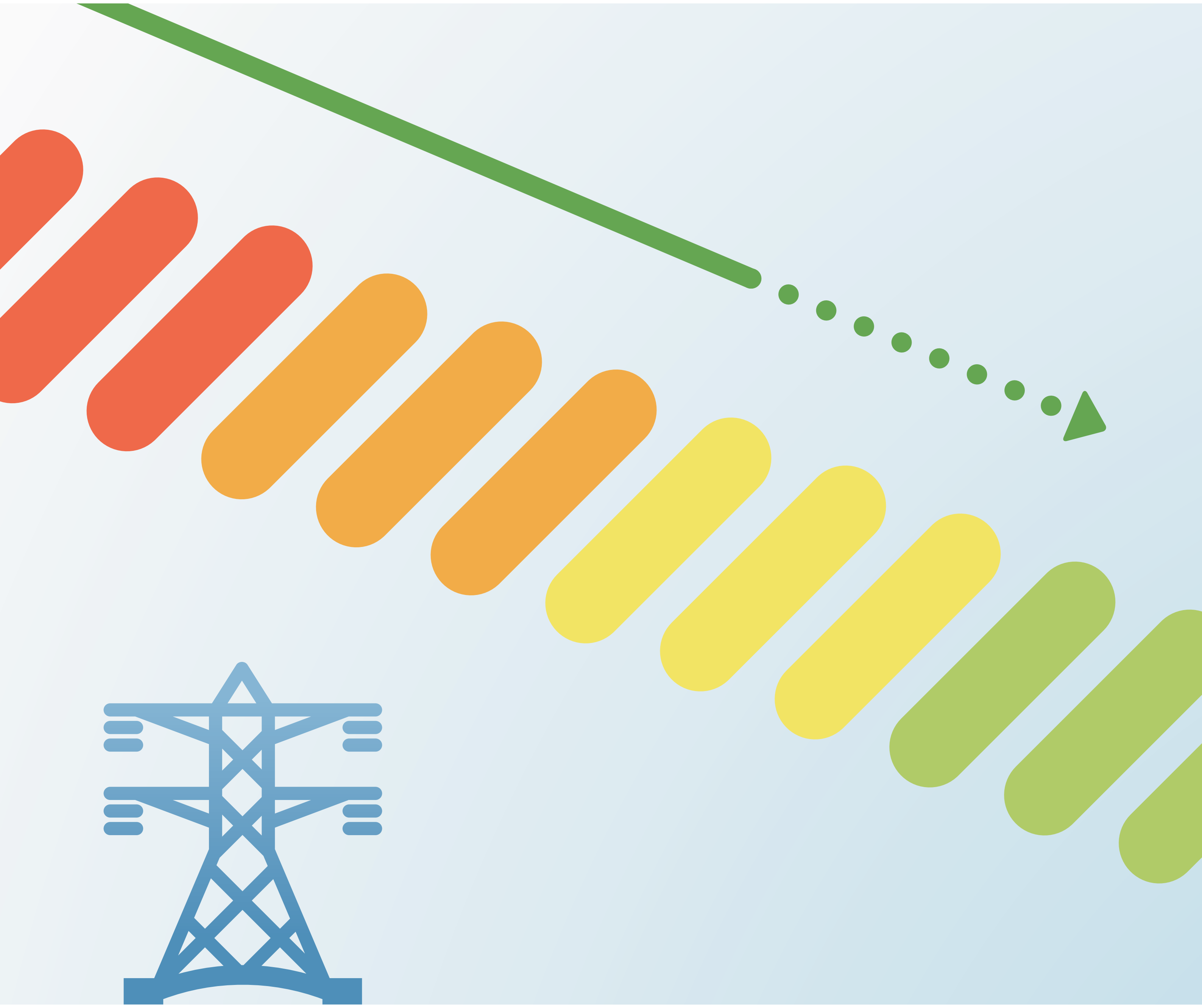

Climate Action Tracker

# Clean electricity within a generation

## Paris-aligned benchmarks for the power sector

September 2023

# Summary

When undertaking a journey, a good map is indispensable. As the world moves to address the climate crisis and journey towards a zero-carbon future, roadmaps which demonstrate the pathway to cut emissions fast, fairly and effectively are essential.

The broad strokes of a Paris-aligned roadmap are clear – we need to roughly halve emissions by 2030, achieve net zero $CO_2$ emissions by 2050 and net zero greenhouse gas emissions soon after. However, the details at the national and sectoral level need to be understood.

Wind and solar are ready to do the heavy lifting in the energy transition, but while positive signs can be seen in some countries, greater effort will be needed to accelerate renewables deployment. Countries are also continuing to build new coal and gas-fired power plants, representing a critical threat to the Paris Agreement.

In this report, the Climate Action Tracker (CAT) provides new 1.5°C compatible benchmarks for the power sector, for the world as a whole and 16 individual countries, a mix of developed and developing. These are: Australia, Brazil, Chile, China, EU27, Germany, India, Indonesia, Japan, Mexico, Morocco, Türkiye, South Africa, United Arab Emirates, United Kingdom, and the USA.

Our new benchmarks show how the shares of coal, fossil gas and renewables need to evolve out to 2050, and what this means for the emissions intensity of electricity generation, giving a roadmap for power sector decarbonisation.

### Power sector 1.5°C compatible benchmarks

| Coal | Fossil gas | Renewables | Emissions Intensity |
|---|---|---|---|
| AUSTRALIA | | BRAZIL | |
| CHILE | | CHINA | |
| EUROPEAN UNION | | GERMANY | |
| INDIA | | INDONESIA | |
| JAPAN | | MEXICO | |
| MOROCCO | | TÜRKIYE | |
| SOUTH AFRICA | | UNITED ARAB EMIRATES | |
| UNITED KINGDOM | | UNITED STATES | |

Our methodology includes pathways produced by both top down (global integrated assessment models) and bottom up (national energy system models) approaches - see section 2 for details. Our benchmarks focus on what is needed to limit warming to 1.5°C. Many developing countries will need significant financial support to achieve the benchmarks set out in this report.

## 1.5°C The world should aim to achieve clean electricity by 2040

**The CAT finds that, to align with 1.5°C, the world should aim to achieve clean electricity by 2040 – within a generation's time – and to support each other to jointly meet these goals.**

Developed countries should take the lead, phasing out coal by 2030 and unabated fossil gas by 2035.

While the pace of action could be slower in developing countries than in wealthier nations, they should still aim to eliminate coal and unabated fossil gas from electricity generation by 2040.

A 1.5°C aligned power sector transition will be driven by renewables, particularly wind and solar. By 2030, the global share of renewables reaches 81–89% in 1.5°C-compatible pathways, growing to 93–98% by 2040 and 95–100% by 2050.

While renewables deployment is beginning to accelerate, there is still an important ambition gap in 2030 that needs to be closed. At current rates, the world is on track to achieve around 50% renewable electricity by 2030.

Worryingly, countries are continuing to build new coal and gas-fired power plants, representing a critical threat to the Paris Agreement.

- There is currently 558 GW of coal either planned or under construction across the world. Of this, 205 GW is already under construction, almost entirely in China, India and Indonesia
- The global pipeline for future fossil gas plants is now greater than that of coal-fired power, with around 790 GW of fossil gas-fired plants either under construction or proposed. Unlike coal, where development plans are limited to a small subset of countries, the dash for gas is global, with almost all countries planning on building new fossil gas plants.

The CAT also finds that carbon capture and storage (CCS) will play, at best, a minor role in the power sector. While contemporary model-based assessments include small levels of fossil gas equipped with CCS post-2040, they also show that CCS would provide at most 1% of global electricity generation – a negligible amount. Given the rapid cost reductions in renewables and storage that are not yet fully reflected in models, there are strong grounds to believe that fossil CCS would have virtually no role in the future power sector.

The need for a rapid transition away from fossil fuels and towards renewables in the power sector remains as urgent as ever. The roadmap is clear and the path ahead achievable. What remains to be seen is whether governments will deliver the policies and investments needed to achieve clean electricity by 2040 and lay the foundations of a zero-carbon future for all.

The future does not have to look like the past, but this will only happen if our future efforts to address climate change break markedly from past efforts. This will require greater action to support renewables deployment, coupled with a clear commitment to end building new fossil-fired power plants and phase out coal and gas in power generation.

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# 1 Introduction

Clean electricity will be the cornerstone of a zero-carbon future. Cutting emissions from the power sector is essential, as burning fossil fuels for electricity generation produced around a third of all fossil $CO_2$ emissions in 2022 (IEA 2023a, Ember 2023b). Cutting power sector emissions will also enable system-wide decarbonisation, as clean electricity displaces fossil fuels in our homes, industries and transport systems.

The transition to clean power is gathering pace. Renewables deployment is accelerating across the world, and power sector emissions are likely to fall in 2023 and enter long-term decline (Ember 2023b).

In this report, the CAT explores what a 1.5°C aligned power sector transition would require. Looking at both a global and national level, we provide benchmarks for the future shares of coal, fossil gas and renewables in the electricity mix, as well as the overall emissions intensity of electricity generation. These benchmarks can help individual countries align their power sector transitions with 1.5°C.

Our benchmarks show that to limit warming to 1.5°C, the era of fossil-fuelled generation needs to come to an end – and with it a transition to global clean power – by 2040.

- Developed countries need to phase out coal by 2030, and unabated gas by 2035, with at best a minimal role for carbon capture and storage (CCS) in the power sector.
- Developing country power sector transitions are not far beyond, phasing out all coal and unabated fossil gas by 2040, again with a minimal role for fossil gas with CCS in the power sector.

Key to achieving clean power is acceleration of renewables deployment. All countries should achieve above 80% of electricity from renewables by 2035 and 90–100% renewable electricity supply by 2050.

We also assess the current status of the power sector transition at the country level, analysing the pace of renewables deployment and current pipelines for building new coal and fossil gas plants (Section 4). A rapid transition to renewables is achievable, with a range of countries demonstrating the feasibility of rapid rollout, across different geographies and income levels.

However, current efforts fall far short of 1.5°C, with the share of global renewables on track to reach only around 50% by 2030 instead of the 80% that would be necessary to align with 1.5°C. An urgent acceleration of renewables deployment is therefore essential to put the world on track to eliminate fossil-based generation and achieve clean power by 2040 — within a generation's time.

# 2 Methods

## 2.1 Country selection

We provide power sector benchmarks both at the global level, and for 16 selected countries.

Countries were selected based on their share of global power generation, scale of power sector emissions, geopolitical importance, and diversity (both geographic and economic). We prioritised countries with large power sectors, such as the USA, China, the EU and Brazil.

We also aimed to cover a diverse range of power generation mixes, as this can help show how the pace and nature of power sector decarbonisation may vary across different contexts. Finally, we focused on countries which generally have existing national studies exploring power sector decarbonisation, as this is a key input to the analysis.

Taking these factors into account, the following countries were selected. Our classification into developed vs. developing countries here is based on a combination of UNFCCC Annex status, and human development index (HDI). We broadly follow Annex I/non-Annex I classifications to define developed vs. developing countries, but classify non-Annex I countries with a very high HDI of > 0.9 as developed. In this classification the UAE is classified as developed. Additionally, we treat Turkey as a developing country despite its Annex I status (see the accompanying methods documentation report for more details).

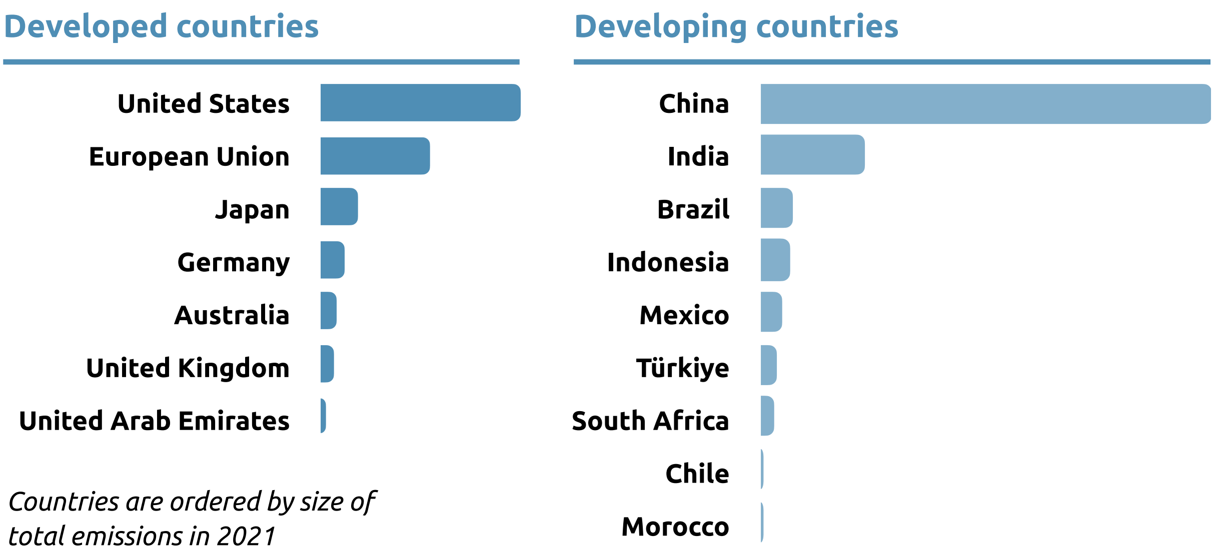


**Figure 1:** Countries selected for analysis

*Countries are ordered in size of total emissions in 2021.*

## 2.2 Benchmark production

Multiple different perspectives will be needed to guide the energy transition at a national level. Country-level roadmaps need to be consistent with the Paris Agreement's global long-term temperature goal, as well as considering national circumstances and local context.

In this report, we use two different lines of evidence: downscaling the latest global pathways as assessed by the IPCC, and an in-depth literature review of the latest power sector modelling at the national level. Our results are therefore based on multiple different lines of evidence, spanning different geographical and temporal scales. Encompassing different perspectives on the energy transition improves the robustness of our method.

The following sections introduce these lines of evidence briefly.

### 2.2.1 Top-down / global perspective: the latest evidence from the IPCC

The top-down / global perspective in our work is provided by downscaling global 1.5°C compatible pathways assessed by the IPCC's latest AR6 report. These pathways are produced by integrated assessment models (IAMs). IAMs are models which attempt to couple together economic, energy system and land-use models to provide a self-consistent picture of how these different systems could evolve together in the future. The pathways produced by IAMs have become increasingly influential in informing discussions on what needs to be done at the global level to limit warming to 1.5°C.

IAMs provide a valuable global roadmap on 1.5ºC aligned transformations. However, IAM pathways need to be carefully used and interpreted to ensure that they provide robust information (Guivarch et al 2022). We make three central steps in order to extract robust insights from IAM pathways. We briefly describe our methodology below, with more details provided in the accompanying methods documentation.

#### 2.2.1.1 Selecting pathways

The IPCC's AR6 report assessed almost 100 1.5°C compatible global pathways (Byers et al 2022). However, many of these pathways are not fully compatible with the Paris Agreement, as they are not consistent with reducing greenhouse gas (GHG) emissions to net zero before 2100. Many also rely on unsustainable levels of carbon dioxide removal (CDR), which raises substantial feasibility concerns and could have significant negative side-effects.

We therefore apply a filtering process to select pathways for the AR6 database which:

A. Represent the latest evidence on the transformations needed to limit warming to 1.5°C
B. Are compatible with the Paris Agreement's call to achieve net zero GHGs before 2100
C. Avoid unsustainable levels of CDR

This provides a set of 32 pathways for analysis. For more details on the filtering process, see the methods documentation report and Climate Analytics (2023).

#### 2.2.1.2 Downscaling pathways

IAMs provide results at the regional, rather than national level. In the IPCC AR6, global pathways are broken up into 10 major world regions, or "macro-regions"[1]. These 'macro-region' results needed to be downscaled to the national level.

To do this, we use the Simplified Integrated Assessment Model with Energy System Emulator (SIAMESE). SIAMESE takes data at a regional level from IAMs and converts it to the national level, providing a perspective on what each country within a given region would need to do to achieve the overarching macro-region pathway. SIAMESE does this by allocating energy consumption to each country in a way that maximises the welfare of the macro-region as a whole – simulating the cost-optimising logic of IAMs. For more details, see Climate Analytics (2021a) and Sferra et al (2019).

1 These R10 regions are North America, Latin America, Europe, Russia and the reforming economies, the Middle East, Africa, India, China, other developing Asia and the Pacific OECD nations.

SIAMESE is used here to downscale the electricity mix in the selected 1.5°C compatible pathways to the national level. This results in 32 possible future electricity mixes for each country. Each electricity mix is part of a global pathway which, across all countries and all sectors, limits warming to 1.5°C. This gives us confidence that the combined set of electricity mixes will remain within the 1.5°C limit when summed across all countries.

#### 2.2.1.3 Adjusting pathways

The CAT then takes the median of these 32 scenarios and makes three key adjustments on a country-level. These adjustments are made to better represent the call in the Paris Agreement for developed countries to take the lead in reducing emissions, the challenges related to stranded assets in 1.5°C compatible transitions (particularly in the developing world), and the current geopolitical context in the aftermath of the fossil gas price crisis.

First, we accelerated the pace of coal and gas power generation phase-out in developed countries[2] from the median to the 75th percentile of the 32 selected pathways. The emissions headroom produced by this step is re-distributed to developing countries to allow a slightly slower reduction in coal power generation in the near-term. This increases the regional differentiation in the benchmarks and allows a still rapid but more feasible phase-out of coal in developing countries, which reduces the level of stranded assets in the pathways.

IAMs have been criticised for failing to account for differences in regional circumstances which may limit the pace of power sector decarbonisation in developing countries (Muttitt et al 2023), and this step responds directly to this critique.

Next, we calculated the committed generation from the current gas-fired power fleet (as of 2022), and applied a "no new fossil gas plants" constraint to all countries. Building new fossil gas plants is a recipe for large-scale stranded assets and increased import dependency on a volatile fossil fuel (Kemfert et al 2022), and should be avoided.

This constraint is only binding in developing countries, where some IAM pathways foresee a growth in gas-fired generation in the 2020s, followed by a rapid reduction in fossil gas. This growth in fossil gas consumption is seen in pathways produced before Russia's illegal invasion of Ukraine and the ensuing fossil gas price crisis. This led to very high prices for fossil gas, with prices likely to remain elevated across the decade (IEA 2022), and has accelerated the transition to renewables. 1.5°C compatible pathways produced after the energy price crisis display a much lower reliance on fossil gas, which is not accounted for in these pathways (IEA 2022).

Any reduction in emissions from gas-fired generation in a particular country is redistributed to the coal-fired power fleet within the same country. This reduces the risk of creating new stranded assets (a rapidly built and equally rapidly decommissioned gas-fired fleet), while reducing the level of asset stranding of existing assets (the current coal-fired power fleet).

Lastly, we adjusted renewables generation at a country level to ensure that total generation in each country remains consistent with the median pathway (in light of these adjustments to the coal/gas generation profiles).

We used country-level emissions factors for coal and gas to ensure that these adjustments, which accelerate decarbonisation in the developed world, avoid a risky expansion into gas in the developing world, and (slightly) relax the pace of coal phase-out in the developing world - and still conserve the global carbon budget.

The top-down / global perspective produces country-level power sector transitions that are part of a global 1.5°C consistent pathway, giving a clear line of sight back to this global goal.

This global perspective also accounts for the current status of the power system in each country when downscaling from the macro-region to the national level. However, this approach does not always fully capture the national circumstances which might also influence the shape of the energy transition, such as the current status of transmission/distribution grids in a country, national renewable potentials or country-specific growth rates for technologies. This is why we complement the top-down global perspective with a bottom-up nationally- focused perspective, described in the next section.

2 We broadly follow the UNFCCC classification into developed vs. developing countries, treating Annex I countries as developed and non-Annex I as developing. However, while Türkiye is an Annex I country, we treat it as a developing country due to its current socio-economic development context. See the Annex for more details.

### 2.2.2 Bottom-up / national perspective: an in-depth literature review of national studies

Our bottom-up perspective is based on an in-depth review of national-level power systems modelling, which is generally better able to capture national circumstances, but is less good at incorporating larger scale influences such as global trade, international technology spill-overs and global climate policy.

We reviewed the current literature on power system transitions in each of the 16 countries covered in this report, assessing over 300 different pathways from over 250 different individual papers. We filtered these studies to select those which are compatible with achieving full decarbonisation of the power sector by 2050 at the latest (ambition), use formal energy system models rather than simpler approaches such as trend extrapolation (methodology), consider growth in electricity demand due to sector coupling in the future (narrative), and match recent developments in the power sector at the country-level (historical accuracy).

This led to an eventual pool of almost 120 pathways from around 80 different academic papers which we used to provide a bottom-up national level perspective on the power system transition. For more details on the studies used, and the selection process applied to identify national studies for use, see the methods documentation report.

These national studies provide a perspective on power sector transitions that accounts for the specific context in each country. This can help ensure that the benchmarks produced are consistent with the reality on the ground in each country. However, it is important to stress that none of these pathways were explicitly testing the feasibility frontier at the national level - that is, the maximum pace of power sector decarbonisation that is possible. Therefore, they should not be seen as an ambition ceiling that cannot be broken, but simply the current state of knowledge in the academic literature on power sector decarbonisation in each country.

The selected power sector modelling studies all achieve a decarbonised power sector by 2050 but display a wide range of levels of ambition on the path to 2050. As they are produced by national-level energy system models, many of them have no clear link back to 1.5°C compatibility. Therefore, when extracting information from these studies on 1.5°C-aligned power sector transitions, we make two further steps:

1. We filter the studies to only consider those studies which fall within the 1.5°C compatible range produced by the 32 downscaled pathways. National studies must align with at least one of the downscaled 1.5°C compatible pathways to be considered.
2. We then take the average of the two most ambitious studies which pass the filter to represent the bottom-up perspective from the literature. If no national studies pass this filter, we take the most ambitious national study as representative of the bottom-up perspective.

We produce a bottom-up perspective for all countries except the UAE. In the case of UAE, there are no existing national studies, so we only use the global top-down perspective.

Additionally, for Japan, we only produce a bottom-up perspective for 2050, not the preceding years. This is because while there are existing national studies for Japan, they do not reduce power sector emissions fast enough in 2030/2040 to align with the 1.5ºC compatible downscaled pathways. The fact that they do not align with the downscaled pathways does not mean the downscaled pathways are infeasible, but simply that a 1.5ºC aligned power sector transition in Japan has yet to be explored at the national level. However, while the studies do not cut emissions fast enough prior to 2050 to align with 1.5ºC, they do demonstrate the feasibility of achieving 100% renewables and 0% fossil generation by 2050 in Japan – and so they are used to help set the 2050 benchmarks.

### 2.2.3 Comparison of the two perspectives

Having calculated a value using both the top-down and bottom-up approach, we present a benchmarking range for each country, with each end defined by the two perspectives.

The bottom-up / national pathways sometimes reduce emissions more slowly than the top-down / global pathways. Cutting emissions more slowly would require faster action in other sectors to compensate for this.

To check the consistency of the bottom-up perspective with 1.5°C, we explore what would happen if every country aligned with the bottom-up national perspective but did not exceed this level. We find that global power sector emissions would still fall within the interquartile range of the selected IAM pathways, but that cumulative $CO_2$ emissions from the power sector over 2020–2050 would be increased by ~16 $GtCO_2$ (see the methods documentation report for more details). This is approximately 4% of the remaining carbon budget for 1.5°C as of 2020 (IPCC 2023). This gives us confidence that all the benchmarks produced by both perspectives remain aligned with 1.5°C but highlights the value of countries aligning with the higher end of the benchmarking range wherever possible.

With this in mind, the CAT argues that:

- Developed countries should aim for the more ambitious end of the benchmarking range wherever possible in order to maximise emissions reductions.
- Developing countries should aim for at least the less ambitious end of the benchmarking range as an ambition floor. This lower level will still require upscaled climate finance from high-income countries and, conditional on sufficient international support, developing countries should aim to exceed the ambition floor and cut power sector emissions even faster.

## 2.3 Producing global benchmarks

To produce our global benchmarks, we use a similar approach as for the national level, using two different lines of evidence to inform our work.

First, we use the selected 1.5°C compatible pathways assessed by the IPCC (see Section 2.2.1). Having produced country-level pathways, we then add these country-level pathways back up to provide a global pathway which accounts for the adjustments described in Section 2.2.1.

We then complement this global pathway with a review of the available literature on global power sector transitions. We only considered studies which cut the emissions intensity of power generation as fast as the 1.5°C compatible scenarios assessed by the IPCC. From this, we selected one central study to complement the IAM pathways, produced by the Energy Watch Group (EWG) and Lappeenranta-Lahti University of Technology (LUT) (Ram et al 2019). This study explores a transition to a 100% renewable electricity system by 2050 in line with 1.5°C. These two data points (IAMs and the EWG LUT study) are used to produce our global benchmarks.

## 2.4 How is equity taken into consideration when defining the benchmarks?

The benchmarks defined in this report explore how fast the power sector should be decarbonised within a given nation (or globally) to be compatible with the Paris Agreement, irrespective of who pays for this transition. In other words, these benchmarks show where action needs to happen, but does not provide information on who should pay.

We do take some elements of fairness and regional differentiation into account when determining the benchmarks. As mentioned in Section 2.2.1, our global perspective includes a constraint that developed countries should decarbonise faster than developing countries, and we use this constraint to relax the pace of coal phase-out very slightly in developing countries. However, this does not represent a full treatment of equity in the global power sector transition.

The very limited carbon budget does not leave much room for some countries to decarbonise more slowly based on differences in their historic responsibilities or current capabilities. As the Paris Agreement requires full decarbonisation by mid-century there will be a need for financial transfers and other support between countries, so the development described by the benchmarks is fair and just. But the extent of this support and how it can be achieved is a separate political discussion that could not be covered in this analysis.

# 3 Results: the roadmap to clean electricity

## 3.1 Share of coal (% of total generation)

Phasing out coal-fired power generation remains a critical step to limiting warming to 1.5°C (Climate Analytics 2019). In 2022, burning coal for electricity generation produced 8.4 $GtCO_2e$ of greenhouse gas emissions (Ember 2023), around two-thirds of power sector emissions. Coal-fired power generation is also responsible for large levels of air pollution, and a coal phase-out would bring considerable health and economic benefits alongside reducing emissions (Climate Analytics and SFOC 2021, Climate Analytics 2021b, CAT 2021b, 2021a)

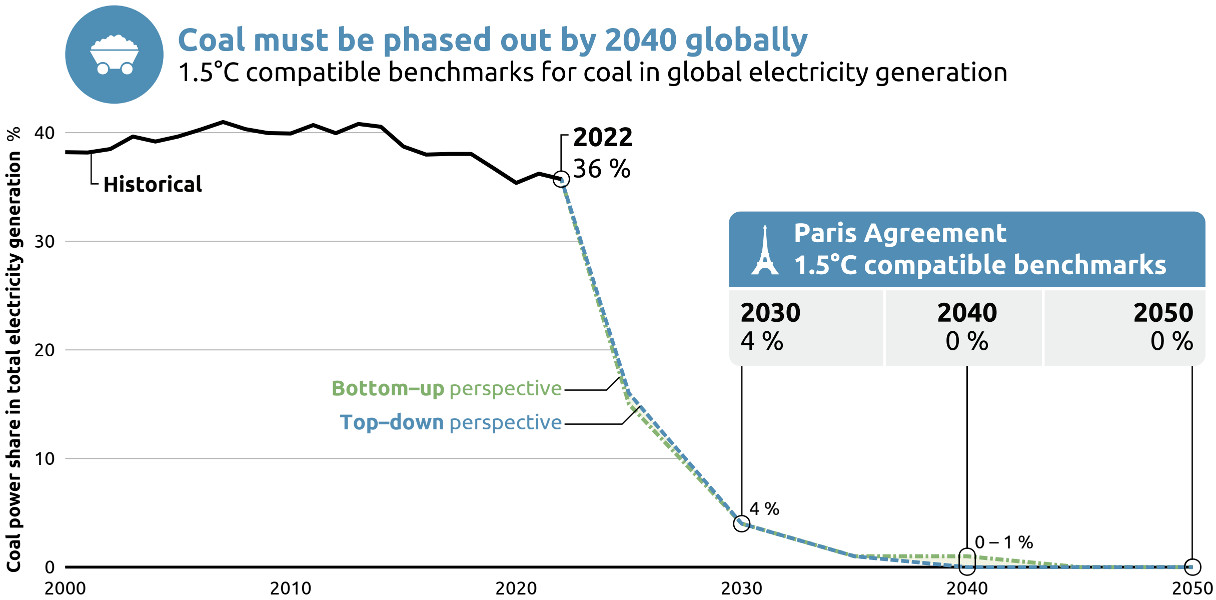


**Figure 2:** 1.5°C compatible share of coal in global electricity generation

*These results are produced by aggregating the country-level downscaled pathways, and complementing this with data from the EWG LUT study (Ram et al 2019).*

To align with the Paris Agreement 1.5°C limit, the world must phase out coal by 2040, reducing its share from 36% in 2022 to 4% in 2030, ultimately reaching 0% in 2040 (Figure 2). This requires that coal-fired power generation falls 87% from 2022–2030.

Figure 3 shows the share of coal in total electricity generation for the sixteen selected countries.

The share of coal-fired generation needs to fall rapidly towards zero, with no room to expand coal-fired generation in 1.5°C compatible pathways. Table 1 shows the final 1.5°C compatible benchmarks for the share of coal in power generation, as determined by the CAT.

In a Paris-aligned coal phase-out, developed countries take the lead, phasing out coal by 2030 in our benchmarks. In Japan in the top-down perspective, some small levels of coal remain, but the share of coal falls to 1% in 2030 and is totally phased out by 2035. A 1% share of coal in 2030 for Japan would be equivalent to a single coal plant of around 400MW operating at 80% capacity. Given the strong co-benefits associated with reduced coal generation (especially around health impacts), and the call in the Paris Agreement for developed countries to take the lead in cutting emissions, we argue that Japan should aim to exceed this level, and totally phase out coal generation by 2030, and hence provide a benchmark of 0% coal generation by 2030 in Japan.

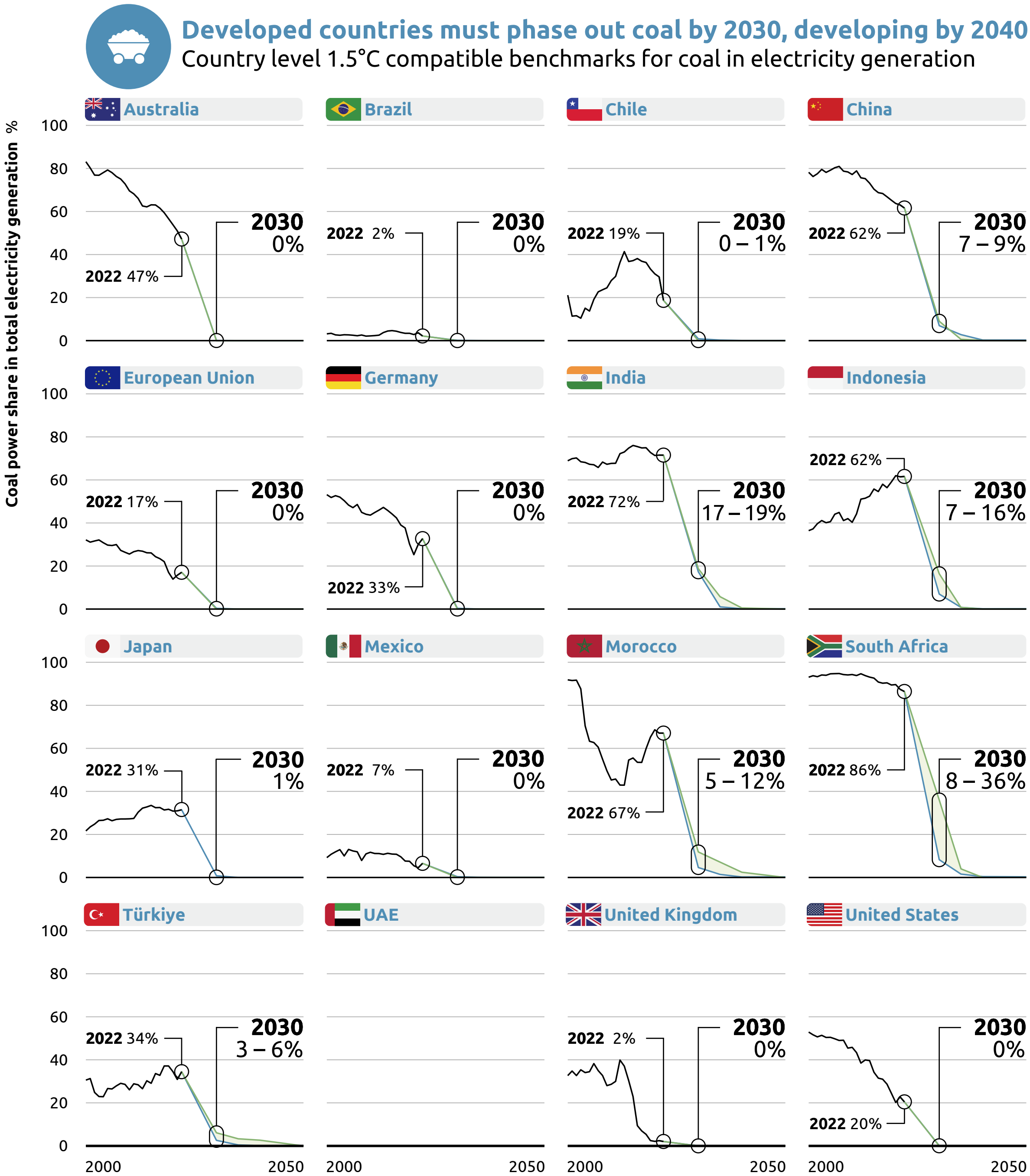


**Figure 3:** 1.5°C compatible share of coal in national-level electricity generation

*These results show a range produced by the two different perspectives - a global top-down perspective produced by downscaling IAM pathways to the national level, and a national bottom-up perspective produced by an in-depth literature review of national power sector studies.*

While the coal phase-out is led by developed countries, developing countries still need to reduce the scale of coal-fired generation rapidly and phase out coal by 2040, if warming is to be limited to 1.5°C[3]. In most developing countries assessed, coal provides less than 10% of electricity generation by 2030 in the Paris-compatible benchmarks. Countries with coal-dominated power systems today, such as South Africa and India, have slightly higher benchmarks in 2030. However, these still require strong and sustained reductions in coal-fired generation. Other countries such as Mexico phase out coal entirely by 2030 in the 1.5°C compatible benchmarks.

3 In Morocco and Türkiye, a small share of coal remains in 2040 in the bottom-up perspective (2% and 3% of generation respectively). However, this is based on a single study in both cases. Given the evidence that coal should be totally phased out by 2040 (IEA 2022), the CAT does not consider these studies in 2040 for Morocco/Türkiye, basing the final benchmark on the top-down perspective only and calling for a full phase-out of coal by 2040.

**Table 1:** 1.5°C compatible benchmarks for the share of total coal-fired power generation

| 1.5°C compatible benchmarks for coal in electricity generation | | | | | |
|---|---|---|---|---|---|
| **Country** | **2022** | **2030** | **2035** | **2040** | **2050** |
| **Global** | 36% | 4% | 1% | 0% | 0% |
| **USA** | 20% | 0% | 0% | 0% | 0% |
| **EU27** | 17% | 0% | 0% | 0% | 0% |
| **Japan** | 31% | 0% | 0% | 0% | 0% |
| **Germany** | 33% | 0% | 0% | 0% | 0% |
| **Australia** | 47% | 0% | 0% | 0% | 0% |
| **UK** | 2% | 0% | 0% | 0% | 0% |
| **UAE** | 0% | 0% | 0% | 0% | 0% |
| **China** | 62% | 7–9% | 1–3% | 0% | 0% |
| **India** | 72% | 17–19% | 1–6% | 0% | 0% |
| **Brazil** | 2% | 0% | 0% | 0% | 0% |
| **Indonesia** | 62% | 7–16% | 1% | 0% | 0% |
| **Mexico** | 7% | 0% | 0% | 0% | 0% |
| **Türkiye** | 34% | 3–6% | 0–3% | 0% | 0% |
| **South Africa** | 86% | 8–36% | 2–4% | 0% | 0% |
| **Chile** | 19% | 0–1% | 0% | 0% | 0% |
| **Morocco** | 67%* | 5–12% | 1–7% | 0% | 0% |

**In Morocco historical data is only available until 2021. Countries are ordered by developed vs. developing, and then by size of emissions in 2021.*

Accelerating the coal phase-out in developing countries will require strong levels of international support in the form of technical assistance and climate finance. The growing number of Just Energy Transition Partnerships (JETPs) which are focused on accelerating coal phase-out are a positive sign (IISD 2022), but the scale of ambition needs to be increased substantially to ensure that a global coal phase-out by 2040 is achieved in an equitable manner.

Most developed countries enjoyed decades of coal-intensive electricity generation throughout the 20th century – it is now time for them to help consign coal-fired electricity to the history books by phasing out coal domestically by 2030 and providing climate finance to support a rapid coal phase-out in the developing world. It is important that coal is phased out in a just and equitable manner, by retraining and compensating workers and ensuring that communities dependent on coal are provided with other economic opportunities.

These benchmarks are for total coal use in the power sector, rather than focusing only on 'unabated' coal. They show that there is no role for CCS-equipped coal generation in the global power sector, with the total share of coal (both abated and unabated) falling to zero in all countries by 2040. Rather, coal-fired CCS is a costly and dangerous distraction to the task at hand. For more details on CCS in the power sector, see Box 1.

## 3.2 Share of fossil gas (% of total generation)

Global gas-fired power generation grew strongly from 2000 until 2020, reaching 23% of total generation in 2020. Growth in gas generation has occurred across the world, with all regions increasing their reliance on fossil gas. However, the share of gas has begun to fall in the past two years, as resurging gas demand in the aftermath of COVID lockdowns and Russia's illegal invasion of Ukraine pushed gas prices to record highs.

In our 1.5°C compatible benchmarks, this move away from fossil gas is rapidly accelerated. The share of electricity produced by fossil gas falls to 5–7% by 2030, 1% by 2040, and reaches 0–1% by 2050 (Figure 4).

The CAT provides benchmarks for total fossil gas generation, rather than focusing only on unabated gas generation. However, it is important to distinguish between the two.

At the global level, the share of unabated fossil gas falls to under 1% in 2040 and 0% by 2050 under both perspectives. This represents a total global phase-out of unabated fossil gas by the early 2040s.

In the top-down perspective produced for this report, there is a minimal role for gas-fired CCS at the global level, with these plants providing around 0.5% of global electricity generation in 2050. On the other hand, the bottom-up perspective envisages a total phaseout of all fossil gas (with and without CCS), with national studies existing in each country and at the global level that achieve 100% zero-carbon electricity without reliance on fossil CCS by 2050.

Therefore, the role of fossil CCS in a decarbonised power sector is either minimal or zero entirely. And while the exact portfolio of flexible generation technologies to complement variable renewables is uncertain, it is clear that fossil CCS suffers from a range of key weaknesses compared to renewables, including the energy penalties of CCS (Sgouridis et al 2019), the non-zero emissions remaining from imperfect capture rates and upstream fugitive emissions (Pehl et al 2017), and the broader environmental and social impacts from fossil fuel extraction (Achakulwisut et al 2022) (see Box 1).

Additionally, as the cost of renewables and battery storage continues to fall, and alternative approaches to balance grids such as turbines burning renewable-based hydrogen, demand-side response, grid interconnection and flexible zero-carbon sources such as geothermal continue to be developed, very low levels of fossil gas generation with CCS could be fully replaced by alternative zero-carbon options (Way et al 2021).

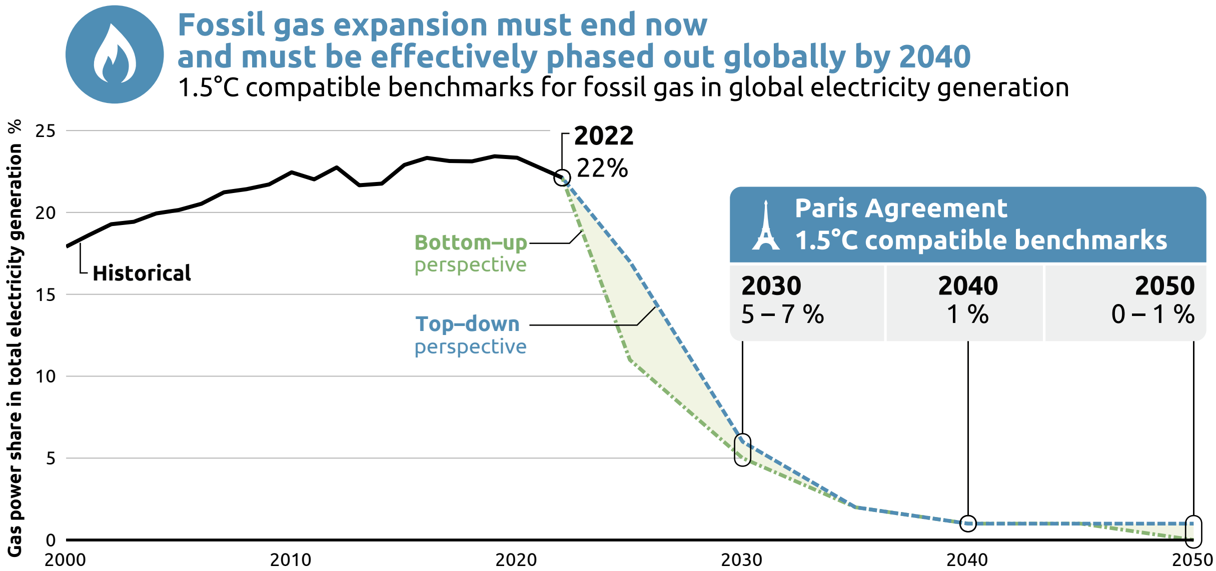


**Figure 4:** 1.5°C compatible share of fossil gas in global electricity generation

*These results are produced by aggregating the country-level downscaled pathways, and complementing this with data from the EWG LUT study (Ram et al 2019).*

Given the climatic, economic and health risks of gas generation, and the challenges facing fossil CCS in the power sector, the CAT argues that the world should aim to phase out fossil gas generation by 2040 at the latest and avoid betting on CCS to enable continued fossil gas generation in a zero-carbon future. If there is any fossil CCS deployed in the power sector, it should be deployed at very minimal levels, avoided wherever possible, and would still result in an effective fossil gas phase-out (fossil gas operating at negligible levels in the electricity system).

Figure 5 shows the share of gas in total electricity generation at the country level. The growth in gas generation that has occurred over the past two decades needs to be halted and reversed in all countries.

Table 2 provides benchmarks for fossil gas use in the power sector in each country analysed.

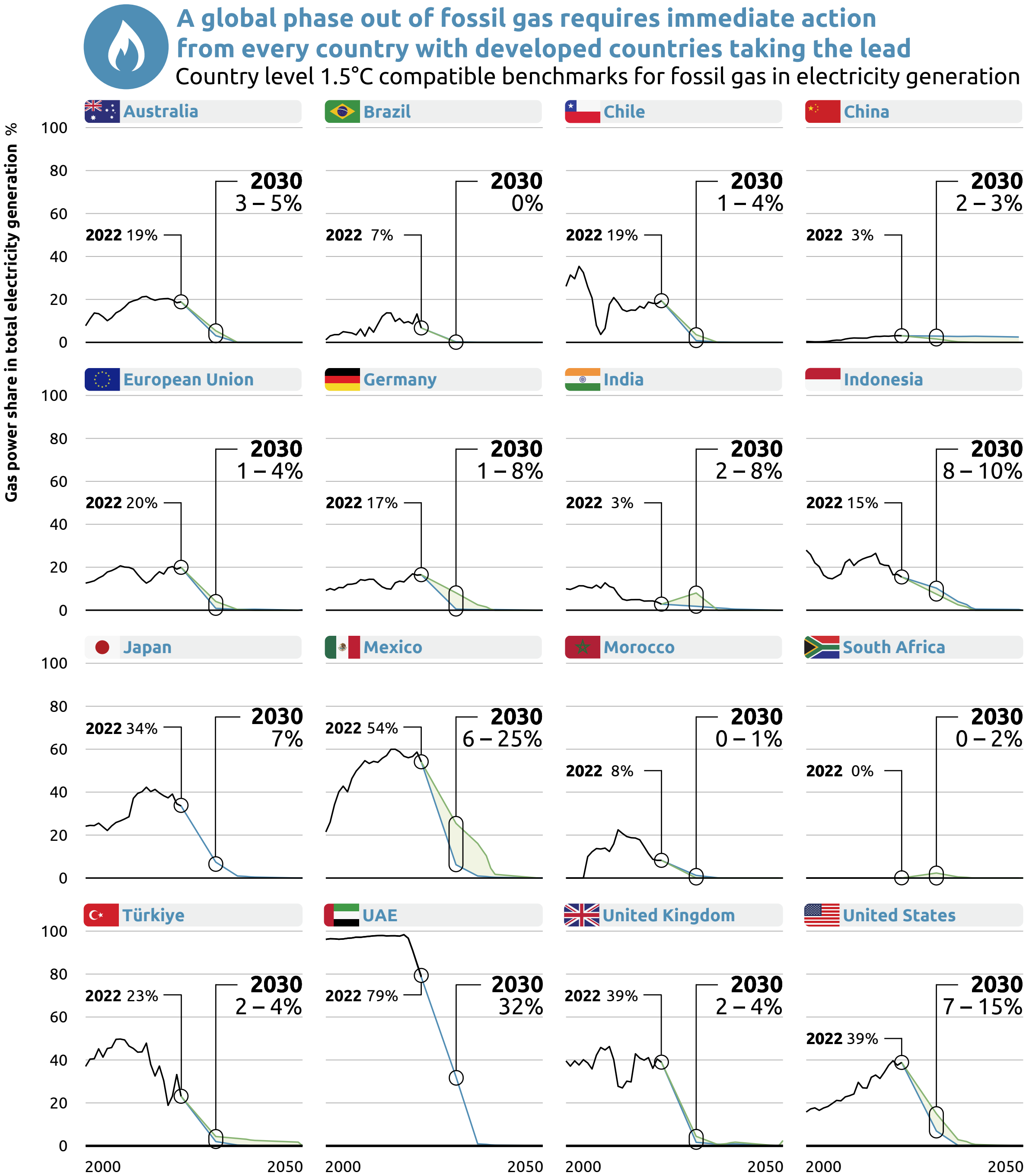


**Figure 5:** 1.5°C compatible share of fossil gas in national-level electricity mixes

*These results show a range produced by the two different perspectives: a global, top-down perspective produced by downscaling IAM pathways to the national level, and a national, bottom-up perspective produced by an in-depth literature review of national power sector studies.*

**Table 2:** 1.5°C compatible benchmarks for the share of total fossil gas power generation

**1.5°C compatible benchmarks for fossil gas in electricity generation**

| Country | 2022 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|
| Global | 22% | 5–7% | 2% | 1% | 0–1% |
| USA | 39% | 7–15% | 0–3% | 0% | 0% |
| EU27 | 20% | 1–4% | 0% | 0% | 0% |
| Japan | 34% | 7% | 1% | 0% | 0% |
| Germany | 17% | 1–8% | 0–3% | 0% | 0% |
| Australia | 19% | 3–5% | 0% | 0% | 0% |
| UK | 39% | 2–4% | 1–2% | 1–2% | 0% |
| UAE[4] | 79% | 32% | 1% | 0% | 0% |
| China | 3% | 2–3% | 0–3% | 0–3% | 0% |
| India | 3% | 2–8% | 0–1% | 0% | 0% |
| Brazil | 7% | 0% | 0% | 0% | 0% |
| Indonesia | 15% | 8–10% | 2–4% | 0–1% | 0% |
| Mexico | 54% | 6–25% | 1–16% | 0–2% | 0% |
| Türkiye | 23% | 2–4% | 0–3% | 0–3% | 0% |
| South Africa | 0% | 0–2% | 0% | 0% | 0% |
| Chile | 19% | 1–4% | 0% | 0% | 0% |
| Morocco | 8%* | 0–1% | 0% | 0% | 0% |

**In Morocco historical data is only available until 2021. Countries are ordered by developed vs. developing, and then by size of emissions in 2021.*

In developed countries, gas-fired electricity generation falls to very low levels (generally providing under 5% of electricity generation) by 2030, and towards zero by 2035 onwards. In the developing world (where coal often dominates the electricity mix), the share of gas in electricity generation is generally lower at present than in the developed world. This share remains low and falls towards zero by 2040 in most countries[5].

As at the global level, the CAT sees no or at most a marginal role for CCS in the power sector. On this basis, developed countries should lead the way and achieve fossil-free electricity by 2035, while developing countries would effectively phase out fossil gas by 2040.

These benchmarks show that developing countries can avoid the gas trap, focusing instead on a transition to zero-carbon electricity. While some have suggested that fossil gas can perform a "bridging role" in the transition to clean electricity, our analysis shows that expanding fossil gas generation is a risky strategy that is not compatible with limiting warming to 1.5°C.

Building new fossil gas plants would bring increased exposure to volatile fossil fuel markets (Climate Analytics 2023b), increased deaths from air pollution (CREA 2021), and a large risk of stranded assets (Global Energy Monitor 2021). As the cost of renewables continues to fall, with it falls the need for fossil gas (Climate Analytics 2022). The narrative of gas as a "bridging fuel" is being increasingly exposed as a fossil fuel industry false narrative (Kemfert et al 2022).

4 In the UAE the share of gas fell rapidly from 2020–2022 as 4 GW of nuclear capacity came online. However, there is only 1.4 GW of further nuclear capacity under construction in the UAE (WNA 2023a). To maintain this level of fossil gas displacement over the coming years will require substantially greater effort to accelerate renewables deployment.

5 Some small amounts of fossil gas remain in 2040 in some countries as seen in Table 3. However these small levels of fossil gas could be replaced by alternative zero-carbon generation, and the CAT calls for countries to effectively phase out fossil gas by 2040. There is a very small amount (2%) of fossil gas that remains in 2050 for China (in the top-down perspective) and Türkiye (bottom-up perspective). In both cases, the other lines of evidence point to a total gas phase-out in 2050. Hence Table 3 shows 0% fossil gas in 2050 in both Türkiye and China.

## Box 1: CCS in the power sector

Carbon capture and storage (CCS) refers to technologies which use engineered methods to capture $CO_2$ from a source and store it geologically. CCS can be applied to a range of different $CO_2$ sources in different sectors.

Proponents of CCS in the power sector have suggested that CCS could be used to capture emissions from coal and gas-fired power stations, enabling their continued operation in a low-carbon power system.

However, the real-world performance of CCS in the power sector has been very poor (Reiner 2016). As of the end of 2022, only one demonstration level plant was currently operational globally (Boundary Dam, in Canada), with only two scheduled to come online in 2023 (GCCSI 2022). There have been multiple failed demonstration plants in recent years (Wang et al 2021), and the Boundary Dam plant has a lifetime underperformance of ~50% (IEEFA 2022).

And while CCS has suffered a "lost decade" (Martin-Roberts et al 2021), the cost of renewables has plummeted, with renewables cheaper than fossil-fuel generation in much of the world (IRENA 2023), and certainly when CCS is also factored in. The declining cost of renewables has significantly eroded the value of CCS in the power sector (Grant et al 2021).

As such, the latest modelling assessed by the CAT finds no role for coal-fired CCS in 1.5°C compatible transitions, and at best a marginal role for fossil gas equipped with CCS.

The general trend of modelling assessments over the years is for less and less CCS in the power sector as cost estimates improve.

A recent assessment of technology learning finds that CCS has exhibited no promising cost improvements so far in its 50-year history (Way et al 2021). Indeed, "within a few decades electricity produced with CCS will likely not be competitive [with renewables] even if CCS is free" (Way et al 2021).

## 3.3 Share of renewables (% of total generation)

An accelerated rollout of renewables will be essential to phase out coal and gas and achieve clean power within a generation.

In 2022, renewable technologies provided around 30% of total power generation (Ember 2023). Hydropower was the main contributor, providing 15% of global electricity demand. Wind and solar provided a further 12%, while other renewable sources accounted for 3%. The share of renewables in electricity generation has grown modestly over the past two decades, increasing from 19% in 2000, with most of this driven by a rapid uptick in solar and wind power generation.

To limit warming to 1.5°C, the pace of renewables deployment needs to accelerate markedly. By 2030, the global share of renewables reaches 81–89% in 1.5°C-compatible pathways, growing to 93–98% by 2040 and 95–100% by 2050 (Figure 6).

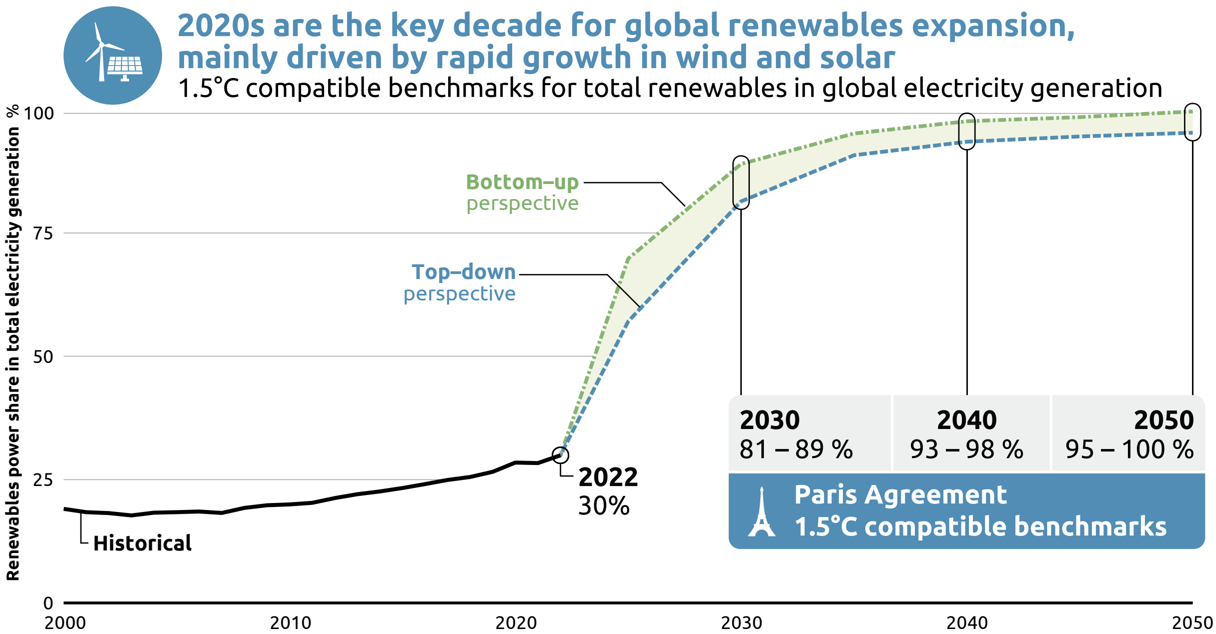


**Figure 6:** 1.5°C compatible share of renewables in global electricity generation

*These results are produced by aggregating the country-level downscaled pathways, and complementing this with data from the EWG LUT study (Ram et al 2019).*

In developed countries, the share of renewables in our benchmarks generally reaches above 80% by 2030, above 90% by 2035, with 100% renewable electricity achieved by 2050 at the latest. There is strong agreement between the two perspectives, with the top-down perspective generally giving slightly higher levels of ambition on renewables than the bottom-up perspective.

Japan is a slight outlier, with a generally slower roll-out of renewables. This is due to the contribution of nuclear in Japan's electricity mix, which the CAT estimates could provide 12–20% of electricity generation in 2030 under current policies (CAT 2023). In the top-down perspective, Japan achieves a clean power sector by the mid-2030s through a combination of renewables and nuclear, which provides 16% of electricity generation in 2030 and 14% in 2050.

This would require nuclear generation to triple to 180 TWh/y by 2050. If such an increase were not achieved, then a higher share of renewables would be needed. It's worth noting that national studies, despite not reducing emissions fast enough by 2030/2040 to align with 1.5°C, demonstrate the feasibility of achieving 100% renewables by 2050 in Japan.

In the bottom-up perspective (national studies), there is also a slower phase-in of renewables in the USA compared to most other countries. The most ambitious US studies achieve a share of renewables of ~68% by 2030. This is lower than the share in some less wealthy countries such as Morocco or China. This is again largely due to nuclear power, which the bottom-up studies assume will provide around

16% of power generation in 2030. Therefore, the share of zero-carbon electricity in the bottom-up studies for the USA reaches around 85% by 2030. In addition, the CAT argues that wealthy countries such as the USA should aim for the higher end of the benchmarking range wherever possible, which would involve the USA achieving 86% of its electricity generation from renewables, with only 7% coming from fossil gas in 2030.

Developing countries also see a rapid increase in renewables under 1.5°C compatible pathways. If developing countries align with the lower end of the benchmarking range, all countries would produce over half of their electricity from renewables by 2030, with many reaching close to 80% renewables and beyond.

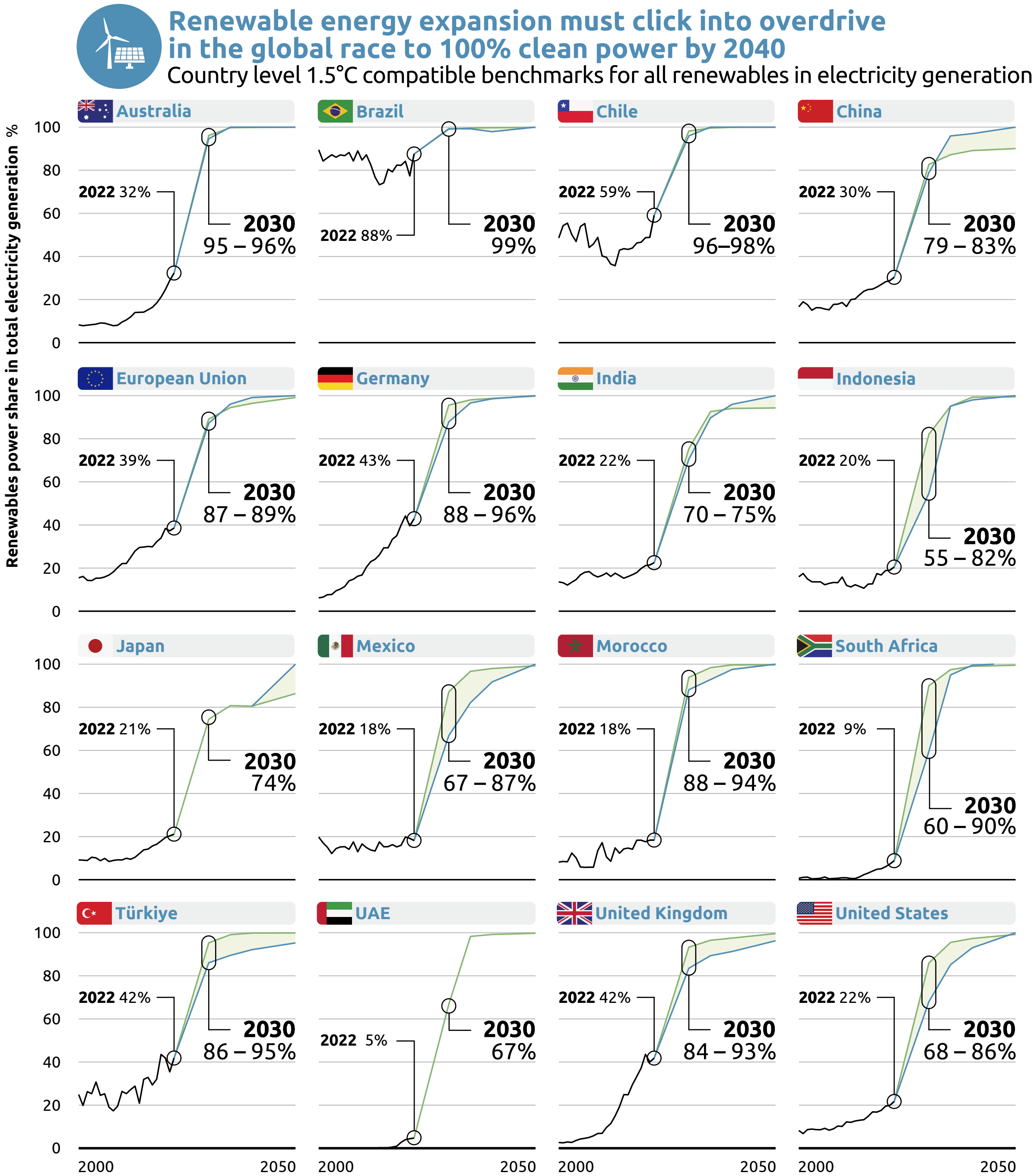


**Figure 7:** 1.5°C compatible share of renewables in national-level electricity generation

*These results show a range produced by the two different perspectives - a global top-down perspective produced by downscaling IAM pathways to the national level, and a national bottom-up perspective produced by an in-depth literature review of national power sector studies.*

At the higher end of the range, all developing countries assessed would achieve over 75% of electricity generation from renewables by 2030, with some countries reaching 90% renewable electricity. The alignment between the two perspectives increases over the time-horizon, with both perspectives showing over 90% renewables by 2040 and achieving 100% renewables or close to this level by 2050.

Figure 7 shows how the growth in renewables deployment is broken down across individual countries. All countries need to accelerate renewables deployment, moving towards 100% renewable electricity by 2050 in most cases.

Table 3 provides benchmarks for the assessed countries.

**Table 3:** 1.5°C compatible benchmarks for the share of renewables in electricity generation

**1.5°C compatible benchmarks for renewables in electricity generation**

| Country | 2022 | 2030 | 2035 | 2040 | 2050 |
|---|---|---|---|---|---|
| Global | 30% | 81–89% | 91–95% | 93–98% | 95–100% |
| USA | 22% | 68–86% | 85–95% | 93–97% | 99–100% |
| EU27 | 39% | 87–89% | 94–96% | 96–99% | 99–100% |
| Japan | 21% | 74% | 81% | 81% | 86–100% |
| Germany | 43% | 88–96% | 97–98% | 99% | 100% |
| Australia | 32% | 95–96% | 100% | 100% | 100% |
| UK | 42% | 84–93% | 89–96% | 91–98% | 96–100% |
| UAE | 5% | 67% | 98% | 99% | 100% |
| China | 30% | 79–83% | 87–96% | 89–97% | 90–100% |
| India | 22% | 70–75% | 90–93% | 94–96% | 94–100% |
| Brazil | 88% | 99% | 99–100% | 99–100% | 100% |
| Indonesia | 20% | 55–82% | 95% | 98–99% | 99–100% |
| Mexico | 18% | 67–87% | 82–97% | 92–98% | 99–100% |
| Türkiye | 42% | 86–95% | 89–99% | 92–100% | 95–100% |
| South Africa | 9% | 60–90% | 95–97% | 99–100% | 100% |
| Chile | 59% | 96–98% | 100% | 100% | 100% |
| Morocco | 18%* | 88–94% | 93–99% | 98–100% | 100% |

*Historical data comes from IEA up to 2021 (IEA 2023e) extended out to 2022 using Ember data (Ember 2023a).*

*Countries are ordered by developed vs. developing, and then by size of emissions in 2021.*

**In Morocco historical data is only available until 2021.*

In developed countries, the share of renewables in our benchmarks generally reaches above 80% by 2030, above 90% by 2035, with 100% renewable electricity achieved by 2050 at the latest. There is strong agreement between the two perspectives, with the top-down perspective generally giving slightly higher levels of ambition on renewables than the bottom-up perspective.

Japan is a slight outlier, with a generally slower roll-out of renewables. This is due to the contribution of nuclear in Japan's electricity mix, which the CAT estimates could provide 12–20% of electricity generation in 2030 under current policies (CAT 2023). In the top-down perspective, Japan achieves a clean power sector by the mid-2030s through a combination of renewables and nuclear, which provides 16% of electricity generation in 2030 and 14% in 2050.

This would require nuclear generation to triple to 180 TWh/y by 2050. If such an increase were not achieved, then a higher share of renewables would be needed. It's worth noting that national studies, despite not reducing emissions fast enough by 2030/2040 to align with 1.5°C, demonstrate the feasibility of achieving 100% renewables by 2050 in Japan.

In the bottom-up perspective (national studies), there is also a slower phase-in of renewables in the USA compared to most other countries. The most ambitious US studies achieve a share of renewables of ~68% by 2030. This is lower than the share in some less wealthy countries such as Morocco or China. This is again largely due to nuclear power, which the bottom-up studies assume will provide around 16% of power generation in 2030. Therefore, the share of zero-carbon electricity in the bottom-up studies for the USA reaches around 85% by 2030. In addition, the CAT argues that wealthy countries such as the USA should aim for the higher end of the benchmarking range wherever possible, which would involve the USA achieving 86% of its electricity generation from renewables, with only 7% coming from fossil gas in 2030.

Developing countries also see a rapid increase in renewables under 1.5˚C compatible pathways. If developing countries align with the lower end of the benchmarking range, all countries would produce over half of their electricity from renewables by 2030, with many reaching close to 80% renewables and beyond.

At the higher end of the range, all developing countries assessed would achieve over 75% of electricity generation from renewables by 2030, with some countries reaching 90% renewable electricity. The alignment between the two perspectives increases over the time-horizon, with both perspectives showing over 90% renewables by 2040 and achieving 100% renewables or close to this level by 2050.

Some differences are seen between the renewables benchmarks across countries. Some countries with coal-dominated electricity mixes (such as Morocco) display very rapid transitions towards 100% renewables, while other countries with gas-dominated mixes (such as the UAE) move more slowly. This is broadly a feature of the global pathways, which generally focus on phasing out coal in the power sector before fossil gas. While the methods used in this report address this behaviour explicitly, minimising asset stranding in the existing coal fleet and accelerating the phase-out of fossil gas, in a 1.5°C compatible power sector transition, phasing out coal remains the number one priority. Achieving this phase-out in a fair manner will require significantly upscaled international support to countries like Morocco.

Achieving a highly renewable power sector across all countries is possible but will require unprecedented effort to accelerate renewables deployment. Equally important will be the range of supporting policies and strategies to integrate renewables into the grid (IEA 2023b). Strengthening grid infrastructure and interconnecting grids to facilitate greater balancing of renewables across broader geographic and temporal scales (Brown et al 2018), deploying energy storage and flexible zero-carbon generation technologies alongside variable renewables (Sepulveda et al 2021) and utilising the opportunities offered by digitisation to expand demand-side flexibility (Söder et al 2018) will all be essential.

In all countries, the 1.5°C compatible benchmark for renewables approaches 100% by 2050. If countries do not reach 100% renewables, any remaining generation would need to be provided by other zero-carbon sources. As seen above, there is, at best, a marginal role for fossil gas equipped with CCS in the power sector (which is also low-carbon at best, rather than zero-carbon). Therefore, the remaining electricity generation would need to be predominantly nuclear generation.

In 2022, nuclear generation provided 9% of global electricity demand, and there are around 60 plants under construction with a total capacity of 60 GW (WNA 2023b). However, while renewables have seen accelerating deployment and rapidly falling costs, nuclear has stagnated, with essentially no growth seen since 2000 (Ember, 2023).

The cost of generating electricity from nuclear is also generally higher than that of renewables (Lazard 2023). Although nuclear electricity generation does not emit $CO_2$, the CAT does not see nuclear as the solution to the climate crisis. This is due to the risks associated with nuclear generation such as nuclear accidents and proliferation, the high and increasing costs (compared to alternatives such as renewables), the long construction times, the incompatibility of inflexible nuclear plants with a flexible supply of electricity from wind and solar, and its vulnerability to heat waves.

## 3.4 Emissions intensity of electricity ($gCO_2/kWh$)

The emissions-intensity of electricity generation serves as a comprehensive metric to assess the progress made in decarbonising the power sector. Under the 1.5°C compatible benchmarks produced here, the emissions intensity of the power sector declines rapidly, falling to 48–80 $gCO_2/kWh$ by 2030, <5 $gCO_2/kWh$ in 2040 and ultimately reaching 0 $gCO_2/kWh$ or below by 2050 (Figure 8). This represents a transition to clean power by 2040, or within a generation's time.

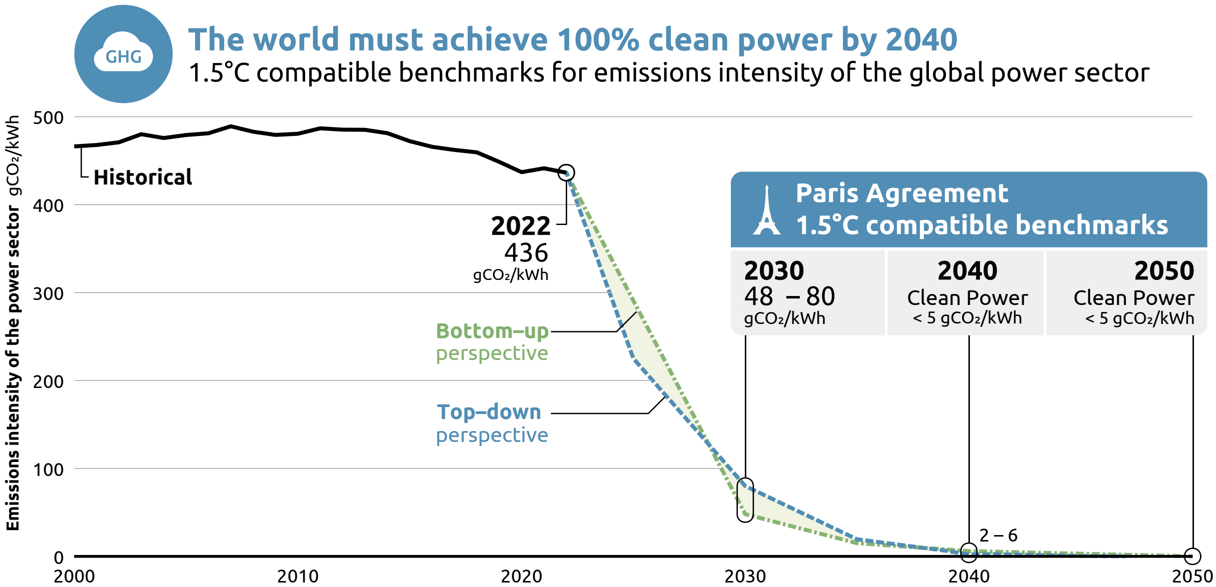


**Figure 8:** 1.5°C compatible emissions intensity of the global power sector

*These results are produced by aggregating the country-level downscaled pathways, and complementing this with data from the EWG LUT study (Ram et al 2019).*

Figure 9 shows how the emissions intensity of the power sector varies at the national level.

# Developed countries must achieve clean electricity generation by 2035, with developing by 2040

Country level 1.5°C compatible benchmarks for emissions intensity of electricity

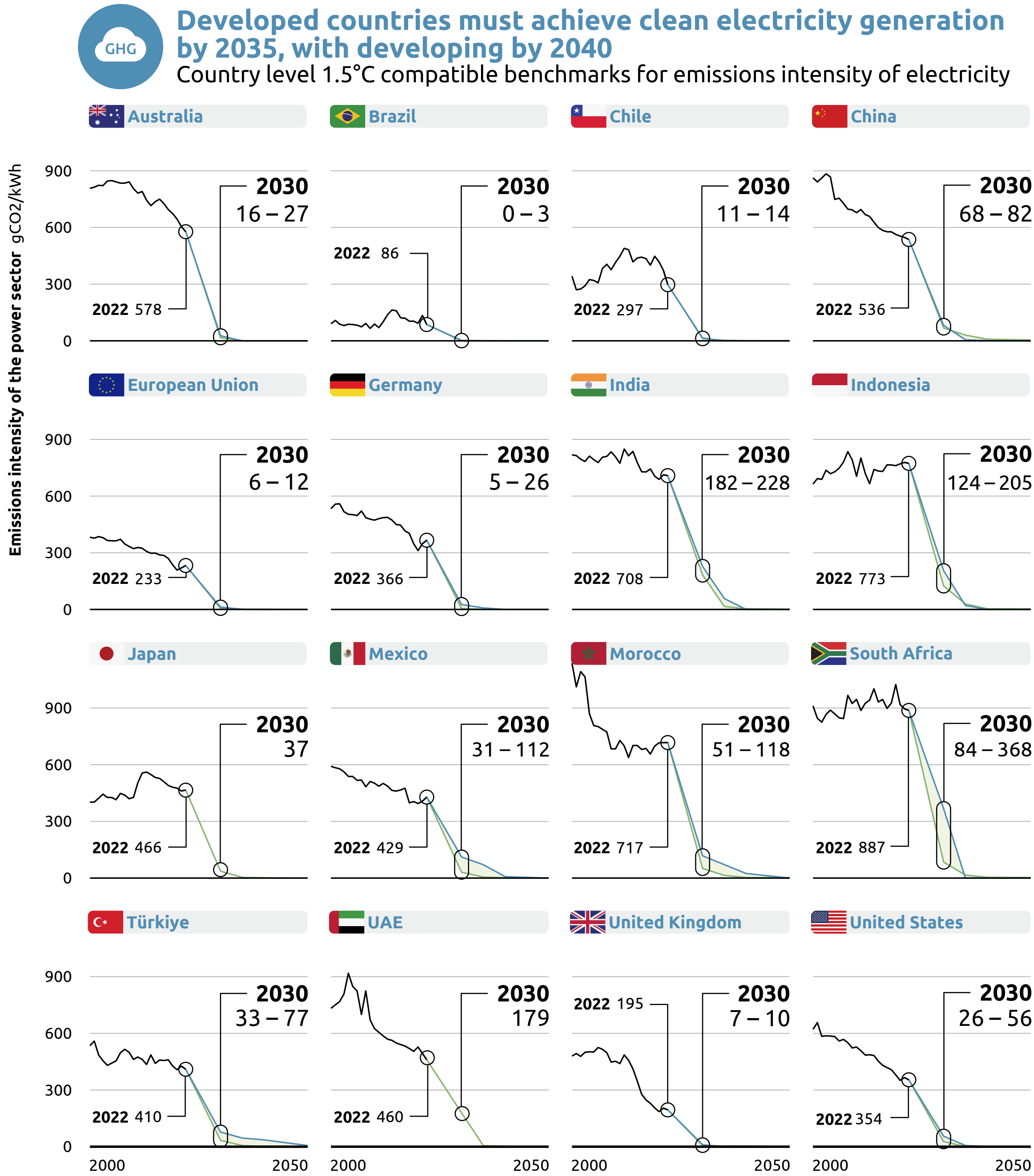


**Figure 9:** 1.5°C compatible emissions intensity at the national level.

*These results show a range produced by the two different perspectives - a global top-down perspective produced by downscaling IAM pathways to the national level, and a national bottom-up perspective produced by an in-depth literature review of national power sector studies.*

Clean electricity is a cornerstone of the energy transition and achieving this is an essential milestone on the road to net zero. In our 1.5° compatible benchmarks, all developed countries achieve this goal by 2035, while all developing countries achieve clean power by 2040 at the latest.

Table 4 summarises the benchmarks as assessed by the CAT. Often the benchmarks do not strictly reach 0 $gCO_2/kWh$. This is often due to residual emissions from a very small amount of fossil gas equipped with CCS (which is low- but not zero-carbon generation). It could also be due to minimal levels of remaining unabated generation, which is retained for security of supply and used minimally (e.g., keeping a fleet of gas peaking plants to guarantee security of supply for a 1-in-a-100-year event of wind/solar shortages and high electricity demand[6]).

**Table 4:** 1.5°C compatible benchmarks for the emissions-intensity of power generation

**1.5°C compatible benchmarks for the emissions intensity of power generation**

| Country | 2022 | 2030 | 2035 | 2040 | 2050 | Units |
|---|---|---|---|---|---|---|
| **Global** | 436 | 48–80 | 15–19 | **2–6** | **0** | $gCO_2/KWh$ |
| **USA** | 354 | 26–56 | **1–6** | **0–1** | **0** | $gCO_2/KWh$ |
| **EU27** | 233 | 6–12 | **1** | **0–1** | **0** | $gCO_2/KWh$ |
| **Japan** | 466 | 37 | **4** | **2** | **0** | $gCO_2/KWh$ |
| **Germany** | 366 | 5–26 | **1–8** | **0–1** | **0** | $gCO_2/KWh$ |
| **Australia** | 578 | 16–27 | **0** | **0** | **0** | $gCO_2/KWh$ |
| **UK** | 195 | 7–10 | **0–3** | **0–3** | **0** | $gCO_2/KWh$ |
| **UAE** | 460 | 179 | **5** | **2** | **0** | $gCO_2/KWh$ |
| **China** | 536 | 68–82 | 6–30 | **0–9** | **0–5** | $gCO_2/KWh$ |
| **India** | 708 | 182–228 | 15–57 | **0–4** | **0–2** | $gCO_2/KWh$ |
| **Brazil** | 86 | **0–3** | **0–1** | **0** | **0** | $gCO_2/KWh$ |
| **Indonesia** | 773 | 124–205 | 21–29 | **0–4** | **0–3** | $gCO_2/KWh$ |
| **Mexico** | 429 | 31–112 | 5–71 | **2** | **0** | $gCO_2/KWh$ |
| **Türkiye** | 410 | 33–77 | 6–46 | **1** | **1** | $gCO_2/KWh$ |
| **South Africa** | 887 | 84–368 | 0–16 | **0–4** | **0–3** | $gCO_2/KWh$ |
| **Chile** | 297 | 11–14 | **0–3** | **0–1** | **0–1** | $gCO_2/KWh$ |
| **Morocco** | 717* | 51–118 | 14–71 | **2** | **0–3** | $gCO_2/KWh$ |

*Historical data comes from IEA up to 2021 (IEA 2023e) extended out to 2022 using Ember data (Ember 2023a).*

**In Morocco historical data is only available until 2021. Countries are ordered by developed vs. developing, and then by size of emissions in 2021.*

*Bold text indicates power sector has clean electricity, which we define as the average of the range being less than 5 grams of $CO_2$ per kilowatt hour.*

The emissions intensity of electricity may not reach exactly zero due to these reasons. However, our benchmarks still represent a 99% cut in the global emissions intensity of electricity generation by 2040. Additionally, the CAT argues that these small remaining sources of emissions in the modelling could potentially be replaced fully with alternative zero-carbon generation or compensated for by negative emissions from bio-electricity with CCS, which is not accounted for in the emissions intensity calculations (see methods documentation report).

Therefore, the CAT calls for the world to achieve clean power by 2040 at the global level, with developing countries achieving this goal by 2035. The CAT here classifies countries as having achieved clean power if the average emissions intensity of electricity generation across both perspectives is 5 $gCO_2/kWh$.

6 The CAT benchmarks are for the share of fossil generation, not capacity. It may well be justified for countries to maintain some of their fossil gas fleet in a 'cold reserve' for some time (Instrat 2021), which is only used in extreme situations to guarantee security of supply. This could still be compatible with fossil fuels providing ~0% of the electricity mix (e.g., if they operate for only a few days per year on average).

# 4 Progress assessment

The previous section has charted a Paris-aligned pathway to achieving clean electricity within a generation, across all countries. The question then arises – are we currently on track? And where does further action need to be taken?

To do this, we need to understand what the rate of renewables roll-out and fossil fuel decline is likely to be under current efforts.

## 4.1 Current trends: an incoming renewables revolution

It is clear that the current pace of renewables deployment is insufficient to limit warming to 1.5°C. In 2023, the world is on track to install over 400 GW of new renewables (IEA 2023c) – but needs to install 1500 GW/y of wind and solar by 2030 to limit warming to 1.5°C (Climate Analytics 2023a). More action is urgently needed to upscale renewables deployment and drive fossil fuels out of the energy mix.

However, it is also clear is that the pace of renewables deployment is accelerating rapidly. The 440 GW of renewable capacity due to be installed this year represents a more than 30% increase on 2022 installations, which were 333 GW (IEA 2023c). As the cost of renewables continues to plummet, and their deployment accelerates, records will tumble faster.

In many places the energy transition will be exponential, not linear (Butler-Sloss and Bond 2023). Technology deployment often follows an s-curve, rather than a straight line. In an s-curve, deployment starts slowly, but then accelerates rapidly. Deployment will eventually flatten out as we approach market saturation, but before we reach that point, there is a period of rapid, exponential growth.

Following this logic, we don't analyse the trend of renewables growth to 2030 as a straight line, but instead fit s-curve models to the share of electricity produced by wind and solar, two technologies which are driving the exponential growth of renewables. Figure 10 shows how the share of wind and solar will increase out to 2050, if countries continue to follow an s-curve fitted to the 2000-2022 historic data.

These illustrative s-curves show that in all countries, renewables are entering the exponential phase of growth, with the share of wind and solar growing rapidly. At the global level, wind and solar are on track to provide 31–34% of electricity generation by 2030, if they continue to follow an s-curve[7].

We then estimate the share of total renewables that would be achieved by 2030, assuming that other renewables (hydro, geothermal and biomass) grow linearly in line with the historical trends of the last five years. Table 5 shows these illustrative shares for 2030, comparing them to the 1.5°C compatible benchmarks calculated.

7 If wind and solar deployment follows an exponential curve (with no slow down in growth), rather than an s-curve, then they could provide even higher levels of electricity generation by 2030.

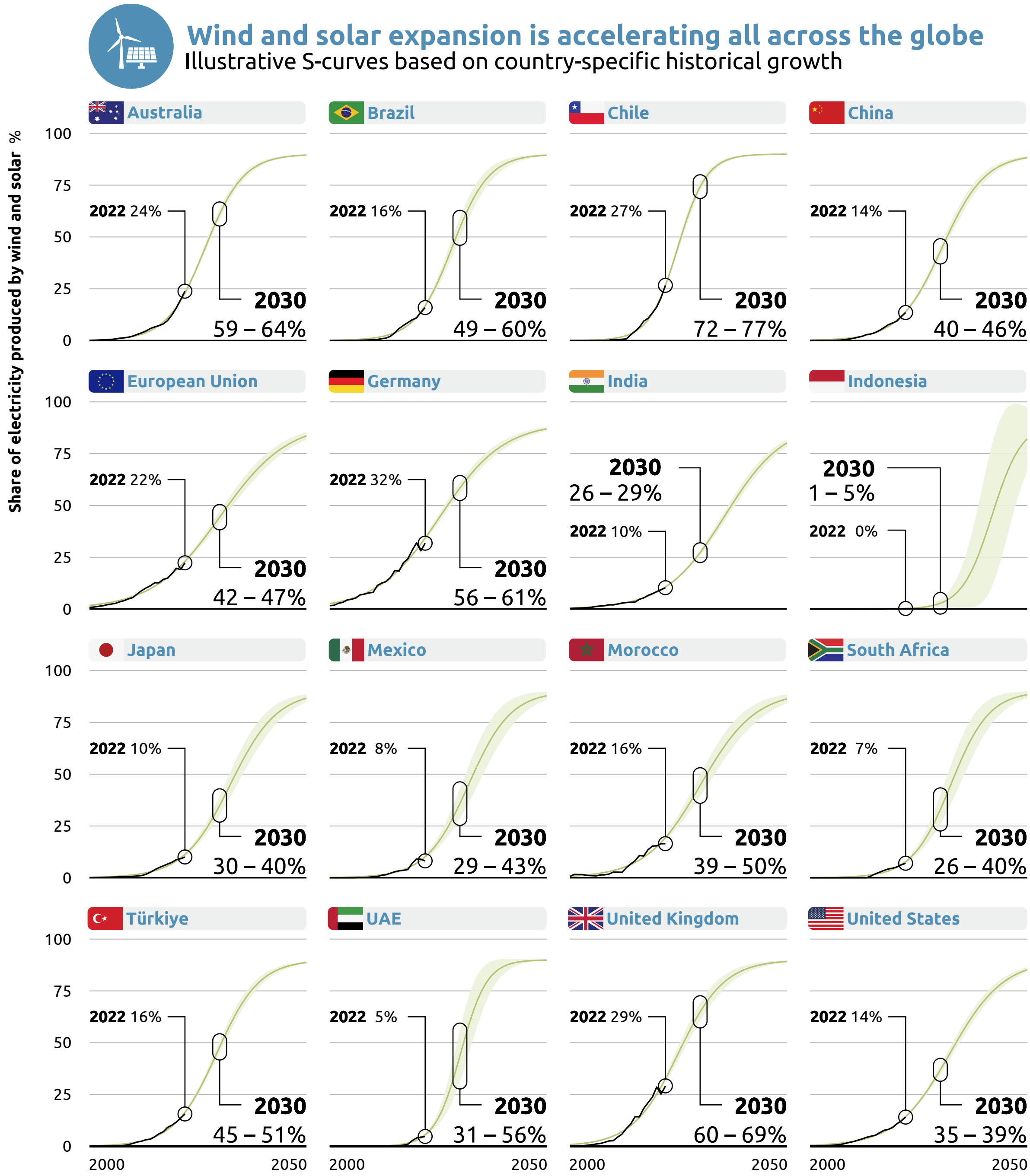


**Figure 10:** The share of electricity from wind and solar under an s-curve deployment.

**Table 5:** The ambition gap in 2030, based on renewables continuing to grow according to historical precedent

**2030 Ambition gap for renewables in electricity generation**

| Country | 2022 level | 2030 share following illustrative trend | 2030 1.5°C compatible benchmark | Ambition gap in 2030 (increase in renewables share required to meet the 1.5°C benchmark) |
|---|---|---|---|---|
| Global | 30% | 48–51% | 81–89% | 30–41% |
| USA | 22% | 40–44% | 68–86% | 24–46% |
| EU27 | 39% | 61–67% | 87–89% | 20–28% |
| Japan | 21% | 44–53% | 74% | 21–30% |
| Germany | 43% | 68–73% | 88–96% | 15–28% |
| Australia | 32% | 64–69% | 95–96% | 26–32% |
| UK | 42% | 79–87% | 84–93% | 0–14% |
| UAE | 5% | 31–56% | 67% | 11–36% |
| China | 30% | 55–60% | 79–83% | 19–28% |
| India | 22% | 40–42% | 70–75% | 28–35% |
| Brazil | 88% | 100% | 99% | 0% |
| Indonesia | 20% | 32–35% | 55–82% | 20–50% |
| Mexico | 18% | 35–49% | 67–87% | 18–52% |
| Türkiye | 42% | 75–81% | 86–95% | 5–20% |
| South Africa | 9% | 29–43% | 60–90% | 17–62% |
| Chile | 59% | 95–99% | 96–98% | 0–4% |
| Morocco | 18%* | 39–50% | 88–94% | 38–55% |

*Historical data comes from IEA up to 2021 (IEA 2023e) extended out to 2022 using Ember data (Ember 2023a).*

**In Morocco historical data is only available until 2021. Countries are ordered by developed vs. developing, and then by size of emissions in 2021.*

These illustrative shares should be seen as exactly that – an illustration of the level of renewables deployment that could be achieved if deployment continues along historical precedents. Modelling 2030 wind and solar deployment by an s-curve requires assumptions to be made about the ultimate saturation level of wind and solar[8] and can be sensitive to the historical data provided.

Importantly, Table 5 also assumes some continuity between the past policy environment that has driven renewables deployment and the future policy environment. This is not necessarily the case – in some countries new policies represent a substantial escalation in ambition (such as the EU27's REPowerEU strategy and USA's Inflation Reduction Act), while in other countries such as the UK, past successes are now at risk as commitment to climate action wavers.

Therefore, this method for estimating the trend in future renewables deployment should be viewed as an illustrative approach only. However, it does provide useful information on the current pace of the energy transition in different countries.

This shows that many countries could achieve a high share of renewables by 2030, if wind and solar deployment continues to accelerate and take market share from other technologies. Brazil and Chile start from a high share of renewables already in 2022 and could achieve >90% renewables by 2030. Türkiye and the UK are able to achieve around 80% renewables in 2030 if current trends continue and are not stopped.

8 We assume wind and solar can provide up to 90% of electricity in a country. The ultimate saturation point may vary from country to country – for example, in Brazil the large share of hydro may be retained, meaning that wind and solar provide <90% of electricity generation. We tested alternative endpoints on a country-specific basis and found that this makes little difference to the share of wind and solar predicted by 2030, in line with other analysis (RMI 2023).

Many of these countries have seen rapid deployment of wind (UK), solar (Chile) or both (Türkiye) in recent years, which, if maintained, would put them close to achieving a 1.5°C compatible power sector transition.

In the case of Brazil, the high share of renewables is mainly due to the existing dominance of hydroelectricity in the system, which means that almost 90% of electricity was renewable in 2022. However, wind and solar deployment is growing rapidly in Brazil, with the share of electricity produced by wind and solar having grown from 1% in 2012 to 16% by 2022. If Brazil maintains its hydroelectricity plants while using wind and solar to displace the remaining fossil generation (mainly fossil gas), it could achieve 100% clean electricity by 2030, with a generation mix of hydroelectricity complemented by wind and solar.

However, despite some positive signs, there is still an important ambition gap in 2030 that needs to be closed. At current rates, the world is on track to achieve around 50% renewable electricity by 2030, but needs to be achieving over 80% of electricity from renewables to align with the 1.5°C compatible benchmarks found in this report.

Developed countries should be aiming for the upper end of the benchmarking range provided. No developed country is currently on track to achieve this when future renewables are estimated using historical data, although the UK comes close. This shows the efforts made to accelerate renewables deployment in developed countries over the past decade, while important, need to be substantially upscaled to align with 1.5°C.

Recent policy developments such as the Inflation Reduction Act in the USA and the REPowerEU strategy in Europe are targeting shares of renewables in 2030 that would break with historical precedent[9] and further close the ambition gap – showing that the future does not have to be constrained by the past. While the full impacts of the Inflation Reduction Act are still unclear (Bistline et al 2023), at the higher end of estimates the IRA could lead to a ~66% renewable share by 2030 – closing the gap to the bottom-up benchmark for renewables. However, the picture for policy development is not so positive elsewhere. In the UK, the huge success in renewables deployment of the past decade now risks being undermined by wavering commitment to climate action, with wind deployment slightly off-track and solar significantly off-track from the levels required to meet the UK's current targets (CCC 2023).

Developing countries should aim for at least the lower end of the benchmarking range as an ambition floor. However, even when looking at this lower end, there remains a noticeable ambition gap between the 1.5°C compatible benchmarks produced in this report, and the illustrative shares of renewables that could be achieved by 2030 if renewables continue to follow historical precedents. This highlights the urgent need for additional climate finance and measures to overcome persistent barriers to wind and solar deployment – such as high financing costs, capacity constraints and competition with heavily subsidised fossil fuels – to break with historical trends and close the ambition gap.

Overall, the picture presented here is mixed. While most countries are not on track to achieve a 1.5°C compatible power sector mix by 2030, the emerging signs of an inevitable renewables revolution can be seen. And as mentioned above, the s-curve adoption of technologies is by no means a cast-iron law. Power sector decarbonisation over the next decade will be a function of the ambition of policies to support renewables rollout, the scale (and geographical distribution) of investment mobilised, and the rate at which the manufacturing base for wind and solar is upscaled (IEA 2023d). Sufficient effort across these different levers can accelerate renewables deployment beyond the s-curve and deliver a 1.5°C aligned power sector transition.

The future does not have to look like the past, but this will only happen if our future efforts to address climate change break markedly from past efforts. This will require greater action to support renewables deployment, coupled with a clear commitment to end building new fossil-fired power plants and phase-out coal and gas.

9 The IRA could lead to 55-66% renewable electricity in the USA by 2030 (DOE 2023) and REPowerEU targets 69% renewable electricity in the EU27 by 3030 (European Commission 2022)

## 4.2 Future pipelines: continued reliance on fossil fuels

However, governments across the world are still failing to commit to a fossil-free future in the power sector. While renewables deployment is accelerating, governments are still planning on building more fossil fuel-fired power generation capacity, both coal and gas. Building new fossil-based generation in the power sector poses huge climate, economic and technological risks, and should be avoided. Figure 11 shows the amount of coal and gas-fired power plants that are either planned or already under construction across the globe.

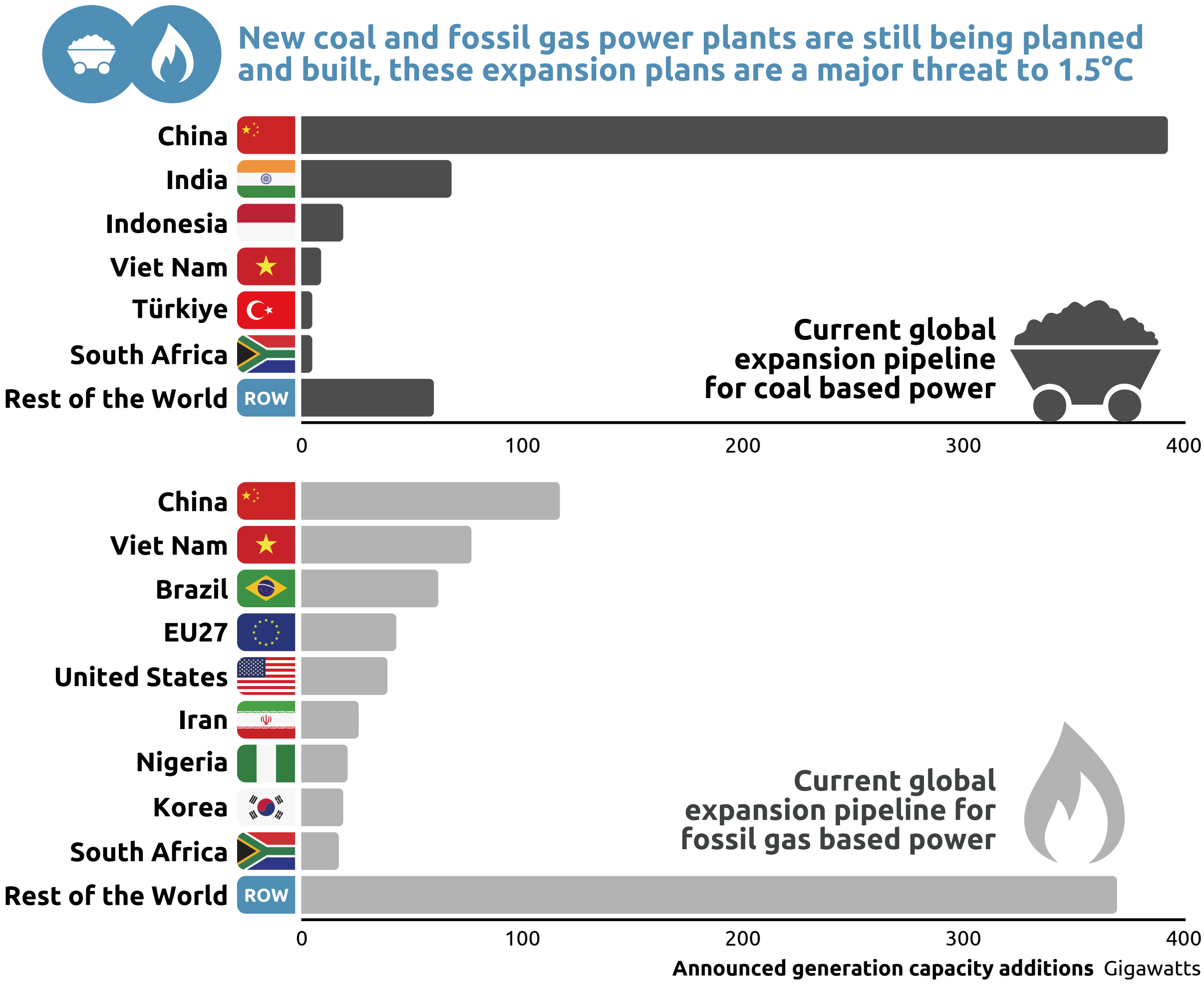


**Figure 11:** The future coal and gas pipeline by country.

As of July 2023, there is currently 558 GW of coal either planned or under construction across the world (Global Energy Monitor 2023b). Of this, 205 GW is already under construction, almost entirely in China (136 GW), India (32 GW) and Indonesia (14 GW). As well as plants under construction, around 350 GW of coal-fired capacity is still being proposed, the majority of which is in China. While proposed coal-fired power capacity has fallen around two thirds since the signing of the Paris Agreement (Global Energy Monitor 2023a), the remaining pipeline of projects and plants under construction shows that there is no room for complacency. An immediate end to new coal is essential if warming is to be limited to 1.5°C.

Of the countries assessed in this report, four have substantial plans to build new coal-fired power stations: China, India, Indonesia and Türkiye. All of these have significant coal mining industries and see coal as a way to balance the grid and achieve energy security. However, all four of these countries are also suffering from overcapacity in their current grids, which is already reducing the utilisation of existing coal power plants (CREA and TransitionZero 2021, IEEFA 2021, TransitionZero 2023b, 2023a). Building more coal-fired power plants will simply exacerbate this issue, preventing these countries from benefiting fully from the renewables revolution.

Nowhere is this misguided reliance on coal-fired power plants greater than in China. The spree of new coal plant permitting which began in mid-2022 has continued into 2023, with construction starting on 40 GW of coal-fired capacity, permitting received for 50 GW and a new 40 GW of capacity announced, all in the first half of 2023 (CREA and GEM 2023). This represents a rate of more than one plant announced, permitted and entering construction per week in the first six months of 2023. Ending the glut of coal plant permitting in China is essential to avoid massive asset stranding of coal plants in the Chinese power sector.

The global pipeline for future fossil gas plants is now greater than that of coal-fired power, with around 790 GW of fossil gas-fired plants either under construction or proposed as of February 2023 (Global Energy Monitor 2023c). Unlike coal, where development plans are limited to a small subset of countries, the dash for gas is global, with almost all countries planning on building new fossil gas plants.

China, Brazil, the EU27, the USA and South Africa have particularly large pipelines. If these gas plants are built, they will either undermine the transition to clean power and jeopardise the 1.5°C temperature limit or will have to be retired prematurely with significant asset stranding. New fossil gas plants represent a huge climate and economic risk that can and should be avoided by accelerating the transition to renewables.

While many governments are justifying investment in new fossil gas plants as needed to balance the grid, this is a false narrative. The scale of investment in fossil gas plants dwarfs any need for flexibility in a highly renewable electricity system. In addition, new sources of flexibility to help integrate renewables are emerging, with energy storage, demand-side response and grid interconnection all eroding the need for fossil gas as a balancing solution. Instead of betting on fossil gas to balance the grid, governments should be focusing on supporting zero-carbon renewables with zero-carbon flexibility solutions.

# 5 Conclusions

Clean power will be the lifeblood of a future zero-carbon world, and accelerating the deployment of clean electricity is one of the key steps urgently needed to limit warming to 1.5°C.

This report provides a roadmap for a 1.5°C-aligned power sector transition, at both the global and national level. Using both global and country-level pathways, we have set benchmarks for the future electricity mix in terms of the share of electricity produced by coal, gas and renewables, and the overall emissions intensity of electricity generation.

The report shows that countries need to make a rapid transition from the electricity system of the past – dominated by centralised, costly, polluting fossil generation, to the electricity system of the future – powered by decentralised, low-cost, zero-carbon renewables.

Developed countries need to phase out coal and gas by 2030/35, achieving clean electricity by the mid-2030s. The pace of power sector decarbonisation is not far behind this in developing countries, with fossil fuels phased out by 2040. The world therefore achieves clean power generation by 2040 – within a generation's time.

The transition to clean power faces many challenges that governments will need to overcome. Current investment to support renewables needs to be upscaled dramatically. It also needs to be distributed more evenly across the world – as investment in renewables is still lagging in many low-income countries (BNEF 2022).

The high cost of capital for renewables deployment in regions such as Latin America and sub-Saharan Africa is hindering the transition to renewables (Songwe et al 2021). We must ensure that everyone benefits from the renewables revolution. Permitting times need to be slashed, new transmission and distribution infrastructure will need to be built, and energy storage deployed at scale.

However, these challenges are surmountable. The current growth in renewables deployment (IEA 2023c) and manufacturing capacity (IEA 2023d) are grounds for hope, and a renewed commitment to the power sector transition can still bring alignment with 1.5°C.

We are currently in the foothills of the energy transition, detecting the first signs of the coming renewables revolution. And while today's summits of renewables rollout are far below the 1.5°C ambition line, the high peaks of climate action are not beyond our grasp. We can still accelerate renewables deployment, consign fossil electricity to the history books, and achieve clean power within a generation.

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Climate Analytics is a non-profit institute leading research on climate science and policy in relation to the 1.5°C limit in the Paris Agreement. It has offices in Germany, the United States, Togo, Australia, Nepal and Trinidad and Tobago.

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