Global and regional coal phase-out requirements of the Paris Agreement: Insights from the IPCC Special Report on 1.5°C

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Report by Climate Analytics
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Cover image
Thermal coal power station in Raichur, India

CLIMATE ANALYTICS

Table of contents

Key messages 3
Introduction 6
Developments and drivers in the coal power sector since 2015 6
  Policy drivers 8
  Financial market drivers 8
  Electricity market drivers 9
Insights from the IPCC Special Report on 1.5°C on coal phase out 9
  Assessment of Paris Agreement compatibility of pathways in the IPCC SR1.5 10
  Focus on coal generation without carbon capture and storage (CCS) 12
  Determination of coal phase-out dates 13
Paris Agreement vs planned and existing coal capacity – global picture 15
  Methodological assumptions 15
  Global results 15
  Indicative share of Paris Agreement coal power carbon budget 16
Paris Agreement vs planned and existing coal capacity – regional picture 17
  OECD countries 18
  Eastern Europe and former Soviet Union 18
  Middle East and Africa 20
  Asia 20
  Latin America 21
Conclusion – powering away from coal is key to ramping up ambition 22
Annexes 24
Annex I – Defining 1.5°C Paris Agreement compatible pathways 24
Annex II – Filtering IPCC SR1.5 scenarios 24
Annex III – Region definitions 27
Annex IV – Coal Generation and Emissions Calculation Approach 28
Annex V – Sensitivity Analysis for Key Assumptions 29
References 32

Key messages

This study unpacks for the first time the implications for coal power of 1.5°C Paris Agreement compatible energy transformation pathways assessed in the IPCC Special Report on Global Warming of 1.5°C[1]. To evaluate the practical implications for a coal phase-out under the Paris Agreement we focus on unabated coal because we consider that the future deployment of carbon capture and storage (CCS) for fossil fuel power plants is very unlikely due to high cost and the absence of CCS in the current coal pipeline.

Based on regional pathways for the five regions considered by the Special Report on Global Warming of 1.5°C by the Intergovernmental Panel on Climate Change (IPCC SR1.5), the main findings are:

- Regardless of the region, coal use for power generation needs to peak by 2020, and be reduced quickly afterwards;
- Unabated coal-fired power generation globally should be reduced to 80% below 2010 levels by 2030 and phased out before 2040, some 10 years earlier than previous estimates;
- Most reductions in coal in the power sector need to happen by 2030, when the share of coal in electricity generation should not exceed 13% anywhere, and be around 6% globally;
- Between 2030 and 2040 all the regions should phase out of coal. The first regions to phase out are the OECD, Eastern Europe and Former Soviet Union countries - by 2031, followed by Latin America by 2032, Middle East and Africa by 2034, and finally non-OECD Asia by 2037, completing a global coal phase-out before 2040.

Table -1 – Phase-out dates of median Paris Agreement compatible regional pathways

Region	Phase-out Date
OECD	2031
Non-OECD Asia	2037
Latin America	2032
Middle East and Africa	2034
Eastern Europe and Former Soviet Union	2031

These results confirm the key findings of our 2016 report in regards to the need for peaking coal use in electricity generation by 2020, the rapid reduction needed afterwards, and the fact that some regions like the OECD and the EU need to phase out earlier than the rest of the world. In 2016, only one Paris Agreement compatible pathway was available. With the availability of a significant number of new pathways it is clear that the global coal phase-out should be much earlier than 2050, as estimated in 2016. Based on examination of all available regional pathways we now estimate that phase-out should be completed at the global level by a median date of 2037.

[1] Paris Agreement compatible pathways consistent with 1.5° C global warming were defined in the IPCC 1.5°C Special Report as model pathways with no or limited overshoot of 1.5° C. In addition, this study applies the IPCC defined sustainability constraints on the pathways analysed which were operationalised in the form of limits for bioenergy combined with carbon capture and storage (BECCS), as well as carbon uptake in the land sector. Applying these criteria this study has analysed 18 scenarios that are consistent with the Paris Agreement.

At present the world is not tracking towards a Paris Agreement compatible phase-out of coal. Current and planned coal power plants globally would lead to a generation increase of 3% by 2030 compared to 2010 levels. If the world follows these present trends, this would lead to cumulative emissions from coal power generation almost four times larger than what would be compatible with the Paris Agreement by 2050.

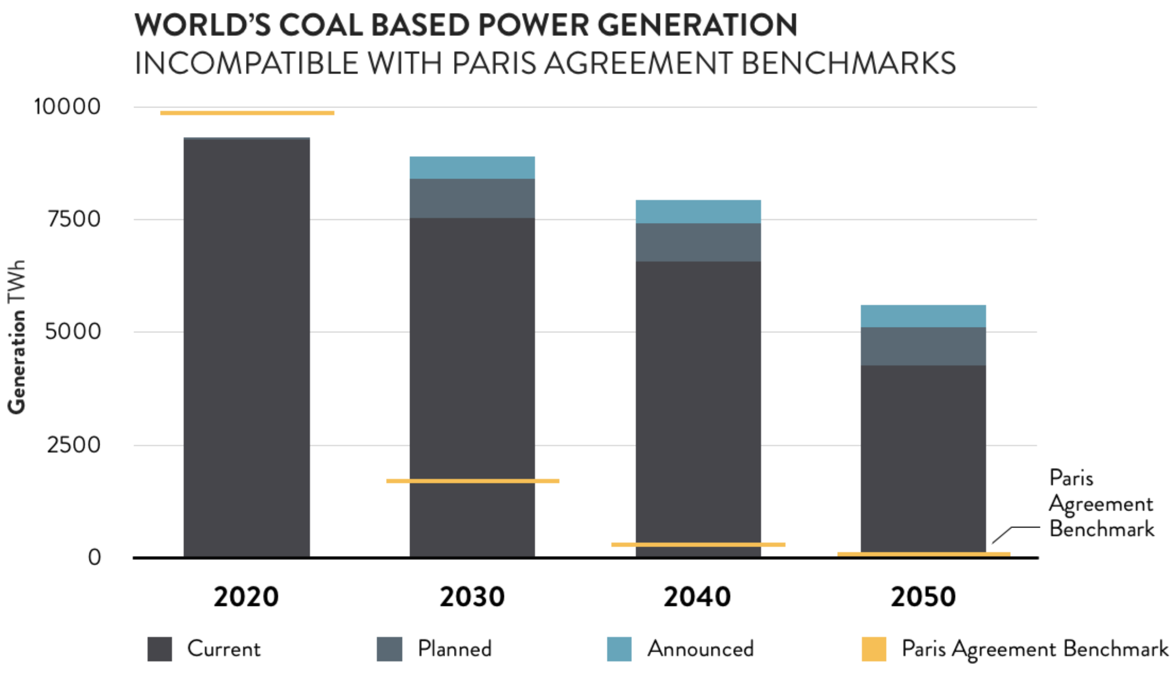

Figure 1 - Future coal generation from current and planned coal power plants against Paris Agreement benchmarks

To keep the door open for staying within the Paris Agreement's 1.5°C limit, countries will need to plan to retire a large number of existing coal power plants early, reduce the capacity factor of those that remain, and refrain from building new coal capacity.

There are some signs of action in the sector, providing cause for optimism on the possibility of an accelerated transition away from coal. The number of new coal power plants in the planning pipeline shrank by nearly 75% globally between 2015 and 2019, and several countries and investors have committed to either restrictions or a complete ban on new coal power generation. The capacity factor of the operating coal fleet continues to decline in several countries, affecting coal utilities' profitability and their willingness to invest in coal asset expansion and refurbishment. As a result, coal assets are becoming increasingly vulnerable to market and policy changes around the world.

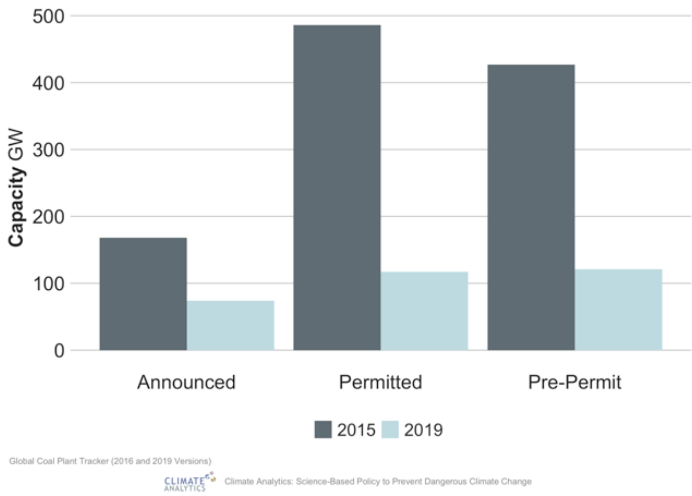

Figure 2 - Change in coal pipeline reported in 2019 compared to reported in 2015

However, progress is far too slow compared to what is required under the Paris Agreement. In addition to the actions being taken by investors and national entities to restrict new coal capacity, a fundamental reconfiguring of the global power sector is needed, led by a shift away from coal (and other fossil fuels). This transformation will benefit from the rapidly falling cost of renewable energy and storage technologies, making a fast transition to renewable energy increasingly feasible.

A critical opportunity to scale up national and international climate ambition is the current revision cycle for Nationally Determined Contributions (NDCs), as laid out in the Paris Agreement. Under the current NDC revision cycle, all countries are expected to submit new, more ambitious climate pledges by 2020. Strengthening governments' commitment to climate policy via the NDCs by including a clear commitment to phase out coal, remove subsidies for fossil fuels, and build support for renewables and energy efficiency, offers new opportunities for industrialised and developing countries alike to build a resilient, low-carbon economy in line with the commitments made in Paris. Doing so would provide many benefits in addition to avoiding climate impacts, including avoided air pollution, increased access to clean and modern energy, employment opportunities, and increased energy independence and security.

At the same time, by enhancing their commitment to the Paris Agreement and planning for an early coal phase-out, governments can reduce the risk of creating stranded assets with their associated costs, and send a signal to large institutional investors to increase their involvement in the low-carbon economy. Doing so would also encourage non-state actors to avoid further investments in coal and reduce their exposure to this risky sector

Introduction

The adoption and entry into force of the Paris Agreement has been key in accelerating the transformation of energy systems globally over the last four years. Achieving the goals of the Paris Agreement requires a rapid transformation of our current energy system. The transformation required is unprecedented both in terms of scale as well as the pace of change.

With rapid declines in the Levelised Cost of Electricity (LCOE) from renewables, we now observe that renewables are within the fossil-fuel range, with some projects significantly cheaper (**Figure 3**). This is an important development, as a rapid transition towards renewable energy in the power sector is widely acknowledged to be cost-effective with currently available technology and of paramount importance in decarbonising the energy system. A key facilitator of this transition to renewable energy is to phase-out coal-fired power generation, which accounted for 29% of global power generation in 2018 (IEA, 2019). Two key questions are of utmost policy relevance while considering such a transition:

- **How quickly does coal-fired power generation have to exit the energy system, if we are to meet the goals of the Paris Agreement?**
- **What is the emissions impact of the current and planned coal fleet, and how does this compare to Paris Agreement benchmarks?**

To answer these questions, Climate Analytics produced a pioneering study in 2016, examining the few 1.5°C compatible pathways available at the time. The key finding of the 2016 study was that unabated coal power generation should be phased out in OECD and EU countries by 2030 at the latest, by 2040 in China, and 2050 in the rest of the world (Climate Analytics, 2016). The study also identified that the committed emissions from the **operating and under-construction plants alone** would exceed a budget for coal generation consistent with 1.5°C and 2°C by 250% and 140% respectively.

Multiple studies have reached similar conclusions about the overcommitted emissions from the current and planned coal fleet (Bertram et al., 2015; Climate Action Tracker, 2015; Climate Analytics, 2016, 2017, 2018b, 2018a, 2019; Davis, Caldeira, & Matthews, 2010; Steckel et al., 2017).

This study is the first to look at coal in the power sector applying the most recent 1.5°C compatible pathways from the IPCC Special Report on Global Warming of 1.5°C (IPCC SR1.5 henceforth) (IPCC, 2018). In this report we aim to provide updated answers to the key questions highlighted earlier, guided by the best available scientific knowledge assessed in SR1.5.

Developments and drivers in the coal power sector since 2015

Significant changes have been observed since 2015 in the planned expansion of the global coal fleet. The urgent need for global action to phase-out coal from the electricity system is contradicted by the real-world growth in coal-fired power generation. We observe a net increase of 63 GW of operating coal-fired capacity between 2015 and 2019[2].

However, this was accompanied by a **significant decrease in plans to expand the coal fleet**. The coal pipeline has shrunk by nearly 75% between 2015 and 2019. This dramatic decrease is shown in **Figure 2**.

[2] All the information about coal fleet and pipeline developments in this report uses as main source the information provided in the July 2019 version of the Global Coal Plant Tracker database (Global Coal Plant Tracker, 2019) and compares it with the June 2015 version of the database used for our 2016 report.

Since 2015, 1034 planned or announced projects for coal plants around the world have been cancelled or shelved, mostly in China. Also, for three years in a row since 2016, leading indicators of coal power capacity growth have declined, including construction starts, pre-construction activity, and plant completions (Shearer, et al. 2019). This points to a clear aversion towards financing new coal-fired power plants among many governments and investors.

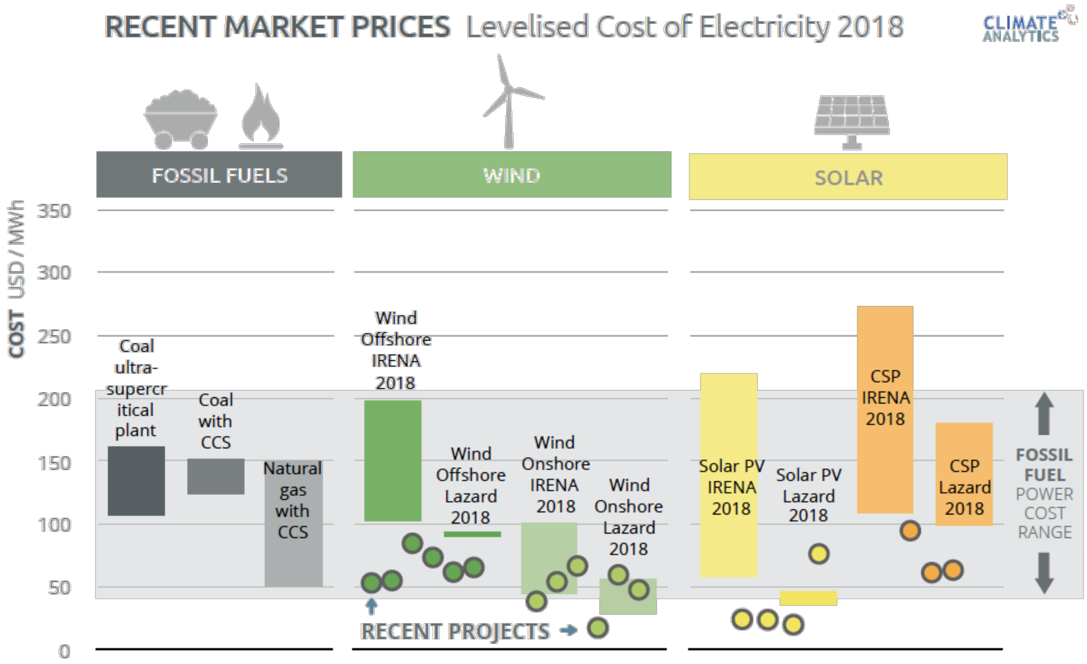

Figure 3 - Levelised cost of electricity comparison between fossil fuels and renewable sources. Source(s): (IRENA, 2019; Lazard, 2018)

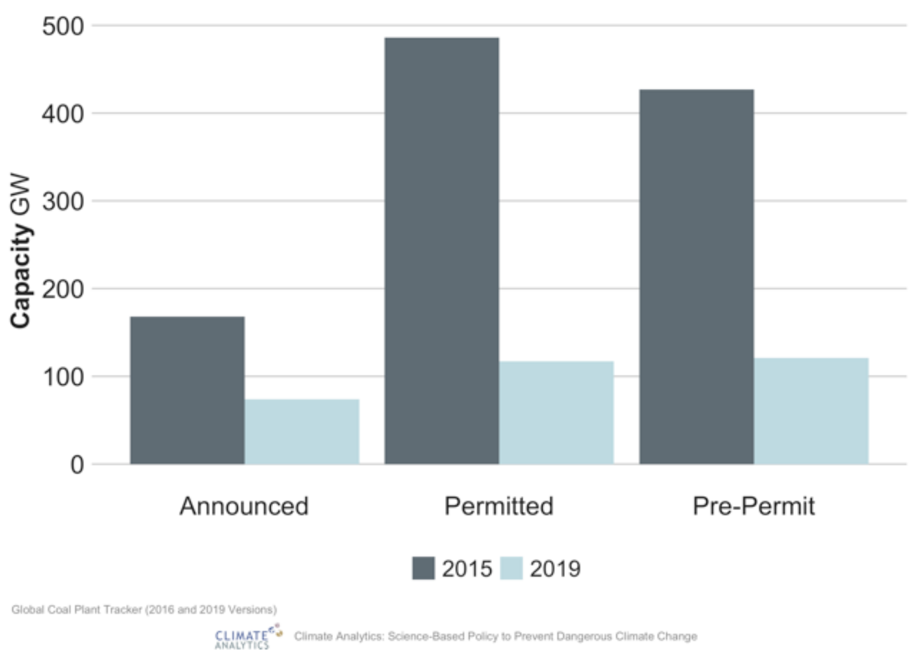

Figure 4 - Change in Coal Pipeline between 2015 and 2019

While the trends and drivers behind the changes observed since 2016 in the existing and planned coal fleet are country specific, there are some key global drivers for progress in the coal sector.

Policy drivers

Several governments, public, private and financial institutions have committed to either restrict or a completely ban new coal power generation, including the members of the Powering Past Coal Alliance (PPCA, 2019). Members of the PPCA subscribe to phasing out coal in OECD countries and the EU by 2030, and by 2050 globally, based on our earlier analysis.

These include most of the over 30 countries and several sub-national jurisdictions with currently operating coal capacity, which have commitments to phase out coal from their electricity system, and are increasingly putting concrete measures and policies in place to achieve this goal.

Apart from climate change concerns, coal assets are becoming increasing vulnerable to other policy changes around the world. These include air pollution regulation, and policies addressing other negative externalities of coal such as soil pollution, competition for land and water resources at the local level.

Other factors making coal assets vulnerable, in particular those related to coal extraction and commercialisation, are policies related to limiting import quantities in key geographies like China and India. This, together with demand reduction from countries phasing down coal, results in increasing uncertainty around the international coal trade market dynamics, in particular for low quality coal.

Recent trends, which are expected to continue in the future, unless global coal production is reduced substantially, are showing an oversupply of production leading to a crash in international thermal coal prices. Compared to 2018, in 2019 the Northwest Europe import reference price API2 market has crashed to around $50/t (-47%); South African API4 to around $60/t (-43%) and the Australian Newcastle to around $75/t (-30%)(Lauberts, 2019).

Financial market drivers

Over 100 significant financial institutions (with assets under management or loans outstanding above US$10 billion), created or strengthened their policies to divest from or ban or restrict financing of thermal coal. This includes 40% of the top 40 global banks, 20 of the biggest global insurers, nine public development finance institutions, 35 export credit agencies, and seven Multilateral Banks including the World Bank, the European Bank for Reconstruction and Development, and the Asian Infrastructure Investment Bank (Buckley, 2019).

Importantly, a growing number of investors have officially declared the achievement of the Paris Agreement as an overarching priority for their business strategies in the Global Investor Statement to Governments on Climate Change, released at COP24 in 2018.

The signatories of the Statement - 477 to the date - (Asia Investor Group on Climate Change et al., 2019), which include some of the world's largest pension funds, asset managers and insurance companies representing over US$34 trillion in assets, called for a complete thermal coal phase-out globally by 2050, in China by 2040, and in the OECD and EU by 2030. These signatories referred to the Paris Agreement benchmarks for the coal sector that Climate Analytics described in its 2016 report (AIGCC, CERES, IGCC, PRI, & UNEP FI, 2018).

In addition to reducing investors' exposure to assets at risk of stranding, these commitments are sending a clear market signal to coal-related businesses, investors and governments, putting them in a stronger position to move away from fossil fuels, while ensuring a sound transition for affected regions and workers.

Electricity market drivers

The capacity factor of the operating coal fleet continues to decline globally, with sharp decreases in key coal geographies, such as the USA, China, the European Union and India. The collapse in average global coal-fired power plant capacity factors has seen record lows each year, dropping from almost 90% in the early 2000's to less than 60% in 2017 (Buckley, 2019).

While the realities of each geography are different, key drivers behind this decline are increased competitiveness and penetration of alternative energy sources in the national electricity mixes, clear signs of coal overcapacity building due to poor energy system planning, stronger air pollution regulations, and difficulties of power plants to operate in a warming world due to factors such as heat stress and water scarcity.

These factors make utilities less willing to invest in coal asset expansion or refurbishment, but also decrease their profitability and credit ratings. This increases the risk and vulnerability profile of these companies, as evidenced by the increasing number of announcements of policies targeted at coal divestment by banking and insurance institutions.

A remarkable change in the global electricity market since 2016 is that now, in a growing number of places, most renewable energy generation technologies are cheaper than new coal capacity and even cost competitive with large shares of the operating coal capacity on an LCOE basis (see). With current market trends it is expected that by next year, solar PV and onshore wind projects will have lower marginal operating costs that 700-900 GW of operating coal-fired power generation capacity (IRENA, 2019).

These cost metrics exclude the cost of the externalities associated with coal, such as contribution to climate change and air pollution. If these externalities were considered and internalised through a high enough carbon price, coal would become by far the most expensive power generation technology everywhere in the world.

Even a moderate carbon price, which does not reflect all the externalities of coal, like the one observed in the European Union since the recent reform of its Emissions Trading Scheme, is already pushing coal out of the market (Carbon Tracker Initiative, 2018).

Insights from the IPCC Special Report on 1.5°C on coal phase out

To help guide implementation of the Paris Agreement, in October 2018, the Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Global Warming of 1.5°C (IPCC SR1.5), following the invitation in the Agreement. In this report, the IPCC assessed the best available science on how global temperature rise can be limited to 1.5°C, consistent with the long-term temperature goal of the Paris Agreement. The IPCC report focuses on the transformations at the global and sectoral levels that are necessary for achieving the 1.5°C goal, as well as opportunities, challenges, and key enabling factors for achieving these transformations.

A key insight from the IPCC Summary for Policymakers (SPM) is: "*In 2050 … In modelled 1.5°C pathways with limited or no overshoot, … the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0-2% interquartile range) of electricity (high confidence)*".

To understand the global and regional policy implications of this important finding and to provide updated answers to policy questions, we unpack the underlying emissions pathways included in the IPCC SR1.5, assess their compatibility with the Paris Agreement, and look in detail at the power sector implications of these pathways both at the global and regional levels.

Assessment of Paris Agreement compatibility of pathways in the IPCC SR1.5

The IPCC SR1.5 assessed 90 pathways that represent emissions trajectories leading to a warming below 1.5°C by the end of the century. Only a fraction of these pathways can be considered Paris Agreement compatible, once the key characteristics of the long-term temperature goal of the agreement (PA LTTG), as well as sustainability criteria are considered. In this briefing, the following criteria are applied to obtain "Paris Agreement consistent" pathways:

- Following the focus in the IPCC SR1.5 Summary for Policy Makers, the Pathway should fall into one of the two categories defined by the IPCC: "Below-1.5°C" or "1.5°C-low-OS (overshoot)". The former includes pathways which limit warming below 1.5°C throughout the 21st century with a 50-66% likelihood. The latter include pathways which limit median warming to below 1.5°C in 2100, with a 50-67% probability of overshooting this level earlier, temporarily but by no more than 0.1°C. For further details on pathway classification, refer Annex I – .

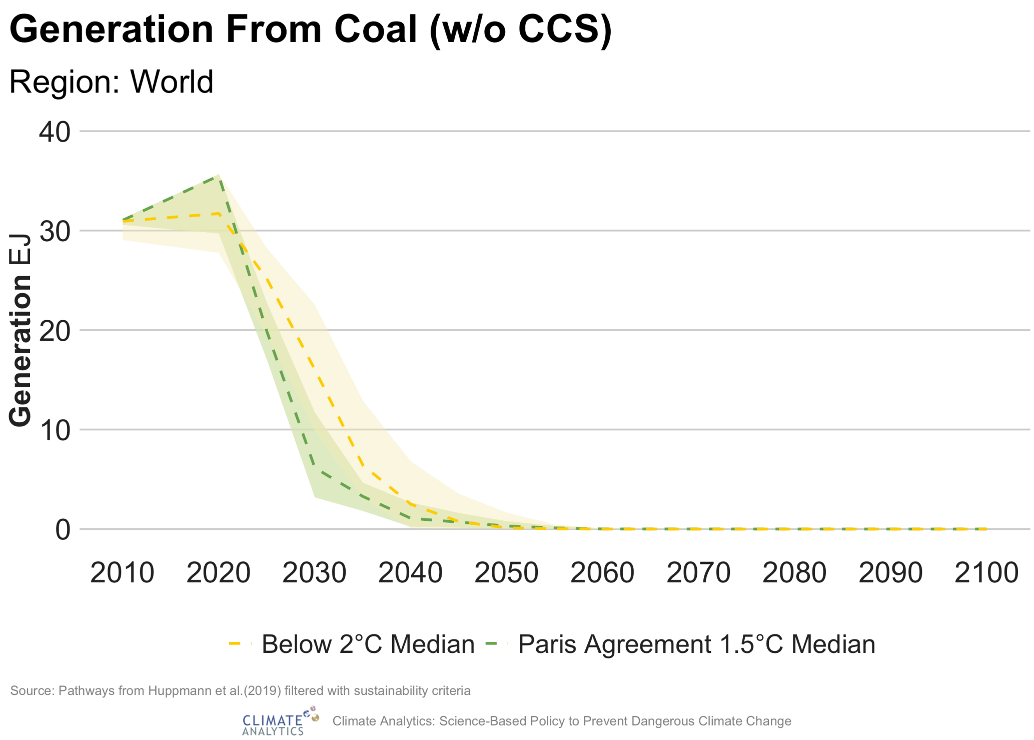

Figure 5 - Generation from coal in Paris Agreement compatible and 'Below 2°C' compatible pathways

- Sustainability considerations are operationalised in the form of limits for bioenergy combined with carbon capture and storage (BECCS), as well as carbon uptake in the land sector. Applying sustainable limits identified in the IPCC SR1.5, we filter out pathways which have more than 5 Gt CO_2/year, Bioenergy with Carbon Capture and Storage (BECCS), on average between 2040-2060 and those for which uptake from Agriculture, Forestry and Other Land Use (AFOLU) is more than 3.6 $GtCO_2$/year on average between 2040-2060. These limits identified in the IPCC SR1.5 are based on estimates of feasibility and sustainability in the published literature. For further details on the filters applied, refer to Annex II – Filtering IPCC SR1.5 scenarios

Applying these criteria to the IPCC SR1.5 mitigation pathways, leaves us with 19 scenarios that are consistent with the Paris Agreement. We also add back to this filtered sample the Beyond two Degrees Scenario (B2DS) from the International Energy Agency(IEA, 2017), which gets filtered out since it does not provide information for the entire second half of the century but provides a close analogue to a 1.5°C compatible pathway and fits in key respects within the electricity pathways from the IPCC SR1.5 scenario set[3]. With this addition we end up with 20 scenarios for coal in the power sector that are consistent with the Paris Agreement

To guide the analysis in the following sections of this report we then calculate the median and interquartile range for coal use in the power sector for our filtered subset (in line with IPCC approaches) to derive the benchmark Paris Agreement compatible pathways.

We find that these resulting pathways exhibit the same general characteristics as the indicative pathway analysed in our 2016 report: under Paris Agreement compatible scenarios, unabated coal electricity generation peaks around 2020, decreases steeply afterwards reaching a 80% (62-90%) reduction below 2010 levels by 2030, a 97% (91-99%) reduction by 2040, and reaching nearly zero by 2050.

Figure 5 shows the median and interquartile range for this subset of pathways, and for comparison purposes, for "Below 2°C"pathways [4].

These pathways confirm the key finding of the IPCC SR1.5 SPM, showing use of unabated coal to be reduced to close to 1% (0-2% interquartile range) of electricity generation by 2050, but allow important conclusions to be derived about the speed of reduction needed in the short-term, as well as identifying regional pathways for coal use.

One important conclusion from the comparison with the IPCC SR1.5 SPM, as well as with the "Below 2°C" ranges (which include pathways with high overshoot of 1.5°C), is that **the steep decline and quick phase-out of coal use for power generation is not a feature unique to "Paris Agreement consistent" pathways**. As shown in Figure 5, both Paris Agreement and "Below 2°C" sets of pathways show a dramatic decrease of coal use for power generation, reaching close to zero by 2050.

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[3] We have applied the same climate model evaluation of warming levels as was applied in the IPCC SR1.5 and earlier IPCC AR5 to the B2DS scenario to check as an analogue to a 1.5°C compatible pathway. If net negative CO_2 from the energy sector were assumed as in other 1.5°C compatible pathways warming would drop to below 1.5°C after the peak at 1.6°C. Therefore, with both the energy-related CO_2 emissions in the B2DS scenario up to 2060, and its peak warming at 1.6°C around 2060, comparable to low-overshoot 1.5°C scenarios, the B2DS scenario until 2060 is confirmed to be a suitable analogue to 1.5°C compatible pathways for the period to 2030. For more details see (Climate Analytics, 2018a)

[4] Defined here as pathways from the IPCC SR1.5 database with high overshoot of the 1.5°C limit or that limit warming to 2°C by the end of the century (which are filtered for the same sustainability criteria as the pathways classified as compatible with Paris Agreement). After applying our filtering criteria, we end up with a total of 55 out of 111 pathways, which are the full sample space of what we hereafter refer to as "below 2°C" pathways.

Moreover, while at first sight the "Below 2°C" pathways seem to show a much slower yearly decline until 2030 than the Paris Agreement pathways (7% vs 16% yearly decline between 2020 and 2030), it must be noted that the former decline is likely strongly underestimated given that the median of this subset of the total group of "Below 2°C" pathways shows stagnation of coal use at 2010 until 2020. This trend is far away from the trends observed globally in coal use during this period, which are much better described by the median of the PA consistent pathways.

In both sets of pathways, coal generation is nearly 0 EJ by 2050. In the 2030-2040 period, reductions in "Below 2°C" pathways reach the same levels as 1.5°C pathways with a typical lag of only 5 years. Given the much lower global carbon budget 1.5°C pathways as assessed in IPCC SR1.5, this means that **the additional emission reductions required** in a 1.5°C pathways compared to "below 2°C" **are not from coal use in the power sector.**

In the rest of this section, we discuss the insights from these pathways for how quickly coal-fired power generation has to exit our energy system, if we are to meet the goals of the Paris Agreement.

Focus on coal generation without carbon capture and storage (CCS)

The Integrated Assessment Models (IAMs) that produce the underlying pathways used for estimating coal generation in line with the Paris Agreement incorporate a number of technologies to achieve emissions reductions.

Among these technologies, most models include the use of carbon capture and storage (CCS) in coal power plants. Among the 20 pathways resulting from our filtering exercise, the only one that does not consider the use of coal with CCS at all is the Low Energy Demand (LED) scenario from the MESSAGE model (Grubler et al., 2018).

In this report, we focus on the relevance of coal-fired power stations for global emissions and therefore consider only coal generation without CCS. The main reasons to exclude coal use with CCS from our report are the following:

- In IAMs, coal power plants with CCS are assumed to emit little or no CO_2, and hence within the model are not relevant for emission budget considerations. In reality, coal power plants with CCS are very likely to emit at the very least a tenth of the average emissions compared with an installation without CCS (World Nuclear Association, 2018) and therefore cannot be considered a zero carbon alternative to coal in the power sector.

- Deployment at scale (i.e. excluding the handful of demonstration and pilot projects across the globe) of CCS for fossil fuel power plants is unlikely given the reduction in electric output efficiency and high costs, especially with the rapidly declining costs of zero-carbon alternatives. The economic and technical performance results of CCS demonstration projects for coal power plants to the date provides evidence in favour of this assumption.
- Most of our policy recommendations are derived by comparing the IAM coal generation pathways against the future potential for generation implied by the current and planned coal fleet. There are no planned CCS-equipped power plants (based on information in the GCPT database), a clear indication that large scale deployment of CCS for coal power plants is extremely unlikely in the relatively short timeframe in which rapid emissions reductions are needed.

Table 1 Comparison of phase-out dates for different regions

Region	Pathways	Phaseout Date	% Reduction of coal generation by 2030 (2010 Baseline)
OECD	12	2031 [2029,2035]	86% [76%,97%]
Non-OECD Asia	12	2037 [2034,2041]	63% [53%,83%]
Latin America	12	2032 [2026,2045]	85% [40%,97%]
Middle East and Africa	19	2034 [2031,2042]	80% [63%,96%]
Eastern Europe and Former Soviet Union	19	2031 [2030,2044]	86% [67%,98%]

- Retrofitting existing coal plants with CCS could present an alternative to early retirement of the existing capacity and might be viable for some coal power plants. However, based on the cost of zero emissions alternatives in the power sector, we consider this development unlikely.

- Focusing on phase-out dates that are based on coal use with CCS would create a false sense of complacency in the coal sector. Instead, we prefer a precautionary approach that only considers the use of coal without CCS and therefore hedges against the risk that CCS technologies will not deliver at the scale currently implied by some of the models.

Determination of coal phase-out dates

Given the dramatic differences in the starting conditions for electricity systems and the underlying socioeconomic emissions drivers in different regions of the world, we approach this question looking at regional pathways for the five regions used in most of the models considered by the IPCS SR1.5: OECD, non-OECD Asia, Latin America, Middle East and Africa, Eastern Europe and Former Soviet Union. Full region definition at the country level in Annex III – Region definitions.

To be consistent with the global pathways, we present here the median (central estimate) and interquartile range (next to median estimate in brackets) results[5].

[5] However, it must be noted that these medians and ranges are not directly comparable across regions (as they would be, if the regional and global pathways were derived from one model like in our 2016 report), given that due to the limited regional resolution of some of the models underlying our benchmark pathways, the sample space for Paris Agreement compatible pathways reduces even more for some regions. Nonetheless, given the high convergence of global pathways for coal use the results presented here are a very good indication of the speed of decline in coal use required in each region.

Using a range of pathways (instead of a single one) and representing the results as medians and ranges is a strength of the approach we follow in this report, which is able to show that the results are robust across a variety of models and scenario assumptions, rather than just one.

Mirroring our 2016 report approach, we define the coal phase-out date as the year in which the underlying pathway for coal use in electricity generation without CCS reaches reductions of 90% or more below 2010 levels (year of calibration of most models with historical data). We follow this approach to determine the phase-out date for each region.

We opt for using this definition of "phase-out" since it is more in line with the characteristics of electricity systems than an "absolute zero" from IAM results. Given the structure and underlying assumptions of IAMs, which often have a built-in inertia to large system changes (as opposed to marginal changes), these pathways exhibit long tails for reaching absolute zero in key variables, which are a modelling artefact and don't reflect what one would expect in the real world.

The main finding from looking at the regional Paris Agreement compatible pathways is that regardless of the region, coal use for power generation needs to peak by 2020, and be reduced quickly afterwards, with the bulk of reductions happening by 2030, where the share of unabated coal in electricity generation should not exceed 13% anywhere, and be around 6% globally.

Between 2030 and 2040 all the regions should reach a phase-out, in the following order: OECD, Eastern Europe and Former Soviet Union by 2031; Latin America by 2032, Middle East and Africa by 2034, and finally non-OECD Asia by 2037, completing a global coal phase-out before 2040.

These results confirm the key findings of our 2016 report in regards to the need for peaking coal use in electricity generation by 2020, the need for rapid reductions afterwards, and that some regions like the OECD and the EU need to phase out earlier than the rest of the world.

However, an examination of the full range of Paris Agreement compatible pathways (as opposed to looking at only one pathway as we did in our 2016 report) **shows that the global coal phase-out should be much earlier than 2050**, based on examination of regional pathways, this phase-out should be completed at the global level by 2037, with a full range varying from 2034 to 2045[6].

All our top-level messages and policy recommendations are based on this definition of coal phase-out. Nonetheless for full transparency, and as indication of the sensitivity of the results to the choice of a particular threshold, we also compare the resulting phase-out dates for all regions using alternative thresholds, such as more stringent reductions below 2010 levels, or the total share of coal in electricity generation, which are used in other reports and studies looking at coal phase-out (see

[6] If the 10% below 2010 levels threshold were to be applied to the global pathways, these dates would be 2036 (2030-2040) due to sample space differences. We, however, refer elsewhere in this briefing with global coal phase-out date to the date where the last region phases out coal.

Annex V – Sensitivity Analysis for Key Assumptions).

The main finding from this comparison is that while the choice of a specific threshold can change the specific phase-out year by as much as five years, from the policy perspective this change is irrelevant as the bulk of reductions needed already take place by 2030 in all regions, with coal-fired electricity generation reaching zero before 2040 for all practical purposes. This means that all the policies and measures to phase out coal need to be implemented in the short-term and target ambitious reductions by 2030.

Paris Agreement vs planned and existing coal capacity – global picture

In this section we answer the second policy guiding question for this report: What is the emissions impact of the current and planned coal fleet, and how does this compare to the Paris Agreement benchmarks?

Methodological assumptions

We compare the median of Paris Agreement compatible pathways with our bottom-up estimates of the current and future electricity generation from the current coal fleet, and the expected generation from the coal plants, which are in the pipeline under a business as usual scenario. For our central estimate, we assume a lifetime of 40 years for each unit, and a conservative capacity factor of 50%. For further details on the methodology and assumptions, refer to Annex IV – Coal Generation and Emissions Calculation Approach.

All the information at the unit level is derived from the Global Coal Plant Tracker database, version July 2019. This database provides information on every known coal-fired power generation unit, including location, status, investor, capacity, combustion technology and fuel, year of opening and planned retirement.

Global results

If all the units that are at varying stages of planning and permitting process are commissioned, even assuming a conservative capacity factor of 50%, then the committed generation from the global coal fleet will grow from 9280 TWh in 2019, to a peak of 9370 TWh in 2021, eventually declining to 8900 TWh in 2030 and 7930 TWh in 2040 and 5620 TWh in 2050. This stands in stark contrast to the required reduction seen in Paris Agreement compatible pathways.

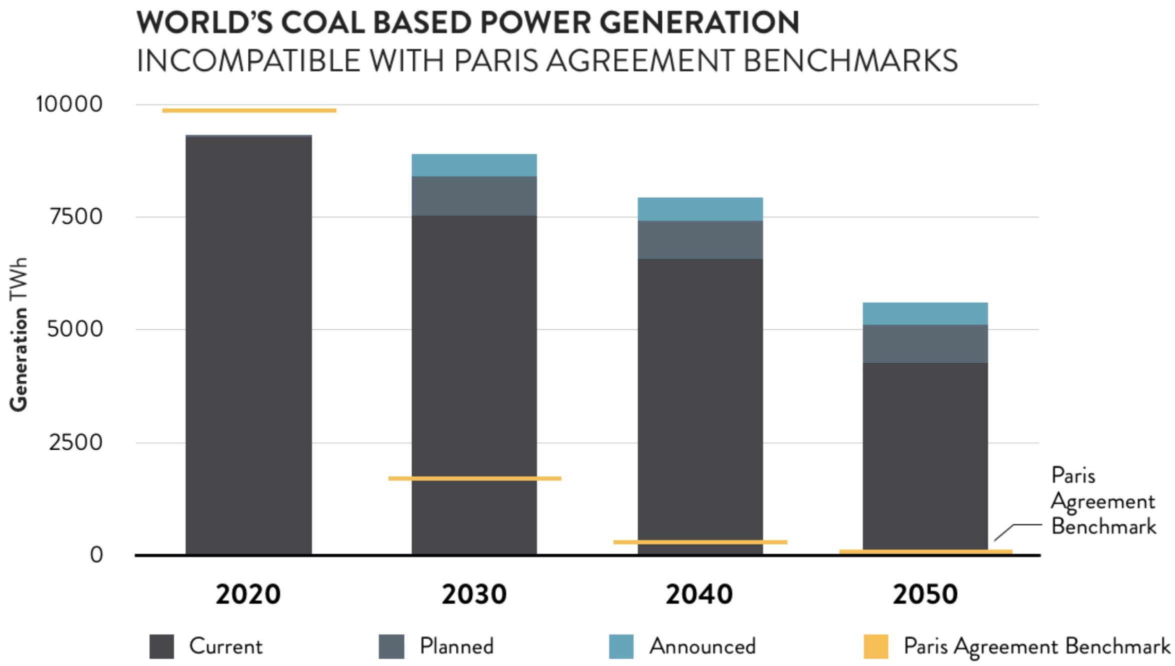


Figure 6 – Potential generation of electricity from coal in the world against Paris Agreement benchmarks

As clearly illustrated by Figure 6, the current coal power generation is incompatible with the Paris Agreement benchmarks. This incompatibility is set to grow sharply in the next decades, with **projected total generation of coal power plants being five times higher than found in IPCC SR1.5 pathways compatible with the Paris Agreement by 2030, and 28 times higher by 2040.**

Even if all the planned and announced coal power plants would be cancelled, shelved, or converted to other fuel, the operating coal plants would exceed the Paris Agreement benchmarks by four times in 2030 and more than twenty times by 2040, highlighting the huge risk of stranded assets that the coal sector will be facing in the next decades.

Indicative share of Paris Agreement coal power carbon budget

In our 2016 study, we calculated the committed emissions from the coal power plants and compared this with the emission budget implied for coal use in the electricity sector from the chosen IAM pathway.

Deriving consistent emissions budgets at the regional and global level is not possible for this report, given that we moved from looking at a single scenario, to looking at the median and interquartile ranges of a set of pathways, which have different starting points, underlying emissions factors, and different sampling spaces at the regional level.

However, to provide an indicative comparison with our 2016 study in this report, we use the following simple approach:

- The emissions at the unit level are calculated using standard assumptions about the heating rate and capacity factor of the units.
- For comparison with the IAM pathways, we calculate a proxy global carbon budget for coal in the power sector by multiplying the generation for the median pathway with the emission factor from

the MESSAGE model (94.6 tCO_2/TJ and an efficiency factor, which reflects our central estimate's capacity factor assumption[7].

We observe the following results at the global level:

Status	Share of Paris Agreement Coal power budget in 2019 (%)
Current	362%
+ Planned	412%
+ Announced	442%

Table 2 - Indicative shares of Paris Agreement coal power budget

While the comparison is only indicative due to the limitations highlighted earlier, the implications of this simple comparison are clear. Despite declining average global capacity factors of operating coal power plants[8] and the substantial reduction of the coal plants pipeline, this decline is not nearly enough to stay within the Paris Agreement compatible budget.

Insufficient progress since 2015 means that cumulative emissions from operating plants and those under construction would be almost four times as much as the reference carbon budget for the sector[9].

This means that active policy intervention will be needed to shut down coal power plants well before the end of their technical lifetime and reduce considerably their capacity factors.

Furthermore, every single new coal power plant that enters the system will exacerbate the problem, locking in the energy infrastructure of many countries into a carbon-intensive pathway for decades and increasing the assets at risk of stranding. Therefore, there is an urgent need to cancel the expansion plans for the coal fleet.

Paris Agreement vs planned and existing coal capacity – regional picture

While the two key global conclusions hold for all regions analysed here, given the remarkably different starting point of different regions in terms of the current share of electricity generated by coal, age profile of their coal fleet, and current plans for expansion, this picture looks different for different regional groupings, and the results of this analysis and its policy recommendations should be interpreted taking these regional differences into account.

[7] https://www.iamcdocumentation.eu/index.php/GHGs_-_MESSAGE-GLOBIOM

[8] For our 2016 study, we used capacity factors of 55.8% for the EU, 63% for the rest of the OECD, 56.1% for China, and 64.1% for the rest of the world. For this study, consistent with the continuous decrease in global average capacity factors, we have applied a conservative (on the low side) default assumption of 50% capacity factor for all plants in the world, with the aim of illustrating that even if current trends in average capacity factors continue and power plants run at the (low) edge for economic feasibility, policy intervention will be needed to reduce even further capacity factors of power plants until their complete shutdown. Annex V provides a sensitivity assessment for this and other assumptions.

[9] Approximately 56 $GtCO_2$ estimated from the median pathway if the IAM Models used here converted from energy units based on a standard emission factor.

In this section, we show the median regional Paris Agreement compatible pathways against our bottom up estimates of future coal power generation to illustrate some of the key regional differences.

OECD countries

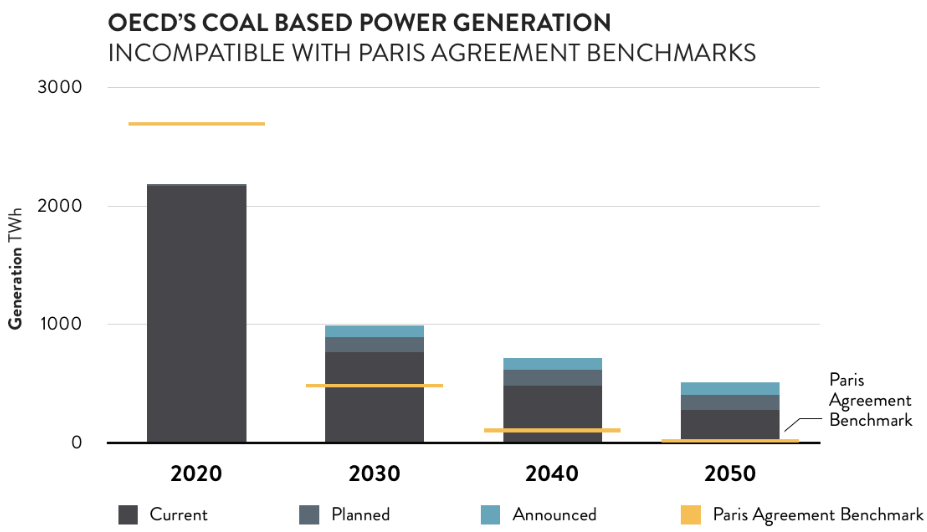


Figure 7 – Potential generation from coal in the OECD against Paris Agreement benchmarks

For OECD countries, generation from coal is already in decline, which is expected to accelerate in the next decade. Depending on the capacity factors observed, generation could even be in line with the median Paris Agreement regional benchmarks for 2020.

However, the rate of decline needs to accelerate rapidly, reaching much lower levels than what is currently planned by 2030.
The regions as a whole will need to see a yearly decline of at least 8% of 2020 levels over the course of the next decade, leading to an eventual phaseout by 2031, with urgent policy action needed in countries with high shares of coal generation, and acceleration of action in countries planning to phase out coal after 2030.

While cancelling planned expansion is a step in the right direction, and reduces the risk of stranded assets, this measure would be far from enough, as it would only lead to a yearly decline of around 6% in our estimates of the generation from the total fleet.

Given the age profile of the coal fleet in the OECD, there is a clear need to retire all coal power plants older than 40 years as soon as possible, to create a clear plan to retire the remaining plants in the next ten years, and introduce measure to significantly reduce their capacity factor.

Eastern Europe and former Soviet Union

A similar trend as for the OECD, with similar policy recommendations, is observed for the Reforming Economies (Eastern Europe and former Soviet Union).

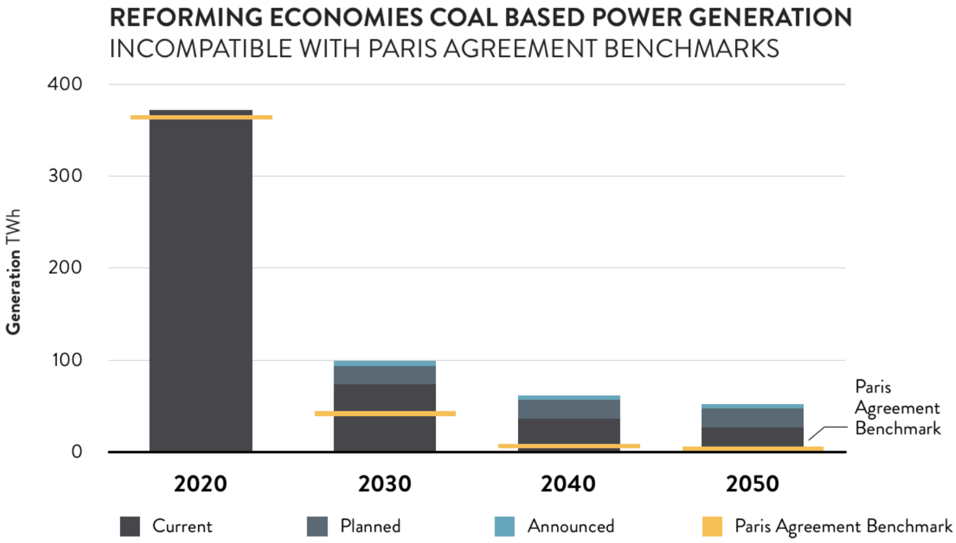
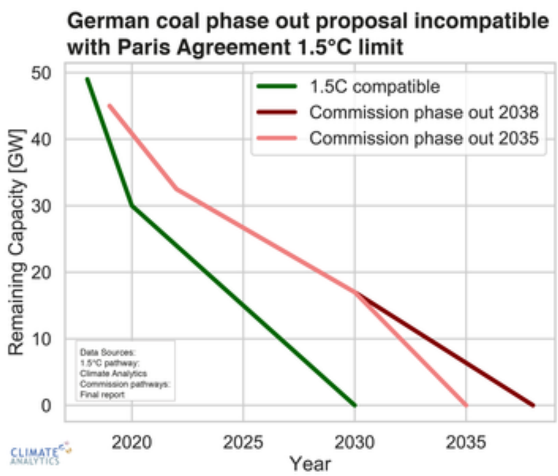


Figure 8 – Potential generation from coal in Eastern Europe and Former Soviet Union against Paris Agreement benchmarks

Matching the Required Rate of Decline: A Challenge for the OECD and the EU



The current coal fleet in many OECD countries is already subjected to the same downward pressure from policy, financial and electricity market drivers. However, it is important that national plans and actions to phase-out coal align with the ambition required by the Paris Agreement. If this ambition is not properly reflected, an additional stranding risk comes from the formulation (and implementation) of an inadequate phaseout policy. This risk is illustrated by the example of Germany, which is implementing a coal exit policy with a planned reduction leading to a full phase-out between 2035 and 2038, in line with the recommendation of the German Coal Commission. However, given that this phaseout date is incompatible with the goals of the Paris Agreement (as identified in Climate Analytics (2018a)), and the planned retirement schedule (rate of decline) is too gradual, 17 GW of remaining operating capacity by 2030 is at risk of stranding under a least-cost strategy for emissions reductions in line with the Paris Agreement. If those power plants continue operation after 2031, Germany will need to reduce an equivalent amount of additional emissions in other sectors, which will increase the cost and complexity of mitigation. OECD countries with more ambitious phase-out plans, such as Austria, Canada, Denmark, Finland, France, Italy, the Netherlands, Portugal, the UK, and Spain, will not be confronted with this specific challenge, given that they are planning to be coal-free by 2030 at the latest.

Middle East and Africa

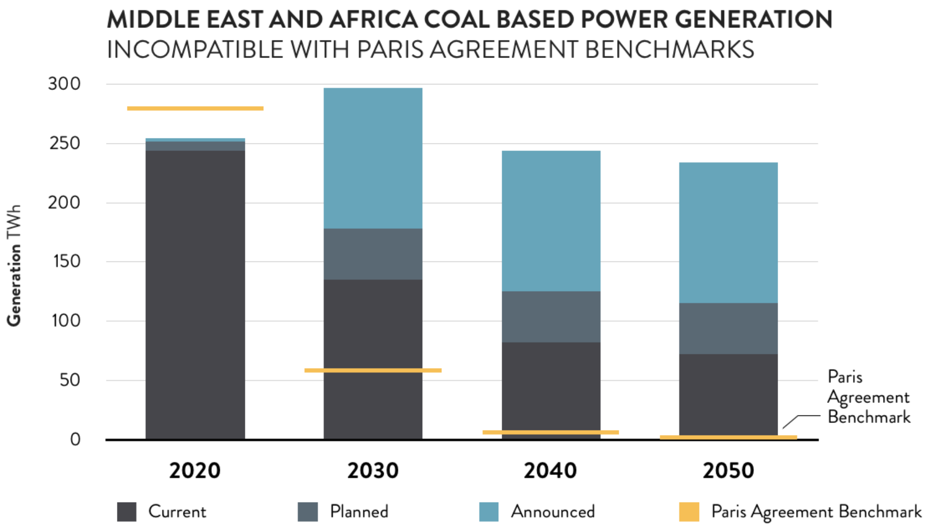


Figure 9 - Potential coal generation in Middle East and Africa against Paris Agreement benchmarks

The Middle East and Africa region has a similar starting point to the OECD, with current generation levels until 2020 being roughly in line with the median Paris Agreement regional benchmark. However, unlike the OECD, the bulk of future generation in this region is expected to come from plants that are not yet in operation.

Planned coal power plants are projected to increase power generation by 32% in 2030, and if announced project were to materialise, they would be responsible for a further 87% increase.

It is clear that the single most important step for these regions to align their power sectors with the Paris Agreement is to cancel the planned coal power plants. Additional efforts would be also required to retire many operating coal power plants before the end of their technical lifetime, and substantially reduce the capacity factor of the remaining operating plants.

Asia

Asia faces the most challenging situation of all regions, and the higher risks of stranded assets as a proportion of their total assets, considering both high starting points and high planned expansion.

When considering the absolute size and relative share in power generation of coal power plants, **Asia is by far the region with highest risk of stranded assets, and policy action in the power sector is particularly critical for the global achievability of the Paris Agreement.**

The planned expansion in a number of these countries is several orders of magnitude higher than the current operating capacity[10].

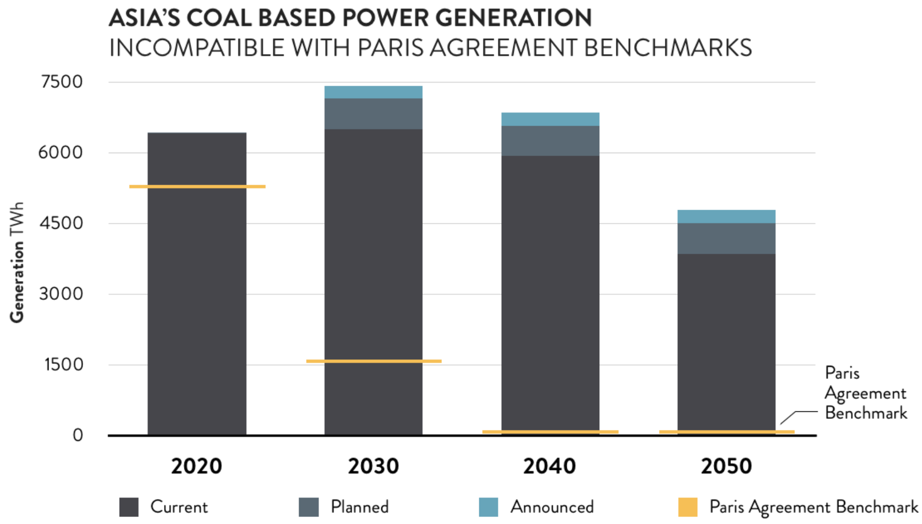


Figure 10 - Potential coal generation in Non-OECD Asia against Paris Agreement benchmarks

This means cancelling the planned coal power plant units in these countries is extremely urgent, in particular those that have not been traditionally dependent on coal as a power generation source. This includes a number of countries in South and South East Asia (Climate Analytics, 2019).

Latin America

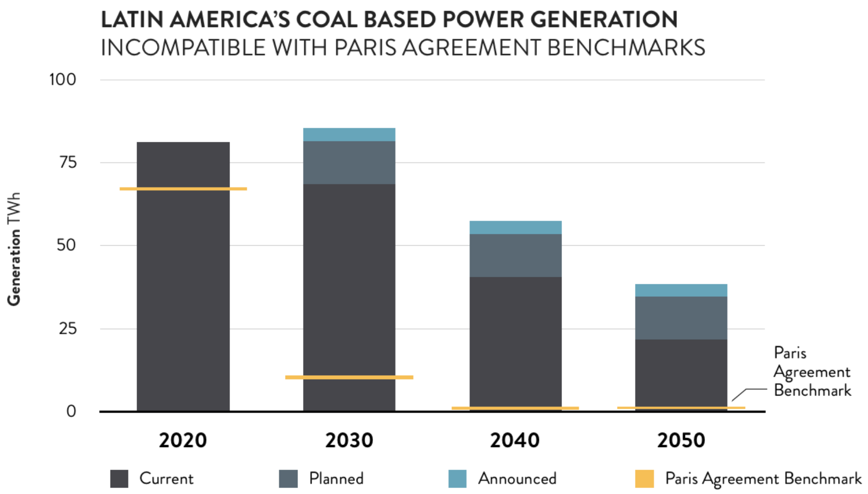


Figure 11 - Potential coal generation in Latin America against Paris Agreement benchmarks

Countries in Latin America are still planning a considerable expansion of their current coal fleet. This means that cancelling the planned coal power plant units in these countries is a very important step.

10 For a full overview of the planned expansion at the country level see Climate Analytics' Lowdown tool: http://tools.climateanalytics.org/lowdown/

Conclusion – powering away from coal is key to ramping up ambition

Due to the high carbon intensity of coal, rapidly reducing coal-based power generation down to 80% below 2010 levels by 2030, and a global phase-out by 2040 at the latest is the single most important step to keep the door open for achieving the Paris Agreement.

Even assuming very conservative capacity factors of coal power plants incompatibility with Paris Agreement benchmarks is set to grow substantially in the next two decades. This highlights the need for countries to retire all coal power plants older than 40 years as soon as possible, and create a clear plan to retire the remaining plants in the next one to two decades, and introduce measures to reduce their capacity factor significantly.

Governments will need to reverse their current trend of expanding coal-fired generation capacity and instead urgently implement policies to enable a quick phase-out of coal from the electricity mix. They will also need to substantially speed up the deployment of low-carbon and carbon-neutral technologies for electricity production, with the aim of phasing out all fossil fuel emissions from the electricity mix by around mid-century.

Redirecting resources currently set aside for expanding the coal fleet towards deploying renewable energy can result not only in substantial emissions reductions compared to a business-as-usual scenario, but could also substantially reduce the risk of stranded assets, while ensuring that the growing energy needs in many regions are met in a sustainable and affordable manner.

Strengthening governments' commitments to climate policy with NDCs that include a clear commitment to coal phase-out, removing subsidies for fossil fuels, and building support for renewables and energy efficiency offer new opportunities for developed and developing countries alike to build a low-carbon economy in line with the commitments made in Paris, with large benefits for sustainable development (Climate Analytics, 2019). This would at the same time reduce the risk of stranded assets and their associated costs, and encourage large institutional investors to increase their involvement in the low-carbon economy.

The time window for stringent policies to reverse the current trends in the coal sector is still open, and the falling costs of renewable energy and storage technologies provide the opportunity for clear and early policy decisions for a coal phase-out at national and regional level.

Taking a clear decision to phase out coal enables the development and implementation of suitable accompanying policies, including carbon pricing, and legislation. This would allow for a planned transition, including early retirements of coal power plants and/or reducing capacity factors, as well as avoiding the development of new capacity.

This 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.

Many countries and sub-national entities are already putting in place relevant policy instruments. These can provide valuable lessons for other countries, and approaches identified as successful could be scaled up in all regions and all relevant countries with existing or planned coal capacity.

Coal phase-out policies need to be accompanied by ambitious renewable energy phase-in strategies. Additionally, these can play an important role in creating alternative employment and spurring regional development in regions currently heavily dependent on the use of coal for power generation.

Coal and other fossil fuels have high political, economic, legal, social and ecological risks. Achieving the Paris Agreement Long-Term Temperature Goal and an accelerated transition to renewable energy, on the other hand, brings numerous benefits and avoided impacts. Informing policy-makers, investors and other decision makers and stakeholders about these risks and benefits will be necessary for the fast dissemination and scaling-up of policy instruments.

The uptake of renewable energy and storage technologies to replace coal-fired power generation is gaining momentum around the world. There are many benefits and opportunities that go beyond emissions reductions, such as access to clean energy, cleaner air, increased energy security, independence, new regional and local employment opportunities. These can be an important driver for the necessary transition away from coal and, eventually, other fossil fuels.

More detailed and meaningful policy recommendations would require specific national level analysis, including downscaling the Paris Agreement benchmarks, calibrating results with historical data and national capacity and emissions factors, and looking at national energy system planning and policies.

Climate Analytics has produced this type of analysis for a number of countries and regions (Climate Analytics, 2017a, 2018b, 2018a, 2019) and will continue to expand its work in this area to cover a larger number and more diverse set of geographies.

Annexes

Annex I – Defining 1.5°C Paris Agreement compatible pathways

Article 2.1 of the Paris Agreement (PA) defines its' Long-term temperature goal (LTTG) as "[h]olding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change". The emissions goals specified in Article 4 - peak global emissions "as soon as possible", and to reach zero net greenhouse gas emissions in the second half of this century – are to be determined according to the best available science so as to be consistent to with the LTTG. The IPCC SR1.5 provides key input for this.

The IPCC SR1.5 currently provides the best available science for operationalising the Paris Agreement LTTG. The SR1.5 Summary for Policymakers (SPM) establishes 1.5°C-compatible mitigation pathways as being pathways with no or limited overshoot. These pathways limit median global warming to 1.5°C throughout the 21st century without exceeding that level ("no-overshoot"), or allow warming to drop below 1.5°C by the end of the century (around 1.3°C warming by 2100) after a brief and limited overshoot of median peak warming below 1.6°C around the 2060s ("low-overshoot").

With a peak warming of <1.6°C these pathways meet several tests with reference to the LTTG, whereas the "hold below 2°C" pathways (used to inform the former Cancun Agreements temperature goal) peaked warming at up to 1.8°C, the 1.5°C-compatible pathways peak warming at a significantly lower level (1.5-1.6°C), hence they can be said to hold warming "well below 2°C", while warming by 2100 typically drops below 1.5°C with chance greater than 50%. In these 1.5°C-compatible mitigation pathways, total greenhouse gas emissions peak around 2020 and decrease rapidly to global zero around 2070.

The Paris Agreement's long-term temperature goal is a strengthening of the previous goal of holding warming "below 2°C", as agreed in Cancun in 2010. Pathways in the scientific literature, including in IPCC's Fifth Assessment Report (AR5), compatible with the former "below 2°C" goal have a typical peak warming of up to 1.8°C, and have a 66% or higher probability of holding warming during the 21st century below 2°C, but generally less than 50% probability of holding warming below 1.5°C. Given the strengthening of the long-term temperature goal in the Paris Agreement, emissions pathways compatible with the Paris Agreement must increase significantly both the margin and likelihood by which warming is kept below 2°C when compared with these former "below 2°C" emissions pathways, and simultaneously satisfy the 1.5°C limit.

Annex II – Filtering IPCC SR1.5 scenarios

In the context of defining the broad features of these pathways it is important to note that the IPCC SR1.5 identified limits based on sustainability and economic constraints on Carbon Dioxide Removal (CDR). These limits were found for BECCS[11] to be below 5 $GtCO_2$/yr globally in 2050 and for AFOLU[12] below 3.6 $GtCO_2$/yr sequestration globally in 2050. We follow these limits in this briefing in order to define Paris Agreement LTTG-compatible pathways as pathways that limit global warming to 1.5°C, or below, throughout the 21st century with no or limited (<0.1°C) overshoot. They are drawn from the "below 1.5°C" and "low overshoot 1.5°C" pathways in the new set pathways from Integrated

[11] Bio-energy with Carbon Capture and Storage, defined in SR1.5 glossary as: "Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that depending on the total emissions of the BECCS supply chain, carbon dioxide can be removed from the atmosphere."

[12] SR1.5 refers to CDR measures in the Agriculture, Forestry and Other Land Use sector and notes such measures are mainly represented in the models as afforestation and reforestation.

Assessment Models (IAMs) assessed in the IPCC SR1.5, filtered to exclude those that exceed the BECCS and AFOLU sustainability limits identified in the IPCC SR1.5. In these pathways global average temperature increases above pre-industrial are limited to below 1.6°C over the 21st century and below 1.5°C by 2100 (typically 1.3°C).

With these considerations the implications for operationalising the Article 4.1 global emission pathways can be outlined. Article 4.1 of the Paris Agreement is designed to operationalise the LTTG with global emission goals "in order to achieve the long-term temperature goal set out in Art. 2.1" – to peak global emissions "as soon as possible", followed by "rapid reductions thereafter", and to reach a balance between anthropogenic sources and sinks of greenhouse gases emissions in the second half of this century – are to be determined "according to best available science" so as to be consistent with the LTTG.

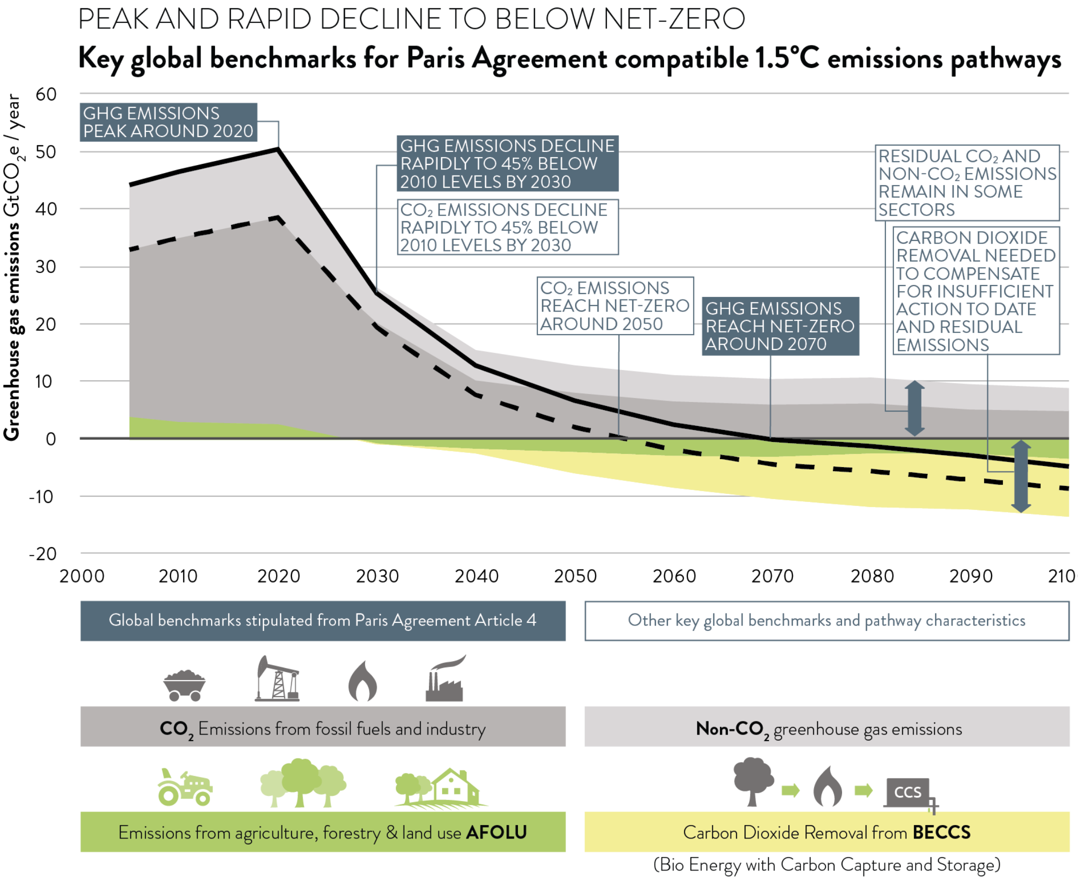


Figure 12 - Illustration of the three benchmarks in Paris Agreement Article 4.1 for operationalisation of Article 2.1 (dark blue boxes) and global decarbonisation benchmarks (white box). This representative pathway is the median across all 1.5°C-compatible pathways from the IPCC SR1.5 that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 from SR1.5 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS)[13].

Excluding pathways that exceed the BECCS and AFOLU sustainability limits identified in the IPCC SR1.5 implies faster reduction of greenhouse gas emissions by 2030 – to a level of 25-28 $GtCO_2eq$/year, instead of 25-30 $GtCO_2eq$/year if all pathways consistent with the PA LTTG are taken into account.

Figure 12 illustrates the PA 1.5°C pathways and the three stages of global transformation and mitigation strategies as outlined in Art. 4.1 (peak, rapid decline and zero GHG emissions) as well as the fourth key

[13] All emissions and removals where calculated from the median emissions levels across the 46 pathways in the SR1.5 scenario database that are 1.5°C compatible and that reported data for all variables included here (Source: SR1.5 scenario database https://data.ene.iiasa.ac.at/iamc-1.5c-explorer, accessed 22 October, 2018)

mitigation benchmark for decarbonisation (zero CO_2 emissions around 2050). These four key global mitigation benchmarks and others are also shown in Table 3

Table 3- Total GHG emissions and fossil-fuel and industry emissions of CO_2 for all 1.5°C-compatible pathways from the IPCC SR1.5 ("no or limited overshoot") that reach levels of Carbon Dioxide Removal (CDR) below the upper end of estimates for sustainable, technical and economic potential around 2050 from SR1.5 in the sector of Agriculture, Forestry and Land-Use (AFOLU), as well as via Bioenergy combined with Carbon Capture and Storage (BECCS)[14]. Values represent median (25th to 75th percentile) levels across pathways.

SR1.5 1.5°C compatible pathways	Year of peak emissions	Absolute annual change in emissions 2020-2030 (GtCO2e/yr)	Emissions 2030 (% below 2010)	Emissions 2050 (% below 2010)	Year of zero emissions	Cumulative emissions 2016 to year of zero emissions (GtCO2)	Cumulative emissions 2016-2100 (GtCO2)
Total GHG emissions	2020	-2.7 (-3.1 -2.4)	48% (45 to 60%)	86% (81 to 90%)	2068 (2061 to 2084)		
Total CO_2 emissions	2020	-2.3 (-2.0 -1.8)	42% (38% to 54%)	94% (88% to 97%)	2055 (2053 to 2063)	640 (590 to 740)	370 (250 to 620)
Fossil-fuel and Industry CO_2 emissions	2020	-1.4 (-1.8 -1.1)	44% (34% to 50%)	85% (82% to 91%)	2064 (2057 to 2081)	680 (630 to 800)	540 (390 to 770)

[14] All emissions and removals where calculated from the median emissions levels across the 46 pathways in the SR1.5 scenario database that are 1.5°C compatible and that reported data for all variables included here (Source: SR1.5 scenario database https://data.ene.iiasa.ac.at/iamc-1.5c-explorer, accessed 22 October, 2018)

Annex III – Region 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 **Africa**n (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 America**n 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

Annex IV – Coal Generation and Emissions Calculation Approach

The Global Coal Plant Tracker (GCPT) database used in this report comprises of detailed information at the unit level, including capacity, status and combustion technology, which allows for the estimation of generation and CO_2 emissions for each unit, using the following formulae (over a time period from 2019-2100):

$$Annual\ Generation\ (in\ MWh) = capacity\ \times\ capacity\ factor\ \times\ 8760$$
$$Annual\ CO_2\ (in\ Mt) = capacity\ \times\ capacity\ factor\ \times\ heat\ rate\ \times\ emission\ factor\ \times\ \Phi^{15}$$

The results are calculated at the unit level, and subsequently aggregated to the regions reported in the IPCC SR1.5, according to the status definitions of the units. The following table presents the status definitions, which we use:

Status	Definition
Current	Plants which have been formally commissioned, or are under construction
Planned	Plants which are various stages of the permitting process
Announced	Plants which have been described in corporate or government plans

Table 4 – Coal power plants status definition

The following data processing steps and assumptions are followed:

- Units which do not have the rated capacity, or the commissioning year (for operating units) are removed. This results in the removal of a total of 117 operating units from the database.
- 132 units that are under construction do not have a commissioning year reported in the database. For these units, we assume that they will be commissioned in the next two years. (i.e. 2021).
- 120 units which are at various stages of the permitting process do not have a commissioning year reported in the database. We assume a commissioning year of 2023 and 2025 for 'permitted' and 'pre-permitted' units respectively. 156 units which have been announced are allocated a commissioning year of 2027 for the same reason.
- We assume a standard capacity factor of 50% for all units, and a lifetime of 40 years. The lifetime assumption reflects the global average lifetime of units which have already retired.
- Indicative emissions estimates are provided using heat rates and emission factors obtained from Sargent and Lundy (2009) and Hong and Slatick (1994).

[15] Φ represents a unit conversion factor (3.97347 x 10^-9) which basically represents 8760 hours per year (to calculate the annual electricity output) divided by 2,202.31 lb/tonne (to calculate the emissions in the standard tonnes unit.

Annex V – Sensitivity Analysis for Key Assumptions

The future generation and emissions which are committed from the coal fleet are highly uncertain. This uncertainty stems from three key sources:

- Uncertainty surrounding the planned expansion of the coal fleet
- Variation in the capacity factor of coal power plants over time, and between different regions
- Variation in the expected lifetime of the coal power plants

In our analysis, we presented a simplified representation of the potential future generation of the coal plants subject to the following assumptions (documented in further detail in Annex III):

- All the units that are either planned or announced will start operating in the near future
- We assume a capacity factor of 50% for our central estimate
- We assume a unit lifetime of 40 years (the global average of retirements from historical observations)
- We assume no further additions of coal generation capacity beyond what is planned at the moment.

In this section, we present a simple sensitivity analysis, which captures the effects of the uncertainty with the latter two assumptions. In the first step, we vary the capacity factor between 40% and 60%, keeping all other things constant to illustrate the effect of different capacity factor assumptions. This does not capture the full effect of spatial variation.

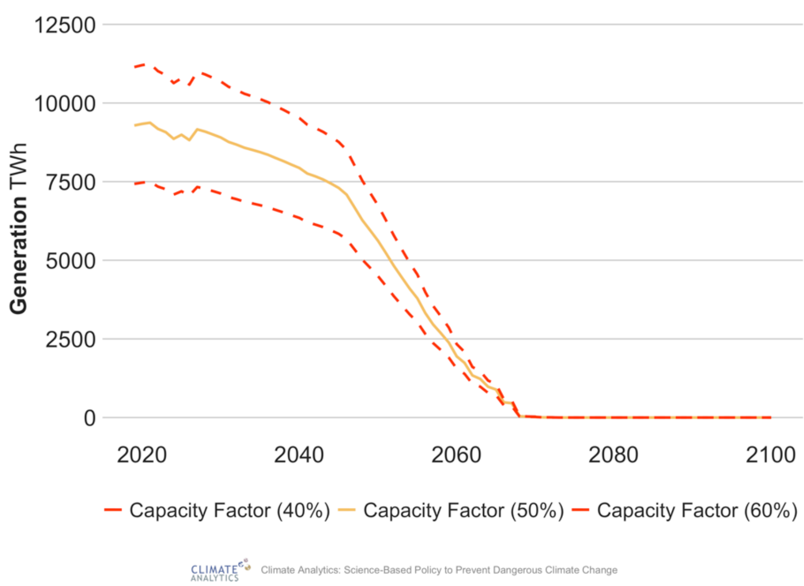


Figure 13 - sensitivity analysis results for capacity factors

The difference in capacity factors impacts the cumulative expected generation (and hence the cumulative expected emissions) from the proposed coal fleet expansion. The generation is higher by 20% in each step for the higher capacity factor assumption of 60%, and 20% lower in each step for the lower capacity factor assumption of 40%.

In the second step, we vary the lifetime assumptions of the units between 30 and 50 years to compare the effect to our central lifetime estimate of 40 years for each unit, keeping all other assumptions constant. The effect is visualised in the figure below.

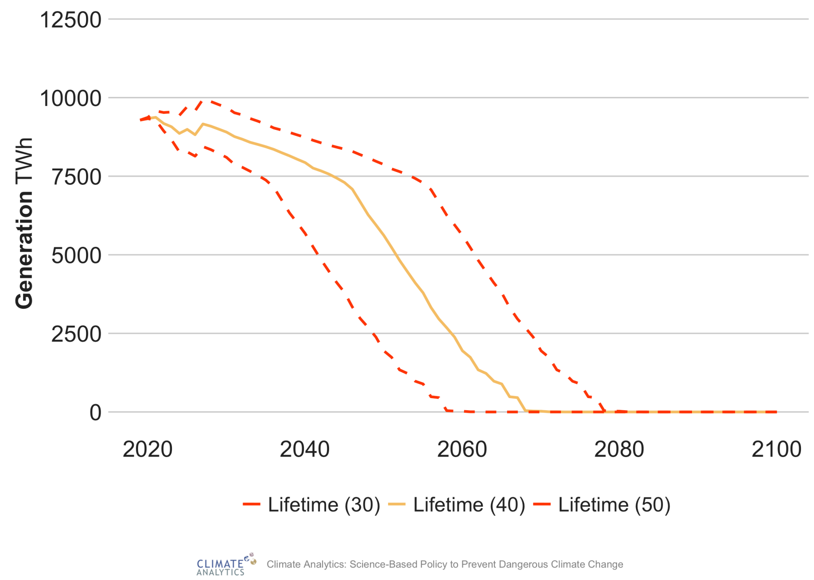


Figure 14 - sensitivity analysis results for lifetime assumption

We observe that the effect of different lifetime assumptions not only impacts the expected future generation from the coal power plants, but also impacts the expected phaseout of the global coal fleet. The percentage change compared to the central estimate is presented in the table below.

	2020	2030	2040	2050
Lifetime (30 years)	-0.05%	-9.03%	-28.43%	-65.36%
Lifetime (50 years)	0.38%	8.81%	10.13%	40.15%

Table 5 - Sensitivity analysis results for lifetime variations

Finally, all our top level messages and policy recommendations in the main text of this report are based on a definition of coal phase-out as the year where generations reaches 90% or more below 2010 levels. As indication of the sensitivity of the results to the choice of a particular threshold, we also compare the resulting phase-out dates for all regions using alternative thresholds such as more stringent reductions below 2010 levels, or the total share of coal in electricity generation, which are used in other reports and studies looking at coal phase-out. The table below summarises the results.

Region	In 2016 Study	% below 2010			% of electricity supply	
		10%	5%	1%	5%	1%
OECD	2030	**2031** [2029,2035]	**2037** [2030,2043]	**2050** [2038,2052]	**2031** [2029,2032]	**2039** [2031,2045]
Non OECD Asia	2040 (China) 2050 (Rest of World)	**2037** [2034,2041]	**2039** [2037,2046]	**2040** [2040,2050]	**2035** [2031,2037]	**2040** [2038,2046]
Latin America	2050 (Rest of World)	**2032** [2026,2045]	**2035** [2029,2049]	**2038** [2033,2051]	**2021** [2021,2023]	**2031** [2022,2034]
Middle East and Africa	2050 (Rest of World)	**2034** [2031,2042]	**2038** [2032,2046]	**2040** [2032,2050]	**2028** [2027,2031]	**2037** [2031,2040]
Eastern Europe and Former Soviet Union	2050 (Rest of World)	**2031** [2030,2044]	**2036** [2030,2048]	**2054** [2030,2057]	**2029** [2028,2030]	**2035** [2031,2041]
World	2050	**2036** [2030,2040]	**2039** [2036,2046]	**2048** [2038,2055]	**2032** [2031,2035]	**2041** [2037,2044]

Table 6 - Sensitivity Analysis results for phaseout dates

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