Wind and solar benchmarks for a 1.5°C world

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

Nigeria

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Executive Summary

Context

- Nigeria has the largest population in the world without electricity, estimated at around 40% of the population in 2021.
- Electricity demand growth is set to soar in Nigeria, driven by robust economic growth and improving levels of electricity access.
- The current electricity system in Nigeria is dominated by gas-fired power plants and off-grid diesel generators.
- In this report, we explore the level of wind and solar that Nigeria would need to install as part of a global 1.5°C compatible pathway. Our benchmarks are also compatible with tripling renewables capacity by 2030.

Key findings

- To meet electricity demand growth while reducing reliance on diesel and gas in the power sector, wind and solar generation would need to grow to 60-90 TWh by 2030.
- Over 50 GW of wind and solar would be needed by 2030 (37 GW of solar and 17 GW of wind).
- A rapid rollout of renewables could help meet electricity demand and provide reliable, zero-carbon electricity to Nigerians, while avoiding continued reliance on diesel and gas.
- However, it will require large-scale investment to help accelerate renewables deployment and drive grid expansion. International support will be key in creating an enabling environment to catalyse private investment in Nigeria.

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 **Nigeria.**

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

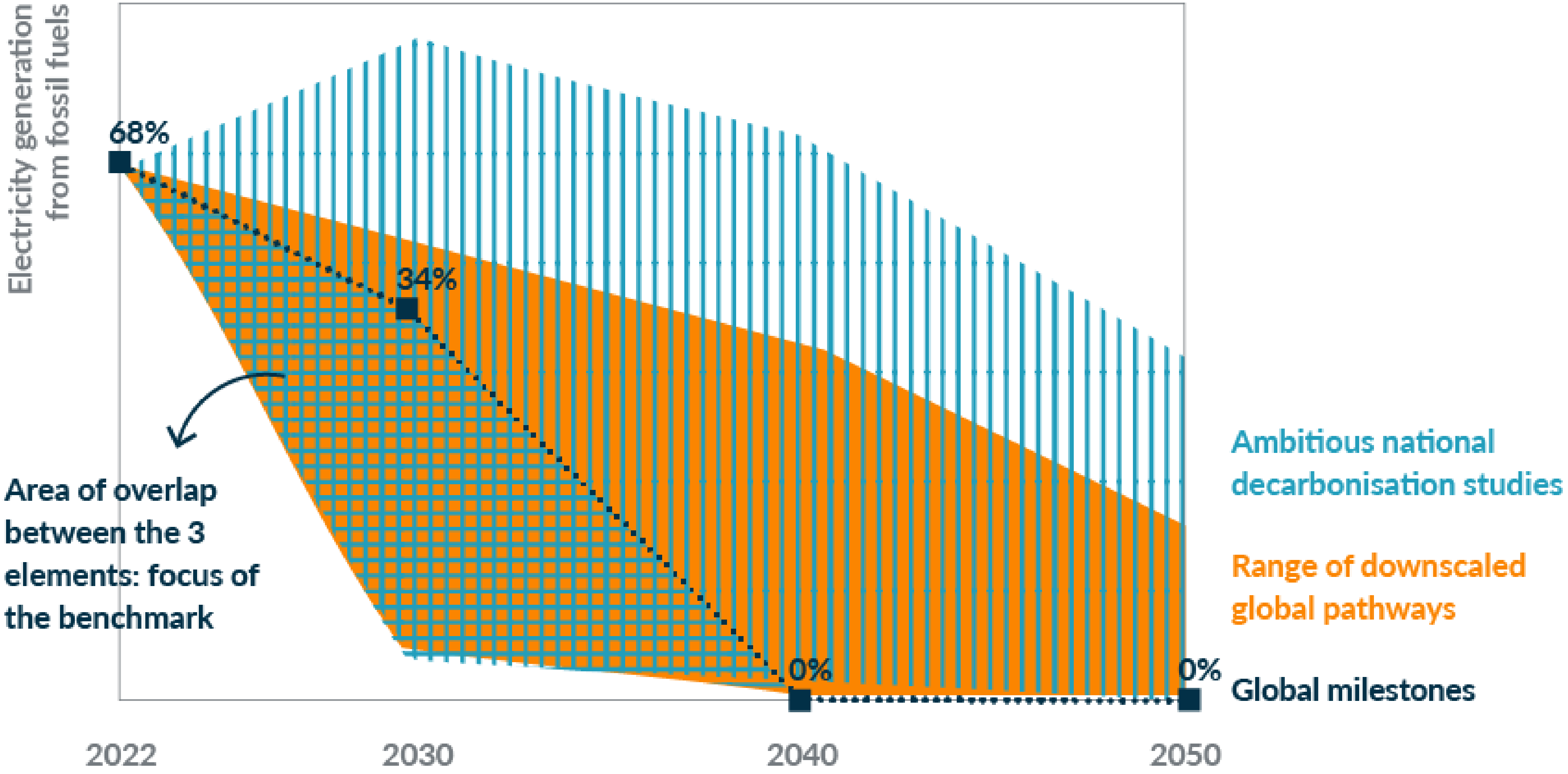
For more details see the Methods Annex

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

Ambitious national decarbonisation studies

Range of downscaled global pathways

Global milestones

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

Nigeria is committed to reducing its emissions by 20% below BAU by 2030 (incl. LULUCF) unconditionally and will reduce its emissions by up to 47% below BAU by 2030, conditional on international support. It has also committed to reaching net zero between 2050 and 2070.

Nigeria's current renewable targets are to reach **6 GW of solar and 0.8 GW of wind by 2030**, as of the National Renewable Energy Action Plan.

Under current policies and market conditions, the IEA estimates that **solar capacity will reach 4.3 GW in 2028**, up from 97 MW (0.097 GW) of solar in 2022. Meanwhile, **wind capacity is not projected to grow at all, remaining at only 6 MW in 2028.**

Results

Future electricity demand

Electricity demand in Nigeria is highly uncertain, with a large component of off-grid generation which is hard to estimate. We take electricity demand from the IRENA study commissioned by the Nigerian Government on a renewable roadmap for Nigeria, focusing on the Transforming Energy Scenario. This study estimates that electricity demand in 2015 was slightly below 120 TWh, with around 100 TWh of this demand being met by fossil fuels, largely off-grid diesel generators.

In this scenario, total electricity generation in Nigeria grows more than five times by 2050 relative to 2015 levels, reaching 560 TWh. This is driven by economic development and increased electrification. Off-grid systems provide around ~25% of electricity demand in 2050.

However, there is a significant range in the studies in terms of the expected electricity generation in 2050 ranging from 400 TWh to 1200 TWh. This would affect the needed growth of wind and solar significantly. Our demand estimate is in the lower range of that estimated by country-level studies.

Pace of fossil phaseout needed

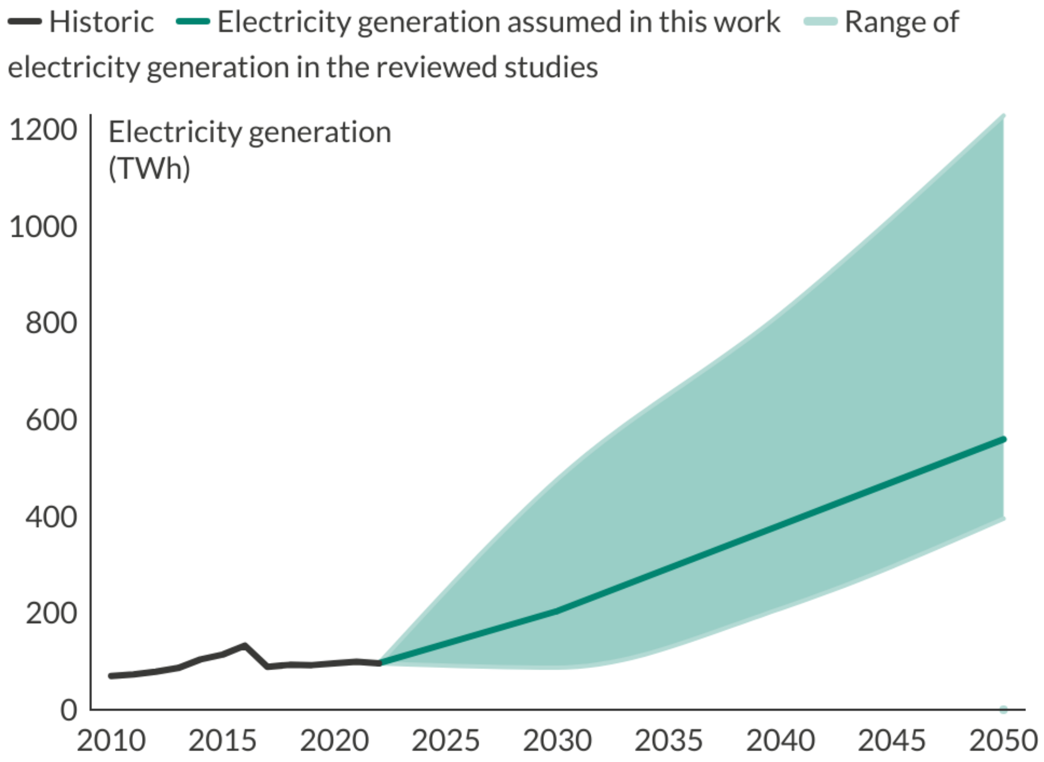
The rate of fossil phase-out is set by the overlap between country-level studies, downscaled 1.5°C compatible global pathways and the global milestones of the IEA's Net Zero roadmap, in which Nigeria achieves a clean power system by 2045.

To align with 1.5°C, fossil fuels must exit the Nigeria power sector before 2045.

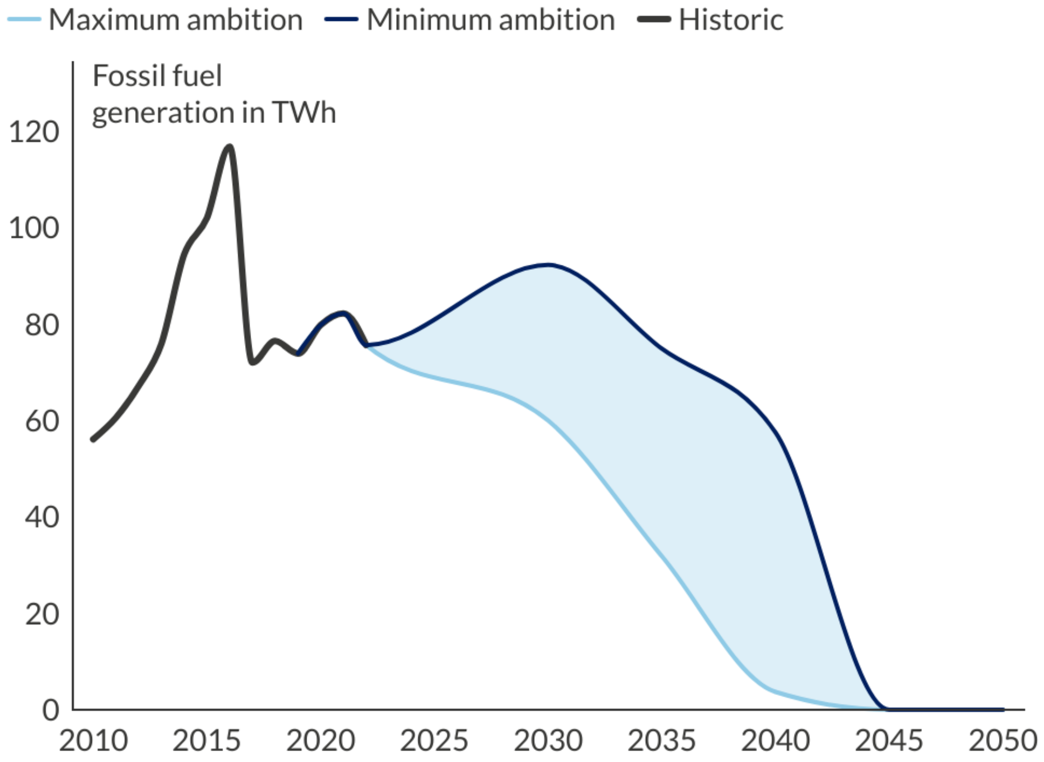
Nigeria's current electricity system is dominated by gas-fired power. Under these benchmarks, gas generation would fall 10–41% by 2030 relative to 2015 levels.

To align with 1.5°C, fossil fuels must exit the Nigeria power sector by 2045, even as electricity demand grows rapidly

Electricity generation grows around five times in Nigeria by 2050



Nigeria would need to achieve clean electricity by 2045



* Historical generation data for Nigeria is limited, particularly for data sources which include off-grid generation. We take a 2015 data point from a recent IRENA study, which estimates that in 2015 total generation was around 110 TWh, of which over 100 TWh came from fossil fuels. We then extend the time series forwards and backwards using growth rates for electricity demand and fossil generation from the IEA (which does not appear to include off-grid generation). This assumes that the growth rates in electricity demand and fossil generation are the same across off-grid and on-grid components.

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 Nigeria would reach 54 TWh by 2030 and 125 TWh by 2050. This is provided by large-scale hydropower, which grows on average to over 40 TWh in 2030 in the country-level studies, and some biomass and solar CSP.

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* 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

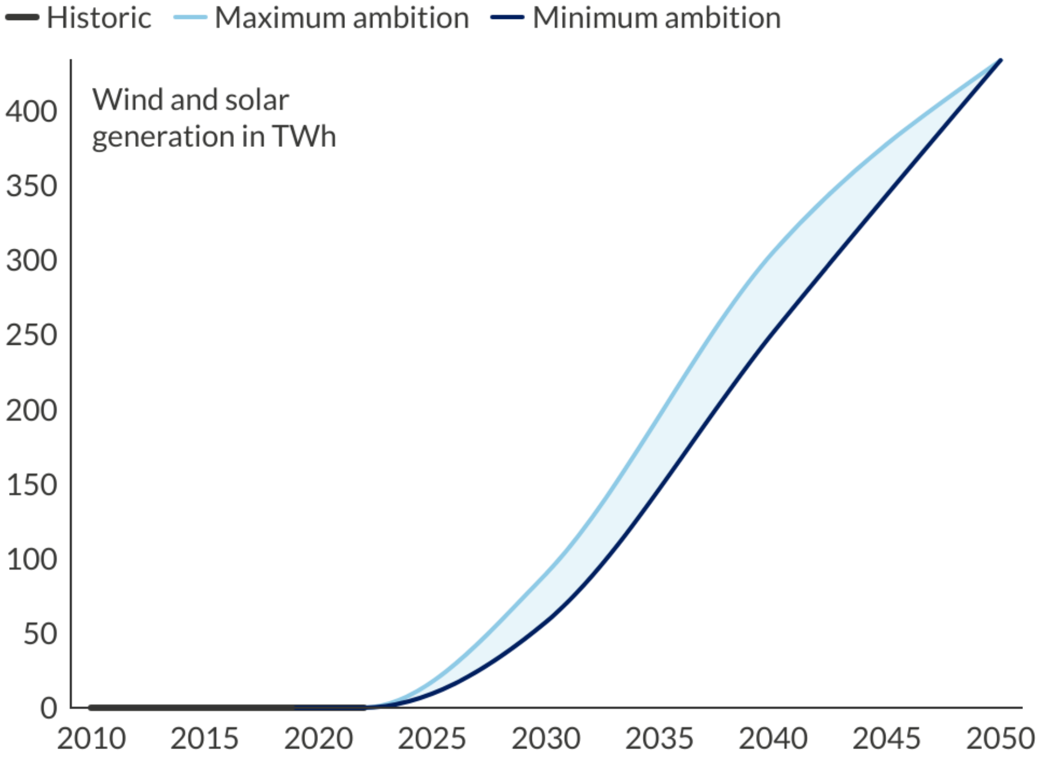
The wind and solar rollout necessary is then calculated by combining projected electricity demand growth, the fossil phase-out necessary to align with 1.5°C, and the assumed generation from other clean technologies.

To align with 1.5°C, wind and solar generation in Nigeria would need to reach between 57 and 90 TWh by 2030, and over 400 TWh by 2050.

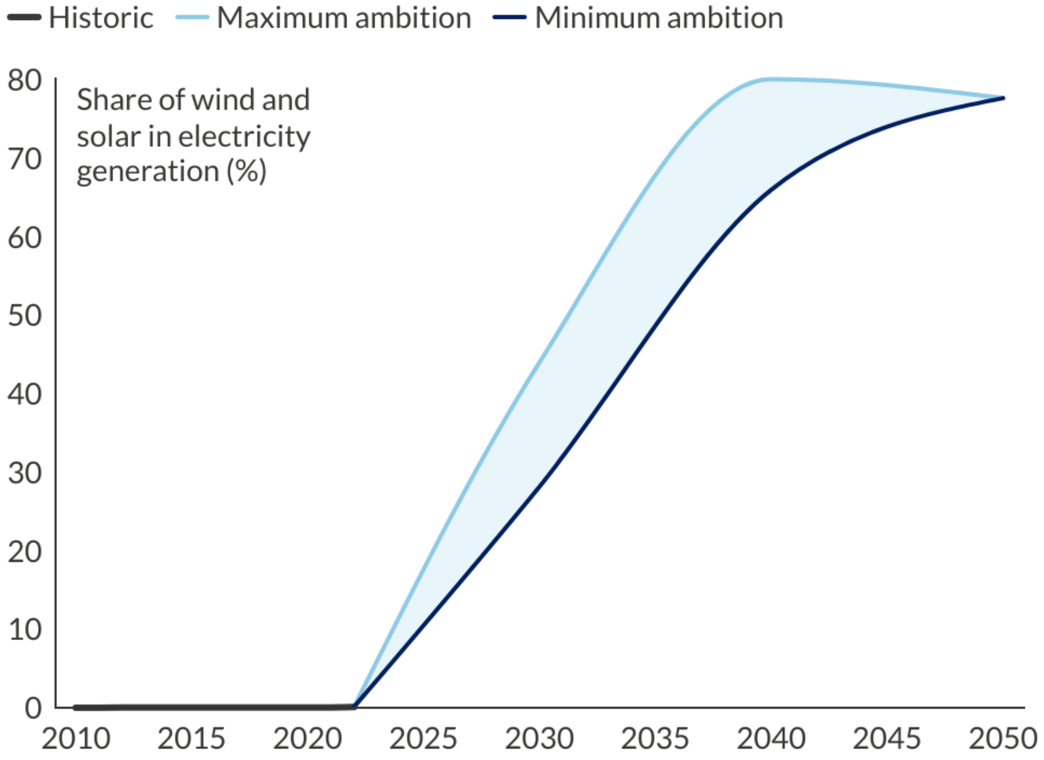
This is broadly aligned with the IRENA TES study in 2030, which deploys 84 TWh of wind and solar by this date. However, in the long-term our benchmarks are more ambitious than the IRENA study, as they achieve a full phase-out of fossil fuels in the power sector before 2050, which the IRENA study does not achieve.

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

Wind and solar generation needs to grow to 60–90 TWh by 2030 in Nigeria



Wind and solar could provide up to 80% of Nigeria's electricity generation needs



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.

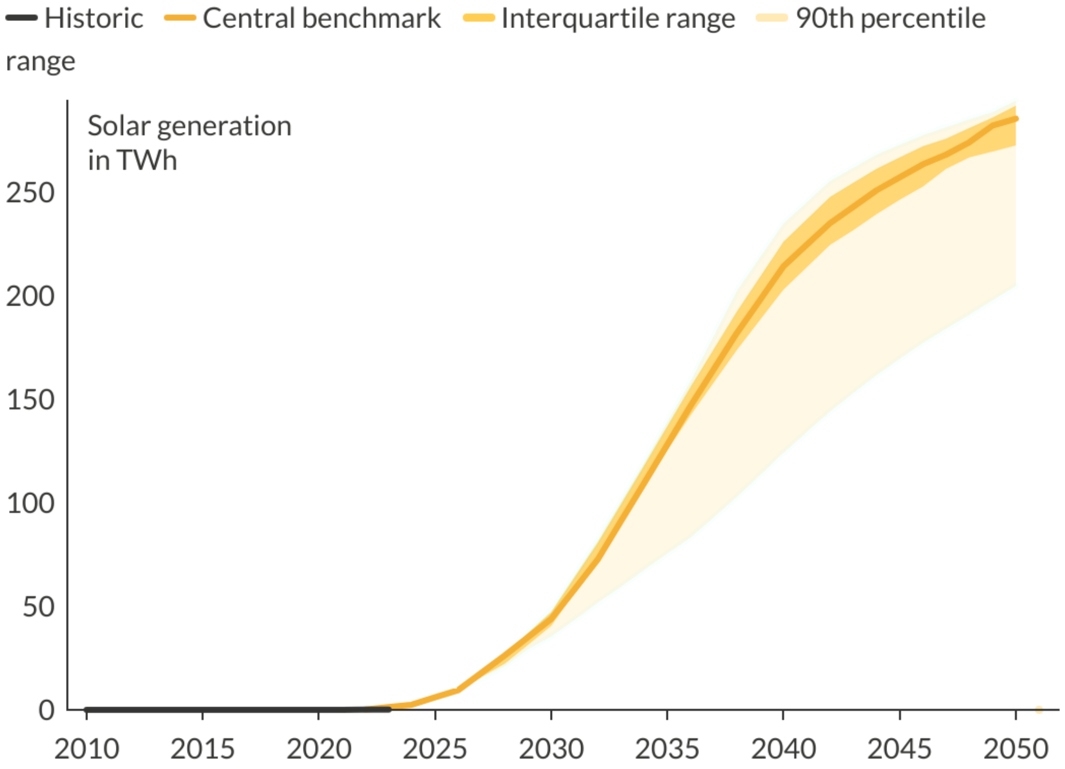
We highlight the median of the range as our **central benchmark**, but do not suggest that this is the only possible breakdown into wind versus solar. In the central benchmarking scenario, solar becomes the main source of generation, providing on average twice as much generation as wind in the electricity mix by 2050. This will require a rapid uptake of non-fossil flexibility options.

In this scenario, **Nigeria would need to deploy over 50 GW of wind and solar by 2030 to align with 1.5°C**. By 2050, total wind and solar capacity would need to reach towards 300 GW. Due to its higher capacity factor, greater wind deployment would reduce total capacity requirements.

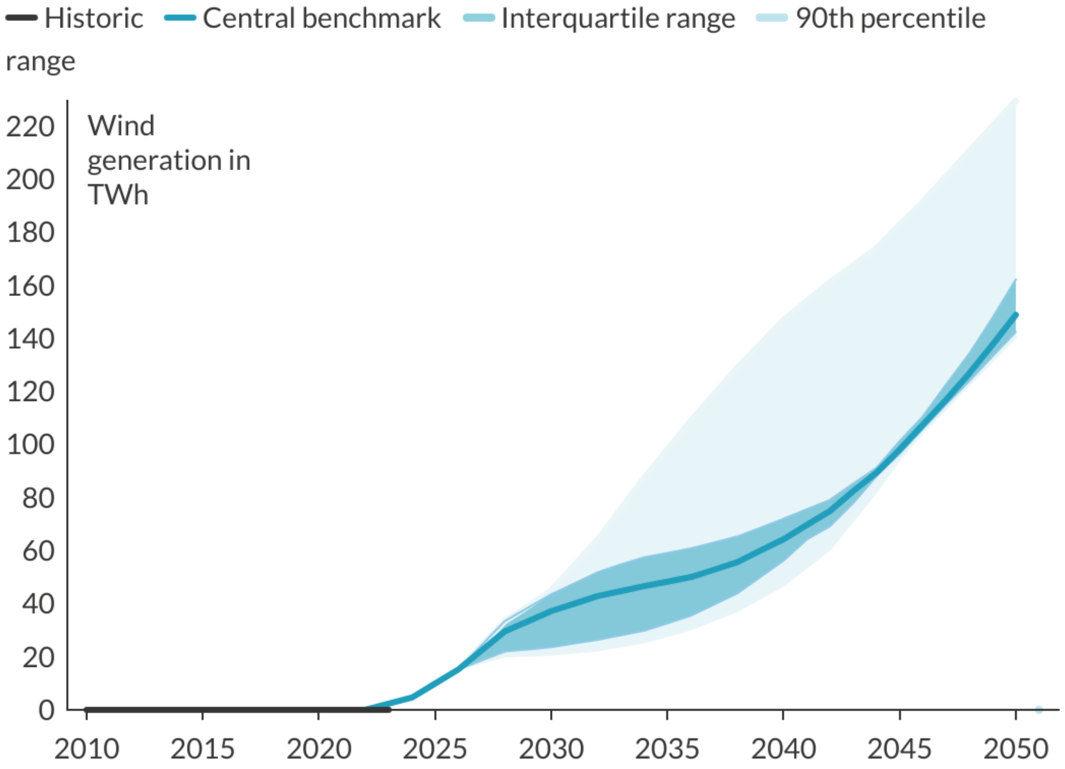
International support, including concessional and grants-based climate finance will be critical in achieving this rate of deployment.

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

Solar generation in Nigeria would reach over 250 TWh by 2050 in a 1.5°C-aligned transition

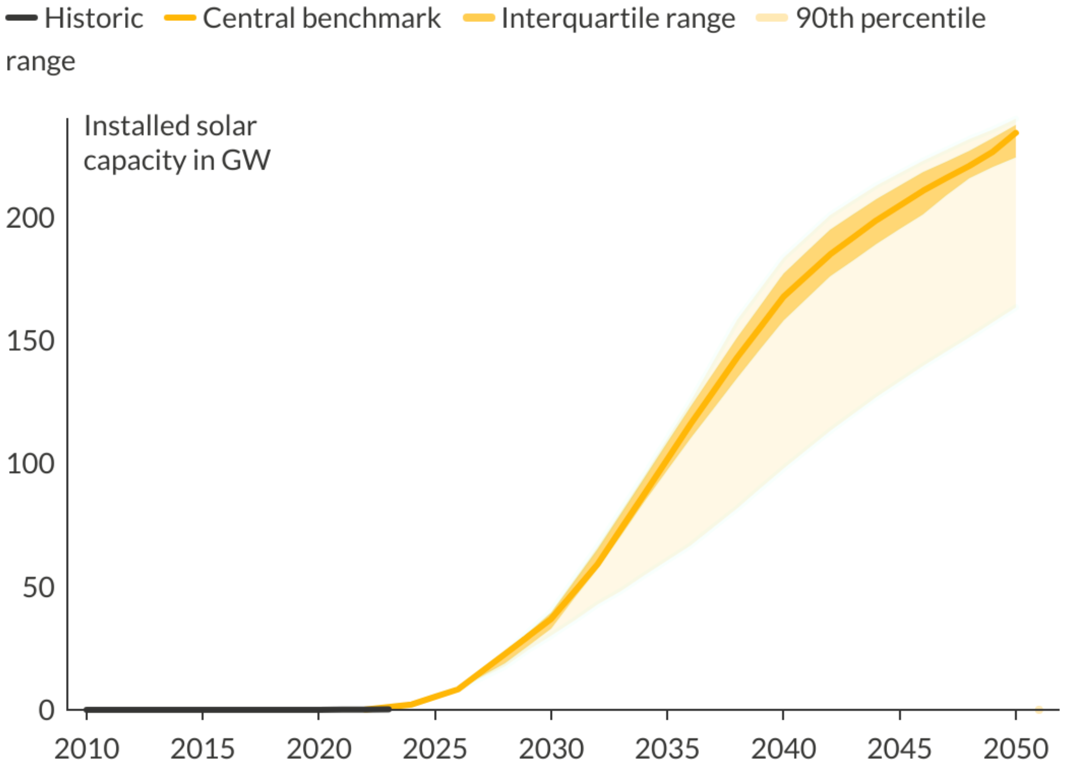


Wind generation in Nigeria would reach almost 150 TWh by 2050 in a 1.5°C-aligned transition

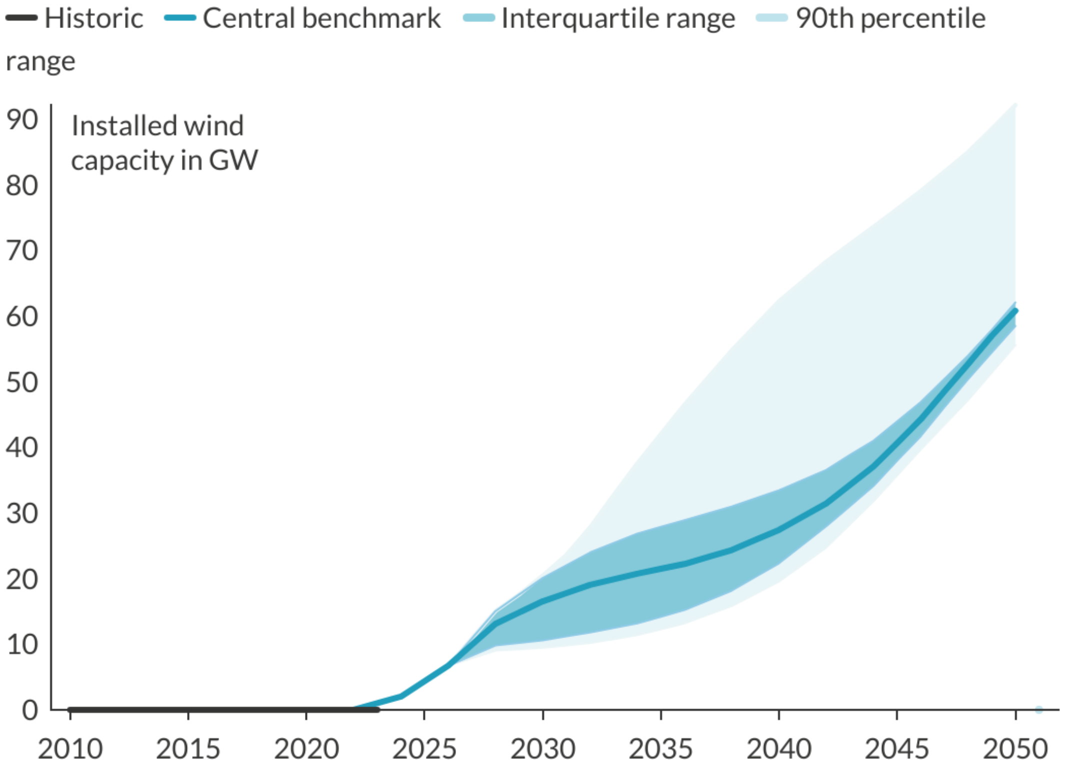


Nigeria needs to install over 50 GW of wind and solar by 2030 to align with 1.5°C

Solar capacity would reach almost 40 GW in Nigeria in 2030 in a 1.5°C-aligned scenario



Wind capacity would reach over 15 GW in Nigeria in 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 both wind and solar in Nigeria is falling behind the levels needed for 1.5°C.

This highlights the urgent need for international support to help address barriers to renewables rollout in Nigeria, and ensure that Nigeria can benefit from a transition to a renewable powered electricity system.

Nigeria's solar and wind rollout needs accelerating to align with 1.5°C

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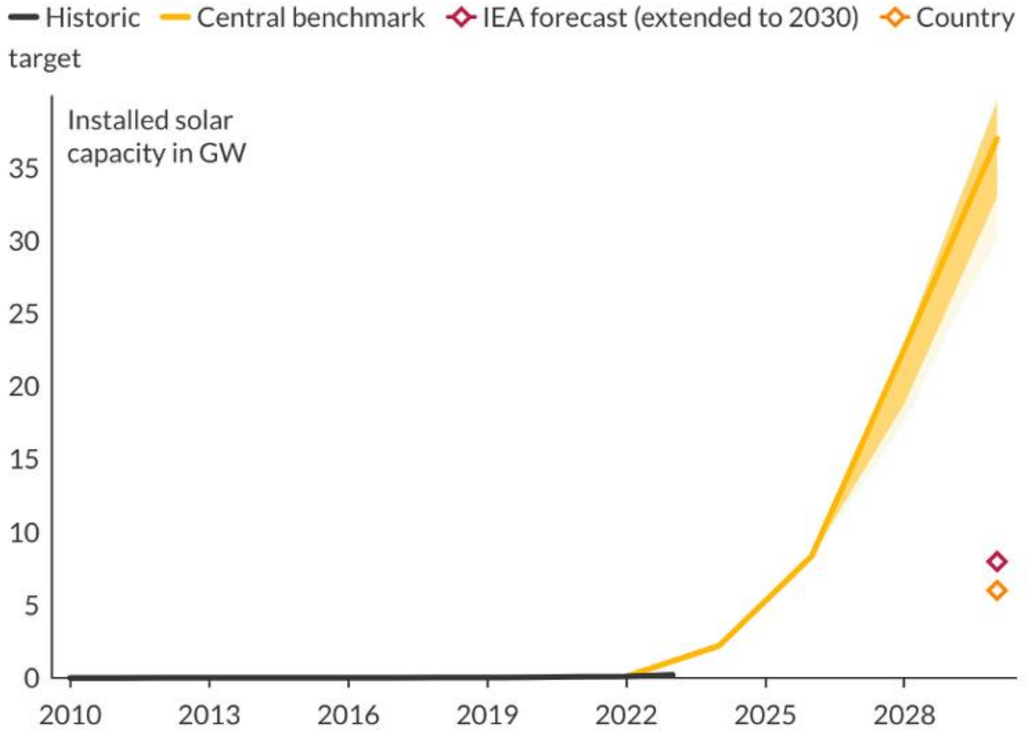
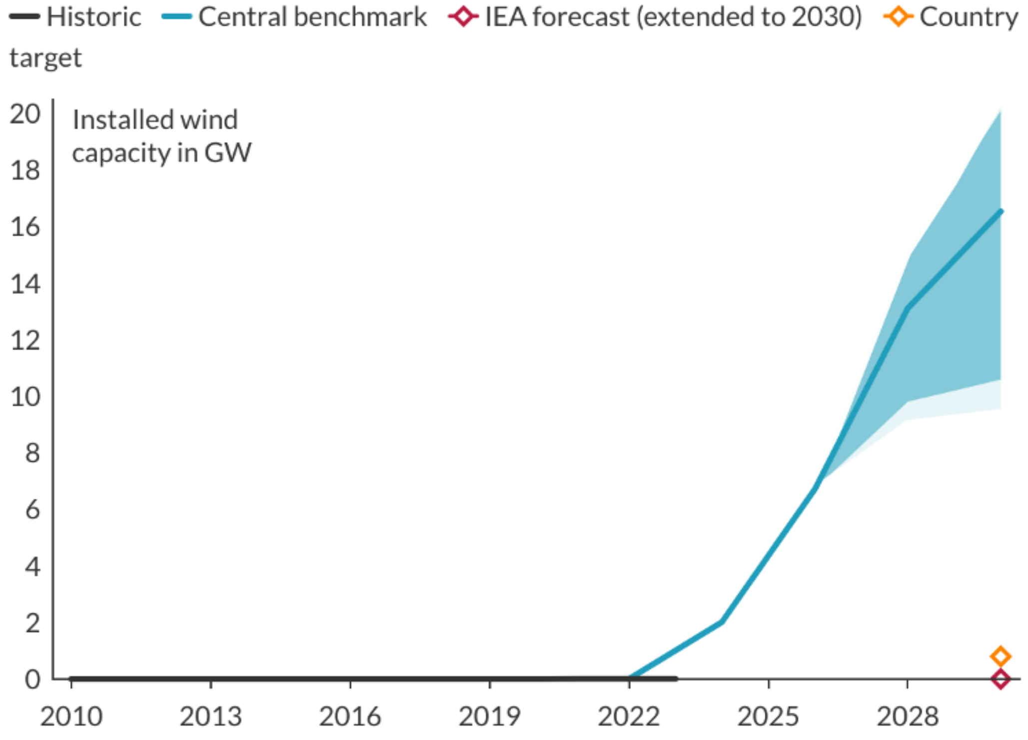


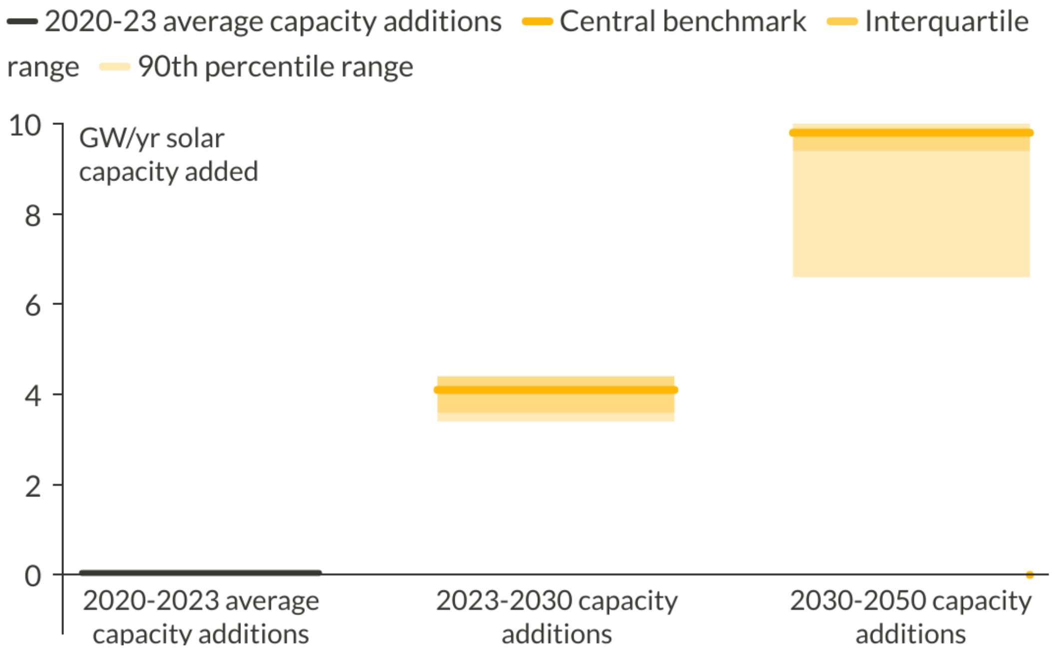
In Nigeria, current rollout of solar is lagging behind 1.5°C-aligned levels



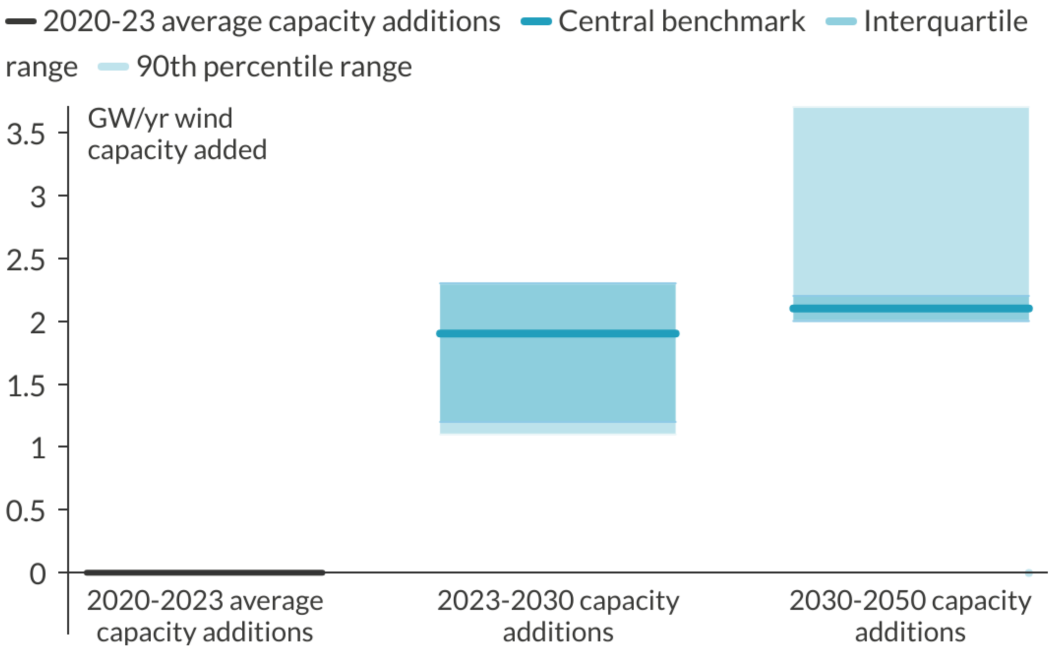
In Nigeria, current rollout of wind is lagging behind 1.5°C-aligned levels

Wind and solar capacity additions in Nigeria accelerate particularly post-2030

Nigeria would need to add on average 4.1 GW/yr of solar capacity until 2030, and 9.8 GW/yr by over 2030–2050.



Nigeria would need to add on average 1.9 GW/yr of wind capacity until 2030, and 2.1 GW/yr by over 2030–2050



Comparison with other studies

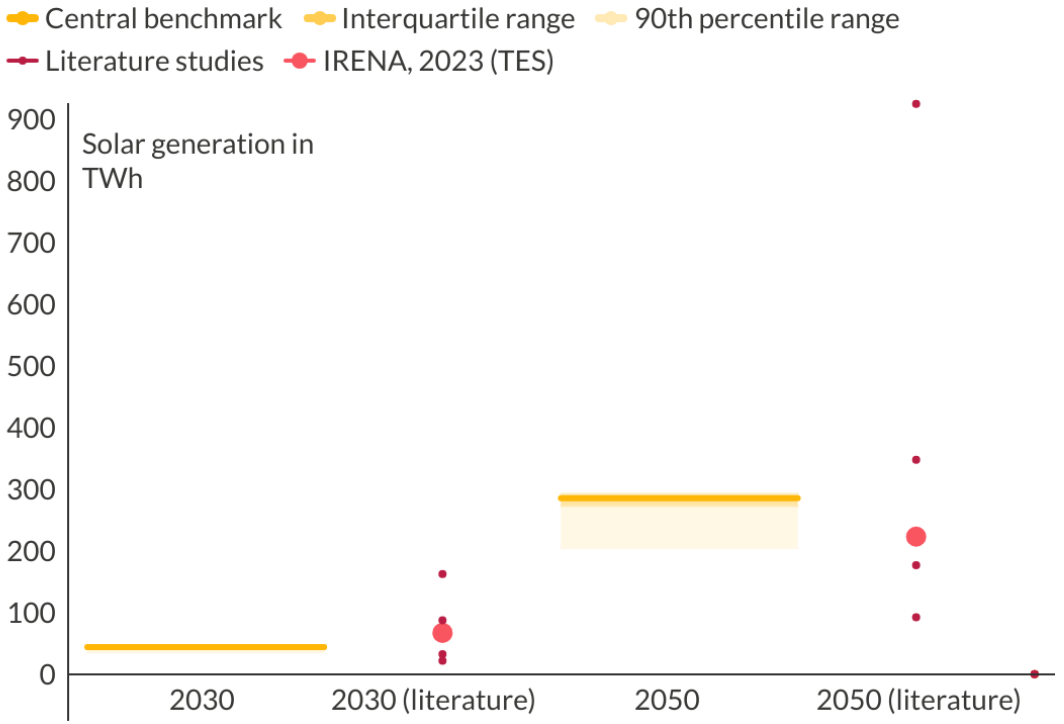
We compare the wind and solar generation seen in our analysis to that in the literature review of country-level studies. In particular, we highlight the results of modelling from the IRENA Transforming Energy Scenario (TES), which achieves an accelerated rollout of renewables in Nigeria.

There is one outlying study, Ishaya et al, 2020, which has much higher rollout than the benchmarks, or other studies. This is due to the much higher demand assumptions in this study, which assumes that electricity demand in Nigeria will grow to over 1200 TWh in 2050, compared to the 560 TWh assumed by these benchmarks.

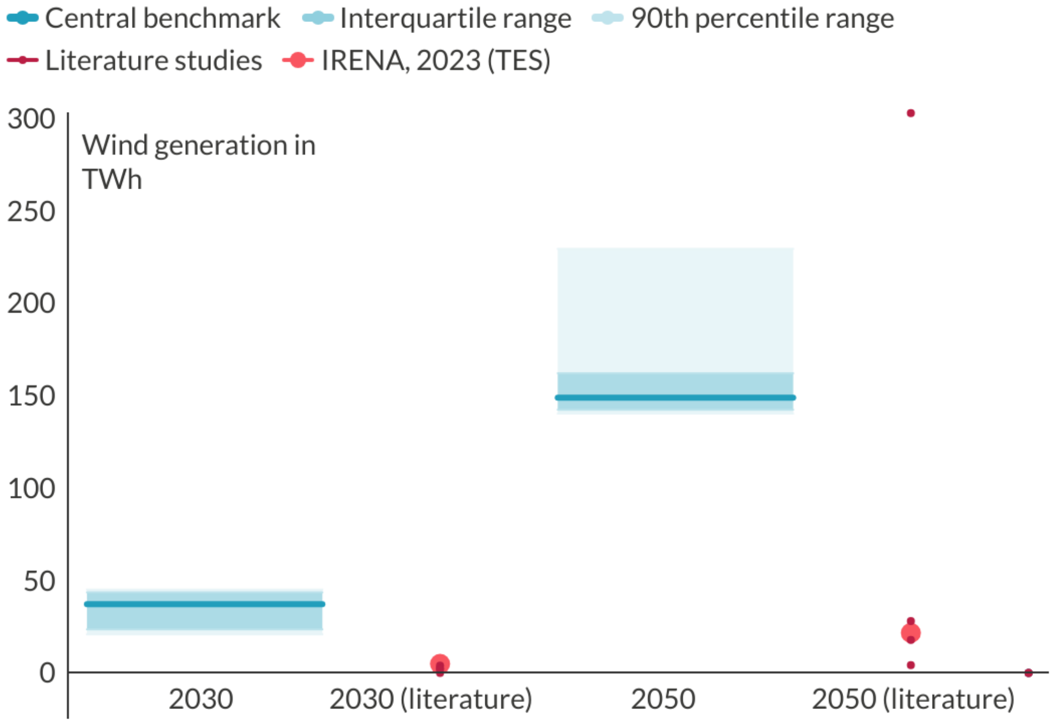
Focusing on the other studies, we see that the rollout of solar seen in our benchmarks is broadly aligned with the wider literature. However, that there is greater rollout of wind in our benchmarks than in other studies reviewed.

Our solar rollout broadly aligns with literature, while our benchmarks deploy more wind than the literature studies

Electricity generation from solar: comparison with literature in Nigeria



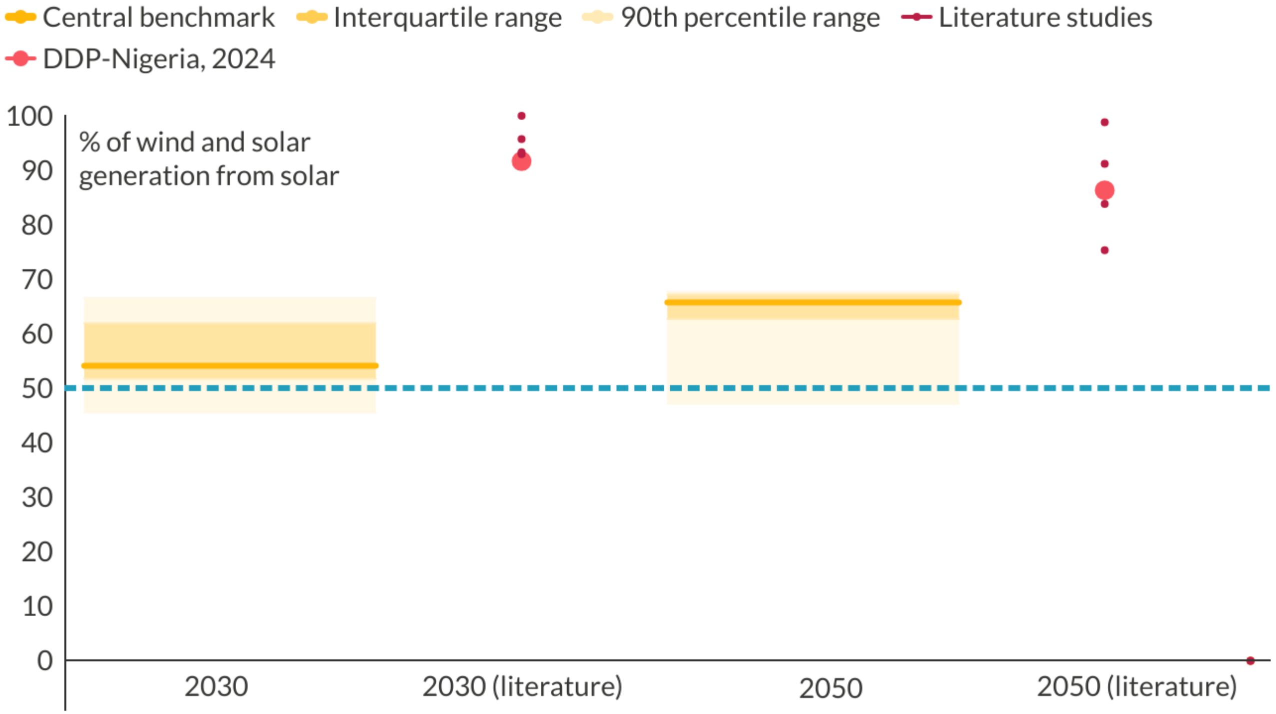
Electricity generation from wind: comparison with literature in Nigeria



In Nigeria, our benchmarks generally suggest that solar will provide more generation than wind

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

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	0.1	44	130	210	290
Central 1.5°C benchmark	Wind generation	TWh	0	37	48	64	150
Central 1.5°C benchmark	Solar capacity	GW	0.1	37	100	170	230
Central 1.5°C benchmark	Wind capacity	GW	0	17	21	27	61

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

Study	Publication	Scenario Selected
Oyewo et. al, 2018	Pathways to a fully sustainable electricity supply for Nigeria in the mid-term future	BPS-3
Ishaya et al, 2020	Renewable Energy scenarios for sustainable electricity in Nigeria	REN-3
IRENA, 2023	Renewable Energy Roadmap Nigeria	• PES • TES
DDP-Nigeria, 2024	Deep Decarbonization Pathways for Nigeria's Low Emission Development up to 2060	RES

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

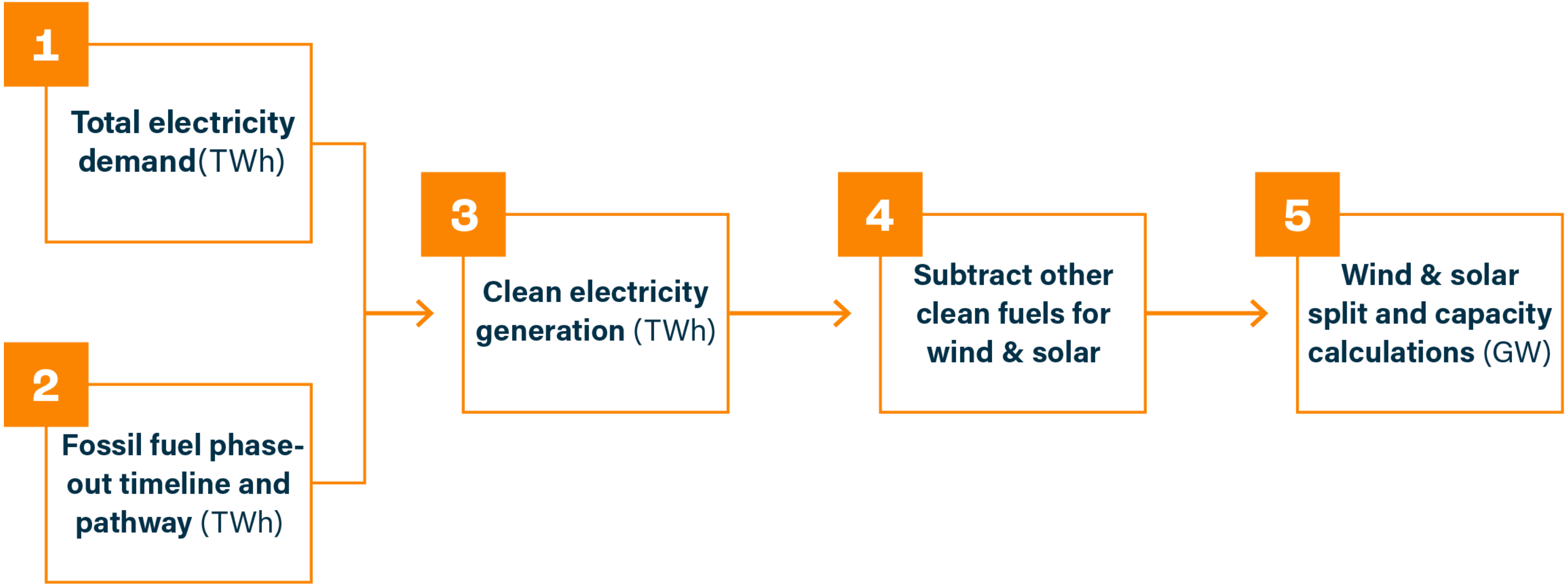
Our method takes a series of steps to calculate the wind and solar generation needed for 1.5°C, and the resulting capacity deployment.

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)

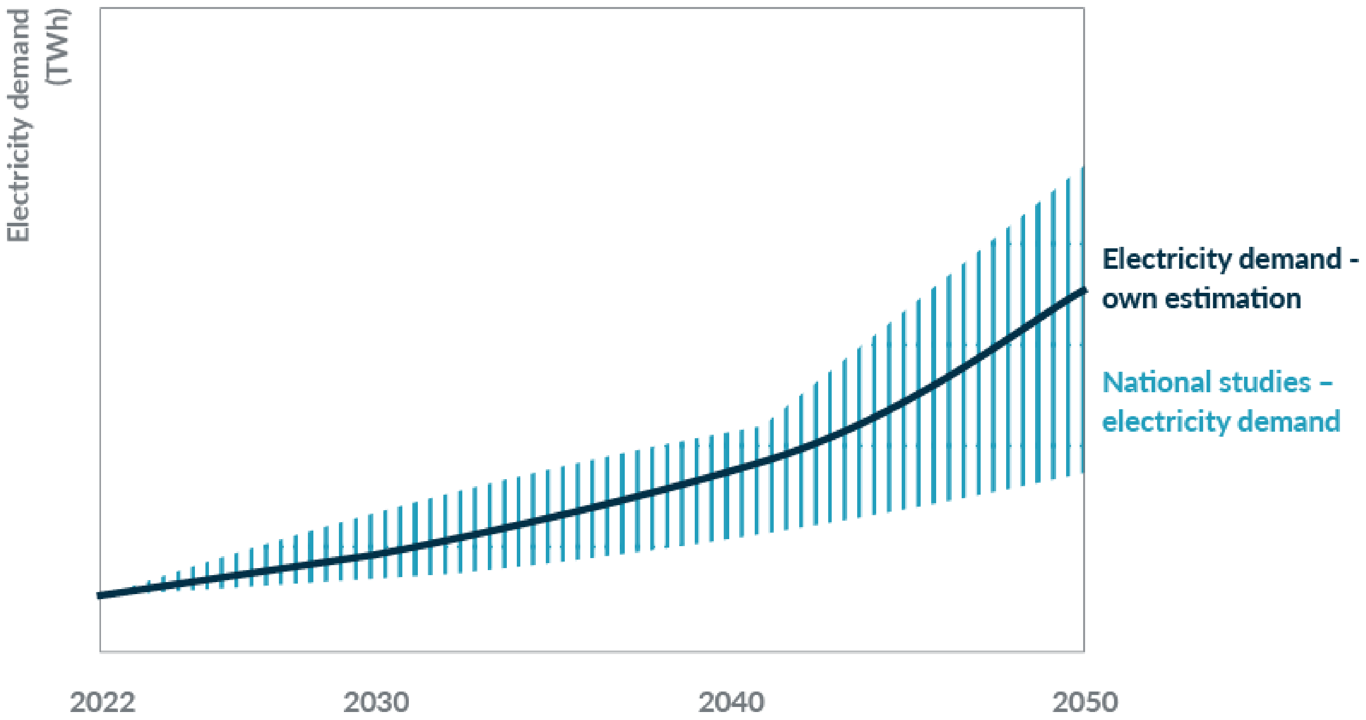
4 **Subtract other clean fuels for wind & solar**

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

For more details see the Methods Annex

1 Total electricity generation

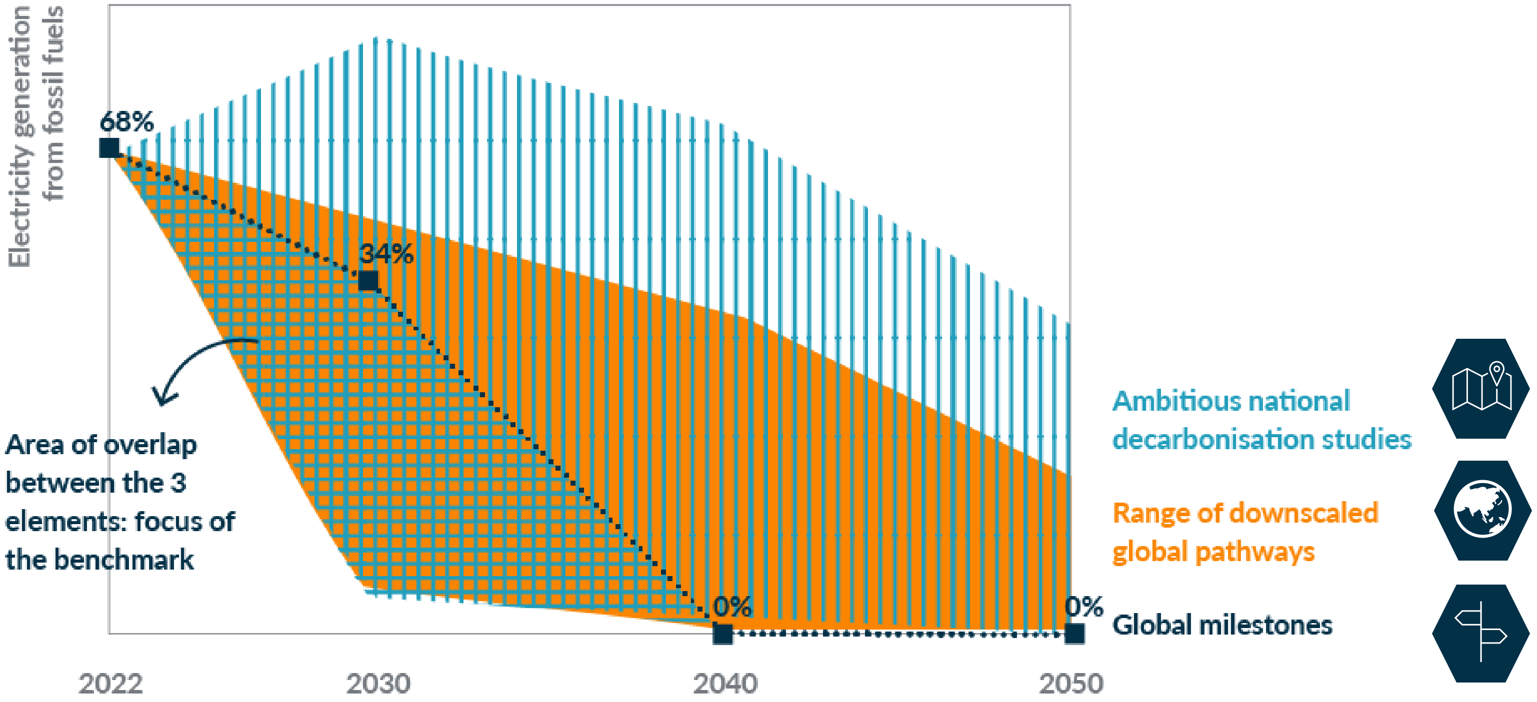
1. We extract electricity generation projections for 2030, 2040, and 2050 from **ambitious country-level studies**.
2. We then identify an electricity generation projection from a scenario to use for our analysis. We focus on identifying studies which capture key elements of the transition, including **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

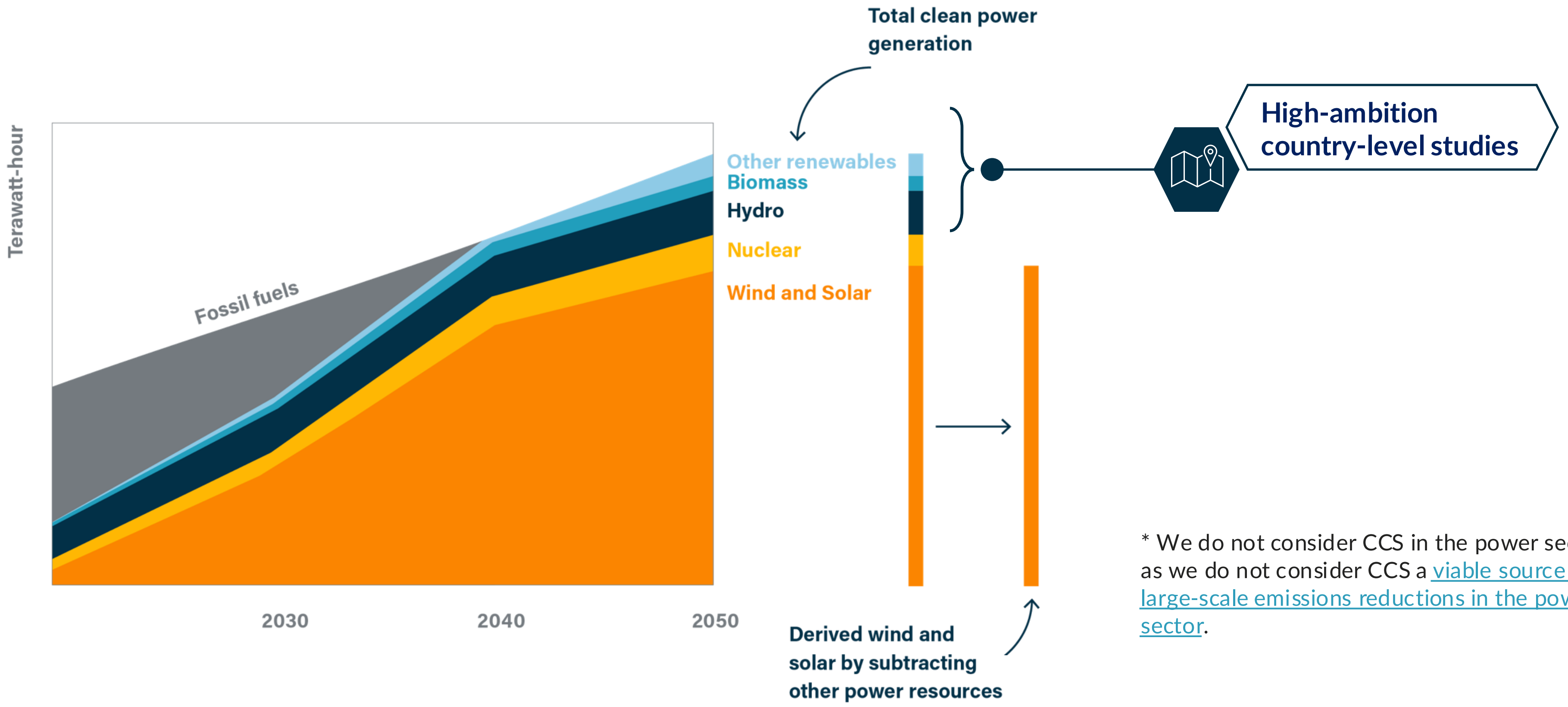
1. We calculate a range of electricity generation pathways from fossil fuels based on **ambitious country-level studies**.
2. We produce a similar range from **downscaled 1.5°C compatible global scenarios**.
3. We identify the intersection of these two ranges, representing the speed and scale of decarbonisation 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

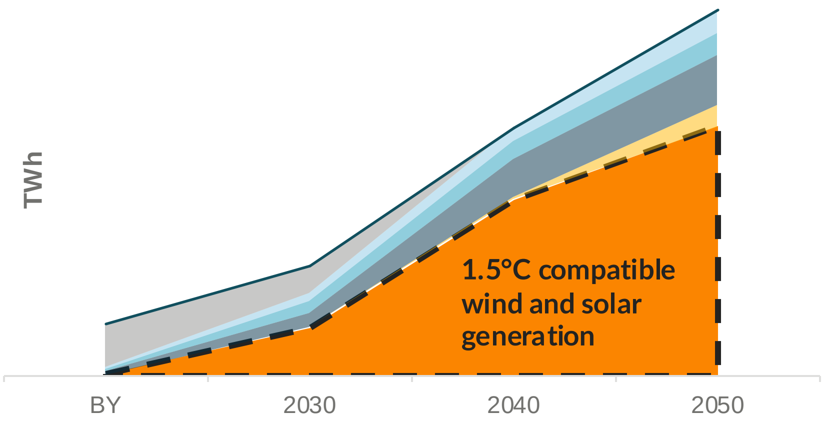
Derived wind and solar by subtracting other power resources

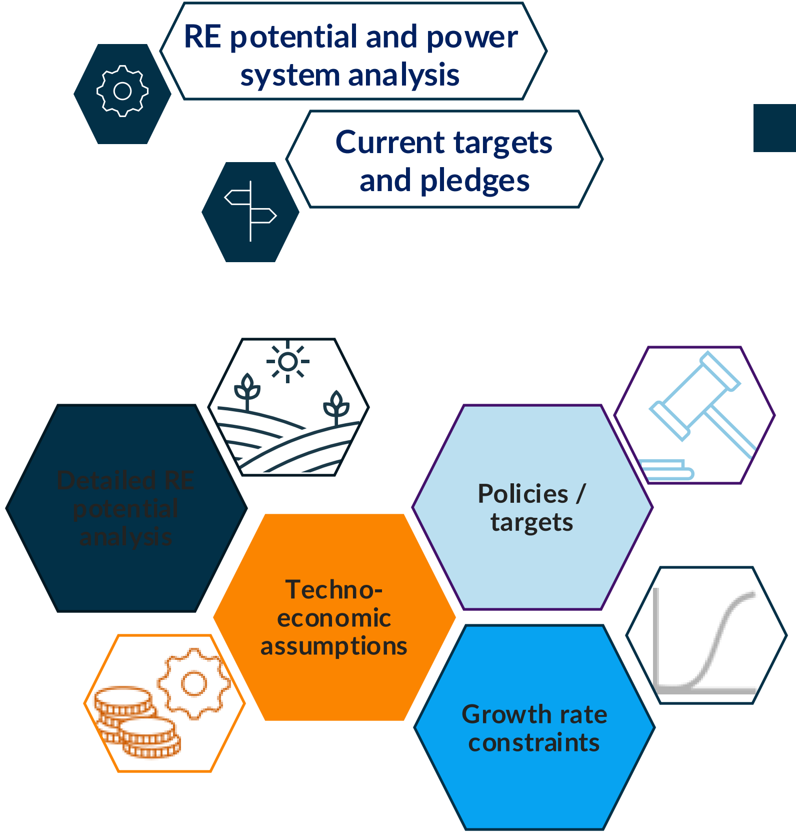
* We do not consider CCS in the power sector, as we do not consider CCS a viable source of large-scale emissions reductions in the power sector.

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)

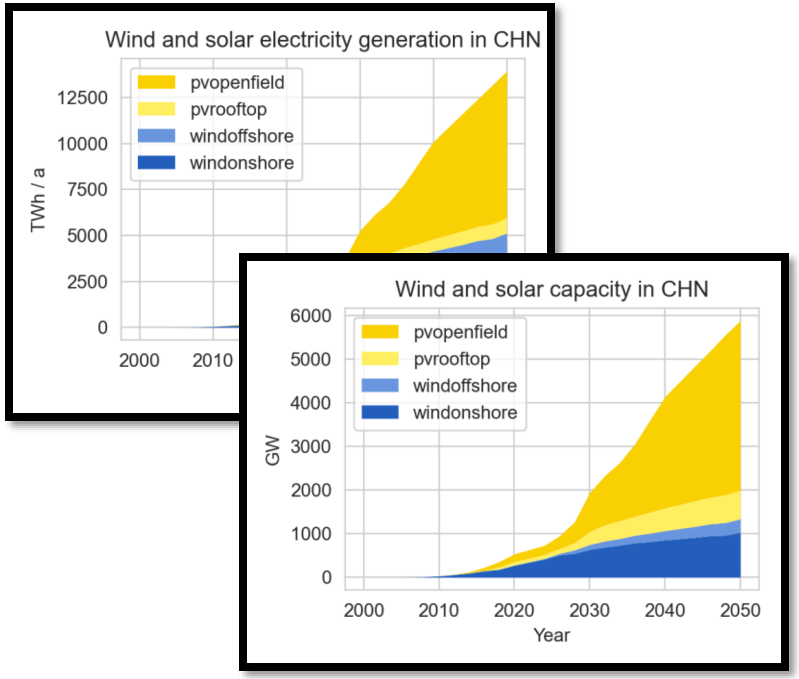




RE potential and power system analysis

Current targets and pledges

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 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.