# Wind and solar benchmarks for a 1.5°C world

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

## South Africa

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# Executive Summary

## Context

- South Africa has an abundant potential for wind and solar deployment. However, at present the electricity system is dominated by coal, which provided 83% of electricity generation in 2023.
- After the 2024 elections, a new South African government can set a new direction for the South African energy transition. This direction will also be needed as countries are requested to submit new 2035 climate targets to the UNFCCC in early 2025.
- In this report, we explore the level of wind and solar that South Africa 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

- South Africa's wind and solar generation needs to grow six to ten times by 2030 to align with 1.5°C, reaching 80–145 TWh of wind and solar.
- Almost 70 GW of wind and solar would be needed by 2030 (49 GW of solar and 16 GW of wind).
- A rapid rollout of renewables could help meet electricity demand and provide reliable, zero-carbon electricity to South Africans.
- However, it will require large-scale investment to help phase down coal power, accelerate renewables deployment, and drive grid expansion. International support will be key in supporting the energy transition via climate finance, some of which could be provided by the JETP.

# 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 **South Africa.**

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

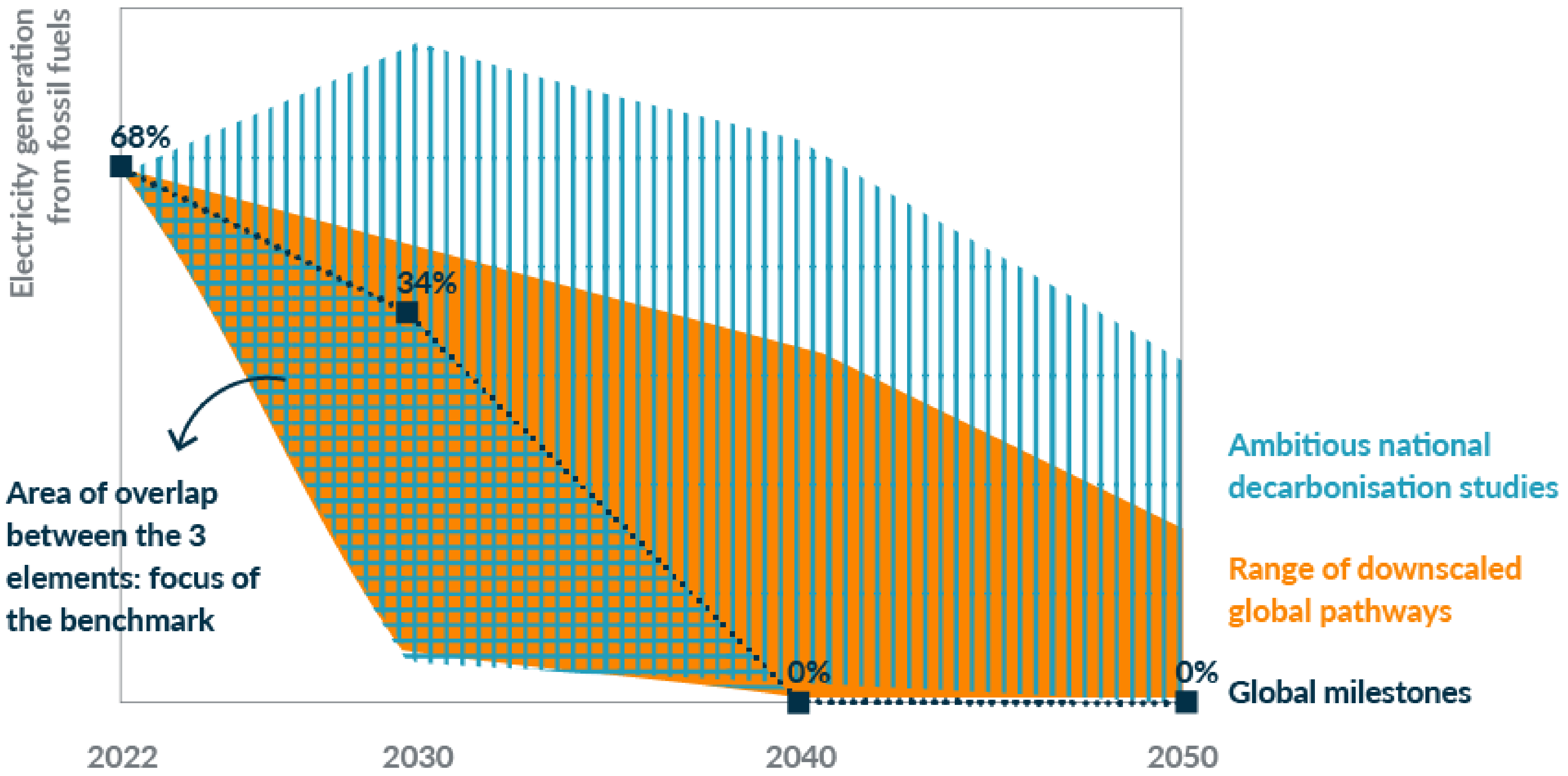
For more details see the Methods Annex

# 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



# 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

South Africa's current NDC is to cut emissions to the 350–420 $MtCO_2e$ range by 2030, a 19-32% reduction on 2010 levels excluding LULUCF. The country does not yet have a formal net zero target but has stated its intention to commit to a net zero $CO_2$ target for 2050.

South Africa's current renewable targets are to reach **8 GW of solar and 18 GW of wind by 2030**, as of the Integrated Resource Plan published in 2019.

Under current policies and market conditions, the IEA estimates that **solar capacity will reach 32.9 GW in 2028**, up from 6.4 GW of solar in 2022. Meanwhile, **wind capacity is projected to reach 6.5 GW in 2028**, up from 3.5 GW in 2022.

# Results

# Future electricity demand

Electricity demand is taken from the University of Cape Town's Energy Systems Research Group (ESRG) study exploring net zero pathways for South Africa. We take demand from the most ambitious pathway, which achieves net zero $CO_2$ emissions by 2050, and limits cumulative GHG emissions in South Africa to 6 $GtCO_2e$ over 2021-2050.

Total electricity generation in South Africa doubles by 2050 relative to 2022 levels, reaching 460 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 460 TWh to 750 TWh. This would affect the necessary growth of wind and solar significantly. Our demand estimate is at the lower end of that estimated by country-level studies. It was chosen partly the basis of stakeholder feedback, and partly because it represents the most recent study from a group of researchers inside South Africa, who have the best understanding of the demand context in the country*.

* Some other country-level studies reviewed are conducted by research groups from outside South Africa. While these still provide valuable information on the energy transition in South Africa, we prioritise the results from in-country modelling groups. For a full list of reviewed studies, see the Annex.

# 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 South Africa achieves a clean power system by 2045.

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

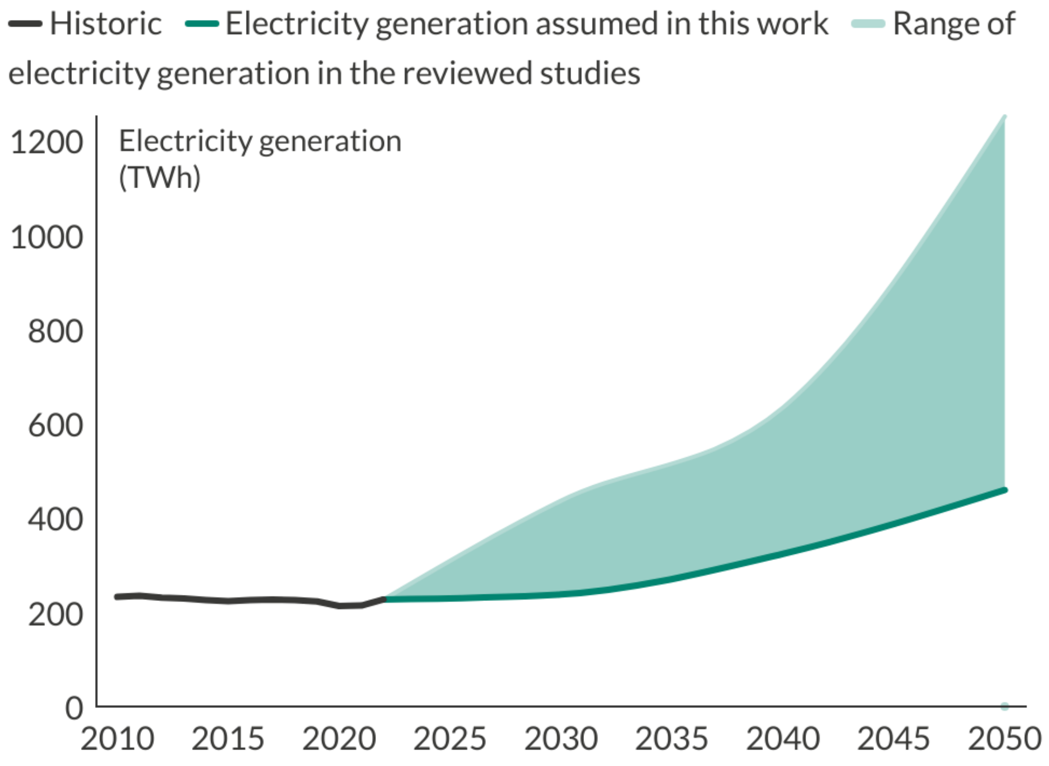
Fossil fuel generation falls by 38 to 71% between 2022 and 2030.

Phasing out fossil fuels while simultaneously meeting growing electricity demand will require substantial international support, including climate finance to help with the early retirement of existing coal-fired power plants

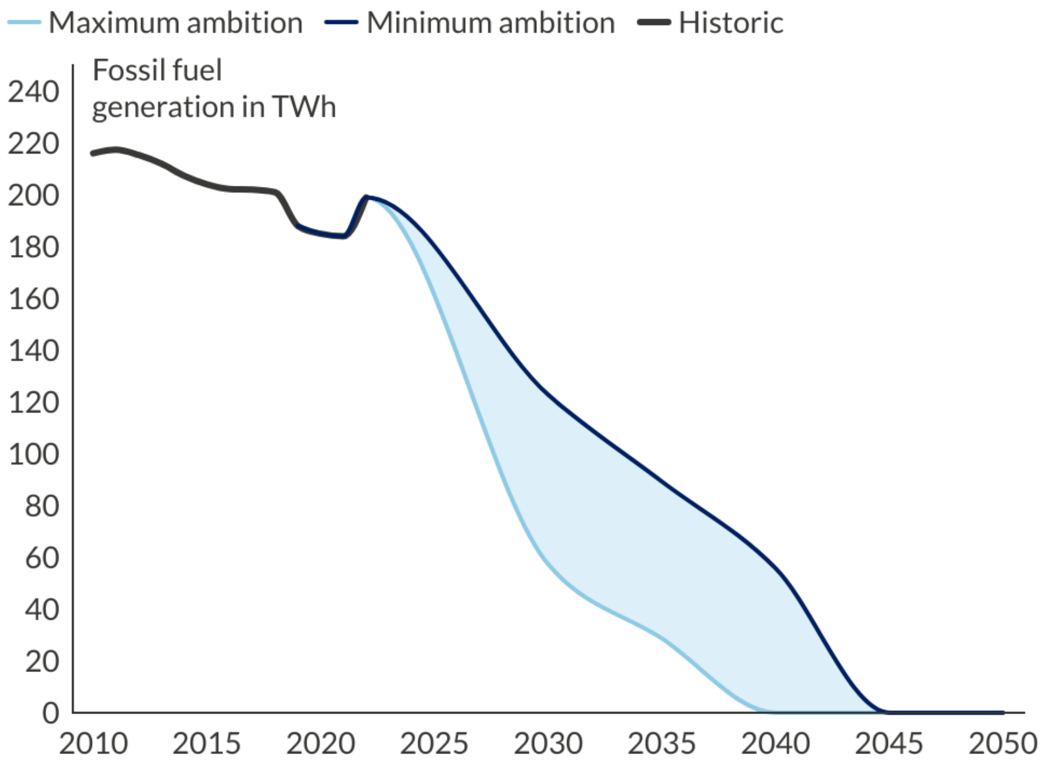
The fastest rate of fossil phase-out is set by the ESRG study.

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

## Electricity generation doubles in South Africa by 2050




## South Africa would need to achieve clean electricity by 2045



# 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 technologies (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 South Africa would reach 35 TWh by 2030 and 34 TWh by 2050. This is provided by a mix of nuclear, biomass and hydro-power.

* 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

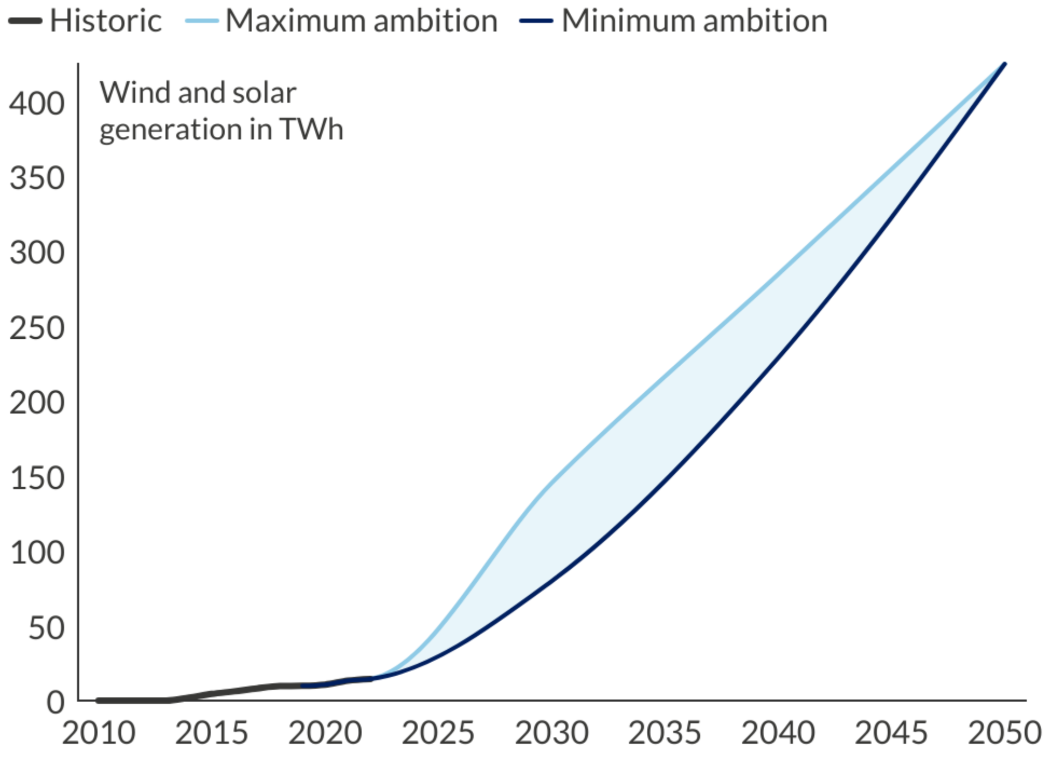
The wind and solar rollout necessary is then calculated by combining projected electricity demand growth, the fossil phase-out necessary to align with 1.5°C, and the assumed generation from other clean technologies.

To align with 1.5°C, wind and solar generation in South Africa would need to reach between 80 and 145 TWh by 2030. Generation in 2022 was 14 TWh. This is therefore a 6 to 10-fold growth in wind and solar.

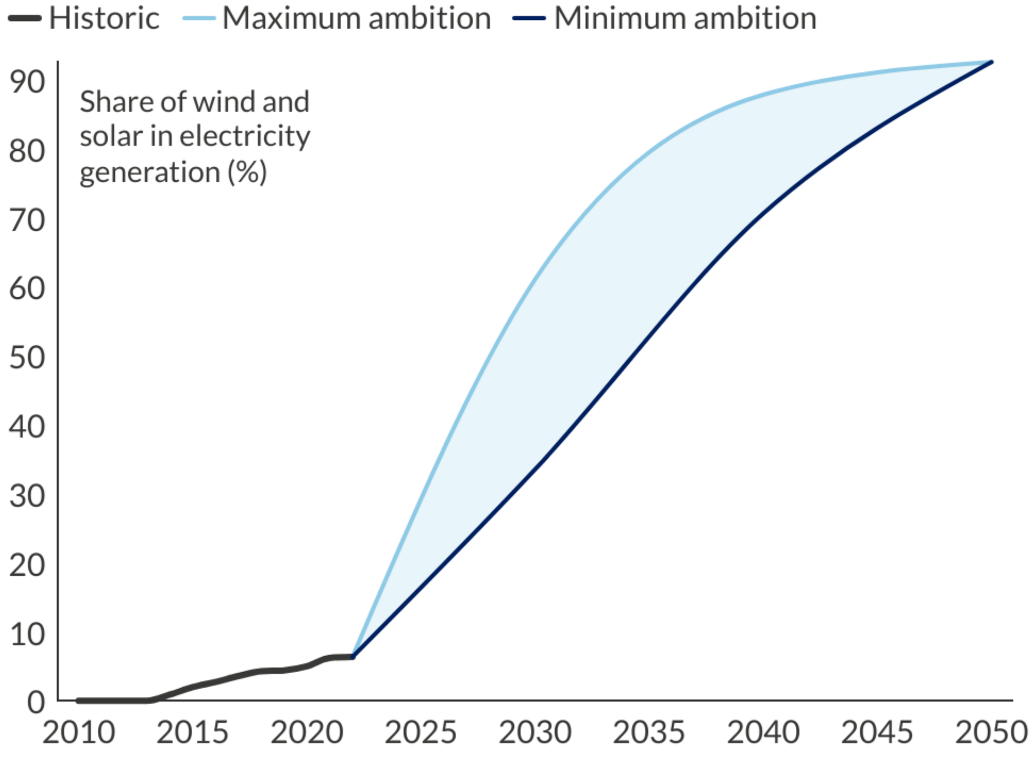
Wind and solar provides 34–61% of overall electricity generation in 2030, and 93% of overall generation in 2050.

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

## Wind and solar generation needs to grow 6-10x by 2030 relative to 2022 in South Africa




## Wind and solar would need to provide over 90% of electricity in South Africa 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 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, **South Africa would need to deploy almost 70 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 220 GW. 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 South Africa

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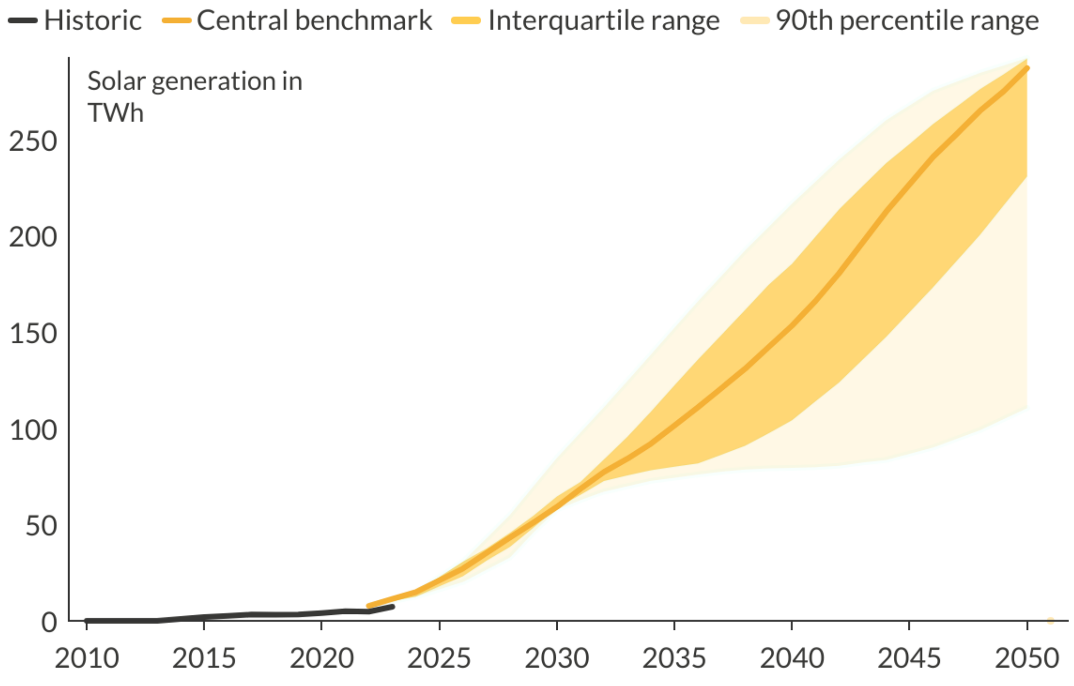
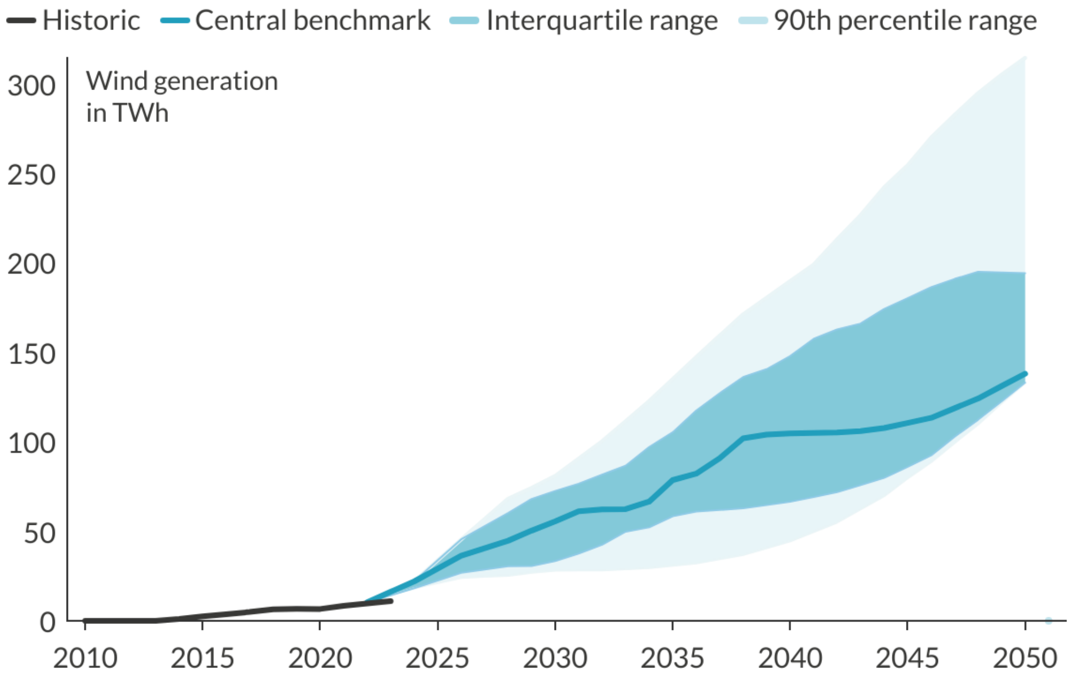
## Solar generation in South Africa would reach almost 290 TWh by 2050 in a 1.5°C-aligned transition




## Wind generation in South Africa would reach almost 140 TWh by 2050 in a 1.5°C-aligned transition



# South Africa needs to install almost 70GW of wind and solar by 2030 to align with 1.5°C

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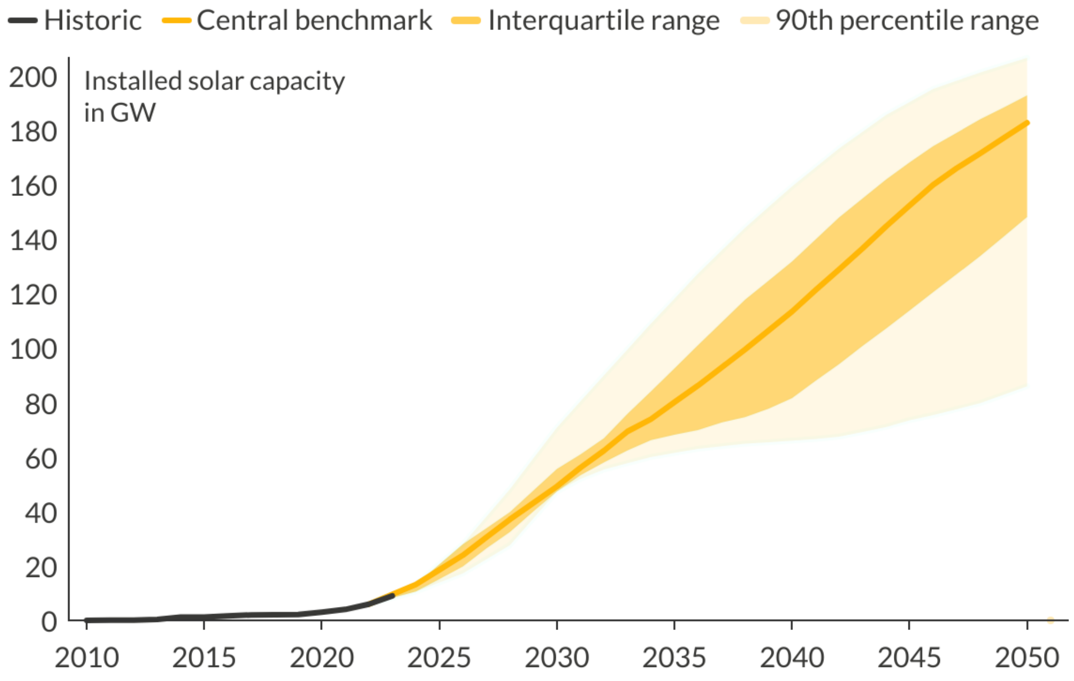
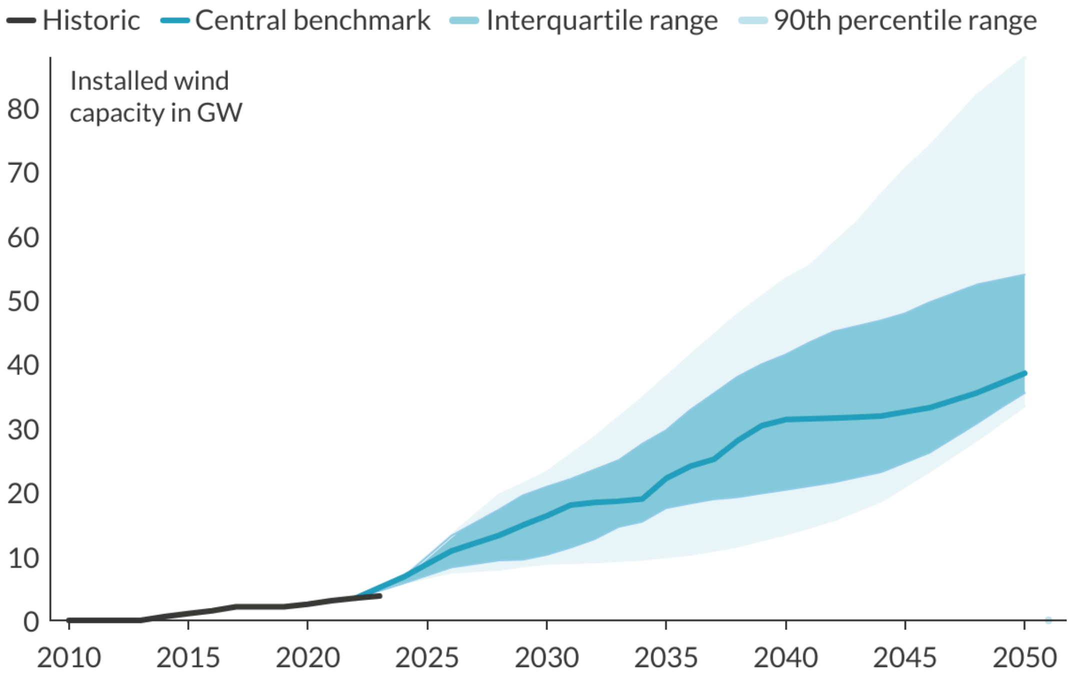
## Solar capacity would reach 49 GW in South Africa by 2030 in a 1.5°C-aligned scenario




## Wind capacity would reach 16 GW in South Africa 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 South Africa broadly aligns with the minimum level required to align with 1.5°C. However, to achieve the highest rates of fossil fuel phaseout, more wind and solar would need to be built, **with the most ambitious scenario installing over 70 GW of solar alone by 2030**. In comparison to the government's solar targets, at least 6 times more capacity needs to be build out.

Meanwhile, the target in the 2019 IRP of 18 GW of onshore wind is broadly 1.5°C aligned, but rollout is falling behind this level. Further action will be needed to drive wind deployment in South Africa at the pace needed.

# South Africa's solar rollout is broadly aligned with 1.5°C, but wind rollout needs to accelerate

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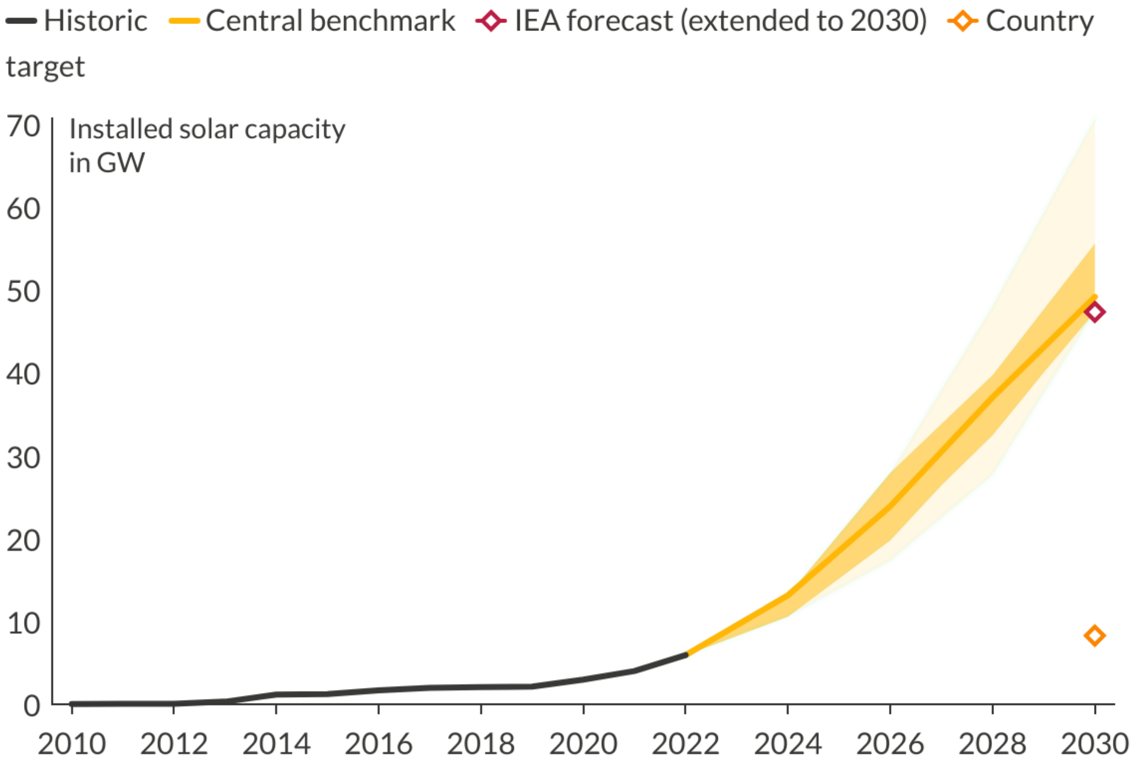
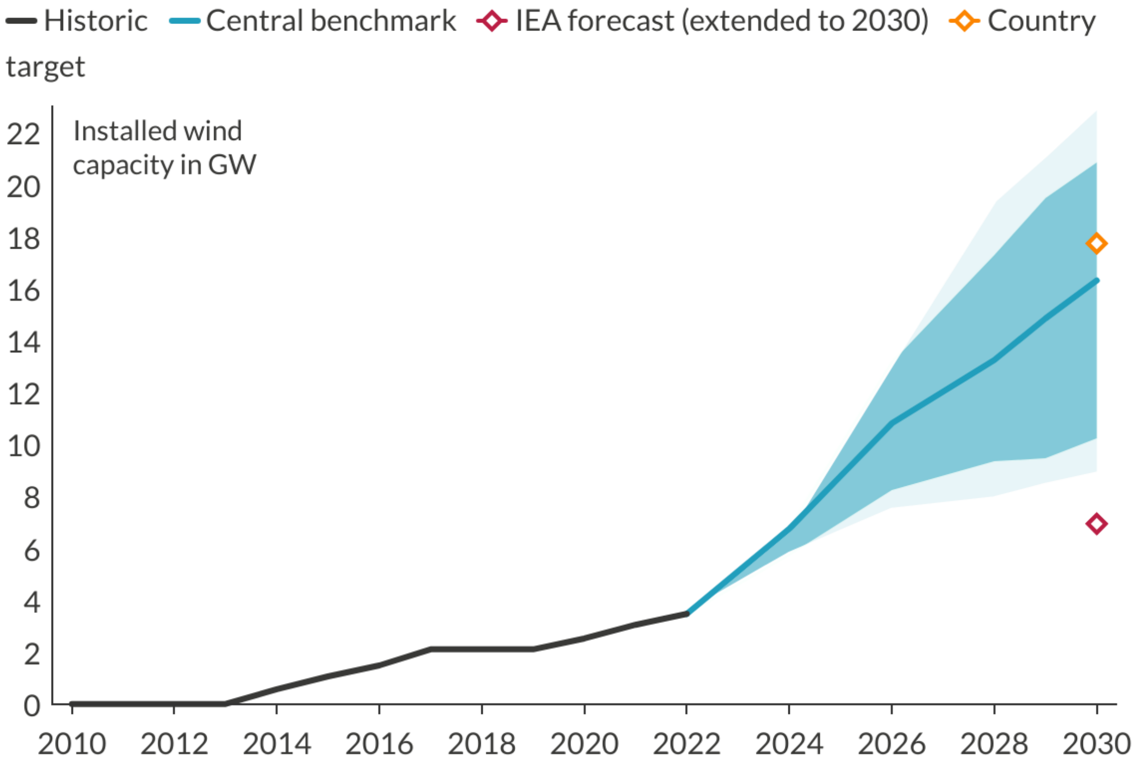
## Current rollout of solar in South Africa comes close to aligning with 1.5°C, but targets need updating




## The current wind capacity target in South Africa aligns with 1.5°C, but current rollout lags behind



# Wind and solar capacity additions in South Africa need to accelerate to align with 1.5°C

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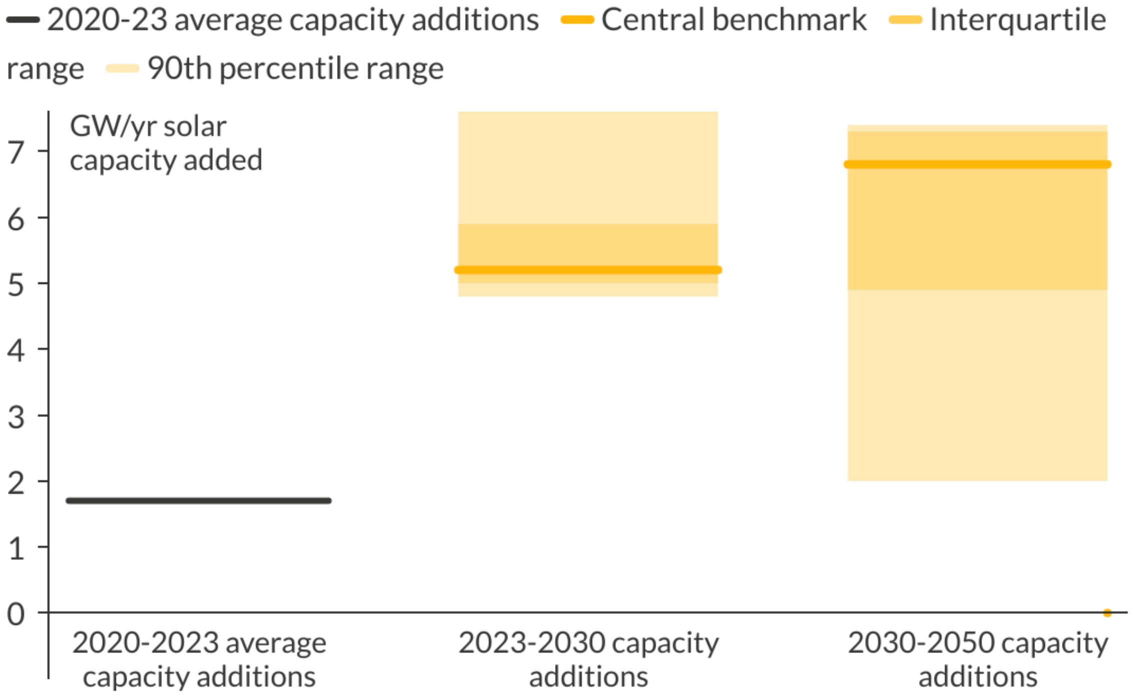
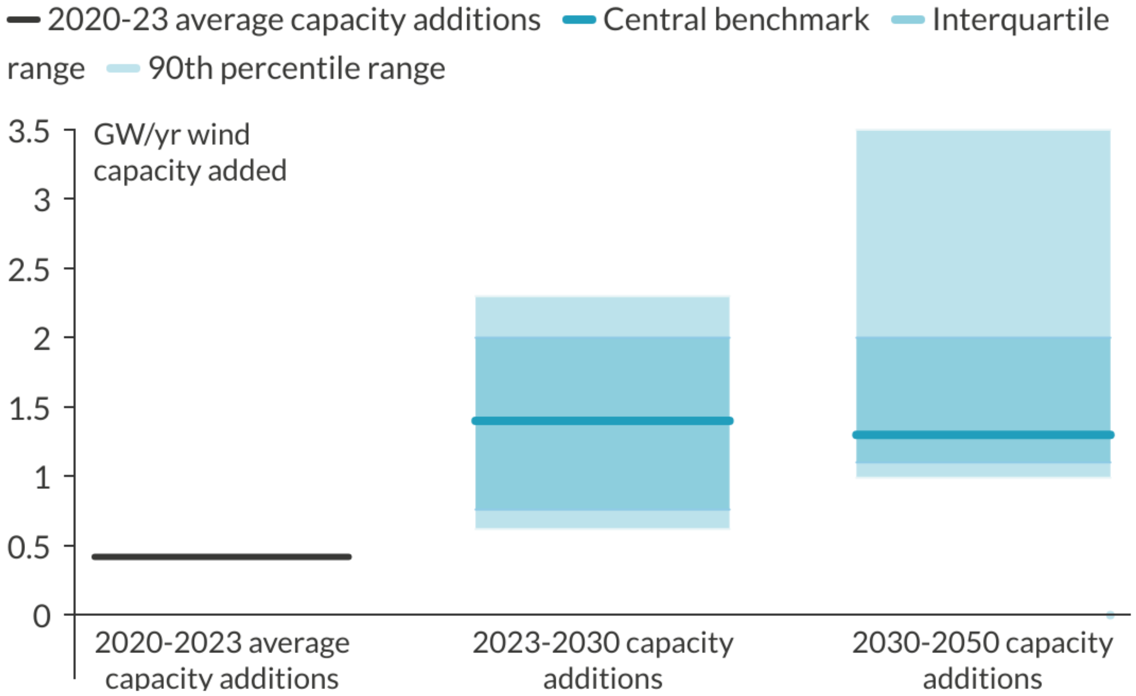
## South Africa would need to add on average 5.2 GW/yr of solar capacity until 2030, and 6.8 GW/yr by over 2030–2050.




## South Africa would need to add on average 1.4 GW/yr of wind capacity until 2030, and 1.3 GW/yr by over 2030–2050



# Wind and solar growth in the light of the JETP

Under the JETP, capacity in 2026 would reach:

- 7.7 GW for Wind
- 7.6 GW for Solar

This amounts to 30% (solar) and 70% (wind) of capacity under the central 1.5°C compatible benchmark scenario in 2026

The amount of financing needed amounts to 233 billion ZAR for solar and 242 billion ZAR for wind. The financing sources needed are mainly commercial loans

JETP includes however a significant amount of other resources (including grants) to enable this development from various ends.

This highlights that efforts should be focused on implementation and scaling can only be achieved if significant amount of international support are provided.

# Comparison with other studies

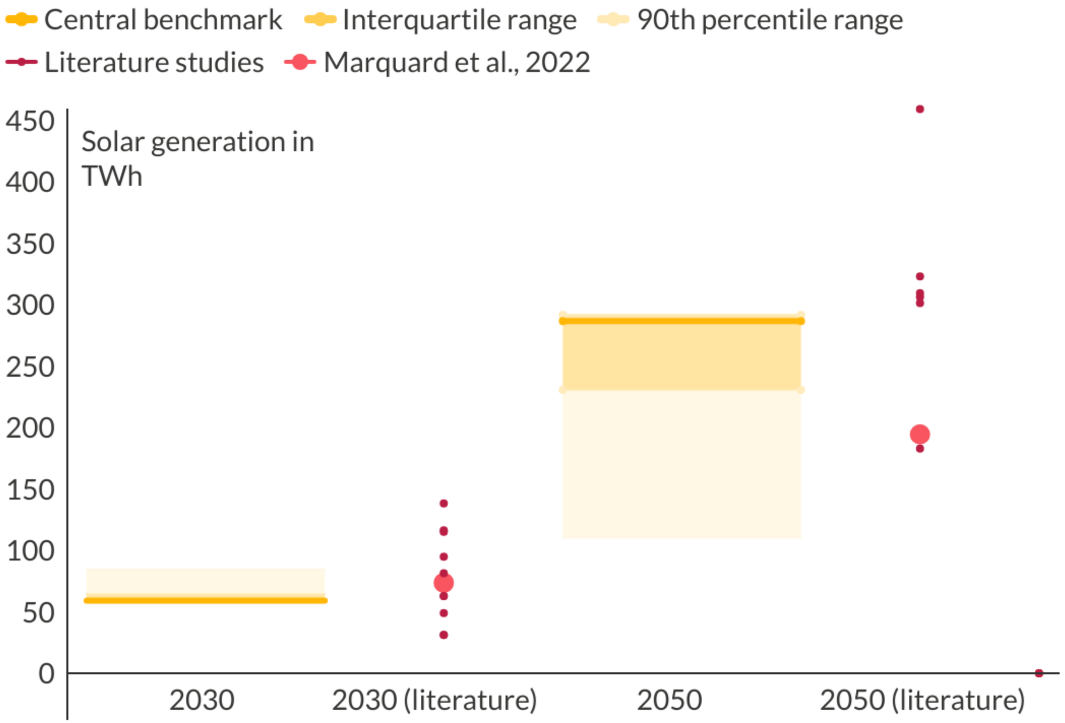
We compare the wind and solar generation seen in our analysis to that in the literature review of country-level studies. In particular, we highlight the results of modelling from the University of Cape Town, exploring net zero pathways for South Africa.

We see that the solar generation that our method produces is broadly within the range of the national literature, while the central wind generation benchmark is slightly below the range of national literature.

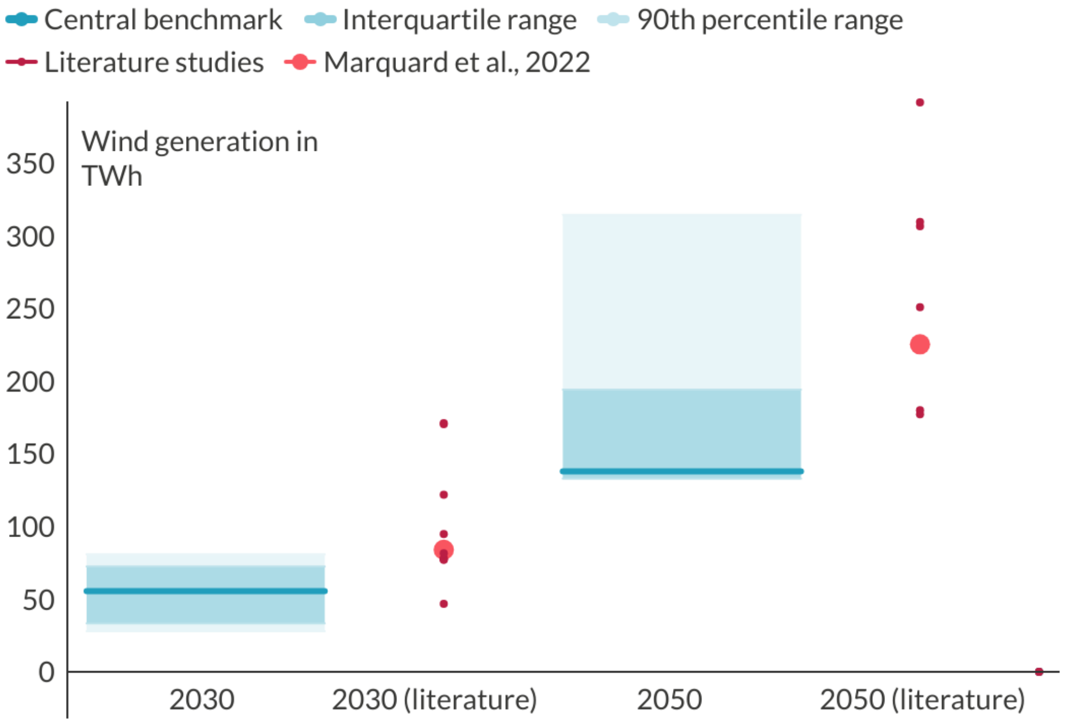
Our analysis currently shows higher solar generation and less wind generation than the study highlighted from University of Cape Town, particularly by 2050. Wind capacity deployment in South Africa likely faces greater challenges than solar capacity, due to grid constraints which are particularly strong in areas of high wind potential.

# Our benchmarks are broadly aligned with the literature

## Electricity generation from solar: comparison with literature in South Africa




## Electricity generation from wind: comparison with literature in South Africa



# In South Africa, our benchmarks generally suggest that solar will provide more generation than wind

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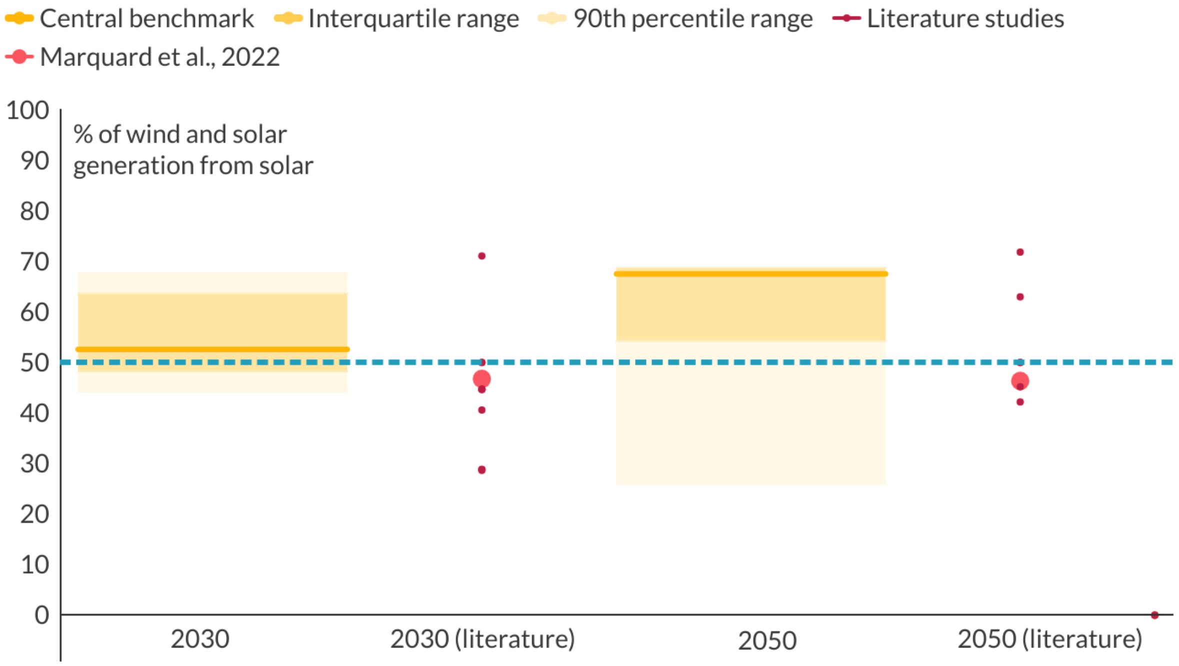
## In South Africa, our benchmarks generally suggest that solar will provide more generation than wind

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 | 8 | 59 | 100 | 150 | 290 |
| Central 1.5°C benchmark | Wind generation | TWh | 10 | 56 | 79 | 110 | 140 |
| Central 1.5°C benchmark | Solar capacity | GW | 6 | 49 | 80 | 110 | 180 |
| Central 1.5°C benchmark | Wind capacity | GW | 3 | 16 | 22 | 31 | 39 |

# 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.*, 2019 | Pathway towards achieving 100% renewable electricity by 2050 for South Africa | Best Policy Scenario |
| Hanto *et al.*, 2021 | Effects of decarbonization on the energy system and related employment effects in South Africa | 2°C scenario |
| IRENA, 2020 | Renewable Energy Prospects: South Africa | REmap case |
| IEA, 2022 | Africa Energy Outlook 2022 | Sustainable Africa Scenario |
| CSIR, 2017 | Long-term electricity sector expansion planning: A unique opportunity for a least cost energy transition in South Africa | Decarbonised (conservative costs) |
| Marquard *et al.*, 2022 | Exploring net zero pathways for South Africa - An initial study | Net Zero – 6 Gt GHG budget – 45 $MtCO_2$ /yr sink |
| 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

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# 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

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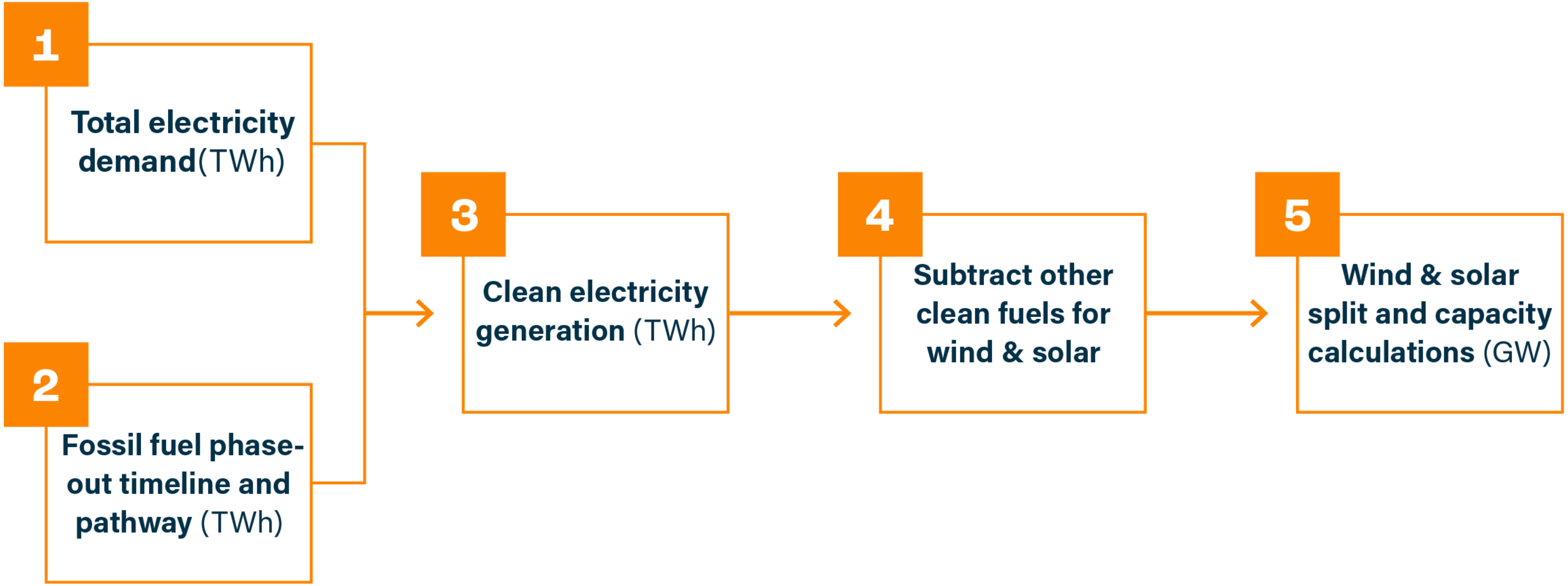
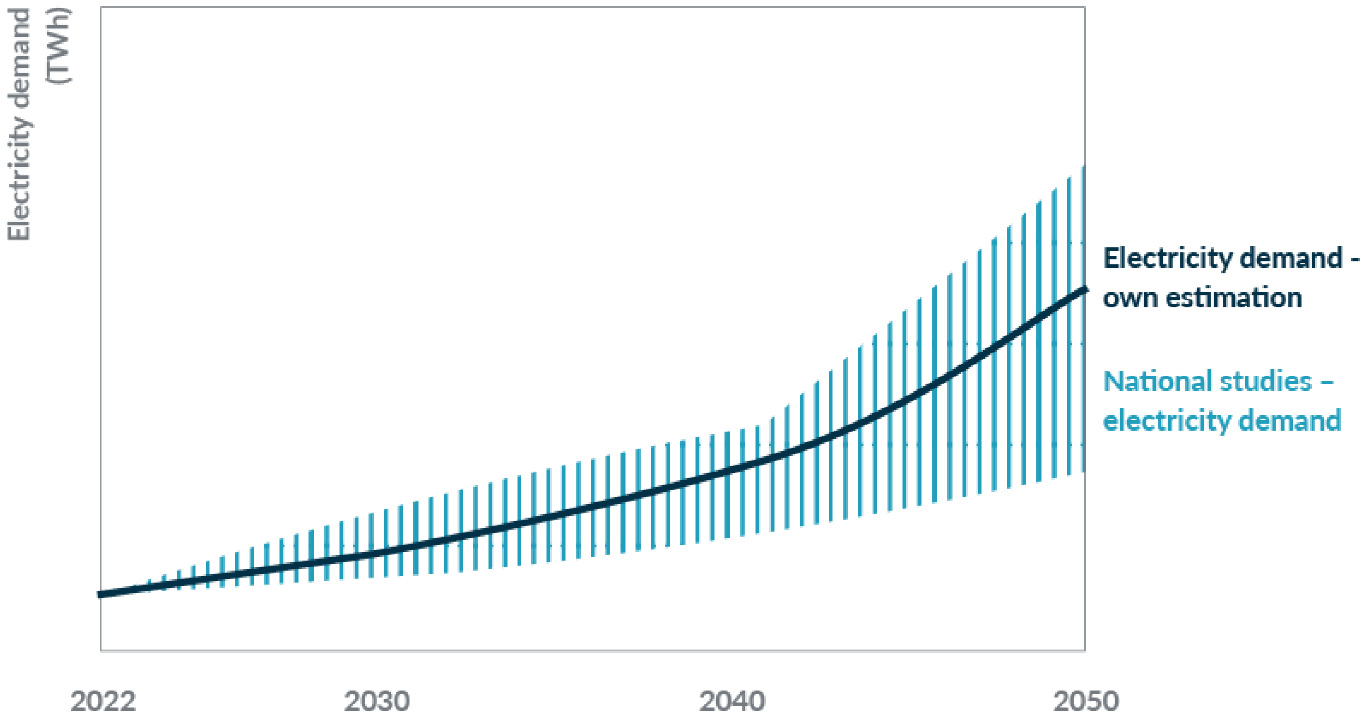



For more details see the Methods Annex

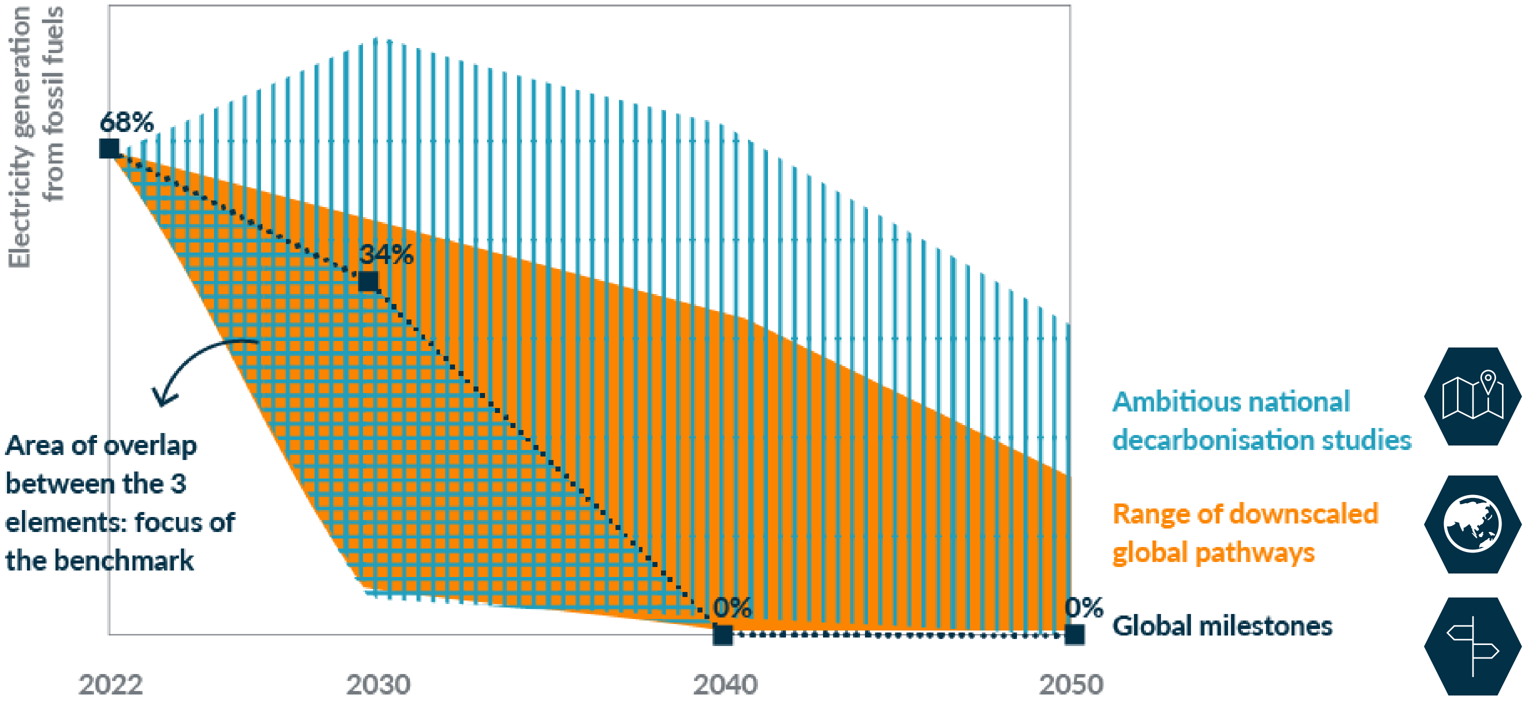
# 1 Total electricity generation

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.



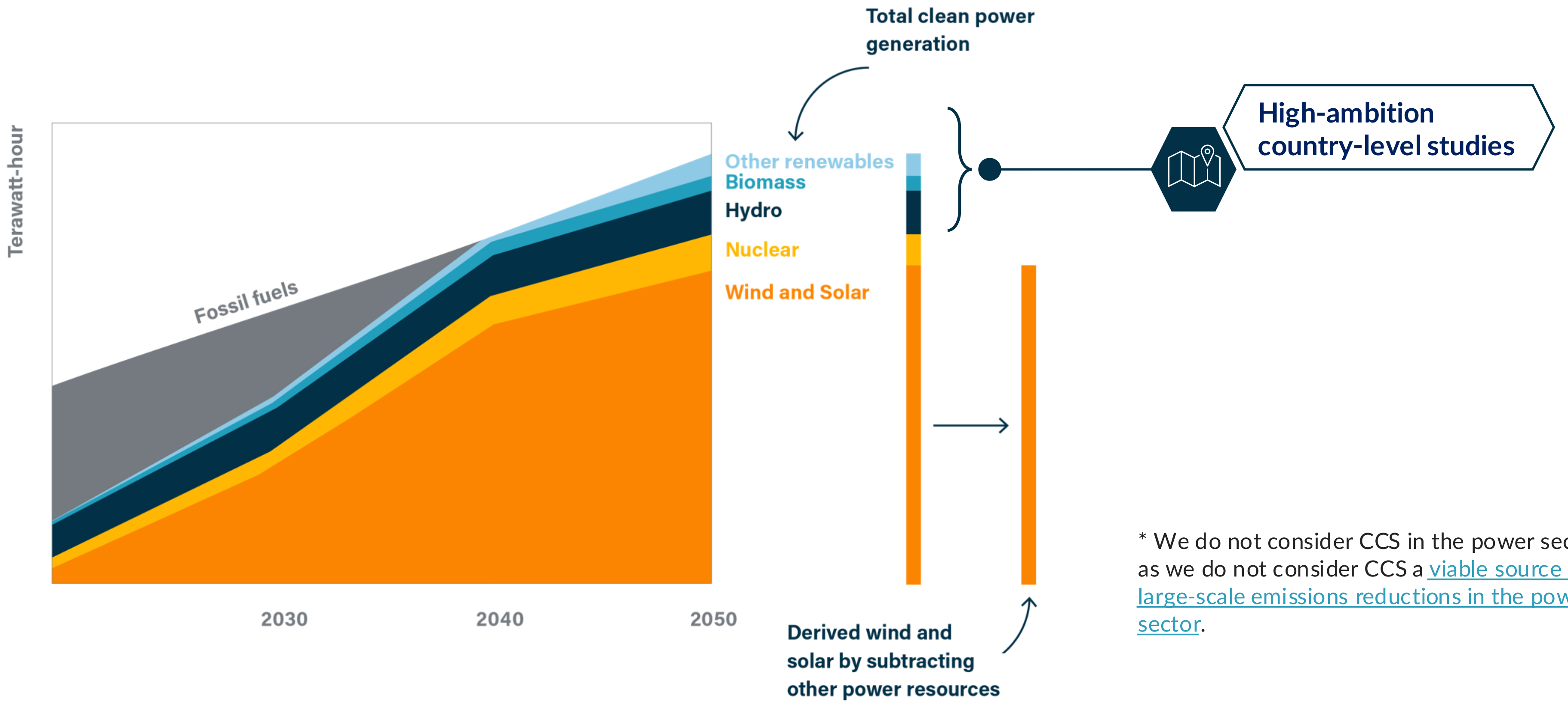
# 2 Fossil fuel phase-out

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

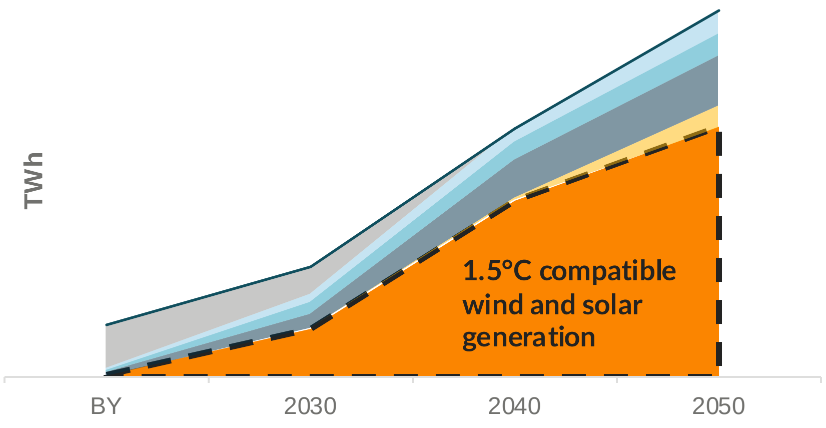
1. We use a detailed geospatial **renewable potential analysis** to calculate the technical potential of each technology in the country. We then feed the wind and solar generation required into a power system model calibrated to these potentials.
2. We force the model to deploy at least the level of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

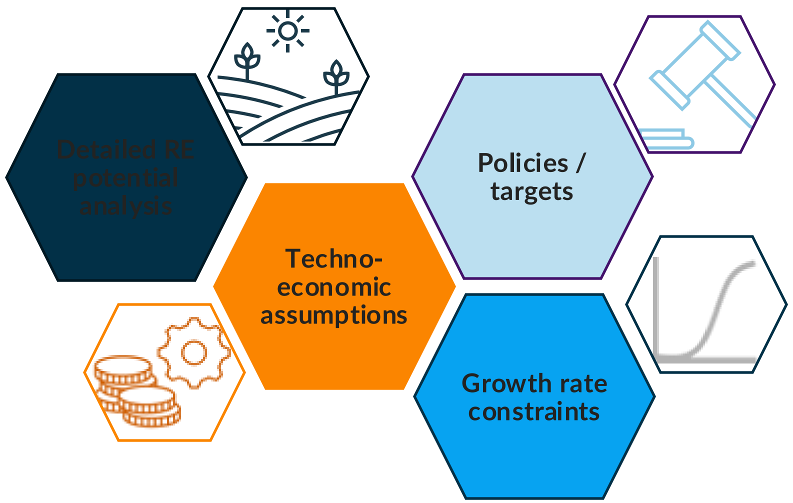
1.5°C compatible wind and solar generation (steps 1-4)

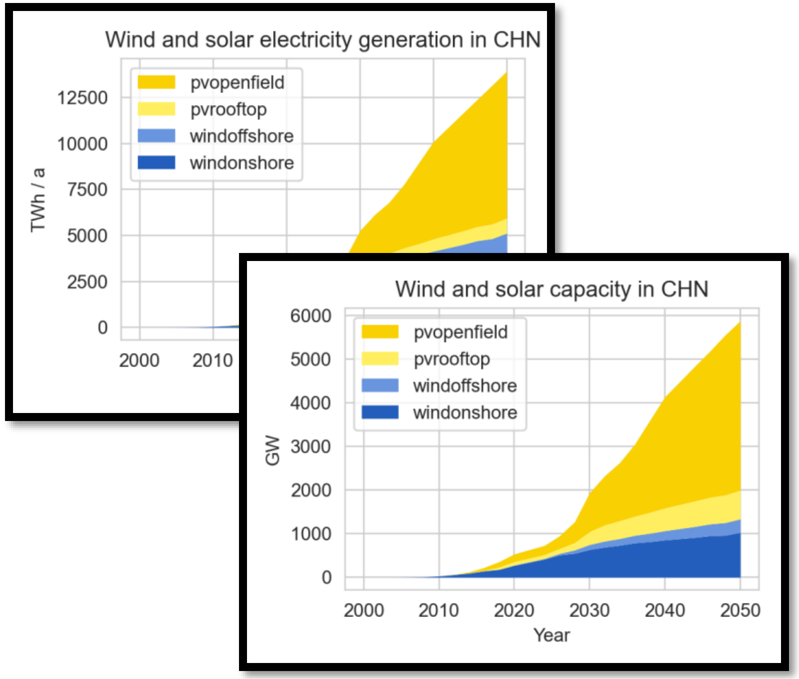
RE potential and power system analysis

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<br>• Wind = 16% per year<br>• Solar = 33% per year<br>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. |