- The **applicability** of mitigation scenarios in climate-related financial analysis brings different considerations when financial sector stakeholders assess financial assets and portfolios. More specifically, providers of methodologies to set climate-related targets or assess climate-alignment for individual entities or assets make use of such scenarios as input. Financial institutions and investors may use such assessments in the context of measuring progress towards their own climate-related targets, as well as to inform investment decisions. In the context of the latter, financial market participants and supervisors increasingly conduct climate transition-related risk assessments and stress testing, which involves analytical dimensions beyond the scope of this paper (see Box 2.1).
- Scientific researchers and climate modellers consider with great care the **characteristics** and feasibility of assumptions that underpin scenarios, scenario pathways and underlying models. In doing so, modellers consider how scenarios may reflect possible futures, while ensuring these characteristics and assumptions remain credible. In turn, such characteristics and assumptions can play an important role in informing and impacting financial sector climate-related target setting and alignment assessment.

Based on these three complementary and interlinked analytical dimensions, this paper analyses the selected scenarios across analytical dimensions, which are summarised in Figure 2.2 and further detailed in Sections 3.1, 4.1, 5.1, respectively. These dimensions entail analysing (1) the Paris consistency of the scenarios as discussed in Chapter 3, (2) the applicability of such scenarios at the level of financial sector assets and portfolios, as discussed in Chapter 4, and (3) the characteristics of the mitigation strategies and assumptions that scenarios are based on, as discussed in Chapter 5. These dimensions guide a comparative analysis across the selected scenarios, against the AR6 database and based on the wider climate change mitigation modelling literature.

Figure 2.2. Dimensions for analysing climate change mitigation scenarios used in climate-alignment assessments of finance

Are climate change mitigation scenarios consistent with the Paris Agreement?

Temperature outcomes
- Median end of century (2100) and peak temperature
- Likelihood of staying below 1.5°C in end of century (2100) and during the century
- Likelihood of staying below 2°C during the century

Emissions outcomes
- Year of peak GHG emissions
- Years of net-zero global GHG and CO_2 emissions
- GHG emissions in 2100

Assessment questions
What is the scenario's level of ambition?
Is the scenario's level of ambition consistent with the mitigation goals of the Paris Agreement?

Are climate change mitigation scenarios fit-for-purpose for use in the financial sector?

Scope and granularity
- Sector
- Geography
- Emissions
- Time

Assessment questions
What is the scenario's scope?
Is the scenario data granular enough to apply in net-zero analyses of finance?

What are the characteristics of mitigation strategies and assumptions of climate change mitigation scenarios?

Mitigation strategies
- Energy supply decarbonisation
- Demand-side reductions
- Carbon Dioxide Removal
- Land emissions reductions

Input and modelling assumptions
- Socio-economic
- Technology
- Policy
- Modelling characteristic

Assessment questions
What are the scenario's mitigation strategies?
Are the mitigation pathways feasible?
What are the scenario's underlying assumptions?
What are the scenario's underlying sources of uncertainties in mitigation pathways?

Box 2.1. Further considerations for using mitigation scenarios for risk management and stress testing

As explained in Chapter 1, the perspective of alignment and risk are closely interrelated. Therefore, there is an overlap in scenario use for both perspectives. However, some additional considerations can be made on the use of scenarios for transition risk management and climate stress testing, and related challenges. There is a growing literature available that can be drawn upon, as also mentioned in Chapter 1.

First, while for climate-alignment typically one scenario is selected, climate stress testing inherently analyses transition risks against a wider range of scenarios (Täger and Dikau, 2023[3]). For stress testing and risk management, a wide spectrum of scenario narratives is needed to avoid the accumulation of systemic risks (Baer et al., 2023[59]). This includes scenarios with abrupt changes in technological advancements and policies, and scenarios with low probability but high impact developments (Baer et al., 2023[59]; Allen et al., 2020[60]). This consideration would broaden the scope of scenarios included, such as the UN PRI Inevitable Policy Response scenario.

Second, mitigation scenario models do not account for the role of the financial sector in climate change mitigation pathways, even though there are likely important feedback loops (Monasterolo, Nieto and Schets, 2023[61]; Allen et al., 2020[60]). There is a need to link climate models to financial models in a circular way, allowing further information on financing cost across low- and high-carbon firms to inform mitigation scenarios (Battiston et al., 2021[62]). Additionally, transmission channels between climate change-related shocks and macro-financial risks need to be further identified to assess quantitatively their impacts on the financial sector (Allen et al., 2020[60]).

Finally, current scenarios will lead to an underestimation of the risk, potentially giving rise to a false sense of security on how the transition may unfold (Baer et al., 2023[59]). This is because current climate models do not adequately cover the full envelope of possible economic and financial frictions, compounding risks, volatility, and acute physical risk disruptions (Baer et al., 2023[59]).

3 Are climate change mitigation scenarios consistent with the Paris Agreement?

This chapter studies the degree of Paris consistency (i.e. consistency with the Paris Agreement mitigation objectives) of the level of ambition of scenarios used in the financial sector (as outlined in Chapter 2). It first briefly presents the framework used to assess the consistency of scenarios with the Paris Agreement mitigation objectives (Section 3.1), which stems from a closely-related analysis (see (Pouille et al., 2023[11])). The framework is then applied to the scenarios in use in financial sector climate target setting and alignment assessment to assess the extent to which those scenarios are consistent with the Paris Agreement's level of ambition (Section 3.2). On that basis, the broader implications for the use of these scenarios are drawn (Section 3.3).

3.1. Framework to assess the Paris consistency of climate change mitigation scenarios

For the purpose of environmental integrity, climate change mitigation scenarios used in financial sector target setting and alignment assessment must be consistent with the Paris Agreement temperature goal and long-term emissions objective. The formulations of this goal and objective are however not sufficiently specific to e.g. define emissions levels or benchmarks in line with its goals and is therefore susceptible to a range of interpretations (Schleussner et al., 2022[63]). Against this backdrop, Pouille et al. (2023[11]) provides an overview of the different ways the Paris Agreement can be interpreted and discusses the implications of these different interpretations for the choice of Paris-consistent climate change mitigation scenarios in terms of level of ambition.

The framework developed by Pouille et al. (2023[11]) considers aspects of both the long-term temperature goal (Article 2.1) and the emissions objective (Article 4) of the Paris Agreement and provides a set of criteria to assess the Paris consistency of scenarios' level of ambition, for two different levels of stringency (Table 3.1):

- To be in line with the Paris Agreement's Article 2.1 long-term temperature target scenarios must remain below 1.5°C by 2100 with limited overshoot (<0.1°C), with 50% chance *and* remain well-below 2°C throughout the century (i.e. have very high likelihoods of not exceeding 2°C);
- *In addition*, to be in line with Article 4 of the Paris Agreement scenarios must see an early peak in GHG emissions and reach net-zero GHG emissions in the second half of the century. A higher level of stringency filters scenarios that peak at the latest in 2025 and achieve net-zero GHG emissions in the second half of the century, and a lower level of stringency filters those scenarios that peak at the latest in 2030 and achieve close to net-zero GHG emissions in the second half of the century.

To analyse the Paris consistency of a given scenario with the Paris Agreement, data on key features of scenarios in terms of their temperature and emissions outcomes is needed, as listed in the last column of Table 3.1.

Table 3.1. Considerations and criteria for assessing the Paris consistency of global climate change mitigation scenarios

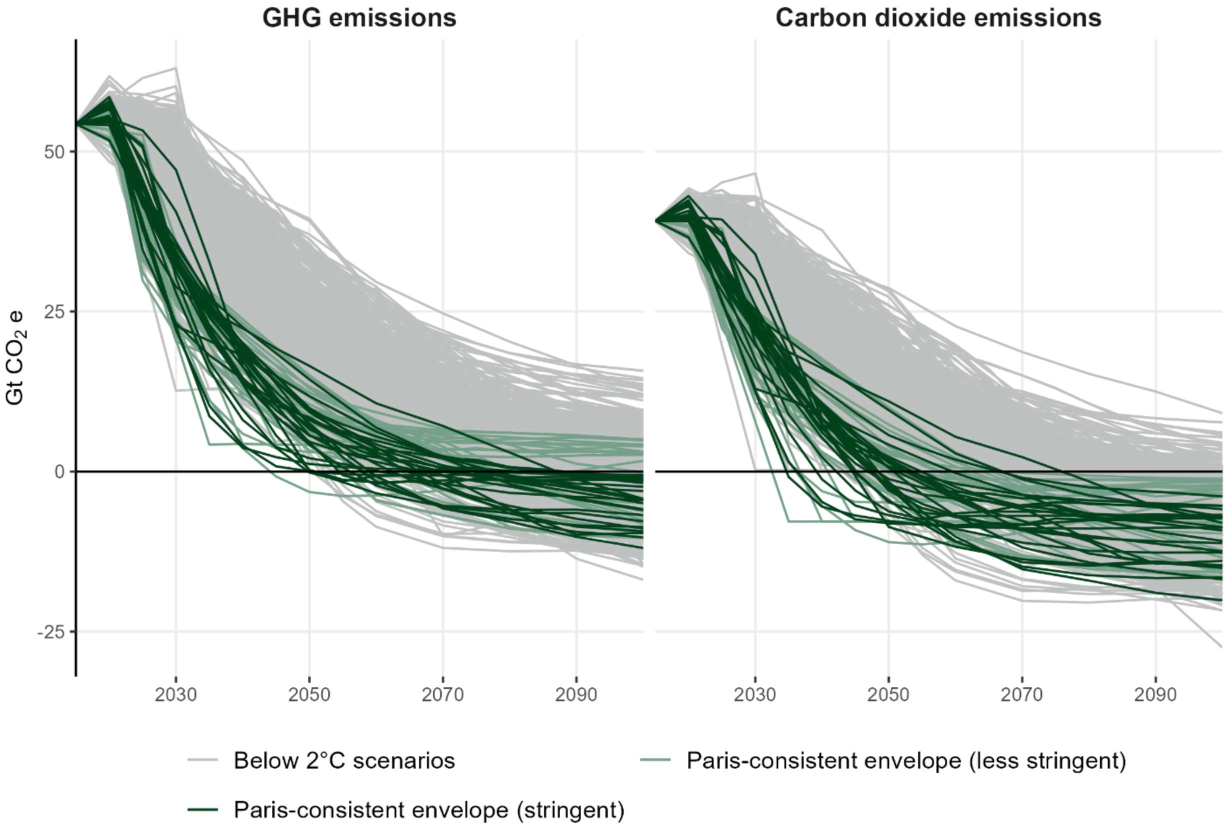
<table>
<tr><th rowspan="2">Paris Agreement Article</th><th rowspan="2">Paris Agreement language elements on mitigation objectives</th><th colspan="2">Possible criteria for mitigation scenarios</th><th rowspan="2">Scenario data required for consistency assessment</th></tr>
<tr><th>More stringent interpretation</th><th>Less stringent interpretation</th></tr>
<tr><td rowspan="2">2.1</td><td rowspan="2">“pursuing efforts to limit the temperature increase to 1.5 °C”</td><td colspan="2">Criterion 1
1.5°C in 2100
In 2100 the scenario must hold global warming below 1.5°C with at least 50% chance.</td><td>Likelihood of staying below 1.5°C in 2100
Or global warming in 2100 at the 50% likelihood level</td></tr>
<tr><td colspan="2">Criterion 2
no or limited overshoot of 1.5°C
Throughout the century, the scenario must hold global warming below 1.6°C with at least 50% chance.</td><td>Likelihood of staying below 1.5°C during the century
Or peak global warming during the century at the 50% likelihood level</td></tr>
<tr><td>2.1</td><td>“holding the increase in global average temperature to well below 2 °C”</td><td>Criterion 3
well-below 2°C throughout the century
Throughout the century, the scenario must hold global warming below 2 °C with at least a 90% chance.</td><td>Criterion 3
well-below 2°C throughout the century
Throughout the century, the scenario must hold global warming below 2 °C with at least an 78% chance.</td><td>Likelihood of staying below 2°C during the century</td></tr>
<tr><td rowspan="2">4.1</td><td rowspan="2">“aim to reach global peaking of greenhouse gas emissions as soon as possible [...and] achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century”</td><td>Criterion 4
peak GHG emissions
The scenario must ensure that global GHG emissions peak before 2025.</td><td>Criterion 4
peak GHG emissions
The scenario must ensure that global GHG emissions peak before 2030.</td><td>Year of peak GHG emissions</td></tr>
<tr><td>Criterion 5
Net-zero emissions
The scenario must achieve global net-zero GHG emissions in the second half of the 21st century.</td><td>Criterion 5
Net-zero GHG emissions
The scenario must achieve global net-zero CO_2 emissions, accompanied by marginal net-zero GHG emissions i.e.. very strong GHG emissions reductions resulting in residual net GHG emissions in 2100 of 5 Gt or less.</td><td>Year of net-zero global GHG and CO_2 emissions
GHG emissions in 2100</td></tr>
<tr><td colspan="2">Number of scenarios in the IPCC AR6 database</td><td>26</td><td>55</td><td></td></tr>
</table>

Source: ENV/EPOC/WPCID(2023)10/REV1.

In the context of Pouille et al. (2023[11]), reference envelopes of global scenarios consistent with the Paris Agreement considerations were derived by applying the criteria identified in Table 3.1 to the latest IPCC scenarios database. As part of the IPCC Sixth Assessment Report (AR6), the IPCC Working Group on Mitigation of Climate Change collected and assessed a large number of quantitative, model-based climate change mitigation scenarios. (Riahi et al., 2022[32]). These include over 2,200 scenarios with global coverage, submitted by over 50 scenario providers. Since the AR6 scenario database represents a large number of scenarios from the climate modelling community, it can be used as a reference point for quantitative climate mitigation-related assessments.

These capture a large spectrum of possible futures, assumptions, and trajectories towards the Paris Agreement's goals. They serve as a point of comparison for the level of ambition of scenarios used by climate-alignment assessments of finance analysed in this paper. A stringent application of the criteria to the AR6 scenarios database results in an envelope of 26 Paris-consistent scenarios. Applying a relaxed interpretation of the criteria results in an envelope of 55 scenarios. These envelopes are illustrated in Figure 3.1.

Figure 3.1. Reference envelopes of scenarios that fulfil Paris-consistency criteria



Note: Net emissions pathways for total GHG (left panel) and CO_2 (right panel), using harmonised values given by the IPCC AR6 database. GHG emissions are aggregated using Global Warming Potentials over 100 years as estimated by the IPCC AR6 (GWP_{100} AR6).Pathways in green correspond to scenarios in the IPCC AR6 scenarios database that fulfil Criteria 1, 2, 3, 4 and 5 (see Table 3.1). Pathways in dark green satisfy the more stringent interpretation for each of the criteria, while pathways in light green satisfy the less stringent level of interpretation of the criteria. The other pathways (in grey) correspond to all other scenarios in the IPCC AR6 scenarios database that remain below 2°C with a 50% chance throughout the century.
Source: Pouille et al. (2023[11]) and IPCC AR6 scenarios database (Byers, 2022[52]).

3.2. Application of the Paris consistency framework to scenarios in use in the financial sector

Providers of scenarios used in the financial sector explain the consistency of their scenarios' levels of ambition with global climate policy goals in different ways (Annex A). In some cases, scenario providers may describe their scenario results as being in line with certain temperature outcome referring at times explicitly to the Paris Agreement. In other cases, scenario providers may also refer to net-zero emissions outcomes in some of their scenarios. A combination of these elements is seldom provided. Analysis in

Pouille et al. (2023[11]) showed that considering the different elements of the Paris Agreement jointly, i.e. its temperature and emissions goals, is crucial to ensure the choice of scenarios yields environmental integrity.

In this paper, such a systematic approach is, therefore, adopted to assess the Paris consistency of the different scenarios used in financial sector target setting and alignment assessment. As such, the approach goes beyond the self-assessment given by individual scenario providers.

This section applies the framework proposed in Pouille et al. (2023[11]) (as explained in Section 3.1) to consistently compare scenarios' temperature and emissions outcomes in the context of the Paris Agreement's global mitigation goals. Sub-section 3.2.1 gives a summary of the comparison between scenarios' characteristics and the criteria from the framework, while sub-sections 3.2.2 and 3.2.3 deep dive into temperature criteria 1-3 and emissions criteria 4-5 respectively (Table 3.1).

In order to assess Paris consistency using the framework, as highlighted in Table 3.1, a full set of key characteristics of emissions and temperature outcomes of scenarios in use is required. This includes end-of-the-century and peak temperatures and associated likelihoods, year of peak emissions and of net-zero GHG for all scenarios analysed. Such data is only partially available in the public domain. Surveys were carried out with scenario providers in order to collect data that is not publicly available and is provided first-hand for the purpose of the analysis undertaken in this paper (Table 3.2).

3.2.1. Overall assessment of Paris consistency

The data shows scenarios are designed to achieve different temperature and emissions targets even when they have the same net-zero ambition (Table 3.2). In terms of temperature outcomes, the scenarios considered are announced by scenario providers to result either in less than 1.5°C, or in below 2°C (1.7°C to 1.8°C) of median temperature rise by the end of the century. Some scenarios result in net-zero GHG and/or net-zero CO_2 emissions in the second half of the century, while others do not. Table 3.2 highlights in grey the scenarios that were designed by providers for a below 2°C ambition, keeping in white the scenarios that were created to achieve a 1.5°C ambition.

Evaluating the key temperature and emissions outcomes of scenarios summarised in Table 3.2 against the criteria for Paris consistency, Table 3.3 summarises the extent to which scenarios are consistent with the different criteria for Paris consistency outlined in Section 3.1. For each criterion, Table 3.3 shows whether a scenario is consistent with the stringent application (dark green), less stringent application (light green), or not consistent with either (orange). Out of the 17 scenarios considered, 2 are fully consistent with all temperature and emissions criteria (depicted by the red rectangles). In fact, these scenarios are mostly consistent with the most stringent interpretation of the Paris Agreement's objectives, apart from the fact that they do not reach net zero GHG emissions in the by the end of the century, keeping residual net GHG emissions of less 5 Gt. The criteria that are least complied with across all scenarios is the limitation of temperature overshoots of 1.5°C over the century and the well-below 2°C criteria, which are strongly correlated.

Table 3.3 also shows that several scenarios do not provide sufficient information to allow for a full assessment of their Paris consistency (grey boxes). In particular, features of GHG emissions pathways (early peak and net zero in the second half of the century) are not available for scenarios that do not model all GHGs, but are an important aspect of the Paris Agreement's emissions objectives in Article 4.1. It may also be difficult to assess whether scenarios keep temperatures well below 2°C throughout the century, because this requires information of temperature outcomes of scenarios at several levels of likelihoods, rather than the median temperature outcome only.

Table 3.2. Key temperature and emissions outcomes of climate change mitigation scenarios

Covered	Partial	Not covered

Variables	IEA NZE	IEA APS	UTS-ISF NZE	JRC GECO 1.5°C	JRC GECO NDC-LTS	NGFS3 NZE 2050	NGFS3 DIV NZE	NGFS3 Below 2°C	NGFS3 Delayed transition	Stringent envelope (26 scenarios)	Less stringent envelope (55 scenarios)
	Scenarios									IPCC scenario envelopes	
						G: GCAM M: MESSAGE R: REMIND	G: GCAM M: MESSAGE R: REMIND	G: GCAM M: MESSAGE R: REMIND	G: GCAM M: MESSAGE R: REMIND		
Scope											
End year	2050	2050	2050	2100	2100	2100	2100	2100	2100	2100	2100
GHGs covered	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other	CO_2 Other
Emission sources covered	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste	Energy Industrial processes AFOLU Waste
Temperature outcomes											
Announced temperature outcome	<1.5°C (50%) in 2100	1.7°C (50%) in 2100	1.5°C (67%)	<1.5°C (50%) in 2100	1,8°C (50%) in 2100	1.4°C (50%) in 2100	1.4°C (50%) in 2100	1.6°C (50%) in 2100	1.6°C (50%) in 2100	Not applicable	Not applicable
Warming in 2100 (50% likelihood)	1.36°C	1.75°C	1.47°C	1.36°C	1.79°C	G:1.51°C M:1.31°C R:1.38°C	G:1.44°C M:1.29°C R:1.39°C	G:1.74°C M:1.50°C R:1.63°C	G:1.64°C M: 1.43°C R: 1.61°C	1.18°C (1.02-1.34)	1.24°C (1.02-1.47)
Peak warming in the century (50% likelihood)	~ 1.6°C	NA	1.67°C	1.72°C	1.84°C	G:1.75°C M:1.53°C R:1.56°C	G:1.70°C M:1.53°C R:1.56°C	G:1.90°C M:1.63°C R:1.69°C	G: 1.89°C M: 1.75°C R: 1.76°C	1.56°C (1.41-1.60)	1.57°C (1.41-1.60)
Likelihood of staying below 1.5°C throughout the century	NA	NA	NA	19%	10%	G: 19% M: 44% R: 39%	G: 25% M: 45% R: 41%	G: 10% M: 31% R: 25%	G: 9% M: 17% R: 25%	42% (35-68%)	40% (34-68%)
Likelihood of staying below 2°C throughout the century	NA	NA	NA	80%	63%	G: 77% M: 92% R: 90%	G: 82% M: 93% R: 90%	G: 61% M: 85% R: 82%	G: 62% M: 78% R: 77%	92% (90-99%)	91% (83-99%)
Emissions outcomes											
Year of peak GHG emissions	NA	NA	NA	2022	2023	G: 2020 M: 2015 R: 2020	G: 2020 M: 2015 R: 2020	G: 2020 M: 2015 R: 2020	G: 2030 M: 2030 R: 2020	2020 (2015-2020)	2020 (2015- 2020)
Year of net-zero CO_2 emissions	2050	2070	2050	2054	2075	G: 2050 M: 2062 R: 2059	G: 2049 M: 2066 R: 2072	G: 2065 M: 2080 R: never	G: 2054 M: 2067 R: never	2049 (2035-2076)	2051 (2033- 2076)
Year of net-zero GHG emissions	NA	NA	NA	2063	never	G: never M: never R: never	G: never M: never R: never	G: never M: never R: never	G: never M:2075-80 R: never	2067 (2050-2089)	2076 (2045-never)
GHG emissions in 2100	NA	NA	NA	-7,6 Gt	3.8 Gt	G: 3.3 Gt M: 5.5 Gt R: 3.4 Gt	G: 3.2 Gt M: 5.2 Gt R: 4.2 Gt	G: 5.6 Gt M: 5.5 Gt R: 3.9 Gt	G: 3.6 Gt M: -1.0 Gt R: 9.4 Gt	-4.4 Gt (-11.9 – -0.5)	-4.3 Gt (-11.9 – 5.0)

Note: The numbers given in the last two columns correspond to the median value, and minimum and maximum values (in parentheses) across all scenarios in the reference envelopes of scenarios.
An uncertainty range of 1Gt CO_2 is used to estimate the timing of net-zero CO_2 emissions for scenarios modelled with REMIND.
Source: Authors' analysis based on publicly available information of and bilateral consultations with scenario providers.

Table 3.3. Synthesis of the assessment of scenarios based on five criteria reflecting the Paris Agreement objectives

Consistent (stringent) | Consistent (less stringent) | Not consistent | Insufficient information

Criteria	Scenarios																
	IEA NZE	IEA APS	UTS-ISF NZE	JRC GECO 1.5°C	JRC GECO NDC-LTS	NGFS3 NZE 2050			NGFS3 DIV NZE			NGFS3 Below 2°C			NGFS3 Delayed transition		
						G	M	R	G	M	R	G	M	R	G	M	R
Criterion 1: 1.5°C in 2100	Consistent (stringent)	Not consistent	Consistent (stringent)	Consistent (stringent)	Not consistent	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Not consistent	Consistent (stringent)	Not consistent	Not consistent	Consistent (stringent)	Not consistent
Criterion 2: limited overshoot of 1.5°C	Consistent (stringent)	Not consistent	Not consistent	Not consistent	Not consistent	Not consistent	Consistent (stringent)	Consistent (stringent)	Not consistent	Consistent (stringent)	Consistent (stringent)	Not consistent	Not consistent	Not consistent	Not consistent	Not consistent	Not consistent
Criterion 3: well-below 2°C	Insufficient information	Insufficient information	Insufficient information	Consistent (less stringent)	Not consistent	Not consistent	Consistent (stringent)	Consistent (stringent)	Consistent (less stringent)	Consistent (stringent)	Consistent (stringent)	Not consistent	Consistent (less stringent)	Consistent (less stringent)	Not consistent	Not consistent	Not consistent
Criterion 4: early peak GHG emissions	Insufficient information	Insufficient information	Insufficient information	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (stringent)	Consistent (less stringent)	Consistent (less stringent)	Consistent (stringent)
Criterion 5: net-zero GHG emissions	Insufficient information	Insufficient information	Insufficient information	Consistent (stringent)	Consistent (less stringent)	Consistent (less stringent)	Not consistent	Consistent (less stringent)	Consistent (less stringent)	Not consistent	Consistent (less stringent)	Not consistent	Not consistent	Consistent (less stringent)	Consistent (less stringent)	Consistent (stringent)	Not consistent

Note: The red boxes indicate the scenarios that are consistent with the less stringent interpretation of the Paris Agreement.
Source: Authors' analysis based on publicly available information of and bilateral consultations with scenario providers.

Indeed, the ability to consistently compare scenarios' outcomes against the Paris agreement's goals is limited by both the lack of disclosure of some information by scenario providers and differences in scopes across climate change mitigation scenarios:

- First, the **temperature outcomes of scenarios may not always be communicated in a way that is consistent with scientific practices**. Scenario providers typically provide information about the temperature outcome of their scenarios but may not provide specific information on both the end-of-the-century temperature or the peak temperature over the century. Overshoots of temperature thresholds during the century are, however, crucial for assessing Paris consistency and more generally for assessing the overall of mitigation ambition of a scenario. Scenario providers may also not provide information on the likelihood level for their scenarios' temperature outcomes. Direct assessments of temperature outcomes of scenarios are always probabilistic, and result in warming projections with different likelihood levels. For instance, a scenario may be consistent with limiting global warming to 1.5°C with 33% likelihood or with 50% likelihood, which are two very different outcomes. In general, scenario providers give the median temperature outcome of a scenario, that is at 50% likelihood level, but this is not always explicitly stated. Moreover, giving temperature outcomes of scenarios at several likelihood levels may be useful to compare a scenario both against the 1.5°C limit and the "well-below 2°C" limit, but this is very rarely provided by scenario modellers. Each scenario always has both an associated probability of limiting warming 1.5°C and probability of limiting it below 2°C.
- Second, when information is provided, scenarios' temperature outcomes may be difficult to compare because the **assessment of the temperature outcome given by scenario providers can be calculated using different methodologies**. In previous versions of these scenarios, a common way to assess the temperature result was to compare the scenarios' modelled cumulative CO_2 emissions with carbon budgets for different temperature limits – an approach that has several important limitations as explained in Box 3.1. More recently, the use of climate models to assess temperature outcomes

has become more common, which represents an improvement. All the temperature outcomes of scenarios in Table 3.2 were estimated using the same climate model called MAGICC[6], however possibly using different versions of the model with differences in the temperature results. Considering climate uncertainties in the temperature response to GHG emissions, using newer versions of a climate model is preferable to reflect the latest understanding of the physical science. The latest versions of MAGICC and of the second climate model used by the IPCC AR6, FaIR,[7] which is open source, were calibrated using the latest findings from the IPCC AR6 about how anthropogenic emissions translate into global warming; they should therefore be prioritised.

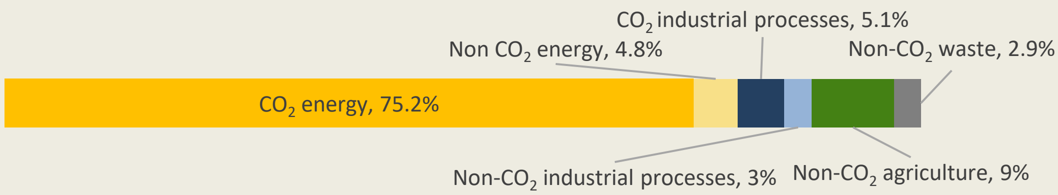
Box 3.1. Anthropogenic emissions sources of different GHGs

GHG emissions include CO_2 emissions and non-CO_2 emissions. Main other GHGs are methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (F-gases).

Anthropogenic GHG emissions can be classified according to their sources in terms of human activities:

- Energy-related emissions, i.e. emissions from fossil fuel combustion. These are primarily emissions of CO_2, but also include other GHG. Energy use, in a range of sectors such as industry, transport and buildings, is the main source of emissions (Figure 3.2).
- Emissions from industrial processes. Some industrial production processes, which chemically or physically transform materials, result in GHG releases (e.g. cement production) (IPCC, 1996[64]).
- Emissions from agriculture, mainly of methane (CH_4) and nitrous oxide (N_2O).
- Emissions from waste, which are mainly non-CO_2.
- Net emissions from land use, land use change and forestry (LULUCF).

Figure 3.2. Relative weight of GHG emissions per source and gas type



Note: For Annex I countries only, in 2019. Excluding LULUCF (net negative emissions). GHG emissions are aggregated using GWP_{100} (global warming potentials over 100 years) values from the IPCC AR4.
Source: Authors based on data from (UNFCCC, 2019[65]).

- Third and last, because of their intended use, scenarios in use have **different coverages of gases and different scopes in terms of emissions sources**, which limits the comparability of their emissions outcomes (also see Section 4.3.2). Box 3.1 provides an overview of the share of different gases and emissions sources in total global GHG emissions**.** While some scenarios, mostly those produced by IAMs, model all GHGs from all possible sources, others may focus on CO_2 emitted through energy use or energy and industrial processes and use complementary data sources for other GHG emissions. For example, JRC and NGFS scenarios cover all GHGs and all anthropogenic emissions sources; other scenarios focus on CO_2 and CH_4 emissions. Scenarios that do not model all GHGs from all sources rely on different methodologies to infill missing gases using data from external sources for

6 Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC).

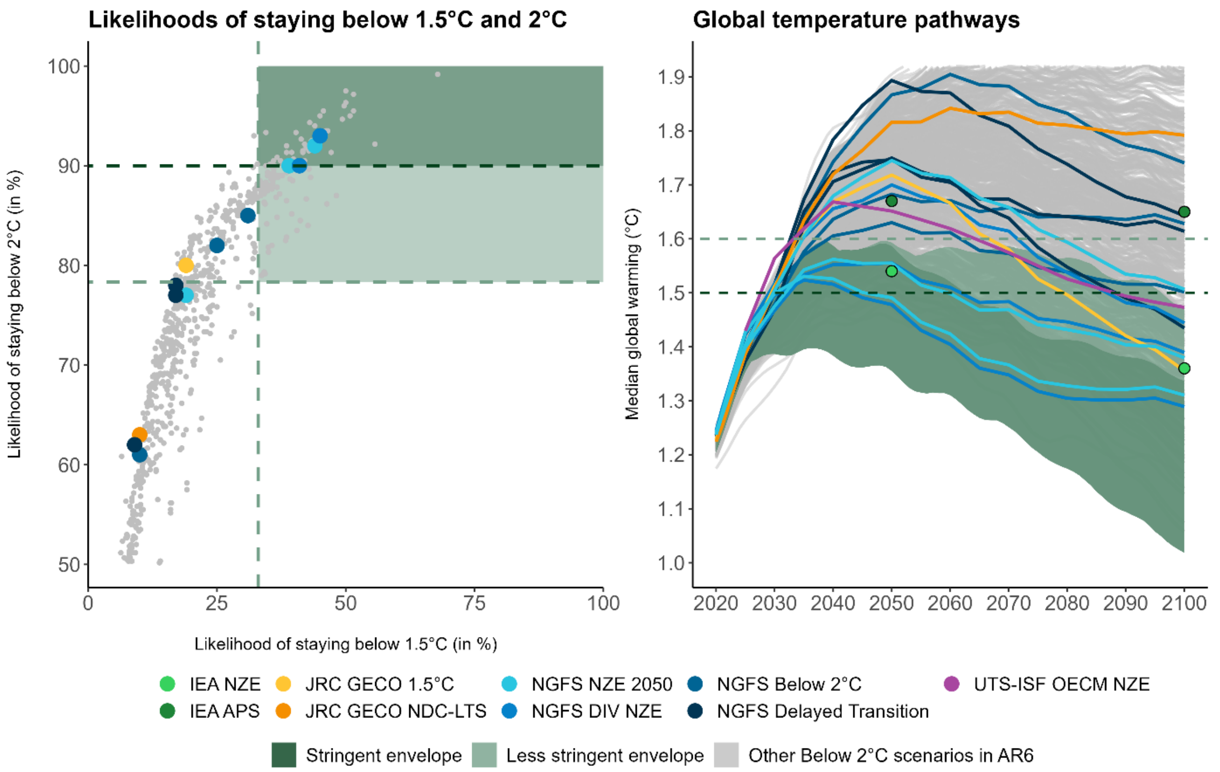
7 Finite amplitude Impulse Response model.

estimating temperature outcomes, but usually give limited access to that data. GHG may also be aggregated using different aggregation metrics, limiting again the comparability of GHG pathways and outcomes such as net-zero timing across scenarios.

3.2.2. End of century and peak warming (criteria 1, 2 and 3 in Table 3.1)

As explained in the framework put forward in Pouille et al. (2023[11]) (Section 3.1), Criteria 1 and 2 translate Paris Agreement's goal of "pursuing efforts to limit the temperature increase to 1.5 °C". Criterion 1 specifies that the 1.5°C target is to be met by the end of the century with a more likely than not chance of at least 50%. Aside from this end-of-century temperature target, mitigation scenarios consistent with Article 2 also limit the chance of overshooting the 1.5°C temperature target throughout the century. This is ensured by criterion 2 which limits overshoots to a maximum of 0.1°C at the 50% likelihood level. This is considered as limited overshoot in IPCC assessments (Riahi et al., 2022[32]). Criterion 3 specifies the likelihood threshold for the "well-below 2°C" objective, i.e. scenarios must have a very likely chance (i.e. 90% chance) for the more stringent set of criteria. The less stringent interpretation loosens this criterion to a lower likelihood of 78%, i.e. in between likely (67%) and very likely (90%). Criterion 2 essentially guarantees both that the 2°C temperature limit is very likely never reached over the full course of the century, and, as a corollary, that the median maximum temperature reached is well-below 2°C.

Figure 3.3. Paris consistency of global climate change mitigation scenarios



Note: Other below 2°C scenarios in AR6 have 50% likelihood of reaching this temperature.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers, as well as using the IPCC AR6 scenarios database (Byers, 2022[52]).

Figure 3.3 shows how the scenarios in use in financial sector target setting and alignment assessments compare against the Paris agreement's temperature goal, as well as against all other below 2°C scenarios in the IPCC database. While there are 7 scenarios that limit the median temperature to 1.5°C by 2100, only 4 do so with a limited overshoot during the century. The left panel maps all scenarios against their likelihoods of staying below 1.5°C and 2°C throughout the century. Scenarios compliant with a stringent interpretation (respectively less stringent interpretation) of the agreement's temperature goal are located in the upper right dark green box (respectively light green box). The right panel shows median (i.e. at the 50% likelihood level) temperature pathways from 2020 to 2100 corresponding to the different scenarios analysed in this paper, as well as to the Paris-consistent AR6 scenario envelopes. To be consistent with the Paris Agreement, median temperature pathways should remain below 1.6°C during the century (limited overshoot of 1.5°C), and return to 1.5°C or below by 2100.

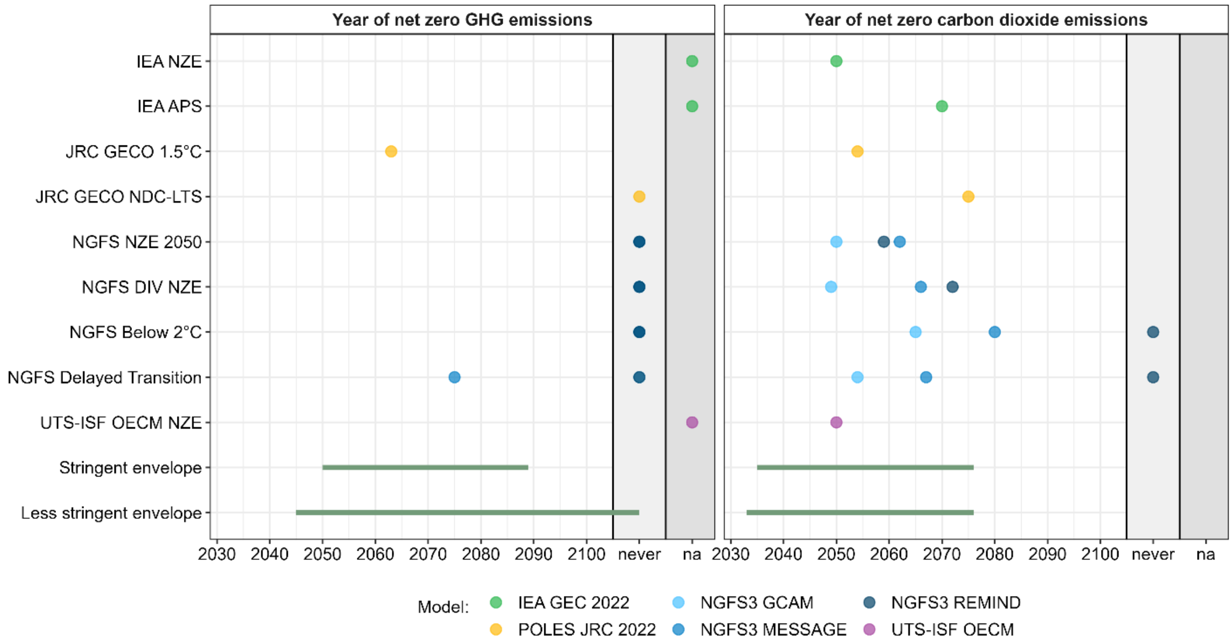
3.2.3. Peak and net zero emissions (criteria 4 and 5 in Table 3.1)

Criteria 4 and 5 translate the emissions objective in Article 4.1 of aiming "to reach global peaking of GHG emissions as soon as possible" and achieving "a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". Reducing the amount of emissions emitted before net zero through fast emissions reductions already this decade is critical for ensuring that the most dangerous impacts of climate change are avoided, notably by avoiding crossing tipping points (OECD, 2022[66]). Criterion 4, therefore, proposes that global GHG emissions peak either before 2025 in its more stringent option or before 2030 in its less stringent one. Criterion 5 additionally translates the Paris Agreement's Article 4.1's objective of reaching net-zero GHG emissions in the second half of the century, which ensures gradual decline in global temperatures in the long-term. The less stringent interpretation loosens this criterion to requiring that GHG emissions are reduced to close to zero by the end of the century, with maximum residual net GHG emissions of 5 Gt. This represents over 90% GHG emissions reductions compared with 2019 levels[8]..

The emissions outcomes displayed in Figure 3.4 reveal that almost all of the scenarios listed reach net-zero CO_2 emissions in the second half of the century. This is indeed required to stabilise global temperatures at any level. The timing of net zero is however very variable across scenarios, as shown in Figure 3.4. On the other hand, not all scenarios model all GHGs, and even when they do, net-zero GHG is rarely attained, including for scenarios that reach stringent temperature limits, as shown in Figure 3.4 as well. GHG emissions on the other hand generally peak early, in the mid-2020s, in almost all represented scenarios, consistent with Criteria 4, except for a scenario explicitly exploring a delayed action trajectory (Table 3.2).

[8] Total global GHG emissions were 59 ±6.6 GtCO2-eq in 2019 according to the IPCC AR6 (with emissions of GHG weighed by global warming potentials with a 100-year time horizon (GWP100) from the AR6) (IPCC, 2022[1]).

Figure 3.4. Year of net-zero CO_2 and net-zero GHG emissions in scenarios used in alignment assessments of finance and in Paris-consistent envelopes



Source: Authors based on publicly available information of and bilateral consultations with scenario providers, and the IPCC AR6 scenarios database (Byers, 2022[63]).

3.3. Implications for the use of scenarios in finance

Providers of financial and corporate sector target setting and alignment assessment methodologies select input scenarios based on their level of ambition. Such level of ambition can be formulated in different ways. For example, organisations supporting climate-related analyses in the financial sector have also started to recommend financial institutions to use scenarios that are 'Paris aligned', 'net zero aligned', or '1.5°C aligned' (IFRS, 2021[67]; GFANZ, 2022[24]). As shown in the analysis presented in this chapter, such general qualifications of scenarios are not concretely considering all parameters needed for assessing Paris consistency and, as such, do not represent a robust framework for selecting scenarios that can be considered as consistent with the Paris Agreement (Section 3.1, Pouille et al. (2023[11])).

Indeed, the lack of clarity in broad qualifications of scenarios may lead financial market players to choose scenarios that could in reality be considered as inconsistent with the Paris Agreement, possibly leading to targets and progress towards those erroneously assessed as Paris-aligned and, thus, to greenwashing. Existing conceptual challenges to defining a 'Paris-aligned' scenario explain inconsistencies, both in definitions used across scenario providers and financial sector participants and stakeholders, as well as with climate science. As explained in Section 3.2, meeting the level of ambition in the Paris Agreement requires simultaneously considering all its mitigation-related provisions. This requires a robust and systematic translation of these provisions into tangible criteria for analysing and selecting scenarios, informed by the latest science, as outlined in Section 3.2.

In the context of these criteria, providers of climate change mitigation scenarios need to disclose a range of scenario parameters for potential scenario users, notably financial market players, to assess the Paris consistency of a given scenario. Notably, both end of century and peak global warming in scenarios matter for global climate change mitigation goals and climate impacts (Pouille et al., 2023[11]). At a minimum, scenario providers need to communicate which of the two they are referring to when giving results on consistency with the 1.5°C or 2°C target, ideally both aspects would be provided. Additionally, the likelihood associated with temperature outcomes is an essential piece of information. For example, an emissions pathway in line with 1.5°C with a 50% chance is different from a pathway in line with 1.5°C with a 33% chance. In turn, alignment assessment providers should communicate any temperature outcome with the associated likelihood, following more scientific formulations of climate outcomes.

As it stands, the information required to assess the Paris consistency of a given scenario with the criteria is often not publicly disclosed by scenario providers, as shown in Section 3.2. Most scenario providers do not currently disclose the complete temperature outcome data, with associated likelihoods and information on whether it refers to peak- or end-of-the-century temperatures, for their scenarios. This challenges the comparison, robust understanding and use of their scenarios' temperature outcomes on which climate-related financial analysis relies.

Based on the framework and criteria to assess Paris consistency, as well as related needs for comprehensive and harmonised data, no scenario currently used in financial sector target setting and alignment assessment can be qualified as fully consistent with a stringent application of the Paris Agreement objectives. Further, only few scenarios are aligned with a fairly stringent interpretation, as shown by Table 3.3. Hence, in many alignment and target setting exercises, the ambition of scenarios used may not be sufficient and in line with the Paris Agreement, indicating that the financial sector needs to apply a more systematic, science-based approach in selecting climate mitigation scenarios that underpin its climate-related target, transition plans and alignment analyses.

4 Are climate change mitigation scenarios fit-for-purpose for use in the financial sector?

After identifying the degree of Paris consistency of scenarios at an aggregate level, understanding whether scenarios are fit-for-purpose to be used in the financial sector requires looking at their applicability (Section 4.1). This chapter does so by providing an overview of the scopes and granularity of the models behind the climate change mitigation scenarios used in the financial sector. In particular, this chapter unfolds the sectoral (Section 4.2), geographical (Section 4.3), emissions (Section 4.4) and temporal (Section 4.5) dimensions of the scenario models. It assesses whether the selected scenarios are sufficiently granular, takes stock of remaining challenges, and reflects on potential implications and solutions for improved applicability to the financial sector (Section 4.6).

4.1. Considerations relating to the applicability of climate change mitigation scenarios for use in the financial sector

The scope and granularity of mitigation scenarios are determined by their underlying modelling frameworks. Previous research highlighted sectoral, geographic, emissions, and temporal scope and granularity are scenario characteristics that have a significant impact on the applicability of scenarios for financial sector target setting and alignment assessments (Noels and Jachnik, 2022[10]).

Where the scenarios' scope and granularity are insufficient for financial target setting and alignment assessment at the level of financial assets, asset classes and portfolios, financial market participants need to make further methodological assumptions. Notably, as scenarios cannot be modelled at the company level, providers of target setting approaches and alignment assessment methodologies have developed several techniques to downscale scenarios to the company-level for corporate-related assessments (Noels and Jachnik, 2022[10]). Such techniques do not currently fall within the domain of scenario development, and hence are not addressed as such as part of the core analysis presented in this paper. The issue of scenario granularity, or the lack thereof is, however directly addressed in the following sub-sections and in the concluding chapter considering possible action areas.

4.2. Sectoral scope and granularity

The scenarios analysed in this paper have different coverage of sectors, as summarised in Table 4.1 which groups sectors according to a sectoral classification used by the IPCC (Dhakal et al., 2022[68]). Observed differences stem from the different underlying modelling approaches. IAMs, which are used by the NGFS, follow a top-down macro-economic approach to produce global scenarios covering all sectors. ISF scenarios are built with a bottom-up energy and transport system model. The IEA's GEC model adopts a hybrid approach combining detailed bottom-up sectoral modelling, in particular of the energy system, and top-down macro-economic modelling. There are advantages and limits both to using IAMs and bottom-up models for producing mitigation scenarios. While IAMs allow to reflect a whole system approach and the interactions between all sectors of the economy, bottom-up models have a more detailed representation of technologies and dynamics within the individual sectors they cover (IPCC, 2022[30]).

Table 4.1. Overview of sectoral scope and granularity of disclosed emissions pathways and model

Covered	Complementary data source	Not included

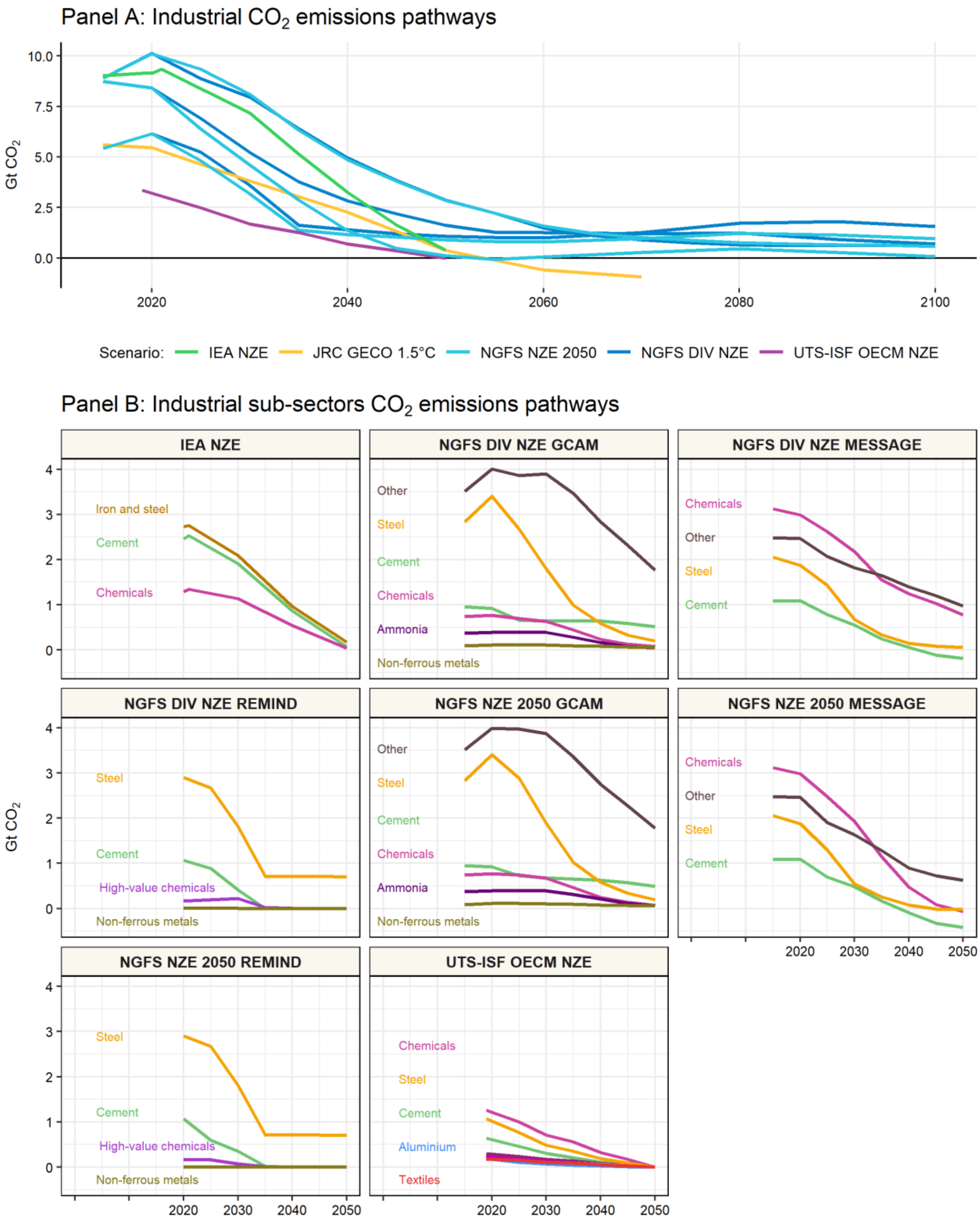
	IEA GEC 2022	POLES-JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
Model coverage of IPCC standard sectors	Energy system	Energy system	Energy system	Energy system	Energy system	Energy system
	Industry	Industry	Industry	Industry	Industry	Industry
	Transport	Transport	Transport	Transport	Transport	Transport
	Buildings	Buildings	Buildings	Buildings	Buildings	Buildings
	AFOLU	AFOLU	AFOLU	AFOLU	AFOLU	AFOLU
Model sectoral resolution	35+ sub-sectors	15+ sub-sectors	14 sub-sectors	10 sub-sectors	14 sub-sectors	17 sub-sectors
Sectoral granularity for emissions pathways output data	4 sectors, 11 sub-sectors Energy (3) Industry (3) Transport (3) Buildings (2)	6 sectors, 10 sub-sectors (sectoral data upon request) Energy (4) Industry (4) Buildings (2) Agriculture Transport Other	5 sectors, 14 sub-sectors Energy (5) Industry (5) Transport (2) Buildings (2) AFOLU	5 sectors, 10 sub-sectors Energy (5) Industry (4) Transport (1) Buildings AFOLU	5 sectors, 14 sub-sectors Energy (5) Industry (5) Transport (2) Buildings (2) AFOLU	6 sectors, following GICS classification, 17 sub-sectors Energy (3) Utilities (3) Buildings Industrials /Transport (3) Materials (8) Consumer staples (food processing)

Note: Considered models include Global Energy and Climate Model (GEC) for IEA scenarios, One Earth Climate Model (OECM) for UTS-ISF scenarios, POLES model for JRC scenarios, 3 IAMs (GCAM, MESSAGEix, REMIND) for NGFS scenarios. Further details in Table A B.1.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

Different sectors will follow different emissions pathways as the timing and speed of emissions reductions depends on for example the initial level of emissions, available mitigation options and marginal abatement costs, as well as distributional equity considerations in terms of which sectors need to move faster (which can also relate to geographical distributional equity considerations as explained in detail in Section 4.3.3). Therefore, for each sector they cover, scenarios are based on sectoral and technological assumptions impacting the scale and speed of emissions reductions over time (as discussed further in Chapter 5).

Granular sectoral emissions pathways are needed at the level of individual financial assets and underlying real economy asset, such as corporates, real estate and infrastructure (Noels and Jachnik, 2022[10]). Where scenarios provide insufficient granularity within sectors, the emissions pathways provided are too aggregate to inform a sufficiently specific assessment and may, thereby, increase the risk of GHG lock-in (OECD, 2023[69]). For example, in real estate, residential buildings, commercial buildings, and warehouses have different emissions profiles (Jachnik and Dobrinevski, 2021[25]). In transport, there are key difference between infrastructure and vehicles (Dobrinevski and Jachnik, 2020[27]). Another example is industry where different sub-sectors such as manufacture of cement and steel emit more than others such as manufacture of textiles (Dobrinevski and Jachnik, 2020[26]).

Figure 4.1. Industry sub-sectoral energy-related CO_2 emissions pathways across scenarios



Note: Sectors are defined by the scenario provider. Hence, the sectoral boundaries and scope may differ. Figure A C.2 provides a zoomed-in image for the UTS-ISF OECM NZE scenario pathways to better distinguish the different sector pathways.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

The selected models have broadly similar sectoral granularity for emissions pathways (Table 4.1). However, UTS-ISF's OECM provides emissions pathways for a larger number of subsectors, including for example food processing and textile manufacturing. While all selected scenario models have sectoral specificity, the level of complexity included for each sector differs. Models tend to have much more detail in their representation of energy supply, than they do for industry (IPCC, 2022[30]) Sectoral specificity is also highly dependent on the quality of the underlying input data.

Sectoral emissions pathways differ across scenario providers, as illustrated in Figure 4.1 for industry. However, sectoral pathways cannot be directly compared across providers and models. Differences in sectoral emissions pathways and decarbonisation speeds are reflective of different scenario assumptions (which are further explored in Chapter 5). Additionally, scenario providers use different sectoral classifications and boundaries.

In practical terms, there is a mismatch between sectoral classifications used in the financial sector and by scenario providers respectively. Financial sector analyses are typically based on data structured based on international sectoral classifications, such as ISIC, NACE, NAICS or GICS, used for corporate and financial accounting purposes (Noels and Jachnik, 2022[10]). However, climate change mitigation scenarios have been developed using sector classifications defined for the purposes of tracking GHG emissions relate more closely to climate policy as these are according to combustion types, such as the IPCC sectoral classification (Battiston et al., 2022[70]; Teske, 2022[71]). The nature of corporate activities is typically better characterised based on granular (4-digit) sub-sectors, which scenario GHG data cannot match. Climate modellers, who provide climate change mitigation scenarios are currently proposing two ways to solve this limitation.

- Mappings of sectoral classifications used in scenarios and climate policy with those in corporate and financial accounting. For example, NACE codes of economic activities can be mapped into climate policy relevant sectors (CPRS) (Battiston et al., 2022[70]), such as those used by the IPCC (Figure 4.2). This approach is put forward by the NGFS for its climate scenarios.
- Start to develop scenarios based on economic classifications. This approach is used by the ISF. To develop scenarios for sectors classified under the GICS, ISF climate modellers significantly improved the technological resolution of the OECM (Teske, 2022[71]). For example, all demand and supply calculations had to be broken down into GICS sectors before the individual pathways could be developed.

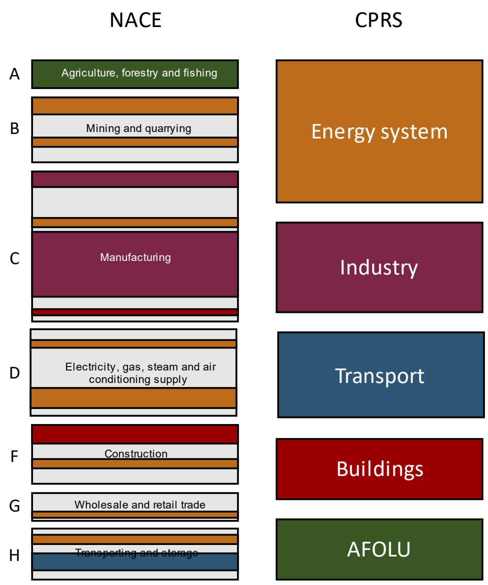
A full assessment of assets within financial portfolios requires a wide coverage of granular sectoral emissions pathways. In practice, granular sectoral emissions pathways are not (yet) developed for all economic sub-sectors (see list of sub-sectors covered by scenario providers in Annex B). Notably some high-emissions sectors are not covered by current scenarios, such as mining and consumer products. On the other hand, pathways for high emitting sectors may be prioritised (Gardes-Landolfini et al., 2023[72]) and sector-agnostic pathways can be used for low-emitting sectors (SBTi, 2021[8]).

Aside from the sector classification and granularity as such, two more current corporate GHG accounting practices influence the use of scenarios. Since companies typically find themselves at a certain stage of a sectoral value chain, corporate GHG accounting considers direct and indirect emissions (i.e. Scope 1, 2 and 3 emissions)[9] (Noels and Jachnik, 2022[10]). The relevance of Scope 3 emissions depends on the sector and where across the value chain a company sits, and link to GHG emissions along supply chains and business relationships (Figure 4.3). Scope 3 represent close to the totality of financial sector GHG

[9] Scope 1 are direct emissions from owned or controlled assets, Scope 2 indirect emissions from the consumption of purchased heat, electricity or steam, and Scope 3 are indirect emissions from any other up- and down-stream activities related to the company's product (World Resources Institute & World Business Council for Sustainable evelopment, 2004[157]). These were defined via the GHG Protocol, a reference point for corporate level reporting and accounting.

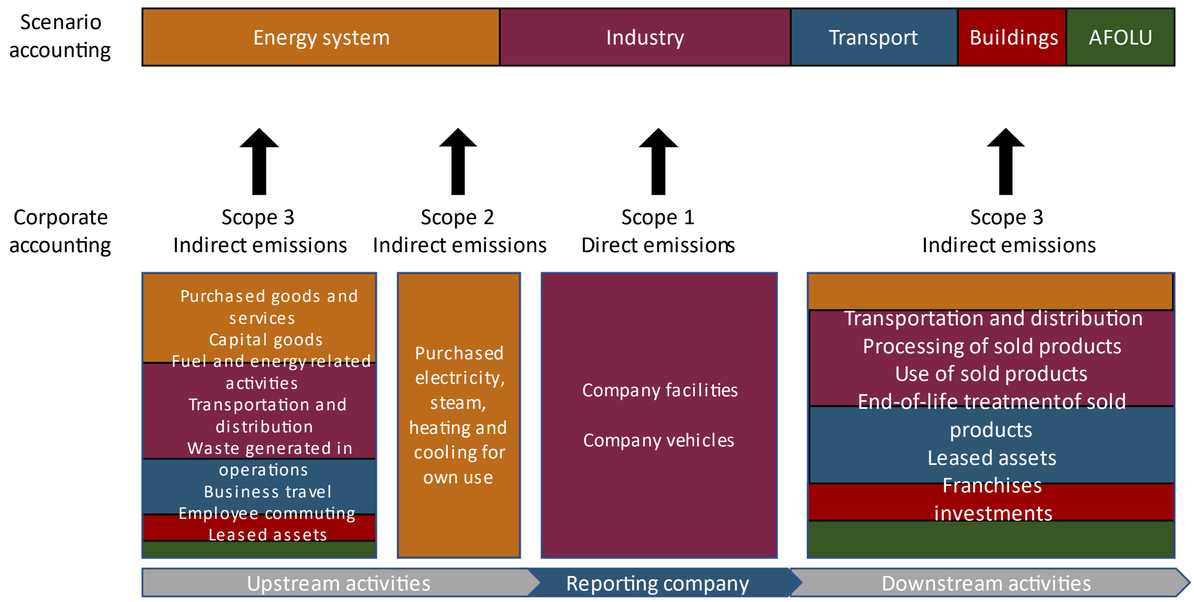
emissions and are hence central to financial institutions' target setting, transition and alignment assessments.

Figure 4.2. Translation of economic sector NACE classification to Climate Policy Relevant Sectors



Source: Authors, adapted from (Battiston et al., 2017[73]).

Figure 4.3. Illustration of Scope considerations for a reporting company



Source: Authors, adapted from GHG Protocol.

Scenarios typically model direct emissions and follow a national production-based GHG accounting approach, based on the IPCC guidelines for national GHG inventories, which differs from the corporate GHG accounting approach based on GHG Scopes 1, 2 and 3, which Figure 4.3 illustrates. As a result, users of scenarios need to make further assumptions to transform scenario pathways to be consistent with corporate emissions accounting practices. This typically implies matching different variables from climate change mitigation scenarios to get reference emissions pathways that include Scope 1, 2 and 3 for a given sector. This is both challenging due to the sectoral classification challenges discussed above and potential double counting. While these practicality issues have traditionally not been addressed in scenario development, the ISF has been the first to include emissions pathways corresponding to all three scopes for the subsectors, for which it has granular data (Teske, 2022[71]). It avoids double counting by defining, for each subsector, a primary class for the primary energy industry, a secondary class for the supply utilities, and an end-use class for all the economic activities that use the energy from the primary- and secondary-class companies.

Box 4.1. Using mitigation scenarios as input to non-GHG metrics of climate change mitigation performance

Climate change mitigation scenarios provide pathways for variables other than emissions. For example, they provide technology development and production pathways, which are further explored in Chapter 5. Such information can support the development of complementary metrics tor assessing the overall climate performance of financial assets.

Several metrics are being developed to track climate performance in the financial sector based on non-GHG data. For example, production outputs based on capital expenditure plans on low-carbon versus carbon-intensive technologies can link more directly to real-economy impacts of decarbonisation efforts (2DII, 2022[74]). Moreover, economic activities that do not generate high GHG emissions can be critical carbon enablers (e.g. pipelines), while climate solutions and enabling activities have no (clear) emissions pathway (e.g. renewables, IT for energy efficiency, etc.). Therefore, some initiatives focus on non-GHG pathway variables from the selected scenarios.

Box 4.2. Individual sector emissions pathways: example for the steel sector

As shown by Figure 4.1, the different scenario providers analysed in this paper provide different emissions pathways for the steel sector. Aside from such scenarios developed by economy-wide scenario models, different industry-led initiatives have developed bottom-up emissions pathways for the steel sector, such as (E3G, 2021[75]), (Mission Possible Partnership, 2022[76]), and (Net Zero Steel, 2021[77])).

These different pathways aim to reflect potential ways for the steel sector to reach net-zero emissions. At the same time, these different pathways have common characteristics. For example, they tend to show that energy efficiency alone is insufficient and the need for breakthrough technologies.

Similarly to economy-wide scenarios that explicitly cover and model the steel sector, such sector-specific scenarios for the steel sector can be used as input to climate-related target setting and alignment assessments for steel companies. Where more specific and granular, such scenarios may be more appropriate to inform steel companies’ climate transition plans. However, an important limitation of stand-alone sector-specific pathways is that, in contrast to sector-specific pathways in economy-wide scenarios, they cannot be tested on their Paris consistency (as explained in Chapter 3).

4.3. Geographical scope and granularity

Global climate change scenarios are needed to test that mitigation pathways comply with global climate objectives in the Paris Agreement (as discussed in Chapter 3). However, exclusively relying on global mitigation pathways does not allow taking into account technical, political and social considerations at the regional and national level (Jiang, Peters and Green, 2019[78]).

For financial sector actors, geographically granular pathways may be needed to analyse the performance of financial assets and underlying real economy actors and assets (Noels and Jachnik, 2022[10]). Indeed, geographic granularity needs differ across asset classes and portfolio segments. Global pathways can be appropriate for assessments of large multinational financial and non-financial corporations. Financial asset classes and portfolio segments that are bounded within a national territory (such as sovereign bonds, infrastructure and real estate, small enterprises) need to consider pathways that account for local and regional economic development needs, priorities, and resource constraints driving country- or region- specific emission budgets (CPI, 2020[79]).

4.3.1. Modelling scope and specificity

All the global scenarios considered as part of this analysis rely on global multi-regional models (Table 4.2). As such, they break down the world into a given number of regions, which are modelled individually using input data (e.g. population, GDP, energy supply etc) at the resolution of each modelled region. While all selected models have a global scope, Table 4.2 shows each has a different geographic breakdown of the world i.e. a different geographic specificity, from up to 66 regions for the POLES model (JRC) down to 11 regions for MESSAGE (NGFS). Regional specificity also differs among the models that underpin different NGFS scenarios, with GCAM having specificity for almost three times more regions in REMIND. Additionally, the models may have higher resolution input data for some of their modules, such as for fossil fuel supply which usually requires more geographic specificity to be accurately represented. For example, the IEA covers input variables such as oil or gas supply for 113 regions, but the model has overall less geographic specificity, with 26 aggregated regions (IEA, 2022[80]).

Table 4.2. Overview of geographic scope and granularity of disclosed emissions pathways

Models		IEA GEC 2022	POLES-JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
Modelled geographic scope of input variables		Global, multi-region	Global, multi-region	Global, multi-region	Global, multi-region	Global, multi-region	Global, multi-region
Modelled geographic specificity of input variables		26 regions, of which 12 countries Higher specificity for oil and coal supply modules	66 regions, of which 54 countries Higher specificity for oil, gas and coal production modules	32 regions, of which 15 countries Higher specificity for land use module	11 regions Higher specificity for land use module	12 regions, of which 4 countries Higher specificity for land use module	10 regions + 19 countries Higher specificity for renewable resources and power supply modules
Geographic granularity for emissions pathways data (output variable)	From modelled specificity	7 regions, 26 subregions of which 6 countries	66 regions, of which 54 countries	32 regions, of which 15 countries	11 regions	12 regions, of which 4 countries	10 regions + 19 countries
	Additional granularity from ex-post downscaling	No	No	185 countries	185 countries	185 countries	No

Note: Considered models include Global Energy and Climate Model (GEC) for IEA scenarios, One Earth Climate Model (OECM) for UTS-ISF scenarios, POLES model for JRC scenarios, 3 IAMs (GCAM, MESSAGEix, REMIND) for NGFS scenarios. Further details in Table A B.2.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

4.3.2. Geographical granularity of GHG emissions pathways

Climate change mitigation models have mainly been developed at the global level (van Soest, den Elzen and van Vuuren, 2021[81]), including as highlighted above, the ones that underpin climate change mitigation scenarios used for financial sector target setting and alignment assessment. Going from global to regional, and even more so national mitigation scenarios is challenging (van Soest, 2022[82]). Different approaches can, however, be followed by climate modellers to obtain scenario pathways for different variables at a finer geographic resolution (Sferra, van Ruijven and Riahi, 2021[83]):

- Increase the geographic specificity of their global models. This can be done through adding more country-specific information and data for different input variables. Modelling specificity involves increasing the level of detail and complexity of a model to capture finer-scale processes and interactions that are relevant to the climate change mitigation scenarios. However, this strategy has remained difficult due to the complexity of climate change mitigation models (e.g. IAMs). Increasing modelling specificity makes a model more data-intensive, expensive and time consuming (Cradock-Henry, Diprose and Frame, 2021[84]).
- Increase geographic granularity through ex-post country-level downscaling of global model outputs (i.e. emissions pathways). To perform downscaling, researchers start with a global or regional emissions scenario generated by their model and then use bottom-up models or data to disaggregate the emissions to the national level. (van Vuuren, Smith and Riahi, 2010[85]; Fujimori et al., 2017[86]; Sferra, van Ruijven and Riahi, 2021[83]). This is the approach taken by the NGFS to obtain emissions pathways for 185 countries, downscaled from the outputs of the models used.
- Alternatively, develop regional and national scale models (rather than global ones), resulting in scenarios for specific national scopes providing high granularity. However, their application in isolation does not make it possible to shed light on whether such scenarios are in line with the global carbon budgets and the Paris Agreement temperature goal (van Soest, den Elzen and van Vuuren, 2021[81]). For the latter, global models are needed as they provide the boundary conditions in terms of global emissions and resulting temperature (Schaeffer et al., 2020[87]). This partially explains why such national scenarios are not currently used by alignment methodologies in the financial sector (Box 4.2). Another reason being that such scenarios are limited in their availability and comparability.

Box 4.3. Global scenarios and national scenarios

Making a link between a pathway for a given region or country and global temperature outcomes (and in turn Paris consistency) requires using pathways derived from global models (Riahi et al., 2022[32]). This is why national pathways given as part of global scenarios, or downscaled using global scenarios, are currently being used in the financial sector when assessing alignment with global climate objectives such as the 1.5°C goal.

However, besides global scenarios such as those explored in this paper, country-level scenarios are increasingly produced using national energy or integrated assessment models and used by governments to inform national policy making and long-term climate strategies (Fujimori et al., 2021[88]). Such national scenarios capture granular country- and sector-specific information and dynamics that can be important at the national or sectoral level, and that cannot be matched by global models despite efforts and improvements to increase their geographic specificity. One example of this is the United Kingdom Balanced Net Zero Pathway (Committee on Climate Chang, 2020[89]), which can inform climate change mitigation alignment assessments of real-economy investments and financing within the United Kingdom (Jachnik and Dobrinevski, 2021[25]).

However, these national scenarios are designed using individual national climate goals/targets. Making the link between a single nationally-produced scenario and global temperature outcomes is not possible (van Soest, den Elzen and van Vuuren, 2021[81]), which does not currently allow for the use of national scenarios in alignment assessments. Moreover, using national pathways to assess financial portfolios and assets would often not be appropriate given that holdings and investments by large financial institutions and investors typically span multiple countries and global regions.

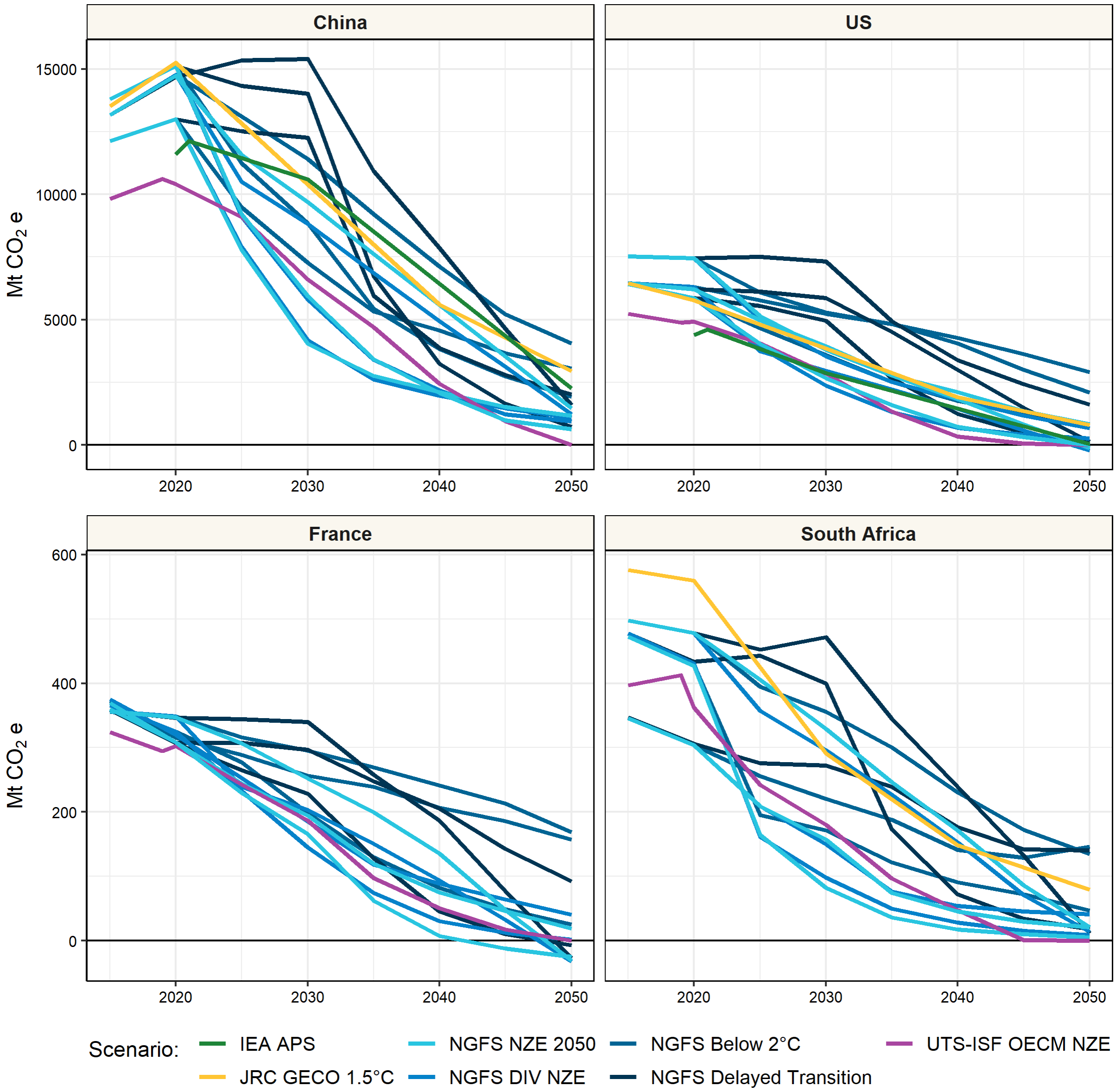
The use of national scenarios in finance is also limited by the difficulty of systematically identifying their existence and accessing underlying data and information. Where they exist, many countries do not make national scenario publicly available and, when they do, information is often dispersed across governmental reports and rarely published in academic papers, (Fujimori et al., 2021[88]). There have been attempts to consistently collect national scenarios. For example, the European Scientific Advisory Board on Climate Change (ESABCC) collected national scenarios to underpin its analysis providing advice the EU 2040 climate target (ESABCC, 2023[90]). The IPCC AR6 also attempted to consistently collect regional and national scenarios, but with only limited success (Byers, 2022[52]).

Global integrated models and national models are however sometimes applied in combination to develop national-level pathways that both allow to meet global climate goals and account for national circumstances (van Soest, den Elzen and van Vuuren, 2021[81]).

The regional and national granularity of emissions pathways from the selected scenario models can differ significantly (Table 4.2). For example, NGFS scenarios provide emissions pathways for 185 countries, while IEA only does so for six. While NGFS has model specificity for 11 to 31 regions (depending on the model), NGFS has made progress to downscale emissions pathways to the national level for 185 countries. NGFS does so by downscaling energy variables to the country level based on short-term projections extrapolated of historic trends and long-term IAM benchmarks" are based on regionally aggregated IAM results, adding conditional convergence and policy adjustments (Richters et al., 2022[91]).

Different scenario providers disclose different pathways for different countries (Figure 4.4). These pathways are also not directly comparable due to different coverage of emissions sources (Chapter 3) and assumptions (Chapter 5). Figure 4.4 also shows the differences in granularity. Most scenario providers model national pathways for a handful of large countries, such as the US and China. However, few provide such pathways for a wide range of countries (typically done through ex-post downscaling). National pathways for developing countries may differ more from one scenario to the other as illustrated for South Africa in Figure 4.4), possibly reflecting larger uncertainty in the underlying data on which it is build.

Figure 4.4. Geographically granular GHG emissions pathways for China, France, South Africa, US



Note: Emissions pathways cover all GHGs from all sources depending on the scenario coverage detailed in Table 3.2.
Source: Authors' analysis based on publicly available information of and bilateral consultations with scenario providers.

4.3.3. Equity considerations

Equity considerations are crucial to international mitigation efforts and international climate policy negotiations (Ganti et al., 2023[92]). Cost-effective scenarios that tap into least cost abatement options globally without considering compensation schemes to equalize the mitigation burden between countries are not designed to account for equity dimensions (Riahi et al., 2022[32]). In such scenarios, which consider a uniform carbon price globally, carbon-intensive countries are allocated more emissions reduction efforts (ibid). Carbon-intensive countries are however usually poorer, raising equity concerns (ibid). There is a large body of literature exploring international burden sharing and emissions reductions financing regimes to accompany globally cost-effective mitigation pathways (Lecocq et al., 2022[93]). Further, while the present section focuses on equity considerations from a geographical perspective, burden sharing assumptions in relation to the contribution of different economic sectors (at global, regional, and national levels), as discussed in Section 4.2, also involve equity-related considerations and implications.

Current climate science literature considers a few potential options to include burden-sharing assumptions for allocating emissions or emissions reductions financing across geographies.

- Country-level emissions pathways can be built by allocating global emissions to countries based **using an equitable effort-sharing regime** (Williges et al., 2022[94]; Pan et al., 2017[95]). This approach uses global emissions pathways or the global carbon budget consistent with climate goals as starting point, and downscales these to individual countries based on the consideration of different effort-sharing principles considered (e.g. combinations of historical responsibility in past emissions, not exceeding country-level feasible emissions reductions etc) (Williges et al., 2022[94]). Such a downscaled approach usually only allows to derive an aggregate national emissions pathway for each country without having the sectoral specificity of model-based scenarios. Further, such an approach does not consider economic feasibility constraints.
- Global scenarios can maintain their cost-effective allocation of emissions reductions but **add financial transfers between countries** (Pachauri et al., 2022[96]). In this case, emission reductions happen where they are the least costly but are paid for by countries based on equity principles through an equitable global emission-trading scheme (Riahi et al., 2022[32]). The magnitude of transfers depends on the burden-sharing principle (ibid). In the AR6 scenarios database for instance, 70 of over 500 scenarios exploring immediate global cost-effective action consider international transfers (Byers, 2022[52]).
- Equity considerations can also be partly included into global models through **geographically differentiated carbon prices** (see more in Chapter 5). In that case, carbon prices are usually differentiated across regions according to their per-capita income, with developed countries having a higher carbon price and developing countries progressively catching up (for example in JRC 2021 scenarios and the ISF scenarios).
- A similar approach is to account for **differentiated policies and emissions targets across countries**, by using countries' NDCs as a starting point for building national scenarios or emissions pathways. This can be done with individual national models, or within global integrated models with sufficient geographic specificity. This ensures the respect of the sovereignty of countries in their mitigation efforts warranted by the Paris Agreement, although there is a debate about whether current NDCs can be considered fair (Lecocq et al., 2022[93]).[10] Scenarios that are built based on all current NDCs however do not allow to keep global warming below the Paris Agreement's target (Lecocq et al., 2022[93]). Bridge scenarios have recently been developed, to bridge the ambition gap between all national emissions pathways based on NDCs and global cost-effective emissions pathways consistent with international climate policy goals (Kriegler et al., 2018[97]; van Soest et al., 2021[98]). These scenarios are built with global scenarios that use NDCs as a starting point but then strengthen national NDC-based emissions reductions by introducing gradual phase-in of a range of additional national policies, rather than immediate cost-effective carbon pricing (*ibid*).

Equity considerations and burden-sharing assumptions are to a large extent not considered by the climate change mitigation models analysed in this paper. They were typically not designed to address these issues, but rather to provide cost-effective global emissions pathways to reach international climate policy goals.

[10] Examples of equity limitations in current NDCs include unsubstantiated equity statements in NDCs (Winkler et al., 2017[155]) and equity approaches based on historical emissions can lead to very stringent budgets for developing countries (van den Berg et al., 2019[156]).

Notably, all models assume a unique price, except for the OECM and the IEA, which only differentiate between developed countries and developing countries (see more in Chapter 5). For scenarios that downscale the modelled emissions pathways at the country-level (NGFS scenarios), equity considerations are only considered to the extent that country-level downscaled CO_2 emissions are adjusted based on current NDCs and mid-century domestic targets (Richters et al., 2022[91]). The gap between domestic emissions targets and the CO_2 emissions downscaled from the modelled cost-effective pathways is then bridged through assumptions on increased use of some mitigation options such as renewables (*ibid*). This approach is therefore similar to the NDC-based bridge scenario approach described above.

Box 4.4. Granularity across scenario dimensions

For climate-related financial analyses, granularity is needed across the different dimensions addressed in this chapter at the same time. For example, financial institutions may want information on sectoral emissions by GHG type for sectors where non-CO_2 GHGs are significant (GFANZ, 2022[18]). Another example is for real estate, where sectoral building pathways are needed at the national level (CRREM, 2020[99]). Such data is generally very limited across scenario providers. Sectoral specificity is also highly dependent on the quality of the underlying input data.

4.4. Emissions scope and granularity

To understand global warming impacts, climate change mitigation-related analyses need to be based on total emissions across all types of GHGs (in CO_2-equivalent terms). These include long-lived GHGs with lifetimes of 100 years or more (notably CO_2 and nitrous oxide) and short-lived GHGs (notably methane and some hydrofluorocarbons) (Dhakal et al., 2022[68]).

Most selected models cover all GHG emissions (Table 4.3), but some only disclose CO_2 emissions pathways. Where non-CO_2 emissions are not disclosed, financial sector analyses of decarbonisation efforts, targets and performance need to estimate those. This is typically done by applying an average share of non-CO_2 emissions compared to CO_2 emissions linearly (Noels and Jachnik, 2022[10]). Especially for sectors where non-CO_2 GHGs are significant (such as, for methane, agriculture, energy and industrial processes with high fugitive emissions, and waste), this could result in inaccurate target setting and alignment assessments. Given the importance of comprehensive GHG coverage in the context of Paris consistency assessments, as detailed in (Pouille et al., 2023[11]) and illustrated here in Chapter 3), scenarios with emissions gaps cannot inform targets that aim to be aligned with the Paris Agreement.

Table 4.3. Overview of emissions scope and granularity of publicly-disclosed emissions pathways

Fully disclosed (green) | Data not disclosed (red)

	IEA GEC 2022	POLES-JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
Disclosed emissions pathways data	CO_2 (fully disclosed)	CO_2 (fully disclosed)	CO_2 (fully disclosed)	CO_2 (fully disclosed)	CO_2 (fully disclosed)	CO_2 (fully disclosed)
	CH_4 (data not disclosed)	CH_4 (fully disclosed)	CH_4 (fully disclosed)	CH_4 (fully disclosed)	CH_4 (fully disclosed)	CH_4 (fully disclosed)
	Other (data not disclosed)	Other (fully disclosed)	Other (fully disclosed)	Other (fully disclosed)	Other (fully disclosed)	Other (data not disclosed)

Note: Considered models include Global Energy and Climate Model (GEC) for IEA scenarios, One Earth Climate Model (OECM) for UTS-ISF scenarios, POLES model for JRC scenarios, 3 IAMs (GCAM, MESSAGEix, REMIND) for NGFS scenarios. Further details in Table A B.3.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

Because information on the emissions for the individual gases is required to consistently assess global warming impacts of emissions, some research further suggests that government and corporate reporting and disclosure of GHG emissions should indicate the separate contribution of each type of GHGs to total emissions in targets and measurement of progress (Allen et al., 2022[100]). In turn, this would require scenario providers to not only model all GHG emissions, but also disclose pathway data broken down for different types of GHG.

4.5. Temporal scope and granularity

Credible financial and corporate sector transition plans towards aligning with the Paris Agreement need to include not only a long-term ambitious target, but also clear interim targets as well as steps and actions towards reaching those (OECD, 2022[9]). These need to be informed by pathway data for GHG and other relevant scenario output variables with both a long-term time perspective and regular time intervals.

In this context, a current challenge to using climate scenarios is that they lack a short-term perspective (GFANZ, 2022[18]; UNEP FI & CICERO, 2021[37]). While available scenarios offer high-level narratives to illustrate the potential trajectories of the economy, they may be difficult to translate into near-term implications for private and public decision makers, notably in terms of transition activities, some of which that may take place at different pace and scale across geographies and sub-sector.[11] In this context, users may not be aware that climate models typically assume linear trajectories of change whereas in reality, transformations often follow non-linear trajectories, where exponential growth in technology may suddenly occur in response to a change in market conditions before finding a maximum rate (GFANZ, 2022[18]; UNEP FI & CICERO, 2021[37]).

For the scenarios in scope of the present analysis, models differ in their temporal scope, in terms of start and end year and intermediate data points (Table 4.4). Some only have data until 2050 while others do so until 2100. A long-term horizon is needed to identify short-, medium-, and long-term changes consistent with a long-term climate objective (UNEP FI & CICERO, 2021[37]). However, the further into the future, the more uncertainty there is around a given datapoint. Further, most models have a modelling start year at or before 2010, meaning that recent years are already projections from an earlier point in time. Only the UTS-ISF OECM model has a more recent start date, meaning it includes more recent information on emissions-relevant variables.

Table 4.4. Overview of temporal scope and granularity of publicly-disclosed emissions pathways

	IEA GEC 2022	POLES-JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
Temporal scope of disclosed emissions pathway data	2010-2050	1990-2070	2005-2100	1990-2100	2005-2100	2019-2050
Temporal granularity (interval) of disclosed emissions pathway data	10 years	10 years	5 years	5 years (1990-2060), 10 years (2060-2100)	5 years (2005-2060), 10 years (2060-2100)	5 years (2019-2040), 10 years (2040-2050

Note: Considered models include Global Energy and Climate Model (GEC) for IEA scenarios, One Earth Climate Model (OECM) for UTS-ISF scenarios, POLES model for JRC scenarios, 3 IAMs (GCAM, MESSAGEix, REMIND) for NGFS scenarios. Further details in Table A B.4.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

[11] This was also one the key takeaways from an OECD workshop on Climate Transition Scenarios: Integrating models into risk assessment under uncertainty and the cost of delayed action organised on 6 July 2022.

The selected models have information on emissions pathways at a five-to-ten-year interval (Table 4.4). Intermediate data points such as 5-year granularity can be helpful as investors need intermediate reference points against which to compare short-term and intermediate targets. Previous research showed that the level of emissions at intermediate points can have a significant impact on alignment assessments of finance (Noels and Jachnik, 2022[10]). Especially, short-term scenario emissions levels are needed for financial sector analyses of net zero and for making short-term financing decisions. In addition, net-zero analysis of finance may need to compare climate performance of financial assets over a time period. In this case the scenarios' emissions pathways need to be allocated over several years, which now requires interpolation of scenario data points between the provided intervals, and makes the begin and end-year as well as the implied pace of decarbonisation highly impactful.

4.6. Implications for the use of scenarios in the financial sector

While the mitigation scenarios currently used in the financial sector are created at a global level, financial institutions and investors need disaggregated scenarios to set climate targets for and assess the climate performance of financial assets, asset classes and portfolios (Noels and Jachnik, 2022[10]). However, there is no agreed approach to downscale global scenarios, due to the absence of political consensus on burden sharing. On the other hand, the alternative solution of increasing the specificity of global models leads to increased complexity, data needs (difficult to fulfil in many geographies) and computing power demands. Hence, there may be a trade-off between granularity and practicality. Still, scenario providers have made progress on sectoral, geographic, emissions and temporal granularity, although further developments are needed as shown in this chapter.

As the speed of decarbonisation will differ across sectors, financial and non-financial corporates should set targets based on and assess alignment against sectoral or sub-sectoral level emissions pathways. As shown in Section 4.2, providers of global scenarios have made progress in providing more granular sectoral pathways. They also started providing pathways using economically relevant sector classifications or translations. Further developments to enhance sectoral granularity can, to the extend made possible by available granular data, address needs to match fine sectoral granularity in financial and corporate accounting. This would allow target setting and assessment of alignment with a sectoral pathway more relevant for a given financial asset, as well as more tailored client engagement and improved transition risk assessments.

Financial institutions typically work with a sector-based pathways approach (GFANZ, 2022[18]). While stand-alone sector-specific pathways are increasingly being put forward by industry initiatives, it is challenging to link these to global carbon budgets and hence to assess their Paris consistency (see Box 4.2). On the other hand, sectoral pathways do not always exist in global models or are not publicly available for every sector. Such lack of granularity in global scenarios and coverage gaps for specific sectors or sub-sectors prevents a complete analysis of a portfolio, both for alignment assessments and transition risk analyses. While sector-agnostic pathways could be considered for certain low-emissions sectors, emissions pathways for several emissions-intensive sectors are still missing. Addressing shortcomings with respect to sectoral, but also geographical, granularity in global emissions pathways are important to address risks of carbon lock-in in transition finance, as credible transition finance often depends on the use of granular emissions pathways (OECD, 2023[69]).

Geographically granular pathways are especially relevant for sovereign bonds, real estate and private equity of smaller companies, but also large listed companies with regional activities, such as electric utilities, as explained in 4.3. Different approaches can be used to obtain scenario pathways for different variables at a finer geographic resolution, including increased modelled geographic specificity, ex-post country-level downscaling, and developing regional and national scale models. The latter approach, which remains underdeveloped, however does not allow to assess consistency of a national pathway with a global temperature without making explicit equity considerations relating to burden sharing. Scenario providers are increasingly providing national pathways through the former two approaches, allowing more tailored climate-related financial analyses. The detailed underlying data needed as inputs to the models on a wide range of socio-economic, technological and policy information by country is not always available, especially in the case of developing countries. Therefore, there may be large uncertainties left in their use.

Granular information gaps for developing countries and an absence of equity considerations in scenarios may have unintended and undesirable implications in terms of portfolio allocation (investment and divestment decisions) when such scenarios are used in target setting, transition planning and alignment assessments. Current climate change mitigation scenarios provide limited granular information for developing countries, many of which are treated as part of broader regions and not explicitly modelled, partially due to limitations in the underlying input data. Moreover, there is limited consideration of equity at the scenario level because these global scenarios are not designed to answer such questions (as explained in Section 4.3.3). Indeed, such questions need to be informed by international policy. Still, applying an equity framework when downscaling the scenarios can at least partially address this concern.

Gaps in scenario data in terms of emissions scope result in providers of target setting and alignment assessments methodologies having to design and implement their own assumptions (Noels and Jachnik, 2022[10]). Some scenario providers do not cover all GHG emissions, as shown in Section 4.4. Partial coverage of GHGs in a climate model means that the full warming impact cannot be assessed. Hence, partial emissions pathways are not well placed to inform targets and alignment assessments. On the other hand, some scenario providers indeed cover all types of emissions, with disaggregated information by type. Such comprehensive coverage can inform comprehensive GHG reduction targets and allows transition plans to detail non-CO_2 GHGs reduction actions in sectors where non-CO_2 GHG emissions are large.

The scope and design of climate change mitigation scenarios implies that they are not suitable inputs to assess some elements commonly put forward in financial and corporate sector GHG targets and transition plans, resulting in misuses and greenwashing if they are. In particular, mitigation scenarios are not designed to assess the extent to which a financial institution or corporation may credibly make use of offsets while maintaining environmental integrity. As scenarios are already designed to optimise costs and emissions reductions across sectors and regions, the emissions pathways reflect the actual emissions reductions that need to happen in the associated sector and region.

Aside from informing long-term GHG reduction, greater temporal granularity in emissions pathways can support better short-term private sector decision making. In the context of transition plans, which need to identify actions towards GHG reductions over time, investors are increasingly demanding short-term interim targets to assess much needed early action. Concrete scenario information with regular intervals is needed to inform such targets. While some scenario providers are already providing information at five-year intervals, more short-term information is relevant to influence short-term decision-making. In this context, steps taken by some scenario providers to increase the temporal granularity of their models (including more regular time intervals), as shown in Section 4.4 is a step in the right direction.

Progress by scenarios providers also resulted in the availability of a range of scenarios for the same sector or country, and sectors can be defined differently by different providers for different use cases. Different assumptions made for obtaining higher-resolution data may lead to different pathways and mitigation strategies to reach a certain target. The use of multiple pathways can contribute to capturing the range of possible outcomes. However, this requires a good understanding of the scenario characteristics and assumptions, which the next chapter further explores.

5 What are the characteristics of mitigation strategies and assumptions of climate change mitigation scenarios?

This chapter analyses the underlying mitigation strategies and input assumptions to achieve the scenario ambition (Chapter 3) given its scope and granularity (Chapter 4). By gaining insights into these dimensions, financial institutions can identify potential inconsistencies between their climate change mitigation scenarios and financial models, assess uncertainties and sensitivities if certain scenario assumptions do not materialise, and enhance their engagement practices. Indeed, as financial institutions engage with investees and borrowers, they may want to understand how far these scenarios are based on plausible mitigation strategies towards achieving their level of ambition. Such information can also inform investment priorities.

In this context, this chapter first provides an overview of dimensions relating to mitigation strategies and assumptions of relevance to characterising scenarios and their mitigation pathways (Section 5.1). It then analyses the mitigation strategies that are followed by scenarios currently used for financial sector target setting and alignment assessments, how they differ across scenarios and which feasibility concerns they entail (Section 5.2). This chapter then dives into the assumptions that underlie the scenarios' mitigation strategies (Section 5.3). In doing so, it seeks to highlight uncertainties in resulting pathways (Section 5.4).

5.1. Overview of key dimensions of mitigation strategies and assumptions

Mitigation scenario providers aim at providing feasible and credible mitigation pathways to reach a given climate change mitigation goal. Each scenario projects one possible **mitigation strategy** i.e. one possible combination of required short-, medium- and long-term transformations and associated GHG emissions reductions to reach a given climate target (Riahi et al., 2022[32]). The IPCC AR6 shows that all pathways in the literature that achieve stringent emissions reductions to likely limit warming to 2°C or below rely on a combination of energy supply decarbonisation, energy demand reductions, land emissions reductions and use of CDR (Riahi et al., 2022[32]). The overall mitigation strategies in climate change mitigation scenarios used by the financial sector can, therefore, be understood by analysing their reliance on different combinations of these mitigation options, acknowledging that there are many other dimensions of mitigation strategies in scenarios.

As a point of comparison for mitigation strategies of scenarios, this chapter relies on the IPCC AR6's **Illustrative Mitigation Pathways (IMPs).** These are a set of five climate change mitigation scenarios that were selected from the IPCC scenarios database to each illustrate and explore a critical mitigation strategy: heavy reliance on renewables (IMP-Ren), strong emphasis on energy demand reductions (IMP-LD), extensive use of CDR in the energy and the industry sectors to achieve net negative emissions (IMP-Neg), mitigation in the context of broader sustainable development (IMP-SP), and the implications of a less rapid and gradual strengthening of near-term mitigation actions (IMP-GS). The IMPs are important points of reference because they are representative of the scenario space, showing the range of possible mitigation strategies that can achieve stringent mitigation goals (Riahi et al., 2022[32]).

Different mitigation strategies are associated with different **feasibility challenges**. The IPCC AR6 provides a framework for assessment of the feasibility of mitigation scenarios, which can serve as a second point of reference. Feasibility analyses evaluate the plausibility of what can be achieved given societal capacities to change within a given period (Brutschin et al., 2021[101]; Riahi et al., 2022[32]). The IPCC framework identifies key feasibility indicators and their low, medium, and high concern thresholds based on the latest scientific literature (as listed in Annex C). The indicators capture the scale and disruptiveness of transformative change implied by scenarios' mitigation strategies (IPCC, 2022[30]). For example, the literature has found that a scale up of solar by 20 percentage points per decade may be technologically challenging (Brutschin et al., 2021[101]).

While this paper adheres to the general definitions and frameworks relating to the feasibility of mitigation strategies in the literature and notably of the IPCC, it is important to acknowledge that those definitions and frameworks often rely on historical trends to assess what is feasible in the future. As such, they may underestimate the potential of systems to undergo disruptive changes. Enhanced understanding of the potential for disruptive and rapid changes through less conservative approaches to assess feasibility may shed light in potential ways forward or achieving deeper and earlier mitigation.

The mitigation strategies projected by scenarios to achieve emissions reductions ultimately depend on key scenario **input and modelling assumptions**. Indeed, scenarios each rely on different assumptions and modelling frameworks, which reflect technological and socioeconomic uncertainties (Guivarch et al., 2022[102]). Understanding the key input and model assumptions is crucial to understand what drives different scenario results and analyse the sources of uncertainty in scenarios' mitigation pathways. Plausibility in the mitigation pathways can be reached by robust choices of realistic assumptions and improvements of models to overcome their limitations, with the aim to lower the uncertainty of the proposed mitigation strategy.

There are three main types of input assumptions that drive mitigation scenarios.

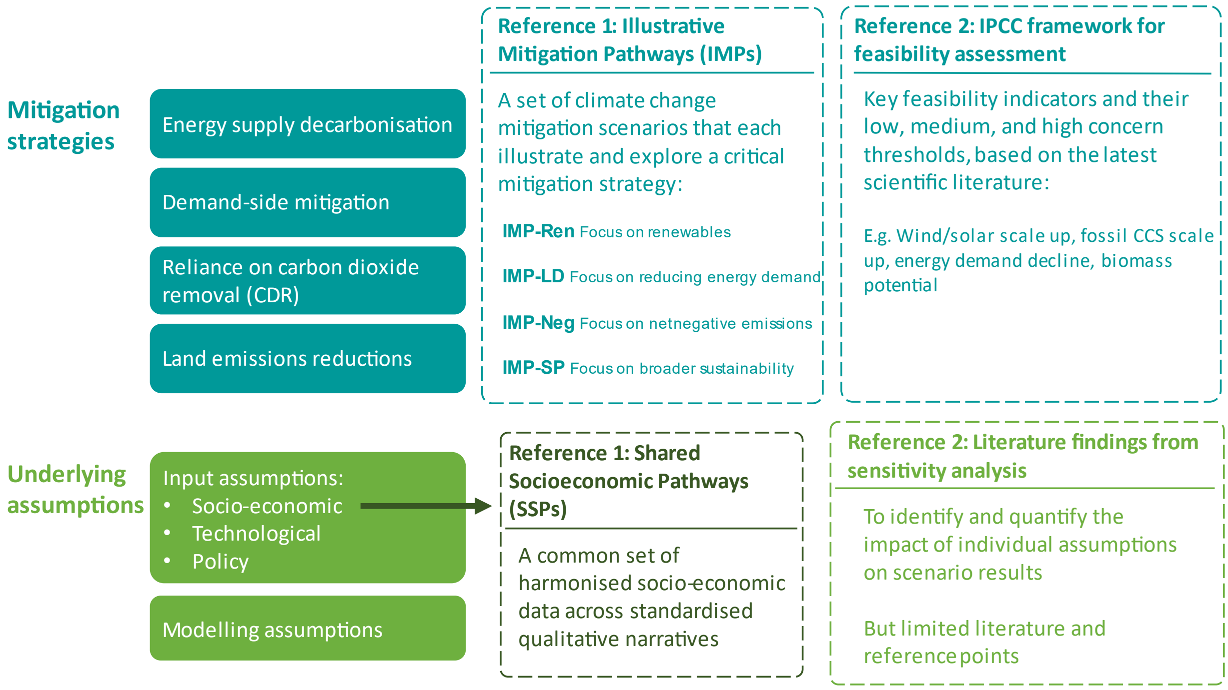
- **Socio-economic assumptions**: Assumptions on future socio-economic trends such as population growth and economic activity, measured through GDP, can influence the modelled use of energy and land, and consequently are key drivers of emissions trajectories in scenarios.
- **Technological assumptions**: Assumptions about technology costs, both initial costs and costs over time, and technology availability, determine mitigation technology deployment in scenarios. Models make such assumptions on many different technologies, including wind, solar, nuclear, fossil fuel power plants, electric vehicles, CCS among others (IPCC, 2022[30]; Giannousakis et al., 2021[103]). This paper focuses on assumptions for solar, wind and biomass.
- **Policy assumptions**: For most scenarios this comes down to the carbon prices, which are often assumed to be uniform. Other scenarios model more detailed and heterogeneous policies as currently implemented by countries.

Other model assumptions which can highly influence scenario outcomes and add uncertainty to these results include whether the model considers climate impacts feedback loops or how far the model considers all possible mitigation measures (IPCC, 2022[30]). These determining modelling characteristics and limitations of the different models used to produce scenarios in use in the financial sector will therefore also be qualitatively discussed in this paper.

All mitigation scenarios necessarily rely on such input assumptions, which means scenario outcomes are inherently uncertain, especially the medium- and longer-term outcomes. It is therefore important to understand these sources of uncertainty when using the scenarios. Few points of comparison for the underlying assumptions exist. For socio-economic assumptions, the Shared Socioeconomic Pathways (SSPs) can be used, which represent a common set of harmonised socio-economic data across five qualitative narratives (van Vuuren et al., 2017[104]). The SSPs were developed by the modelling community and the IPCC to standardise socio-economic drivers of emissions across climate change mitigation scenarios[12]. Further, sensitivity analyses evaluate differences in scenario outcomes subject to changes in assumptions (IPCC, 2022[30]). Sensitivity analyses can therefore help identify and quantify the impact of individual assumptions on scenario results such as emissions outcomes. However, sensitivity analyses for climate change mitigation scenarios remain rare in the literature and are usually focused on understanding sensitivities in one specific model, generally an IAM (IPCC, 2022[30]).

The main dimensions relating to mitigation strategies and underlying assumptions are summarised in Figure 5.2, together with possible points of reference for analysing feasibility and uncertainty respectively. In the following two sections of this chapter, these dimensions are explored for the most ambitious scenarios of the selected scenario providers (See Chapter 2), namely the JRC's GECO 1.5°C scenario, the IEA's NZE 2050 scenario, the NGFS' NZE 2050 and Divergent NZE scenarios, and the UTS-ISF's OECM NZE scenario.

Figure 5.1. Summary of dimensions for the assessment of mitigation strategies and assumptions of climate change mitigation scenarios



Source: Authors, using (Riahi et al., 2022[32]; IPCC, 2022[30]).

[12] The five qualitative narratives of the SSPs are: SSP1 Sustainability, SSP2 Middle of the Road, SSP3 Regional Rivalry, SSP4 Inequality, SSP5 Fossil-fuelled Development.

5.2. Mitigation strategies in climate scenarios and associated feasibility considerations

The different climate change mitigation scenarios used in financial sector target setting and alignment assessments each explore a different mitigation strategy relying on different combinations of key mitigation options to achieve a given level of ambition (Figure 5.2). As points of comparison, Figure 5.2 displays four IMPs with focus on different mitigation options. Three of them allow to keep temperatures below 1.5°C with limited overshoot (IMP-Ren, IMP-LD, IMP-SP).

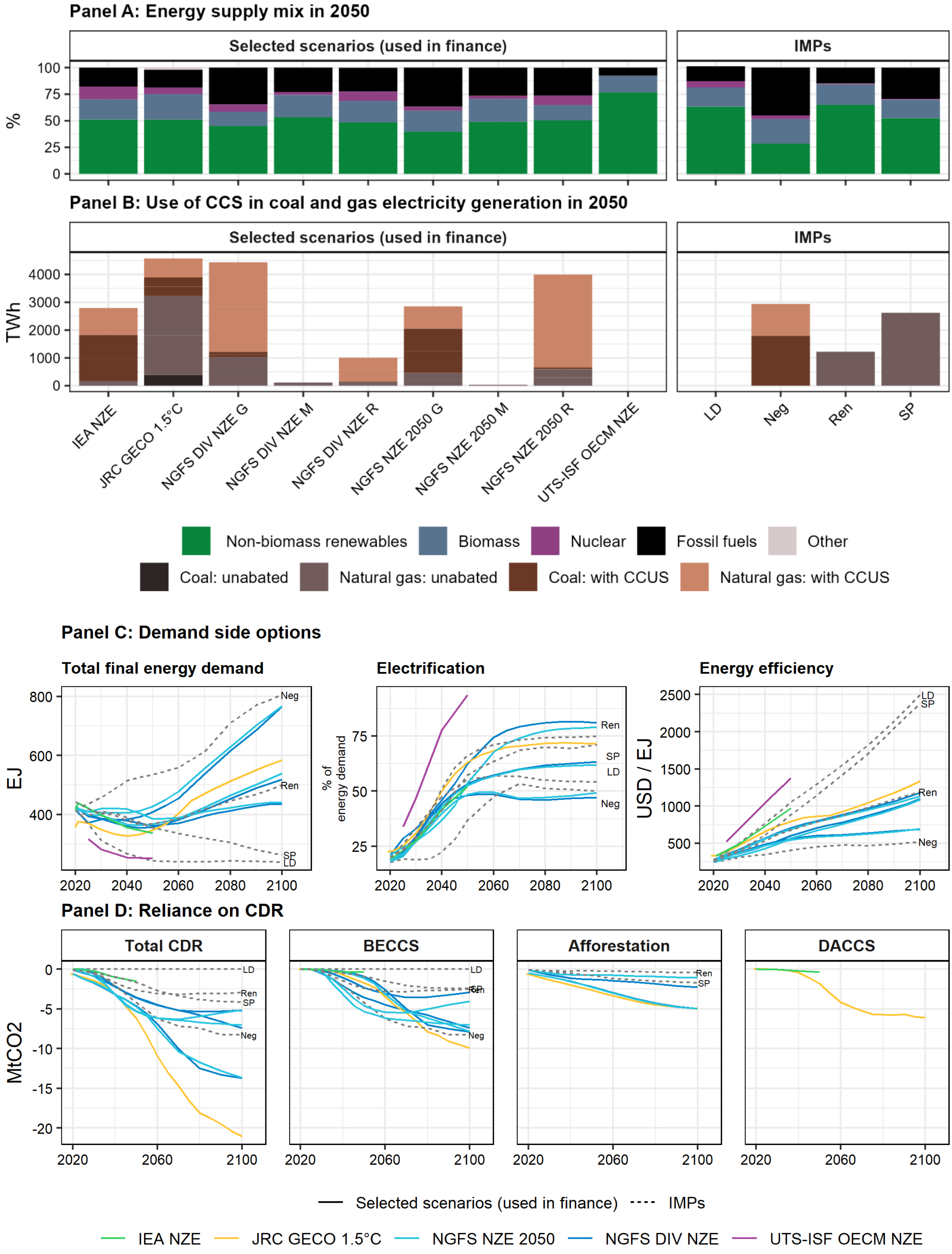
Overall, all scenarios that achieve stringent climate goals imply rapid scale-up and large-scale deployment of new technologies and mitigation options, with trade-offs between the different options. The speed and scale of these transformations are associated with different feasibility concerns, as introduced in Section 5.1. The different scenarios face different types and levels of feasibility challenges (Table 5.1).

Decarbonising energy supply is a first essential aspect of all mitigation scenarios that limit global warming. All scenarios considered in this paper see a significant decrease in fossil fuel energy supply, and large increases in renewable energy sources (Figure 5.2, Panel A shows the levels reached in 2050). The OECM Net Zero, IEA Net Zero and GECO 1.5°C scenarios, which have more ambitious mitigation objectives, rely heavily on higher rates of deployment of renewable energy by 2050. The OECM in particular is very ambitious on renewable scale-up and sees non-biomass renewables reach over 75% of total energy supply by 2050, exceeding the level in IMP-Ren (65%), but remaining within the technical potentials evaluated by the literature (Table 5.1). Some research has even found that it can be technologically and economically viable to achieve even 100% renewables in the energy supply mix by mid-century (Diesendorf and Elliston, 2018[105]; Brook et al., 2018[106]), as renewable technologies have seen rapid recent drops in costs. However, this possibility depends on many assumptions on energy systems and prices made in scenarios and is still debated in the literature (Riahi et al., 2022[32]). As a result, the rapid scale-up of wind and solar technologies relied on by many of the scenarios explored raises feasibility concerns, which medium and high feasibility challenge ratings in Table 5.1 reflect.

Some scenarios maintain a higher reliance on fossil fuels, with a large deployment of CCS technologies in fossil fuel power plants (Figure 5.2, Panel B shows the levels reached in 2050). Several NGFS scenarios rely on higher levels of CCS deployment, thereby more similar to the IMP-Neg, which explores a focus on net negative emissions. Also the IEA NZE scenario relies more heavily on CCUS for remain coal and natural gas use. While the scale-up of CCS in fossil fuel in most selected scenarios does not necessarily go beyond what is deemed theoretically feasible according to the literature (at least until 2050 and where data is available, see Table 5.1), widespread commercial deployment of CCS technologies continues to be uncertain (Gambhir et al., 2017[107]; Budinis et al., 2018[108]). Still, unabated fossil fuel use, in particular unabated coal energy, are typically completely phased out by 2050 (Figure 5.2, Panel B). Only JRC's GECO 1.5°C scenario retains a higher reliance on unabated natural gas compared to other scenarios. Nuclear power can also be part of the mitigation strategies, but none of the scenarios considered in this paper explore high-nuclear energy mixes, consistent with such option being seldom explored in the literature (Riahi et al. (2022[32]), Figure 5.2).

Demand-side mitigation levers are a second mitigation strategy dimension, which all scenarios considered in this paper rely on and that the broader literature explores. These include gains in energy efficiency as well as electrification of energy use across sectors (including transportation, industry and buildings), and for some models, other demand-side interventions leading to behavioural and lifestyle changes and reduced energy demand.

Figure 5.2. Mitigation strategies across scenarios



Note: the IEA numbers for renewables include biomass.

Source: Authors' analysis based on publicly-available information and bilateral consultations with scenario providers.

Scenarios differ in the scale and pace of these demand-side changes (Figure 5.2, Panel C). The IEA NZE and UTS-ISF's OECM NZE scenarios see higher decreases in energy demand, with higher energy efficiency gains and electrification of energy use. Such decreases are comparable to the IMP-LD with very low demand for energy based on and less energy-intensive lifestyles. The UTS-ISF's OECM NZE relies on very rapid energy efficiency gains and electrification of energy use, even more so than the IMP-LD, which already assumes energy efficiency improvement rates far above historic values. While the feasibility of a profound decoupling of energy demand and economic growth is debated in the literature (Kemp-Benedict, 2018[109]), the IPCC AR6 assesses considerable potential for demand-side mitigation to reduce emissions (Riahi et al., 2022[32]). Overall, the energy demand changes in the selected scenarios hold limited feasibility concerns according to thresholds proposed by literature (Table 5.1).

The model type used by the different scenario providers partially explains the differences in the use of demand-side levers. The IEA and ISF scenarios show higher energy efficiency gains and electrification of energy use than GECO and NGFS scenarios. This can in part be attributed to their use of more detailed bottom-up models of different energy demand sectors, that allow them to represent demand-side interventions and behavioural changes in more detail. IAMs, which are also relied on by the NGFS, have on the other hand often been criticised for their less detailed demand-side mitigation options representation and their limited use of demand-side mitigation potential (Riahi et al., 2022[32]; Grubler et al., 2018[110]). These models lack demand-side options other than energy efficiency gains, and especially fail to consider behavioral changes.

Carbon dioxide removals (CDR)[13] is a third mitigation strategy dimension most scenarios assessed in the IPCC AR6 rely on to reach stringent mitigation goals. Negative emissions achieved through CDR can play an important role in accelerating emissions reductions in the medium-term to lower peak warming. They also allow reaching long-term net negative emissions to ensure a long-term decline in temperatures (Riahi et al., 2022[32]). In scenarios that achieve stringent temperature limits, CDR deployment supplements rather than replaces substantial emissions reductions in all other sectors and can compensate for residual emissions in hard-to-abated sectors.

Overall, all scenarios show a limited reliance on CDR in the first part of the century (0-7Gt in 2050), but some scenarios largely rely on negative emissions thereafter, as is the case for GECO and NGFS delayed transition scenarios (Figure 5.2, Panel D). These go beyond the CDR reliance considered by IMP-SP and IMP-Neg. Bioenergy with carbon capture and storage (BECCS) and afforestation/reforestation are the most common CDR solutions in the considered scenarios (Figure 5.2, Panel D), consistent with the broader scenarios literature. Direct air carbon capture and storage (DACCS) is more rarely considered by scenarios, as only the IEA and JRC include it in their models (Annex C), but this technology is increasingly being incorporated by different providers.

The selected scenarios do not tend to go beyond high feasibility concern thresholds considered by the current literature except for a limited number of scenarios specifically for limitations relating to biomass potential and BECCS technology scale-up (Table 5.1). However, there are major concerns about the technical, economic, political feasibility of deployment of CDR, as well as major concerns with regards to broader sustainability implications (Strefler et al., 2018[111]). In particular, there is a fervent debate in the scientific community about the feasibility and sustainability challenges associated with large-scale deployment of BECCS (Fuss et al., 2014[112]; Anderson and Peters, 2016[113]; Strefler et al., 2021[114]). The DACCS technology, on the other hand, has not been tested at large scale (Realmonte et al., 2019[115]; Gambhir and Tavoni, 2019[116]). Current progress in innovation and deployment of CDR technologies is in any case largely below what is required in scenarios that rely on such technologies (Minx et al., 2018[117]; Fuss et al., 2018[118]) and the urgency to address this gap is not reflected in policies (Nemet et al., 2018[119])

[13] CDR refers to "anthropogenic activities removing CO_2 from the atmosphere and durably storing it (...) but excludes natural CO_2 uptake not directly caused by human activities." (IPCC, 2022[148])

In contrast, limited reliance on CDR, such as in the OECM net zero, requires a more rapid and larger transition in other sectors, with quick and deep emission reductions that are also assessed as technically infeasible and associated with higher transitional challenges associated with fossil fuel phase-out and renewable scale-up. Indeed, scenarios with limited reliance on negative emissions through CDR require very rapid declines in emissions in the near term and rely on faster transformation of the energy sector, with larger demand-side measures, electrification, and energy efficiency, and faster scale-up in energy supply decarbonisation through renewables deployment. This is especially the case for the ISF Net zero scenario, which as a design choice, does not rely on BECCS at all.

Table 5.1. Feasibility assessment of scenarios' mitigation strategies

Level of feasibility challenge	Low	Medium	High	Insufficient data or not applicable

	Time period	Energy supply							Demand-side	CDR	Land
		Wind potential	Solar potential	Wind scale up	Solar scale up	Nuclear scale up	Fossil CCS scale up	Energy demand decline	Biomass potential	BECCS scale up	Forest cover increase
IEA NZE	2020 – 2030	Low	Low	Medium	Medium	Low	N/A	Low	Low	Low	N/A
	2030 – 2040	Low	Low	Medium	Medium	Low	N/A	Medium	Low	Low	N/A
	2040 – 2050	Low	Low	Low	Low	Low	N/A	Low	Medium	Low	N/A
JRC GECO 1.5°C	2020 – 2030	Low	Low	Low	Medium	Low	Low	Low	Low	Low	N/A
	2030 – 2040	Low	Low	Low	Low	Low	Low	Low	Medium	Low	N/A
	2040 – 2050	Low	Low	Low	Low	Low	Low	Low	Medium	Low	N/A
NGFS NZE 2050 GCAM	2020 – 2030	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Medium
	2030 – 2040	Low	Low	Medium	Low	Low	Low	Low	Medium	Low	Low
	2040 – 2050	Low	Low	Low	Low	Low	Medium	Low	Medium	Medium	Medium
NGFS NZE 2050 MESSAGE	2020 – 2030	Low	Low	High	High	Low	Low	Low	Low	Low	High
	2030 – 2040	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium
	2040 – 2050	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
NGFS NZE 2050 REMIND	2020 – 2030	Low	Low	Medium	High	Low	Low	Low	Low	Low	Medium
	2030 – 2040	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low
	2040 – 2050	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	Low
NGFS DIV NZE GCAM	2020 – 2030	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Medium
	2030 – 2040	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
	2040 – 2050	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low
NGFS DIV NZE MESSAGE	2020 – 2030	Low	Low	High	High	Low	Low	Low	Low	Low	High
	2030 – 2040	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium
	2040 – 2050	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low
NGFS DIV NZE REMIND	2020 – 2030	Low	Low	Medium	High	Low	Low	Low	Low	Low	High
	2030 – 2040	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low
	2040 – 2050	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
UTS-ISF OECM NZE	2020 – 2030	Low	Low	Medium	Medium	Low	N/A	Low	Low	N/A	N/A
	2030 – 2040	Low	Low	Low	Low	Low	N/A	Low	Low	N/A	N/A
	2040 – 2050	Low	Low	Low	Low	Low	N/A	Low	Low	N/A	N/A

Note: This table shows how feasible the mitigation strategies on which the different scenarios rely are. It does so by comparing the size of the changes in different mitigation strategy indicators (such as wind scale up) to reference thresholds found in the current literature, as summarised by the IPCC. An overview of the feasibility thresholds for each indicator can be found in Table A C.3.
Source: Authors' analysis based on publicly-available information and bilateral consultations with scenario providers.

Agricultural and land use emissions reductions are a further mitigation strategy dimension that is, however, not considered by all selected scenarios. Indeed, as shown in Chapter 4, most models used in the considered scenarios do not cover the agricultural and land use sector (Table 4.1). For models that do include it, agricultural and land use change emissions reductions can be achieved through many different mitigation options, including reduced deforestation, methane reductions in rice production, introduction of new agricultural practices to enhance soil carbon, agroforestry, restoration of wetlands, as well as demand-side measures with dietary changes and food waste reduction. In addition, reforestation/afforestation is a land-based CDR option that allows to achieve negative emissions. Scenarios that provide data on land use change rely on forest cover increase for negative emissions and are all associated with medium to high feasibility challenges (Table 5.1).

Box 5.1. Mitigation scenarios and sustainability goals

Synergies and trade-offs of climate change mitigation scenarios with SDGs

Article 2 of the Paris Agreement places climate change mitigation and resilience objectives "in the context of sustainable development and efforts to eradicate poverty". Climate change mitigation comes with a range of synergies and trade-offs with other societal goals, which are usually not considered in the design and modelling of mitigation scenarios. Understanding the degree of desirability of scenarios in terms of adequation with sustainability goals will prove increasingly important to align financial flows with those broader sustainability and ESG goals, beyond climate.

Trade-offs and synergies between climate mitigation and other sustainability goals can be analysed on a range of issues and SDGs, including energy access, air pollution and health, water, hunger, and biodiversity. While some scenarios directly provide quantitative variables relevant to the analysis of sustainability – e.g. water consumption, inequalities, air pollution and associated premature deaths, air quality, mineral resources, food prices, population at risk of hunger – most models do not have a comprehensive coverage of SDGs, if any. In particular, the scenarios used in finance do not provide coverage of SDGs. Ex-post analysis of the potential trade-offs and synergies for some scenarios have been analysed in ad-hoc studies (Bertram et al., 2018[120]; Jakob and Steckel, 2016[121]).

Development of integrated sustainable development scenarios: opportunities for the financial sector

The scenario scientific community has recently developed the modelling of integrated "sustainable development pathway" (SDP). This is an integrated scenario of climate mitigation covering all SDGs by combining IAMs and other models (Soergel et al., 2021[122]). There is now ongoing development of the next generation of integrated SDP scenarios (IASA conference) thanks to recent methodological advances in integrated SDG modelling.

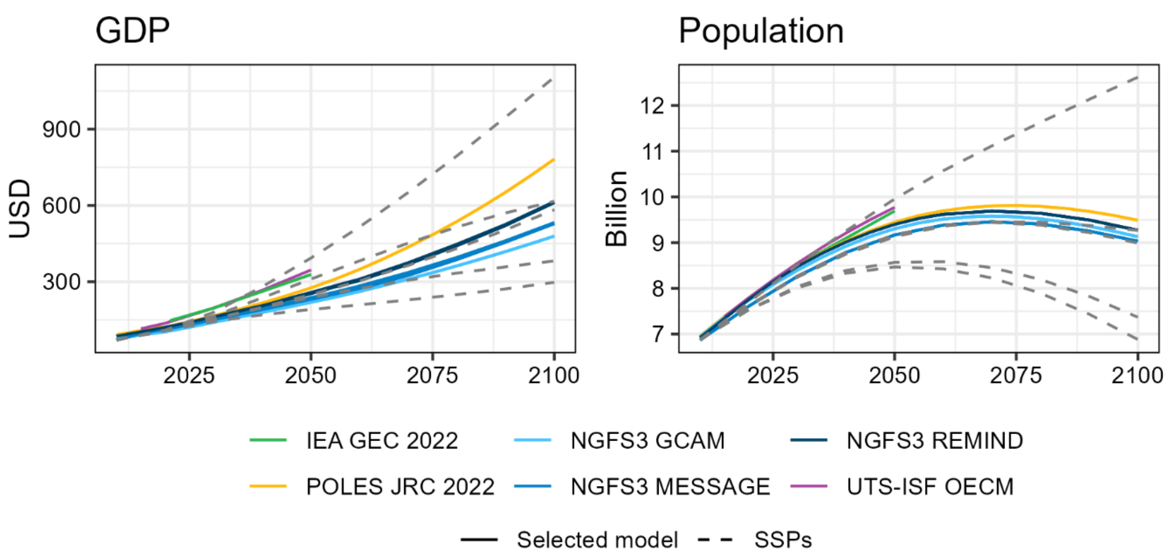
5.3. Underlying assumptions and uncertainties in mitigation scenarios

Emissions pathways and mitigation strategies provided by climate mitigation scenarios, as discussed in Chapter 4 and Section 5.2, are heavily influenced by the assumptions that are inputted in models that produce these scenarios. This includes assumptions on future socio-economic trends, policies, and technological characteristics.

5.3.1. Socio-economic assumptions

Projections of global economic growth and population are the two main socio-economic trends, on which scenario models rely. Using external data sources[14] such as the International Monetary Fund (IMF) and the United Nations (UN), most scenarios analysed in this paper assume a GDP and population growth close to the "middle of the road" SSP i.e. SSP2, where population stabilises after 2050 (Figure 5.3). Over 90% of scenarios collected in the AR6 scenarios database, and therefore of the scenarios analysed in this paper, rely on the SSP2 for their socio-economic input assumptions. NGFS even directly uses the SSP projections as its socio-economic input assumptions. In contrast, ISF and IEA scenarios rely on population and GDP projections that lie at the higher end of the range of projections used by other scenarios.

Figure 5.3. Socio-economic assumptions in selected scenarios



Source: Authors' analysis based on publicly available information and bilateral consultations with scenario providers.

Using different sets of socio-economic assumptions, for example different SSPs, has a direct impact on the ability of meeting a given climate target and the potential pathways to it (UNEP FI & CICERO, 2021[37]). This is not surprising as higher GDP and population can potentially lead to higher modelled energy consumption, and hence higher modelled emissions. Sensitivity analyses have shown that assumptions about future economic growth are a main driver of emissions outcomes in scenarios, while population assumptions have a lower impact (Marangoni et al., 2017[123]). Using different GDP projections indeed significantly affects the emissions outcomes of scenarios. A sensitivity analysis looking at IAMs showed that shifting from a "middle of the road" (SSP2) to a SSP3 projection of GDP has up to a 20% impact on cumulative CO_2 emissions until 2050, depending on the model (Marangoni et al., 2017[123]). For other types of models, this relationship may be less straightforward. For example, while IEA scenarios use population and economic growth projections that are on the high-end of projections in SSPs, modelled energy demand remains lower, based on the assumption that other measures, notably energy efficiency on the demand side, have the potential to counteract the impact of high socio-economic assumptions.

[14] Different scenario developers use different external sources to input socio-economic projections into their models. Common data sources for population and GDP growth are the projections made by the UN, IMF, OECD and IEA.

5.3.2. Policy assumptions

Scenarios take different approaches to policy assumptions, most notably, as summarised in Table 5.2, in terms of speed of action and policy implementation, extent to which they differentiate carbon pricing in different geographies, and whether policies other than a carbon price are represented, such as net-zero and decarbonisation targets, targets for access to energy, renewable energy shares, electrification, and buildings renovation. All the selected scenarios that achieve 1.5°C by the end of the century[15] apply immediate optimal action (Table 5.2, first column), assuming carbon pricing or other mitigation policies are implemented immediately. Pathways with delayed action cannot comply with 1.5°C. Less ambitious scenarios, such as the IEA APS and GECO NDC-LTS, consider delayed action until 2030, potentially taking into account current national policies and pledges until 2030. These scenarios project the consequences of current national emissions policies, targets and pledges, but it has been shown that current national climate targets are ambiguous and could lead to a range of outcomes in terms of emissions (Rogelj et al., 2023[124]).

Table 5.2. Policy assumptions in selected climate change mitigation scenarios

	Assumed timing of global action	Carbon pricing: geographic differentiation assumption	Additional policy assumptions
IEA NZE	Immediate	Differentiated	Yes
IEA APS	Delayed, preceded by NDCs	Differentiated	Yes
JRC GECO 1.5°C	Immediate	Uniform	No
JRC GECO NDC-LTS	Delayed, preceded by NDCs	Uniform	No
NGFS3 NZE 2050	Immediate	Uniform	Yes
NGFS3 DIV NZE	Immediate	Uniform	Yes
NGFS3 Below 2°C	Immediate	Uniform	No
NGFS3 Delayed transition	Delayed, NDCs not considered	Uniform	No
UTS-ISF OECM NZE	Immediate	Differentiated	No

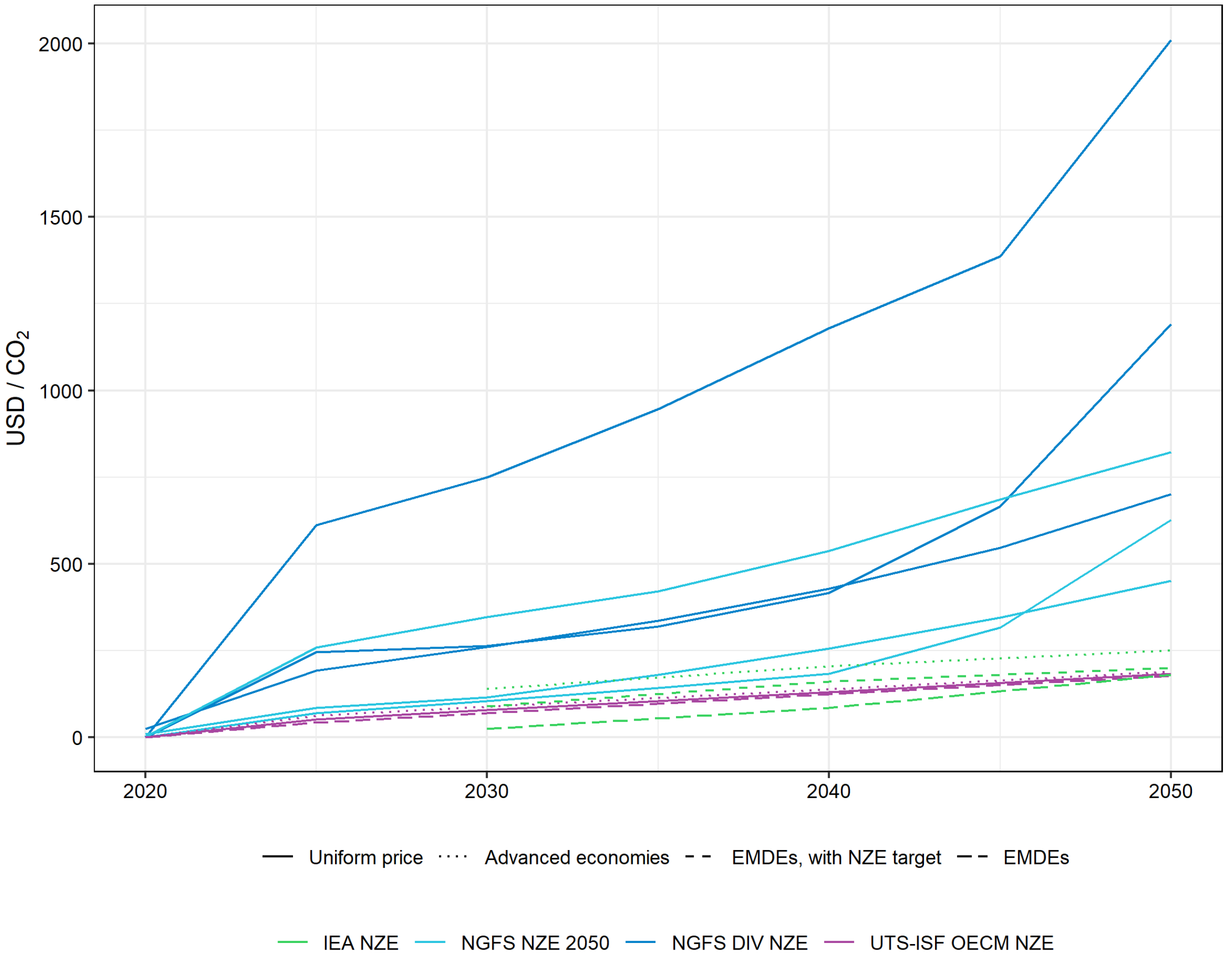
Note: Immediate action = before 2030. Delayed action = after 2030. IEA differentiates its carbon price between advanced / emerging with net-zero pledges / other emerging economies. UTS-ISF's OECM differentiates its carbon price between OECD countries and other countries. Additional regional and sectoral policies can take the form of net-zero and decarbonisation targets, targets for access to energy, renewable energy shares, electrification, and buildings renovation.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

Most scenarios use a globally uniform carbon price (Table 5.2, second column), which can vary widely across scenarios (Figure 5.4). Only the IEA and the UTS-ISF's OECM are built on carbon prices that are differentiated across regions. The carbon price in UTS-ISF's OECM for developed countries is only slightly higher than for developing countries. In the IEA scenarios, the carbon price in advanced economies is more than double that for developing countries in 2030 (Figure 5.4).

While carbon prices vary across scenarios, it can be misleading to directly compare them. Carbon prices across scenarios are sensitive to whether the models consider other policy assumptions or not. In most scenarios, carbon prices are the only form of policies included (Table 5.2, last column). In such cases, the carbon price is used as a proxy for overall climate policy intensity and as a modelling parameter to reach the required climate goal. The carbon prices can in this case best be understood as an indicator of the overall policy intensity, rather than the actual expected price of carbon (NGFS, 2022[33]). Scenarios that exclusively rely on carbon pricing are not designed to inform on which exact policies should be implemented to achieve emissions reductions.

[15] With 50% likelihood or more.

Figure 5.4. Carbon prices in selected scenarios



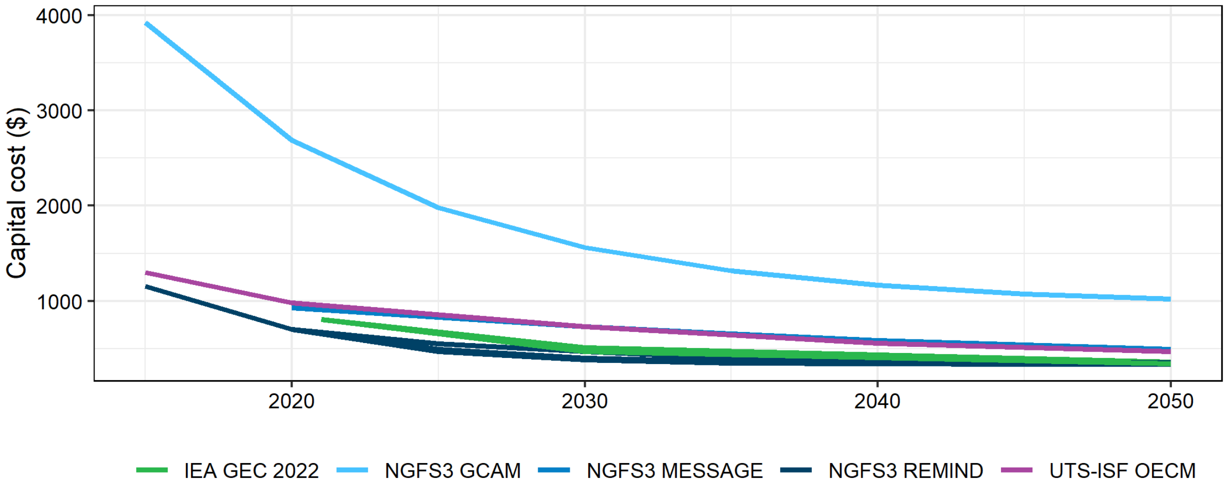
Source: Authors' analysis based on publicly available information and bilateral consultations with scenario providers.

A few other scenario providers include other policy assumptions (Table 5.2, last column). For example, the IEA scenarios combine carbon prices for electricity and industry with emissions standards for the transport sector, amongst many other policies (IEA, 2022[53]). When other policies, such as fuel taxes, subsidies, standards, capacity targets, R&D, and feed-in-tariffs, are not modelled, it can limit the comparability of scenario results (UNEP FI & CICERO, 2021[37]). The mix of climate policy instruments used has an impact on how emissions reductions take place across sectors and countries, and hence can change the shape of the emissions pathways.

5.3.3. Technological assumptions

Assumptions about technology characteristics, including resource potential, capacity (or availability), capital costs, operating and maintenance (O&M) costs, conversion efficiency and lifetime, are key components of models used to produce climate change mitigation scenarios (Krey et al., 2019[125]). The selected scenario providers tend to share data on key assumptions for power sector technologies, such as capital costs of solar photovoltaics (PV) by region (Figure 5.5). Data on technology assumptions for other key sectors, such as industry and AFOLU are scarcer.

Figure 5.5. Assumptions on capital costs for solar PV in the EU



Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

Technology costs assumptions are a large driver of uncertainty in climate models, as small changes in technology cost assumptions can have significant effects on modelled technology and emissions pathways (UNEP FI & CICERO, 2021[37]). Sensitivity analysis of scenarios produced by an IAM[16] to technology costs shows that input assumptions about energy supply costs for different technologies as well as about carbon dioxide removal (CDR) availability have a large impact on emissions and other mitigation outcomes. The biggest impacts were due to assumptions on CCS, biomass and wind costs, and on low-carbon vehicles costs (Giannousakis et al., 2021[103]). However, IAMs have also systematically underestimated cost reductions in solar, as integrating policy support, non-monetary consumer and industry preferences, and technological learning is challenging (UNEP FI & CICERO, 2021[37]).

While capital costs can vary significantly across models (Figure 5.4), it is difficult to compare them (Krey et al., 2019[125]). Different models apply different approaches in projecting technology characteristics. For example, costs are endogenous in some models, while they are exogenous in others. Further, the relative differences between different technologies in the same model have more impact than the differences of the same technology across models, as the former drive the technology choice.

5.3.4. Other modelling assumptions

Further underlying model assumptions and model characteristics can increase uncertainty in modelling results and limit comparability of results, in particular discount rates. In climate models that optimise costs, future costs are discounted to compute the net present value. Cost-benefit IAMs have been heavily criticized for using high discount rates, which means that future climate damages are reduced relative to the cost of mitigating those damages today (UNEP FI & CICERO, 2021[37]). However, discount rates can impact on the timing and choice of mitigation measures. A lower discount rate will bring mitigation forward in time, which translates into less need for carbon dioxide removal later (Emmerling et al., 2019[126]). Similarly, a higher discount rate pushes mitigation further into the future and therefore places a higher burden on future generations. The discount rate therefore represents a value-laden assumption. Information on the discount rates used by models is rarely accessible (indeed, none of the selected

[16] REMIND

scenario providers disclose the discount rate used), and there is arguably too little sensitivity analysis of how the discount rate affects modelled outcomes.

Other modelling characteristics influence scenario results and add uncertainties. One of the main blind spots of current models used to produce climate change mitigation scenarios such as the ones considered in this paper is that these models do not consider climate impacts already occurring below 1.5°C to 2°C of global warming. Recently, the research community has begun to combine mitigation pathway analysis with ex-post analysis of associated climate impacts and the benefits of mitigation (Drouet et al., 2021[127]). The NGFS scenarios, in particular, are assessed against a wide range of climate impacts to derive the magnitude of physical risks under the different scenarios. The scenarios are inputted into climate impact models to project the climate impact outcomes for the different scenarios. However, climate impacts feedback loops are rarely represented directly at the scenario modelling stage. Another important blind spot is precisely that the financial sector relies on scenarios produced by models that do not account for the financial system and its role in the transition. Thus, the feedback loop between the financial sector and mitigation pathways is not taken into account (Battiston et al., 2021[62]).

The availability of critical minerals, which are critical to the large-scale deployment of a number of low-GHG technologies (IEA, 2021[128]), could further constraint mitigation models (Wang et al., 2022[129]). Interactions between climate objectives, energy transitions, and critical minerals have not been fully integrated in climate change mitigation models. The more stringent the temperature objective the higher mineral demand. However, such materials are exposed to specific supply-side risk and demand-induced pressure (Miller et al., 2022[130]). Production capacity expansion below anticipation, limited economic mineral reserve, and potential geo-political constraints may derail humanity from a more sustainable trajectory towards 1.5°C target (Wang et al., 2022[129]).

5.4. Implications for the use of scenarios in finance

Climate-alignment assessment and target setting methodologies can choose from a range of scenarios with different mitigation strategies. It is not clear how such methodologies currently prioritise scenarios with different mitigation strategies, but they could explore multiple scenarios with different mitigation strategies as these face different feasibility challenges. As shown in Section 5.2, the ambitious scenarios by the different providers tend to follow different mitigation strategies and some follow relatively well certain IMPs. For example, the OECM NZE scenarios and IMP Ren both rely heavily on renewables. Alignment assessments of finance indeed have started to use scenarios of multiple providers (Noels and Jachnik, 2022[10]), but have not yet started to communicate the different mitigation strategy narratives that these may follow. Qualitatively highlighting the mitigation strategies as done in the IMPs allows to more easily understand the characteristics of targets and assessments based on specific scenarios.

Financial sector climate transition risk management and stress testing exercises already rely on multiple scenarios by nature. However, the scenarios currently used in finance have an incomplete representation of mitigation options. As explained in Section 5.2, most pathways exclude many granular demand-side and land-based mitigation options. A more comprehensive understanding of the different mitigation strategy options available and the different mitigation strategies followed by the scenario used can inform priorities and shed light on blind spots for financial institutions and investors. This in turn can enhance their client engagement, both to help drive actual GHG emissions reductions and in the context of their portfolio allocation and investment decisions.

The financial sector is also considering scenario pathways of different elements of their mitigation strategies, such as energy technology mix information, to develop complementary metrics of climate performance. For example, PACTA uses scenario projections of capacity and production volumes of different technologies to relate to corporate capital expenditures (2DII, 2022[74]). Such information can contribute to the design of real-economy transition metrics, e.g. capital invested committed toward transition and transition-enabling activities or capital deployed toward managed phase out schemes as proposed by GFANZ (2022[24]), thereby complementing GHG-based metrics.

As scenario analysis inherently comes with uncertainties, stakeholders using them for financial sector target setting or transition and alignment assessments may want to communicate those with users. However, such uncertainties are rarely specified (Noels and Jachnik, 2022[10]). This can be explained by the fact that uncertainty analysis of scenarios is highly complex. As discussed in Section 5.3, there are remaining technical and practical challenges to comparing the underlying assumptions of scenarios that drive scenario emissions pathways and mitigation strategy options. On the one hand, underlying assumptions cannot always be compared as model approaches may differ. On the other hand, data and information on those assumptions is not always available or disclosed in a comparable way.

There is indeed a rising demand from the financial sector to improve the comparability of climate scenario analyses and results (Monasterolo, Nieto and Schets, 2023[61]). In this context, differences in assumptions, especially on technology costs and characteristics, may significantly affect scenario outcomes, as shown by existing sensitivity analyses (Section 5.3), making comparisons between scenarios that rely on different assumptions difficult. NGFS scenarios were designed to provide a common set of scenarios, promoting some harmonisation in scenario assumptions, for example through the use of the SSPs, while using multiple models (NGFS, 2021[131]). This has allowed certain users in the financial sector to use several scenarios for more robust analysis. Further harmonisation efforts of assumptions (SSPs, SPAs) (Giarola et al., 2021[132]) can be relied on to standardise input assumptions and make scenarios outcomes more comparable. However, there is a trade-off between standardisation and the ability to reflect uncertainty. While standardised assumptions imply better comparability of alignment assessments across scenarios used, it also implies a smaller range of uncertainties and of possible socio-economic, technological and political developments is covered.

There is also a need to improve the transparency of model assumptions, both to compare scenarios and to understand whether climate scenarios' assumptions are consistent with financial models (GFANZ, 2022[18]). As explained in Section 5.3, scenario providers do not always disclose comparable data on underlying assumptions. This may limit the ability of scenario users to understand what drives scenario results and their key uncertainties, as well as to compare scenarios from different providers. Further, sensitivity studies could help enhance scenario users' understanding of model behaviour and drivers of change in scenarios. In doing so, users of scenarios can better characterise drivers behind scenario results and uncertainties, keeping in mind that scenarios relying on very different underlying assumptions and model approaches are difficult to compare.

Climate alignment assessments and transition analysis of finance tend to update their scenarios as they are improved and updated (Noels and Jachnik, 2022[10]). Although challenging, input assumptions and socio-economic projections in models should aim to reflect the latest technological developments, policies, and knowledge of mitigation options and to take stock of the most up-to-date projections and real-world developments. For example, the latest iteration of NGFS scenarios updated socio-economic assumptions to reflect the impacts of the COVID-19 pandemic. Such updating of scenario assumptions and further scenario development more broadly are regularly undertaken in the scenario modelling community through so-called inter-model comparison projects.[17] Such projects encourage the transparent disclosure of data and improved comparability of models, which several of the scenario providers explored in this paper participate in.

Scenarios do not currently model the financial sector, and what drives investors' decisions, and the ability to finance the climate transition. Some, however, give an indication (typically partial) of investment needs. Such scenario information can also be used to identify investment opportunities and financing contributions for the financial sector. Further, investments can bring down the feasibility challenges and technology cost

[17] Examples include IIASA, IPCC, EMF, ADVANCE.

characteristics described in this chapter. In addition, alignment with these scenarios cannot be achieved if policy makers do not address the challenges associated with financing of the transition and put in place the adequate policy landscape to allow redirection of financial flows. Investors' decisions ultimately depend on the credibility of climate policies. While scenario models do not aim to prescribe the exact mix of climate fiscal and regulatory policies that can be and are implemented by governments, they all assume strong and immediate action to reach 1.5°C, as discussed in Section 5.3. Notably, policymakers have a crucial role to play to bring down feasibility challenges found in ambitious scenarios (Section 5.2) to improve the viability of more options and strategies for financial and non-financial corporates to transition.

6 Conclusions and recommendations

Financial institutions and investors are increasingly relying on climate change mitigation scenarios for climate-related analyses and various decision-making processes, increasingly encouraged by voluntary frameworks supporting net-zero emissions. The choice of mitigation scenario on which they base their assessment has a significant influence on the results of climate alignment and transition risk assessments of financial assets, asset classes and portfolios. In this context, and as explored in this paper, there are concerns relating to the environmental integrity, applicability, and uncertainty associated with currently used scenarios and underlying assumptions. Building on the analysis of climate change mitigation scenarios currently used in financial sector target setting and alignment assessments presented in the previous chapters, this concluding chapter summarises current practices and remaining challenges, as well as suggests recommendations for the improved design and use of scenarios in the financial sector.

6.1. Bridging information gaps: current practices and challenges

This study develops an analytical approach to examine climate change mitigation scenarios commonly used in the financial sector for climate-related financial analyses, acknowledging that most scenarios were not initially designed for that purpose. These scenarios originate from four scenario providers, namely the IEA, ISF, JRC, and NGFS. Specifically, the approach analyses common practices, challenges and needs in developing and using scenarios across three stakeholder communities, namely the climate policy community, financial market participants and stakeholders, and scenario modellers. The three analytical dimensions are: (i) the degree of Paris consistency (i.e. consistency with the Paris Agreement's long-term temperature goal and emission reduction objective), (ii) the applicability of the scenarios in the financial sector, and (iii) the characteristics of underlying mitigation strategies and input assumptions.

None of the scenarios that providers qualify as net zero, 1.5°C or below 2°C currently used by the financial sector to set targets and assess alignment are assessed as fully consistent with stringent interpretations of all five criteria of the Paris-consistency framework relied on for this study. Only two are aligned with all criteria when considering a slightly less stringent interpretation. Hence, target setting and alignment approaches based on these scenarios may underestimate the needed efforts for aligning with the Paris Agreement.

The lack of specificity, comparability and transparency in qualifying the temperature outcomes of scenarios across scenario providers and stakeholder communities raises further challenges to the environmental integrity of target setting and alignment assessments in the financial sector. The information required to assess the Paris consistency of a given scenario is not always disclosed by scenario providers. Given that the formulation of the Paris Agreement mitigation-related provisions leaves some room for interpretation, there is a need for scenario providers to be more transparent in communicating in a clear and comprehensive manner the peak and end-of-century temperature outcomes of their scenarios and associated likelihoods, as well as aggregate GHG emissions. In turn, to enhance transparency, users of scenarios should refer to the specific elements of the temperature outcome of scenarios rather than using loose, vague and at times opaque scenario labels, such as "net zero" or "below 2°C".

Current scope limitations in scenario models restrict both the ability of potential users to conduct a comprehensive assessment of the scenarios' climate outcome, and of their applicability to climate-related analyses in the financial sector. Climate change mitigation models selected and used by the financial sector do not always match the full scope of GHGs, emissions sources, and sectors relating to the range of assets typically found in financial portfolios. As a result, methodologies to set targets and assess alignment need to rely on complementary assumptions to fill in coverage gaps in scenario data. Further, some scenarios currently used in financial sector target setting and alignment assessments have an incomplete representation of mitigation options as they tend to omit many granular demand-side and land-based mitigation options.

Limited sectoral and geographical granularity of emissions pathways provided by scenarios may restrict their applicability for financial sector climate-related target setting and alignment assessments, as well as have undesirable portfolio allocation and investment implications, including risks for carbon lock in. Scenario providers are making progress on enhancing the granularity of their scenarios, including on pathways for emissions and other variables, which is critical for climate-related analyses of financial assets. Still, geographical disaggregation remains insufficient, especially for developing countries where data is more limited. Further, pathways or data for several high-emitting subsectors are still missing, while pathways for technologies and solutions enabling the climate transition across sector are not clear. There are also several challenges in matching sectoral classifications of climate-policy relevant sectors used in scenarios with economically-relevant sectors used in financial analyses. Additionally, providers could consider disclosing a five year or more frequent data interval where that is not the case yet to better match the need for and help inform short-term climate transition planning and decision making in the financial sector.

Differences between scenarios and financial and corporate GHG accounting imply that scenarios cannot be used to assess if and to what extend the intended reliance on offsets in financial and corporate sector climate transition and alignment plans is consistent with the Paris Agreement mitigation-related objectives. Corporate GHG targets and transition plans often rely on offsets, despite best practice in target-setting calling for offsets to only be considered to finance additional emission reductions beyond an entity's own target. Targets that include a reliance on offsets cannot be compared to climate change mitigation scenarios. Mitigation scenarios optimise emissions reductions across sectors. Hence, any sectoral pathway within such scenarios shows actual emissions reductions, already reflecting cost optimisation beyond the sectoral value chain.

The range of global, sectoral and national scenario pathways reflect that there are different possible pathways and mitigation strategies to reach a certain climate outcome, leaving room for choice in climate-related target setting and alignment assessment. At the same time, scenarios cannot be directly compared due to differences in scope and modelling approaches. In this context, it is not clear how providers currently prioritise and select scenarios with different mitigation strategies.

While global climate change mitigation scenarios are not designed to address burden sharing across countries nor to model in detail policy action and investments, these issues will however be important determinants of the real-economy transition. While scenario models do not aim to prescribe the exact mix of policies that can be implemented by governments, pathways assessed as Paris consistent all assume strong and immediate action. Moreover, while scenarios may partly model and estimate investment needs, they are not designed to address constraints relating to mobilising and accessing the financing needed, nor who finances what.

In updating and further developing climate change mitigation scenarios, there will always be trade-offs between complexity and practicality. Furthermore, climate change mitigation scenario development is a dynamic field. Scenario models are frequently updated and are increasingly taking into account the needs of different types of scenario users, including financial sector ones.

6.2. Potential actions for improved scenario design and use for the financial sector

Different stakeholder communities can take actions and collaborate to enhance the use of climate change mitigation scenarios in climate-related analyses in the financial sector. Based on the challenges and gaps identified in this paper, this section puts forward suggestions to inform climate scenario providers, financial market stakeholders (including climate-related assessment methodology providers), and climate policy makers on how they may contribute to improved design and use of mitigation scenarios in financial sector analyses, notably climate-related target setting and alignment assessments.

Providers of climate change mitigation scenarios can facilitate an accurate use and interpretation of the scenarios they develop, as well as address information needs from the financial sector. To do so, they could:

- **Standardise the disclosure used for characterising scenarios and disclose scenario variables and climate outcomes**: Instead of using different qualifiers of scenario ambitions, scenario providers can adopt a more coordinated approach to formulate scenario ambition, for instance based on frameworks such as the one proposed in Pouille et al. (2023[11]). This can increase clarity and comparability for users of such scenarios. Further, scenario providers often follow different scopes, units and measures to disclose emissions pathways and underlying assumptions. Increased standardisation in the disclosure of such scenario variables can facilitate the use of scenarios in the financial sector as well as by other economic actors. One way of doing this in practice is through submitting scenarios to IPCC coordinated efforts to collect and assess existing scenarios. This can enable comparability as well as scientific peer review. Additionally, scenario providers could also qualify their reliance on different mitigation strategies, building on the Illustrative Mitigation Pathways.
- **Develop and use harmonised sets of input assumptions**: Building on the experience of harmonising socio-economic data across standardised qualitative narratives (SSPs), harmonised qualitative narratives could also be created for other input assumptions, including for technology and policy. This can improve scenario transparency and comparability, as well as create easy-to-understand narratives. In doing so, there will be a trade-off between developing harmonised and simplified narratives, on the one hand, and reflecting the range of uncertainties, on the other hand.
- **Increase the transparency and comprehensiveness of the disclosure of climate change mitigation scenario data**: First, all scenario providers would ideally produce and report a complete temperature assessment of their scenarios, using the most recent versions of climate models. In particular, they could disclose more complete temperature outcome data, with peak and end-of-the-century temperatures associated with several likelihoods. Second, scenario providers can increase the transparency of country-level and sectoral-level specificity in their models. Third, they could increase the transparency of input and modelling assumptions, providing data on more variables and increasing model documentation.
- **Expand the scope of scenario models**: While this may be constrained by existing models, scenario providers should in particular aim to include all GHGs and emission sources beyond energy-related emissions. Scenarios can also improve their scope by including AFOLU and a wider range of mitigation options, in particular on the demand-side.
- **Enhance the granularity of scenario output variables to the extent possible based on available granular data**: Improved granularity in emissions pathways is needed both for geographical, sectoral, emissions and temporal dimensions, as well as across those different dimensions. Priority areas include pathways for large developing countries and for high-emitting sectors, such as mining. Further, increased granularity in pathways of other output variables, such as technology deployment, can inform the development of complementary non-GHG metrics in the financial sector. However, the need for increased granularity may be constrained by model design and data availability, as well as should be

carefully balanced with the risks of increasing rather than decreasing uncertainty by making assumptions (including equity-related ones) at highly disaggregated levels.

Users of climate change mitigation scenarios in the financial sector need to accurately account for and communicate gaps, limitations and uncertainties in their scenario-based targets and assessments. While the diversity of available mitigation scenarios helps reflect the range of possible pathways to net-zero emissions, they should also ensure that the scenarios they select are both Paris consistent and provide at least some of the granularity needed to assess specific financial assets and asset classes. More specifically, users of scenarios in the financial sector could:

- **Select high-ambition Paris-consistent scenarios for climate target setting and alignment assessments**: Providers of target setting and climate-alignment assessments in finance should prioritise scenarios with high levels of ambition in temperature and emissions outcomes. This entails selecting scenarios that avoid or have limited overshoot of 1.5°C, maintain a very high likelihood of staying below 2°C, peak emissions early, and achieve net-zero GHG emissions. Aligning with ambitious scenarios is needed in the face of high climate uncertainties.
- **Select scenarios that are comprehensive in scope and granular in the output data they provide**: Providers of target setting and climate-alignment assessments in finance should prioritise scenarios that account for all emissions sources and all GHGs. The sectoral and geographical granularity of scenarios should be evaluated against the needs relating to different financial assets, asset classes and portfolio sectoral segments. Where gaps in granular output variables remain, scenario users should communicate to scenario providers their priorities in seeing those gaps being filled.
- **Make use of multiple scenarios to better reflect diversity and uncertainty in mitigation strategies and assumptions**: Recognising the inherent uncertainties in scenarios' climate outcomes and in their proposed mitigation strategies and underlying assumptions, financial stakeholders can consider a range of scenarios. This could entail considering scenarios with different assumptions, models, and mitigation strategies to account for different future real economy developments, as different mitigation strategies face different feasibility challenges.
- **Transparently communicate climate outcomes, likelihoods, and uncertainty when disclosing scenario-based targets and alignment assessments results**. Such information should further include the critical difference between peak and end-of-century temperatures. In this context, standardised and transparent disclosure should be used to express the level of climate ambition associated with alignment results or net-zero targets, building on practices from climate modellers.
- **Communicate narratives and uncertainties of mitigation strategies and assumptions**: Building on enhanced harmonisation of narratives on mitigation strategies and assumptions by scenario providers, scenario users in the financial sector can qualify their targets and assessments using such harmonised narratives. This can also contribute to shed light on associated uncertainties and feasibility challenges.
- **Apply scenarios taking into account design characteristics**: An improved understanding of design characteristics and limitations, as well as the inherent differences between GHG accounting in scenarios and GHG accounting in the financial sector, can prevent their misuse and reduce greenwashing. For example, targets relying on offsets cannot be compared to climate change mitigation scenarios.
- **Make use of non-emissions data and pathways provided by scenarios**: Scenarios provide a wealth of variables of how to achieve mitigation across emitting sectors, other than GHG emissions pathways. Such variables can be used by the financial sector to develop complementary metrics tor assessing the overall climate performance of financial assets.

Climate policymakers can further enable accurate use of mitigation scenarios and support their development. To do so, they could:

- **Promote standardised disclosure of climate outcomes of targets and alignment assessment, grounded in the latest science**: This can be done through encouraging a consistent interpretation of the Paris Agreement, as well as standardised data disclosure across scenario-based financial analyses, in particular in terms of temperature and emissions outcomes. This will increase consistency and comparability across different scenario-based analyses in the financial sector, as well as across jurisdictions.
- **Support improved availability of granular input data for scenarios**: Policymakers can provide mechanisms to support the availability of geography and sector specific input data to inform the design of global scenarios. For example, they can support improved data disclosure in national energy accounts and support data collection in developing countries. Access to granular and accurate data is essential for scenario development and analysis in the financial sector.
- **Contribute to reduced scenario uncertainty and increased scenario granularity, while maintaining international comparability**: Climate policy makers can contribute to reducing scenario uncertainty by ensuring climate policy certainty and specificity within their jurisdiction, which could include sector-specific climate change mitigation targets. Developing a range of national-level sector-specific scenarios, reflecting planned and potential policies, would go even further in informing the development of global scenarios more reflective of geographical specificities and circumstances. Combining this with standardised disclosure of climate outcomes and scenario information would allow maintaining international comparability.
- **Make use of enhanced scenario information and applications for assessing progress towards Article 2.1c of the Paris Agreement**: Harmonised scenario disclosure, information and data, as well as improved granularity, comprehensiveness and applicability of scenarios can better inform climate policy makers when tracking progress on aligning financial activities with climate policy goals, i.e. both investments into economic sectors of their national economy, as well as capital stock and new investments by investors and financial institutions domiciled within their jurisdiction. Such efforts could in turn contribute to informing aggregate-level assessments of progress, including under the UNFCCC (e.g. Global Stocktake and Biennial Assessment and Overview of Climate Finance Flows).

The potential actions outlined in this chapter are technical in nature but can be viewed within the broader policy and investment environment that can strongly impact scenario uncertainty and viability. While the financial sector can proactively invest in climate solutions and the climate transition, thereby also contributing to the viability of more mitigation options and strategies by bringing down technology costs and increasing technology commercialisation and roll-out, public policy retains a central role in increasing the overall feasibility and financial viability of the climate transition. Scenarios that keep global warming at 1.5°C (with 50% likelihood by end of century), all assume ambitious and immediate policy action. As such, the feasibility of scenario outcomes and of investors' decisions based on such scenarios ultimately depend on the credibility and effective implementation of ambitious climate policies.

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Annex A. Description and objectives of scenarios used in climate-related analyses in the financial sector

Table A A.1. Description and objective of scenarios in use in finance alignment assessments

Scenario	Provider	Definition and overview	Objective
Net Zero Emissions 2050 (NZE)	IEA	"The Net Zero Emissions by 2050 (NZE) Scenario maps out a way to achieve a 1.5 °C stabilisation in the rise in global average temperatures, alongside universal access to modern energy by 2030.." "It sets out a comprehensive and detailed view of how the energy sector could respond coherently to the challenges of climate change while taking account of concerns about energy security and affordability. "	To "provide projections for energy markets and energy security through scenarios and examines what those outlooks imply for energy-related emissions and achievement if the world's sustainable goals
APS	IEA	"The Announced Pledges Scenario (APS) assumes that all aspirational targets announced by governments are met on time and in full, including their long-term net zero and energy access goals." "To show the trajectory and energy transition implied by the full achievement of all climate pledges."	
GECO 1.5°C	JRC	"The 1.5°C Scenario outlines a cost-efficient pathway for limiting global temperature rise to 1.5°C by the end of the century."	"to provide a global picture of energy markets as they transform over the next decades, under the simultaneous interactions of economic development, technological innovation and climate policies."
GECO NDC-LTS	JRC	"This scenario considers the policies of NDCs in the medium term and the LTSs in the longer term. This scenario assumes that the objectives in the NDCs (including conditional objectives) are reached in their relevant target year (2030 in most cases). […] Beyond 2030, the objectives of the countries' LTS, where they exist, are pursued."	
Net Zero 2050	NGFS	"Net Zero 2050 is an ambitious scenario that limits global warming to 1.5 °C through stringent climate policies and innovation, reaching net zero CO_2 emissions around 2050. Some jurisdictions such as the US, EU and Japan reach net zero for all greenhouse gases by this point. This scenario assumes that ambitious climate policies are introduced immediately. CDR is used to accelerate the decarbonisation but kept to the minimum possible and broadly in line with sustainable levels of bioenergy production. Net CO_2 emissions reach zero around 2050, giving at least a 50 % chance of limiting global warming to below 1.5 °C by the end of the century, with no or low overshoot (< 0.1 °C) of 1.5 °C in earlier years.."	"NGFS scenarios' objective is to provide a common and up-to-date reference point for understanding how climate change (physical risk) and climate policy and technology trends (transition risk) could evolve in different futures. Each scenario was chosen to show a range of higher and lower risk outcomes."
Divergent Net Zero Policies	NGFS	"Divergent Net Zero reaches net-zero by 2050 but with higher costs due to divergent policies introduced across sectors and a quicker phase out of fossil fuels. This scenario differentiates itself from the Net Zero 2050 by assuming that climate policies are more stringent in the transportation and buildings sectors. This mimics a situation where the failure to coordinate policy stringency across sectors results in a high burden on consumers, while decarbonisation of energy supply and industry is less stringent. Furthermore, the availability of CDR technologies is assumed to be lower than in Net Zero 2050. Emissions are in line with a climate goal giving at least a 50 % chance of limiting global warming to below 1.5 °C by the end of the century, with no or low overshoot (<0.1 °C) of 1.5 °C in earlier years."	
Below 2°C	NGFS	"Below 2 °C gradually increases the stringency of climate policies, giving a 67 % chance of limiting global warming to below 2 °C. This scenario	

		assumes that climate policies are introduced immediately and become gradually more stringent though not as high as in Net Zero 2050. CDR deployment is relatively low. Net-zero CO_2 emissions are achieved after 2070."	
Delayed Transition	NGFS	"Delayed Transition assumes global annual emissions do not decrease until 2030. Strong policies are then needed to limit warming to below 2 °C. Negative emissions are limited. This scenario assumes new climate policies are not introduced until 2030 and the level of action differs across countries and regions based on currently implemented policies, leading to a "fossil recovery" out of the economic crisis brought about by COVID-19. The availability of CDR technologies is assumed to be low pushing carbon prices higher than in Net Zero 2050. As a result, emissions exceed the carbon budget temporarily and decline more rapidly than in Well-below 2 °C after 2030 to ensure a 67 % chance of limiting global warming to below 2 °C."	
UTS-ISF OECM 1.5°C	ISF	"The 1.5°C scenario aims to achieve a global energy-related CO2 emission budget of around 450 Gt, accumulated between 2015 and 2050. The 1.5°C Scenario requires immediate action to realize all available options. It is a technical pathway, not a political prognosis. It refers to technically possible measures and options without taking into account societal risks or barriers. Efficiency and renewable potentials must be deployed even more quickly than in the 2.0°C Scenario."."	"This research aimed to develop practical pathways to achieve the Paris climate goals based on a detailed bottom-up examination of the potential of the energy sector, in order to avoid reliance on net negative emissions later on."
UTS-ISF OECM 2°C	ISF	"This scenario aims to achieve an ambitious emissions reduction to zero by 2050 and a global energy-related CO2 emissions budget between 2015 and 2050 of around 590 Gt.. The 2.0°C Scenario represents a far more likely pathway than the 1.5°C Scenario, because the 2.0°C case takes into account unavoidable delays due to political, economic, and societal processes and stakeholders."	
ISF Net Zero	ISF	"Sectoral pathways for five key high-emitting sectors, on a global level and for two regions (Europe and North America), to achieve net zero emissions by 2050, and to inform the development of sector-based targets for decarbonization."	"The Net Zero Asset Owner Alliance commissioned the […] ISF to apply their model to sectors as defined by sector classification schemes commonly used in finance (GICs, BICs, and NACE). The aim was to develop sectoral pathways to net zero by 2050 with carbon emissions (scope 1-2) and energy intensity and carbon intensity (scope 1-2) milestones in 5-year intervals for agreed high emitting sectors. "A 1.5°C pathway to support [the Alliance's] 5-year intermediary target setting commitment described in the initial Alliance 2025 Target Setting Protocol. […] Describe in decision-useful terms for financial actors sectoral pathways."

Source: (IEA, 2022[53]; IEA, 2021[31]; Keramidas, 2022[57]; NGFS, 2021[131]; Teske, 2019[133]; Teske, 2022[71]).

Annex B. Scope and granularity of emissions pathways and underlying model resolution of scenario models currently relied on in climate-related analyses in the financial sector

This annex provides further detail on the Annex B. Scope and granularity of emissions pathways and underlying model resolution of scenario models currently relied on in climate-related analyses in the financial sector, as discussed in Chapter 4.

Table A B.1 clarifies further the information provided in Table 4.1. The information summarised in the table may be open to some interpretation as the level of granularity may differ between model variables. The interpretation in this table aims to include the highest level of granularity found for at least one variable.

Table A B.1. Sectoral scope and granularity for emissions pathways

Model	Indicator	Information

IEA GEC 2022	Number of modelled sectors	3+ energy sub-sectors: energy supply (oil, natural gas, coal, bioenergy), electricity generation and heat production, other energy transformation
		27 industry sub-sectors:
		- heavy industries:
		  ○ Chemicals and petrochemicals: high value chemical production, methanol production, ammonia production, other chemical production
		  ○ Iron and steel: material and fuel preparation, iron production, steel production, semi-finishing and finishing processes.
		  ○ Non-metallic minerals: raw material and fuel grinding, clinker production, finished cement, other non-metallic mineral production,
		  ○ Non-ferrous metals: Alumina refining, aluminium production, finishing, other non-ferrous metal production,
		  ○ Paper, pulp and printing: pulp production, paper production, printing and finishing processes,
		- light industries: transport equipment, machinery, mining and quarrying, food and tobacco, textile and leather, wood and wood products, construction, non-specified industry
		5+ transport sub-sectors: road (scrappage functions are extended across all vehicle types to improve sectoral representation), aviation, navigation, rail, other (includes pipeline and non-specified transport)
		2 buildings sub-sectors: residential, services. (Note that energy demand is further subdivided into six standard end uses in buildings, namely space and water heating, appliances (divided into four different categories: refrigeration – fridge and freezer; cleaning – washing, drying machines and dish washers; brown goods – TVs and computers; and other appliances), lighting, cooking and space cooling – air conditioners and fans.)

	Number of disclosed sectoral emissions pathways	3 energy sub-sectors: combustion activities, electricity and heat sectors, other energy sector 3 industry sub-sectors: Iron and steel, chemicals, cement 3 transport sub-sectors: road (passenger cars, heavy duty-trucks), aviation, shipping 2 buildings sub-sectors: residential, services

POLES-JRC 2022	Number of modelled sectors	4+ energy transformation sub-sectors: electricity sector, heat production, hydrogen, synthetic liquids, other transformation and losses 4 industry sub-sectors: iron and steel, chemicals, non-metallic minerals (cement, lime, glass, ceramics, other non-metallic minerals), other industry (other manufacturing, mining and construction) 2 buildings sub-sectors: residential, commercial 4 transport sub-sectors: road (cars, motorcycles, buses, light trucks, heavy trucks), rail, air and water transport Agriculture (no sub-sectors) Other (no sub-sectors)
	Number of disclosed sectoral emissions pathways	Energy transformation, industry, buildings, agriculture, transport, other
NGFS GCAM	Number of modelled sectors	5 energy sub-sectors: electricity, gases, heat, liquids, solids 5 industry sub-sectors: steel, chemicals (1 sub-sector: Ammonia), cement, non-ferrous metals, other 2 transport sub-sectors: freight, passenger 2 buildings sub-sectors: residential, commercial AFOLU (no sub-sector)
	Number of disclosed sectoral emissions pathways	Idem
NGFS REMIND	Number of modelled sectors	5 energy sub-sectors: electricity, gases, heat, liquids, solids 4 industry sub-sectors: steel, chemicals, cement, other 4 transport sub-sectors: aviation-passenger, maritime-freight, rail (2 sub-sectors: freight, passenger), road (3 sub-sectors: freight, passenger-bus, passenger-LDV) Buildings (no sub-sector) ADOLU (no sub-sector)
	Number of disclosed sectoral emissions pathways (outputs)	Idem
NGFS MESSAGE	Number of modelled sectors	5 energy sub-sectors: electricity, gases, heat, liquids, solids 4 industry sub-sectors: steel, high-value chemicals, cement, non-ferrous materials 1 transport sub-sector: aviation Buildings (no sub-sector) AFOLU (no sub-sector) AFOFI (no sub-sector)
	Number of disclosed sectoral emissions pathways	Idem
UTS-ISF OECM	Number of modelled sectors	6 GICS sectors: Energy; Utilities; Buildings; Industrials (Transport); Materials; Consumer Staples 24 GICS subsectors: - Energy: Coal; Oil; Gas; - Utilities: Power Utilities; Gas Utilities; Water Utilities ; - Industrials (Transport): Aviation; Shipping; Road;; - Materials: Fishing Industry; Forestry & Wood Products; Chemical Industry; Textile & Leather; Aluminium Industry; Steel; Iron & Steel; Cement; - Consumer Staples (Agriculture, Food Processing & Tobacco): no sub-sector Buildings: no sub-sector
	Number of disclosed sectoral emissions pathways	- Idem

Source: Authors' analysis based on publicly available information (including (IEA, 2022[80])) of and bilateral consultations with scenario providers.

Table A B.2 provides further detail on the information summarised in Table 4.2.

Table A B.2. Geographic scope and granularity of models used

Scenario model	Indicator	Information
IEA GEC 2022	Number of modelled regions	7 regions: North America, Central & South America, Europe, Africa, Middle East, Eurasia, Asia Pacific 26 sub-regions including 12 individual countries Several supply-side input variables have higher regional granularity: - 32 regions of which 19 countries for coal supply module - 113 regions of which 102 countries for oil and gas supply module
	Number of disclosed emissions pathways	7 regions: North America, Central & South America, Europe, Africa, Middle East, Eurasia, Asia Pacific 8 sub-regions including 6 individual countries: USA, Brazil, EU, Russia, China, India, Japan, Southeast Asia
POLES-JRC 2022	Number of modelled regions	66 regions, including 54 individual countries
	Number of disclosed emissions pathways	66 regions, including 54 individual countries
NGFS GCAM	Number of modelled regions	32 regions: Africa (Eastern), Africa (Northern), Africa (Southern), Africa (Western), Argentina, Australia & New Zealand, Brazil, Canada, Central America and the Caribbean, Central Asia, China, Columbia, EU-12, EU-15, European Free Trade Association, Europe (Non-EU), India, Indonesia, Japan, Mexico, Middle East, Pakistan, Russia, South Africa, South America (Northern), South America (Southern), South Asia, Southeast Asia, South Korea, Taiwan, USA
	Number of disclosed emissions pathways	32 regions: same as above 185 countries
NGFS MESSAGE	Number of modelled regions	11 regions: Sub-Saharan Africa; Centrally Planned Asia; Central and Eastern Europe; Former Soviet Union; Latin America and the Caribbean; Middle East and North Africa; North America; Pacific OECD; Other Pacific Asia; South Asia; Western Europe
	Number of disclosed emissions pathways	11 regions: same as above 185 countries
NGFS REMIND	Number of modelled regions	12 regions: CAZ (Canada, Australia and New Zealand); China; European Union; India; Japan; Latin America; Middle East and North Africa; non-EU member states; other Asia; reforming countries; Sub-Saharan Africa; United States
	Number of disclosed emissions pathways	12 regions: same as above 185 countries
UTS-ISF OECM	Number of modelled regions	10 regions 19 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, UK, US
	Number of disclosed emissions pathways	10 regions 19 countries: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Mexico, Russia, Saudi Arabia, South Africa, South Korea, Turkey, UK, US

Source: Authors’ analysis based on publicly available information of and bilateral consultations with scenario providers.

Table A B.3 provides further detail on the information summarised in Table 4.3.

Table A B.3. Overview of emissions scope and granularity of disclosed emissions pathways

Covered — Not fully disclosed

	IEA GEC 2022	POLES-JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
Model resolution	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
	CH_4	CH_4	CH_4	CH_4	CH_4	CH_4
	Other	Other	Other	Other	Other	Other
Disclosed emissions pathways	CO_2	CO_2	CO_2	CO_2	CO_2	CO_2
	CH_4	CH_4	CH_4	CH_4	CH_4	CH_4
	Other	Other	Other	Other	Other	Other

Source: Authors' analysis based on publicly available information of and bilateral consultations with scenario providers.

Table A B.4 provides further detail on the information summarised in Table 4.4.

Table A B.4. Overview of emissions scope and granularity of disclosed emissions pathways

		IEA GEC 2022	POLES-JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
Model resolution	**Temporal scope**	1970-2050	1990-2070	2005-2100	1990-2100	2005-2100	2005-2050
	Temporal granularity	Annual	Annual	5 years	5 years (1990-2060), 10 years (2060-2100)	5 years (2005-2060), 10 years (2060-2100)	Annual (2005-2025) 5 years (2025-2050)
Disclosed emissions pathways	**Temporal scope**	2010-2050	1990-2070	2005-2100	1990-2100	2005-2100	2019-2050
	Temporal granularity (interval)	10 years	10 years	5 years	5 years (1990-2060), 10 years (2060-2100)	5 years (2005-2060), 10 years (2060-2100)	5 years (2019-2040), 10 years (2040-2050)

Source: Authors' analysis based on publicly available information of and bilateral consultations with scenario providers.

Annex C. Additional figures and tables

Table A C.1. Socio-economic assumption sources

Models	Population projection source	GDP projection source
IEA 2022	medium variant of the United Nations projections (UN DESA, 2019)	IEA analysis based on Oxford Economics (2022) and IMF (2022)
NGFS3	SSP2 standard societal assumptions	SSP2 standard societal assumptions, adjusted for COVID-19 impact
GECO 2022	Eurostat, 2021 and JRC-IIASA projections (Lutz, Goujon, Kc, Stonawski, & Stilianakis, 2018)	2022 summer forecast (European Commission, 2022) and 2021 Ageing Report for the EU (European Commission, 2021) for the EU; for the rest of the world, the IMF World Economic Outlook (IMF, 2022) and the OECD CIRCLE project (OECD, 2018)
UTS-ISF OECM	UNDP Population projections 2017 (to 2050) – medium variant	GDP development projections based on average annual growth rates for 2015–2040 from IEA (WEO 2016a, b) and on IEA extrapolations

Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

Table A C.2. CCS and CDR options represented by models

	IEA GEC 2022	POLES JRC 2022	NGFS GCAM	NGFS MESSAGE	NGFS REMIND	UTS-ISF OECM
CCS (energy, industry)	Yes	Yes	Yes	Yes	Yes	No
DACCS	Yes	Yes	No	No	No	No
BECCS	Yes	Yes	Yes	Yes	Yes	No
Reforestation/afforestation	No	Yes	Yes, but no data	Yes	Yes	Yes
Other land sinks	No	No	No	Yes	No	Yes

Source: Authors' analysis based on publicly available information of and bilateral consultations with scenario providers.

Table A C.3. IPCC framework for assessment of the feasibility of mitigation scenarios

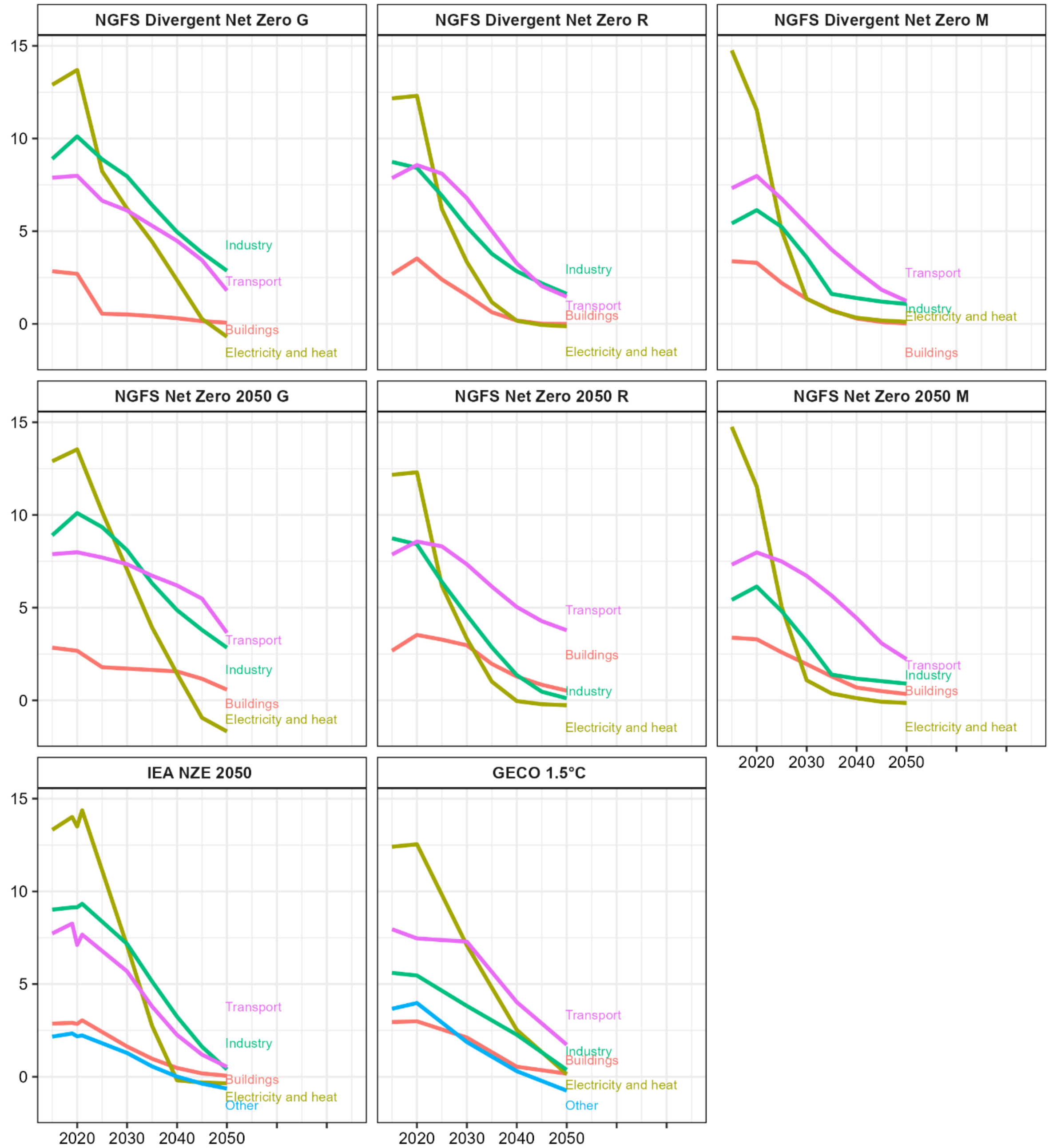
Feasibility dimensions, associated indicators and thresholds for the onset of medium and high concerns about feasibility

Indicators	Computation	Medium	High	Source
Solar potential	Total primary energy generation from solar in a given year	1600 EJ	50 000 EJ	Rogner et al. (2012); Moomaw et al. (2011)
Wind potential	Total secondary energy generation from wind in a given year	830 EJ	2 000 EJ	Deng et al. (2015); Eurek et al. (2017)
Nuclear scale up	Decadal percentage point increase in the nuclear share in electricity generation	5pp	10pp	Brutschin et al. (2021); Markard et al. (2020); Wilson et al. (2020)
Wind/solar scale up	Decadal percentage point increase in the wind/solar share in electricity generation	10pp	20pp	Brutschin et al. (2021); Wilson et al. (2020)

Fossil CCS scale up	Amount of CO_2 captured in a given year	3.8 $GtCO_2$	8.8 $GtCO_2$	Budinis et al. (2018)
Energy demand decline	Decadal percentage decrease in demand	10%	20%	Grubler et al. (2018)
Biomass potential	Total primary energy generation from biomass in a given year	100 EJ	245 EJ	Frank et al. (2021); Creutzig et al. (2014)
BECCS scale up	Amount of CO_2 captured in a given year	3 $GtCO_2$	7 $GtCO_2$	Warszawski et al. (2021)
Forest cover increase	Decadal percentage increase in forest cover	2%	5%	Brutschin et al. (2021)

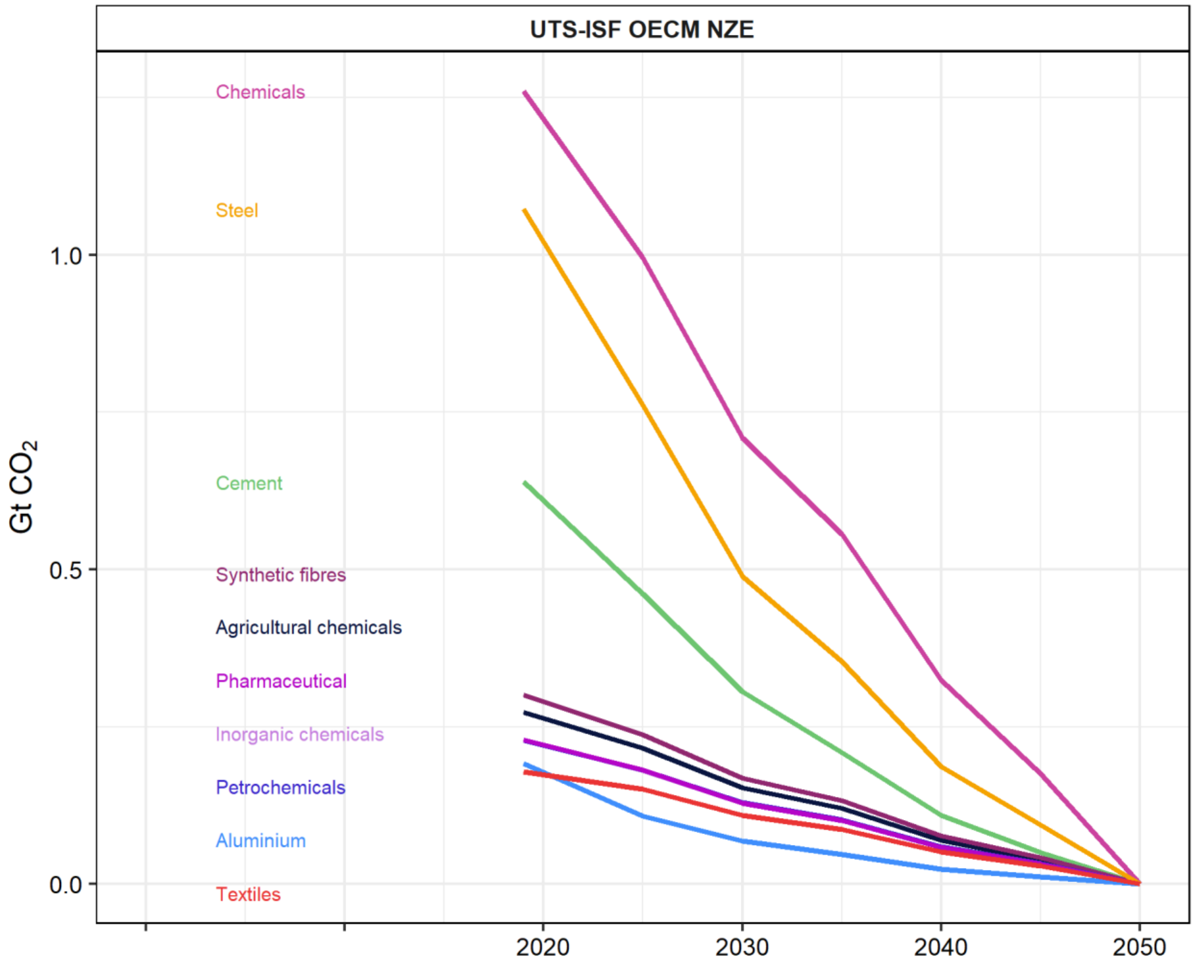
Source: (IPCC, 2022[30]).

Figure A C.1. Sectoral CO_2 emissions pathways across scenarios



Note: Energy-related CO_2 emissions only.
Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.

Figure A C.2. UTS-ISF OECM NZE industrial sub-sector emissions pathways



Source: Authors' analysis based on publicly-available information of and bilateral consultations with scenario providers.