Lighting the Path:

What IPCC energy pathways tell us about Paris-aligned policies and investments

IISD REPORT

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International Institute for Sustainable Development

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Executive Summary

This report outlines key implications for governments and investors aiming to align their policies and investments with the 1.5°C target of the Paris Agreement, based on different energy pathways published by the Intergovernmental Panel on Climate Change (IPCC) in its *Sixth Assessment Report,* published in April 2022. In the report, Working Group III of the IPCC provides a picture of multiple possible futures for the energy system. These pathways—based on varying policy assumptions and environmental and distributional implications—provide a crucial indication of the course of action that governments, companies, and investors need to follow to align with the goals of the Paris Agreement.

No new oil and gas fields should be developed, and no exploration conducted in order to limit warming to 1.5°C

The IPCC warns that greenhouse gas emissions associated with current climate policies are far off track and are likely to lead to a rise in temperature between 2.4°C to 3.5°C by 2100. This report is based on the pathways that limit warming to 1.5°C and that do not exceed the IPCC's assessment of the feasible and sustainable levels of carbon capture and storage and of carbon dioxide removal from the atmosphere, as the IPCC notes that the deployability of these unproven-at-scale technologies is one of the greatest risks to limiting warming to 1.5°C.

We find these *feasible* 1.5°C pathways imply that no new oil and gas fields should be developed, and no exploration conducted in order to limit warming to 1.5°C. According to these pathways, the world must decrease global oil and gas production and consumption by 30% by 2030, in just 8 years. This is equivalent to an annual average decrease of 3% for both oil and gas until the end of the decade.

Increasing renewable energy capacity, electrification, and energy-efficiency measures can provide the rapid and sustained emissions reduction necessary to achieve a fast and well-managed phase-out of fossil fuels. Among all mitigation options analyzed, the IPCC finds that wind and solar technologies have the biggest potential to mitigate greenhouse gas emissions by 2030 at the lowest cost.

The feasible IPCC 1.5°C pathways show that wind and solar capacity addition needs to increase by 18% and 19%, respectively, on average annually between 2020 and 2030.

This implies that by 2030, wind and solar deployment needs to be double the forecasted estimates under current policies; additional supportive policies are necessary to enable this growth.

We also find that the annual investment needs necessary to deploy wind and solar energy consistent with 1.5°C pathways will be above USD 830 billion by 2030. However, under current projections, annual investments are only expected to deliver about USD 380 billion by 2030.

There is an urgent need to plug the yearly USD 450 billion investment gap for wind and solar.

Yet the oil and gas industry is forecast to increase to nearly USD 600 billion its spending on as-yet-undeveloped oil and gas fields, which is inconsistent with limiting warming to 1.5°C. As the IPCC report states, the world needs a "whole of society approach to mobilizing diverse capital. There's no shortage of money globally: it is simply that it has yet to travel to where it's most needed" (IPCC, 2022a, Ch. 15, p. 79).

The IPCC report suggests several policy options to fill this gap. Governments must create enabling environments to facilitate and mobilize capital flows toward the energy transition. Regulatory frameworks, fiscal reforms, and monetary policies can lower capital costs, change incentive structures, and re-direct capital flows. Investment managers also need to prevent the financing of projects incompatible with IPCC pathways limiting warming to 1.5°C in order to have adequate net-zero strategies.

Financial institutions need to adopt 1.5°C-aligned fossil fuel policies consistent with oil and gas phase-out timelines in feasible IPCC pathways.

The world can still bridge the wind and solar investment gap and reduce oil and gas emissions in line with 1.5°C. The IPCC pathways show how this remains feasible. It shows the scale and speed at which the energy system needs to phase out oil and gas production and expand renewable energy capacities. By unpacking these 1.5°C pathways, this report offers governments and financial institutions practical guidance on how to align their strategies with the goals of the Paris Agreement.

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1.0 Introduction

The International Panel on Climate Change (IPCC) Working Group III reviews the latest science on climate change mitigation. Its latest report (IPCC, 2022a), published on April 4, 2022, is the third piece of the IPCC's *Sixth Assessment Report,* following reports by Working Group I on the physical science of climate change and Working Group II on impacts and adaptation. The IPCC Working Group III provides insights on the scientific community's consensus on the technological, environmental, economic, and social aspects of tackling climate change.

The IPCC report[1] finds that limiting warming to 1.5°C with no or low overshoot requires global carbon dioxide (CO_2) emissions to decline by 50% by the early 2030s and reach net-zero by the middle of this century (IPCC, 2022a). The IPCC shows that this is achievable but requires immediate action by governments and investors; maintaining the ambition level in line with the current nationally determined contributions (NDCs) until 2030 would put the 1.5°C target out of reach. The report describes what additional action is needed and offers a series of policy options that can be applied to combat the climate crisis.

This latest assessment from the IPCC is published at a time of climate and energy crisis. The war in Ukraine is causing profound suffering for those living in affected areas; moreover, it is disrupting an already volatile energy market. The conflict, largely financed by fossil fuels, which constitute about 63% of Russia's export revenues (Organisation for Economic Co-operation and Development [OECD], 2022), has prompted the world to confront its dependence on fossil fuel resources. As oil and gas continue to fund wars, pollute the environment, and destabilize the climate, this latest conflict is now leading European governments to seek to reduce their dependence on Russian fossil fuel imports.

However, phasing out fossil fuels requires international coordination and rapid deployment of renewable energies. The IPCC report assesses numerous options for how the future may unfold, generated using highly complex computer models of the energy, land, and economic systems. This IISD report offers an overview of what alignment with the Paris Agreement temperature target entails, with a specific focus on energy system transformation, especially in oil and gas, renewable energy, and investments. It aims to draw out the implications of these models in the current context and help inform decisions by financial institutions and policy-makers.

[1] Throughout this report, "the IPCC report" refers to the Working Group III contribution to the IPCC's *Sixth Assessment Report* (IPCC, 2022a), unless otherwise indicated.

2.0 Feasible Levels of Carbon Capture and Removal in IPCC Pathways

The IPCC Working Group III report analyzes the results of over 1,200 pathways offering various possible energy system transitions and temperature outcomes. The pathways are available in a database published by the Integrated Assessment Modelling Consortium and hosted by the International Institute for Applied Systems Analysis (Byers et al., 2022). This report focuses on 97 of these pathways that are aligned with limiting warming to 1.5°C with low or no overshoot. These pathways are generated from 10 different integrated assessment models, each resting on thousands of assumptions and distinctive strategies to stabilize the temperature to 1.5°C by the end of the century. The pathways are drawn from studies in the academic literature. They were created to serve a range of scientific purposes, including, commonly, to answer "What if …?" questions (Evans & Hausfather, 2018). To inform policy decisions, we need to focus on the pathways that are relevant to those decisions. This section explains how we do this.

2.1 Carbon Sequestration and Net-Zero Emissions

In most 1.5°C pathways, global CO_2 emissions reach net-zero around 2050. Therefore, any remaining sources of carbon emissions by mid-century have to be compensated by CO_2 removals (CDR), either through technologies such as bioenergy with carbon capture and storage (BECCS) or by means of biological systems such as afforestation and reforestation. However, the IPCC warns that overreliance on unproven technologies at scale such as CDR to remove CO_2 from the atmosphere or carbon capture and storage (CCS) to remove it from fossil fuel combustion processes constitutes a major risk to the achievability of the Paris goals (IPCC, 2022a).

Many of the pathways considered in the IPCC report rely on CDR technologies to sequester carbon emissions well beyond levels considered safe or feasible by the IPCC's own assessment. Such reliance might compensate for a slower transition away from carbon-intensive energy sources but would impose an unfair burden on future generations. Therefore, based on the IPCC's assessment of the feasibility and sustainability of CDR/CCS, this report focuses on pathways that limit their deployment, thus avoiding the most dangerous risks associated with these technologies.

Large-scale deployment of CDR technologies has not been demonstrated and attempts at implementing the maximum technical potential of CDR would have significant negative consequences on agriculture, land use, water stress, and biodiversity.[2] The IPCC assessment of cross-sectoral mitigation strategies lists several significant potential issues. Among others, it warns that large-scale CDR could "obstruct near-term emission reduction efforts, mask insufficient policy interventions, might lead to an overreliance on technologies that are still in

[2] The IPCC WGIII calculated that deploying the maximum technical potential of BECCS, estimated at about 11.5 $GtCO_2$/year would require 380-700 Mha of land, representing 25–46% of the planet's arable and cropland by 2100 (IPCC, 2022a).

their infancy, could overburden future generations, might evoke new conflicts over equitable burden-sharing, could impact food security, biodiversity or land rights, or might be perceived negatively by stakeholders and broader public audiences. CDR deployment might not deliver the intended benefit of removing CO_2 durably from the atmosphere" (IPCC, 2022a, Ch. 12, p. 39; see also Center for International Environmental Law & Heinrich Böll Stiftung, 2022).

Many pathways also rely heavily on technologies to capture CO_2 emissions from the waste streams of power plants and factories, as a form of CCS. These are a little more established than CDR technologies but still lack well-tested and large-scale applications: to date, only 26 large-scale commercial projects exist worldwide, only eight of them for long-term storage of CO_2 (the others are used in enhanced oil recovery) (BloombergNEF, 2020). These projects currently capture 56.7 $MtCO_2$ per year, while only 20% of this amount is actually intended for dedicated geological storage (BloombergNEF, 2022). However, several models assume that these technologies could sequester several thousand $MtCO_2$ in a couple of decades. Moreover, the IPCC warns that large-scale CCS deployment may interfere with other priorities. The IPCC report states that "the water impacts of carbon capture are large" and that there are significant trade-offs with Sustainable Development Goal (SDG) 6 on clean water (IPCC, 2022a, Ch. 6, p. 126).

The IPCC report employs a feasibility framework in order to assess medium to high concerns about the technological feasibility of new technologies (Brutschin et al., 2021). Based on this risk assessment and feasibility concerns about BECCS (the primary CDR technology used in the pathways) and CCS used in fossil fuel combusting facilities, this report focuses on pathways with low to medium feasibility concerns over their deployment.[3]

A second form of CDR widely used in the pathways is afforestation and reforestation. Excessive reliance on this approach raises significant concerns due to the land area required, which has a significant impact on biodiversity, global food production, and forest-dependent communities (IPCC, 2022a, Ch. 7, p. 49). We therefore limit our analysis to pathways that do not exceed the maximum sustainable potential for forest-based CDR.[4]

Restricting BECCS, fossil CCS, and afforestation/reforestation to the IPCC's feasibility and sustainability limits gives a set of 26 1.5°C pathways based on three integrated assessment models that therefore offer a better guide for policy recommendations. In this report, we refer to these pathways as "feasible 1.5°C pathways." While there are many dimensions of feasibility, our focus is on these dimensions because they are highlighted as posing particular risks to achieving the Paris goals, and because these risks have attracted concerns from policy-makers and investors.

In the text that follows, we focus on the median of these 26 pathways (essentially, the middle pathway); the appendix compares this to the full range of pathways, to alternative selection criteria, and to specific individual pathways, including the IPCC's Illustrative Mitigation Pathways and the International Energy Agency's (IEA's) Net Zero Emissions by 2050 (NZE) scenario.

[3] See IPCC Working Group III Annex III, Table II.1: "Feasibility dimensions, associated indicators, and thresholds for the onset of medium and high concerns about feasibility" (IPCC, 2022a). Following this framework and using an average between 2040 and 2060 for BECCS and fossil CCS deployment, pathways with more than 3 $GtCO_2$/year and 3.8 $GtCO_2$/year of BECCS and CCS, respectively, were excluded from this analysis.

[4] IPCC afforestation and reforestation sustainable potential were limited to 3.6 $GtCO_2$.

3.0 IPCC Pathways: Implications for oil and gas phase-out

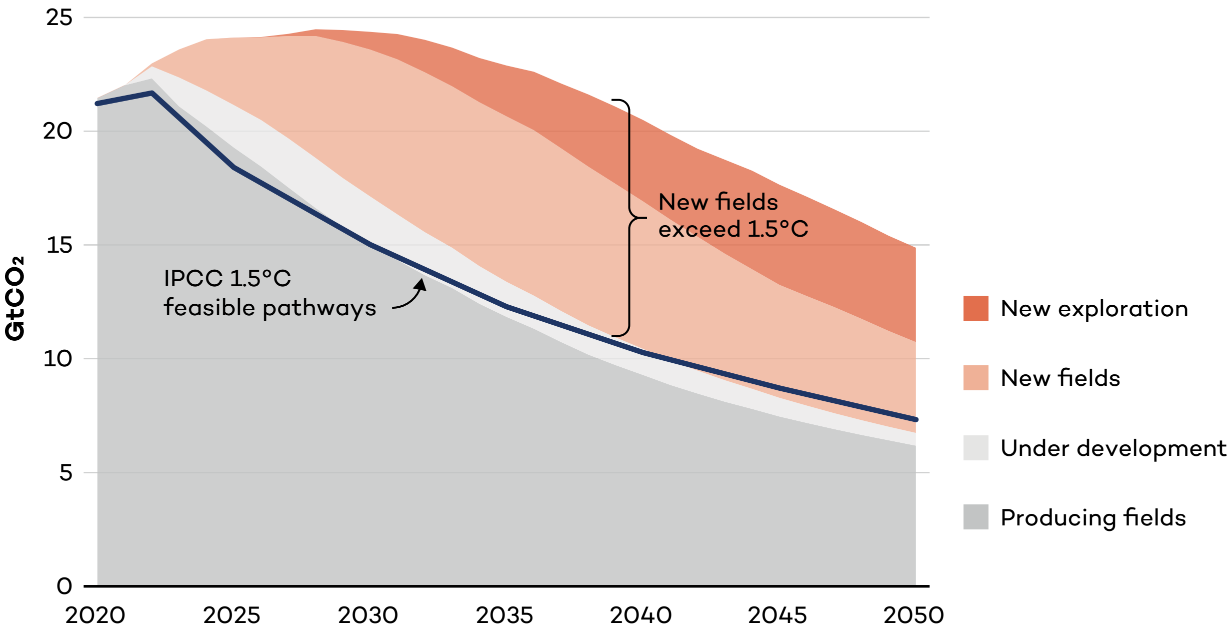
Currently, fossil fuel CO_2 emissions represent around 64% of total anthropogenic greenhouse gas (GHG) emissions and are by far the largest contributor to climate change (IPCC, 2022a). The share of fossil fuels in the mix of energy sources over the coming decades will strongly determine the chances of success at limiting temperature rise to 1.5°C. While there is widespread agreement that coal must be rapidly phased out, especially from power generation, there has been less policy agreement around the role of oil and gas in the energy system. This section reviews the levels of oil and gas production consistent with the assessed 1.5°C pathways and draws out the policy implications of aligning with these levels.

3.1 Phase-Out of Oil and Gas Production and Consumption

After a small drop in production in 2020 due to the COVID-19 restrictions, oil and gas production has been increasing and has reached new highs above pre-pandemic levels (Rystad, 2022). The feasible 1.5°C pathways analyzed in this report show that oil and gas production needs to decrease by 30% by 2030 and by 65% by 2050. This is equivalent to an annual reduction of 3% on average for both oil and gas between 2020 and 2030. Figure 1 shows this reduction in oil and gas production consistent with the assessed 1.5°C pathways. Accordingly, the IPCC 1.5°C feasible pathways line represents the median estimate of the 26 1.5°C low or no overshoot scenarios taken from the IPCC Scenario Explorer (Byers et al., 2022). The resulting pathway shown is then compared with the expected oil and gas production from fields at different stages of their life cycles: those that are already producing, those under development, those discovered but undeveloped, and those licensed but yet to be found through exploration.

We see from Figure 1 that production from all licensed resources would generate emissions well beyond levels consistent with the 1.5°C target, implying a need to end new oil and gas licensing. Furthermore, since emissions from currently producing fields and the ones under development are already expected to exceed 1.5°C-consistent levels, this implies that any new fields developed would need to be compensated for by the closure of an equivalent field already in production or under development. The high risks and costs linked to carbon lock-in and stranded assets suggest that it is preferable not to develop new fields in the first place (Fisch-Romito et al., 2021), even where licences have already been awarded. This is consistent with the finding of the IEA's NZE scenario (IEA, 2021).

Figure 1. Global oil and gas production



Source: Byers et al., 2022; Rystad, 2022.

The IPCC report notes that some of the world's current fossil fuel-consuming infrastructures—such as power plants, factories, and transport infrastructure—will need to be retired early: "Without early retirements, or reductions in utilization, the current fossil infrastructure will emit more GHGs than is compatible with limiting warming to 1.5°C" (IPCC, 2022c, p. 54). Accordingly, the development of downstream oil and gas power generation infrastructures would eventually generate additional stranded assets and threaten to further lock in energy systems in a carbon-intensive dependence. From Figure 1, we see that the same conclusion applies to fossil fuel-producing infrastructure.

3.2 Oil and Gas Developed Reserves Versus the Remaining Carbon Budget

The preceding analysis considers the flows of CO_2 emissions over time by assessing the geological oil and gas deposits in the form of licensed reserves and considers the impact of their extraction, production, and combustion on keeping temperatures below 1.5°C. We arrive at similar results by assessing the stocks of carbon in oil and gas reserves and resources, compared to the remaining carbon budgets[5] for 1.5°C (Trout et al., 2022).

The IPCC's Working Group I offered the latest estimates of the remaining carbon budgets for limiting warming to 1.5°C. It observed that as of 2020, the world had no more than 500 $GtCO_2$ emissions left to emit for a 50% chance of staying below 1.5°C or 400 $GtCO_2$ for a 67% chance (IPCC, 2021). Deducting the emissions that occurred in 2020 and 2021 (IPCC, 2022a), we can conclude that as of the beginning of 2022, the world only has about 420

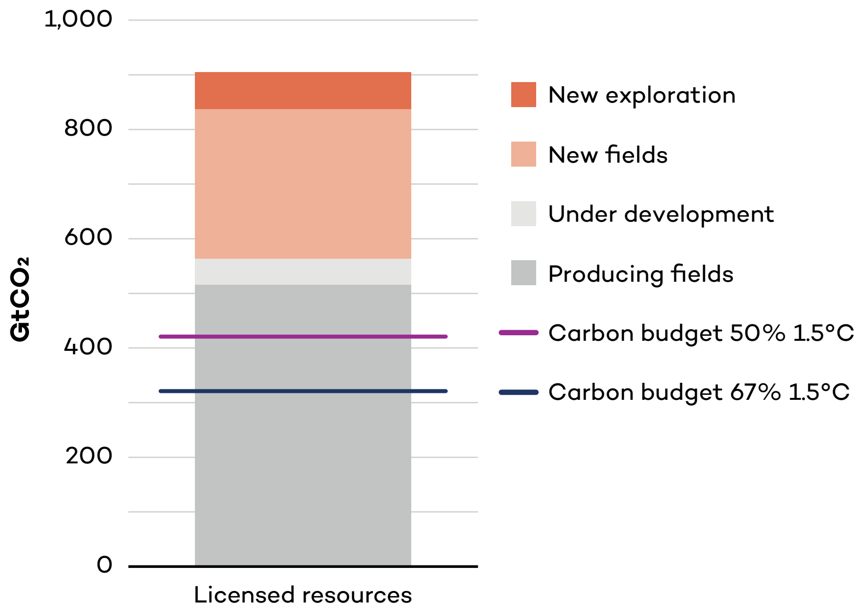
[5] The carbon budget represents the maximum amount of CO_2 that can be emitted over a period of time in order to limit global temperature under a certain threshold; e.g., 1.5˚C above pre-industrial levels.

GtCO2 or 320 $GtCO_2$ remaining—which represents, respectively, 10 or 8 years of current emissions—if one of these two targets is to be reached.

Accordingly, Figure 2 contrasts the embodied emissions of oil and gas licensed reserves to the remaining carbon budgets required for remaining below 1.5°C by the end of the century. We find that, if fully exploited, licensed oil and gas resources would emit more than three times the carbon budget for a 67% chance of staying below 1.5°C and more than two times the 50% budget. This is before even considering emissions from other sources, such as coal, industrial processes (e.g., cement production), and land-use change. This reinforces the conclusion that the embodied emissions in currently producing fields are, by themselves, sufficient to fully consume the carbon budget, leaving no room to develop new fields.

Moreover, Figure 2 also shows that in the absence of CCS or CDR, a significant share of fields already in production today will have to retire before the end of their economic life. While the pathways in Figure 1 are limited to *feasible* levels of CCS and CDR, these limits still include significant use of these strategies: up to 3 $GtCO_2$ per year of BECCS, up to 3.8 $GtCO_2$ per year of CCS in fossil fuel plants and up to 3.6 $GtCO_2$ per year of forest CDR. More precautionary limits on CCS and CDR would lead to a correspondingly faster decline in fossil fuel production and consumption.

Figure 2. Fossil CO_2 emissions in current oil and gas reserves



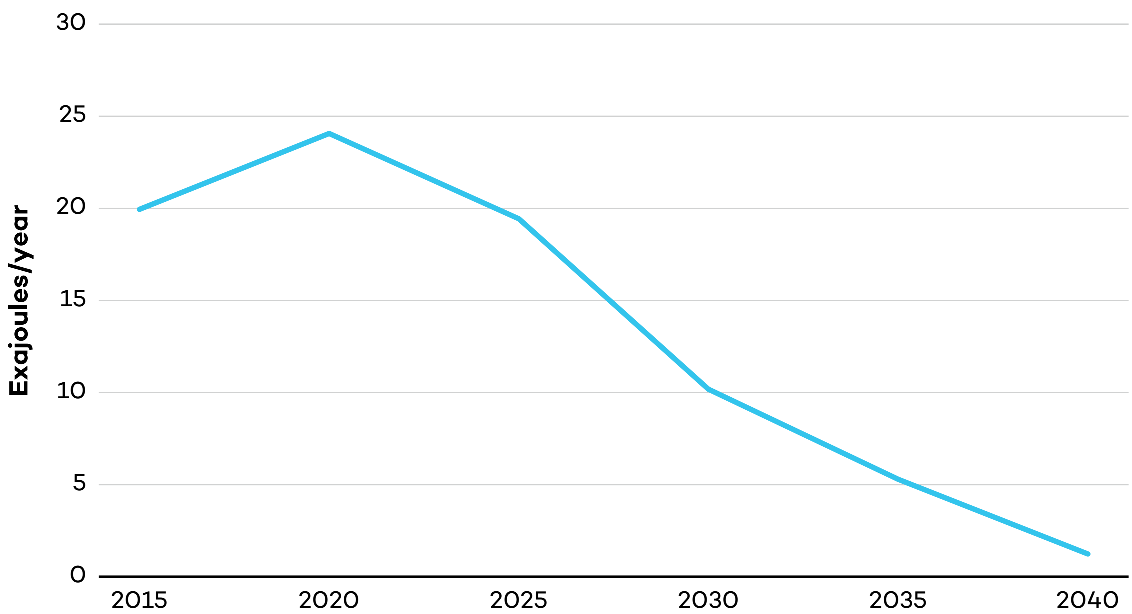
Note: The embodied emissions from licensed resources were taken from the Rystad EnergyUcube and represent the latest estimates as of January 2022.
Source: Rystad, 2022; IPCC, 2021.

A report by the Tyndall Centre at Manchester University applies equity considerations to these carbon budgets without the use of any CDR and CCS technologies. The analysis reinforces the conclusion that no new fields should be developed in order to provide a 50% chance of limiting warming to 1.5°C without relying on CCS or CDR but goes further, finding that all countries would need to phase out their oil and gas production between 2034 and 2050 (Calverley & Anderson, 2022). Taking into account countries' capacities to enable a just transition, countries with relatively higher non-oil GDP per capita would need to decrease their production faster than lower-income countries with high fossil fuel dependencies. In this context, developed nations with large fossil reserves (such as Australia, Canada, and the United States) would need to phase out their existing production faster than the global median estimates reported by IPCC pathways.

3.3 Phase-Out of Gas Power Generation

It is also instructive to examine what the feasible 1.5°C pathways tell us about gas power generation, which accounts for the largest share of global gas consumption at 38% (IEA, 2021). We see in Figure 3 that unabated global gas power generation decreases by 58% by 2030 and by 95% by 2040. Since gas power plants commonly last for 30 or 40 years (or longer), this implies no new unabated gas power plants should be built. We focus on unabated plants (without CCS) because it is more expensive to retrofit an existing plant with CCS than to incorporate CCS in the original construction and because given the uncertainties on CCS (Section 2), it would be risky to build unabated plants with future promises to add CCS.

Figure 3. Global unabated gas power generation in feasible 1.5°C pathways



Source: Byers et al., 2022.

Since unabated gas power generation falls to close to zero by 2040, this implies no new unabated gas plants anywhere in the world and, conversely, rapid phase-out or retrofitting of existing ones. However, there is no need for gas in power generation: utility-scale wind and solar photovoltaic power are already the cheapest sources[6] of new-build power generation in

[6] Measured in terms of the levelized cost of energy.

countries that account for two thirds of the world's population and 85% of total generation (BloombergNEF, 2020), and their costs continue to fall.

Additionally, gas power generation is not necessary to balance variable supplies in power grids, as cheaper balancing options are available at the low levels of renewable energy penetration present in most countries, including flexible market design, time-of-day pricing, and demand response (Muttitt et al., 2021). More substantive physical investments need to be added only at higher penetration levels, such as strengthening transmission infrastructure and adding storage (Cochran et al., 2014; International Renewable Energy Agency [IRENA], 2017; Lund et al., 2015), and by the time penetration reaches these levels, costs will have fallen further and institutional experience increased. Indeed, the cost of batteries has fallen at such pace that wind-plus-battery or solar-plus-battery systems are now cheaper than peaking gas plants in much of the world (BloombergNEF, 2020).

Box 1. Energy crisis and the invasion of Ukraine

The war in Ukraine has generated concerns over energy supplies and high prices in global energy markets. In light of Russia's invasion and the disruption in the supply chain of gas-dependent European nations, the European Union has designed plans to reduce its reliance on Russian oil and gas. The European Union's REPowerEU program aims to stop importing any fossil fuels from Russia by 2030 and reduce Europe's demand for Russian gas by two thirds by the end of 2022 (European Commission, 2022).

Policy response has focused on reducing fossil fuel dependence more broadly through demand reduction and the expansion of renewable energy. In the early phase of the war, several European governments reasserted or even accelerated their decarbonization targets. As high prices have worn on, however, governments are seeking non-Russian gas supplies. For example, Germany is considering building liquified natural gas terminals, while new gas pipelines are being planned in eastern Europe (Gatopoulos, 2022; Rashad & Steitz, 2022).

Efforts to boost alternative oil and gas supplies are unlikely to be successful, as the world has very little capacity that can increase production in the short term. Developing new fields typically requires 3–4 years minimum before commercial extraction is possible, and therefore would not help the present supply crunch. In the short term, energy-efficiency measures can be deployed significantly faster and would be better suited to addressing both the short-term supply crunch and the long-term energy concerns (IEA, 2022). In the medium term, renewable sources of energy could be deployed, ensuring long-term energy security at a lower cost. Hence, while the short-term supply crunch may persist, future volatility would be prevented and dependence on foreign energy sources significantly reduced.

Developing new fossil fuel infrastructure would lock in carbon-intensive infrastructure and dependencies for many decades. And as Figures 1 and 3 show, the world needs to rapidly reduce its consumption of oil and gas, such that if climate goals are met, new production will lead to stranded assets, a problem that will only intensify if Russian supplies eventually come back online at some future date.

3.4 Implications for Oil and Gas Policy and Investments

We have seen above that CO_2 emissions from licensed oil and gas resources would significantly exceed the carbon budget for limiting warming to 1.5°C. Therefore, a first step governments should take is to stop awarding licences for further expansion. A growing number of governments have taken this step. Led by the governments of Denmark and Costa Rica, Beyond Oil and Gas Alliance (BOGA) launched at the Glasgow Climate Summit (the 26th Conference of the Parties of the United Nations Framework Convention on Climate Change) and calls on governments to begin a managed phase-out of oil and gas production. Its core members—which also include France, Greenland, Ireland, Quebec, Sweden, and Wales—have committed both to stopping the awarding of new oil and gas licences and to phasing out extraction on their territories by a date aligned with the Paris goals. The IPCC endorses the idea of such "climate clubs" building on the concept that "international climate policy architectures […] could incentivize a coalition of like-minded countries to raise their mitigation ambition beyond what is stated in their current NDC" (IPCC, 2022a, Ch. 3, p. 80).

In contrast, continued expansion of oil and gas production will require faster emissions reductions at some later date and also potentially impose a higher reliance on CDR technologies. To this effect, the IPCC report warns that there exists a three-way trade-off between near-term emissions developments until 2030, transitional challenges during 2030–50, and long-term CDR deployment post-2050 (IPCC, 2022a, Ch. 3, p. 77). Failing to mitigate sufficiently in the 2020s (e.g., if companies continue to develop new fields) will create much larger risks for the future, such as stranded assets caused by more rapid post-2030 reductions and/or reliance on the uncertain availability of unproven CDR technologies.

Additionally, subsidies for fossil fuel production constitute one of the biggest obstacles preventing the decline of this industry. These subsidies are estimated to have increased by 30% in 2019, reversing a previous downward trend (OECD, 2021). The IPCC report observes that: "global fossil fuel subsidies represent more than half of total energy subsidies with predominantly adverse environmental, economic, and social effects" (IPCC, 2022a, Ch. 6, p. 21). These subsidies constitute a significant barrier to a managed energy transition, as they create fossil lock-in effects and make cleaner technologies less competitive. For example, Canada's four largest fossil fuel production provinces provided at least CAD 2.5 billion in fossil fuel subsidies in the fiscal year 2020/2021 (McKenzie et al., 2022). Moreover, the COVID-19 pandemic also led multiple governments to further subsidize the fossil fuel sector as a means to stimulate their economies. Short-term tax exemptions and one-time direct transfers were mainly handed out to fossil fuel producers but some also went to airlines or took the form of consumer rebates.

Reducing oil and gas production by 30% by the end of this decade will require additional policies that significantly raise the ambition to transform energy systems. In particular, there is no room for developing new fields beyond those already producing or under development under the feasible 1.5°C pathways, including new fields that are already licensed. However, there are several legal barriers under international investment law that limit governments' ability to enforce these limits. A significant share of existing licensed reserves is granted special protection through an international arbitration system known as investor–state dispute settlement (ISDS). Accordingly, asset holders of fossil fuel projects or undeveloped reserves can demand compensation in cases where a country decides to prevent further extraction of its fossil fuel reserves. Fossil fuel companies represent almost 20% of all litigation cases under the ISDS system (di Salvatore, 2021).

The IPCC has acknowledged that ISDS could prevent or delay states from measures designed to phase out their oil and gas production (IPCC, 2022a, Ch. 15 p.66). Globally, it is estimated that total government liability to ISDS claims for limiting fossil fuels could reach up to USD 340 billion (Tienhaara et al., 2022). While the Energy Charter Treaty (ECT) is the largest investment treaty protecting oil and gas assets with about 17% of all fossil fuel cases (di Salvatore, 2021), there exist multiple bilateral and international investment treaties subjecting states to potential lawsuits against their climate action. Nevertheless, several BOGA Members who are also signatories of the ECT, have successfully committed to phasing out their oil and gas production within the current legal framework. Moreover, governments part of these treaties can also work to amend them through renegotiations. Ultimately withdrawal for these international investment treaties and agreements should be considered if they are incompatible with mitigation efforts under the Paris Agreement temperature target.

The rapid transition away from fossil fuel investments toward renewable energies will require structural shifts across most sectors and economic activities. As shown in this section, both upstream and downstream oil and gas development jeopardize the achievement of the Paris Agreement temperature target. While gas power generation has become especially contentious in light of the war in Ukraine, IPCC pathways clearly show that unabated gas power generation needs to be practically phased out within 20 years. Hence, new development would lock in fossil emissions beyond this timescale and would risk generating stranded assets. Governments have a responsibility to ensure that no public finance is invested in oil and gas projects because these will increase the chances of a disorderly transition—or worse, breach the Paris temperature targets. The transition to net-zero requires instead a sustained global effort to accelerate the pace of renewable energy growth to ensure energy access, a clean environment, and a safe climate.

4.0 Renewable Energy Expansion

While the previous section reviewed the needed decline of oil and gas in feasible 1.5°C pathways, this section looks at the corresponding scale-up needed in renewable energy. In comparing the mitigation options available by 2030, the IPCC concludes that wind and solar technologies have the biggest potential as well as the lowest cost per tonne of CO_2 displaced (IPCC, 2022b, p. 50). By offering a competitive alternative to fossil-fuelled energy generation, they have a considerable role in displacing carbon emissions worldwide.

Successful implementation of ambitious energy policies and a transition away from fossil fuels can also provide multiple benefits. The IPCC report observes that "phasing out fossil fuels in favor of low-carbon sources, is likely to have considerable SDG benefits" (IPCC, 2022a, Ch. 6, p. 126). Adding renewable energy capacity and increasing electrification tends to "support and reduce the costs of key elements of human development, such as education, health, and employment" (IPCC, 2022a, Ch. 6, p. 126). Moreover, increased electrification also improves indoor and outdoor air quality and helps to prevent premature deaths by reducing emissions of harmful pollutants.

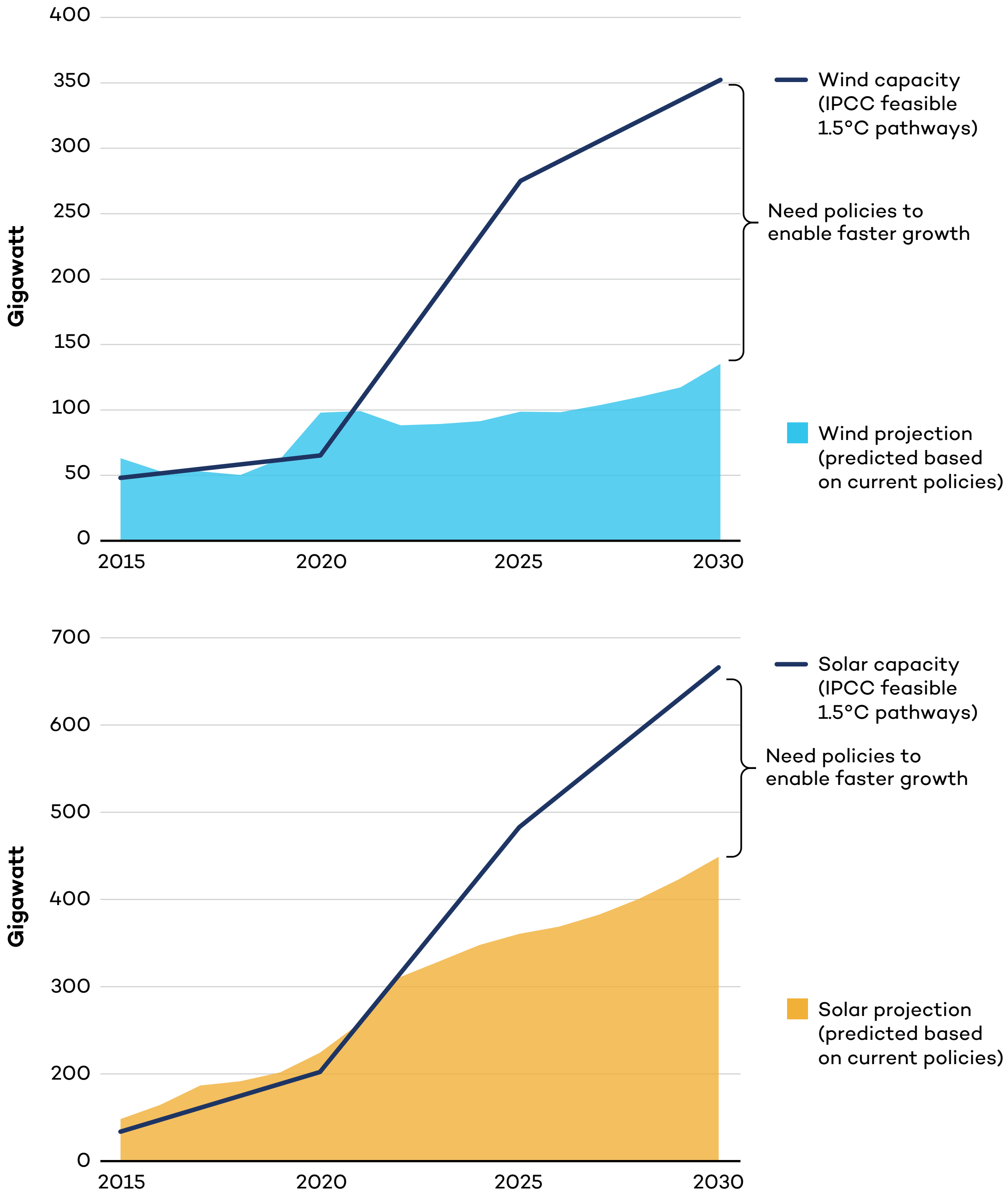
Developing a vibrant renewable energy sector nationally also has many positive economic repercussions. For instance, the IPCC observes that "fossil fuels are estimated to generate only 2.65 jobs per USD 1M as compared to projected 7.49 from renewables" (Garrett-Peltier, 2017). Overall, the IPCC concludes that "the scope for positive interactions between low-carbon energy systems and SDGs is considerably larger than the tradeoffs" (IPCC, 2022a, Ch. 6, p. 126).

4.1 The Renewable Energy Deployment Gap

In feasible 1.5°C pathways, solar and wind capacity additions reach 660 GW and 350 GW annually by 2030, respectively a five-fold and four-fold increase from current levels. By comparison, 2021 levels were just 133 GW and 93 GW for solar and wind capacity addition, respectively (IRENA, 2022). Figures 4 illustrates this deployment gap. The figure shows that according to Bloomberg's forecasts—based on the pipeline of planned and under-development projects plus those projected under policies currently in place—the annual new capacity additions for solar and wind capacity are only expected to deliver 400 GW and 135 GW for solar and wind per year, respectively, by 2030 (BloombergNEF, 2022). Therefore, the annual capacity addition needs to be more than 50% higher for solar compared to what forecasts predict and about 2.5 times higher for wind by 2030 for the world to be on track with limiting warming to 1.5°C and displacing oil and gas in the energy mix. Note that Bloomberg is among the most bullish of forecasters of renewable energy: the shortfall is even greater when compared to more conservative forecasts.

Additional supporting policies are necessary to accelerate growth in renewables capacity addition. The IPCC suggests that regulatory frameworks like efficiency and technology standards combined with market-based instruments have proved effective with such mature technologies (Kitzing et al., 2020; Polzin et al., 2015). Moreover, favourable financial incentives such as feed-in tariffs, auction programs that award long-term power purchase agreements, federal income tax credits, and net metering have proved very effective to accelerate the installation of solar capacity (IISD, 2021; Wolske & Stern, 2018).

Figure 4. Capacity deployment gap for wind and solar energy



Source: Byers et al., 2022; Bloomberg NEF, 2022.

The IPCC report states that "the global technical potential of direct solar energy far exceeds that of any other renewable energy resource and is well beyond the total amount of energy needed to support ambitious mitigation over the current century (high confidence)" (IPCC, 2o22a, Ch. 6, p. 23). It also notes that since 2015, costs of electricity generation from onshore and offshore wind energy have declined by 18% and 40%, respectively. The cost of solar photovoltaics has also decreased by an estimated 62% since 2015. Both technologies are already competitive with oil and gas in most of the world, and their costs are expected to continue decreasing over the coming years. However, additional policies are needed to create an enabling environment for fast renewable energy growth.

4.2 Barriers to Accelerating the Energy Transition

The current project pipeline and policies are only expected to deliver a fraction of the required capacity addition consistent with feasible 1.5°C pathways. As shown in Figures 4, energy policies need to significantly accelerate the deployment of wind and solar capacity. However, the IPCC observes that financing costs constitute a significant barrier to the deployment of renewables in developing countries (2022a, Ch. 6. p. 24). The growth of these technologies is often constrained by the lack of access to low-cost finance (Creutzig et al., 2017). As renewable energy projects are particularly capital intensive, requiring large initial investments, higher interest rates and perceived risks in developing countries can significantly increase capital costs for these projects. In turn, this can decrease the competitiveness of those wind and solar technologies compared to other alternatives (Schmidt et al., 2019; Steckel & Jakob, 2018). As shown in Section 6, enabling environments and financial instruments can help in de-risking investment and bring down the cost of these wind and solar projects.

International cooperation is essential to alleviate the transition costs in countries with a lower capacity and has been linked with decreasing long-run mitigation costs, faster technological developments, and improved economic outcomes (Paroussos et al., 2019). Lack of access to technologies and related expertise to implement them at scale in lower-income countries can also significantly inhibit the capacity to leapfrog carbon-intensive development. Technological transfers have proved an efficient mechanism to accelerate renewable energy deployment and develop local capacity to implement various mitigation measures (United Nations Environment Programme–Technical University of Denmark, 2019).

The benefits and advantages of transitioning to a low-carbon energy system have been increasing as the costs of renewable technologies have decreased. However, the IPCC states that "achieving co-benefits is not automatic but results from coordinated policies and implementation strategies. Similarly, avoiding trade-offs requires targeted policies" (2022a, Ch. 3, p. 95). Despite the competitiveness of renewables with fossil fuel energy sources, there remains critical underinvestment throughout the entire renewable energies supply chain. To deliver this energy transition sufficiently fast to meet the Paris-aligned wind and solar deployment targets, a re-orientation of financial flows is necessary. The next section addresses these concerns and offers a review of policy options to mobilize capital to finance the supply-side shift in the energy sector.

5.0 Shifting Financial Flows to Finance the Energy Transition

Energy infrastructure consistent with feasible 1.5°C pathways will require a significant upscaling of public and private investments toward renewable energies. Deploying these vast sums of capital requires governments to create an enabling environment to facilitate the financial sector's ability to efficiently and rapidly re-orient capital flows toward renewable energies. As mentioned in the previous section, the IPCC report finds that wind and solar technologies have the largest GHG mitigation potential at the cheapest cost. This section, therefore, focuses on the investment needs required to fulfill the capacity addition of these technologies consistent with IPCC pathways limiting warming to 1.5°C.

5.1 Investment Needs Wind and Solar Energy

Figure 5 shows investment needs for wind and solar energy under feasible 1.5°C pathways. It shows that investment increases 3 times over for solar and 4.5 times over for wind between 2020 and 2030, reaching USD 830 billion combined by 2030. The graph multiplies the capacity additions in Figure 4 by the capital cost forecast by IRENA (IRENA, 2019b, 2019a). Figure 5 also contrasts these investment needs with investment forecasts based on current investment plans and policies. Unless other new policies are implemented and ambitions raised, investment levels are only expected to deliver USD 380 billion of investment in wind and solar energy combined by 2030.[7]

Therefore, we expect an annual investment gap of more than USD 450 billion by 2030. Currently, the world's largest offshore wind farm project is expected to cost more than USD 43 billion and is forecast to have a maximum capacity of 8.2 GW by 2030 (Shin, 2021). By that time, the world will need to invest more than 10 times this amount yearly to achieve the required growth in capacity addition consistent with 1.5°C pathways.

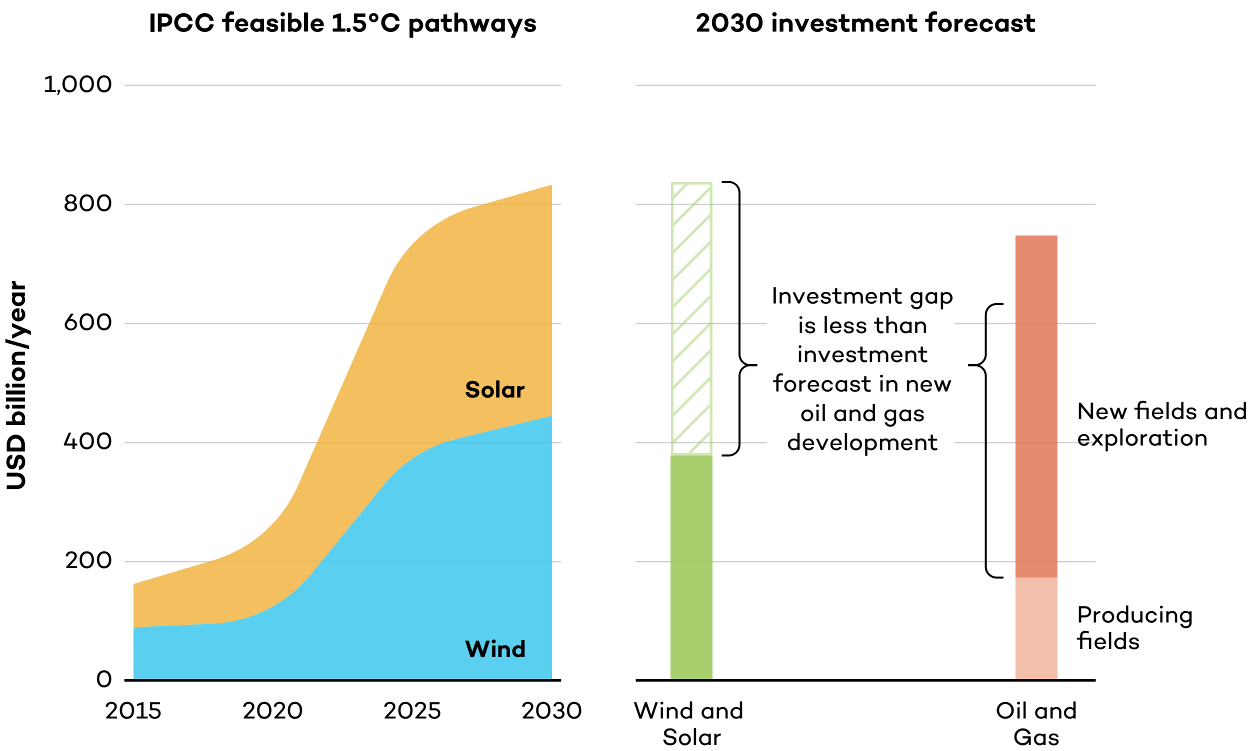
5.2 Displacing Fossil Fuel Investments

Based on current projections, cumulative capital and operation expenditures for the exploration and extraction of oil and gas in new fields are expected to reach more than USD 4.2 trillion in total between 2020 and 2030 and climb to USD 570 billion annually by the end of the decade (Rystad, 2022). As shown in Section 3, reductions in oil and gas production consistent with assessed 1.5°C pathways indicate that these new developments would exceed the feasible 1.5°C pathways. In addition, investments in new fossil-fuelled power generation are also expected to keep growing under current policies and reach nearly USD 150 billion by 2030. Avoiding investments in new fields (beyond those already under development) and preventing further exploration could therefore free up a significant share of the required capital in the financial sector, which could eventually be redeployed toward renewables. As the

[7] The investment estimates are based on BloombergNEF capacity deployment forecasts and IRENA capital costs estimates. See Appendix for details.

IPCC observes, "There's no shortage of money globally: it is simply that it has yet to travel to where it's most needed" (2022a, Ch. 15. p. 79).

Figure 5. Energy transition investments



Source: Byers et al., 2022; IRENA 2019a, 2019b; Rystad, 2022.

Globally, oil and gas companies, which represent some of the largest corporations and investors in energy infrastructures, are estimated only to invest less than 1% of their capital expenditure into low-carbon solutions (IEA, 2020). While bridging this renewable energy investment gap will require channelling multiple sources of capital toward financing renewable energy infrastructure, oil and gas companies could play a role by redeploying their capital toward wind and solar technologies. Overall, the clean energy investment gap, including other renewables such as hydroelectricity, as well as transmission, distribution, and storage capacity, will be much larger than shown in Figure 5. Therefore, significant structural changes will be required to operate a managed transition to a low-carbon economy and will require an enabling environment partly delivered through regulatory frameworks and fiscal reforms.

To this effect, the IPCC report documented several policy options that government and investors can use to address the barriers raised in the previous sections of this report. It finds that government spending on renewables can crowd in private sources of finance. It suggests that fiscal spending or investment made by public finance institutions could indeed play a significant role to "(i) provide capital to assist with overcoming financial barriers, (ii) signal and direct investments towards green projects, and (iii) attract the private investors by taking up a de-risking role" (IPCC, 2022a, Ch. 15, p. 58). State-owned enterprises and green investment banks can also contribute to upscaling renewable energy investments by developing valuable local expertise in project development and in partnering with private actors to leverage their investments (OECD, 2016; Prag et al., 2018).

Moreover, imposing mandatory reporting on climate-related disclosure for companies can also provide additional transparency and enable a better evaluation of climate risks faced by financial institutions (Zenghelis & Stern, 2016). Adoption of climate reporting frameworks can also enable improved assessments of the embodied GHG emissions associated with institutional investors' portfolios and project finance. This can in turn facilitate investors' alignment with Paris-compatible temperature targets.

However, despite the recent growth in reporting standards and climate commitments, the IPCC report observes that the 60 largest banks have provided USD 3.8 trillion to fossil fuel companies since 2016 (2022a, Ch. 15, p. 81). Beyond assessing finance-related risks related to holding fossil fuel assets, financial institutions also need to align with the implications of limiting warming to 1.5°C on the energy sectors. Therefore, investment managers should also ensure that they are not financing companies that are planning to develop any new oil and gas fields beyond those already under development. Financial institutions should additionally develop 1.5°C-aligned fossil fuel policies consistent with oil and gas phase-out timelines in feasible IPCC pathways.

6.0 Conclusions and Key Policy Recommendations

In this report, we have provided guidance on how to interpret IPCC scenarios. We have based our analysis on 1.5°C scenarios with no or limited overshoot and that take a sustainable and feasible approach to CDR/CCS. We derived the consistent policy implications that are required to align with the Paris Agreement temperature target of 1.5°C for oil and gas production, clean energy deployment, and investment levels. To comply with such pathways, fossil fuel emissions, which remain the largest sources of planet-warming gases, need to rapidly decline. Governments and financial institutions have a critical role to play to enable this unprecedented shift. In Paris-aligned mitigation pathways,

1) Global production of oil and gas needs to decrease by 30% by 2030 and by 65% by 2050 to limit warming to 1.5°C.

Assessment of IPCC pathways with limited CDR/CCS shows that existing oil and gas fields would supply more fossil fuels than would be consistent with limiting warming to 1.5°C. Therefore, the approval of new oil and gas fields and awarding of licences for further exploration are incompatible with Paris-aligned 1.5°C pathways. Financial institutions should therefore also refrain from providing or arranging financial services for projects that are incompatible with limiting warming to 1.5°C. Accordingly,

2) No new fields should be developed beyond those already producing or under development. Any extraction beyond this threshold risks creating significant financial losses in the form of stranded assets.

Alternatively, phasing out fossil fuel production while meeting the world's energy demand will require a rate of deployment for renewable energy capacities which is several times higher than current levels. The 1.5°C IPCC pathways consistent with the Paris temperature targets show that

3) Global capacity additions of wind and solar need to be twice as high as projected under current forecasts by 2030. This represents annual increases of wind and solar capacity of 18% and 19%, respectively, until 2030. More ambitious policies are urgently needed to enable this growth.

Current forecasts are only expected to deliver about 30% of the total investment required by 2030 to deploy the necessary wind and solar capacity consistent with limiting warming to 1.5°C. The investment gap for the annual capacity deployment of wind and solar infrastructure amounts to USD 850 billion by 2030. In order to bridge the investment gap,

4) Investment for wind and solar capacity growth needs to be more than three times higher annually by 2030 compared to expected levels under the current forecast.

Governments can enable faster deployment of capital by regulatory and fiscal interventions designed to promote renewable infrastructure investments. Bridging the renewable energy investment gap will require channelling multiple sources of capital away from fossil fuels and toward wind and solar technologies. Therefore,

5) Financial institutions need to adopt 1.5°C-aligned fossil fuel policies consistent with oil and gas phase-out timelines in feasible IPCC pathways.

This report has shown that significant structural changes are required in the energy sector to align with pathways limiting warming to 1.5°C. The pathways consistent with the IPCC's assessment of feasible and sustainable deployment of CDR and CCS technologies leave no room for delayed action. The oil and gas phase-out timelines presented in this report constitute the ambition level consistent with the best estimates of the current and future capacity of mitigation technologies. Accordingly, this report presented the key implications for governments and financial institutions aiming to align their policies and investments with feasible 1.5°C pathways. Its recommendations should urgently be used as a benchmark to guide the understanding of the Paris alignment, consistent with the IPCC findings, and should inform plans to strengthen and amplify policy interventions.

References

Beyond Oil and Gas Alliance. (2022, May 22). https://beyondoilandgasalliance.com/

BloombergNEF. (2020, April 28). *Scale-up of solar and wind puts existing coal, gas at risk.* https://about.bnef.com/blog/scale-up-of-solar-and-wind-puts-existing-coal-gas-at-risk/

BloombergNEF. (2022). *Data Products.*

Byers, E., Krey, V., Kriegler, E., Riahi, K., Schaeffer, R., Kikstra, J., Lamboll, R., Nicholls, Z., Sanstad, M., Smith, C., van der Wijst, K.-I., Lecocq, F., Portugal-Pereira, J., Saheb, Y., Strømann, A., Winkler, H., Auer, C., Brutschin, E., Lepault, C. … Khourdajie, A. A. (2022). *AR6 Scenarios Database.* Hosted by IIASA. International Institute for Applied Systems Analysis. https://doi.org/10.5281/zenodo.5886912

Calverley, D., & Anderson, K. (2022). *Phaseout pathways for fossil fuel production within Paris-compliant carbon budgets.* International Institute of Sustainable Development. https://www.iisd.org/publications/report/phaseout-pathways-fossil-fuel-production-within-paris-compliant-carbon-budgets

Center for International Environmental Law & Heinrich Böll Stiftung. (2022). *IPCC unsummarized: Unmasking clear warnings on overshoot, techno-fixes, and the urgency of climate change.* https://www.ciel.org/wp-content/uploads/2022/04/IPCC-Unsummarized_Unmasking-Clear-Warnings-on-Overshoot-Techno-fixes-and-the-Urgency-of-Climate-Justice.pdf

Cochran, J., Miller, M., Zinaman, O., Milligan, M., Arent, D., Palmintier, B., O'Malley, M., Mueller, S., Lannoye, E., Tuohy, A., Kujala, B., Sommer, M., Holttinen, H., Kiviluoma, J., & Soonee, S. K. (2014). *Flexibility in 21st century power systems.* Clean Energy Ministerial. http://www.ercot.com/

di Salvatore, L. (2021). *Investor–state disputes in the fossil fuel industry.* International Institute for Sustainable Development. https://www.iisd.org/publications/report/investor-state-disputes-fossil-fuel-industry

Evans, S., & Hausfather, Z. (2018, October 2). Q&A: How "integrated assessment models" are used to study climate change. *Carbon Brief.* https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change/

Fisch-Romito, V., Guivarch, C., Creutzig, F., Minx, J. C., & Callaghan, M. W. (2021). Systematic map of the literature on carbon lock-in induced by long-lived capital. *Environmental Research Letters, 16*(5), Article 053004. https://doi.org/10.1088/1748-9326/aba660

Fuss, S., Lamb, W. F., Callaghan, M. W., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T., Luderer, G., Nemet, G. F., Rogelj, J., Smith, P., Vicente, J. V., Wilcox, J., del Mar Zamora Dominguez, M., & Minx, J. C. (2018). Negative emissions—Part 2: Costs, potentials and side effects. *Environmental Research Letters, 13*(6). https://doi.org/10.1088/1748-9326/aabf9f

Garrett-Peltier, H. (2017). Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model. *Economic Modelling, 61,* 439–447. https://doi.org/10.1016/j.econmod.2016.11.012

Gatopoulos, D. (2022, April 29). New gas pipeline boosts Europe's bid to ease Russian supply. *Associated Press.* https://apnews.com/article/russia-ukraine-covid-health-business-germany-274aae7fd9dfa88bab1dd26200db9423

Intergovernmental Panel on Climate Change (IPCC). (2021). *Climate change 2021: the physical science basis.* Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/

Intergovernmental Panel on Climate Change. (2022a). *Climate change 2022: Mitigation of climate change.* Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_FullReport.pdf

Intergovernmental Panel on Climate Change. (2022b). Summary for policymakers. In: *Climate change 2022: Mitigation of climate change.* Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

Intergovernmental Panel on Climate Change. (2022c). Technical summary. M. Pathak, R. Slade, P.R. Shukla, J. Skea, R. Pichs-Madruga, D. Ürge-Vorsatz,2022: Technical summary. In: *Climate change 2022: Mitigation of climate change.* Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press. https://report.ipcc.ch/ar6wg3/pdf/IPCC_AR6_WGIII_FinalDraft_TechnicalSummary.pdf

International Energy Agency. (2020). *The oil and gas industry in energy transitions.*

IEA. (2021). *Net Zero by 2050 - A Roadmap for the Global Energy Sector.* https://www.iea.org/reports/net-zero-by-2050

International Energy Agency. (2022). *A 10-point plan to reduce the European Union's reliance on Russian natural gas.* www.iea.org/t&c/

International Institute of Sustainable Development. (2021). *Achieving a fossil-free recovery: GSI report.* https://www.iisd.org/publications/report/achieving-fossil-free-recovery

International Renewable Energy Agency (IRENA). (2017). *Electricity storage and renewables: Costs and markets to 2030.* https://www.irena.org/publications/2017/oct/electricity-storage-and-renewables-costs-and-markets

International Renewable Energy Agency. (2022). *Renewable capacity statistics 2022.* https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022

Kitzing, L., Fitch-Roy, O., Islam, M., & Mitchell, C. (2020). An evolving risk perspective for policy instrument choice in sustainability transitions. *Environmental Innovation and Societal Transitions, 35,* 369–382. https://doi.org/10.1016/J.EIST.2018.12.002

Lund, P. D., Lindgren, J., Mikkola, J., & Salpakari, J. (2015). Review of energy system flexibility measures to enable high levels of variable renewable electricity. *Renewable and Sustainable Energy Reviews, 45,* 785–807. https://doi.org/10.1016/J.RSER.2015.01.057

McKenzie, J., Beedell, E., & Corkal, V. (2022). *Blocking ambition: Fossil fuel subsidies in Alberta, British Columbia, Saskatchewan, and Newfoundland and Labrador.* https://www.iisd.org/publications/blocking-ambition-fossil-fuel-subsidies-canadian-provinces

Muttitt, G., Sharma, S., Mostafa, M., Kühne, K., Doukas, A., Gerasimchuk, I., & Roth, J. (2021). *Step off the gas: International public finance, natural gas, and clean alternatives in the Global South.* International Institute of Sustainable Development. https://www.iisd.org/publications/natural-gas-finance-clean-alternatives-global-south

Organisation for Economic Co-operation and Development. (2016). *Green investment banks: Scaling up private investment in low-carbon, climate-resilient infrastructure.* https://www.oecd.org/env/cc/green-investment-banks-9789264245129-en.htm

Organisation for Economic Co-operation and Development. (2021). *OECD companion to the inventory of support measures for fossil fuels 2021.* https://doi.org/10.1787/e670c620-en

Organisation for Economic Co-operation and Development. (2022). *OECD inventory of support measures for fossil fuels: Country notes – Russian Federation.* https://www.oecd-ilibrary.org/sites/23fe599b-en/index.html?itemId=/content/component/23fe599b-en

Paroussos, L., Mandel, A., Fragkiadakis, K., Fragkos, P., Hinkel, J., & Vrontisi, Z. (2019). Climate clubs and the macro-economic benefits of international cooperation on climate policy. *Nature Climate Change, 9,* 542–546. https://doi.org/10.1038/s41558-019-0501-1

Polzin, F., Migendt, M., Täube, F. A., & von Flotow, P. (2015, May). Public policy influence on renewable energy investments – A panel data study across OECD countries. *Energy Policy, 80,* 98–111. https://doi.org/10.1016/j.enpol.2015.01.026

Prag, A., Röttgers, D., & Scherrer, I. (2018). *State-owned enterprises and the low-carbon transition* (OECD Environment Working Papers, No. 129). OECD Publishing. https://doi.org/10.1787/19970900

Rashad, M., & Steitz, R. (2022, April 20). *Analysis: As Germany joins LNG import race, a long and crowded track awaits.* Reuters. https://www.reuters.com/business/energy/germany-joins-lng-import-race-long-crowded-track-awaits-2022-04-19/

Rystad. (2022). UCube Browser v. 2.3.2. www.rystadenergy.com/energy-themes/oil-gas/upstream/u-cube/

Schmidt, T. S., Steffen, B., Egli, F., Pahle, M., Tietjen, O., & Edenhofer, O. (2019). Adverse effects of rising interest rates on sustainable energy transitions. *Nature Sustainability, 2*(9), 879–885. https://doi.org/10.1038/s41893-019-0375-2

Steckel, J. C., & Jakob, M. (2018). The role of financing cost and de-risking strategies for clean energy investment. *International Economics, 155,* 19–28. https://doi.org/10.1016/j.inteco.2018.02.003

Tienhaara, K., Thrasher, R., Simmons, B. A., & Gallagher, K. P. (2022). Investor–state disputes threaten the global green energy transition. *Science, 376*(6594), 701–703. https://doi.org/10.1126/science.abo4637

United Nations Environment Programme–Technical University of Denmark. (2019). *From needs to implementation: Stories from the technology needs assessments.* TNA – Technology Needs Assessment. https://tech-action.unepdtu.org/wp-content/uploads/sites/2/2019/11/2019-11-tna-stories-web2.pdf

Warszawski, L., Kriegler, E., Lenton, T. M., Gaffney, O., Jacob, D., Klingenfeld, D., Koide, R., Costa, M. M., Messner, D., Nakicenovic, N., Schellnhuber, H. J., Schlosser, P., Takeuchi, K., van der Leeuw, S., Whiteman, G., & Rockström, J. (2021). All options, not silver bullets, needed to limit global warming to 1.5°C: A scenario appraisal. *Environmental Research Letters, 16*(6). https://doi.org/10.1088/1748-9326/abfeec

Zenghelis, D., & Stern, N. (2016). *The importance of looking forward to manage risks: Submission to the Task Force on Climate-Related Financial Disclosures* (Policy paper). https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2016/06/Zenghelis-and-Stern-policy-paper-June-2016.pdf

Appendix A. Additional Pathway Comparison

1. Intergovernmental Panel on Climate Change Illustrative Mitigation Pathways

The Intergovernmental Panel on Climate Change (IPCC) Working Group III report contains three Illustrative Mitigation Pathways (IMPs) to illustrate archetype combinations of emissions mitigation options and how they can steer energy systems in directions consistent with 1.5°C (with low or no overshoot). They offer three distinct pathways, focusing on a 1) heavy reliance on renewables (IMP-Ren), 2) strong emphasis on energy demand reductions (IMP-LD), and 3) focus on sustainable development (SP).[8] The scale and speed of greenhouse gas emissions reductions under these pathways vary significantly. The first two of these IMPs, IMP-Ren and IMP-LD, focus on emissions mitigation in the energy system and are therefore highlighted in this appendix.[9]

The combined emissions from oil and gas in the IMP-Ren and IMP-LD reduce at a rate that is about three times faster compared to the unfiltered 97 scenarios limiting warming to 1.5°C with no or low overshoot. This shows the outsized influence that relying on future unproven carbon sequestration potential has on enabling higher levels of fossil fuels energy models. This motivates a precautionary approach for energy policies over the large-scale deployment of carbon dioxide removals (CDR) and carbon capture and storage (CCS). An overreliance on these measures followed by unsuccessful implementation would impose a significant risk of irreversible levels of climate change.

Illustrative mitigation pathways featured in the Working Group III that focus on energy sector transition while limiting warming to 1.5°C with no or low overshoot (IMP-Ren and IMP-LD) show that renewable energy deployment needs to accelerate significantly faster than in the 97 scenarios limiting warming to 1.5°C with no or low overshoot.

This appendix illustrates and compares these pathways in relation to the subset of scenarios selected for this report. It also presents the filtering methodologies used to select subsets of scenarios consistent with a precautionary approach over the deployment of large-scale CDR and CCS measures.

2. Scenarios Filtering Methodology

The scenarios selected to inform the analysis in this report were chosen based on the feasibility assessment of the deployment of new technologies. Fossil-CCS and BECCS scale-up potential were limited to the thresholds for the onset of medium concerns over the feasibility of their deployment. Based on the thresholds presented in IPCC Working Group III

[8] Two other IMPs—focused on widespread deployment of CO_2 removal (CDR) and carbon capture and storage (CCS) technologies (IMP-Neg), and on delaying mitigation actions (IMP-GS)—are categorized as likely below 2°C.

[9] The third, IMP-SP, largely focuses on emissions reductions from the land use sector, where emissions accounting and mitigation potential are more uncertain.

Table II.1, scenarios with more than 3 $GtCO_2$/year for BECCS and 3.8$GtCO_2$/year for fossil CCS by 2050 were excluded. To prevent irregularities in deployment in the second half of the century, the average amount of sequestered carbon between 2040 and 2060 was used to apply this filtering criteria.

Table A1. List of the 26 feasible 1.5°C pathway limiting CDR and CCS deployment

Model	Scenario
MESSAGEix-GLOBIOM 1.0	LowEnergyDemand_1.3_IPCC
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_450
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_500
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_COV
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR1p
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR2p
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR3p
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR4p
MESSAGEix-GLOBIOM_1.1	NGFS2_Divergent Net Zero Policies
MESSAGEix-GLOBIOM_1.1	NGFS2_Net-Zero 2050
MESSAGEix-GLOBIOM_1.2	COV_GreenPush_550
MESSAGEix-GLOBIOM_1.2	COV_NoPolicyNoCOVID_550
MESSAGEix-GLOBIOM_1.2	COV_Restore_550
MESSAGEix-GLOBIOM_1.2	COV_SelfReliance_550
MESSAGEix-GLOBIOM_1.2	COV_SmartUse_550
REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-minCDR
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP2-1p5C-minCDR
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600f_COV
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000
REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_ HighRE_Budg900
WITCH 5.0	EN_NPi2020_400f
WITCH 5.0	EN_NPi2020_450
WITCH 5.0	EN_NPi2020_450f
WITCH 5.0	EN_NPi2020_500
WITCH 5.0	EN_NPi2020_500f

Moreover, to reflect the IPCC's stated stated concern regarding the sustainable use of afforestation and reforestation as carbon sinks, total sequestered carbon through these means was constrained to the maximum estimate of the total sustainable potential. As in the IPCC special report on 1.5°C based on the analysis provided by Fuss et al. (2018), the maximum sustainable potential for afforestation and reforestation is estimated at 0.5 to 3.6 $GtCO_2$/year. The upper end of this range was applied to the total sequestered carbon in the AFOLU[10] sector in order to ensure greater data availability (there are inconsistencies in how afforestation and reforestation are accounted for in different models) (Warszawski et al., 2021).

This filtering method provided 26 scenarios from 3 integrated assessment models and their variations, which were used to extract data supporting the findings in this analysis. See Table A1, for the completed list of models and specific scenarios retained for this report.

3. Sensitivity Analysis

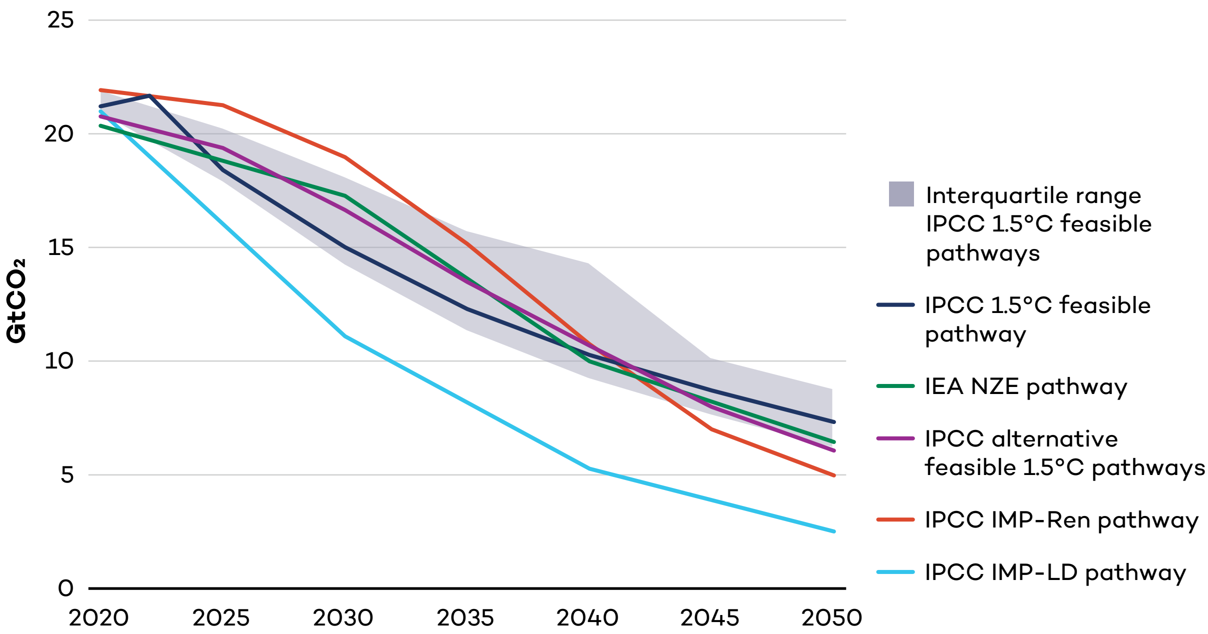
A sensitivity analysis also was conducted in order to assess a range of other possibilities, shown in the figures A1 to A3. First, we show the interquartile range of our selected set of feasible 1.5°C pathways. Second, we show the results of an alternative filtering method. The feasibility limits imposed for the onset of significant concerns over the feasibility of BECCS and fossil-CCS were kept constant as in the set of feasible 1.5°C pathways used in this report, but a more stringent threshold was applied to carbon sequestration from afforestation and reforestation. Using the middle value from the sustainable potential range as presented above for afforestation and reforestation instead of the top of the range provided a smaller sample of 14 scenarios representing a more precautionary approach over the deployment of CDR measures. Third, we include the two IMPs focused on energy system transition (IMP-Ren and IMP-LD) presented in the IPCC Working Group III report. Fourth, we show the IEA Net Zero Emissions by 2050 (NZE) scenario, as an important policy-relevant and well-known pathway.

As shown in Figure A1, global consumption and production of oil and gas decrease slightly slower in the IMP-Ren and IEA NZE pathways and in the alternative feasibility selection, compared to the set of feasible 1.5°C pathways selected for this analysis. The decrease is significantly faster in the IMP-LD pathway, which does not use any CCS in either BECCS or on fossil fuel plants, thus giving less opportunity to delay fossil-CO_2 emissions reduction.

Furthermore, the policy conclusion from the IEA NZE that there is no room for new fields to be developed beyond those already producing or under development is reinforced by our analysis. In fact, limiting the deployment of CDR and CCS to levels shown to be feasible and sustainable gives a stronger conclusion: that even fields currently under development will generate more emissions than would be consistent with 1.5°C.

[10] AFOLU: agriculture, forestry and other land use

Figure A1. Global oil and gas production

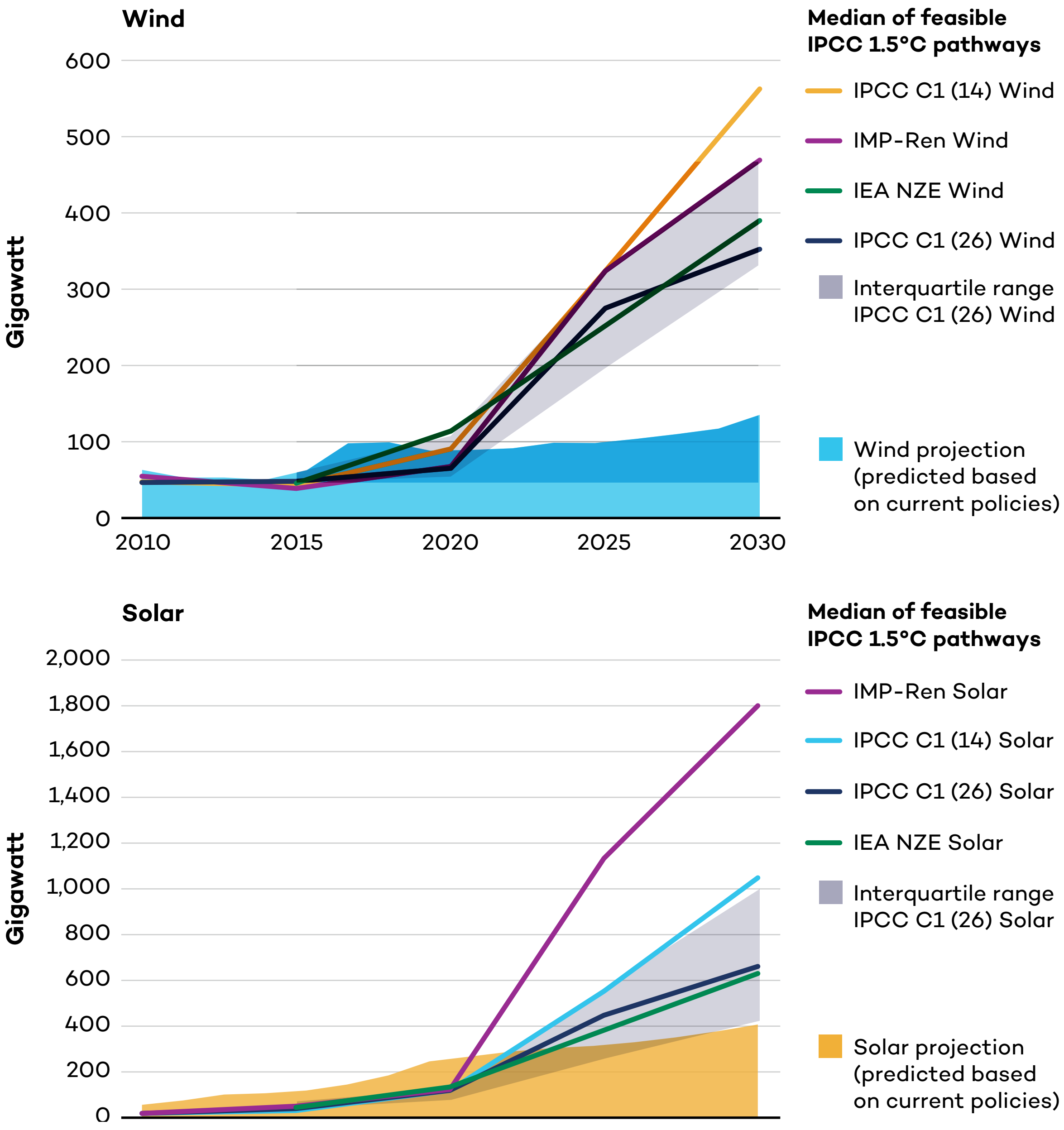


Source: Byers et al., 2022; Rystad, 2022.

The renewable energy deployment gap under the different pathways is shown in Figure A2. Apart from the IMP-Ren, which relies heavily on solar energy deployment in the 2030s, all other pathways fall either within the interquartile range of the set of feasible 1.5°C pathways selected for this analysis, or above it. These results suggest that our conclusions are possibly conservative. Therefore, the required capacity deployment for both wind and solar remains roughly consistent with other comparable pathways and represents the lower end of the spectrum of the deployment from this sensitivity analysis.

The investment levels required to deploy the required annual capacity addition are calculated using capital cost projections from the International Renewable Energy Agency until 2030. They show that the investment gap is highly sensitive to the choice of pathways. The C1 (14) subset of scenarios imposing the most stringent limitation on these technologies shows that the investment gap could be up to USD 844 billion by 2030. This would require investment levels for wind and solar energy to be three times higher than in BloombergNEF projections. The IMP-Ren shows by far the largest investment needs with an investment gap of more than USD 1.2 trillion by 2030. On the other hand, the IEA NZE levels of investment are equivalent to the estimates based on the subset of 26 scenarios that informed the analysis of this report. Therefore, the sensitivity analysis emphasizes the finding that limiting warming to 1.5°C will require investment levels in wind and solar energy above USD 800 billion per year by 2030.

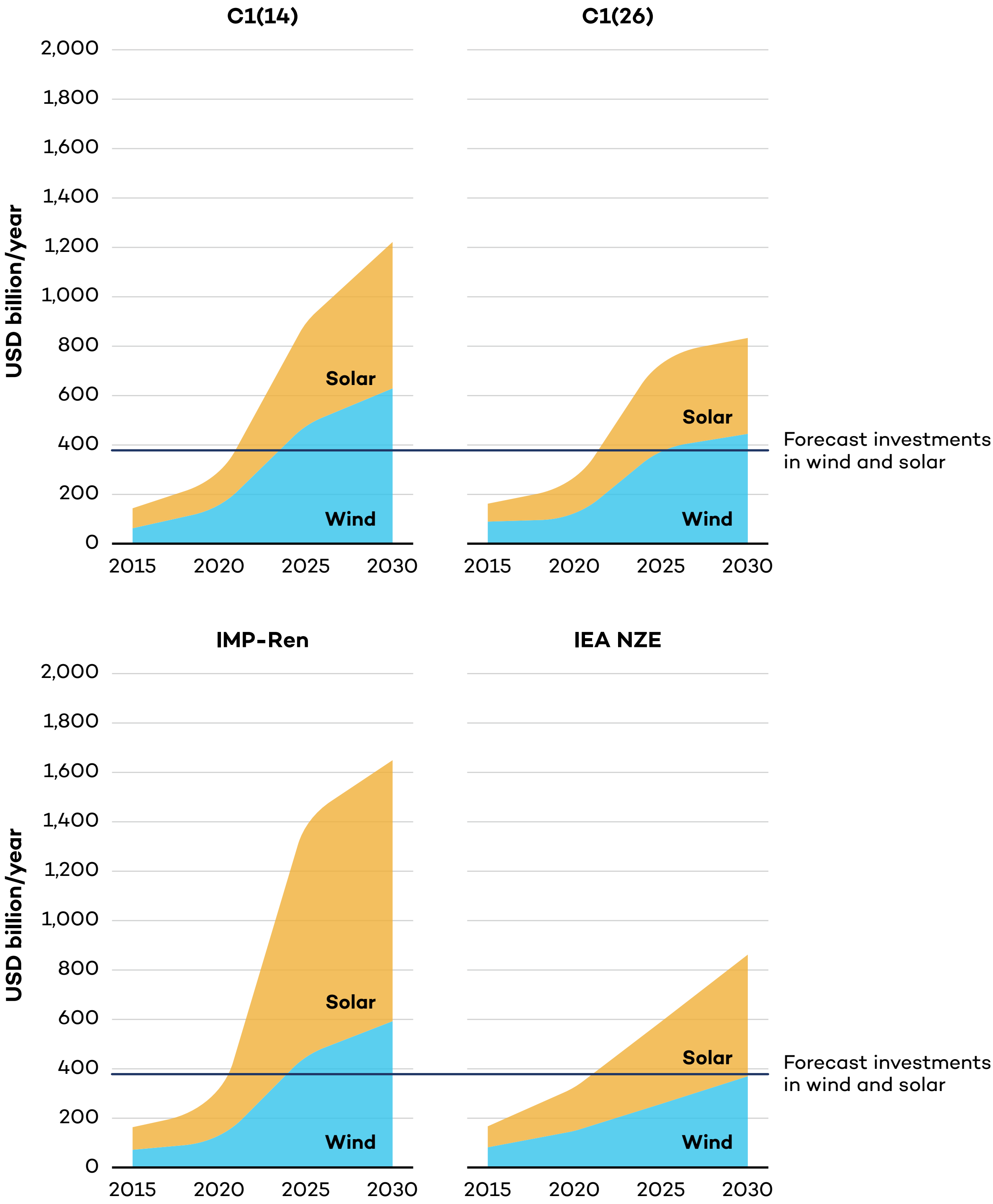
Figure A2. Annual wind and solar capacity addition



Source: Byers et al., 2022.

The sensitivity analysis provided in this appendix illustrates the robustness of the findings presented in the report. It gives an indication that the constraints imposed on the CDR and CCS deployment have an impact on the short-term emissions reduction in the oil and gas sector. Applying stringent thresholds on the use of large-scale carbon sequestration and negative emissions in the second half of the century provides a clear roadmap for the energy sector. Guiding policy decisions in line with current technologies and the most efficient mitigation options available today offers a realistic assessment of the renewable energy deployment needs and consistent investment levels to meet the world's energy demand in a 1.5°C world.

Figure A3. Annual investment in wind and solar capacity growth



Source: Byers et al., 2022; IRENA 2019a, 2019b; Rystad, 2022.

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