CLIMATE ANALYTICS

Fossil gas: a bridge to nowhere

Phase-out requirements for gas power to limit global warming to 1.5°C

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AUTHORS
Claire Fyson, Gaurav Ganti, Neil Grant, Bill Hare

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We regret any errors or omissions that may have been unwittingly made.

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Executive summary

The war in Ukraine and the on-going energy crisis have made it clear that a green energy transition is not only essential for avoiding the worst impacts of climate change. It is also a security matter. While there is growing consensus on the need for a power sector coal phase-out, fossil gas has largely flown under the radar.

This report assesses how fast fossil gas power generation must be phased out in different parts of the world to keep the Paris Agreement's 1.5°C temperature goal in reach. The scenarios used here were developed before Russia's invasion of Ukraine and the recent spike in oil and gas prices. Security and economic concerns may compel a faster phase-down of gas in some regions.

Key findings

Global gas phase-out dates

- Using global 1.5°C compatible pathways from the IPCC's Special Report on 1.5°C (SR15), we find that unabated fossil gas power generation needs to be effectively phased out (with less than a 2.5% share of generation) by 2045 in all regions of the world.
- The latest pathways assessed in the IPCC's sixth assessment report (AR6) show an even earlier phase-out date, by around 2040. A rapid phase-out of fossil gas from the power sector is becoming both more urgent, due to rising emissions, and more feasible, due to the falling costs of renewables and storage.
- The decline in fossil gas power generation starts immediately in 1.5°C pathways. Fossil gas use falls to 15% of total global electricity generation by 2030, reaching very low levels by 2035 (below 10% in SR15 pathways, and lower in AR6 pathways).
- Comparing these results with the International Energy Agency's (IEA) Net Zero Scenario gives a similar picture, with unabated fossil gas power generation dropping to 17% of total generation in 2030, and being phased out by 2050. It is worth noting that the IEA's Net Zero Scenario deviates substantially from IPCC 1.5°C pathways when we look at fossil gas use beyond the power sector: the IEA Net Zero scenario has significantly higher total unabated gas consumption over the next decade, reflecting more conservative assumptions over the availability of low carbon alternatives for non-electricity fossil gas applications.

At the regional level

- Developed countries see a faster fossil gas phase-out, with gas power generation falling below 10% of total electricity generation by 2030, to be effectively phased out by 2035.
- For developing countries, the pace varies between regions, but on average the share of fossil gas power generation falls below 10% by 2035 and is phased out by 2045 in SR15 pathways. However, our preliminary analysis of AR6 scenarios at the global level suggests that a faster phase-out is both cost-effective and necessary.

Table S1: Regional benchmarks for fossil gas power generation in 1.5°C Paris Agreement scenarios, given to the nearest five years

Region	Effective gas phase-out date *(2.5% threshold)*	Coal phase-out date
Developed countries	2035	2030
Developing countries	2045	2040

- Fossil gas cannot have a role as a transition fuel in the power sector. The fossil gas phase-out date occurs at most 5-10 years after the coal phase-out date in both developed and developing economies. Given the dramatic plummet in the cost of renewable energy, investing in new fossil gas power generation in the 2020s carries the risk of creating stranded assets.

Table S2: Regional coal phase-out dates compared with fossil gas phase-out dates, given to the nearest five years

Region	Coal phase-out date	Effective gas phase-out date
OECD	2030	2035
Non-OECD Asia	2035	2040
Latin America	2030	2030
Middle East and Africa	2035	2045
Eastern Europe and former Soviet Union	2030	2040

Achieving a rapid fossil gas exit in many developing countries will require financial, technical and, depending on the circumstances, transitional support from developed countries. The legal and ethical basis of this stems from the principle of common but differentiated responsibility and capability that underpins the climate regime and is encoded in the Paris Agreement

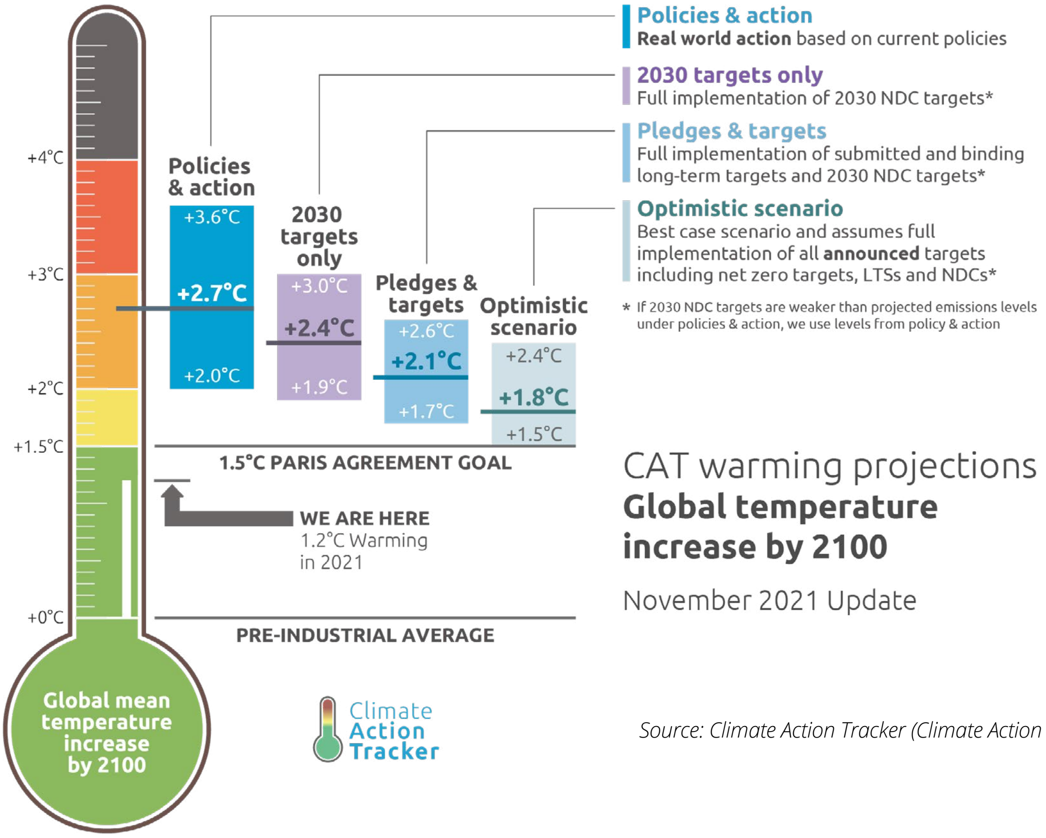
The gas phase-out dates presented here need to be considered in the context of sustainable development objectives and risks, such as the stranding of infrastructure and other assets in the face of continually declining costs of renewables and storage, and the challenges posed by volatile fossil fuel prices.

These results are based on globally cost-effective pathways generated by Integrated Assessment Models, and will need to be cross-referenced against other approaches to modelling 1.5°C pathways at the national level, particularly as IAM and IEA scenarios are often criticised for using conservative cost assumptions for renewable energy. They will also need to be updated to fully incorporate the latest generation of IAM scenarios assessed in the IPCC's sixth assessment report, to understand the implications of these newer scenarios for gas phase-out benchmarks in different countries and regions.

Introduction

More than six years on from the adoption of the Paris Agreement (and the 1.5°C warming limit enshrined therein – see Annex I), the collective effect of governments' emissions reduction targets in the near-to-medium term would still result in 2.4°C of warming by 2100. When only considering the collective effect of policies that have been put in place, representing real action on the ground, end-of-century warming would reach an alarming 2.7°C (Climate Action Tracker, 2021b). The disparity between global promises, targets and and action can be observed in Figure 1 below: not only are current policies far from meeting the 1.5°C warming limit but also from meeting pledges put forward by governments.

Figure 1: Projected end of century warming under (i) targets announced by countries and (ii) current policy projections



Source: Climate Action Tracker (Climate Action Tracker, 2021a)

One of the key short-term steps to close the ambition gap for 2030 is a rapid decarbonisation of the electricity sector. Our work from 2019 illustrated the need for a global coal phase-out from electricity generation by 2040, with OECD countries taking the lead by phasing out coal by around 2030 (Climate Analytics, 2019). There have been some positive developments in this regard. G7 countries[1] recently agreed to halt public financing for unabated coal power generation abroad and reiterated their domestic commitments to phasing out coal in the 2030s (Harvey, 2021). China has also promised to halt the financing of coal overseas.[2] Despite these positive developments, Australia China, Russia, India, Turkey, and Saudi Arabia have so far pushed back at any attempt to forge consensus on a coal phase-out among G20 member countries. Nevertheless, the UK COP 26 presidency made it clear that they expected "*[...] COP26 to be the COP where we consign coal power to history*" (Chestney, 2021), and the need to "phase down" coal power generation featured in the Glasgow Climate Pact (UNFCCC, 2021). This is the first time a reference of this kind has been included in a COP cover decision.

1 *G7 members include Canada, France, Germany, Italy, Japan, UK and the US. The EU (represented by the President of the European Council, and the President of the European Commission) participates as a guest.*

2 *See https://theconversation.com/china-will-no-longer-build-overseas-coal-power-plants-what-energy-projects-will-it-invest-in-instead-168614 and https://www.nature.com/articles/d41586-021-02645-w*

While there is growing consensus on the need for a coal phase-out from the power sector, fossil gas has, to some extent, flown under the radar, largely because supporters of this fossil fuel present it as a cleaner alternative to coal (we explore these arguments in further detail in the next section of this brief). A clear example of this is the European Commission's proposal to label fossil gas as "sustainable" under the EU's green taxonomy rules (Simon, 2022). This is despite the fact that fossil gas has contributed to nearly 50% of the growth in global fossil CO_2 emissions over the past few years, with the share of fossil gas for electricity and heat growing rapidly (Peters et al., 2020), and being responsible for over half of methane emissions from oil and gas production (IEA, 2021c).

This reality has shifted in light of the invasion of Ukraine by the Russian Federation, which has demonstrated the risks of European reliance on fossil gas, both in the power system as well as the broader energy system.

In the International Energy Agency's (IEA, henceforth) latest iteration of its Stated Policies scenario, which was developed before the Russian invasion of Ukraine, the growth of fossil gas is projected to persist under current, and stated government policies, (IEA, 2021e). This is largely driven by growth in generation in non-OECD countries in this scenario, while OECD countries see fossil gas power generation largely flatlining between 2020 and 2030. Globally, fossil gas power generation in this scenario was projected to account for nearly 21% of total electricity generation by 2030, and 70% of the projected increase in fossil CO_2 emissions. But projections of fossil gas use can be expected to change significantly when the IEA updates its assessment later this year, in light of recent geopolitical unrest and rising fossil fuel prices.

The IEA's Stated Policies scenario is far from being consistent with the Paris Agreement's 1.5°C warming limit (see Annex I, for a discussion on the long-term temperature goal of the Paris Agreement). The IEA assessed that this scenario would lead to end of century warming of 2.6°C with a 50% chance (or, 2.8°C, with a 66% chance). Whether or not the gap to a 1.5°C compatible pathway is closed will depend on how governments respond to the crisis. There are rising concerns that some countries (for instance, UK, the host of COP 26) may pivot further towards a fossil gas driven strategy in light of concerns over energy prices and inflation, following global market responses to the invasion of Ukraine and the persistence of the COVID-19 pandemic.

Analysis of 1.5°C compatible scenarios from the IPCC Special Report on 1.5°C shows that unabated use of fossil gas in total primary energy supply (TES) globally should already have peaked and be declining globally, and that it needs to drop by more than 30% below 2020 levels by 2030, and 65% below 2020 levels by 2040 (Climate Analytics, 2021c). The need to rapidly curb the supply of and demand for gas in the transition to a 1.5°C aligned energy system has been highlighted by the Beyond Oil and Gas Alliance, which was launched at COP26. The core members of this alliance have committed to set a Paris Agreement aligned date for ending oil and gas production (Beyond Oil and Gas Alliance, 2021).

This report focuses on the power sector component of present fossil gas demand, which consumes about 40% of demand. More concretely, we explore the global and regional role of fossil gas use in power generation in a world that meets the goals of the Paris Agreement and provide benchmarks for the phasing out of gas from the electricity system. Along with corresponding benchmarks for coal generation (see Climate Analytics (2019)), these benchmarks provide guidance to investors, governments and other stakeholders as to the level of fossil gas that is 1.5 degree compatible in power systems globally.

Developments and drivers of fossil gas in the power sector

While trying to understand the developments in, and drivers of fossil gas use in the power sector, it is important to note that the use(s) of fossil gas in the energy system are more versatile than those of coal. Globally, fossil gas use for power generation accounts for nearly 40% of total fossil gas consumption (Tsafos, 2014), with the proportion varying regionally – while OECD countries tend to have a diversified set of uses for fossil gas, non-OECD countries tend to use a higher proportion of fossil gas in the power sector (Peters et al., 2020).

A central argument raised by fossil gas proponents is that its use and expansion in the power sector is desirable and consistent with a Paris Agreement compatible energy transition, and in particular a transition to net zero, given its lower carbon intensity (compared to coal and oil) and ability to provide flexibility to the power system and support systems with high variable renewable energy (VRE) penetration. This argument has had implications for the ***demand*** for fossil gas and has guided the investment by countries and institutional investors in ensuring growing supply of fossil gas, including the rapid growth of LNG infrastructure (Climate Analytics, 2021b).

Demand

The (inaccurate) view that large-scale fossil gas power generation on a multi-decadal timeframe is consistent with the Paris Agreement has resulted in countries and regions – many of which have presented themselves as leaders in climate policy – supporting the expansion of fossil gas. The UK, which is pushing for a coal phase-out globally, is supportive of the expansion of fossil gas infrastructure – the country largely achieved rapid reductions in coal-fired power generation by switching to fossil gas, and to a smaller extent, nuclear power (Carbon Brief, 2017). The UK is still planning to bring 14 GW of additional gas capacity online, even though a recent analysis from Carbon Tracker has indicated that a clean energy portfolio in the UK is already cost competitive when compared to gas power plants (Carbon Tracker Inititative, 2021). Meanwhile, the European Commission has deferred its decision on including fossil gas within its sustainable finance taxonomy driven by support by some member states for the role of fossil gas as a "transition fuel".

Germany and the UK are among the top eight countries in the world in terms of net import of fossil gas for consumption in the energy system, making them highly vulnerable to supply disruptions and cost fluctuations. The desire to increase the role of fossil gas in power generation can be observed in South-East Asian economies, which are developing LNG-to-power value chains (IEA, 2021b). South Korea, in a stated attempt to reduce emissions and air pollution, has committed to converting 12.7 GW of coal capacity to fossil gas over the next decade in the 9th Basic Energy Supply and Demand Plan (MOTIE, 2020).

While this is by no means a comprehensive overview of the demand dynamics in play, the examples provided in this section have highlighted that many governments are planning to expand the role of fossil gas in their power systems, and the associated value chains.

Supply

Given the demand signals highlighted above, it is unsurprising that major fossil gas producers are competing among themselves to both capture a large share of the fossil gas market(s) and lock in long-term fossil fuel use, despite a clear finding from the IEA's net zero analysis that no new oil and gas field development is needed in a Paris Agreement compatible world (IEA, 2021d). Major countries that are net exporters of fossil gas include Russia, Qatar, Norway, Australia and USA. Australia is touting projections that domestic gas usage will rise by at least 20% by 2060, and strong projected export demand (primarily to other Asian countries) as a justification to build more gas and in particular LNG infrastructure as part of their Covid-19 recovery package (Crowe & Foley, 2020).

On the side of private investors, even relative frontrunners in the climate policy arena, including Axa and Allianz, who have adopted policies to restrict coal insurance and investment as part of climate risk policies either have vague commitments when it comes to fossil gas projects and companies, or explicitly support a future role for fossil gas in the global energy mix (Allianz, 2018). Allianz has also recently purchased a 75% stake in Portugal's largest fossil gas distribution network (Allianz, 2020).

The alternatives

The arguments in support of gas power generation are increasingly undermined by the ever-increasing economic case for switching to renewable energy instead.

Lazard's most recent review of the levelised cost of energy generation sources shows that solar photovoltaic (PV), particularly utility scale, but also often in the case of rooftop, is less expensive than gas peaking units,[3] and wind is increasingly cost competitive with fossil gas combined cycle power plants (Lazard, 2021a). While that report is careful to state that without storage, solar PV and wind "lack the dispatch characteristics, and associated benefits" of conventional technologies, Lazard's review of the levelised cost of storage shows that for "in-front-of-the-meter" applications, solar PV and storage systems are already cost competitive with gas peaking units (Lazard, 2021b). This finding is supported by recent technical work by Californian utilities, which indicates that gas peaker plants are increasingly non-economic in important electricity markets (Bullard, 2020).

In Australia, the low cost of renewables and storage means that the early retirement of the Eraring coal plant is not leading to replacement by increased gas power generation. Analysis of the impact of this plant's early retirement shows that total gas power generation capacity either remains the same (but with reduced gas power dispatch) or declines in the short term, and in the longer term decreases, while investments in solar, wind and battery storage become increasingly attractive. (J. Zapata et al., 2022)

The cost competitiveness of renewable energy and storage systems is expected to increase compared to fossil-powered systems, as declining cost trends are set to continue for some time (IRENA, 2021). This has implications in contexts where coal needs to be phased out as well as in countries where the electricity system needs to be expanded to meet growing demand.

The deployment of renewables and storage increases dramatically over this decade in 1.5°C compatible energy transformation pathways. For example, solar PV and wind capacity increases around five-fold between 2020 and 2030 in the IEA's Net Zero Scenario, reaching around 8000 GW in 2030 (IEA, 2021d). Such a rapid scale-up can be expected to drive further cost reductions. This will require a huge shift in investment patterns away from fossil fuels and into clean energy (McCollum et al., 2018; Rogelj et al., 2018). According to McCollum et al, investments in renewable electricity generation in 2030 in 1.5°C compatible pathways are a factor of 10 larger than those made in unabated fossil fuel generation, illustrating what a major investment opportunity the clean energy transition presents (McCollum et al., 2018). In the context of both changes in the economics of power generation and the strengthening of climate policy, reliance on fossil gas and long-term investment in its associated infrastructure come with a high risk of carbon lock-in and the crowding out of investment in renewable energy (Gürsan & de Gooyert, 2021).

3 *Gas peaking power plants, also known as "peaker" plants, generally only operate when there is high electricity demand, and in high penetration variable renewable energy-based electricity systems can be deployed where there is insufficient storage or other means of backup. Typically, one can see in 1.5°C transition pathways that gas power generation capacity remains relatively high whilst utilisation drops rapidly, with fossil gas use following the actual utilisation level.*

Global and regional benchmarks for fossil gas in power generation

Methodology

We briefly present the methods underlying this brief here, with a detailed description in the Annexes. We first construct a scenario ensemble building off the scenarios underlying the IPCC's Special Report on Global Warming of 1.5°C (SR1.5) (Huppmann et al., 2018), including 1.5°C scenarios that have been published since 2018 (Bertram et al., 2021; Strefler et al., 2021).

Not all of these scenarios are created equal – some overshoot the 1.5C warming limit by a significant margin, deploy unsustainable levels of bioenergy and afforestation/reforestation related carbon dioxide removal (CDR), and do not make use of demand side or non-CO_2 emission reductions in line with best estimates in the literature. To account for this we proceed to identify a subset of the scenario ensemble that are fully consistent with the warming limit of the Paris Agreement, sustainability thresholds with respect to CDR deployment (Climate Analytics, 2019, 2021a), and a diversified use of different mitigation options (following the approach laid out in (Warszawski et al., 2021)). These criteria are discussed briefly, along with the justification for the thresholds in Table 1. The application of these thresholds leaves us with a subset of 18 scenarios (see Annex II) that we use to identify benchmarks for the share of fossil gas in electricity generation. We add in a 100% renewable electricity scenario from the GENeSYS-MOD model, that was reported to SR1.5 (Löffler et al., 2017).

Table 1: Description of filters used to select benchmarking ensemble

Criterion	Threshold selected	Justification
Climate outcome	SR1.5 categories: "Below 1.5°C" and "1.5°C low overshoot"	The only emissions pathways from the IPCC SR1.5 report that are in line with the Paris Agreement LTTG are those categorised as "no or low overshoot 1.5°C pathways" that are "as likely as not" to limit peak warming to below 1.5°C throughout the 21st century (with a probability of more than 33%) and to limit warming to below 1.5°C in 2100 with at least 50% chance. Pursuing such an emissions reduction pathway would also give a 'very likely' (>90%) probability of not ever exceeding 2°C, in line with the interpretation of 'well below 2°C' as a 'defence line that needs to be stringently defended'. We explore this further in Annex I.
BECCS deployment within sustainability constraints	5 Gt CO_2 / yr by mid-century	Sustainability thresholds are applied for bioenergy with carbon capture and storage (BECCS) and carbon uptake drawing from estimates published by Fuss and others in (Fuss, Lamb, Callaghan, Hilaire, Creutzig, Amann, Beringer, Minx, et al., 2018), where the mid-century threshold is applied to the average of the 2040-2060 value from the scenario ensemble, following the approach we have previously adopted in (Climate Analytics, 2019).
Afforestation/ reforestation within sustainability constraints	3.6 Gt CO_2 / yr removal by mid-century	
Energy efficiency	At least 0% increase in final energy demand in 2050 relative to 2018 levels	Warszawski and others define several mitigation levers, and associated thresholds for "reasonable" and "speculative" use of these thresholds. The use of these levers to further down-select the ensemble helps to capture the balanced use of several mitigation options, without an excessive reliance on any one.
Carbon intensity of energy	At least 75% below 2018 levels by 2050	

We present the results for different thresholds, i.e., when the share of fossil gas in the region falls below 10%, 5%, 2.5%, and 1% of electricity generation, because there is no single definition of what a phase-out threshold would be. In this brief, we refer to the “effective phase-out” as the year when the share of fossil gas power generation falls below 2.5%, and the “total phase-out” as the year when the share falls below 1%.

This is effectively a “halving time” for the share of fossil gas power generation; at these low shares, fossil gas power generation generally only plays the role of a “peaking technology” or provides back-up during times of disruption to VRE systems, and therefore has a low-capacity factor. At low shares of fossil gas power generation, the remaining peaking plants may not be able to recover their investment costs, especially when there are possible overcapacities in the electricity system in these modelling frameworks at higher penetration of wind and solar (see Pietzcker et al. (2017)). Dedicated energy system models, which resolve the electricity system in more detail (an example of such a model, which was also assessed in SR15, is the GENeSYS-MOD 1.0) see a complete phase-out of gas in high mitigation scenarios (i.e., they achieve an absolute zero of fossil gas power generation). Such models also find techno-economically feasible pathways to a 100% renewable electricity system by mid-century.

We opt for using a definition of “phase-out” that is more in line with the characteristics of electricity systems than an “absolute zero” from models’ results. The choice of an “effective phase-out” at 2.5% is meant to indicate the year when remaining fossil gas assets will play a very specific role in the electricity system but will effectively be phased out as alternatives (for example, hydrogen for long-term energy storage) are phased into the system as a replacement.

For the purpose of deriving benchmarks, we focus on the share of **unabated gas power generation** in total electricity generation. The reason for this is threefold:

1. **The limited role of carbon capture and storage (CCS) in our benchmarking scenario ensemble:** In our benchmark scenario set, fossil gas with CCS reaches a median share of power generation of around 3% of total power generation in 2050 (the IEA’s Net Zero scenario sees even lower shares). This small share is unlikely to be necessary given the range of alternative technologies to provide dispatchable low-carbon power, including hydrogen turbines, geothermal and long-duration energy storage (Luderer et al., 2021).

2. **The unlikely deployment of CCS in the power sector:** Fossil fuel power plants with CCS have an energy penalty associated with the addition of a CCS unit because additional energy is needed in the process of capturing, transporting and storing carbon. For fossil gas power plants, this energy penalty can range from 5 – 20%, depending on the type of technology (Budinis et al., 2018). Coupled with the already high marginal cost of fossil gas power generation, and in light of the rapidly falling costs of battery storage for short-term grid balancing (highlighted earlier) and the co-benefits that renewable power can provide, the feasibility and value of fossil gas with CCS for grid balancing purposes is increasingly questionable, or just plain uneconomic. CCS in the power sector has not shown the necessary improvements in cost. A 2015 review (Rubin, Davison, and Herzog 2015) found that the costs of CO_2 capture from a range of power plants, when compared on a like-for-like basis, had increased by around 32-49% compared to estimates in the 2005 IPCC Special Report on CCS (IPCC 2005).

3. An additional hurdle is that not all CO_2 from fossil fuel combustion can be captured; capture rates from existing commercial CCS facilities are reported to be far lower than 90% (Howarth & Jacobson, 2021), meaning that carbon dioxide removal would be required to balance out uncaptured CO_2 emissions from gas plants with CCS.

Our results provide a first look at benchmarks for fossil gas power generation in different regions and globally, but need to be interpreted and contextualised carefully.

On the technical side, the new generation of pathways that underpin the IPCC’s sixth assessment reports (AR6), have less gas on average compared to the current generation because of the declining costs of renewables and storage in the power sector as well as the emergence of zero carbon alternatives in the so-called hard to abate sectors, which may otherwise use fossil gas. An update of this analysis will be needed to incorporate the latest insights from the global modelling community.

A preliminary analysis highlights that the need to rapidly phase out fossil gas from the power sector is becoming both more urgent and more feasible, as the remaining carbon budget consistent with 1.5 °C shrinks, and the cost of renewables continues to fall. In the latest pathways included in AR6, the share of unabated gas in electricity generation is lower by 2030, and the effective phase-out date of fossil gas at a global level is brought forward from around 2045 to 2040 (Byers et al., 2022; Riahi et al., 2022).

This is consistent with other analysis which has explored how the latest scenarios assessed by the IPCC assess coal phase-out requirements (Ember, 2022). Here again, the combination of a dwindling carbon budget and rapidly falling renewable costs means that an accelerated coal phase-out is both more urgent and more feasible. Subsequently, 1.5 °C compatible coal generation in 2030 is 50% lower in the latest set of pathways assessed by AR6, compared to those assessed in SR1.5.

On the policy and implementation side, it has to be emphasised that these results are based on global cost-effective pathways produced by Integrated Assessment Models (IAMs), and do not take into account a number of important factors. The regional level energy system transformations within these pathways are those that produce a global least-cost, or cost-effective, outcome, but have nothing to say about who should pay for this transformation. In other words, the pathways used here give a reasonably good picture of the physical changes that will be needed in a regional energy system in order to meet the Paris Agreement's 1.5°C limit, but they offer no insight into the level of financial, technological or other support that will be needed in developing countries to achieve the transformations consistent with these benchmarks and to enable a just and equitable transition.

The benchmarks developed here provide general guidance to countries and regions in relation to fossil gas deployment levels consistent with the Paris Agreement. Over time, this needs to be supplemented by nationally specific analysis which may show slightly slower or slightly faster transitions, depending upon national circumstances. For many developing countries the benchmarks we have derived can inform the level of international financial and / or other support that would be needed if their electricity systems are not to exceed an emissions level consistent with the Paris Agreement. Achievement of these benchmarks cannot be seen separately from the availability of climate finance and technology for many developing countries.

Gas power generation benchmarks at the regional level

The results for five aggregated regions commonly used in IPCC assessments are shown in Table 2. A list of members of each region is provided in **Annex III**. Here, we present the date when the threshold is crossed in the median of the pathways, with the range across all the pathways included in **Annex II.** Since most modelling groups report their outputs in 5 or 10-year timesteps, we interpolate values linearly for years in between.

Table 2: Year of crossing different thresholds (10%, 5%, 2.5%, and 1%) in unabated gas power generation across different regions

Region	Share of gas power generation in 2010	10% threshold	5% threshold	2.5% threshold	1% threshold
Non-OECD Asia	11%	2032	2036	2040	2047
Latin America	22%	2027	2029	2030	2033
Middle East and Africa	49%	2037	2040	2047	2055
OECD	22%	2030	2034	2036	2040
Eastern Europe and former Soviet Union	42%	2035	2038	2040	2049
World	22%	2034	2039	2043	2050

We use the regional definitions of the IPCC SR1.5 database (see annex III)

The key observation from **Table 2** is that fossil gas is effectively phased out across all regions by around 2045. Developed countries (OECD and EU countries) see the share of fossil gas in total generation halved (compared to the share in 2010) over this decade, and an effective phase-out around 2035. Asian countries and countries in Eastern Europe and the former Soviet Union see an effective phase-out of fossil gas power generation by 2040. As noted above, these are conservative estimates given that the latest scenarios assessed by the IPCC show on average a decline in fossil gas power generation.

Our regional results are unpacked further below, but when interpreting these results there are some crucial caveats to bear in mind. These caveats stem from the general insight that models agree on high-level decarbonisation characteristics needed to meet low carbon targets, but the more granular results (for instance, the specific regional electricity mixes) are a function of diverse assumptions underlying the modelled system (for instance, the regional cost trajectories for different technologies) (Krey et al., 2019). Importantly, the regional resolution of these large-scale models can limit their use for direct policy advice at the national level (Schreyer et al., 2020). Nonetheless, such models can provide very useful insights into regional trends that can form the basis for more targeted national-level benchmarking exercises.

An illustration of such interpretation challenges can be seen in the Latin American region. Latin America sees the earliest phase-out of fossil gas power generation in these results. This likely relates to the low share of fossil gas power in many countries and the high share of renewables, in particular hydroelectric power generation. The adverse effects of drought on hydroelectric generation in Latin America have been observed in recent years; increasingly frequent droughts and a reduction in generation have been linked to both climate change impacts and deforestation (Arias et al., 2020; Cuartas et al., 2022), although there is considerable uncertainty in the response of hydropower potential to future climate impacts (V. Zapata et al., 2022). In general, climate change impacts are not well incorporated into most existing IAM scenarios, and efforts are underway to change this. It is clear, though, that Latin America has one of the most dynamic renewable energy markets in the world (IRENA, 2016), and that the role of hydropower is transitioning towards supporting the rapid development of variable renewable energy systems. Renewables experienced record growth in Latin America in 2021 that seems likely to continue (Wood MacKenzie, 2021), providing an opportunity for a rapid transition to clean and low cost power in the region.

In the OECD region there is a rapid decline in levels of fossil gas power generation that accelerates over this decade and next, reaching an effective phase-out by the mid-2030s. This is consistent with the IEA's Net Zero 2050 scenario, which has 2% of fossil gas power generation in 2035 among advanced economies (IEA, 2021a). Within this region, European countries in particular face increasing security challenges that are exacerbated by reliance on Russian gas, adding further impetus for a rapid transition from gas power generation to renewables and storage, combined with an accelerated roll-out of heat pumps, electric vehicles and other end-use electrification and energy efficiency measures (Climate Analytics, 2022b; IEA, 2022).

In the rest of Asia, where a number of countries are currently planning a transition from coal power to fossil gas power generation, the share of gas power falls gradually in the 2020s but picks up pace in the 2030s to reach an effective phase-out by 2040. There will be a substantial risk of stranded assets within these countries and in exporting economies if current gas infrastructure expansion plans are implemented. Across this diverse region, improved energy access will be fundamental for supporting sustainable development, which can be achieved through the largely untapped renewable energy development.

Eastern Europe and the former Soviet Union currently have a high share of gas power generation, but in the pathways assessed here this drops to 10% by 2035 and reaches an effective phase-out by 2040. Many of the countries in this region are heavily dependent on fossil fuel imports, with coal and/or fossil gas the dominant power generation fuel. Import reliance is increasingly challenging from an economic, political, environmental and security perspective, particularly in the context of the current geopolitical and energy crises. Renewables, energy efficiency and electrification measures provide an increasingly economic and stable alternative to fossil fuels, but financial support will be needed for many countries in this region to scale them up at pace.

The Middle East and Africa is the region with the highest current share of gas power generation, although there is substantial variation in the power mix across the region. By the late 2030s these pathways show on average only 10% remaining and an effective phase-out is reached in the mid 2040s. For many countries in this region, access to electricity will need to increase over the next one-to-two decades, and renewables are an economic and versatile option for achieving this, and also for supporting economic development objectives of the region. New investments in fossil gas infrastructure come with a high risk of becoming stranded assets as international investors and energy companies shift away from fossil fuels (Climate Analytics, 2022a). But realising a rapid scale-up of renewables and resilient power grids in this region will require investment from wealthier nations to develop supply chains and upskill the workforce needed to install and maintain a renewables-based power system.

Comparison with the IEA Net Zero 2050 scenario

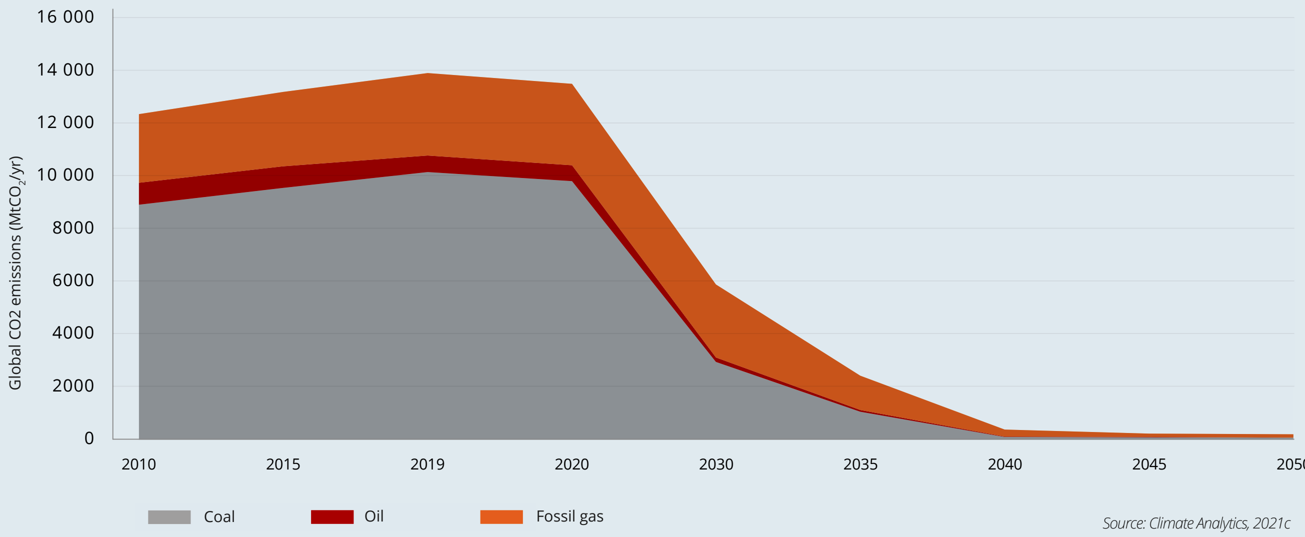
Box 1: *Fossil gas power generation in the IEA Net Zero 2050 scenario*

The IEA's Net Zero 2050 scenario is claimed to be completely consistent with the 1.5°C warming limit of the Paris Agreement. Our analysis shows that this pathway can be classified as a "1.5°C low overshoot" pathway, and was further confirmed by more analysis presented in the 2021 edition of the World Energy Outlook (Brecha et al., 2021; IEA, 2021d).

With respect to fossil gas, the IEA only reports global data in the scenario that it released. In this scenario, global gas power generation (unabated) accounts for 17% of total generation in 2030 and falls to 0% by 2050. The median of our benchmarking scenario ensemble has an unabated gas power generation share of 15% in 2030, indicating that the IEA net zero scenario is broadly consistent with our benchmark scenarios in terms of fossil gas power generation. The IEA net zero scenario also sees a marginal role for fossil gas with CCS (~1% in 2050), reiterating the unlikely deployment of CCS in the power sector.

A key benchmark from the IEA's Net Zero by 2050 roadmap is for the power system to have net zero emissions globally by 2040. By this date, the roadmap sees only a very small share (1%) of unabated gas power generation remaining, and the emissions from gas power generation are balanced by CO_2 removal from the deployment of BECCS to achieve net zero emissions (Figure 2). This illustrates the trade-off between the pace of gas power generation phase-down and the level of reliance on CDR.

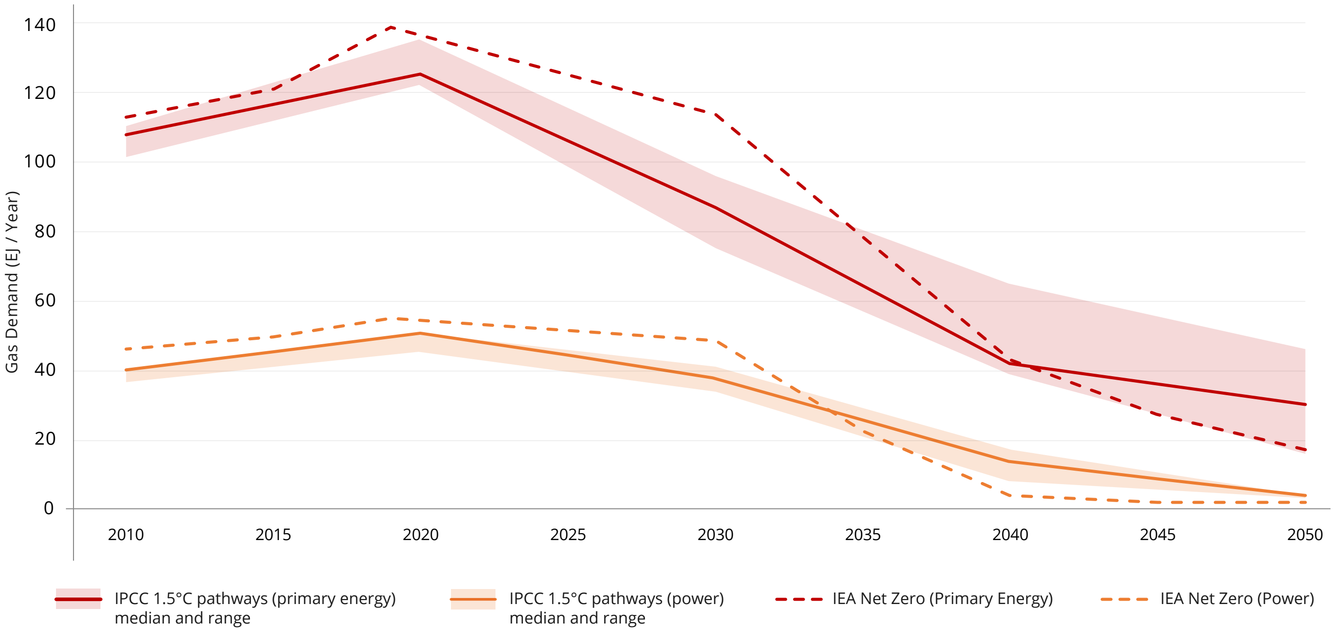
Figure 2: CO_2 emissions from electricity and heat sectors and their constituents in the IEA's Net Zero 2050 scenario



Source: Climate Analytics, 2021c

The results in our analysis are broadly consistent with the IEA's Net Zero scenario (see box 1). However, when we look beyond the power sector at fossil gas use in total primary energy supply, the IEA's scenario deviates substantially from the IPCC 1.5°C compatible pathways. The IEA Net Zero scenario has significantly higher total unabated gas consumption over this decade than the IPCC pathways (Figure 3). Given recent technology trends and the availability of low carbon alternatives for non-electricity fossil gas applications, the IEA's assumptions are likely to be too conservative, leading to an inflated reliance on fossil gas in the energy system. (Climate Analytics, 2021c)

Figure 3: Unabated fossil gas use in total primary energy and electricity under 1.5°C compatible scenarios compared with the IEA's Net Zero scenario



Source: Climate Analytics, 2021c

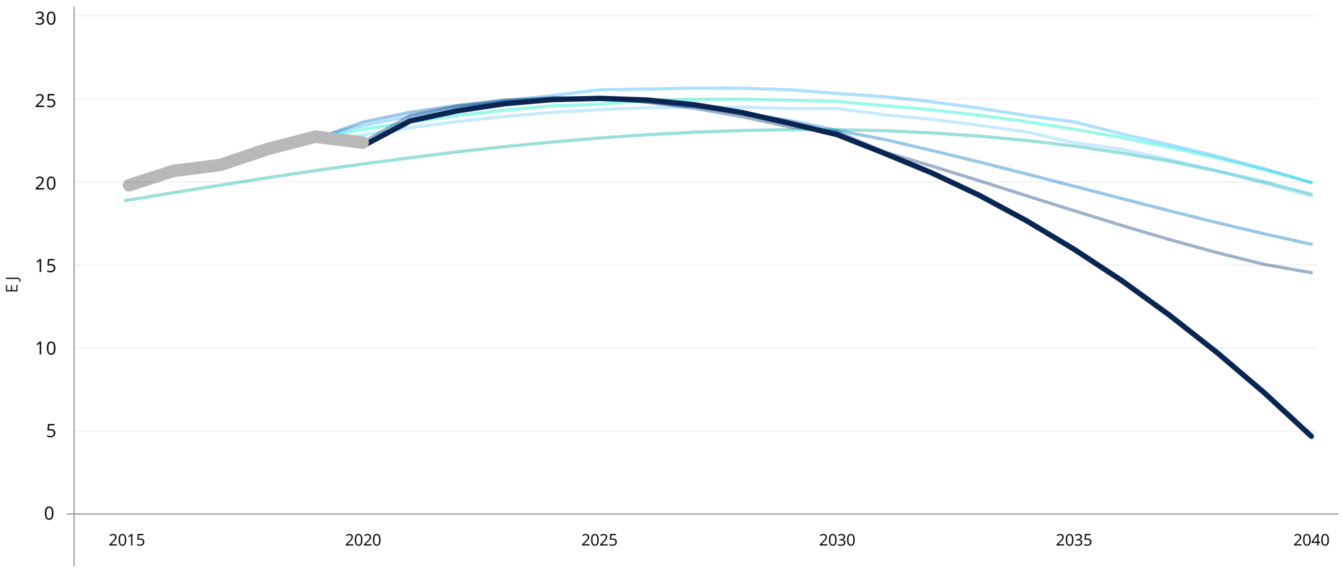
Both the IEA's Net Zero scenario and the set of 1.5°C compatible pathways analysed in this report give results that likely represent the upper limit on fossil gas use in a Paris Agreement compatible world. This is because of the rapid and ongoing decline in the costs of renewable power generation sources and storage, combined with the many drawbacks inherent to the development of gas power infrastructure (including stranded asset and lock-in risks, increased reliance on CDR, and the challenges associated with fossil CCS).

IAMs used to generate the pathways we assess have been criticised for using out-dated and/or conservative assumptions on the cost of renewable generation and storage technologies (e.g. Creutzig et al., 2017). Accounting for the observed rapid decline in these costs can drive a faster energy system transition and erode the value of CCS with gas in the power system (Bogdanov et al., 2019; Grant et al., 2021). The most recent generation of IAM scenarios assessed in the IPCC AR6 show a more rapid rollout of renewable generation and storage technologies than previous generations.

In addition, IAMs rely to differing degrees on CDR, and this also has implications for the pace of decarbonisation in different scenarios. A recent analysis showed that limiting the use of negative emissions technologies such as BECCS in modelled mitigation scenarios leads to a fall in gas power generation when compared with scenarios without such a limit (Grant et al., 2021). Different assumptions over the availability and desirability of different CDR options can therefore affect the pace of gas phase-out in modelled mitigation pathways. If a policy maker assumes that reliance on CDR is unwise then fossil gas use would need to be reduced faster than in the alternative case. In other words, allowing large-scale fossil gas use to continue for decades would impose an obligation for greater levels of CDR use in the future.

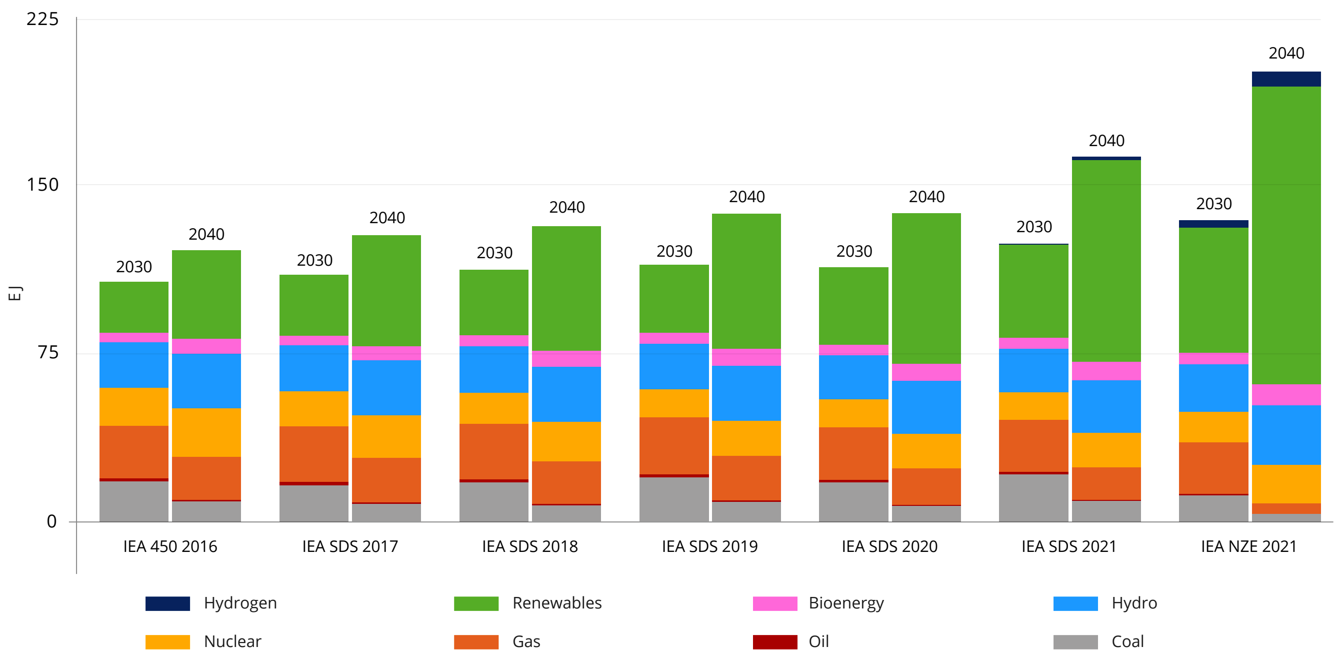
When we look at how the IEA's scenarios have evolved over time, we can see a clear downwards revision in projected gas power generation and an associated acceleration in the scale-up in renewables (see figures 4 and 5). Initial analysis of IPCC AR6 scenarios shows a similar tightening up of fossil fuel benchmarks when compared to those assessed in previous reports, including the SR1.5 scenarios used here.

Figure 4: Historic and projected fossil gas power generation under successive IEA scenarios published in the years from 2016 to 2021



Source: Climate Analytics, 2021c

Figure 5: Projected power generation mix in 2030 and 2040 under different IEA scenarios



Source: Climate Analytics, 2021c

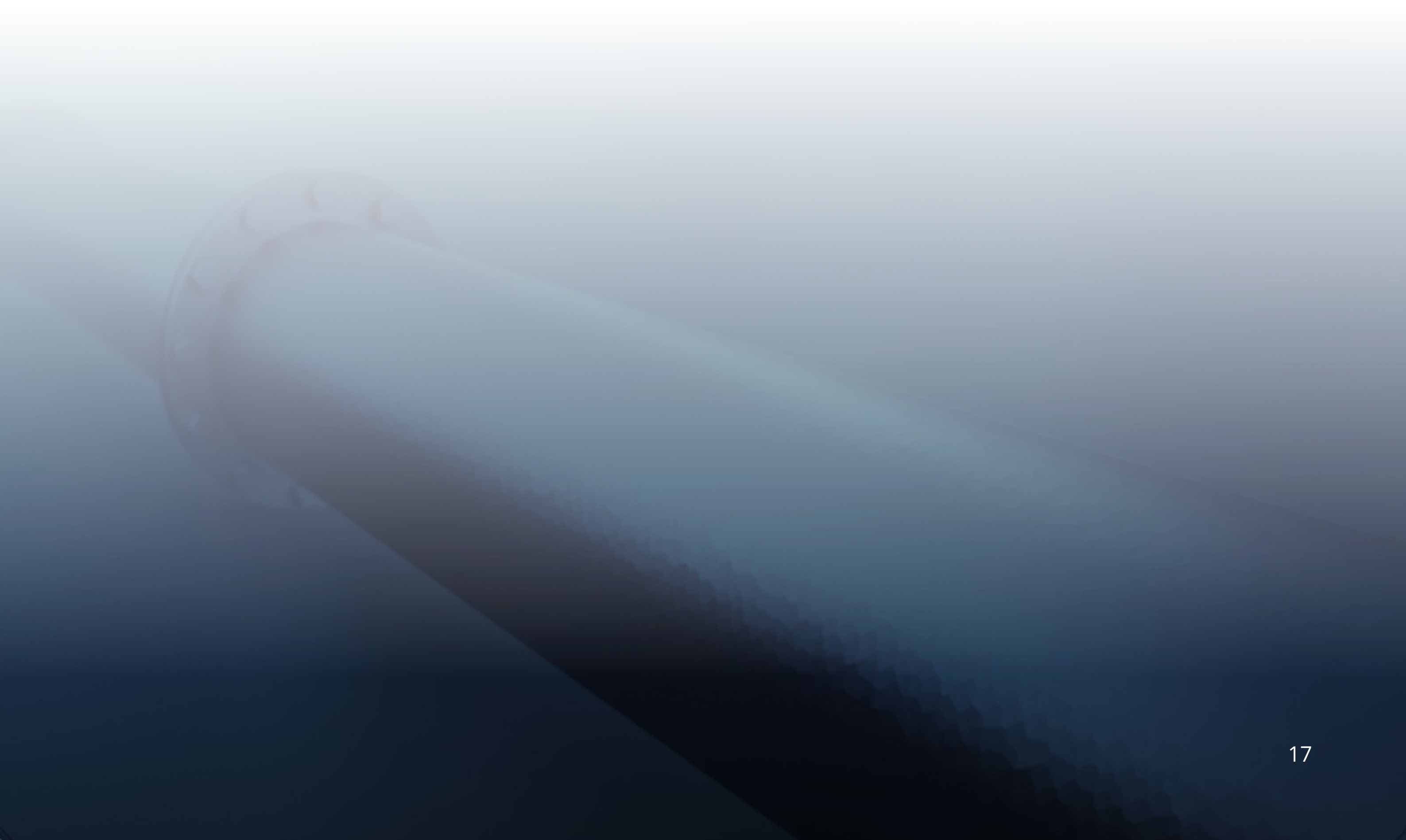
Gas phase-out follows closely behind coal phase-out

Having established an initial set of benchmarks for fossil gas in electricity generation, we now compare these benchmarks to updated coal phase-out benchmarks for the same set of scenarios (Table 3). The key observation is that the fossil gas phase-out occurs at most 5-10 years after the coal phase-out across all world regions, reiterating the importance of a managed, yet rapid decline in the role of fossil fuels in the electricity system.

In the same way that many developing countries would need international support to achieve such a rapid phase-out of coal – covering the need for additional investment, transitional costs and grid infrastructure changes – many of these same countries would need support to achieve such an early phase-out of fossil gas in the power sector. Whilst there are undoubted benefits in many cases from switching away from fossil fuels in terms of reducing the need for expensive imports, reduced air pollution and other environmental damages, there are also substantial social and economic adjustment needs.

Table 3: Updated regional coal phase-out dates compared with fossil gas phase-out dates, given to the nearest five years

Region	Coal phase-out date	Effective gas phase-out date
OECD	2030	2035
Non-OECD Asia	2035	2040
Latin America	2030	2030
Middle East and Africa	2035	2045
Eastern Europe and former Soviet Union	2030	2040



Beyond the power sector

A lot of focus has been placed on the role of fossil fuels in the electricity system, but the role of fossil fuels in the broader energy system is just as important to benchmark. Our recent Why gas is the new coal report provides a first quantification of the future of gas in a Paris Agreement compatible energy system, confirming that gas is not a viable "bridging fuel" (Climate Analytics, 2021c). Further scientific analysis is needed on the future of fossil fuels in specific sectors. We take an initial look at the role of coal used in the industrial sector in Box 2.

Box 2: ***Coal use in the industry sector in 1.5C pathways***

The IEA estimated that, under stated policies, coal use in the industry sector will grow to 52EJ in 2030, and fall slightly to 50.8 EJ in 2040. To assess how this stacks up against 1.5°C consistent pathways, we assess the "Net Zero 2050" scenarios from the MESSAGE and REMIND models that were part of the Network for Greening the Finance System (NGFS) scenario database (Bertram et al., 2021), and also part of our benchmarking ensemble. The reason we select these pathways is because they explicitly report the consumption of coal for industry.

These two scenarios see strong reductions in coal use in the industry sector over the next decade. The MESSAGE Net Zero 2050 scenario sees coal use in industry falling to 17 EJ in 2030, 5 EJ by 2040, and nearly 0 EJ by 2050.

The REMIND Net Zero 2050 scenario sees coal use in industry falling even faster over this decade, to 7 EJ by 2030, 2 EJ by 2040, and persisting at low levels thereafter.

While these are only two scenarios, limiting the ability to derive robust benchmarks, they do indicate a rapidly diminishing coal use beyond the electricity sector. Further work, including using IAM scenarios assessed in the IPCC's AR6 would help to develop more detailed benchmarks.

Conclusion

Given the long lifetime of fossil fuel related infrastructure, the milestones of the global energy system transformation presented in this report are at odds with the continued expansion of coal and gas assets. Increasing recognition and attention to this problem is evident for the coal sector, however fossil gas is still perceived by many as viable option for a net zero energy system.

We have established that fossil gas does not have a role as a transition fuel in the power sector.

In a Paris compatible energy transition the share of fossil gas in power generation falls below 10% in the regions we assess in the 2030s and is ultimately phased out at the global level by around 2040. This finding adds impetus to the urgent need to scale-up renewable power generation and storage infrastructure.

In the 1.5°C compatible pathways that we've assessed, the OECD would lead the phase-out of unabated coal (by 2030) and gas power generation (2035). In the non-OECD Asian, Middle East and African regions, these phase-out dates fall on average 5-10 years later.

Governments and oil and gas majors trying to construct a future for gas in a low-carbon transition will need to reassess their approach. This push, if continued, would lead to the build-up of infrastructure that risks making fossil gas the new coal, and would leave countries with expensive stranded assets whether they be power stations, LNG import terminals or gas pipelines - or all three. Instead, resources need to rapidly shift to investments in renewable energy and storage.

COP26 made an important step in highlighting the decline of coal power generation and the need to phase out fossil fuel subsidies. The establishment of the Beyond Oil and Gas Alliance was also a key step in encouraging governments to set a Paris Agreement aligned end-date for oil and gas production (Beyond Oil and Gas Alliance, 2021). However, the absence of gas from the Glasgow Climate Pact shows that there is work to be done.

Clear signals from governments regarding the phase-out of fossil fuels are an important step towards ensuring such an allocation of resources occurs. The transition needs to be well managed and complemented with region-specific measures focusing on creation of alternative employment opportunities, in particular for regions that will have to undergo deep structural change.

Achieving such a rapid fossil gas exit in many developing countries will require financial, technical and, depending on the circumstances, transitional support from developed countries, to facilitate a just and equitable transition. The legal and ethical basis of this stems from the principle of common but differentiated responsibility and capability that underpins the climate regime and is encoded in the Paris Agreement.

This study is based on outputs from IAMs that aim to optimise mitigation action across regions to find cost-effective solutions; the value in using IAMs lies not in the results from a single scenario, but in examining the trends and outputs from a wide variety of scenarios in which many technological parameters can be varied. The gas phase-out benchmarks reported here will need to be cross-referenced against other approaches to modelling 1.5°C pathways at the national levels, risks such as stranding of infrastructure and other assets in the face of continually declining costs of renewables and storage, energy security concerns and other sustainable development objectives.

A preliminary look at the latest IPCC scenarios suggests that unabated gas power generation falls even faster in these new scenarios, reflecting the need for accelerated action to limit warming to 1.5 °C, as well as rapid technological progress in renewables.

Reducing reliance on fossil gas is not only crucial for addressing climate change. The Russian invasion of Ukraine and the ongoing energy crisis have shown that it is also a matter of security and socio-economic wellbeing. All signs are pointing to the end of all fossil fuels, and the start of a clean energy era.

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Annex I – The Paris Agreement's Long Term Temperature Goal

Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC) defined the goal of the Convention to "*achieve stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system*." Since 1992, the Parties to the UNFCCC have determined the long-term temperature goal (LTTG) that aligns with the prevention of dangerous climate change, in light of best available science. Prior to the Paris Agreement (from 2010 – 2015) the LTTG was defined as "below 2°C", but in 2015, on adoption of the Paris Agreement and based on scientific developments, the LTTG was updated to "*well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 °C*" (article 2.1(a) Paris Agreement).

As part of a formal review of the adequacy of the LTTG, which took place over 2013-2015, an extensive science-policy dialogue was undertaken. This dialogue, known as the Structured Expert Dialogue (SED), concluded in its summary report that based on the extensive evidence reviewed, "*the 'guardrail' concept, in which up to 2°C of warming is considered safe, is inadequate and would therefore be better seen as an upper limit, a defence line that needs to be stringently defended*", and that efforts should be made to "*push the defence line as low as possible*", noting that a warming limit of 1.5°C would come closer to a "safer guardrail" (UNFCCC, 2015b).

The Paris Agreement defined a new LTTG in its Article 2.1(a) based on the outcome of this review. The LTTG delineates the permissible space for future warming, and caters for two interpretations: establishing a 1.5°C limit as a ceiling that should not be exceeded; or allowing for a temporary exceedance (overshoot) of the 1.5°C limit, while warming should always remain "*well below 2°C*" (Mace, 2016).

The reports of the Intergovernmental Panel on Climate Change (IPCC) provide the best available science for the determination of emissions reduction pathways that are in line with the LTTG under the Paris Agreement. The only emissions pathways from the IPCC SR1.5 report that are in line with the Paris Agreement LTTG are those categorised as "no or low overshoot 1.5°C pathways" that are "as likely as not" to limit warming to below 1.5°C throughout the 21st century (with a probability of more than 33%) and to limit warming to below 1.5°C in 2100 with at least 50% chance.

Annex II – Methodology

In this report, we use the scenarios underlying the Special Report on 1.5°C as a starting point. To this, we add the scenarios assessed in the Network for Greening the Financial System (Bertram et al., 2021) and the scenarios from Ref. (Strefler et al., 2021). We filter this scenario ensemble to include only "low overshoot" scenarios, i.e., scenarios that have at least a 33% chance of keeping warming below 1.5°C over the course of the century as well as at least a 50% chance of keeping warming below 1.5°C in 2100. This leaves us with a set of 63 scenarios that are consistent with the warming limit of the Paris Agreement.

However, many of these scenarios rely heavily on Carbon Dioxide Removal (CDR), calling into question the sustainability of these scenarios. To account for this, we down select the ensemble of scenarios to consider the sustainability thresholds for CDR via Bioenergy with Carbon Capture and Storage (BECCS) and Afforestation/Reforestation (A/R) as presented in Ref. (Fuss, Lamb, Callaghan, Hilaire, Creutzig, Amann, Beringer, De Oliveira Garcia, et al., 2018). We further consider the application of other mitigation levers assessed by Ref. (Warszawski et al., 2021). We collect the 2018 values for the mitigation levers from the World Energy Outlook of the International Energy Agency (IEA, 2020). The IEA estimates that Total Final Consumption (TFC) in 2018 was 9959 Mtoe, or 416.96 EJ (1 Mtoe = 0.041868 EJ). The IEA estimates that emissions from energy and industrial processes amounted to 35,679 Mt CO_2. Thus, the carbon intensity of final energy amounts to 85.5 Mt CO_2 / EJ in 2018.

Of the 63 scenarios, only 18 scenarios pass all the criteria laid out above. We refer to these scenarios as our "Benchmarking ensemble" (**Table A1** below). We also include a 100% renewable energy scenario from the GenESYS-MOD model, that was reported to the SR1.5 database (the 19th scenario in our benchmarking set).

Table A1: Benchmarking ensemble

Model	Scenario
AIM/CGE 2.0	SSP1-19
	SSP2-19
IMAGE 3.0.1	IMA15-LiStCh
	SSP1-19
MESSAGE-GLOBIOM 1.0	ADVANCE_2020_1.5C-2100
MESSAGEix-GLOBIOM 1.0	LowEnergyDemand
MESSAGEix-GLOBIOM 1.1	Divergent Net Zero
	Net Zero 2050
POLES EMF33	EMF33_1.5C_cost100
	EMF33_1.5C_limbio
	EMF33_1.5C_nofuel
	EMF33_WB2C_nobeccs
	EMF33_WB2C_none
REMIND-MAgPIE 2.1-4.2	Divergent Net Zero
	Net Zero 2050
REMIND-MAgPIE 2.1-4.2 IntegratedPhysicalDamages (95th)	Net Zero 2050
REMIND-MAgPIE 2.1-4.2 IntegratedPhysicalDamages (median)	Net Zero 2050
WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_400
GENeSYS-MOD 1.0	1.0

Fossil gas benchmarks

The resulting fossil gas benchmarks across regions are in **Table A2** below:

Table A2: Fossil gas benchmarks (median and range)

Region	Approach	10% threshold	5% threshold	2.5% threshold	1% threshold
R5ASIA	max	2042	2052	2062	2070
	median	2032	2036	2040	2047
	min	2015	2022	2024	2032
R5LAM	max	2040	2048	2052	2060
	median	2027	2029	2030	2033
	min	2015	2020	2023	2024
R5MAF	max	2046	2051	2100	2100
	median	2037	2040	2047	2055
	min	2015	2031	2034	2035
R5OECD90+EU	max	2040	2043	2047	2089
	median	2030	2034	2036	2040
	min	2024	2025	2032	2034
R5REF	max	2053	2058	2060	2072
	median	2035	2038	2040	2049
	min	2015	2024	2025	2028
World	max	2040	2049	2060	2100
	median	2034	2039	2043	2050
	min	2023	2025	2032	2034

Annex III – Regional definitions

Here we use the regional definition of the IPCC SR1.5 database. The regions are defined as:

OECD = Includes the OECD 90 countries, therefore encompassing the countries included in the regions **Western Europe** (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom), **Northern America** (Canada, United States of America) and **Pacific OECD** (Australia, Fiji, French Polynesia, Guam, Japan, New Caledonia, New Zealand, Samoa, Solomon Islands, Vanuatu).

REF = Countries from the **Reforming Economies** region (Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Georgia, Hungary, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Malta, Poland, Republic of Moldova, Romania, Russian Federation, Slovakia, Slovenia, Tajikistan, TFYR Macedonia, Turkmenistan, Ukraine, Uzbekistan, Yugoslavia).

ASIA = The countries included in the regions **China** + (China, China Hong Kong SAR, China Macao SAR, Mongolia, Taiwan) , **India** + (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka) and **Rest of Asia** (Brunei Darussalam, Cambodia, Democratic People's Republic of Korea, East Timor, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Papua New Guinea, Philippines, Republic of Korea, Singapore, Thailand, Viet Nam) are aggregated into this region.

MAF = This region includes the **Middle East** (Bahrain, Iran (Islamic Republic of), Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen) and **African** (Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cote d'Ivoire, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Democratic Republic of the Congo, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libyan Arab Jamahiriya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Reunion, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Tunisia, Uganda, United Republic of Tanzania, Western Sahara, Zambia, Zimbabwe) countries.

LAM = This region includes the **Latin American** countries (Argentina, Bahamas, Barbados, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad and Tobago, Uruguay, Venezuela).

For additional information see:
http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome


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