2030 targets aligned to 1.5°C

Evidence from the latest global pathways

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Summary

Global wind and solar capacity needs to grow five-fold by 2030, with installation ramping up to at least 1.5 TW per year, and fossil fuel production needs to drop 6% each year to stay within the 1.5°C limit and minimise reliance on carbon dioxide removal.

The IPCC's sixth assessment report (AR6) provides crucial information on how to tackle climate change, in particular identifying pathways that limit warming to 1.5°C with no or limited overshoot. However, many of the pathways in the AR6 database are not fully Paris Agreement compatible in that they do not bring emissions to net zero in the second half of this century. Many also rely on unsustainable levels of carbon dioxide removal and/or do not factor in recent progress, such as the declining cost of renewables.

In this briefing, we extract 24 pathways from the IPCC AR6 database that can guide the global energy transition to net zero in a sustainable way. These Paris-compatible pathways show what's needed to limit warming to 1.5°C if we don't bet on likely unfeasible levels of future carbon dioxide removal. From these we set robust 1.5°C-aligned 2030 targets, including for renewable rollout and fossil fuel decline.

Our five key global 2030 targets aligned with 1.5°C are:

1. **Install *at least* 1.5 TW of new wind and solar capacity per year by 2030 – that's a five-fold increase from 2022 levels of 0.3 TW. Total wind and solar capacity should reach around 10 TW by the end of the decade, five times the 2 TW of capacity in 2022.**

   This target is achievable if the recent acceleration in capacity additions is maintained. It should be seen as a floor – if electricity demand grows as quickly as in the IEA's Net Zero Emissions scenario, then solar and wind installations would need to be closer to 2 TW/yr by 2030.

2. **Set a global renewables target of at least 70% of electricity generation by 2030, more than doubling today's share of around 30%.**

3. **Cut global fossil fuel production by 6% each year from 2022 onwards to reduce fossil fuel use by around 40% over the decade.**

4. **Cut global GHG emissions in half (by 48%) by 2030 compared to 2019.**

   This is faster than the 43% reduction highlighted by the IPCC and is necessary to significantly reduce dependence on carbon dioxide removal. This means reducing emissions by 8% per year (2021-2030).

5. **Cut methane emissions in the energy sector by 66% by 2030**.

   Methane emissions in the energy sector need to fall around twice as fast as total methane emissions, which drop by 34% over the decade. The 30% cut in the Global Methane Pledge is not aligned with 1.5°C pathways.

The rapidly falling costs of wind and solar mean that carbon capture and storage (CCS) is not a cost-effective way decarbonising the power sector. Our Paris-compatible pathways show at best a marginal role for fossil CCS, which makes up only 0.1% of global electricity generation in 2030.

These collective global goals are designed to mobilise action towards a safer, more liveable world. The rapid changes identified here are achievable, and with global emissions as high as ever, the need to revisit and update 2030 ambition in NDCs remains a crucial ask ahead of COP28.

Introduction

The first Global Stocktake (GST) under the Paris Agreement will culminate at COP28 in Dubai. The GST assesses where the world is heading based on current climate action, as well as what's needed to achieve the Paris Agreement's long-term goals.

It is clear that the necessary transitions are not happening fast enough.[1] Under current climate policies, global temperatures are expected to increase 2.7°C by 2100 – and keep rising.[2] Even the most optimistic assessments of national targets, which assume rapid emissions cuts after 2030 to make up for delays this decade, would push past the Paris Agreement's limit, climbing to 1.8°C of dangerous warming by 2100.[3]

The reality is that we need faster action before 2030 to keep the 1.5°C limit in reach and prevent climate impacts from increasing unchecked for the next 30 years.

Setting key near-term targets in line with the Paris Agreement is essential to assess the world's progress and close remaining gaps. In particular, calls have been made for global targets for renewables phase-in and fossil fuel phase-out.

Global modelled scenarios can provide vital evidence for setting these targets, but not all scenarios are consistent with achieving the Paris Agreement's goals sustainably. In this briefing we use a subset of global pathways assessed by the IPCC as part of its sixth assessment report (AR6) to assess key areas of action for 2030.

A Paris Agreement compatible set of global pathways

IPCC AR6 provides a set of 97 global pathways which limit warming to 1.5°C with no or low overshoot. These pathways are produced by integrated assessment models (IAMs), which combine economic, energy, and land models to produce integrated pathways of future societal and environmental change.

IAM pathways can be combined with other lines of evidence to understand what transitions are needed to limit warming to 1.5°C. Our method filters out pathways that are inconsistent with the Paris Agreement or raise feasibility concerns. Out of the 97 pathways, we select 24 based on the following considerations.

Paris compatibility

Not all pathways assessed by the IPCC are fully compatible with the Paris Agreement.[4] The mitigation pathways we consider as consistent with the Paris Agreement and its long-term temperature goal have the following features:

- Long-term warming is limited to 1.5°C and peak warming does not exceed 1.6°C (termed "no and limited overshoot" pathways by the IPCC)
- Pathways are consistent with achieving net zero global greenhouse gas emissions in the second half of the century (as indicated in Article 4.1 of the Paris Agreement)

Feasibility concerns

IAMs have been widely criticised for producing pathways which rely on levels of carbon dioxide removal (CDR) which are likely infeasible[5] and can have strong negative side effects.[6] At the same time, the regional distribution of decarbonisation efforts in IAM pathways has been criticised for ignoring socio-political realities which may limit the pace of decarbonisation in emerging economies.[7]

To address these concerns, we select pathways in which:

- Global CDR deployment is limited according to sustainability constraints[8,9]
- High income countries take the lead, with faster emissions reductions in the developed economies up to 2030, in % reduction terms

We also exclude older pathways to ensure that we take the latest available evidence on limiting warming to 1.5°C. For further details on our filtering approach, see the technical appendix.

2030 targets aligned to 1.5°C

Using the selected Paris-compatible global pathways, we define five key 2030 targets aligned to 1.5°C.

Halve global emissions by 2030

In the selected pathways, **emissions need to fall by half (by 48%) by 2030** relative to 2019 to 29 $GtCO_2e$/yr (median of all pathways)**.** This is greater than the emissions reductions highlighted in IPCC AR6, which finds that emissions need to fall 43% from 2019-2030 across all 1.5°C compatible pathways.[10] Reduced reliance on CDR leads to faster near-term emissions reductions. In our filtered set of pathways, which attempt to avoid excessive CDR deployment, emissions need to fall even faster in the 2020s.

Achieving this cut from 2019 would have required that global emissions fall 6.5% per year. However, emissions have not fallen, but rebounded to pre-pandemic levels by 2021.[11] This means that emissions need to fall even faster, by at least 7.9% per year from 2021 to achieve this target. Early evidence suggests that global emissions grew again in 2022[12], which will require even deeper cuts.

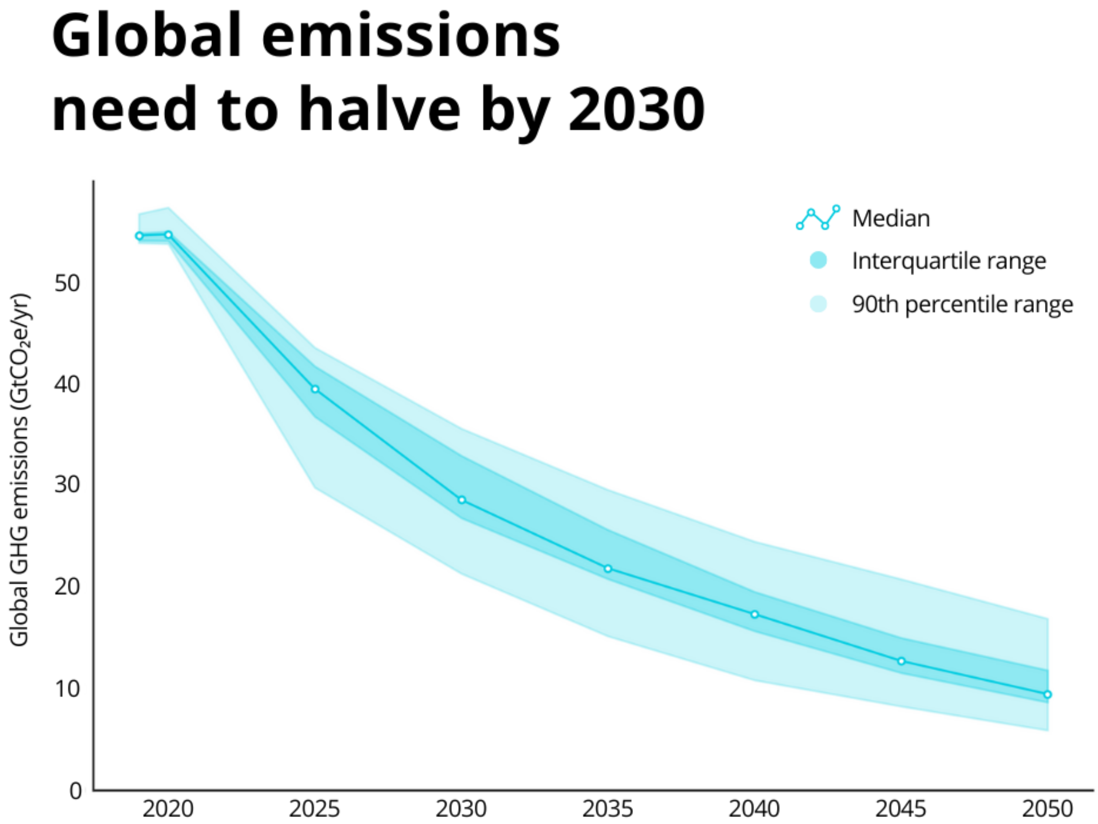

Figure 1: Global greenhouse gas emissions in the selected Paris-compatible pathways
Figure shows total emissions calculated using AR6 GWP_{100} global warming potential. Central markers show the median, while the interquartile and 90th percentile range are shown in shaded ranges.

Current NDCs are calculated to reduce emissions by 1-7% over the decade,[13] falling far short of what is needed. We are more than a third of the way through this critical decade for emissions reductions, and the lack of ambition in current policies and targets represents the number one threat to the Paris Agreement's temperature goal. The call governments made at COP26 to revisit NDCs and bring them in line with the 1.5°C limit remains as urgent as ever.

Generate more than 70% of electricity from renewables by 2030

The power sector is at the heart of climate action in the 2020s.[14,15] Electricity and heat production was responsible for over a fifth of all greenhouse gas emissions in 2019,[16] with the majority of this coming from coal-fired generation.

Zero-carbon electricity will also be a key building block of our future energy system, as buildings, transport and industry are increasingly electrified.[17] At the same time, the plummeting costs of renewables mean that solar and wind are now the cheapest form of electricity production in most countries.[18]

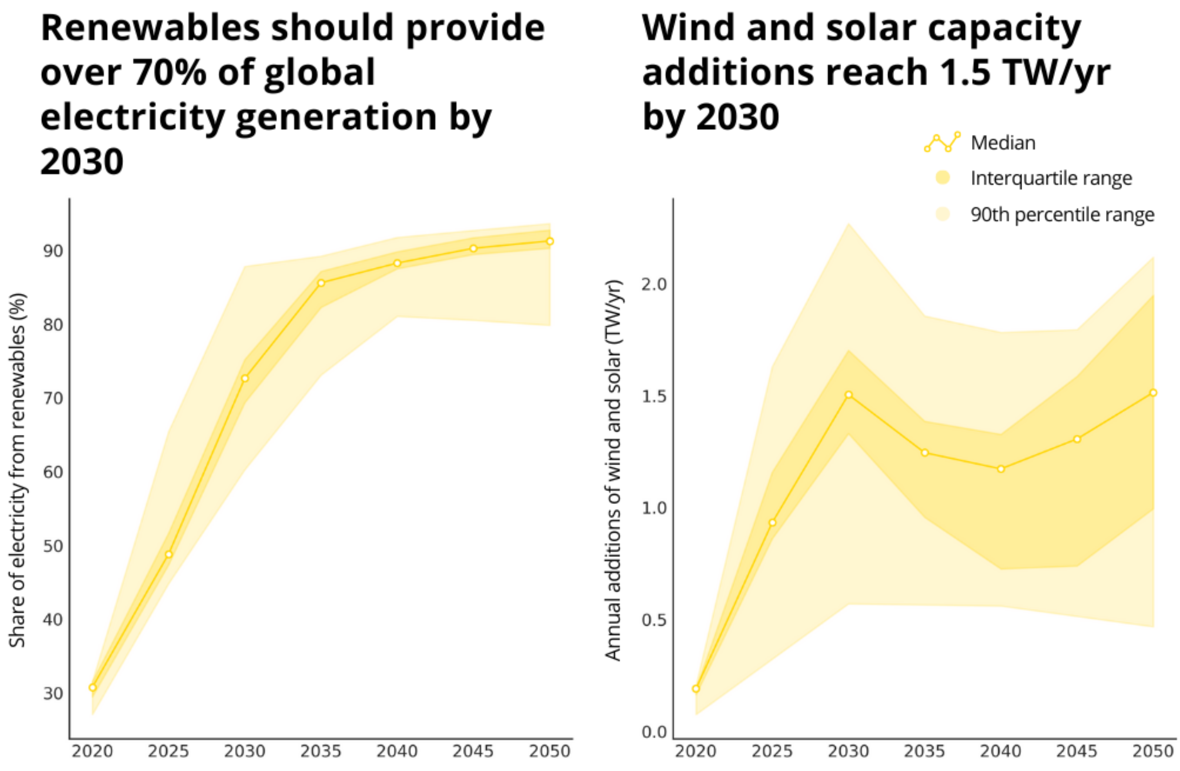

Figure 2: Renewables deployment in selected Paris-compatible pathways

Figure 2 shows the share of global electricity production that comes from renewables in selected pathways (left) and the annual capacity deployments of wind and solar required to achieve these shares (right).

In the selected pathways, there is a rapid transition towards clean electricity. **The median share of renewables in the global power sector reaches 71% by 2030, up from around**

30% today.[15] Other lines of evidence highlight that the share of renewables could reach even higher levels, to over 80% by 2030.[19,20] A 70% share of renewables by 2030 should be seen as the minimum ambition, and governments should make every effort to accelerate action further.

Install 1.5 TW of additional wind and solar a year by 2030

The growth in renewables is underpinned by unprecedented deployment of wind and solar in particular, which provide around 90% of new renewable generation from 2020 to 2030.[a]

Future capacity deployments are closely linked with future electricity demand growth. This will be governed by the competing drivers of electrification and demand reduction. As transport, buildings and industry are increasingly electrified, demand for electricity will grow rapidly. At the same time, efficiency improvements and behavioural change can reduce demand growth rates and associated capacity requirements.

Current evidence suggests that electrification is outpacing demand reduction. Global electricity demand is still growing strongly, at 2.5% per year in 2022.[15] If current trends continue out to 2030, global electricity demand will be around 30% higher in 2030 than in 2020, increasing the need for rapid renewable capacity deployment.

In the selected pathways, the median annual installations of wind and solar is 1.4 TW/yr by 2030, remaining around this level up to 2050. However, some of the global pathways show low levels of electricity demand growth, of under 10% across the decade. This seems unrealistic given current electrification trends. Table 1 shows how greater electricity demand growth requires more wind and solar additions.

Electricity demand growth 2020-2030	Wind and solar capacity deployment in 2030 (TW / y)
No minimum level (average 26%)	1.4
At least 10% (average 31%)	1.5
At least 20% (average 34%)	1.6
At least 30% (average 37%)	1.7
At least 40% (average 42%)	1.8

Table 1: Annual wind and solar capacity deployment needed in 2030 based on different rates of electricity demand growth

When removing pathways with demand growth of under 10% from the set, electricity demand grows on average by 31% over the decade - tracking current rates of electrification – and **average annual installations of wind and solar reach 1.5 TW/yr by 2030.** Beyond

[a] Renewables generation also includes non- wind and solar technologies such as hydroelectric, biomass and geothermal generation. However, their future generation growth is limited by geographical, economic or sustainability concerns, and therefore future renewables deployment is driven predominantly by wind and solar.

2030, capacity installations remain at around this level, showing a sustained build-out for several decades.

In a world where electrification continues at around current trends, then on average, **wind and solar installations need to reach 1.5 TW/yr by 2030, up from 0.3 TW/yr in 2022**.[19] **Total wind and solar capacity reaches 9.6 TW by 2030, up from 2.0 TW in 2022.**[20] This means that, compared to 2022 levels, we need to see a five-fold increase in both total wind and solar capacity and the rate of new capacity additions.

The rate at which electricity demand grows will partly depend on the level of action taken to improve efficiency and reduce overconsumption, particularly in developed economies. Demand-side solutions can have huge benefits for wellbeing,[21] enable faster decarbonisation[22] and are consistent with achieving decent living standards for all.[23] Demand-side solutions could reduce the scale of capacity deployment needed and reduce the wider impacts of renewables buildout**.**

On the other hand, if electricity demand growth *accelerates*, then greater levels of wind and solar would need to be deployed to avoid increased fossil generation in the power sector. The greatest deployment of renewables is seen in the High Renewables illustrative pathway.[24] Here, a strong focus on electrification and relatively limited demand-side action results in electricity demand growth of over 35%, and wind and solar capacity deployments of 2.25 TW/yr by 2030.

This highlights that, without significant changes in demand-side ambition, the **1.5 TW/yr target should be seen as a deployment floor**, as even greater action may be required.

This annual target for installed wind and solar exceeds the IEA[14] target for wind and solar capacity additions of around 1.1 TW/y by 2030. This is despite faster growth in electricity generation in the IEA's Net Zero Emissions scenario (41% over the decade). These differences may result from a range of factors, including faster power sector decarbonisation in our set of Paris compatible pathways and greater biomass and nuclear deployment in the IEA's Net Zero scenario[b]. However, other studies do find wind and solar capacity deployments of 1.5 TW/yr and above by 2030,[17,25] which aligns with our analysis.

The rapid growth in renewables deployment forecast for 2023,[19] supported by a burgeoning manufacturing base,[26] is a positive outlook for the energy transition and suggests that our target can be achieved if this acceleration can be maintained. Support should be targeted at

[b] Global electricity generation in the IEA's Net Zero scenario reaches 38000 TWh/y in 2030, over 1500 TWh greater than the median generation in the Paris-compatible filtered subset identified in this briefing (filtering for pathways with electricity demand growth of at least 10% across the decade). However, the IEA's Net Zero scenario displays greater fossil generation than the IAM pathways (~3000 TWh more fossil generation in 2030), and greater nuclear/biomass deployment (by ~2000 TWh in 2030). As a result, total wind and solar capacity is reduced by ~1.4 TW in 2030 in the IEA's Net Zero scenario (8.2 TW by 2030) compared to the median of the IAM pathways (9.6 TW), and capacity additions are correspondingly lower. Accelerating power sector decarbonisation and reducing reliance on biomass/nuclear requires greater capacity additions of wind and solar.

lower income countries where growth rates are slower due to a lack of finance, high capital costs and other barriers.

Fossil CCS plays a minor role in the power sector

A 1.5°C-aligned power sector transition is one dominated by renewables. Fossil fuels equipped with CCS play at best a very minor role, providing only 0.1% of power generation by 2030 in these Paris compatible pathways, and 0.7% of global electricity in 2050. This is even less than in the IEA's Net Zero scenario, in which fossil CCS provides 0.7% of electricity in 2030 and 1.8% by 2050.[14] However, both IEA and IAM pathways provide the same overall message – that CCS has at best a minor role in power sector decarbonisation.

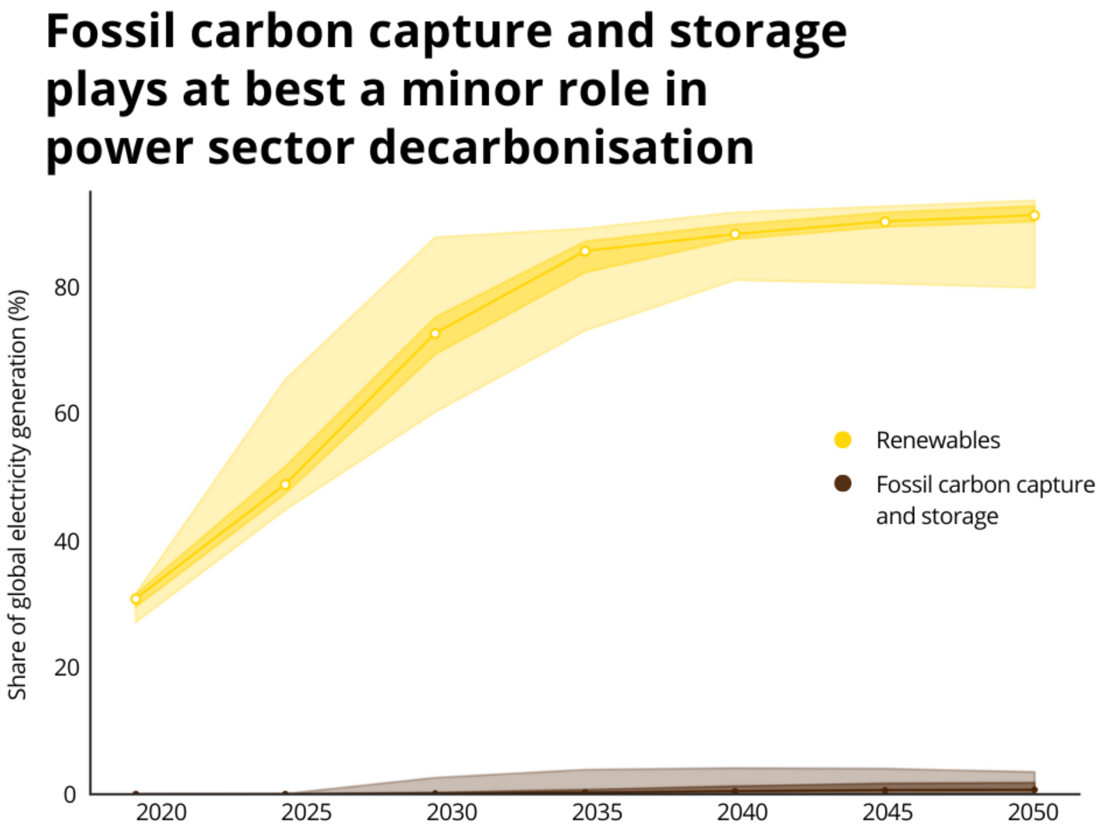

Figure 3: Fossil CCS accounts for just 0.1% of global electricity generation by 2030

The rapidly declining costs of wind and solar mean that CCS is an uneconomic option for decarbonising the power system.[27] Recent analysis has shown how deeply wind and solar costs undercut coal and fossil gas with CCS.[28] As the global potential for geological CO_2 storage could be very limited,[29] it should be prioritised for high-value applications such as to address process-based emissions from industry or to facilitate permanent removals via direct air capture, not squandered on fossil CCS deployment for electricity generation.

Cut fossil fuel production by 40% over the decade

Burning fossil fuels is the leading cause of global warming. All pathways that limit warming to 1.5°C require immediate and deep cuts in fossil fuel consumption. In the selected Paris-compatible pathways, **fossil fuel production falls by around 40% over the decade** (median of all pathways), as renewable electricity displaces fossil fuels as the main source of energy**.** Coal declines the fastest, at 79%, but strong reductions are needed in all fossil fuels. Fossil fuel production would need to have fallen by 5% per year from 2020 to 2030 to achieve this reduction. However, fossil fuel production is still moving in the wrong direction. Since the Paris Agreement, coal, oil and gas use combined grew by on average 1% each year, with gas growing the fastest (2.5% per year), and fossil fuel production has rebounded to pre-pandemic levels.[30] Accounting for delayed action since 2020, a faster decline of **at least 6% per year is needed from 2022 to 2030**.

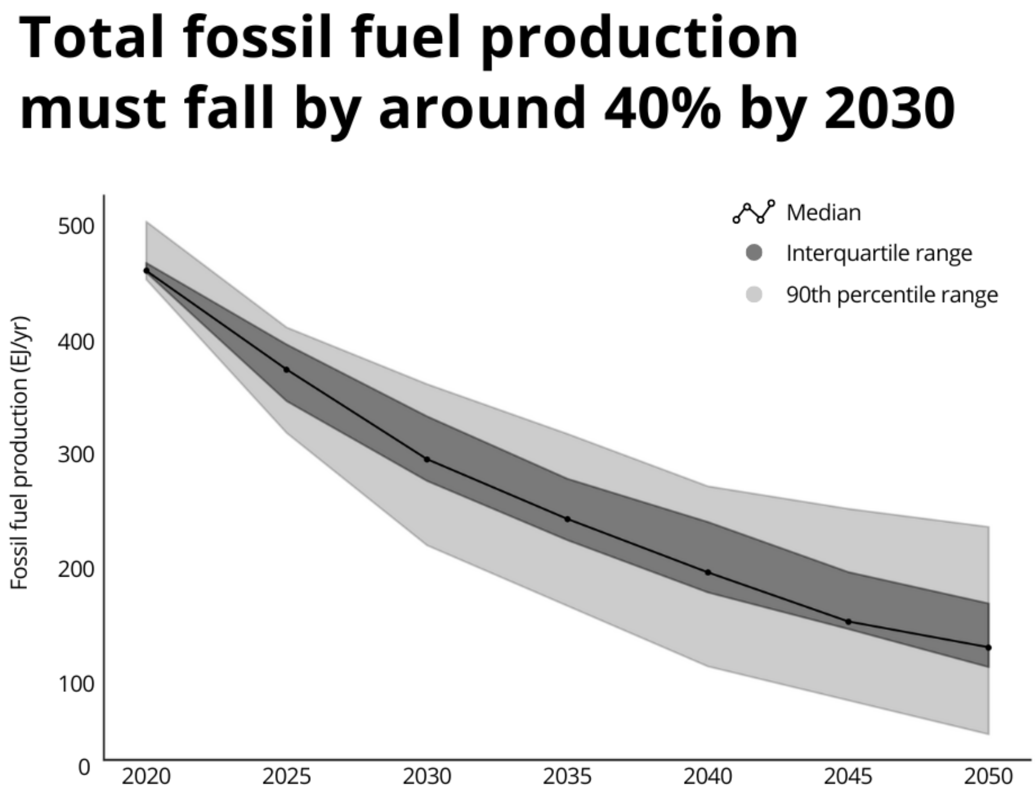

Figure 4: Total fossil fuel production in selected Paris-compatible pathways
The figure shows total fossil fuel production of coal, oil and gas combined.
Limiting warming to 1.5°C will require immediate, strong and sustained action to cut fossil fuel usage. By 2050, fossil fuel demand in these pathways falls by 72% compared to 2020 levels. In comparison, the IEA's Net Zero Emissions scenario shows deeper cuts by 2050 of 80%.

Design features in IAM pathways mean that they maintain some fossil fuel demand for energy by mid-century, even though a faster phase-out is both feasible and desirable. For example, further limitations to the availability of CDR would place more pressure on cutting fossil fuel use.

Recent developments in synthetic fuels and other options for reducing fossil fuel demand – which are often not well captured in these pathways – also suggest faster reductions could be feasible and cost effective. In addition, IAMs often struggle to capture economies of scale as zero carbon technologies scale-up,[31] nor do they capture likely challenges in future fossil fuel supply chains, as demand winds down.

Note that these numbers and Figure 4 are based on total fossil demand, which includes the use of oil and gas as feedstocks in chemicals production. The use of fossil fuels for energy will fall faster than their use as a feedstock, with the majority of oil and gas consumption in 2050 being for non-energy purposes.[32] A phaseout of fossil fuels in the energy sector is achievable first, while non-energy demand for fossil fuels could be further reduced using different approaches, such as the circular economy or bio-based feedstocks.[33]

Other lines of evidence have demonstrated the need to avoid new investments in fossil fuel supply,[14,34] and that a total fossil fuel phaseout is achievable.[35,36] Together, the path forward is clear – strong and sustained reductions in fossil extraction towards a fully renewable future.

Cut methane emissions by 34% over the decade, and by 66% in the energy sector

Cutting methane emissions is one of the most effective ways to limit near-term warming. Methane has a short lifetime in the atmosphere of around 10 years. This means that cuts to methane emissions can reduce its contribution to global warming almost immediately.

In the selected pathways, **global methane emissions fall by 34% from 2020 to 2030** (median of all pathways). The Global Methane Pledge commits signatories to cutting emissions by 30% over this timeframe. The pledge should be expanded to cover all countries and increase its ambition to align fully with the 1.5°C limit.

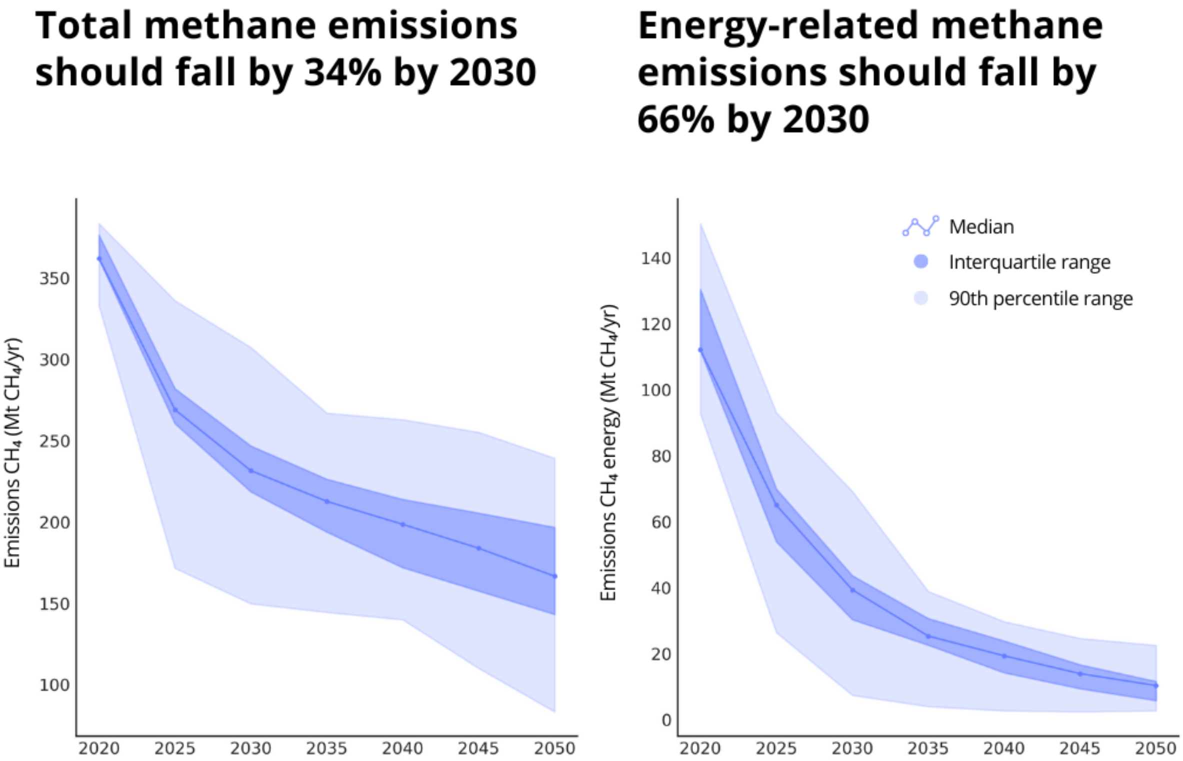

Figure 5: Total methane emissions and energy sector methane emissions in selected Paris compatible pathways

The figure shows total methane emissions (left) and energy-related methane emissions (right) in the selected subset of Paris-compatible pathways.

Central to cutting methane emissions in the 2020s is an immediate reduction in methane emissions from the energy sector. **Energy-related methane emissions need to fall by two-thirds (66%) from 2020 to 2030** in Paris-compatible pathways (median of the distribution). This represents 60% of all methane emissions reductions this decade, and broadly aligns with IEA's Net Zero scenario, in which methane emissions fall 75% over the decade.[14]

Methane emission reductions are driven partly by addressing fugitive emissions in coal, oil and gas production, for which low-cost measures are readily available.[37] However, as energy-related methane emissions originate from fossil fuel extraction, cutting these emissions will also require cuts in fossil fuel use. The reductions in fossil extraction seen in Paris-compatible pathways lead to strong reductions in methane emissions, as well as falling CO_2 emissions from burning fossil fuels.

Conclusions

While the outcomes of the Global Stocktake will not be finalised until COP28, its overall findings can already be anticipated. The world is badly off track in its efforts to address the climate crisis and deliver the goals of the Paris Agreement.[38,39] Without immediate, rapid and sustained action, global temperatures will continue to rise, and climate impacts will continue to escalate across the world.

While climate action is set at the national level, setting global collective goals can help mobilise ambition and provide yardsticks against which to measure the action of the international community. In this briefing, we provide five key global targets for this critical decade of action:

1. Install over 1.5 TW/yr of new wind and solar capacity by 2030
2. Achieve at least 70% renewables in electricity generation by 2030
3. Cut fossil fuel production by around 40% by 2030 – 6% per year
4. Halve global emissions by 2030, making annual cuts of 8% per year
5. Cut methane emissions by 34% over the decade and energy sector methane emissions by 66%.

These results are broadly aligned with the IEA's Net Zero Emissions scenario. The Paris-compatible set identified in this briefing shows a greater build-out of renewables and faster fossil fuel declines by 2030 than the Net Zero Emissions scenario. The IEA's scenario achieves deeper energy sector methane reductions, at 75% by 2030, demonstrating that faster cuts are possible.

In both analyses, the implications for decisionmakers, civil society and us all are clear. The energy transition is already underway, and the rapid changes identified here are possible,[40] but not inevitable. Scaling up ambition and moving from words to action remains as urgent as ever.

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Technical Note: Selecting pathways for analysis

We apply five key steps in our filtering process, which we detail below and show in Figure 5.

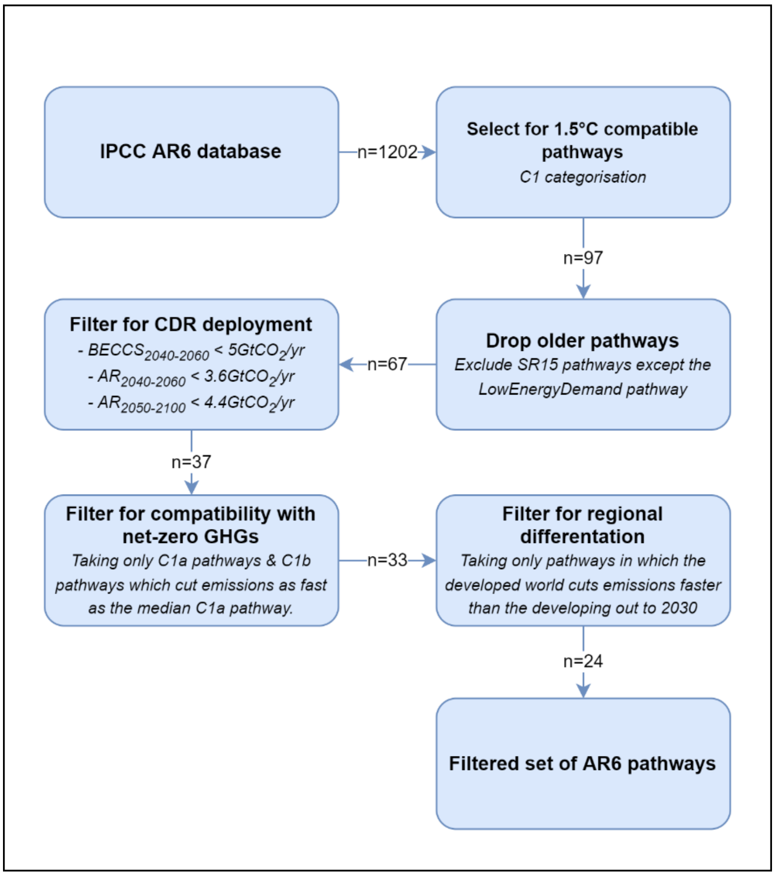

Figure 6: Filtering process to select pathways

Step 1: Focus on 1.5°C compatible pathways

First, we filter to select only pathways compatible with limiting warming to 1.5°C with no or low overshoot.

This means that they:

- Limit warming to 1.5°C in 2100 with a likelihood of greater than 50%
- Exceed warming of 1.5°C during the 21st century with a likelihood of 67% or less

In other words, 1.5°C compatible pathways are not likely to exceed 1.5°C over the 21st century. Such pathways exhibit a limited overshoot of about 0.1°C or less (median estimate) or no overshoot at all.

These pathways are given the C1 category in the AR6 database. C1 pathways are compatible with the long-term temperature goal of the Paris Agreement set out in Article 2.1, which commits signatories to hold warming to “well below” 2°C and pursue efforts to limit warming to 1.5°C. There are 97 such pathways in the AR6 database.

Step 2: Drop older pathways

The AR6 database captures the global pathways which were produced across the sixth assessment cycle, which occurred between 2015-2023. A key moment in the assessment cycle was the publication of the Special Report on 1.5°C (SR1.5), which was published in 2018.[41] This report provided key evidence on global pathways compatible with 1.5°C and was a catalyst in accelerating climate action in recent years.

In the AR6 WGIII report, the 53 1.5°C pathways which were included in SR1.5 were resubmitted to the database. All scenarios in the AR6 database were vetted to ensure that they were aligned with historical data for nuclear, solar, and wind electricity generation, as well as primary energy demand and emissions.[42] 31 of the pathways from SR1.5 which were resubmitted to AR6 passed this vetting process, received a climate assessment and were classified as 1.5°C compatible.

We exclude these scenarios from our analysis because they do not represent the latest evidence**.** To be included in the SR1.5 database, pathways had to be submitted in 2017. This means they represent the status of IAM pathways as of 2017 or earlier. IAMs are continually being developed to improve their representation of key dynamics such as the representation of new technologies[43] renewable cost reductions,[24] scenario design[44,45] and other areas. Therefore, excluding these older pathways can ensure that we take the latest available evidence on 1.5°C compatible pathways. The most recent global pathways show faster renewables deployment and fossil phaseout in the power sector than pathways included in the SR1.5,[46] which demonstrates the development of integrated assessment modelling over the past four years that we seek to capture in our filtered set.

The one exception to this step is the Low Energy Demand pathway.[47] The reason for this is that the transition dynamics represented in this scenario have not been repeated in other pathways in the IPCC AR6 database. It therefore still provides a unique perspective on the energy transition, which is demonstrated by its use as an illustrative pathway in the IPCC's AR6 report.

Step 3: Avoid excessive CDR deployment

All 1.5°C compatible pathways assessed by the IPCC show deployment of carbon dioxide removal (CDR) to some degree. But IAMs have been heavily criticised for relying on CDR to levels which raise serious feasibility concerns and may transgress sustainability thresholds. CDR deployment can dilute the urgency for systemic change in IAM pathways, leading to risky pathways which do not reduce emissions fast enough in the near-term.

We therefore filter to avoid pathways with CDR deployment that crosses a set of literature defined filters. Our filters are defined in Table 2.

Criteria	Value	Source

A / R deployment (2040-2060 average)	< 3.6 $GtCO_2$ / y	Reference [9]
A / R deployment (2050-2100 average)	< 4.4 $GtCO_2$ / y	Reference [9]
BECCS deployment (2040-2060 average)	< 5 $GtCO_2$ / y	Reference [8]

Table 2: CDR filtering criterion applied

For afforestation and reforestation (A/R), we filter to avoid pathways which rely on more than 3.6 $GtCO_2$/yr by mid-century. We also exclude pathways which sequester more than 4.4 $GtCO_2$/yr in the second half of the century. This is because the potential for A/R may well be reduced due to increasing climate impacts, even if warming is limited to 1.5°C.[48] Land availability may also limit the potential for increasing sequestration beyond 2050.[9] This therefore represents a precautionary approach, avoiding reliance on a sink which is vulnerable to climate impacts and may have limited long-term potential. Both thresholds are calculated from a recent study which explores the feasible potential for CDR on the basis of an expert survey.[9] Where possible we filter the database using the variable "Carbon Sequestration|Land Use|Afforestation", but where IAMs do not report raw sequestration data we use "Emissions|CO2|AFOLU" as a proxy for A/R deployment.

We also filter to exclude pathways which deploy more than 5 $GtCO_2$/yr of BECCS by mid-century.[8] While recent estimates of the feasible potential for BECCS are lower,[9] we retain this value. This is because we currently take BECCS as a proxy for all technical CO_2 removal, i.e., also including direct air carbon capture and storage (DACCS).[c] Many IAMs still do not represent DACCS at all, or do not represent the low-temperature route for direct air capture which represents the most promising route for DACCS deployment.[50] Pathways with more DACCS deployment tend to rely less heavily on BECCS. Therefore, we currently apply a less stringent threshold for BECCS, based on the assessment that DACCS potential is likely underestimated in most IAM pathways. Using BECCS as a proxy for a wider range of CO_2 removal efforts aligns with other recent work.[51] As IAMs work to represent a wider range of CDR technologies,[43] this approach could evolve to specific filters for individual CDR options. The median of the selected pathways deploys 2.7 $GtCO_2$/yr of BECCS by 2050. However, given pervasive uncertainty around the feasibility of large-scale CDR, the most robust strategy remains to cut emissions as fast as possible to minimise reliance on CO_2 removal.

Step 4: Ensure consistency with net zero greenhouse gas emissions

In Article 4.1, the Paris Agreement sets out the objective of achieving a balance between sources and sinks of greenhouse gas emissions in the second half of the century.[52] This represents an intention to achieve net zero GHG emissions before 2100. Pathways which achieve net zero GHG emissions exhibit declining long-term temperatures, which can substantially reduce long-term climate impacts such as sea level rise.

[c] While the energy system integration of BECCS/DACCS do differ[49], their impact on overall emissions trajectories and hence near-term mitigation strategies are similar[5]

The IPCC AR6 WGIII introduced a specific classification of pathways which meet this goal, termed C1a pathways. These pathways reach net zero GHG emissions around 2070-2075, and are consistent with both Article 2.1 and 4.1 of the Paris Agreement.[4] Some reports focus only on these C1a pathways to determine benchmarks,[39] excluding pathways which limit warming to 1.5°C without reaching net zero GHGs, which are termed C1b pathways in the AR6.

However, these C1b pathways, while not wholly consistent with the Paris Agreement, can provide valuable information. Many of them were produced as part of the ENGAGE project, which explored how to avoid overshoot of the carbon budget through rapid action. They therefore represent a precautionary approach to limiting warming to 1.5°C with particularly rapid action in the near-term.

Rather than fully exclude C1b pathways from analysis, we consider all pathways which are either subcategory C1a (and therefore fully consistent with Article 4.1 of the Paris Agreement), as well as those C1b pathways which display faster global emissions reductions out to 2050 than the median of the selected C1a pathways. These selected C1b pathways exhibit rapid reductions towards net zero, and could therefore achieve this goal in the second half of the century under different scenario design choices after peak warming.

Step 5: Filter for regional differentiation

IAM pathways have been criticised for the way global mitigative effort is distributed across different regions.[53,54] Limiting warming to 1.5°C will require immediate and rapid action to reduce emissions across the globe.[10] However, if pathways place too high a proportion of this in the developing world, this represents not only an inequitable division of effort, but raises substantial feasibility concerns.[55] With greater financial, technical and institutional barriers to rapid decarbonisation in the developing world, pathways which rely on faster near-term emissions reductions in the developing world compared to the developed may pose additional challenges to political feasibility. In addition, the Paris Agreement calls for developed countries to take the lead in climate action. While developed country leadership should also include substantially upscaling climate finance and other actions, it should also apply to direct action to reduce emissions.

We therefore filter to exclude scenarios in which emissions fall faster from 2020-2030 in the developing world[d] than in the developed world, in % reduction terms. This does not lead to a fully equitable allocation of mitigative effort, and therefore climate finance remains a critical requirement of developed countries. However, it does partially address concerns around the political feasibility of these pathways. The resulting set of 24 pathways are shown in Table 3.

Model	Scenario
COFFEE 1.1	EN_NPi2020_400
MESSAGEix-GLOBIOM 1.0	LowEnergyDemand_1.3_IPCC

[d] Defined as in Ganti *et al* (2023) as R5MAF, R5LAM and R5ASIA

MESSAGEix-GLOBIOM_1.1	NGFS2_Net-Zero 2050
REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50
REMIND 2.1	R2p1_SSP1-PkBudg900
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-fullCDR
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-minCDR
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_200f
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_300f
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400f
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_500
REMIND-MAgPIE 2.1-4.2	NGFS2_Divergent Net Zero Policies
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-95th
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-median
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000
REMIND-MAgPIE 2.1-4.2	SusDev_SSP1-PkBudg900
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

Table 3: Selected set of AR6 pathways for analysis