Wind and solar benchmarks for a 1.5°C world

Developing national-level benchmarks to achieve renewables deployment in line with the Paris Agreement

Brazil

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Executive Summary

Context

- Brazil generates most of its electricity from clean sources, 91% in 2023. Hydropower dominates the mix (60%).
- Wind and solar deployment is already underway, positioning the country at the forefront of wind energy in the region. Wind and solar contributed to 21% of the power mix in 2023, well above the global average (13%)
- While only 9% of Brazil's power supply came from fossil fuels in 2023, it fluctuates annually due to hydro availability.
- Despite having one of the cleanest power systems in the world, an increase in wind and solar power can reduce its vulnerability to droughts, while meeting growing electricity demand – in 2023, annual electricity demand grew by 5%
- To decarbonize other sectors, Brazil must increase its electrification levels, which is currently below 20%. This will require greater deployment of wind and solar.

Key findings

- Although Brazil does not need to triple renewables to stay on the 1.5°C pathway, our analysis suggests that solar capacity would need to triple and wind capacity double by 2030 compared to 2022 levels to meet growing demand.
- Brazil's current wind and solar rollout broadly aligns with the 1.5°C compatible benchmarks set out in this report.
- To stay aligned with the 1.5°C target, Brazil must maintain at least the same pace of annual wind and solar capacity additions over the remainder of this decade as in recent years.
- It is essential that Brazil avoids deploying new fossil fuel capacity. A dash for fossil gas in the power sector is an economic and climate risk that can, and should, be avoided.
- Our modelling envisages that wind will generate more electricity than solar in next decades in a 1.5°C compatible transition, in line with country-level studies and developments in the last decade.

Context

At COP28, governments agreed to triple global renewable capacity by 2030 globally. This report highlights the potential implications of this COP28 decision at the national level, focusing on **Brazil**.

Wind and solar deployment is accelerating around the world. However, expected wind and solar capacity deployment under current policies falls short of what is needed for 1.5°C, and is concentrated mainly in a few regions.

Research is needed to understand the pace of wind and solar deployment that aligns with the highest possible ambition and is compatible with 1.5°C

This project aims at answering the following questions:

- **How much wind and solar generation is needed (TWh) at the national level?**
- **How much wind and solar needs to be built (GW of capacity)?**
- **When does it need to be built by?**

Summary of our method

Our method takes a series of steps to calculate the wind and solar generation needed for 1.5°C, and the resulting capacity deployment. The key methodological steps are highlighted below.

1. We project future electricity demand in the country.
2. We calculate the pace of fossil fuel phase-out needed to align with 1.5°C.
3. Bringing these trajectories together defines the level of clean electricity generation required to meet electricity demand growth while phasing out fossil fuels in the power sector.
4. We project non- wind and solar clean electricity generation based on country-level literature. This allows us to identify the wind and solar generation necessary to align with 1.5°C.
5. Having produced this wind and solar generation trajectory, we feed it into a simplified electricity system model, which calculates for a given set of cost assumptions around wind and solar, a split into wind versus solar and the associated capacity requirements.

Our method is focused on including multiple different analytical elements

Integrating multiple different elements

High-ambition country-level studies

Use ambitious country-level studies as inputs to inform key parameters of the methodology

1.5°C compatible IPCC global pathways

Link to global goal of tripling renewable capacity by 2030

Renewable energy potential and power system analysis

Capture local potential for wind and solar

Key global milestones

Include key global guardrails on the pace of fossil phase-out and the level of electrification

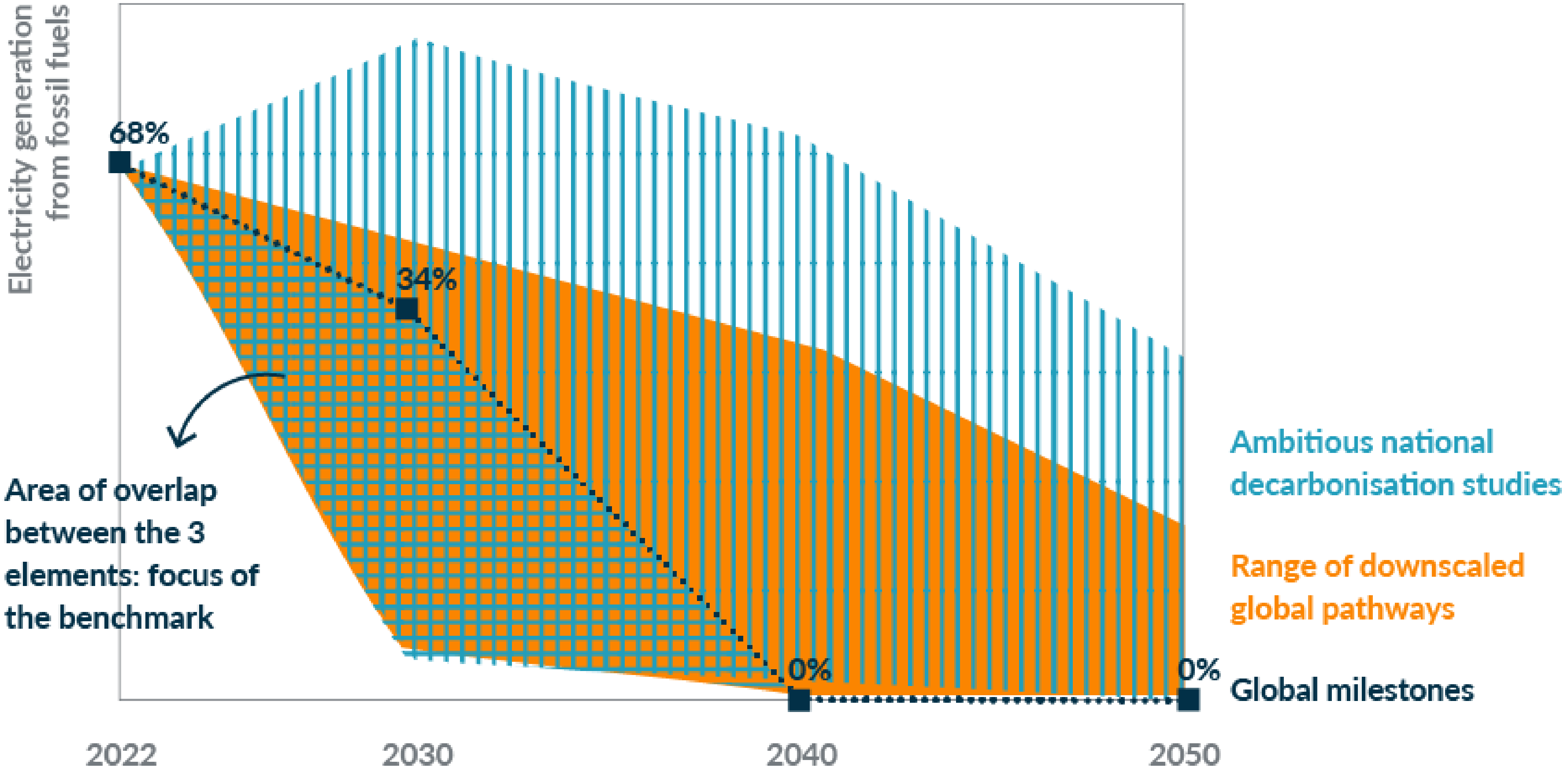
For more details see the Methods Annex

Overlap of different elements

Our method focuses on the overlap between different elements. By looking at the range of fossil phase-out which is outlined in both high ambition country-level studies and downscaled 1.5°C compatible global pathways, and is informed by key global milestones, we identify benchmarks which are both consistent with a global least cost pathway to limiting warming to 1.5°C but are also aligned with national–level modelling.

Combining multiple different analytical elements can help identify the most robust path to achieving a zero-carbon energy system.

Overlapping multiple analytical elements can provide more robust benchmarks



Area of overlap between the 3 elements: focus of the benchmark

National enabling factors

Key enabling factors for ambitious wind and solar rollout include:

- **Institutional capacity.** A rapid build-out of wind and solar will require the governance and institutional capacity to develop, implement and enforce policy frameworks.
- **Just transition.** A just transition will be needed to take along all stakeholders, particularly those employed by the fossil economy.
- **Grid development.** Substantial increases in both transmission and distribution grid infrastructure will be necessary to integrate large-scale new wind and solar generation into the power system.
- **Fossil phaseout.** Existing fossil fuel infrastructure often will need to be retired earlier than its economic lifetime. Policies need to be developed to achieve the early phase out of fossil fuel plants.
- **System flexibility.** Energy storage (diurnal and seasonal), flexible generation technologies such as hydro and geothermal, and increased demand side flexibility will all be crucial.
- **Market design.** Reform of market designs and regulation to incentivize and mobilise investments to install renewable energy at the scale needed (e.g., minimise cost of capital, ensure revenue certainty, etc)

International support

The key analytical elements (high ambition country-level studies and downscaled 1.5°C compatible global pathways) do not consider financing requirements.

Significant global resource transfers will be required in line with 'common but differentiated responsibilities and respective capabilities' to achieve these benchmarks.

We do not quantify the technical and financial support needed to achieve the wind and solar rollout presented in this report. This should be a country driven exercise and some countries have already initiated such processes, including under the JETP umbrella.

High-income countries will need to provide substantially increased climate finance to support emissions reduction abroad, in line with their 'fair share' of climate action.

Achieving these benchmarks in lower-income countries is therefore a global responsibility, rather than a domestic responsibility.

Policy context

Brazil's current NDC limits net GHG emissions to 1.2 $GtCO_2e$ by 2030, a 15% reduction below 2010 levels excluding LULUCF. The country announced "climate neutrality" target by 2050 but has incomplete information regarding GHG emission coverage and its legal status.

Brazil has already surpassed its target of reaching 84% renewable electricity by 2030. Brazil plans to reach **47 GW of solar and 31 GW of wind by 2030**, as of ten-year Energy Expansion Plan (PDE) (2022-2031) prepared by the Energy Research Office (EPE) in 2022.

Under current policies and market conditions, the IEA estimates that deployment of both wind and solar will far exceed the EPE's plans for 2030. According to the IEA, **solar capacity will reach 115 GW in 2028**, up from 27 GW in 2022. Meanwhile, **wind capacity is projected to reach 40 GW in 2028**, up from 24 GW in 2022.

Targets need to be updated to reflect the projected rollout of wind and solar.

Results

Future electricity demand

Electricity demand is taken from the *National Energy Plan 2050* of the Energy Research Office (EPE). This study includes a scenario with 100% renewable expansion for Brazil. This scenario achieves full decarbonization of the power sector by 2050, with the most significant progress occurring between 2030 and 2040.

Total electricity generation in Brazil more than doubles by 2050 relative to 2022 levels, reaching 1,635 TWh. This is driven by economic development and, to lesser extent, electrification.

However, there is a significant range in the studies in terms of the expected electricity generation in 2050 ranging from 1,070 TWh to 1,880 TWh. Our demand estimate is in the middle of that range estimated by country-level studies.

The reference study projects a 24% electrification rate by 2050, much lower than the 52-55% global average indicated by international studies on global net zero pathways (IEA and IRENA). A higher electrification rate in Brazil would significantly impact the anticipated growth of renewable energy in the country.

Pace of fossil phaseout needed

The rate of fossil phase-out is set by the overlap between country-level studies, downscaled 1.5°C compatible global pathways and the global milestones of the IEA's Net Zero roadmap.

In 2023, just 9% of Brazil's electricity supply came from fossil fuels. **Our analysis suggests that electricity generation from fossil fuels should drop to 0-2% by 2030**, consistent with national studies showing 0-5% by 2030.

To align with 1.5°C, Brazil should phase out fossil fuels during the 2030s, even as electricity demand grows rapidly

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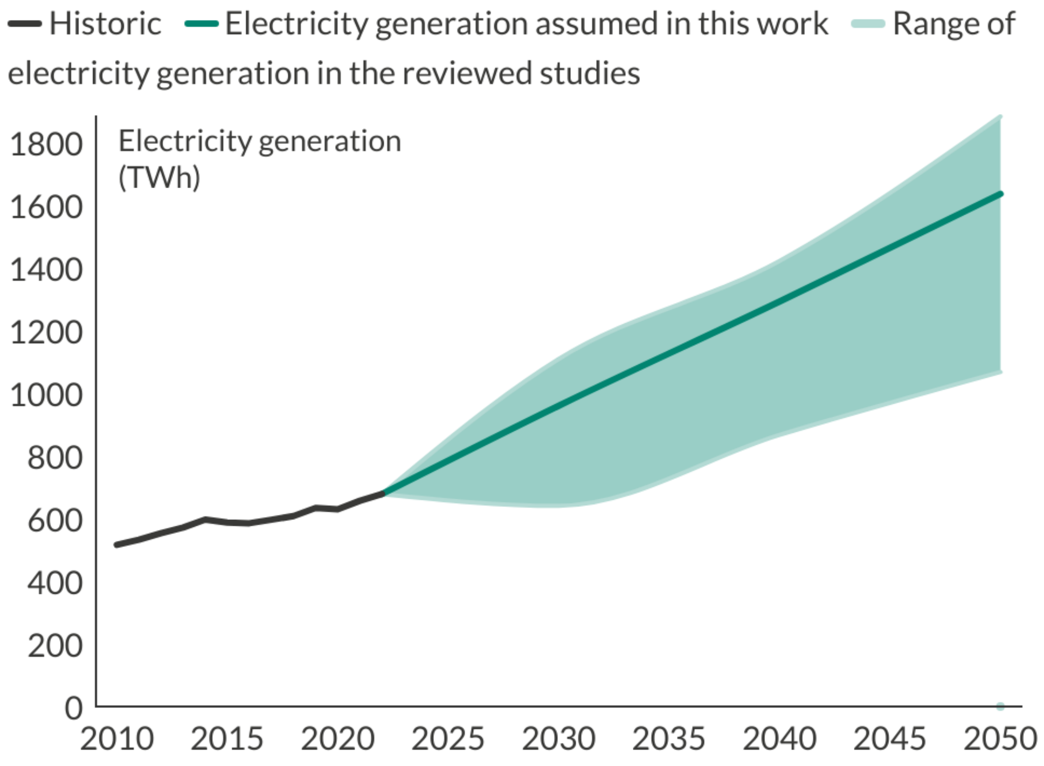
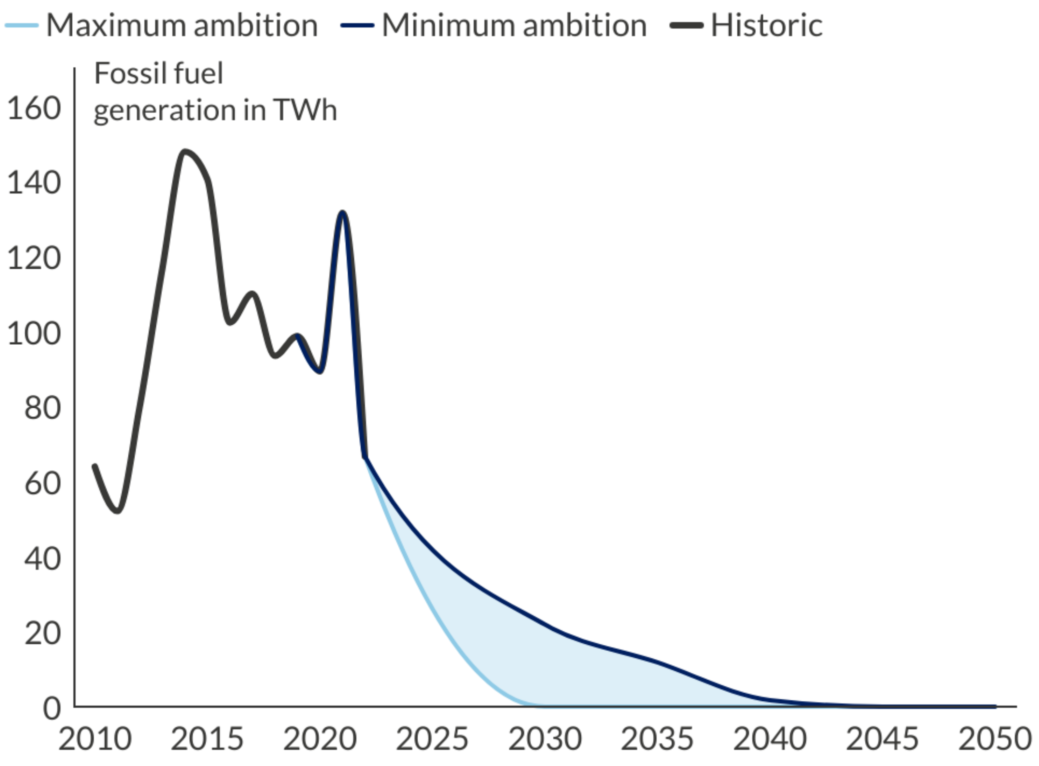
Electricity generation more than doubles in Brazil over 2022–2050



Brazil would need to achieve clean electricity by 2045



The role of other clean electricity generation

In 2023, Brazil generated 91% of its electricity from clean sources, with hydropower contributing 60% of the total. Although wind and solar will play a greater role in the future than they do today, other clean electricity generation will still play a key role in future electricity supply. We estimate the role of non- wind and solar clean electricity generation* (largely hydro, biomass, nuclear and geothermal) from country-level studies.

In our modelling, we assume that generation from non-wind and solar clean technologies in Brazil would reach 660 TWh by 2030 and 600 TWh by 2050. This is provided mostly by hydropower, alongside a small contribution from nuclear and biomass.

The potential to scale up wind and solar capacity to meet growing energy demand can also reduce the country's vulnerability to droughts, ensuring a more resilient and diverse energy supply.

* We do not consider CCS in the power sector, as we do not consider CCS a viable source of large-scale emissions reductions in the power sector.

Total wind and solar generation needed to align with 1.5°C

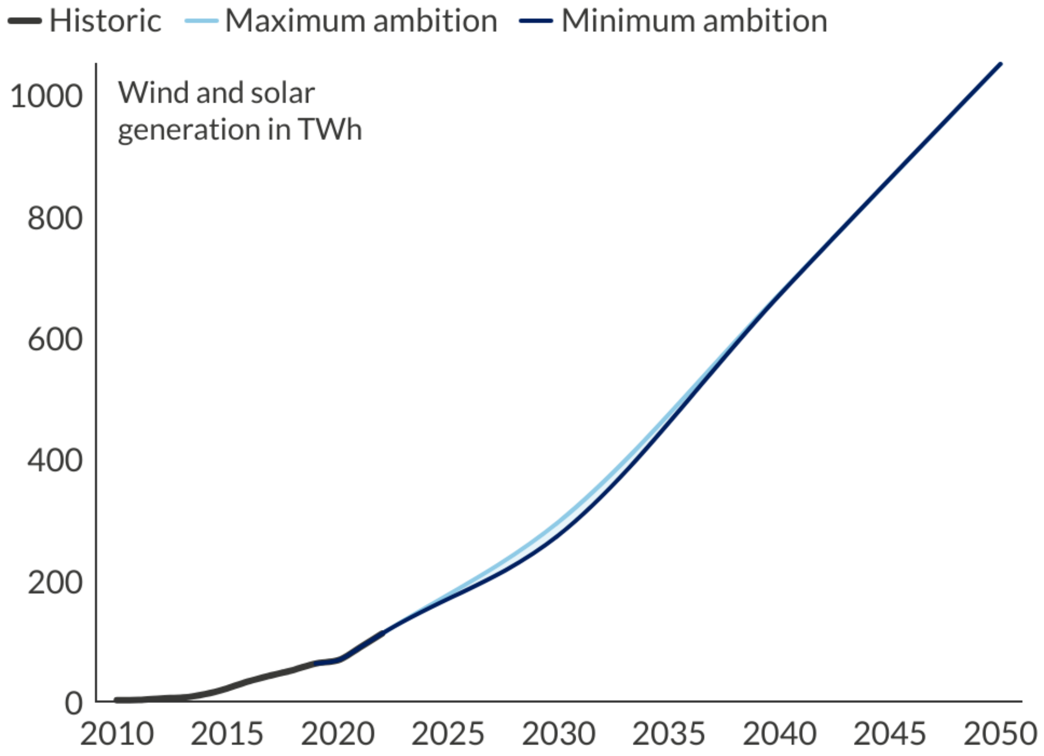
Wind and solar expansion in Brazil will be crucial to meet the growing electricity demand, beyond enabling the phase out of fossil fuels. We also recognize the key role of other non-wind-and-solar clean technologies (mainly hydropower, biomass, nuclear), which is informed from country-level studies.

To align with 1.5°C, wind and solar generation in Brazil would need to reach between 270 and 300 TWh by 2030. Generation in 2022 was 122 TWh. This represents an increase in wind and solar generation of 2.5-2.6 times.

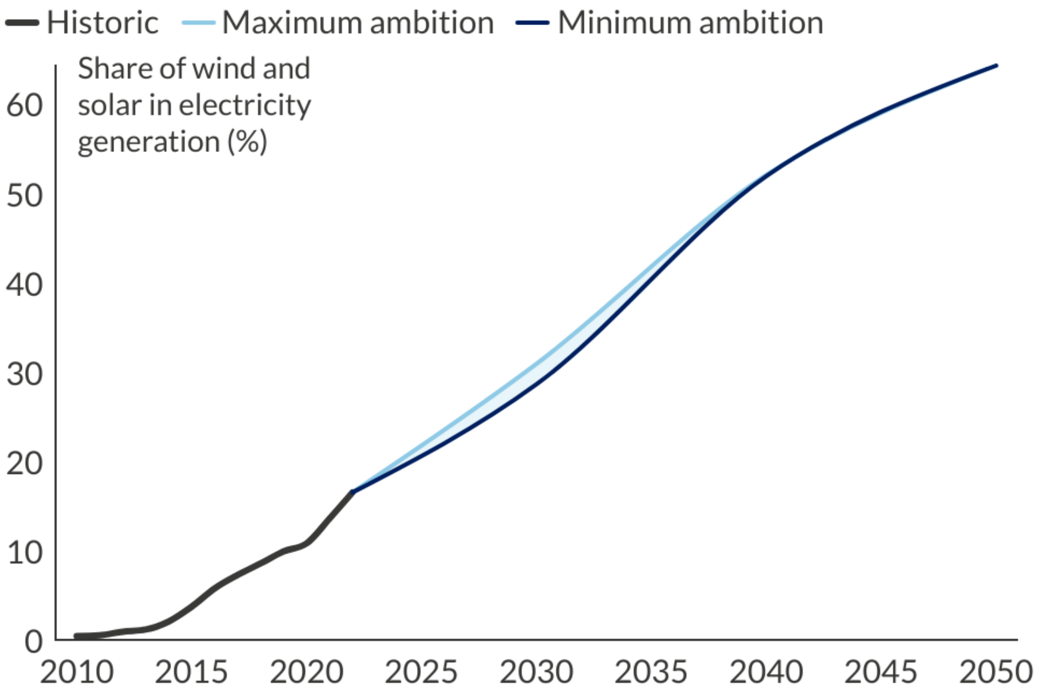
Our analysis shows that **wind and solar will contribute 29–31% of total electricity generation in 2030, and 64% in 2050**. This is broadly in line with the most ambitious scenarios in the *National Energy Plan 2050* of the Energy Research Office (EPE), which show a 26-28% share of electricity generation from wind and solar by 2030, and 62-66% share by 2050.

To align with 1.5°C, Brazil's wind and solar generation would need to grow 2.5-2.6x over 2022-2030

Wind and solar generation needs to more than double by 2030 relative to 2022 in Brazil



Wind and solar would need to provide almost two-thirds of electricity generation in Brazil by 2050



Possible splits into wind and solar

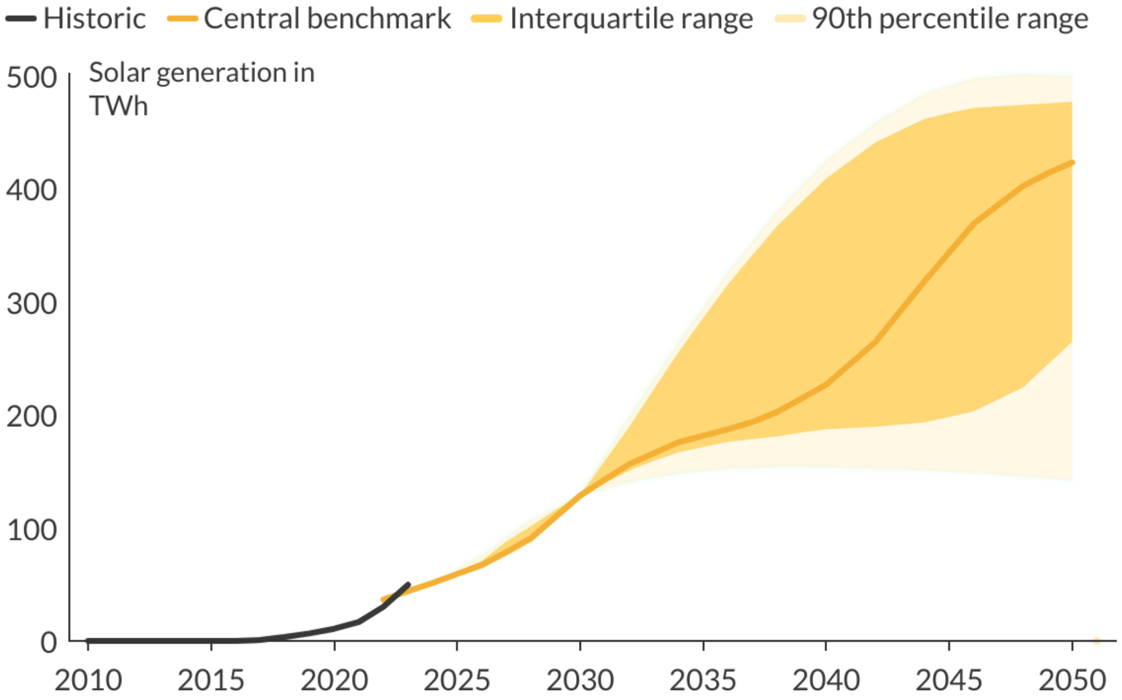
The relative share of wind and solar deployment will vary depending on how various factors develop in the future. We explore one key uncertainty, the relative cost of solar and wind electricity generation (see methods). When accounting for this uncertainty, we see a range of possible future generation mixes between wind and solar.

We highlight the median of the range as our **central benchmark**, but do not suggest that this is the only possible breakdown into wind vs. solar. In the central benchmark scenario, wind is the main source of generation, providing on average about 40% more electricity than solar in the generation mix by 2050. The significant contribution of hydropower will be key to providing system flexibility and enabling the rapid uptake of wind and solar.

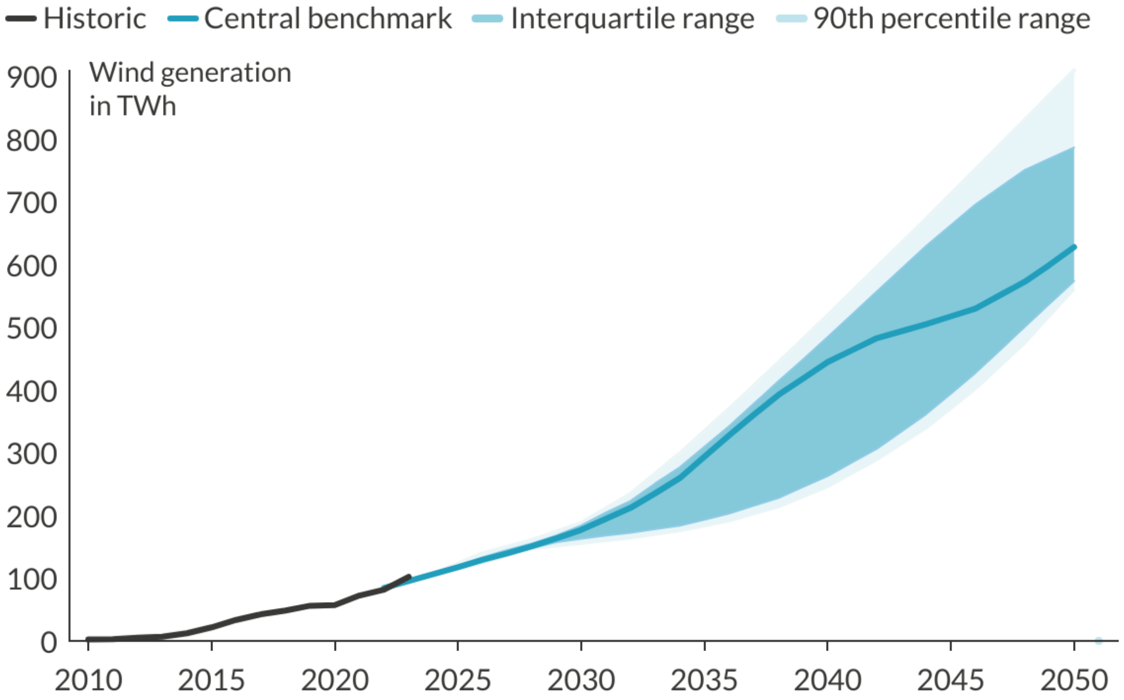
In this scenario, **Brazil would need to deploy around 135 GW of wind and solar by 2030 to limit warming to 1.5°C**. By 2050, total wind and solar capacity would need to reach towards 440 GW. Due to its higher capacity factor, greater wind deployment would reduce total capacity requirements.

Wind and solar electricity generation need to continue growing strongly in Brazil

Solar generation in Brazil would reach over 400 TWh by 2050 in a 1.5°C-aligned transition

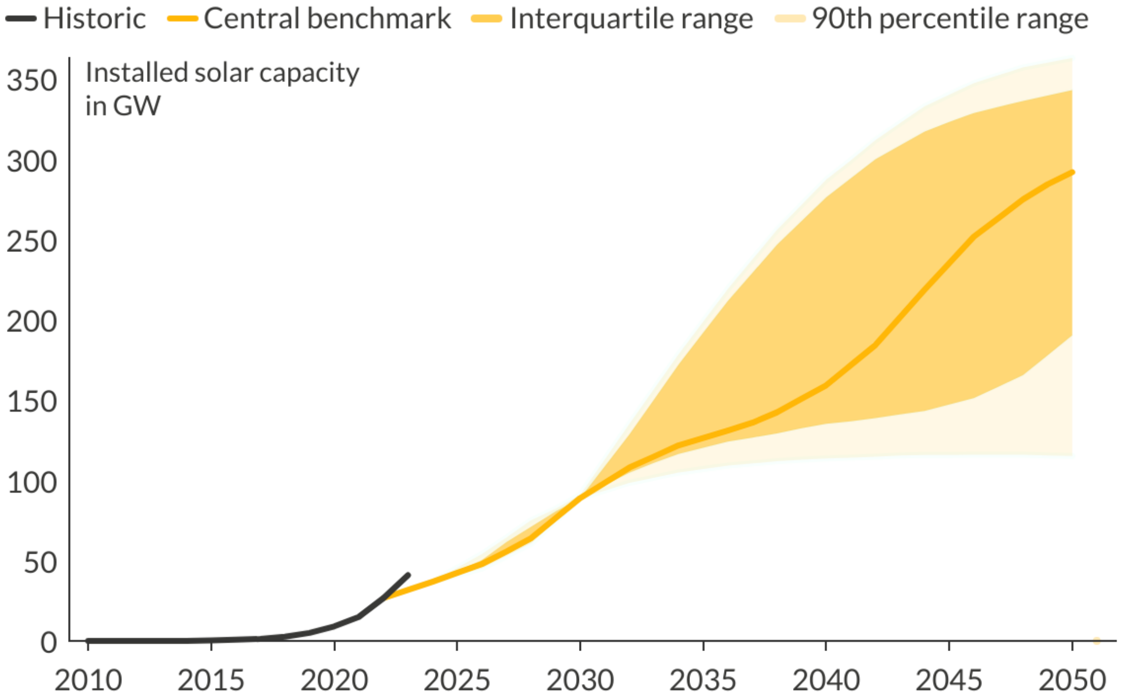


Wind generation in Brazil would reach over 600 TWh by 2050 in a 1.5°C-aligned transition

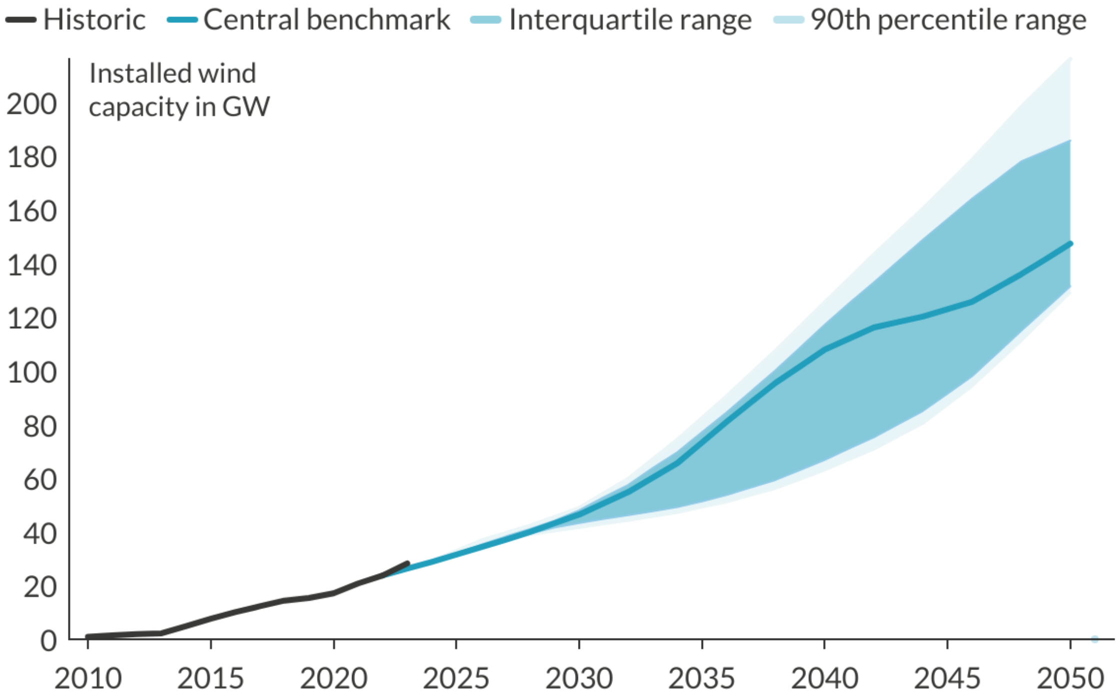


Brazil needs to install 135 GW of wind and solar by 2030 to align with 1.5°C

Solar capacity would reach 89 GW in Brazil by 2030 in a 1.5°C-aligned scenario



Wind capacity would reach 46 GW in Brazil by 2030 in a 1.5°C-aligned scenario



Comparison to current rollout

Under current policies and market conditions*, Brazil’s rapid wind and solar deployment aligns with the 1.5°C pathway, exceeding national targets. **Solar PV deployment in Brazil is on track to surpass the 1.5°C compatible pathways by 2030, while the wind rollout aligns with the benchmark.**

To stay on track, Brazil must build on the momentum of recent years to **maintain annual capacity additions at least at the same pace over remainder of the decade**.

The rapid deployment of wind and solar in Brazil towards 2030-2050 is driven primarily by the need to meet growing electricity demand and, to a lesser extent, to phase out fossil fuels from the electricity.

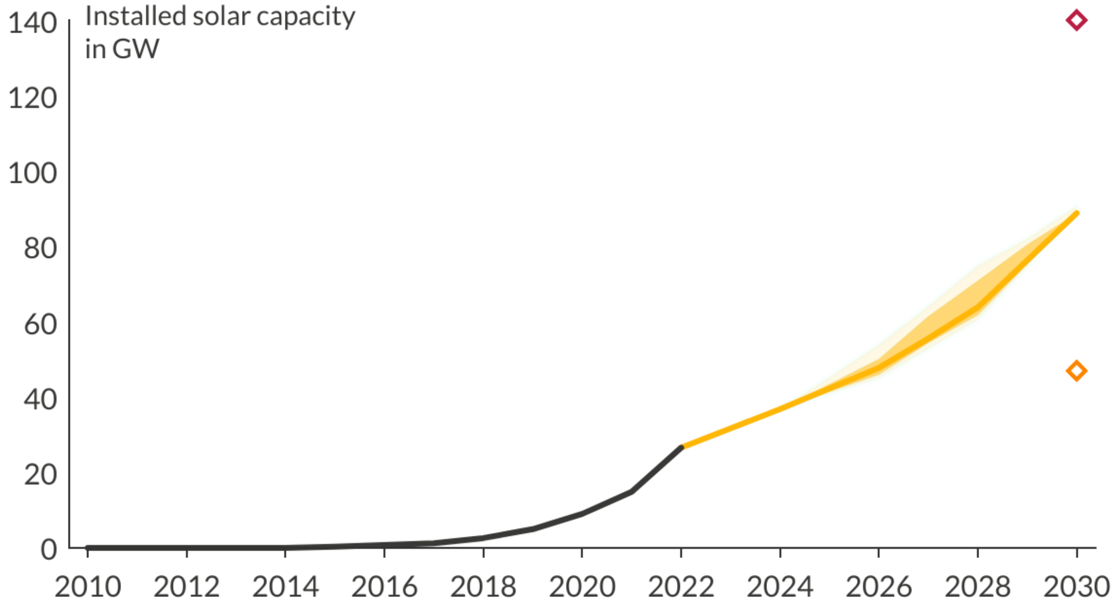
However, a full decarbonization of the economy will require action in other sectors, for which end-use electrification is a key solution. Higher electrification rates will further increase electricity demand, requiring even greater deployment of wind and solar. This is not considered in the benchmarks presented here.

* We extend the IEA’s capacity forecast for wind and solar (which is provided out to 2028) to 2030 and compare to the benchmarks presented in this report.

Brazil's solar rollout exceeds 1.5°C, while wind rollout broadly aligns with 1.5°C

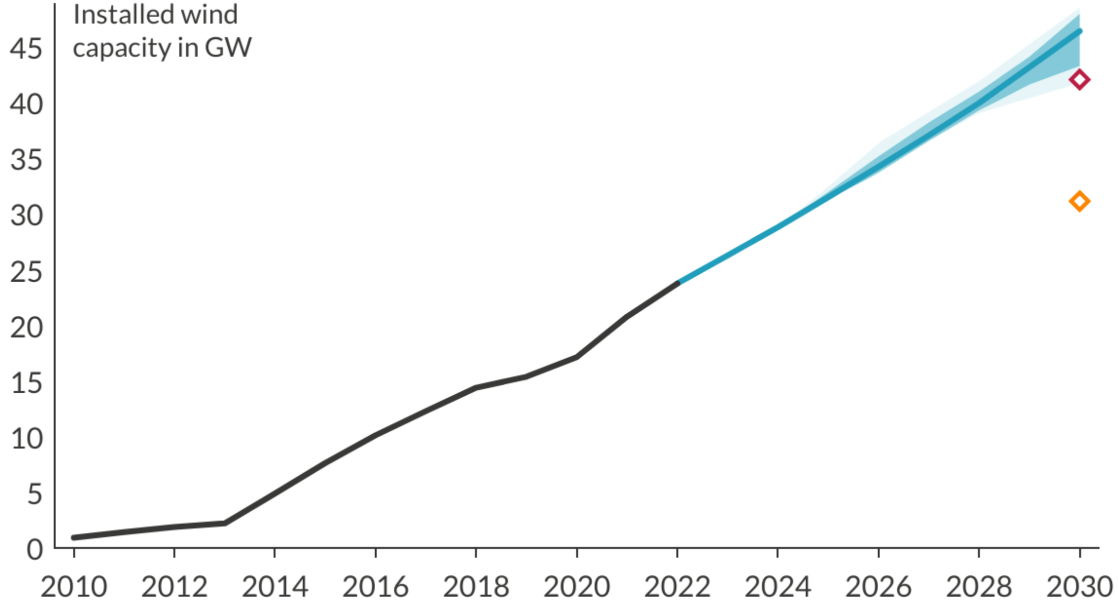
Current rollout of solar in Brazil could go beyond 1.5°C-aligned levels, driving an even faster fossil phaseout

— Historic — Central benchmark ◇ IEA forecast (extended to 2030) ◇ Country target



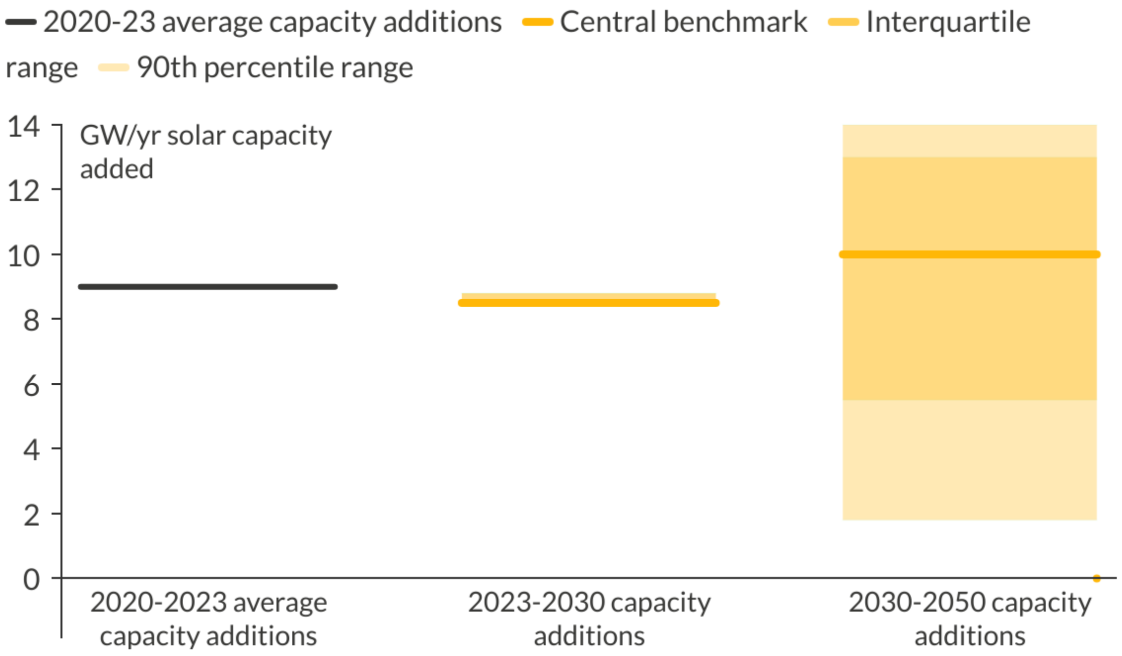
Current rollout of wind in Brazil aligns with 1.5°C, but targets need updating

— Historic — Central benchmark ◇ IEA forecast (extended to 2030) ◇ Country target

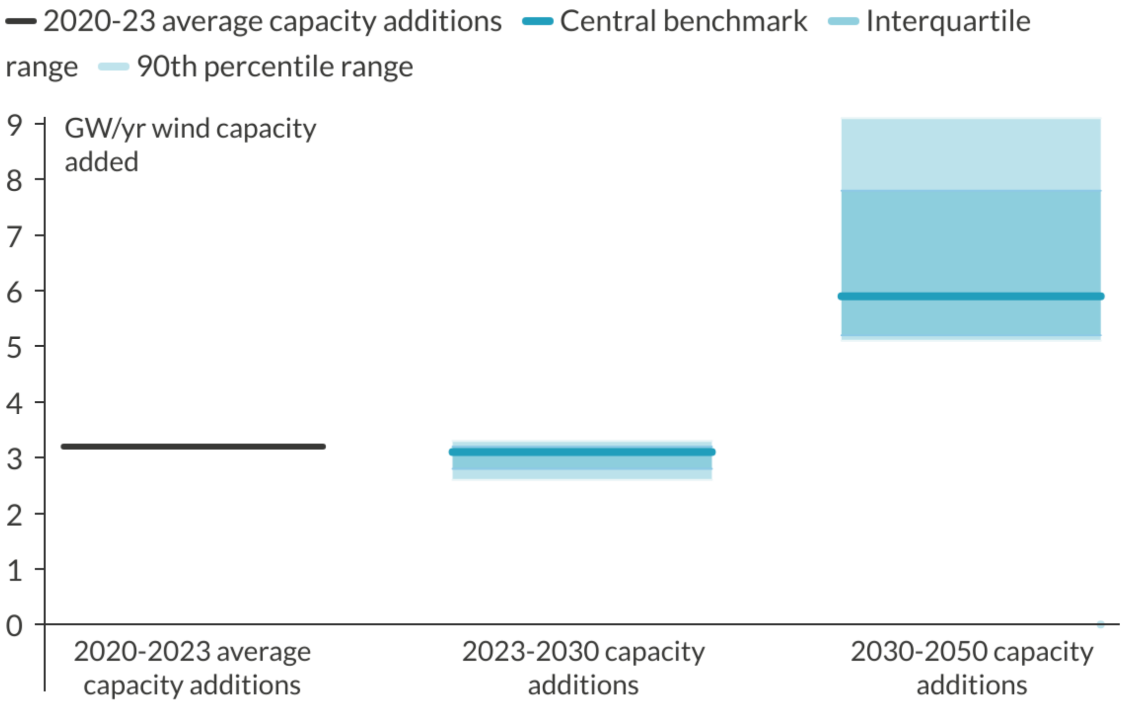


To stay aligned with 1.5°C, Brazil must maintain its current pace of annual wind and solar capacity additions over the remainder of this decade

Brazil would need to add on average 8.5 GW/yr of solar capacity until 2030, and 10.0 GW/yr by over 2030–2050.



Brazil would need to add on average 3.1 GW/yr of wind capacity until 2030, and 5.9 GW/yr by over 2030–2050



Comparison with other studies

We compare the wind and solar generation seen in our analysis to that in the literature review of country-level studies. In particular, we highlight the results of modelling from the *National Energy Plan 2050* of the Energy Research Office (EPE), exploring full decarbonization pathways for Brazil.

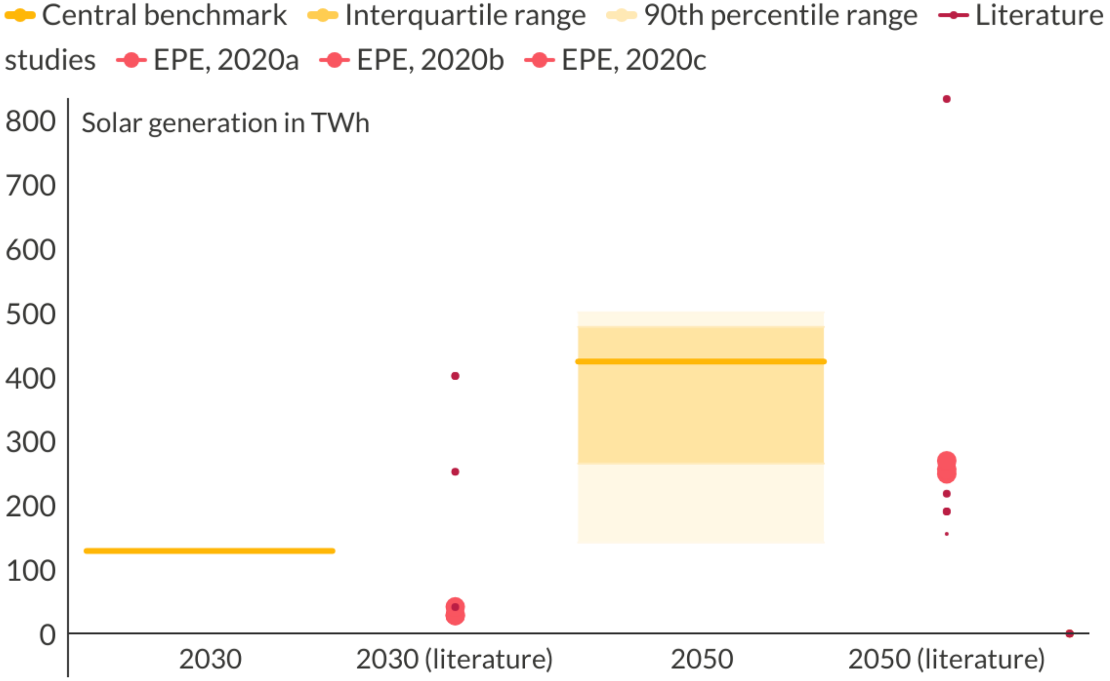
We see that the combined wind and solar generation form our analysis is broadly within the range of the national literature.

Both our modelling and country-level studies see wind as providing the largest share of generation in 2030, 2040 and 2050. For wind, our analysis is generally on the lower end of the range of the national studies.

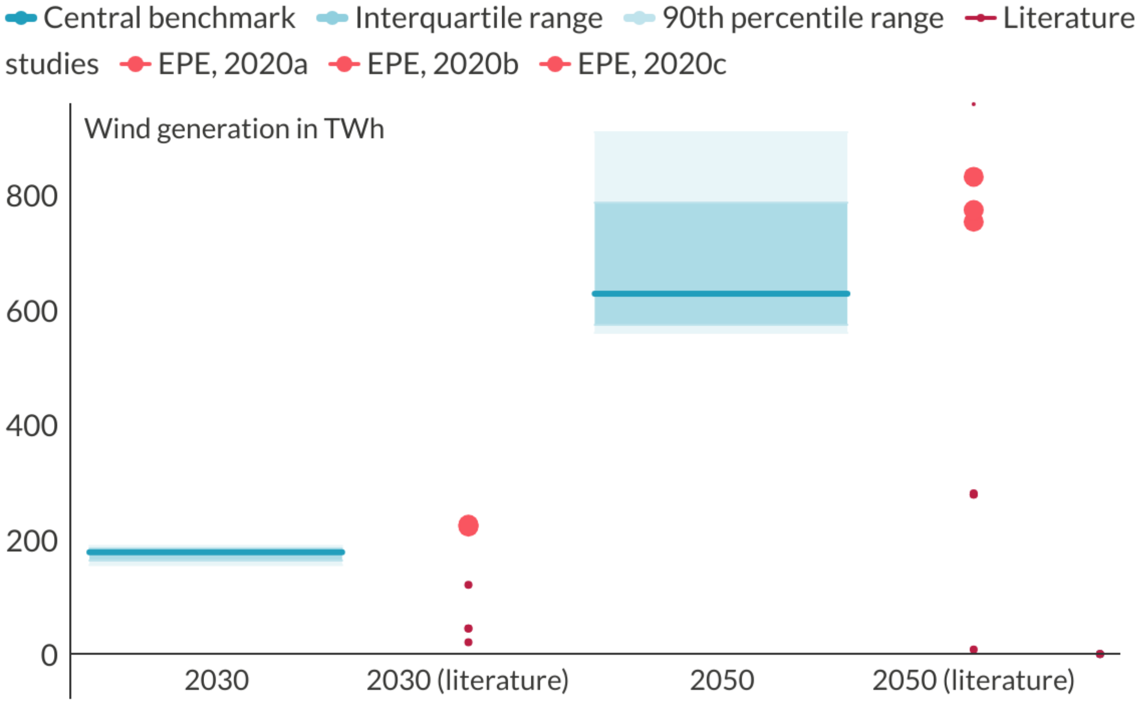
Conversely, our analysis show higher generation form solar than in national studies. Our analysis shows a slight lean towards solar generation compared to the scenarios in the EPE study, which presents a larger role for wind.

Our benchmarks are broadly aligned with the literature

Electricity generation from solar: comparison with literature in Brazil



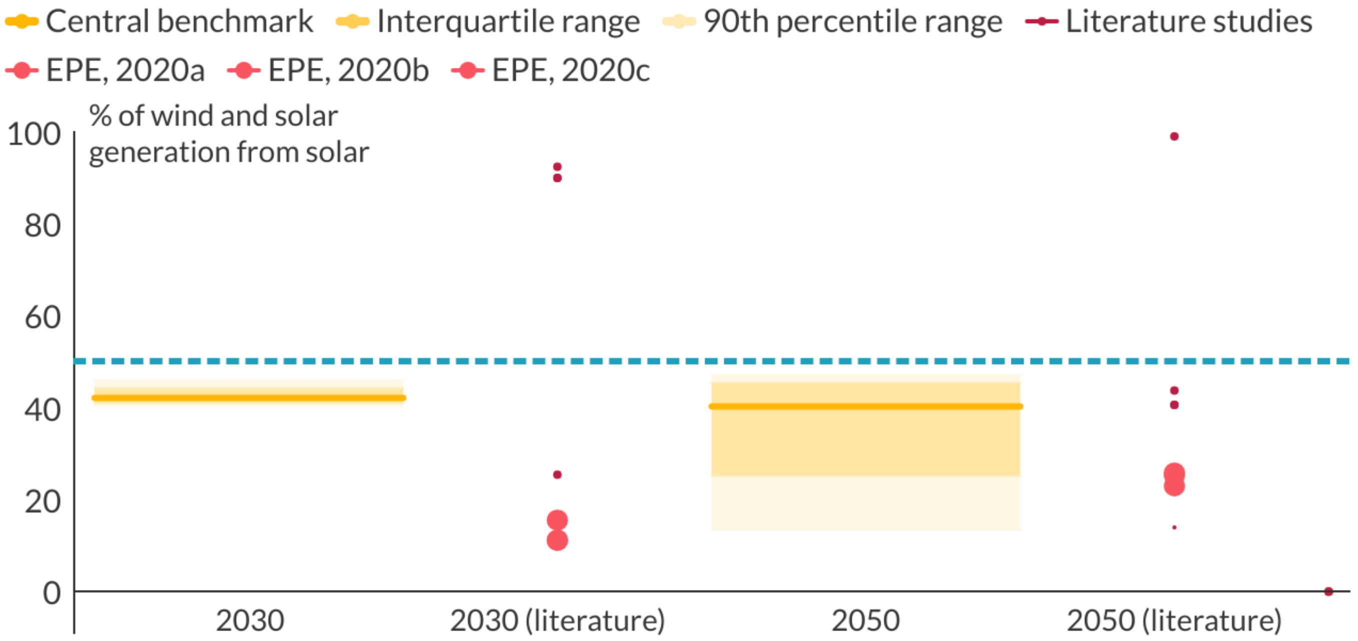
Electricity generation from wind: comparison with literature in Brazil



In Brazil, our benchmarks generally suggest that wind will provide more electricity than solar

Share of wind and solar generation that comes from solar: comparison with literature in Brazil

The area above the blue dashed line represents a power system in which solar provides more electricity generation than wind.



Summary data

The following table shows the wind and solar deployment needed to align with the central 1.5°C compatible benchmark produced. 2022 is historical data. All benchmark data from 2030 onwards is reported to two significant figures.

Scenario	Variable	Unit	2022	2030	2035	2040	2050
Central 1.5°C benchmark	Solar generation	TWh	37	130	180	230	420
Central 1.5°C benchmark	Wind generation	TWh	84	180	290	440	630
Central 1.5°C benchmark	Solar capacity	GW	27	89	130	160	290
Central 1.5°C benchmark	Wind capacity	GW	24	46	73	110	150

Annex 1

Overview of analytical elements

Different analytical elements

Our method takes multiple different analytical elements to try and understand a possible 1.5°C aligned wind and solar rollout that is informed by both bottom-up approaches and top-down perspectives.

The integration of multiple different analytical elements can help compensate for the limitations of any individual perspective, and provide a more robust and better-informed ultimate set of results.

In the following section, we provide some further detail on three of the main analytical elements. For more detail, please see the Methodology Report.

Global pathways

We use the global 1.5°C compatible pathways to bring a link back between national level action and the global goal of limiting warming to 1.5°C. All our benchmarks are consistent with pathways which achieve this goal at the global level, and in which renewable capacity triples by 2030 relative to 2022.

We focus on a set of 24 pathways from the IPCC's Sixth Assessment Report which avoid unsustainable levels of CDR deployment, as defined by the literature, and in which high-income countries take the lead in reducing emissions faster than low and middle-income countries. For more details see here.

Having selected these pathways, we then downscale them from the regional level (e.g. Sub-Saharan Africa) to the national level. We do this using the SIAMESE tool, which provides a cost-effective breakdown of energy consumption and emissions at the national level.

Country-level studies

We use national-level studies, whether conducted by in-country actors (preferable), or otherwise external studies, to help provide national context. These studies help to ground-truth the top-down evidence being provided by the global downscaled pathways.

Studies are then filtered based on level of

- **Ambition**: We select studies which full decarbonise the power sector by the 2050s at the latest
- **Scope**: We prioritise studies with energy-wide sectoral representation, high levels of electrification and that provide data out to 2050
- **Robustness**: We focus on detailed power system modelling studies, avoiding simple heuristics

The resulting set of filtered studies are used to help inform future electricity demand, the future fossil fuel phase-out schedules in the country, and the level of non-wind and solar clean electricity generation that could be deployed out to 2050.

Country-level studies

List of scenarios selected (1/2)

Study	Publication	Scenario Selected
Barbarosa *et al., 2016*	Hydropower and Power-to-gas Storage Options: The Brazilian Energy System Case	Integrated Scenario
Breyer *et al.*, 2017	Solar photovoltaics demand for the global energy transition in the power sector	
EPE (Ministry of Mining & Energy), 2020	PNE 2050 – Plano Nacional de Energia	• Matriz Elétrica com expansão 100% renovável • Matriz Elétrica com expansão a partir de tecnologias não emissoras de GEE • Efeitos das Mudanças Climáticas (redução de disponibilidade hídrica) sem emissões • Frota de veículos leves integralmente elétrica em 2050
IEA, 2023	World Energy Outlook 2023	Announced Pledges Scenario (APS)
Gils *et al.*, 2017	100% Renewable Energy Supply for Brazil – The Role of Sector Coupling and Regional Development	Base

Country-level studies

List of scenarios selected (2/2)

Study	Publication	Scenario Selected
Luz *et al.*, 2019	100% Renewable energy planning with complementarity and flexibility based on a multi-objective assessment	
Luz *et al.*, 2019	Power generation expansion planning with complementarity between renewable sources and regions for 100% renewable energy systems	Regional
Ramos *et al.*, 2019	CENÁRIOS PARA A MATRIZ ELÉTRICA 2050	SATC-FEE
Teske *et al.*, 2023	Net-zero 1.5°C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets	1.5°C

Global milestones

As well as the high-ambition country-level studies and the downscaled global pathways, we ensure that our benchmarks are compatible with the milestones identified in the IEA's net zero scenario, which sees:

- Advanced economies achieving net zero power sector emissions in 2035
- China achieving this milestone in 2040
- All other economies achieving this in 2045

Annex 2

Step-by-step method

Summary of our method

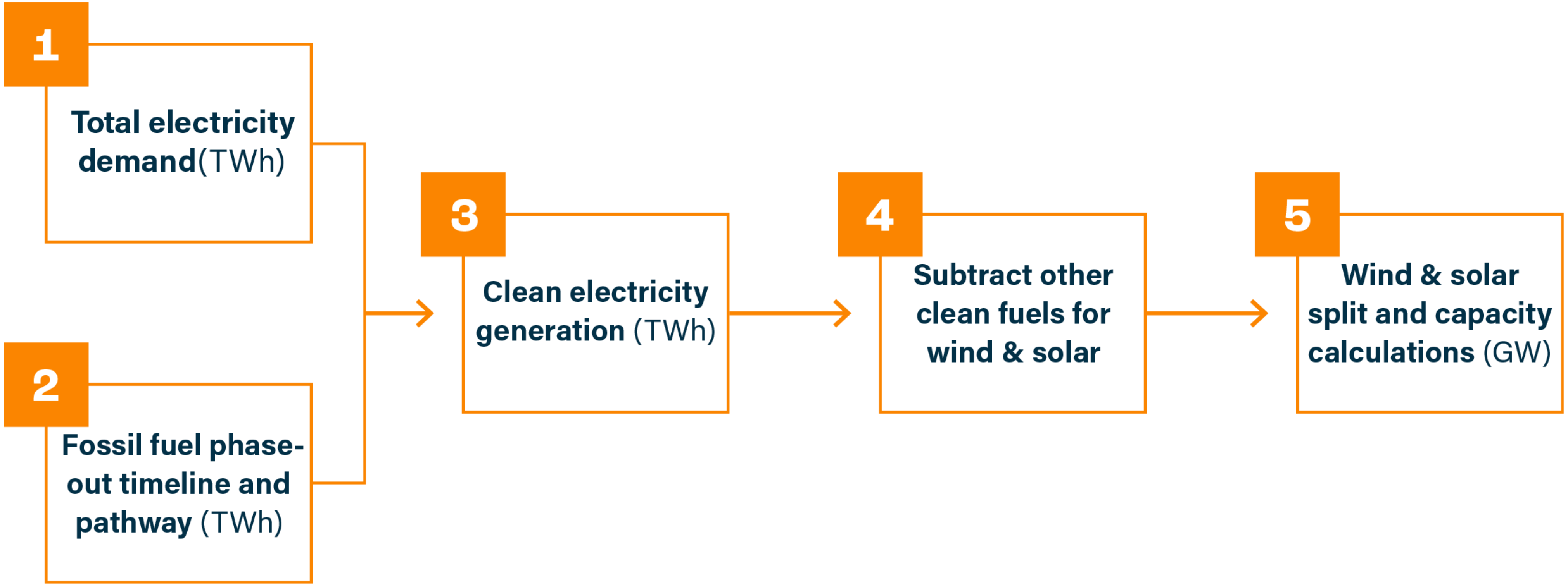
Our method takes a series of steps to calculate the wind and solar generation needed for 1.5°C, and the resulting capacity deployment.

First, we project future electricity demand. We then calculate the pace of fossil fuel phase-out needed to align with 1.5°C. Bringing these data points together, we can calculate the level of clean electricity generation required. We subtract non-wind and solar generation to calculate the wind and solar generation necessary to meet electricity demand growth and phase out fossil fuels in line with 1.5°C.

Having produced this wind and solar generation trajectory, we feed it into an electricity system model (PyPSA), which can then calculate for a given set of cost assumptions around wind and solar, a split into wind versus solar and the associated capacity requirements.

The following section further summarises the method. For a detailed overview, please see the methodology paper released in 2023.

We use a step-by-step method to calculate our benchmarks



1 **Total electricity demand**(TWh)

2 **Fossil fuel phase-out timeline and pathway** (TWh)

3 **Clean electricity generation** (TWh)

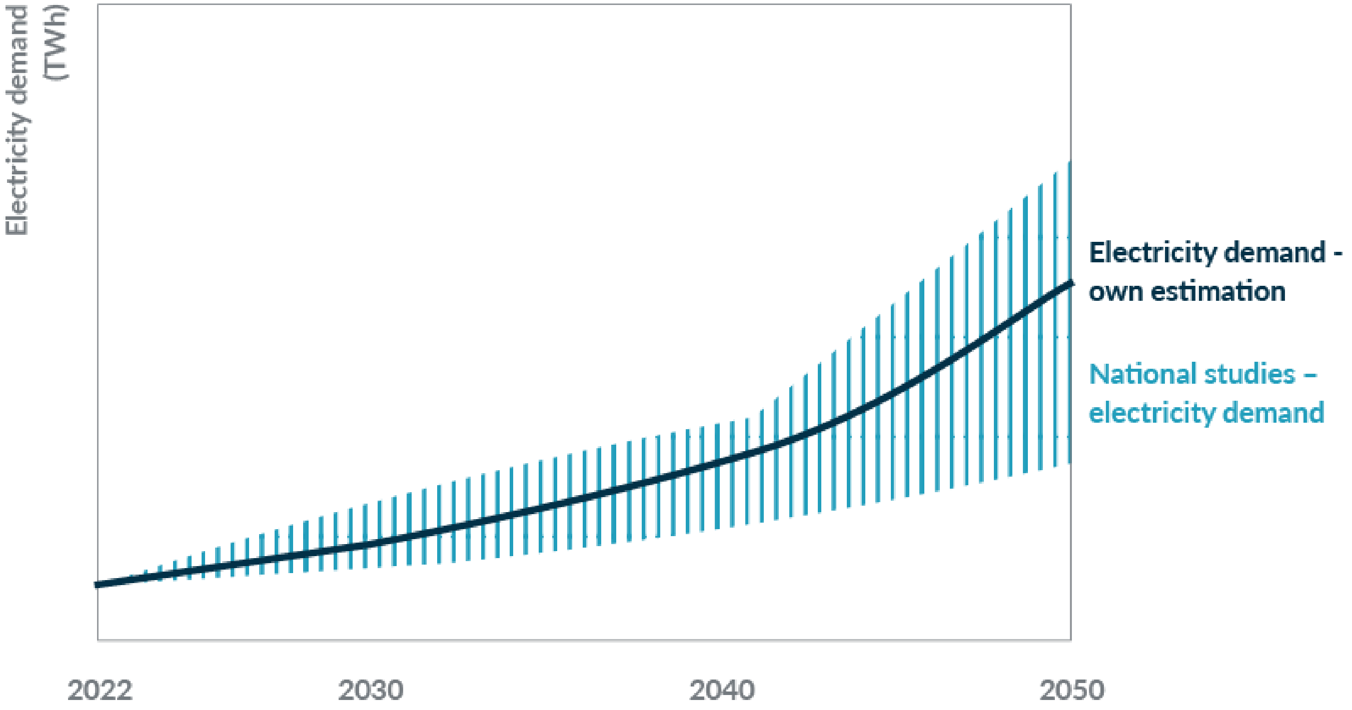
4 **Subtract other clean fuels for wind & solar**

5 **Wind & solar split and capacity calculations** (GW)

For more details see the [Methods Annex]()

1 Total electricity generation

1. We extract electricity generation projections for 2030, 2040, and 2050 from **ambitious country-level studies**.
2. We then identify an electricity generation projection from a scenario to use for our analysis. We focus on identifying studies which capture key elements of the transition, including **high electrification**, and which have been conducted using **detailed energy system models** by **country-level experts**. We incorporate feedback from stakeholders to identify these studies which inform the electricity demand trajectory.



2

Fossil fuel phase-out

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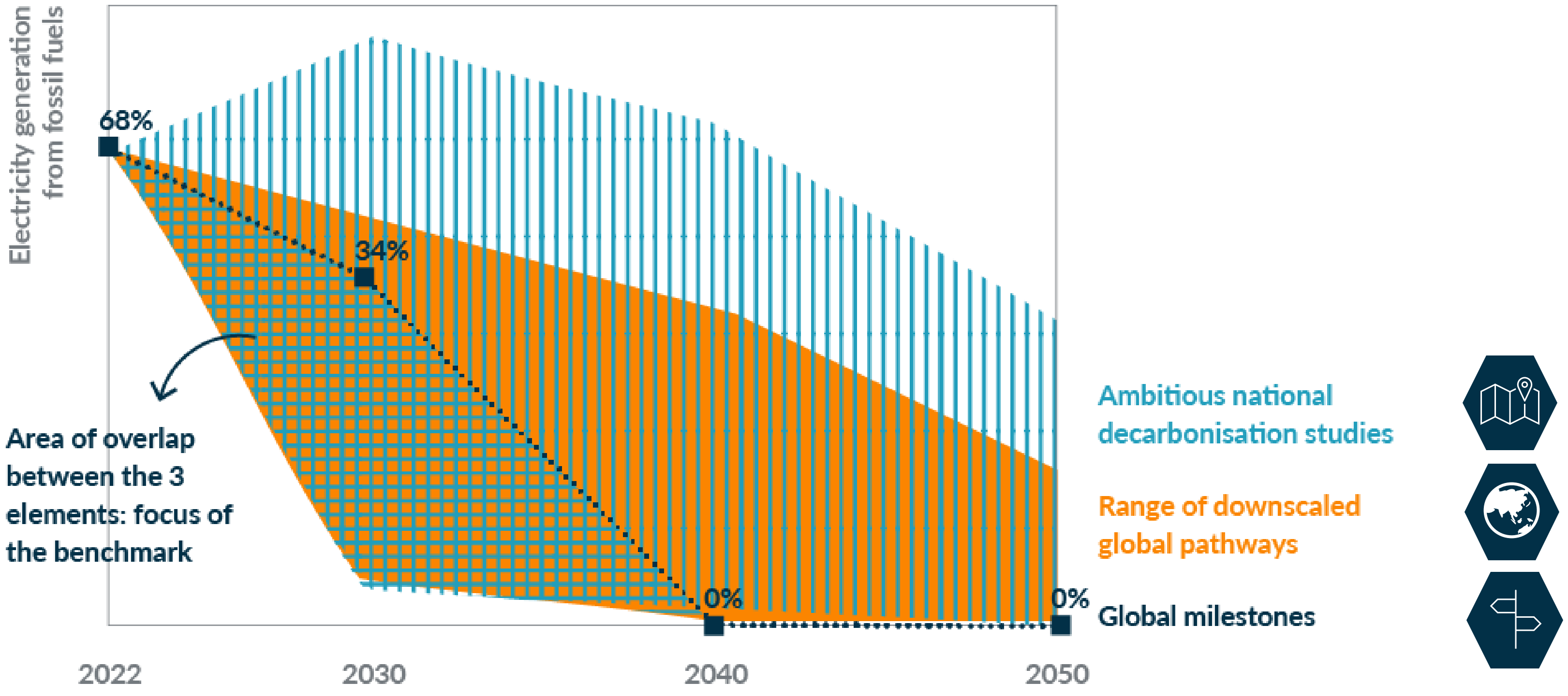
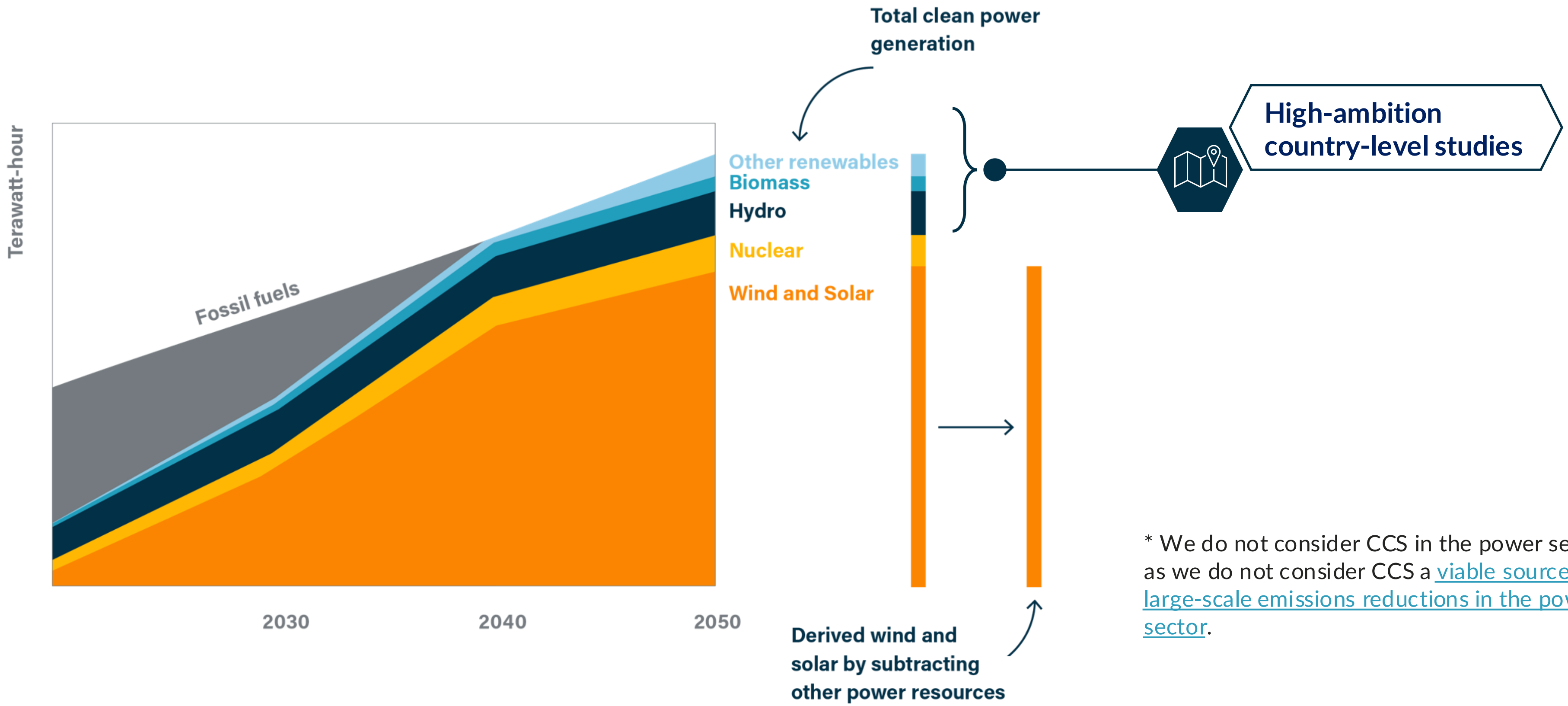
1. We calculate a range of electricity generation pathways from fossil fuels based on **ambitious country-level studies**.
2. We produce a similar range from **downscaled 1.5°C compatible global scenarios**.
3. We identify the intersection of these two ranges, representing the speed and scale of decarbonisation pathways that aligns with the goals of the Paris Agreement while capturing local circumstances in countries.
4. We integrate differentiated timelines for phasing out fossil fuel electricity generation, applied as **global milestones** (2035 for advanced economies, 2040 for China, and 2045 for emerging economies).



Area of overlap between the 3 elements: focus of the benchmark

3 4 Calculate wind and solar generation

1. We obtain electricity generation from carbon-free resources: from total electricity generation (step 1), subtracting fossil-fired generation (step 2).
2. We then subtract estimates of electricity generation attributed to hydroelectricity, biomass, other renewable resources, and nuclear power – informed from **country-level studies’** estimates – from the total clean electricity generation* to infer the wind and solar generation



Total clean power generation

High-ambition country-level studies

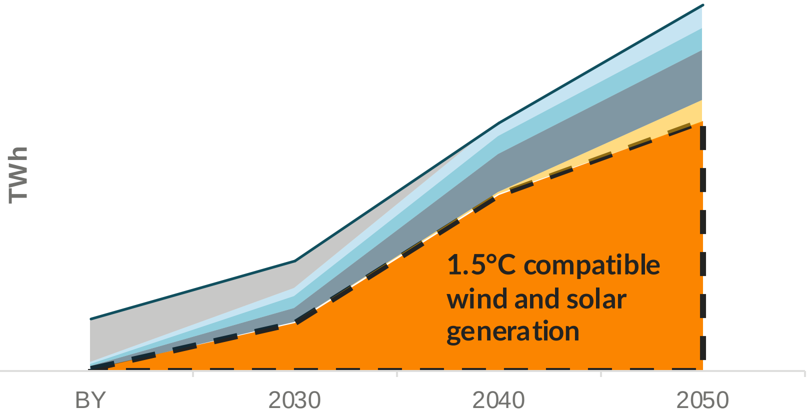
Derived wind and solar by subtracting other power resources

* We do not consider CCS in the power sector, as we do not consider CCS a [viable source of large-scale emissions reductions in the power sector](#).

5 Wind and solar breakdown

1. We use a detailed geospatial **renewable potential analysis** to calculate the technical potential of each technology in the country. We then feed the wind and solar generation required into a power system model calibrated to these potentials.
2. We force the model to deploy at least the level of solar and wind seen in countries’ **current targets and pledges**.
3. The power system model then gives a split of wind and solar in the country and the resulting capacity requirements.

1.5°C compatible wind and solar generation (steps 1-4)



RE potential and power system analysis

Current targets and pledges

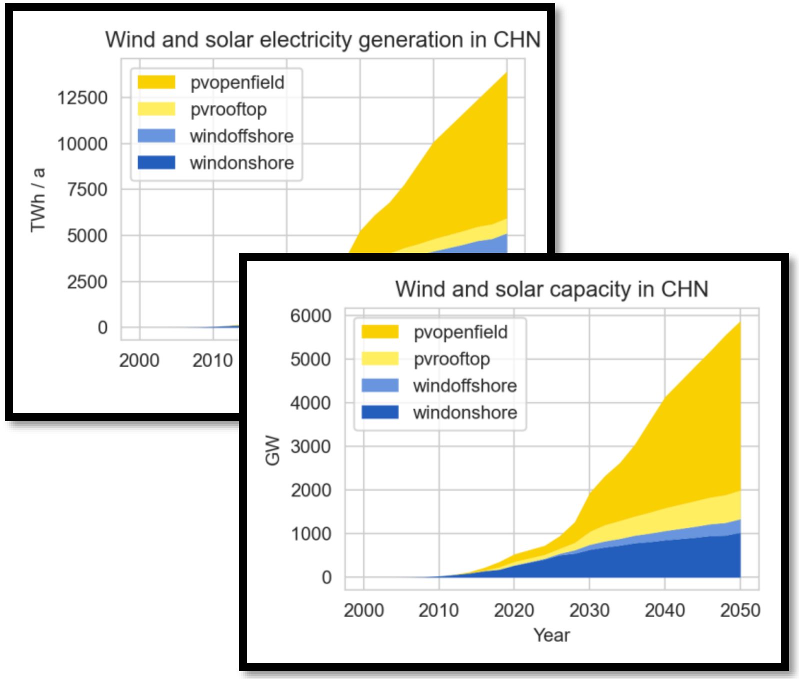
Detailed RE potential analysis

Techno-economic assumptions

Policies / targets

Growth rate constraints

Generation and capacity of wind and solar



Key modelling parameters in the analysis

The following table highlights some of the most relevant parameters which influence the PyPSA modelling used to help estimate the split into wind versus solar

Model feature	Details
Cost resolution	Detailed cost curve for wind and solar produced based on geospatial weather data
Growth rates	Solar and wind growth rates constrained to technology specific growth rates set based on analysis of past technology rollout. Current default growth rates are set as • Wind = 16% per year • Solar = 33% per year These constraints are applied to both total capacity and capacity additions.
Adequacy factor	In addition to the total annual electricity generation from wind and solar having to be met, we require that at a certain proportion of the hourly load is always met by wind and solar. The default value for this constraint in Brazil is 50%. This factor captures the level of storage and dispatchable generation available to meet electricity demand. A higher factor means that wind and solar need to more closely match hourly loads, without the use of storage/dispatchable generation to smooth out mismatches between generation and demand. This would generally lead to an overbuild of wind and solar to ensure adequate power supply at all times, and greater curtailment. Meanwhile a factor of 0% would mean that wind and solar generation can fall to zero for significant periods of time, as long as over the whole year, total wind and solar generation needed is provided. This would imply that there is greater availability of batteries and other dispatchable zero-carbon generation to meet demand in times of low wind and solar output.
Wind and solar costs	We produce a range of different cost curves for wind and solar in each country, based on IRENA data. For more details see the technical annex.