Wind and solar benchmarks for a 1.5°C world

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

China

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Executive Summary

Context

- China is rolling out renewables faster than any other country in the world. 2024 could mark a turning point, with Chinese power sector emissions on the brink of peaking and beginning a structural decline.
- However, to align with 1.5°C, China needs to not only peak emissions but achieve sustained and rapid reductions in emissions thereafter. The need to substantially displace fossil generation while meeting growing electricity demand means that wind and solar deployment will need to further accelerate.
- In this report, we look at national studies and global energy system models to assess how much China's wind and solar capacity needs to grow to align with the global goal to triple renewables by 2030 and the Paris Agreement's warming limit.

Key findings

- China's wind and solar generation needs to grow between five and six times by 2030 to align with 1.5°C.
- This equates to 6600–7700 TWh of wind and solar generation in 2030, up from almost 1200 TWh in 2022.
- 4.5 TW of new wind and solar would be needed by 2030 (2.9 TW solar, 1.6 TW wind).
- Despite impressive growth, the rollout of solar and wind needs to accelerate further to align with 1.5°C and drive reductions in emissions post-peaking.
- China's wind capacity is on course to more than double by 2030 but needs to more than quadruple to meet the Paris goal.

Context

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

Wind and solar deployment is accelerating around the world. However, expected wind and solar capacity deployment under current policies falls short, 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 plausible 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

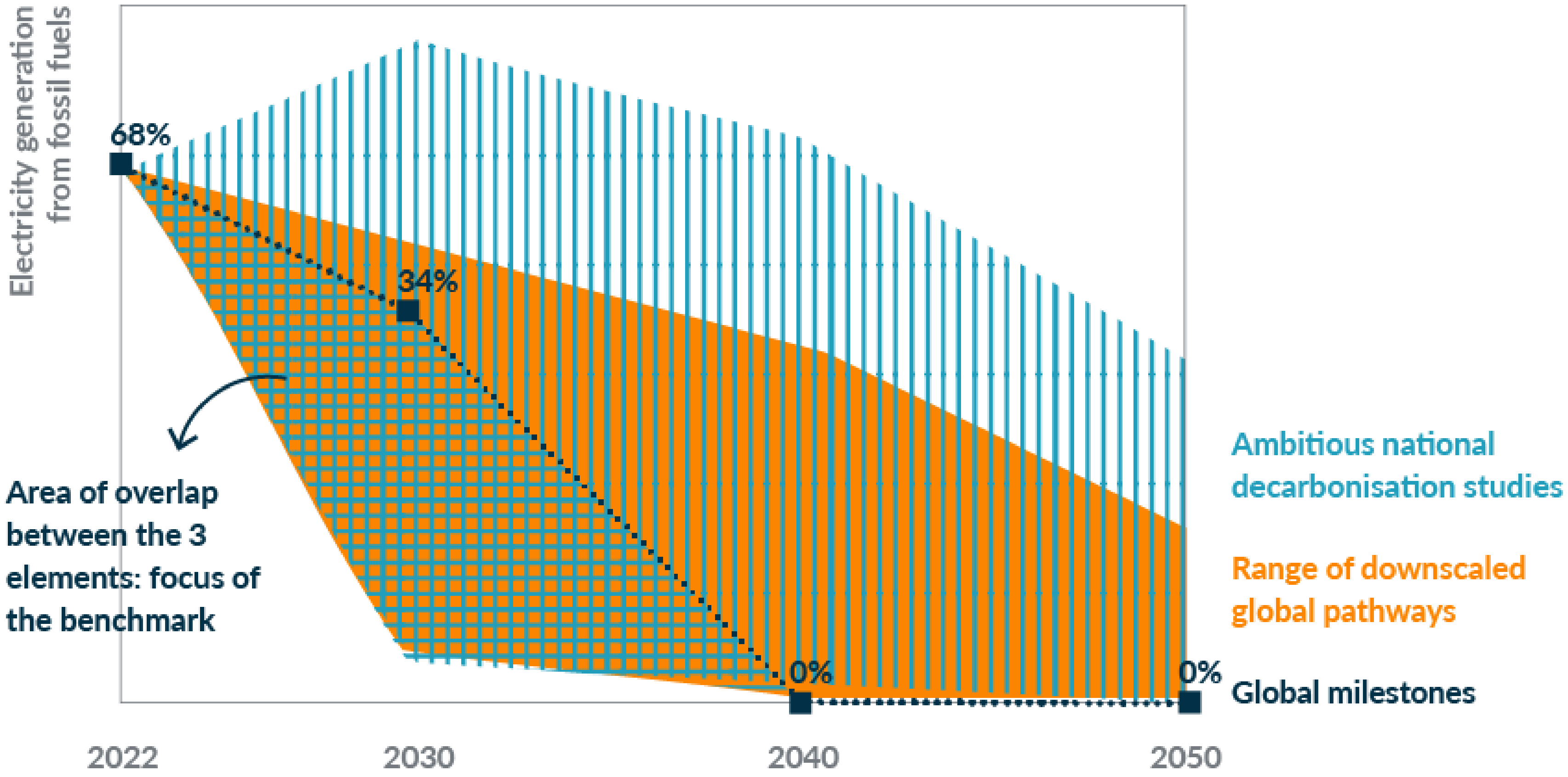
For more details see the Methods Annex

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



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)

Policy context

China's current NDC has four main energy-related targets:

- Peaking CO_2 emissions before 2030 and achieving carbon neutrality before 2060
- Reduce carbon intensity in 2030 by over 65% relative to 2005
- Increase the share of non-fossil fuels in primary energy to over 25% in 2030
- Install 1200 GW of wind and solar by 2030

China is on track to exceed this wind and solar target during 2024. A national forecast from GEIDO, a Government-affiliated think-tank, suggests that by 2030 China would have **1025 GW of solar and 800 GW of wind by 2030**. We use this as a proxy for the targets of the Chinese government.

Under current policies and market conditions, the IEA estimates that **solar capacity will reach 1950 GW in 2028**, up from 429 GW of solar in 2022. Meanwhile, **wind capacity is projected to reach 805 GW in 2028**, up from 365 GW in 2022.

Results

Future electricity demand

Electricity demand is taken from the China Energy Transformation Program study exploring carbon neutrality pathways for China. We take electricity demand from the CNS-1, which achieves net zero CO_2 emissions in the energy system by 2055. We use this scenario because it is one of the most recent studies, which captures the reality of rapid electricity demand growth in China which some of the country-level studies have underestimated. It is also consistent with ambitious electrification, with electricity providing 54% of final energy by 2050.

In this study, **total electricity generation in China doubles by 2050 relative to 2022 levels, reaching 18,000 TWh**. This is driven by economic development and increased electrification.

However, there is a significant range in the studies in terms of the expected electricity generation in 2050 ranging from 11,000 TWh to 29,000 TWh. This would affect the necessary growth of wind and solar significantly. Our demand estimate is at the higher end of that estimated by country-level studies for 2030, and near the middle of the range in 2050.

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 which China achieves a clean power system by 2040.

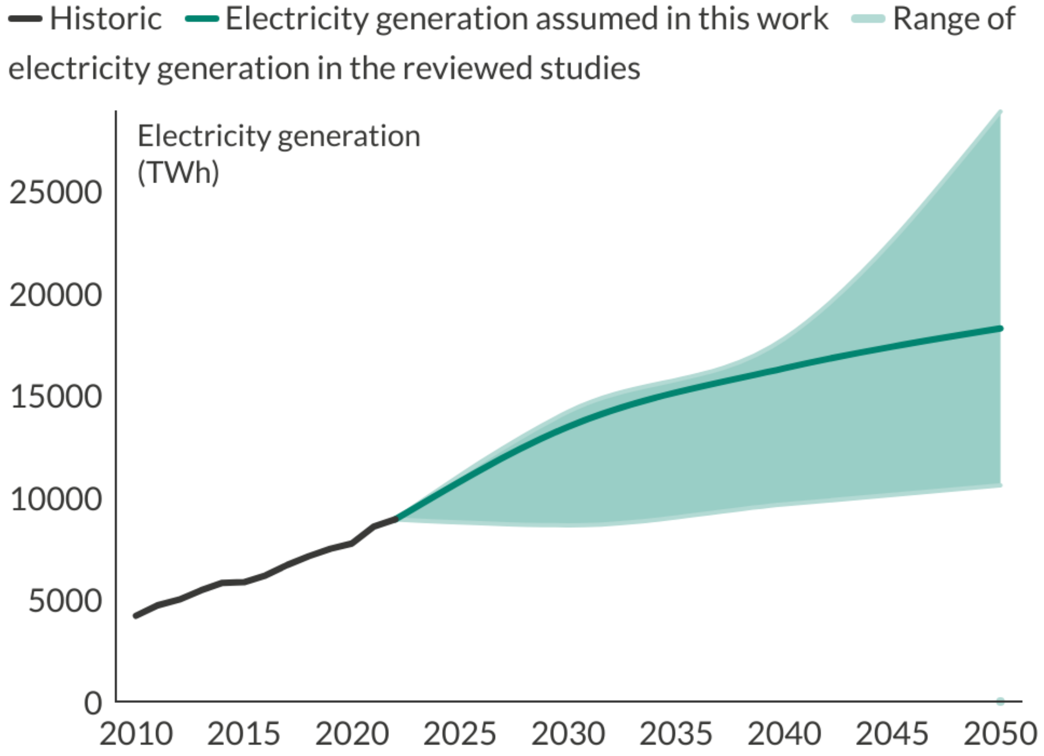
To align with 1.5°C, fossil fuels would need to exit the Chinese power sector before 2040

Fossil fuel generation falls by 28–47% between 2022 and 2030.

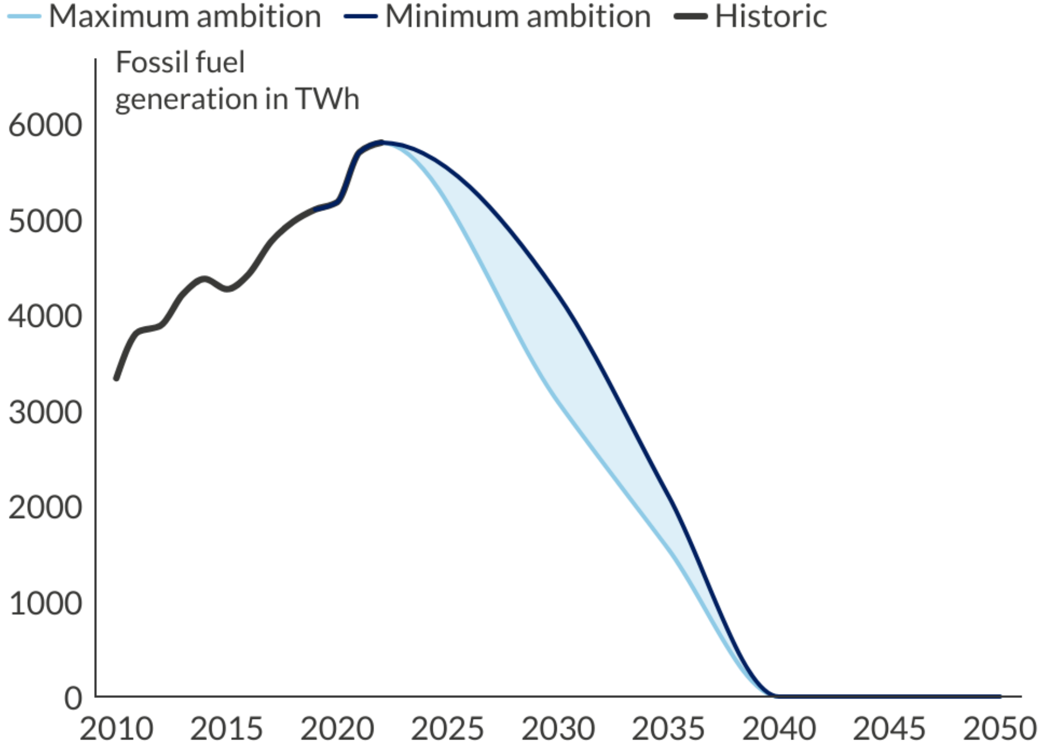
The fastest rate of fossil phase-out is set by a study from Lugovoy et al., 2021, exploring the feasibility of China achieving a zero emissions power system by 2050.

To align with 1.5°C, fossil fuels must exit the power sector in China by 2040, even as electricity demand grows rapidly.

Electricity generation grows around 50% from 2022–2030 in China



China would need to achieve clean electricity by 2040



The role of other clean electricity generation

While wind and solar will be the workhorse of the energy transition, other clean electricity generation may play a role, particularly in certain countries. 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 China would reach 2700 TWh by 2030 and 3600 TWh by 2050. This is provided primarily by hydropower, followed by nuclear and some limited biomass generation.

* 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.

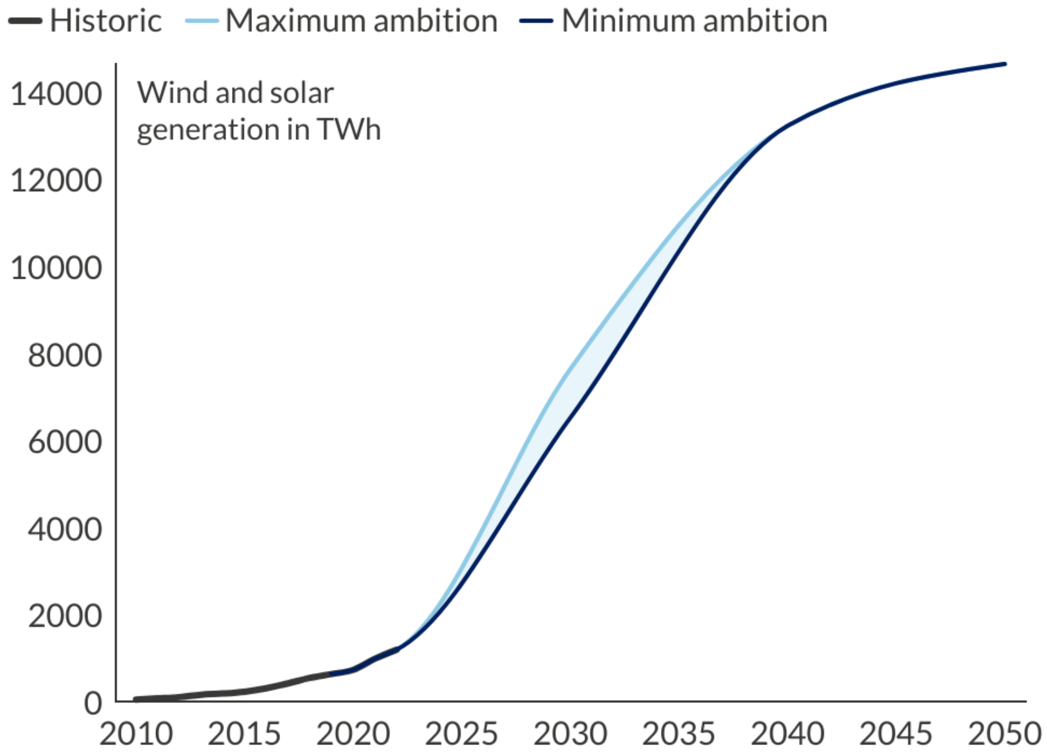
Total wind and solar generation needed to align with 1.5°C

To align with 1.5°C, wind and solar generation China would need to reach between 6,500 and 7,700 TWh by 2030. Generation in 2022 was 1190 TWh. This is therefore a 5.5 to 6.4-fold growth in wind and solar generation relative to 2022.

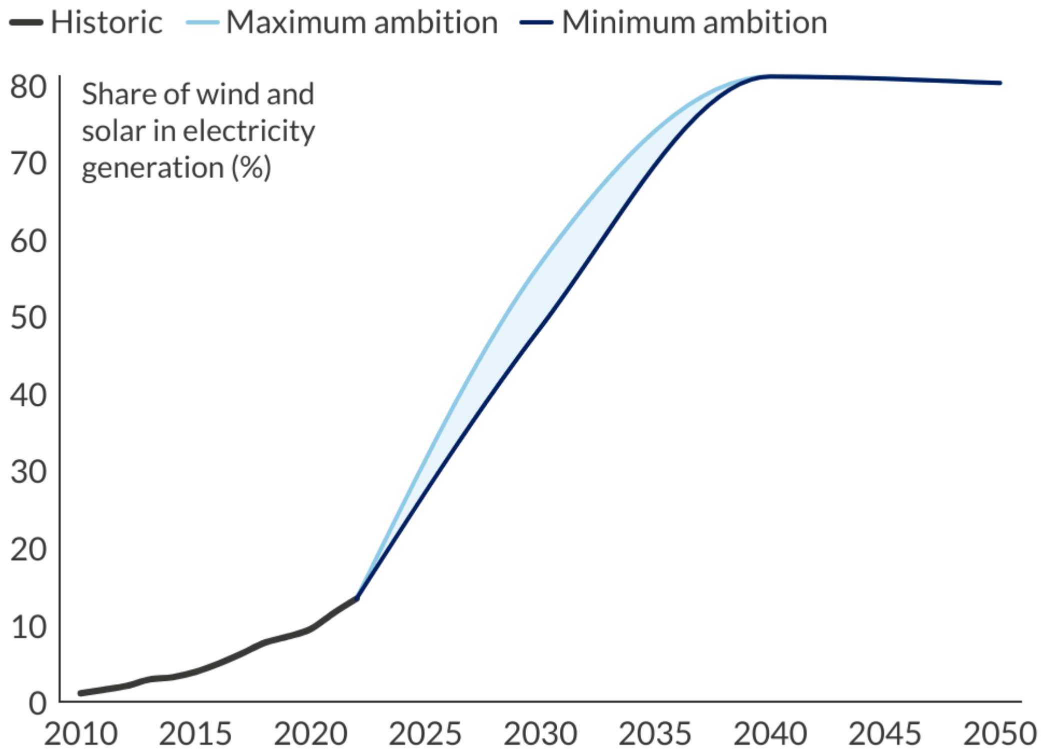
Wind and solar provides 48–57% of overall electricity generation in 2030, and 80% of overall generation in 2050.

To align with 1.5°C, wind and solar generation would need to grow rapidly in China

Wind and solar generation needs to grow 5-6x by 2030 relative to 2022 in China



Wind and solar would need to provide around 80% of electricity generation in China 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 benchmarking scenario, solar becomes the main source of generation, providing on average twice as much generation as wind in the electricity mix by 2050. This will require a rapid uptake of non-fossil flexibility options

In this scenario, **China would need to deploy around 4.5 TW 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 10 TW. Due to its higher capacity factor, greater wind deployment would reduce total capacity requirements.

On average, solar provides twice as much electricity as wind by 2050 in China

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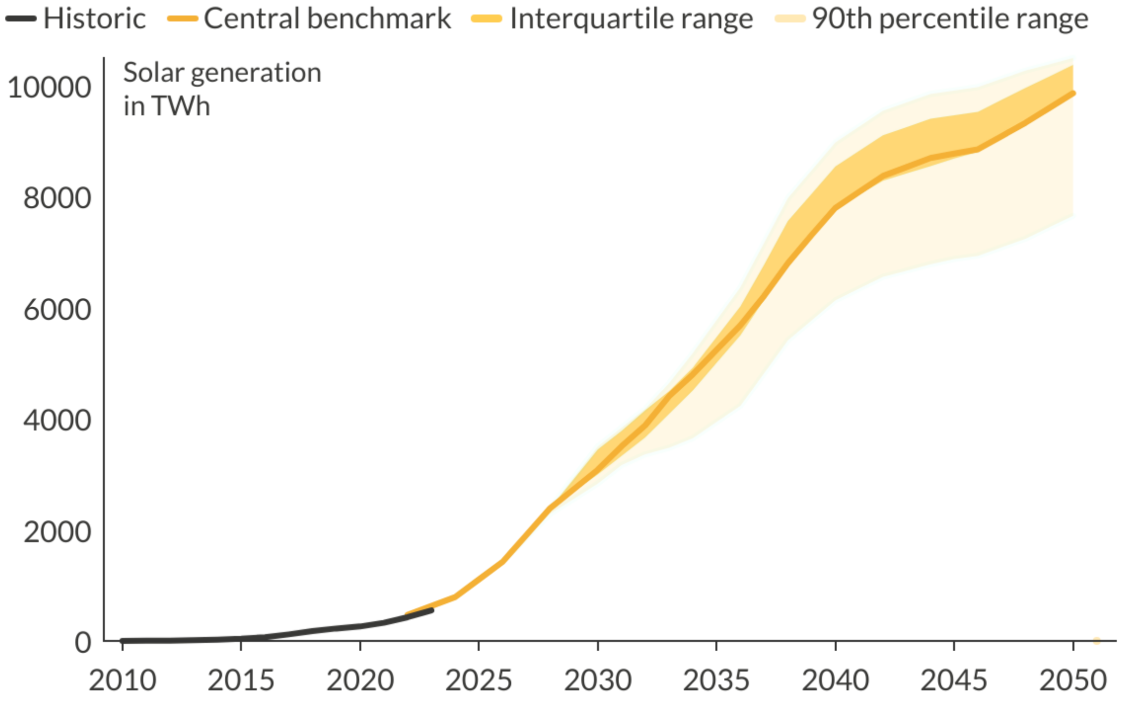
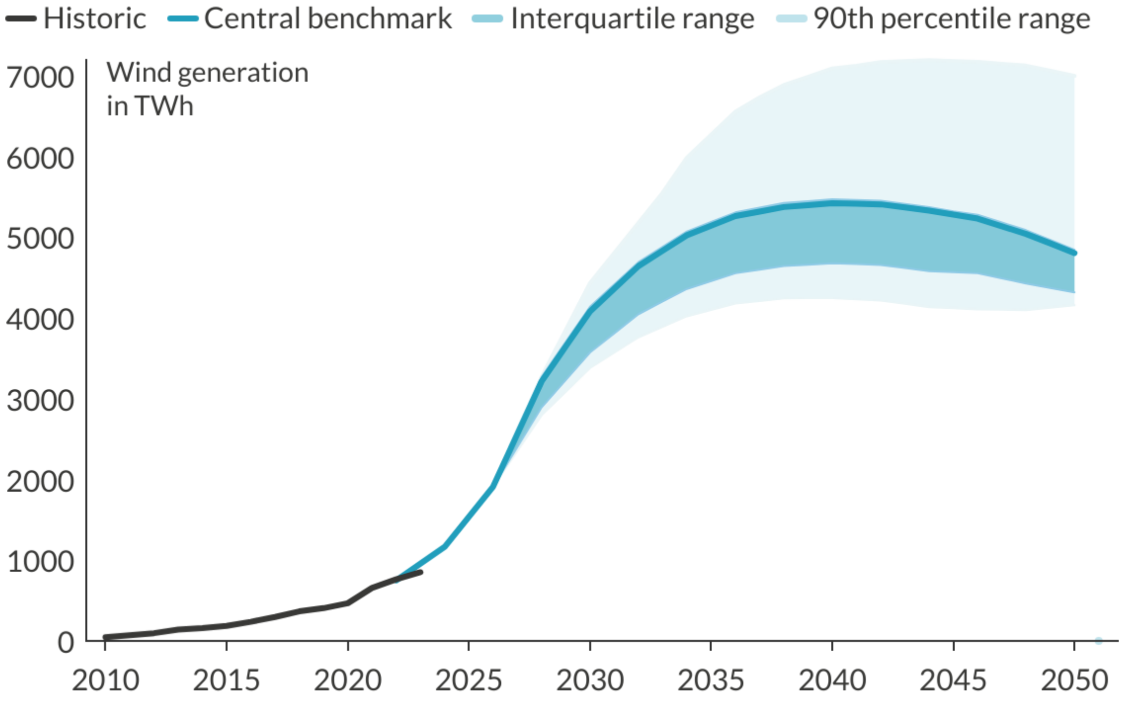
Solar generation in China would reach almost 10000 TWh by 2050 in a 1.5°C-aligned transition



Wind generation in China would reach almost 5000 TWh by 2050 in a 1.5°C-aligned transition



China needs to install almost 4.5 TW of wind and solar by 2030 to align with 1.5°C

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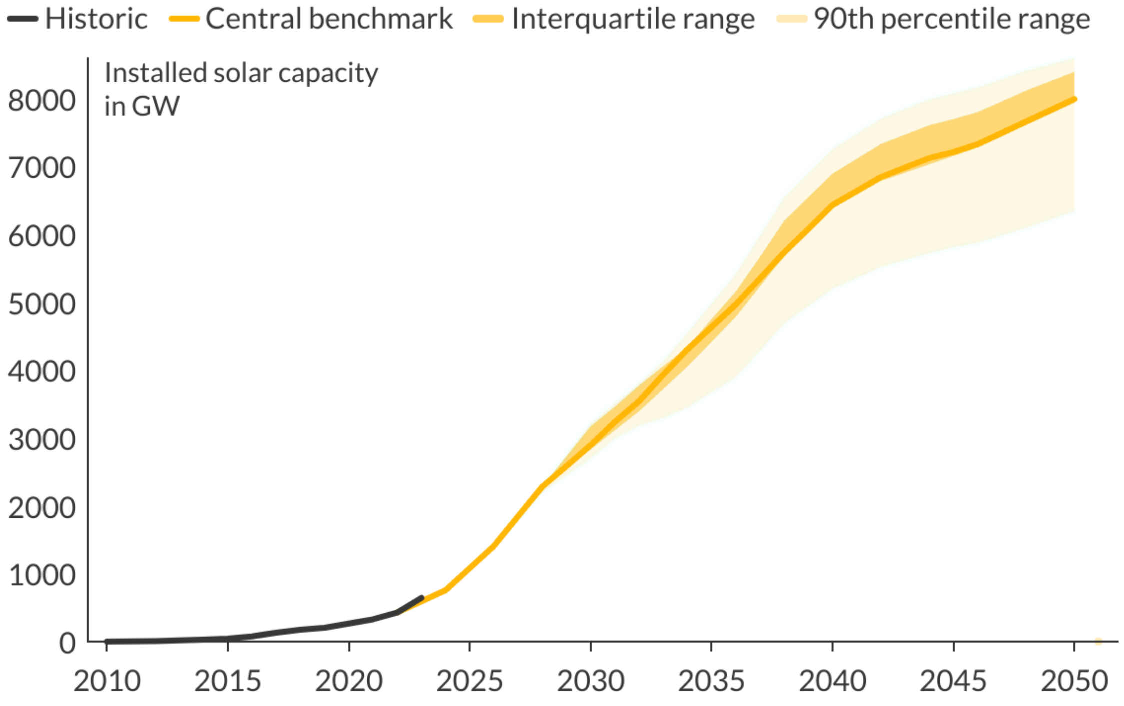
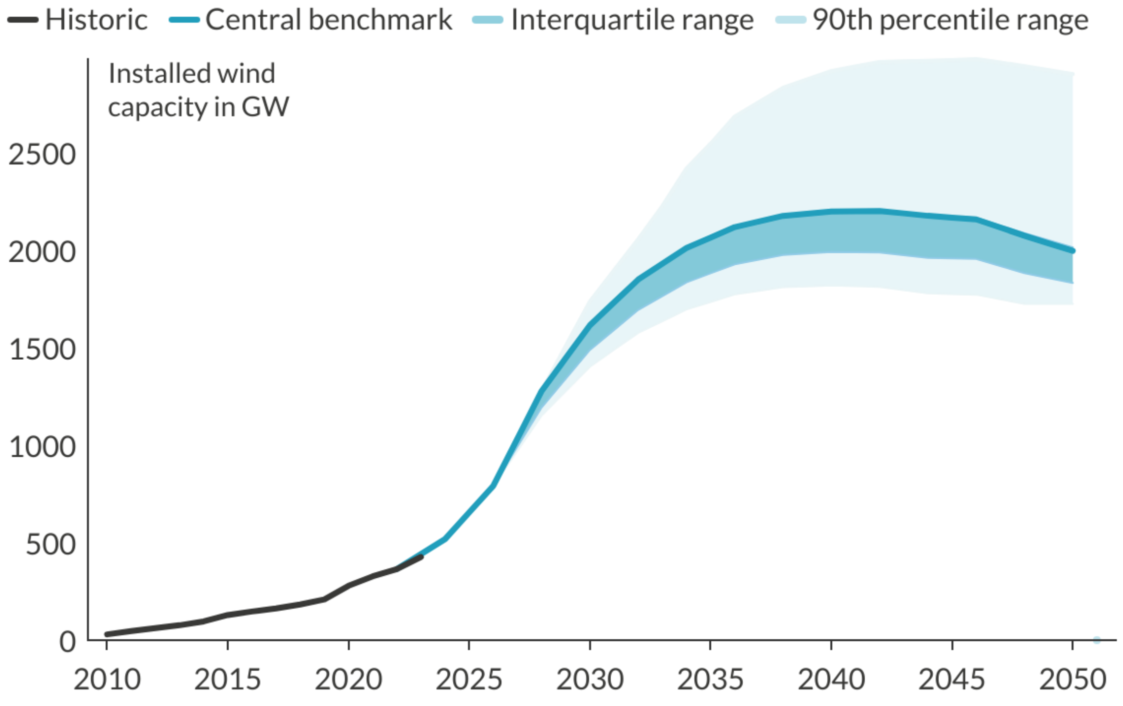
Solar capacity would reach 2900 GW in China by 2030 in a 1.5°C-aligned scenario



Wind capacity would reach 1600 GW in China by 2030 in a 1.5°C-aligned scenario



Comparison to current rollout

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.

Under current policies and market conditions, deployment of solar PV in China almost aligns with the minimum level required to align with 1.5°C, reaching 2600 GW. Our central benchmark would require 2900 GW of solar installed by 2030.

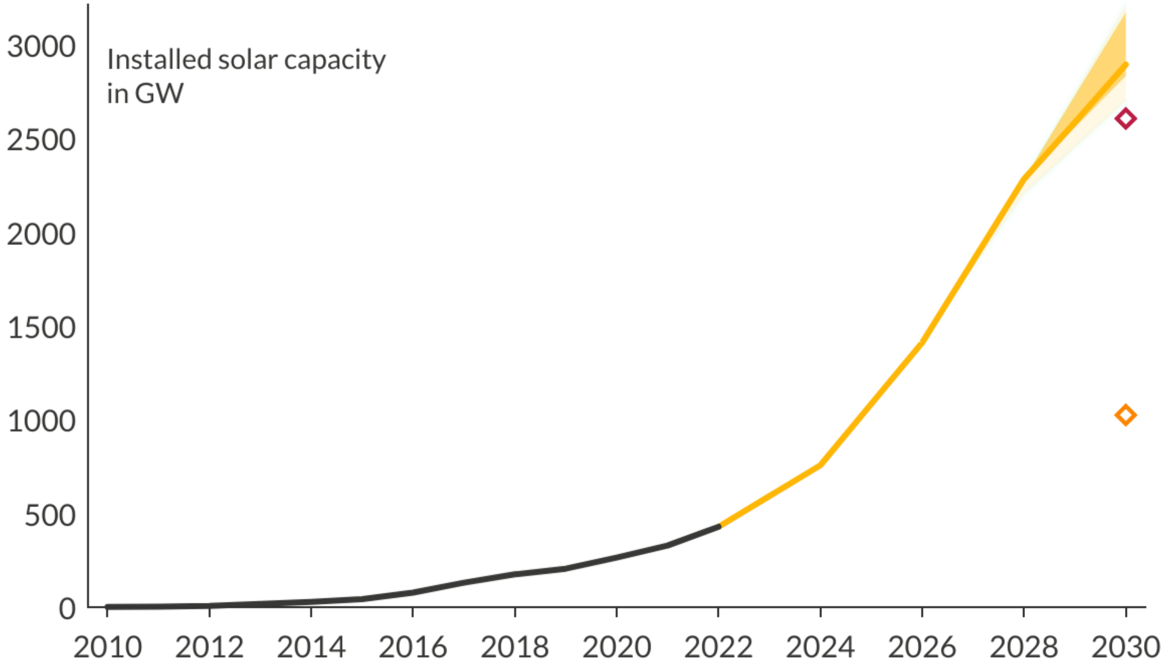
Meanwhile, we estimate that under current policies and market conditions, wind capacity would reach around 1000 GW in 2030, which is 600 GW below the central benchmark set here of 1600 GW.

However, achieving 4.5 TW of wind and solar capacity installed in China by 2030 would require that wind and solar capacity grow at ~24% per year from 2022–2030. This average annual growth rate is the same as that achieved by China's wind and solar sector in 2018–2023. This highlights the feasibility of achieving these benchmarks.

China’s solar rollout almost aligns with 1.5°C, while wind rollout needs accelerating

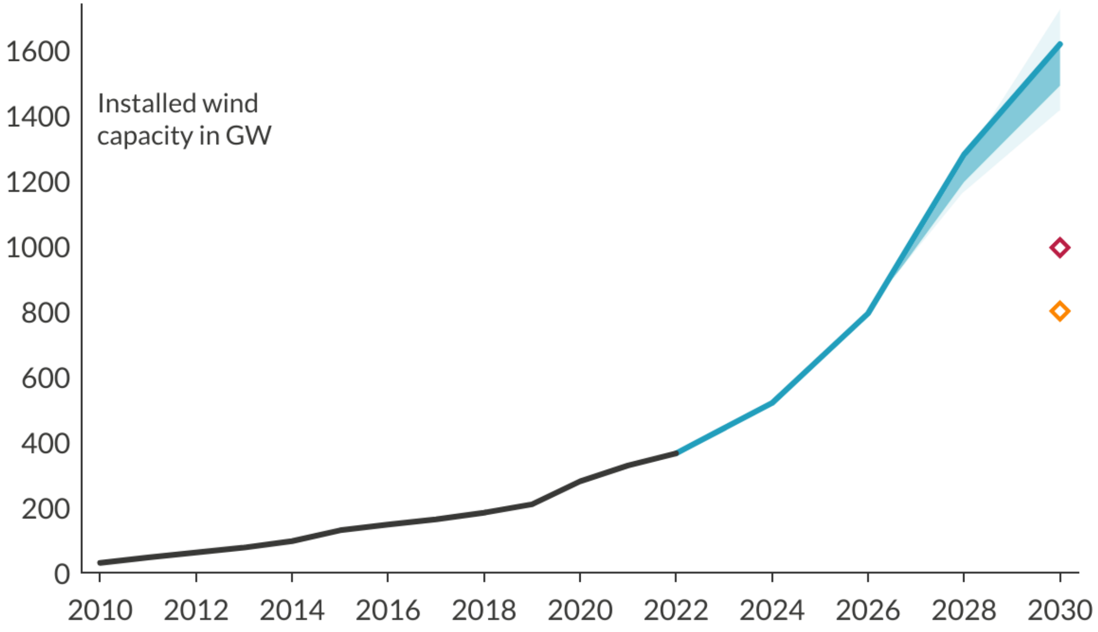
Current rollout of solar in China comes close to aligning with 1.5°C, and significantly overperforms the target

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



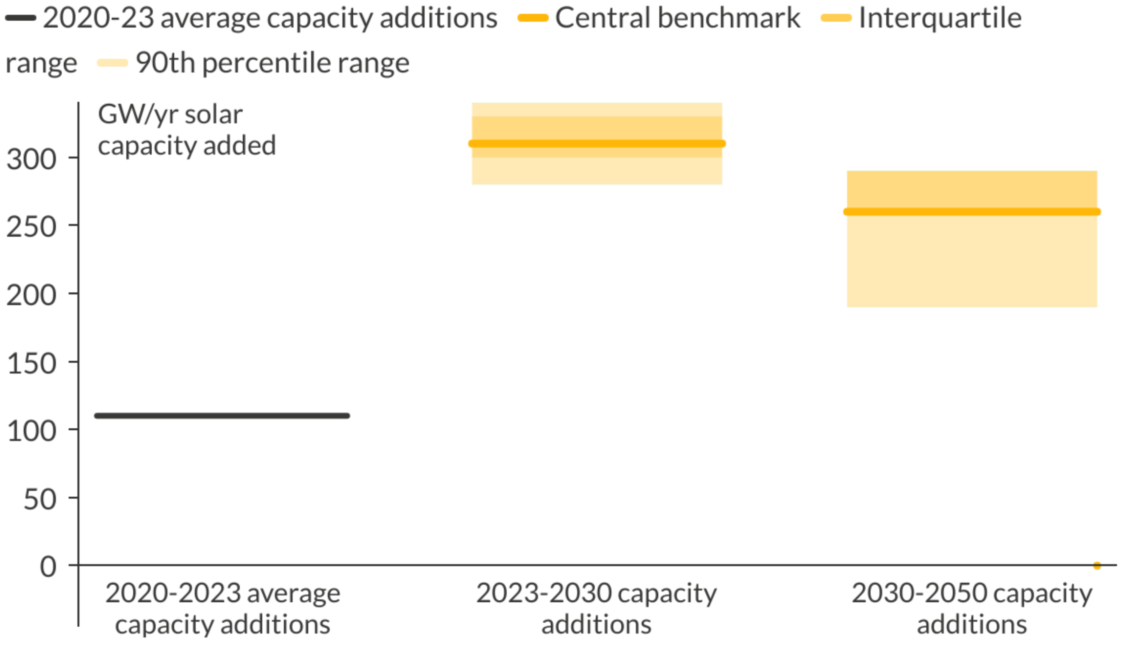
Another 600 GW of wind would need to be installed in China by 2030 compared to the rollout under current policies

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

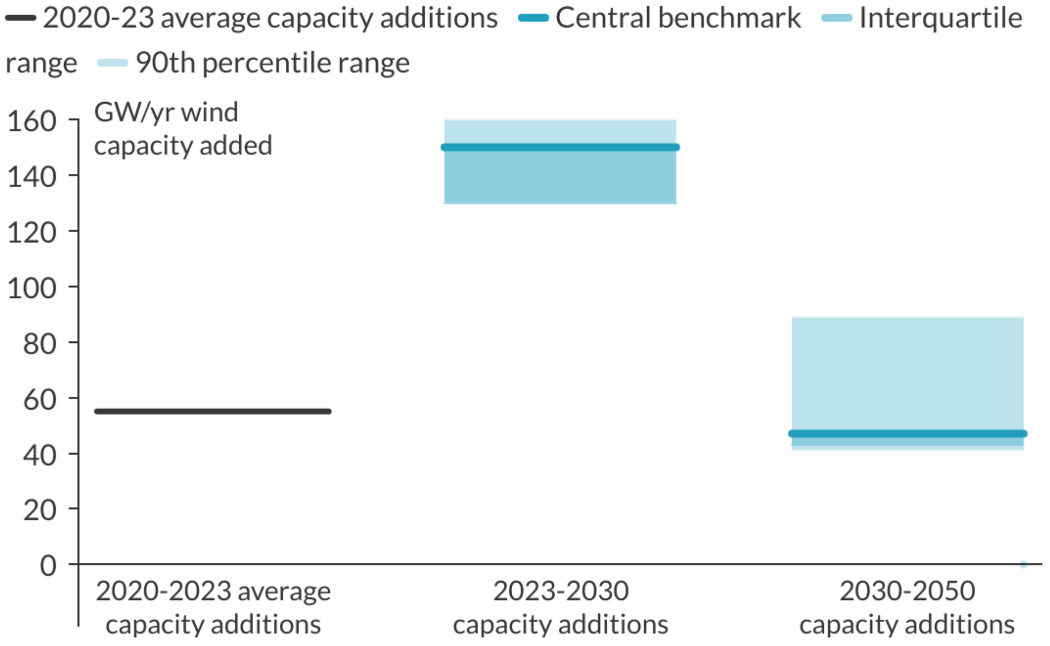


Wind and solar capacity additions in China need to accelerate to align with 1.5°C

China would need to add on average 310.0 GW/yr of solar capacity until 2030, and 260.0 GW/yr by over 2030–2050.



China would need to add on average 150.0 GW/yr of wind capacity until 2030, and 47.0 GW/yr by over 2030–2050



Wind and solar growth in the light of coal expansion

China still adding significant coal capacity. This is not in line with the latest science which demonstrates that new fossil fuel infrastructure is incompatible with 1.5°C.

The phase-out schedule for coal assumed in this work will require the early retirement of most existing coal plants. Assuming a 40-year lifetime, only 10% of China's coal plants would have retired by 2040.

Rapidly growing wind and solar in China has already begun to displace coal-fired generation in 2024.

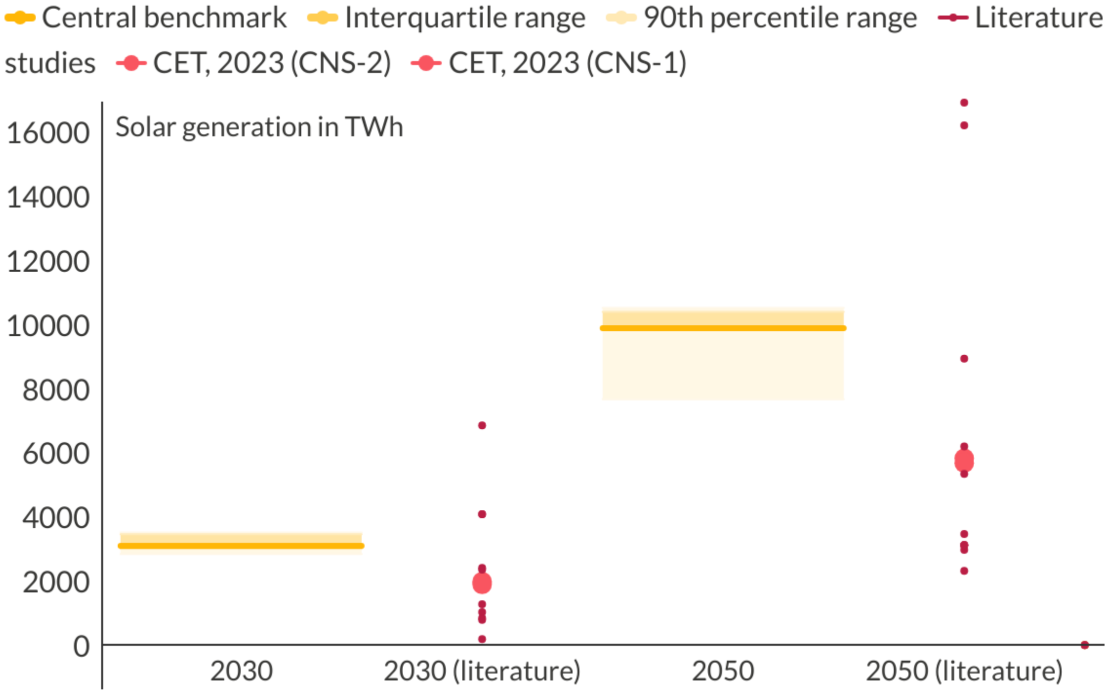
Comparison with other studies

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 China Energy Transition Program (CET), exploring net zero pathways for China.

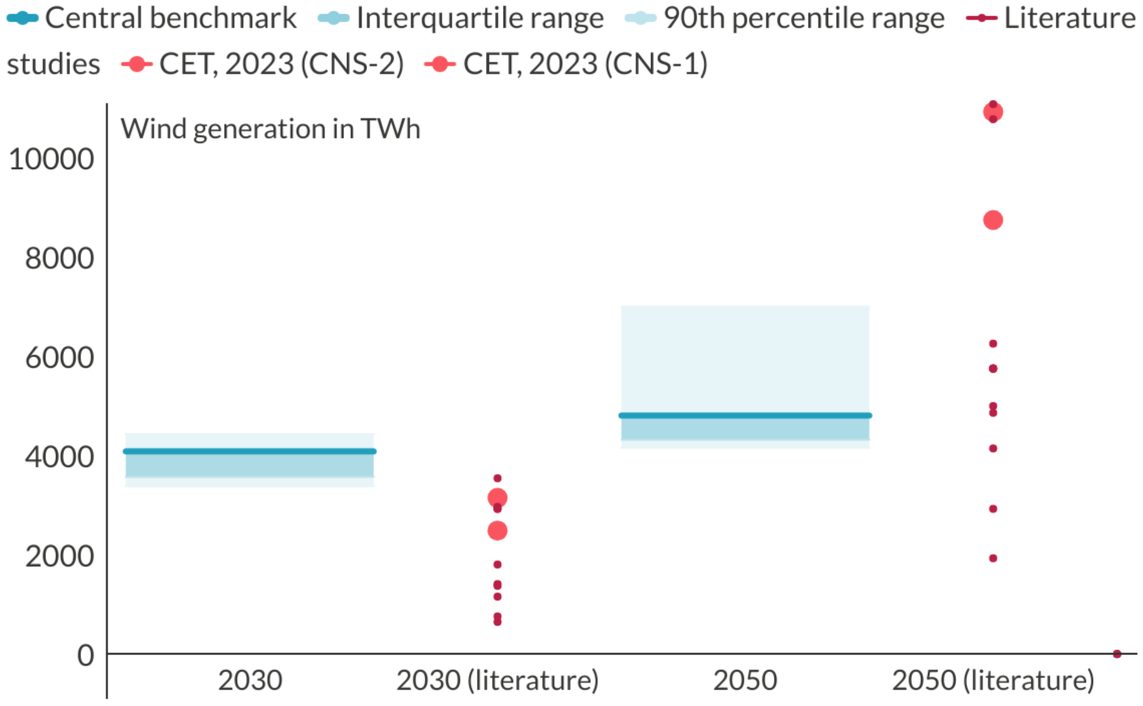
- Our analysis generally shows higher solar generation than the national studies. However, a question is how much these studies have taken account of recent PV growth and cost reductions in PV in China.
- For wind our figures are closer to the average of the range of existing studies, and less than the wind generation demonstrated by the CET scenarios.
- Both country-level studies and our modelling sees wind still as providing the largest share of generation in 2030. Our scenarios then move to a solar dominated system by 2050, while the country-level studies show a range of possible generation splits in 2050 between wind and solar.

Our benchmarks are broadly aligned with the literature

Electricity generation from solar: comparison with literature in China



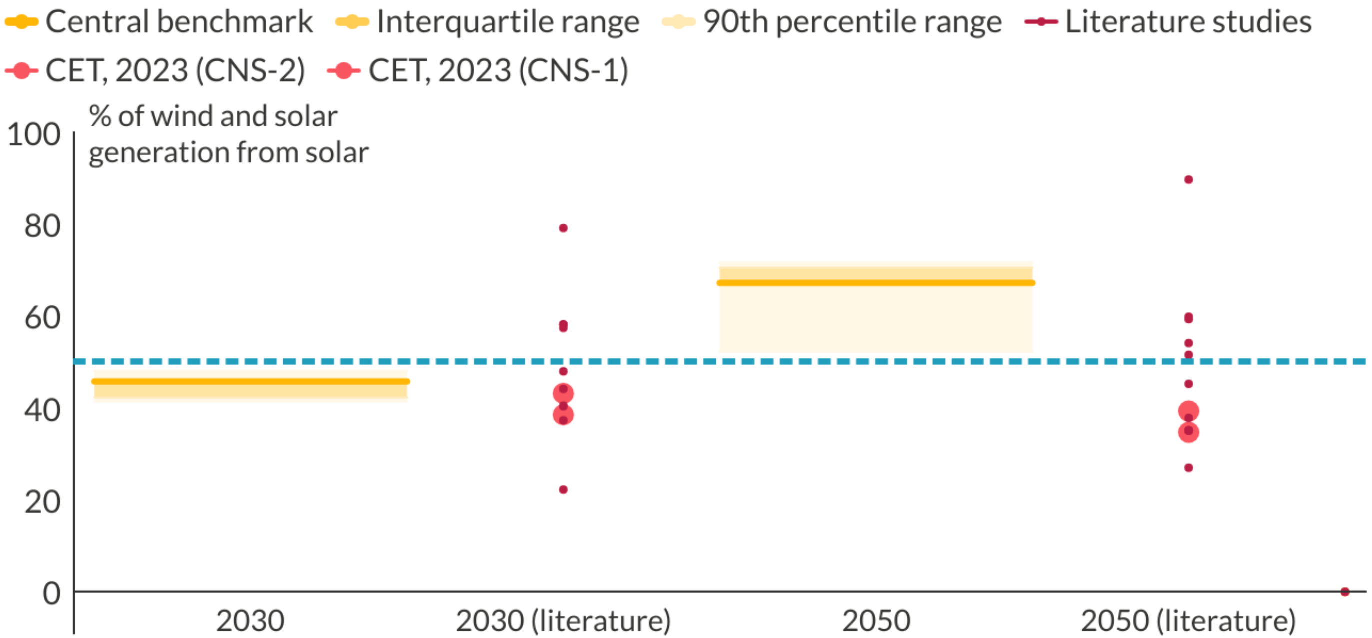
Electricity generation from wind: comparison with literature in China



In China, our benchmarks generally suggest that solar will provide more generation than wind after 2030

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

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	471	3100	5200	7800	9900
Central 1.5°C benchmark	Wind generation	TWh	750	4100	5100	5400	4800
Central 1.5°C benchmark	Solar capacity	GW	429	2900	4600	6400	8000
Central 1.5°C benchmark	Wind capacity	GW	365	1600	2100	2200	2000

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

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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

Study	Publication	Scenario Selected
Burandt et al., 2019	Decarbonizing China's energy system-	Ambitious
Qiu et al., 2021	Energy demand and supply planning of China through 2060	
Lugovoy et.al, 2021	Feasibility study of China's electric power sector transition to zero emissions by 2050	F-NPL-25
He et al., 2020	Rapid cost decrease of renewables and storage accelerates the decarbonization of China's power system	C80
Teske, 2015	energy [r]evolution : A Sustainable World Energy Outlook 2015	• Advanced Energy [r]evolution • Energy [r]evolution
ICCSD of Tsinghua University et al., 2023	China's long-term low-carbon development strategies and pathways	2 degrees

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

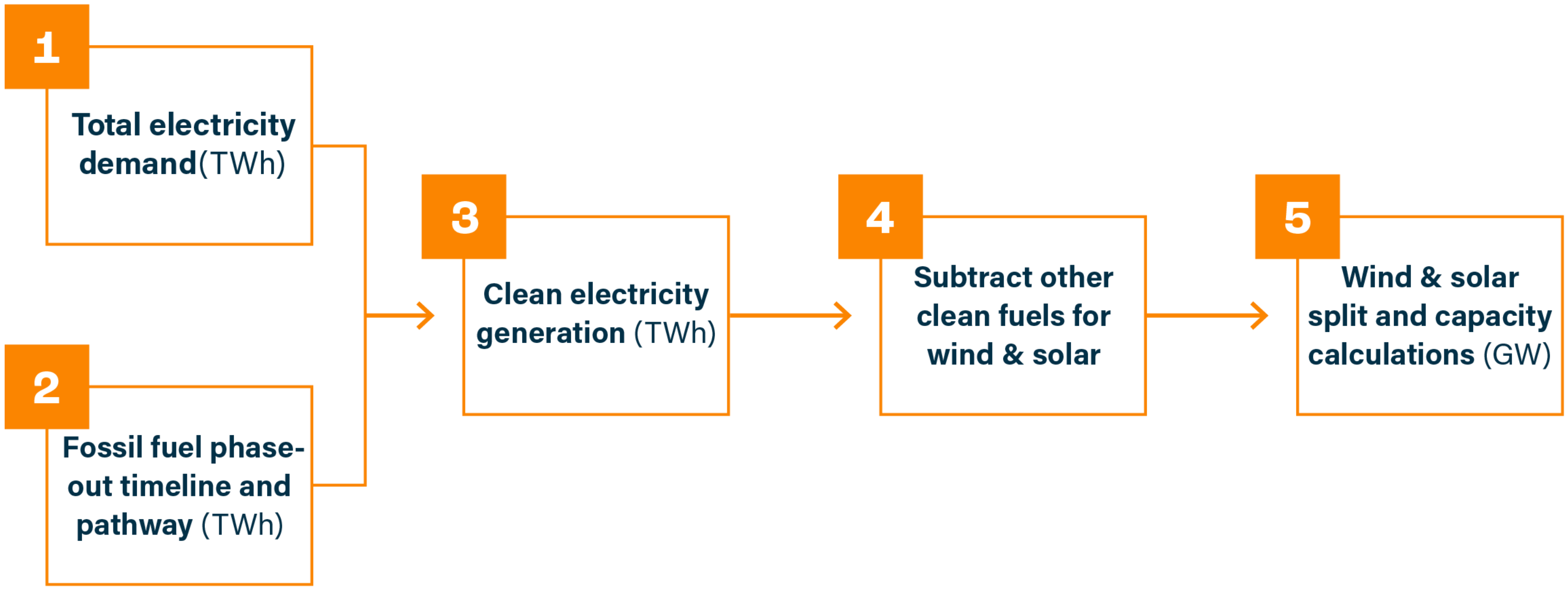
Our method takes a series of steps to calculate the wind and solar generation needed for 1.5°C, and the resulting capacity deployment.

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.

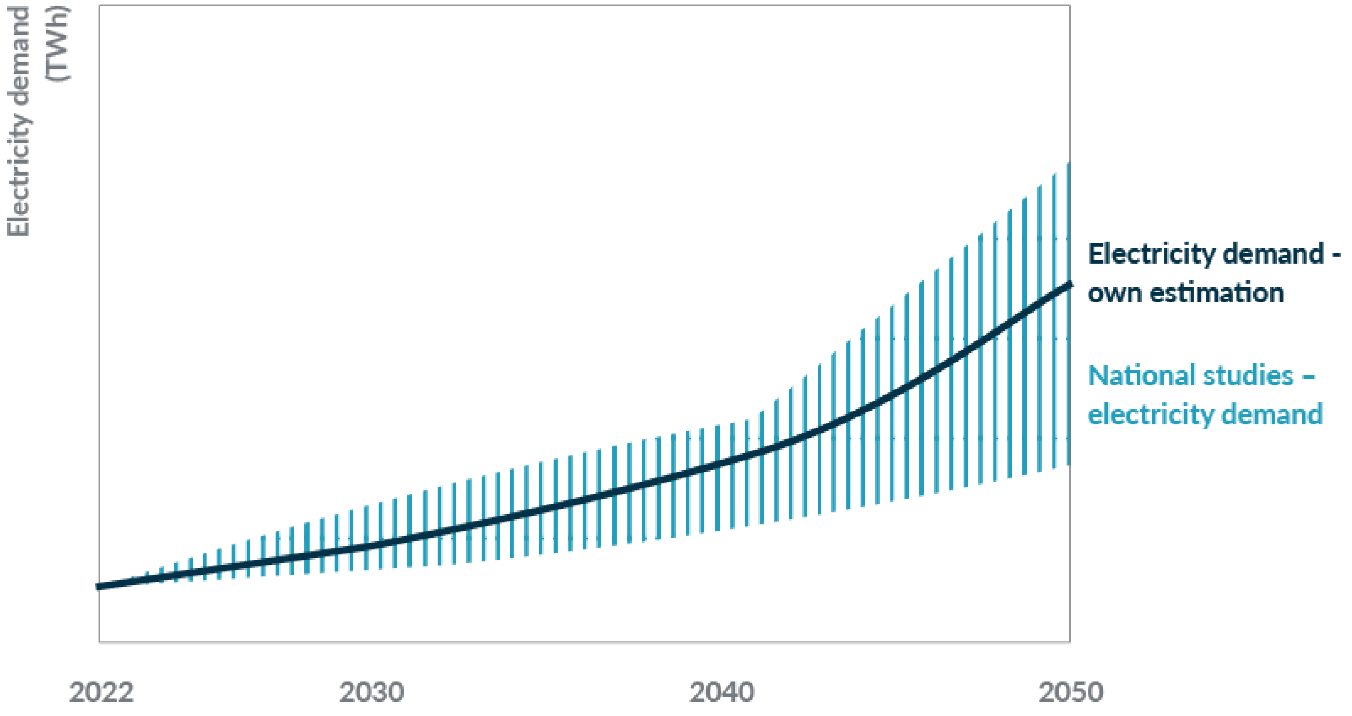
We use a step-by-step method to calculate our benchmarks



For more details see the Methods Annex

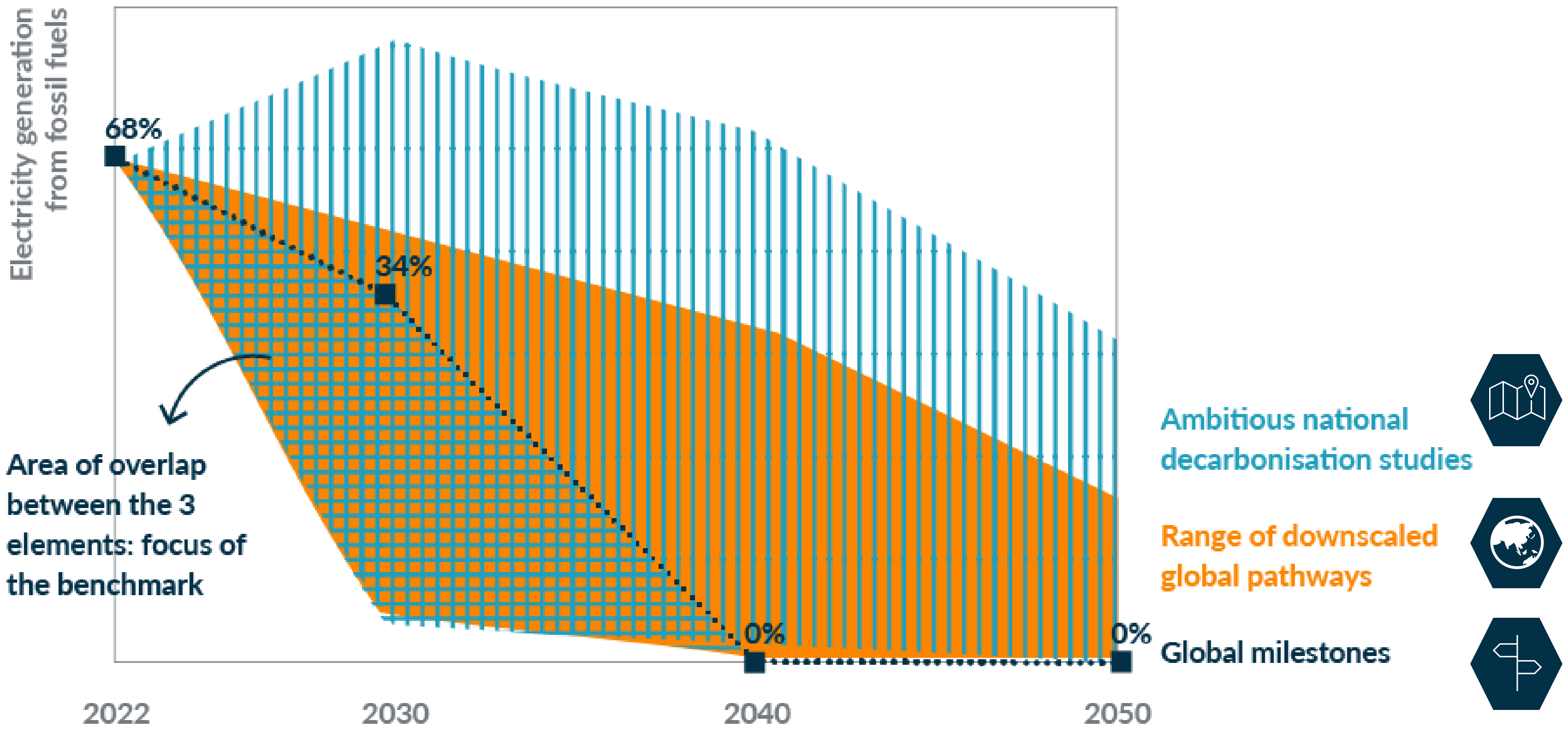
1 Total electricity generation

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.



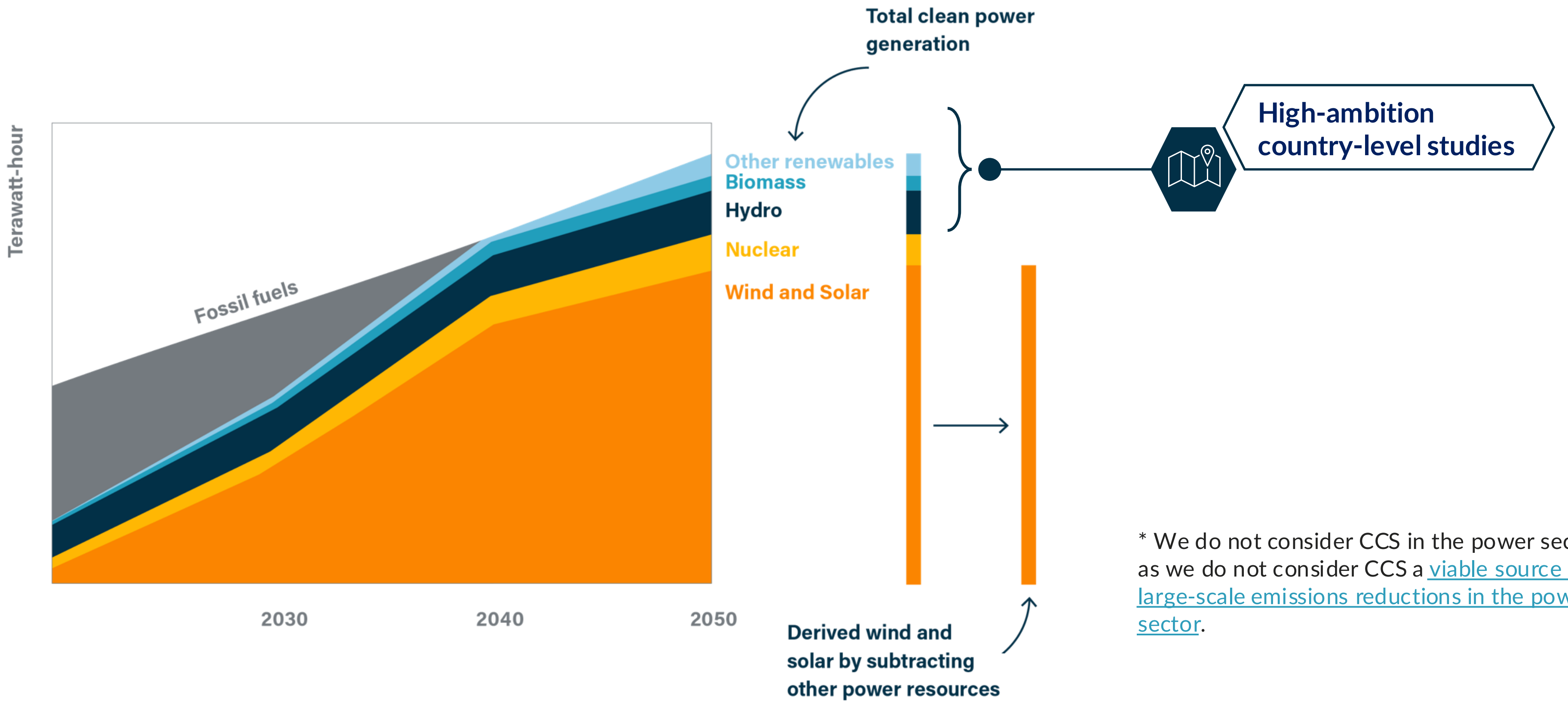
2 Fossil fuel phase-out

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).



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.

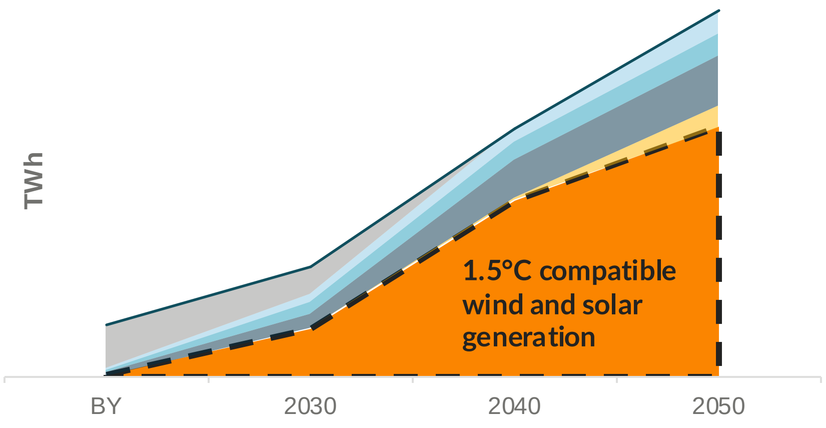


* We do not consider CCS in the power sector, as we do not consider CCS a viable source of large-scale emissions reductions in the power sector.

5 Wind and solar breakdown

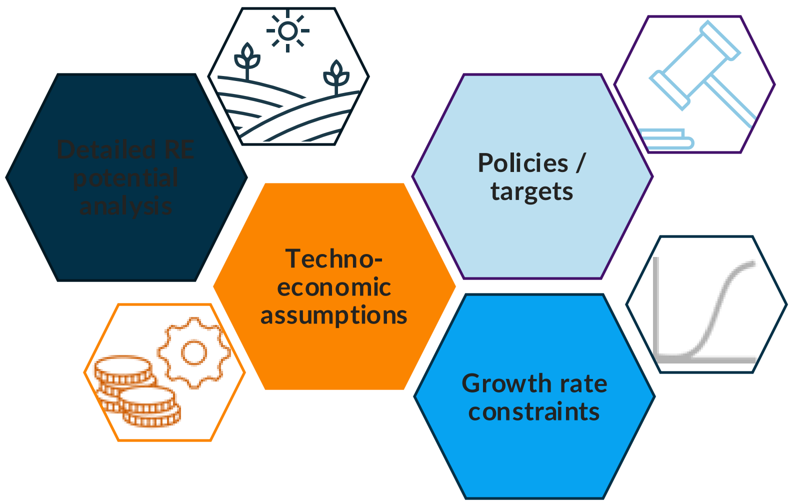
1. We use a detailed geospatial **renewable potential analysis** to calculate the technical potential of each technology in the country. We then feed the wind and solar generation required into a power system model calibrated to these potentials
2. We force the model to deploy at least the level of solar 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)

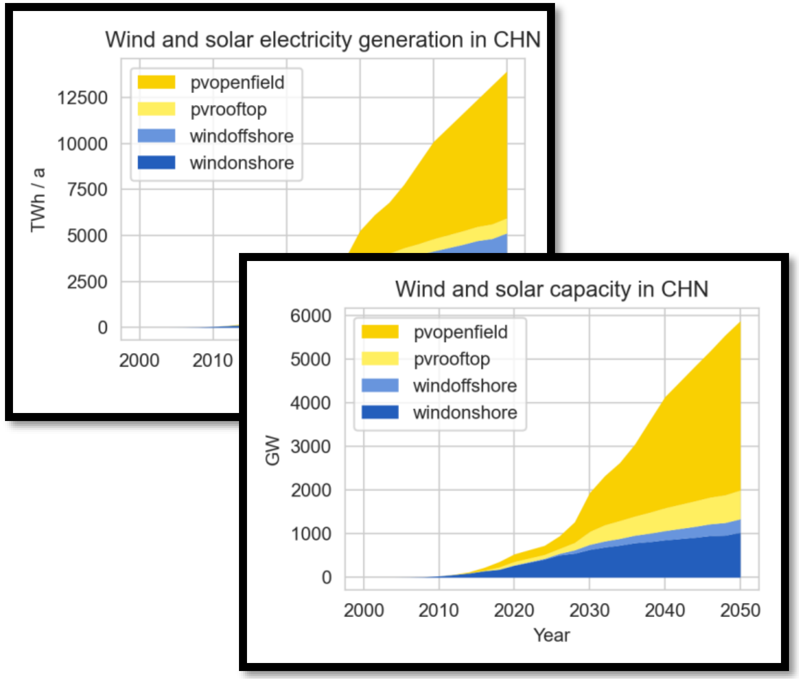


RE potential and power system analysis

Current targets and pledges



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 = 33% per year • Solar = 41% 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 is 25%. 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.