Wind and solar benchmarks for a 1.5°C world

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

Indonesia

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Executive Summary

Context

- In 2022, 80% of Indonesia's electricity was sourced from fossil fuels. Per capita emissions were below the global average.
- With rising electricity demand over the past two decades – growing 7% annually from 2015 to 2019 – the country has turned to coal and gas to meet its energy requirements.
- Hydro is the main clean energy source in the power mix (8%). Wind and solar contributed only 0.2% in 2023.
- Indonesia targets a 34% RE share in its power mix by 2030 under its Just Energy Transition Partnership (JETP), with power emissions peaking at 250 $MtCO_2$ by 2030 and reaching net-zero by 2050. However, this excludes a significant off-grid captive coal pipeline.
- As the country significantly increases its wind and solar capacities, its archipelago nature may pose challenges for integrating high shares of variable renewable energy (VRE).
- This report examines the wind and solar capacity installation Indonesia needs for a 1.5°C compatible pathway, aligning with the goal of tripling renewables by 2030

Key findings

- For Indonesia to meet electricity demand growth while transitioning away from fossil fuels, 77 GW of solar and 29 GW of wind by 2030 is needed.
- Electricity demand is expected to increase by 1.4x in 2030, 3.2x in 2040, and 4.5x in 2050, compared to 2022 levels. Wind and solar (alongside other renewables such as geothermal) can help meet the growing demand – 115 TWh of solar and 100 TWh of wind are needed by 2030.
- Indonesia has enough wind and solar potential to drive the transition. By 2050, around two-thirds of electricity could be provided by wind and solar.
- Meeting captive electricity demand from industrial sites would further boost the need for wind and solar and, consequently, additional international financial support.
- While our modelling finds solar power will generate more electricity than wind, our results indicate a more balanced split between wind and solar compared to country-level studies, which show a significant emphasis on solar power alone.

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 **Indonesia.**

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

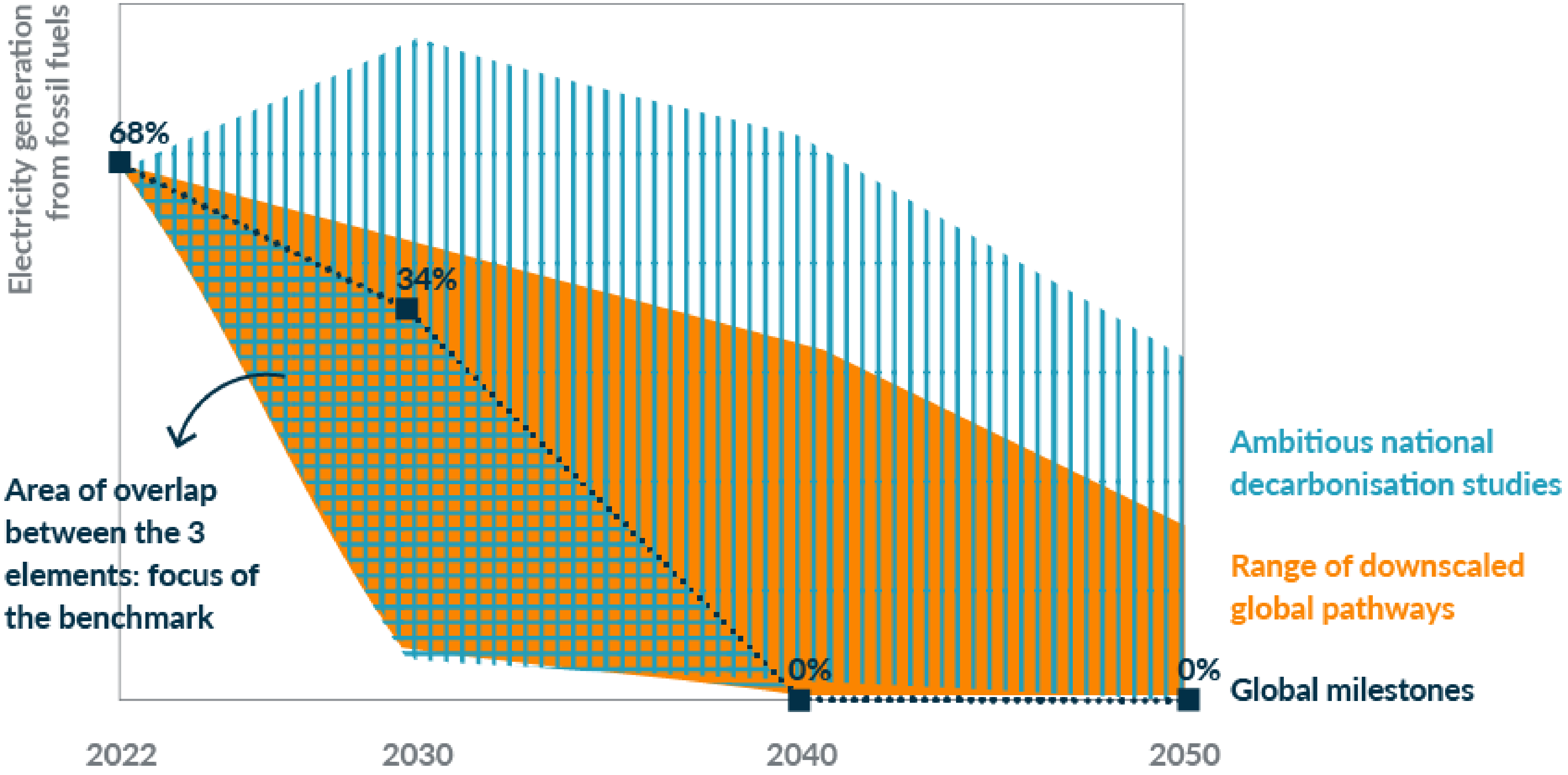
For more details see the Methods Annex

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

Indonesia's unconditional NDC target aims to cut emissions by 29-32% below the 2030 BAU scenario, reaching 1805 $MtCO_2e$ in 2030 (excl. LULUCF), which is **148% above the 2010 levels**. The country is updating its 2035 NDC, which is expected to include a net-zero GHG target by 2060.

Indonesia's current renewable targets are to reach **29 GW of solar and 9 GW of wind by 2030**, as per the Just Energy Transition Partnership (JETP) Indonesia from in 2023.

Under current policies and market conditions, the IEA estimates that **solar capacity will reach 8.8 GW in 2028**, up from 0.3 GW of solar in 2022. Meanwhile, **wind capacity is projected to reach 0.7 GW in 2028**, up from 0.2 GW in 2022.

The archipelago nature of the country could pose challenges to integrating a high share of variable renewable energy. Additionally, a realistic decarbonization pathway must also address captive coal plans, requiring significant additional deployment of renewable energy to meet off-grid electricity demand in the industry sector.

Results

Future electricity demand

Electricity demand is taken from the IEA's study "An Energy Sector Roadmap to Net Zero Emissions in Indonesia" exploring net zero pathways for Indonesia. We take demand from the pathway which achieves net zero CO_2 emissions by 2050. Total electricity demand grows strongly out to 2050, driven by economic development and increased electrification.

This scenario excludes the potential rise of new off-grid coal plants to power heavy industrial facilities, particularly for critical mineral processing. Including this demand would increase the need for wind and solar capacity, requiring additional international financial support.

Future electricity demand growth in Indonesia is highly uncertain: the IEA's net zero scenario for Indonesia only reaches 1700 TWh in 2050, while in the IRENA 1.5°C scenarios, electricity demand reaches 2300-2500 TWh.

There is a significant range in the studies in terms of the expected electricity generation in 2050 ranging from 950 TWh to 2900 TWh. This would affect the necessary growth of wind and solar significantly. Our demand estimate is in the middle of that estimated by country-level studies

Pace of fossil phaseout needed

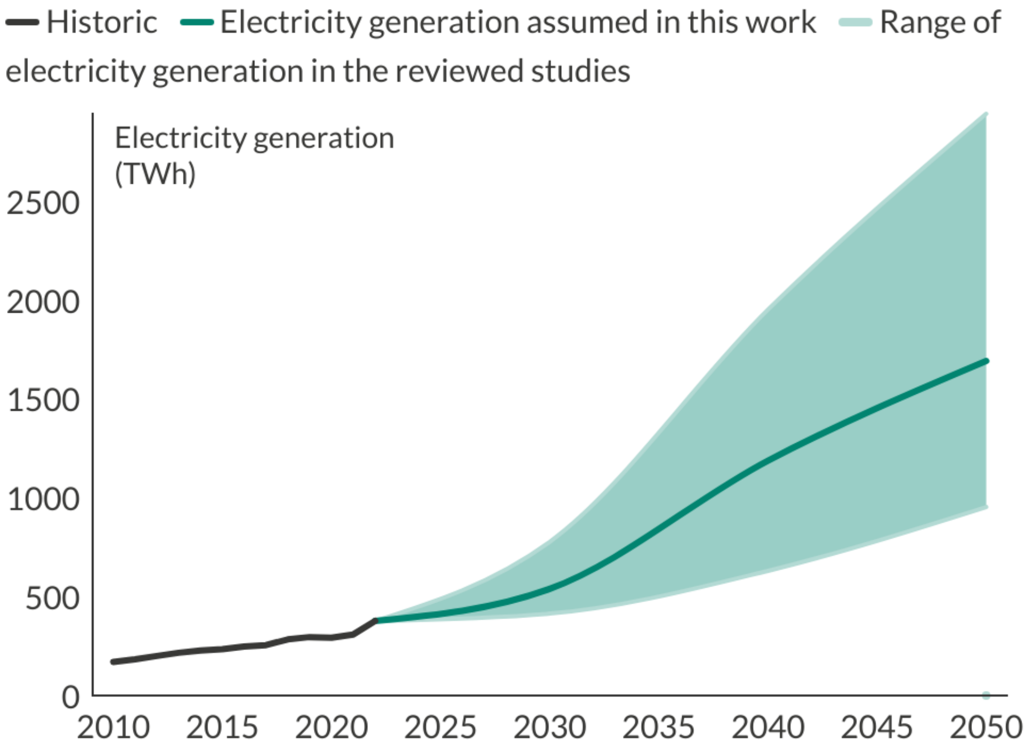
The rate of fossil phase-out is set by the overlap between country-level studies, downscaled 1.5°C compatible global pathways and the global milestones of the IEA's Net Zero roadmap, in which Indonesia achieves a clean power system by 2045.

To align with 1.5°C, fossil fuels must exit the Indonesian power sector during the 2040s. Fossil fuel generation falls by 25-46% by 2030, compared to 2022 levels

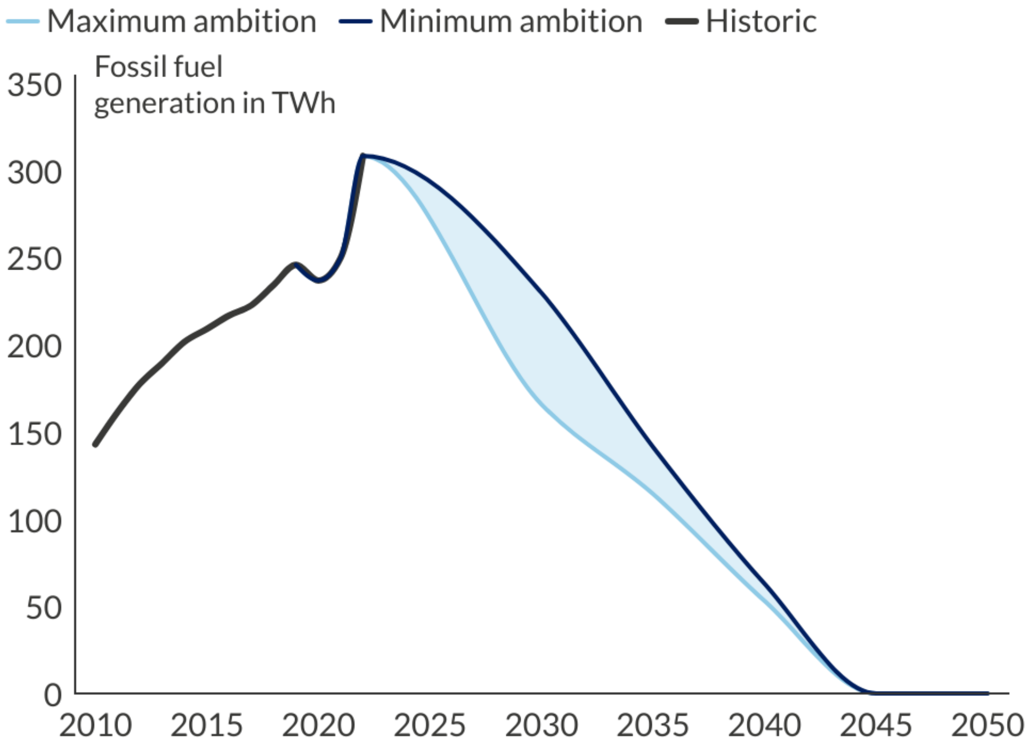
The fastest rate of fossil phase-out is set by the IEA's net zero by 2050 scenario for Indonesia.

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

Electricity generation grows more than four times in Indonesia over 2022–2050



Indonesia 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 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 Indonesia would reach 135 TWh by 2030 and 624 TWh by 2050. This is provided by other renewables such, particularly geothermal and hydropower, with a smaller contribution from biomass. There is no nuclear deployment assumed in these benchmarks.

Flexible zero-carbon generation from other renewables can help balance wind and solar generation, and support integrating them into the grid.

* 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

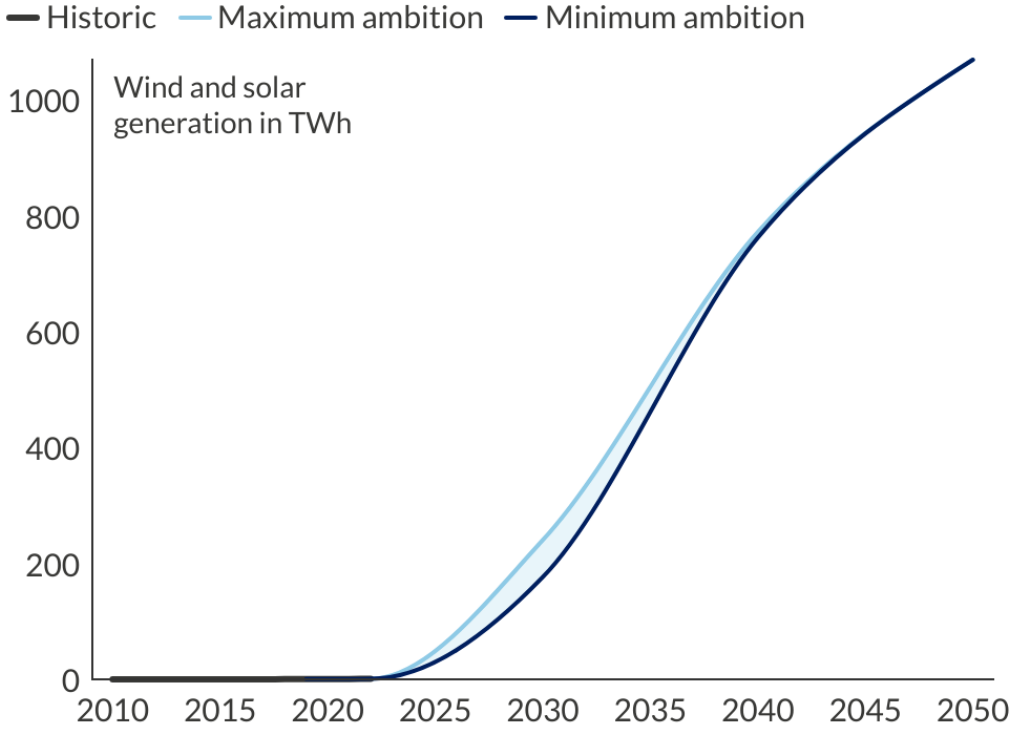
The wind and solar rollout necessary is then calculated by combining projected electricity demand growth, the fossil phase-out necessary to align with 1.5°C, and the assumed generation from other clean technologies.

Wind and solar is then needed to meet electricity demand growth and to drive the phaseout of fossil fuels.

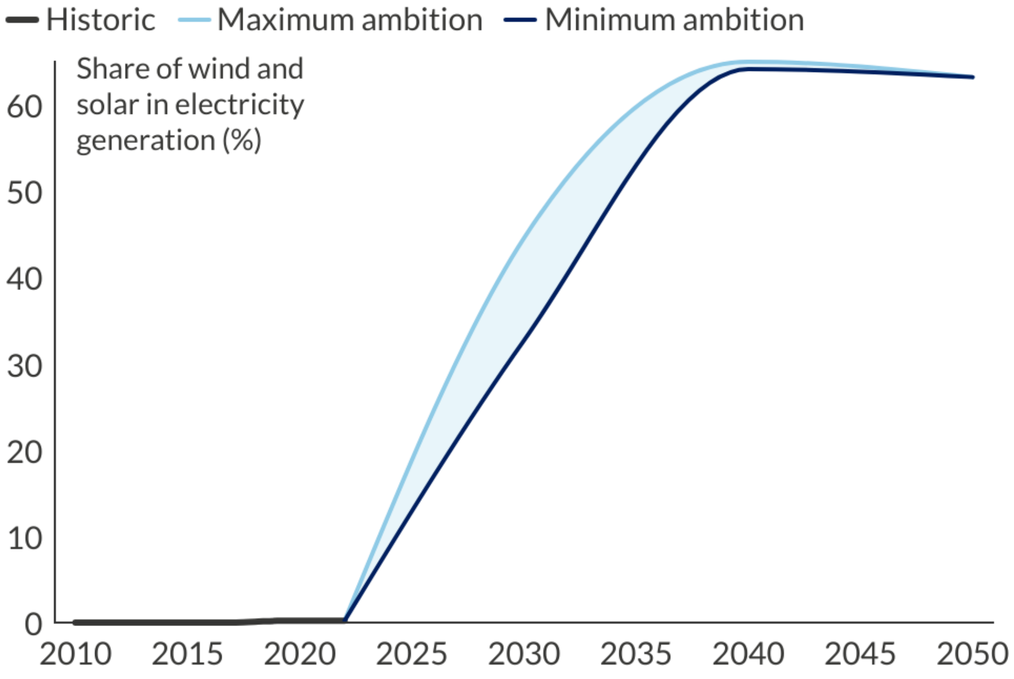
To align with 1.5°C, wind and solar generation in Indonesia would need to reach 176–240 TWh by 2030. Wind and solar provides 33–45% of overall electricity generation in 2030, and 63% of overall generation in 2050.

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

Wind and solar generation needs to grow to around 200 TWh by 2030 in Indonesia



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



Possible splits into wind and solar

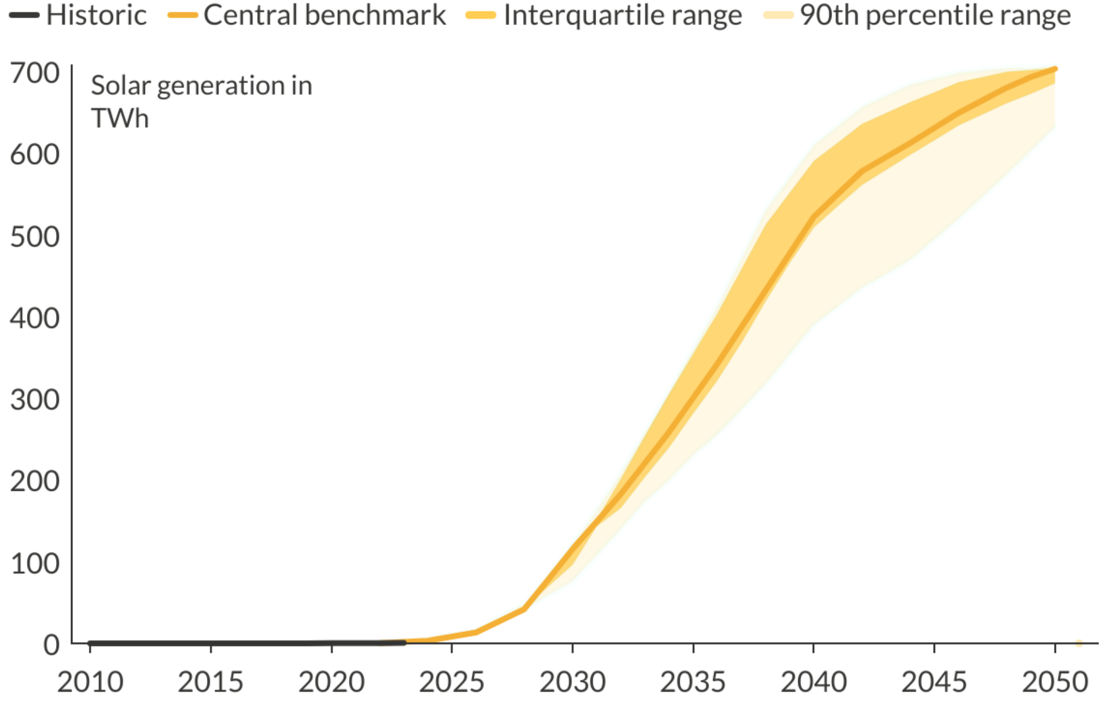
The relative share of wind and solar deployment will vary depending on how various factors develop in the future. We explore one key uncertainty, the relative cost of solar and wind electricity generation (see methods). When accounting for this uncertainty, we see a range of possible future generation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

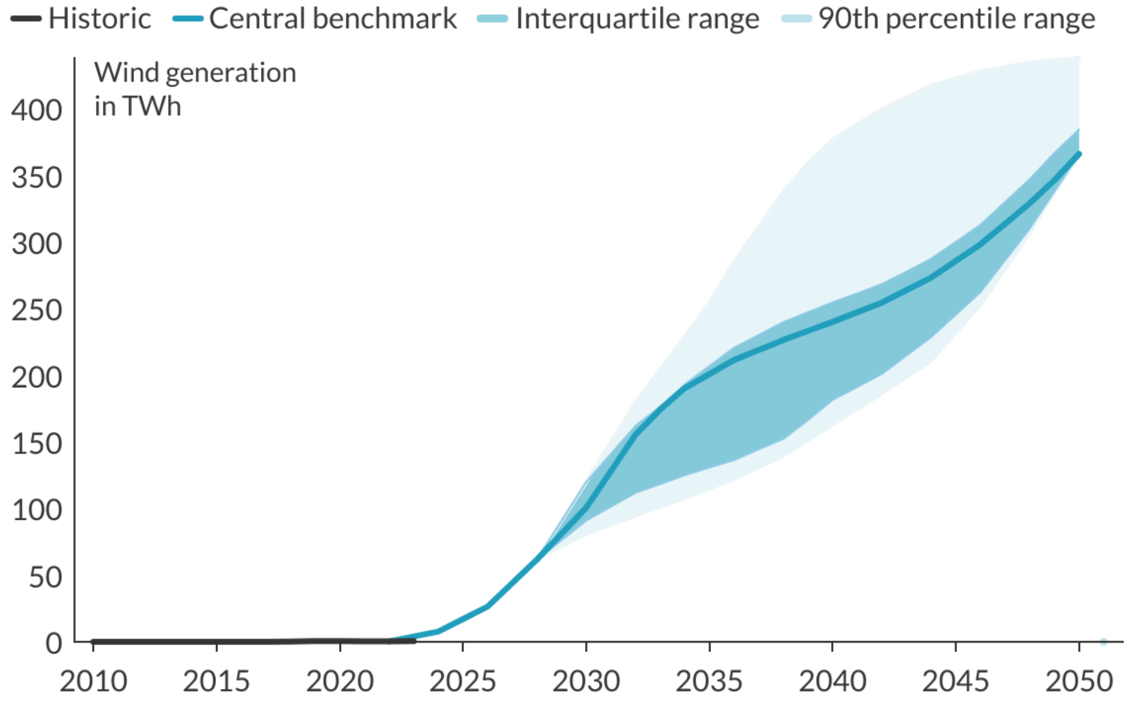
In this scenario, **Indonesia would need to deploy around 107 GW of wind and solar by 2030 to limit warming to 1.5°C**. **By 2050, total wind and solar capacity would need to reach over 730 GW**. Due to its higher capacity factor, greater wind deployment would reduce total capacity requirements. In Indonesia, solar is generally the dominant form of generation over wind.

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

Solar generation in Indonesia would reach around 700 TWh by 2050 in a 1.5°C-aligned transition



Wind generation in Indonesia would reach over 350 TWh by 2050 in a 1.5°C-aligned transition



Indonesia needs to install almost 110 GW of wind and solar by 2030 to align with 1.5°C

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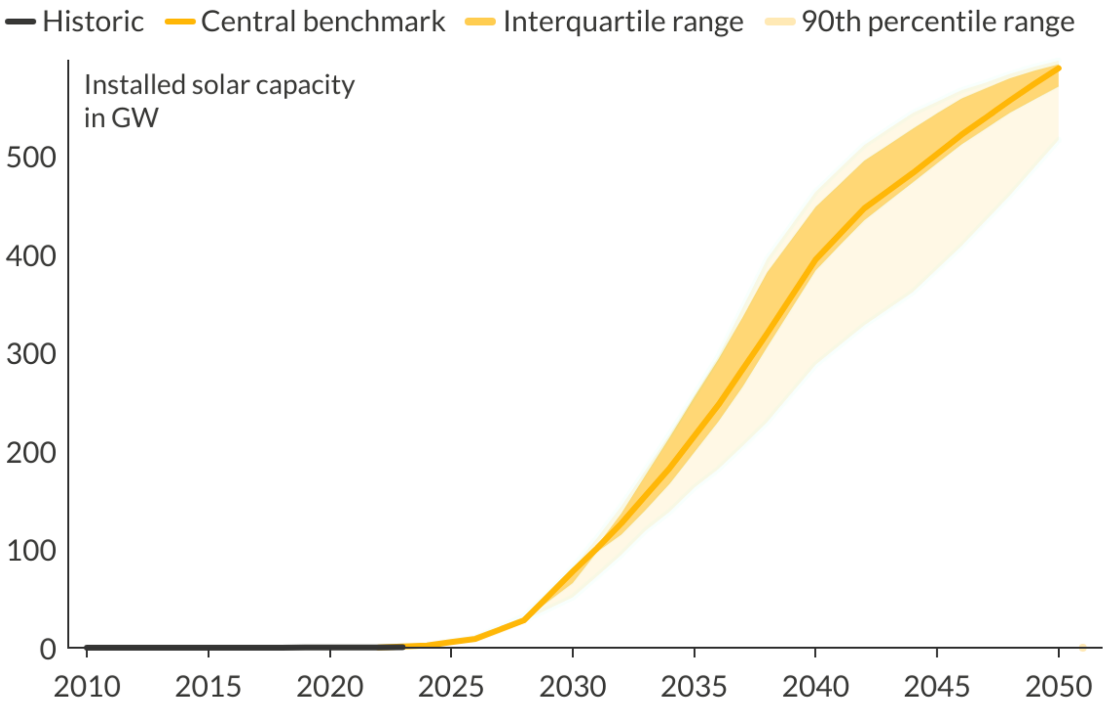
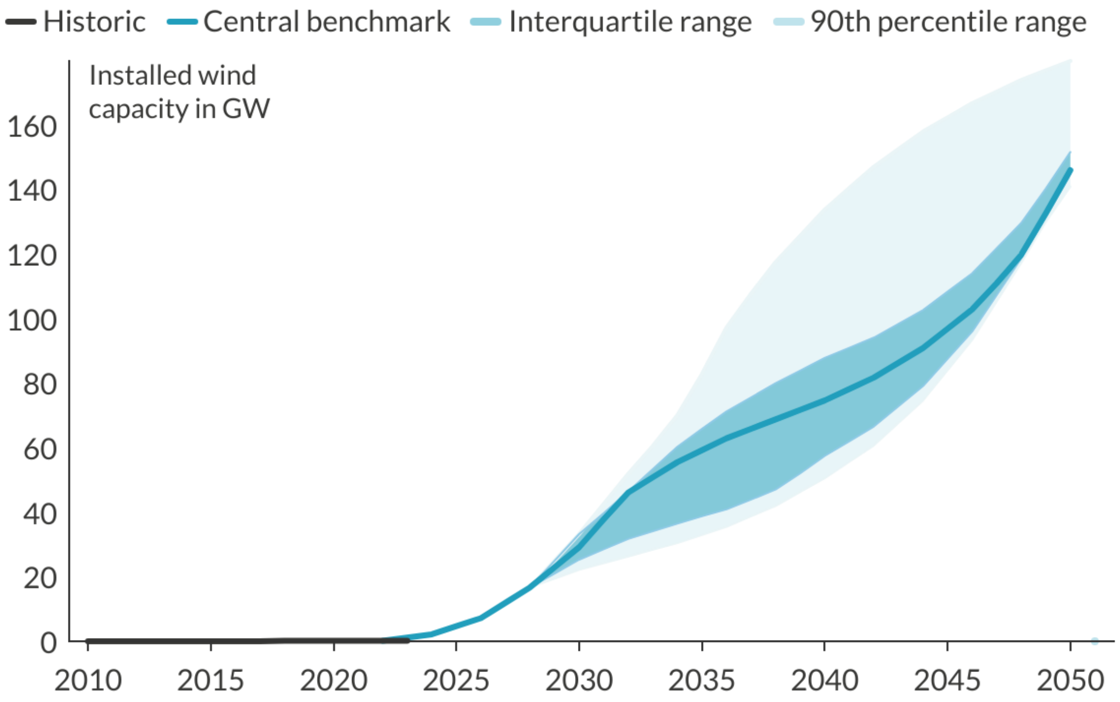
Solar capacity would reach 77 GW in Indonesia by 2030 in a 1.5°C-aligned scenario



Wind capacity would reach 29 GW in Indonesia by 2030 in a 1.5°C-aligned scenario



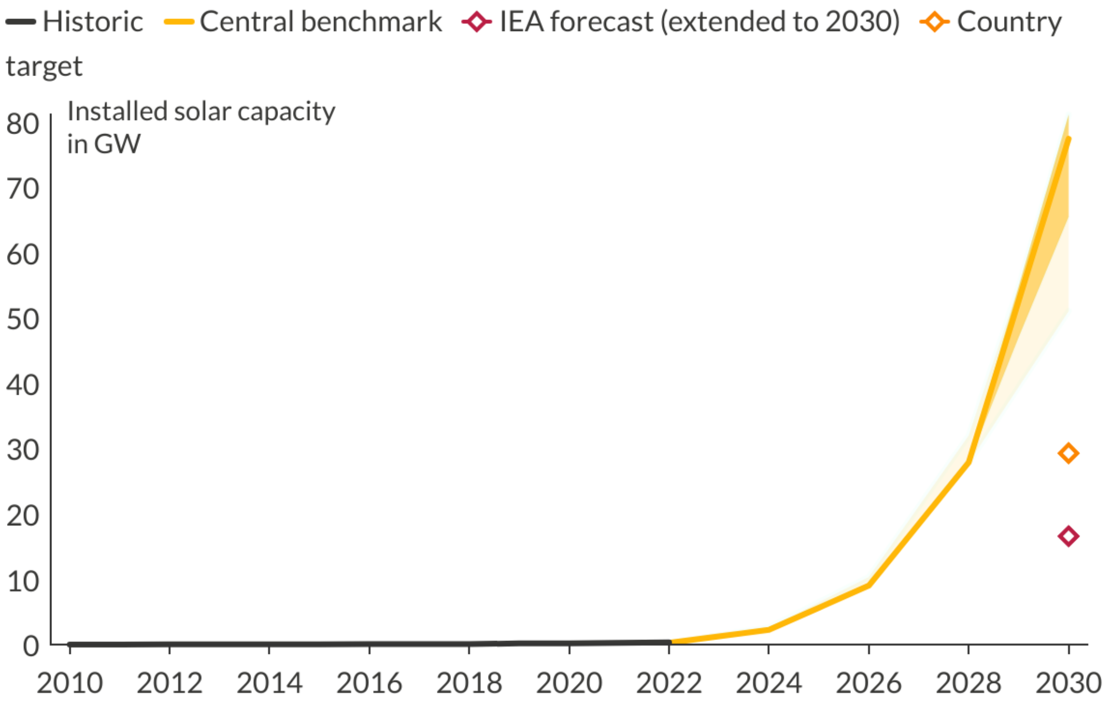
Comparison to current rollout

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.

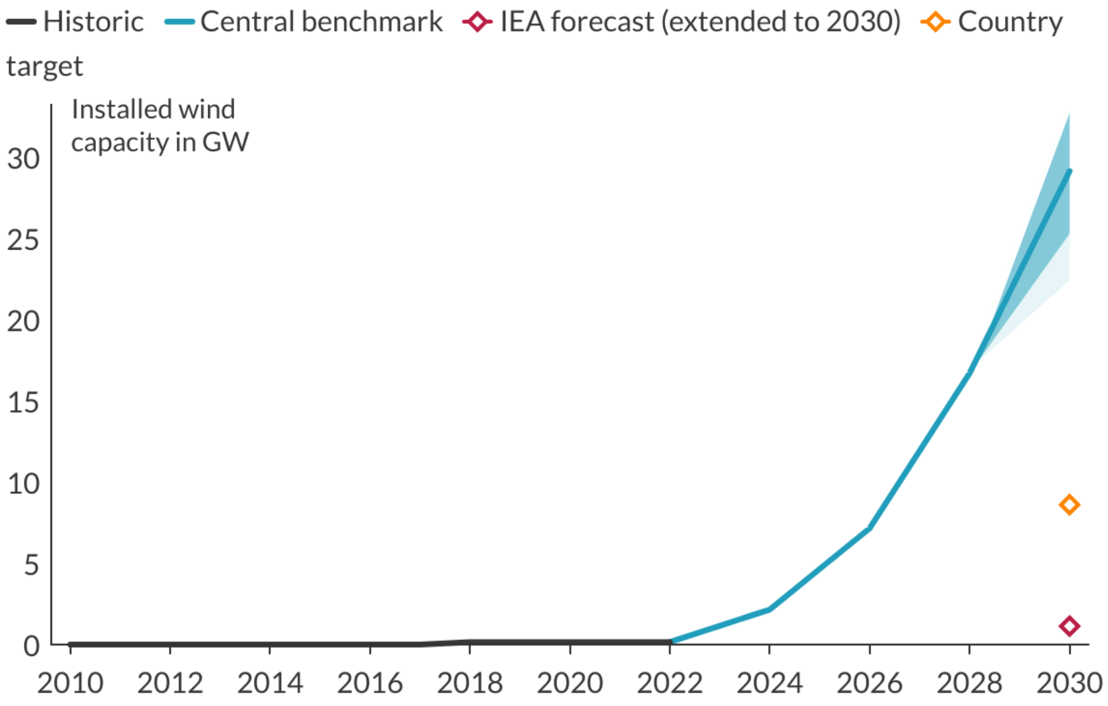
The negligible participation of wind and solar in Indonesia's current electricity generation means that the country needs to substantially increase the installation of these technologies to meet its targets, let alone align with 1.5°C benchmarks. This requires substantial action over the remainder of this decade, supported by the JETP initiative and additional international support.

Indonesia's wind and solar rollout needs to accelerate to align with 1.5°C

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

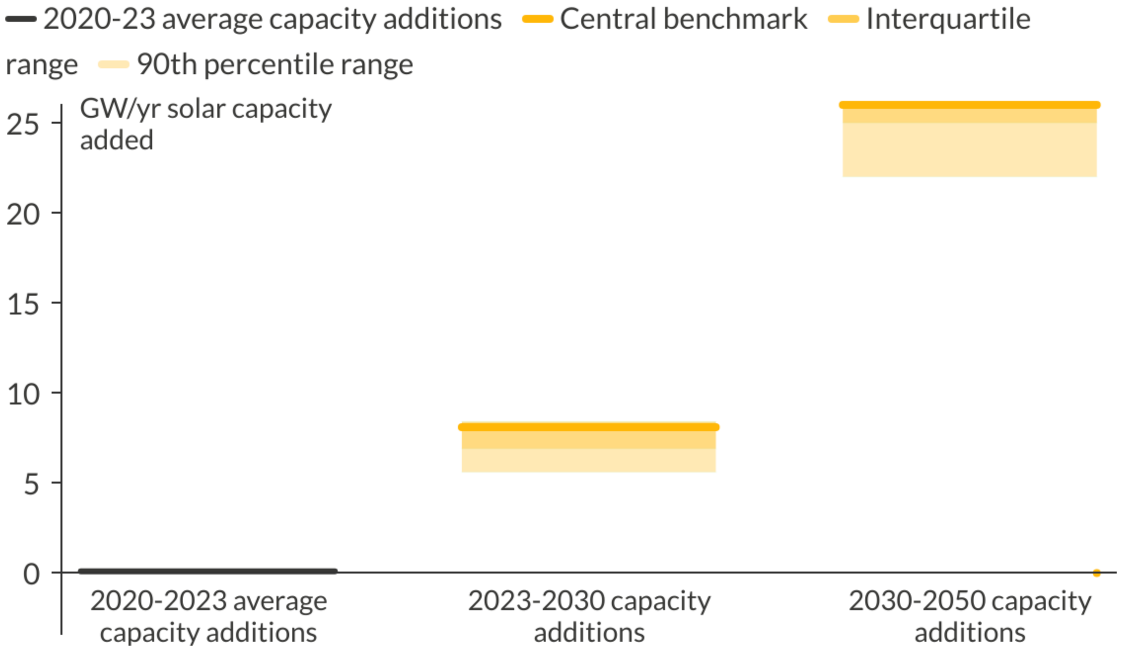


In Indonesia, current rollout of wind is lagging behind 1.5°C-aligned levels

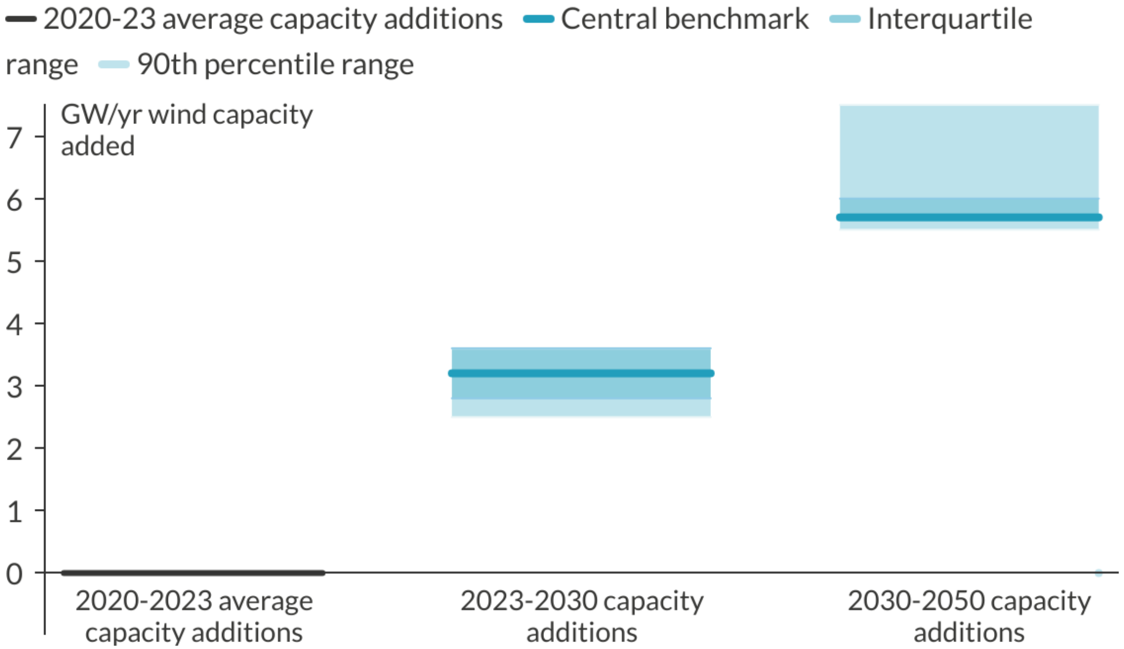


Indonesia needs to accelerate annual additions of wind and solar to align with 1.5°C. This will need additional international support

Indonesia would need to add on average 8.1 GW/yr of solar capacity until 2030, and 26.0 GW/yr by over 2030–2050.



Indonesia would need to add on average 3.2 GW/yr of wind capacity until 2030, and 5.7 GW/yr by over 2030–2050



Wind and solar growth in the light of the JETP

Under the JETP, power sector emissions from the grid would be below 250 $MtCO_2$ in 2030 and be net-zero by 2050. The share of renewables in electricity generation would reach 44% by 2030 and 92% by 2050, with 14% from wind and solar in 2030 and 36% in 2050. This amounts to 38 GW (29 GW of solar and 9 GW of wind) of installed capacity of VRE in 2030 and 309 GW in 2050. Additionally, a study of off-grid captive systems will be conducted to help build a roadmap for decarbonization.

The amount of financing needed amounts to 20 billion USD in the coming three to five years. The financing sources needed are a mix of public and private sources, with the main source being market rate investments.

JETP includes other resources (including concessional loans, guarantees, and 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 is provided.

Comparison with other studies

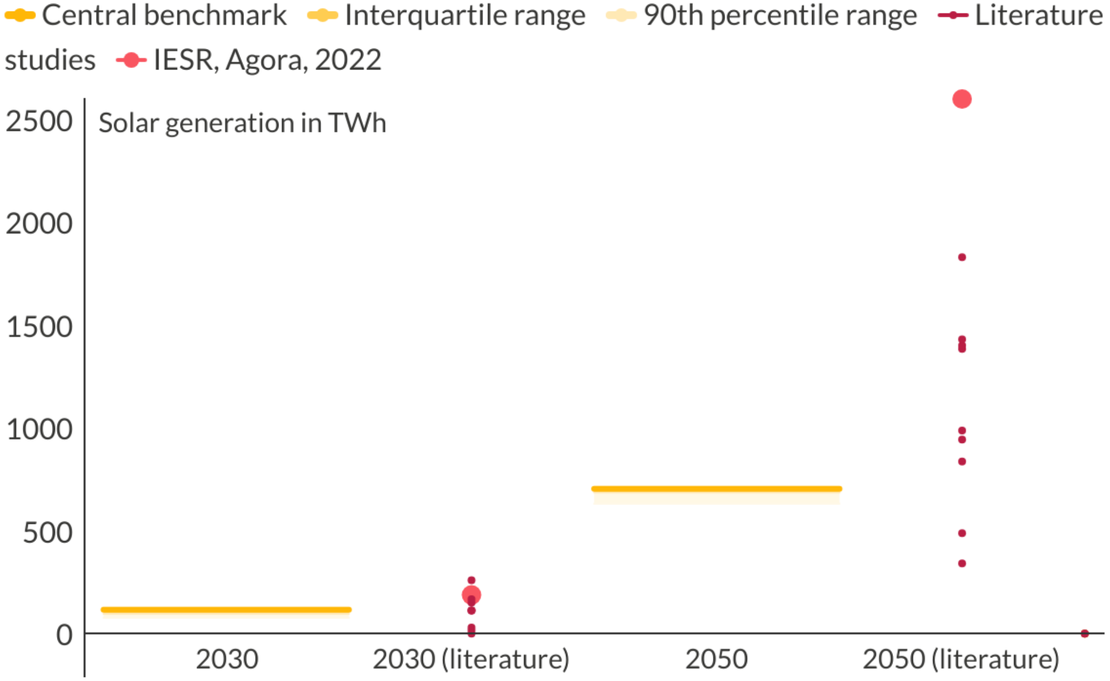
We compare the wind and solar generation seen in our analysis to that in the literature review of country-level studies. In particular, we highlight the results of modelling from IESR, conducted in collaboration with Agora-Energiewende and LUT University, exploring a pathway to net zero pathways for Indonesia.

While our modelling predicts that solar will provide more power generation than wind in 2030, 2040, and 2050, our results indicate a more balanced split between wind and solar compared to country-level studies, which show a significant emphasis on solar power, and negligible wind generation.

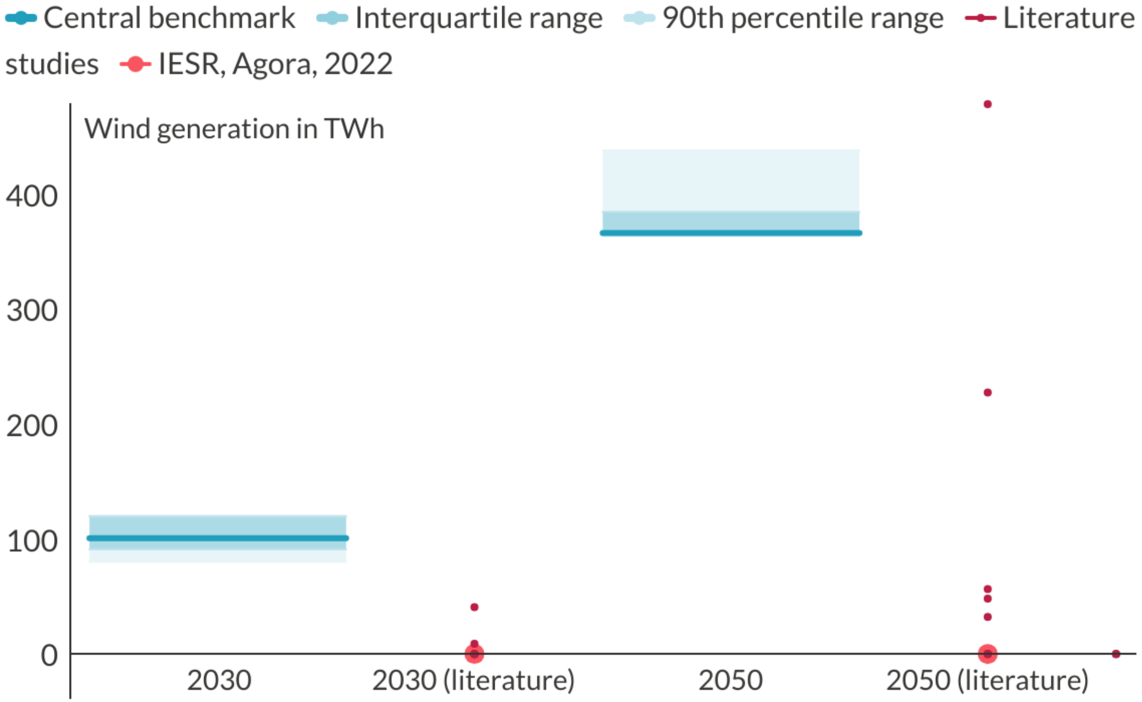
Our analysis shows higher wind generation and less solar generation most of the literature, including the IESR study. This difference between our modelling and the literature is most evident in 2050.

Our benchmarks are broadly aligned with the literature

Electricity generation from solar: comparison with literature in Indonesia



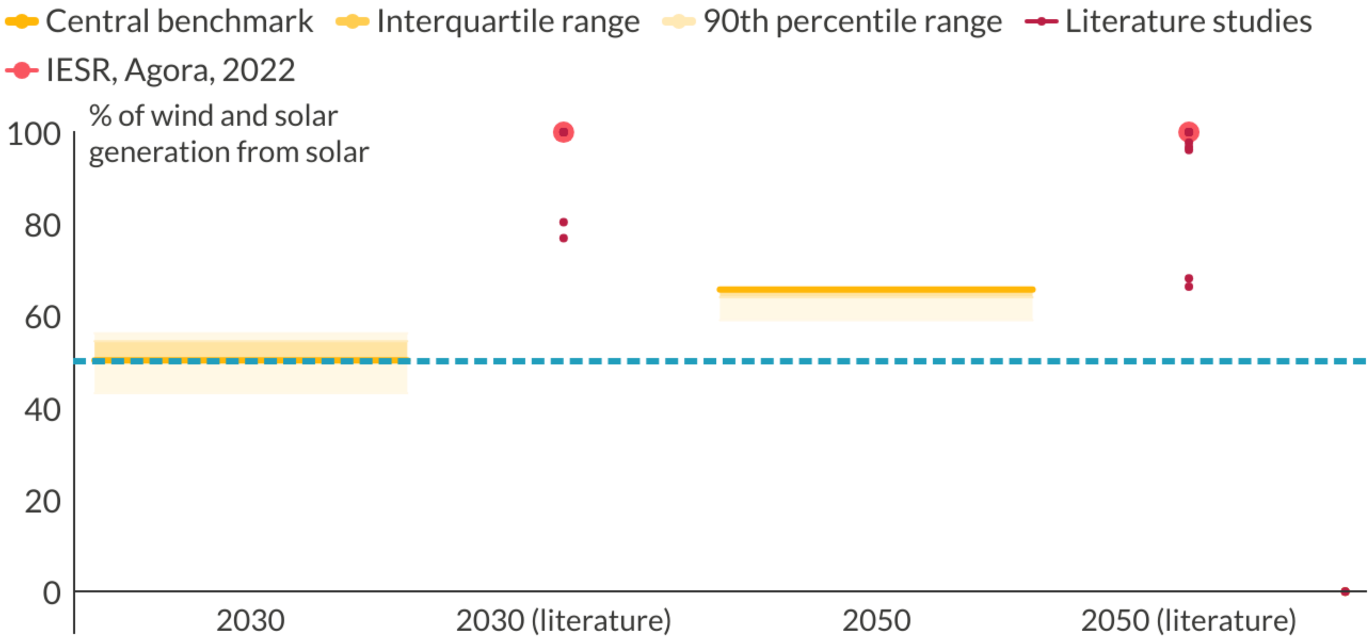
Electricity generation from wind: comparison with literature in Indonesia



In Indonesia, 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 Indonesia

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	0.4	120	300	520	700
Central 1.5°C benchmark	Wind generation	TWh	0.3	100	200	240	370
Central 1.5°C benchmark	Solar capacity	GW	0.3	77	220	390	590
Central 1.5°C benchmark	Wind capacity	GW	0.2	29	59	75	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

Study	Publication	Scenario Selected
IEA, 2022	An Energy Sector Roadmap to Net Zero Emissions in Indonesia	• Announced Pledges Scenario (APS) • Net Zero by 2050
IESR & Agora Energiewende, 2022	Deep decarbonization of Indonesia's energy system: A Pathway to zero emissions by 2050	Best Policy Scenario (BPS)
IRENA, 2022	Indonesia Energy Transition Outlook	• 1.5 Degrees scenario (1.5-S RE85) • 1.5 Degrees scenario (1.5-S RE90) • 1.5 Degrees scenario (1.5-S RE100)
Reyseliani & Purwanto, 2021	Pathway towards 100% renewable energy in Indonesia power system by 2050	• 100% RE • 100% RE excluding nuclear
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

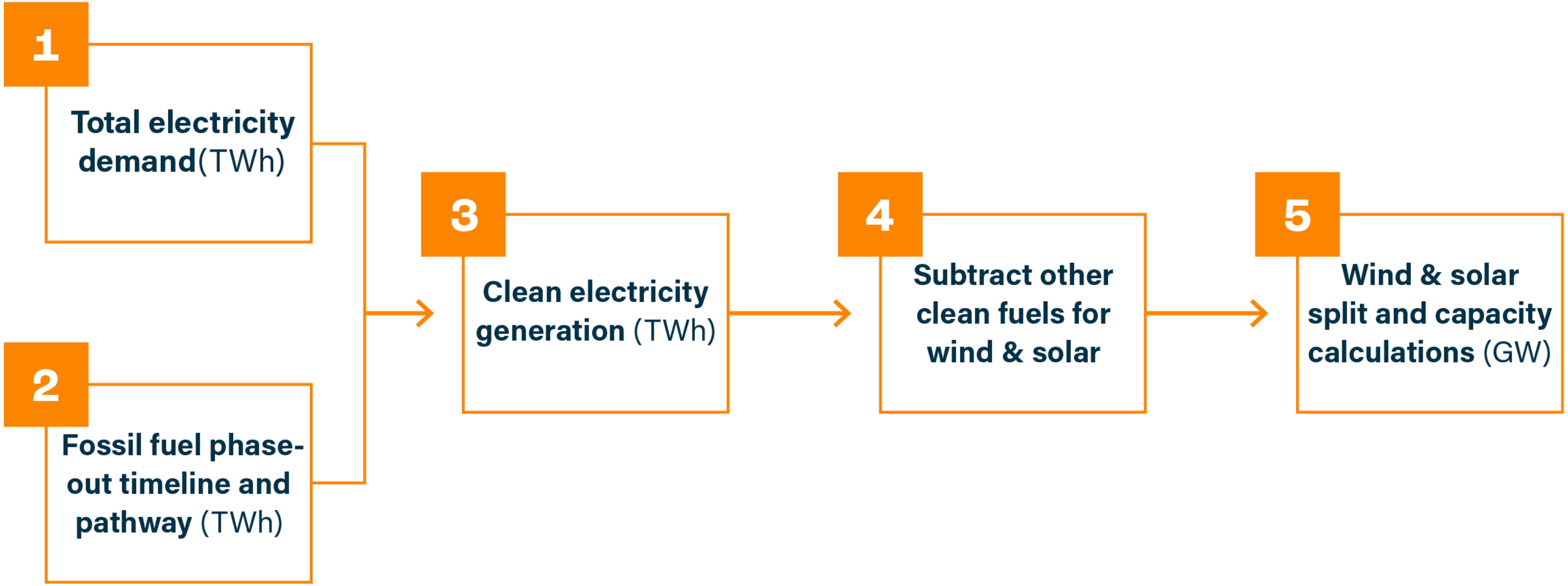
Our method takes a series of steps to calculate the wind and solar generation needed for 1.5°C, and the resulting capacity deployment.

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

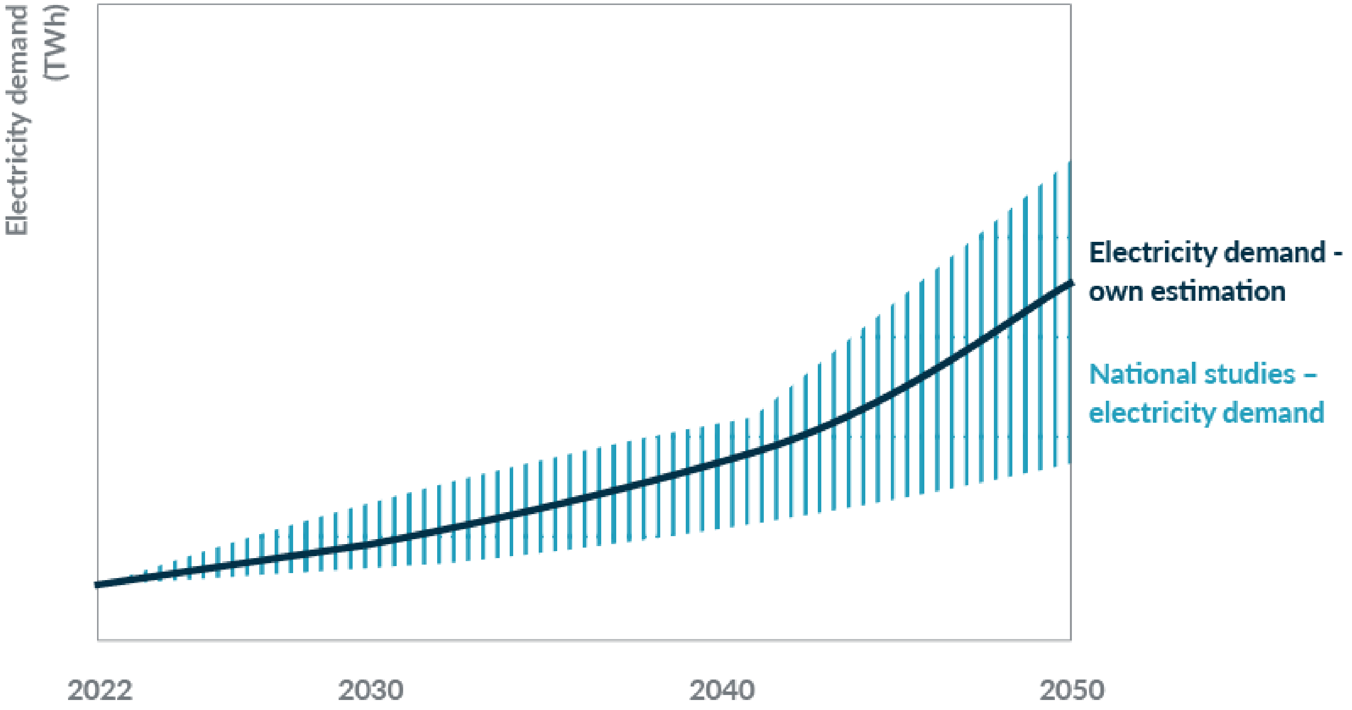
5

Wind & solar split and capacity calculations (GW)

For more details see the [Methods Annex]()

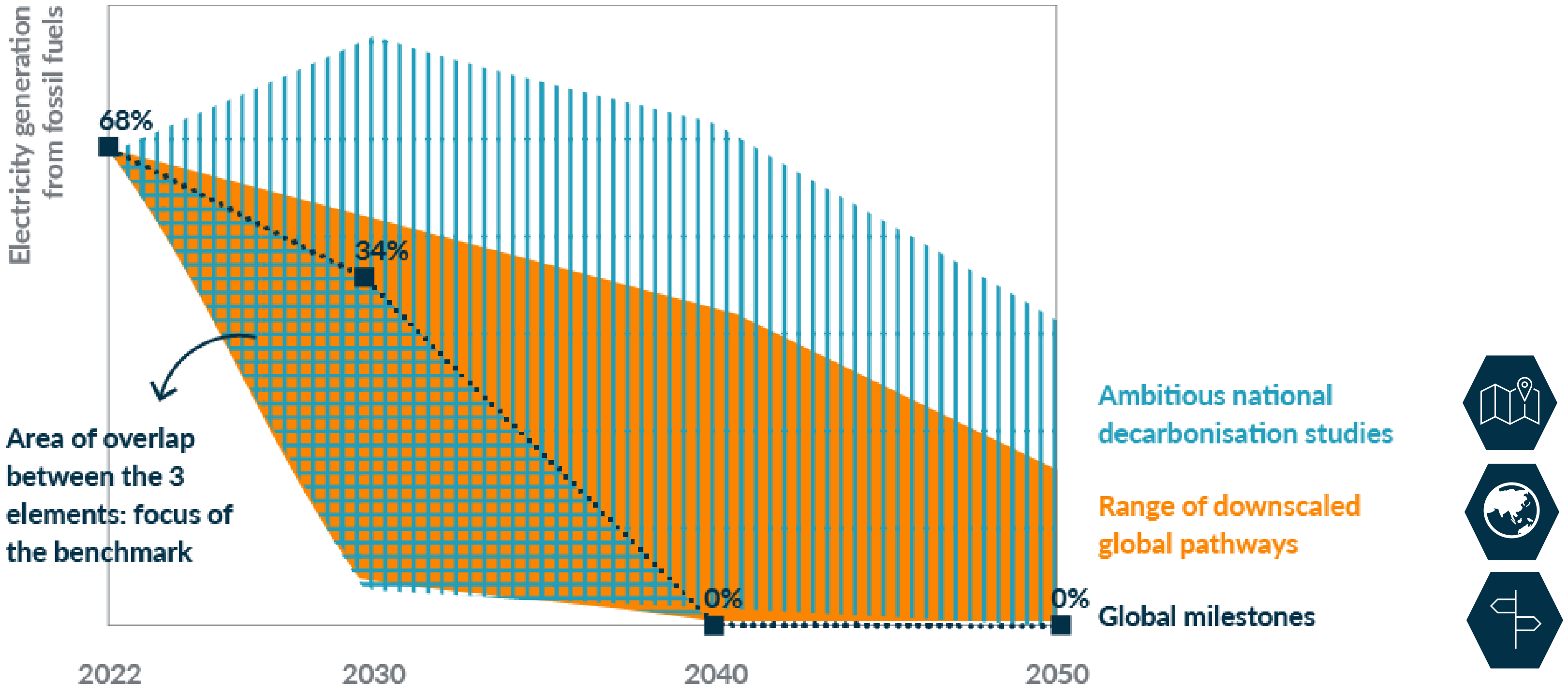
1 Total electricity generation

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.



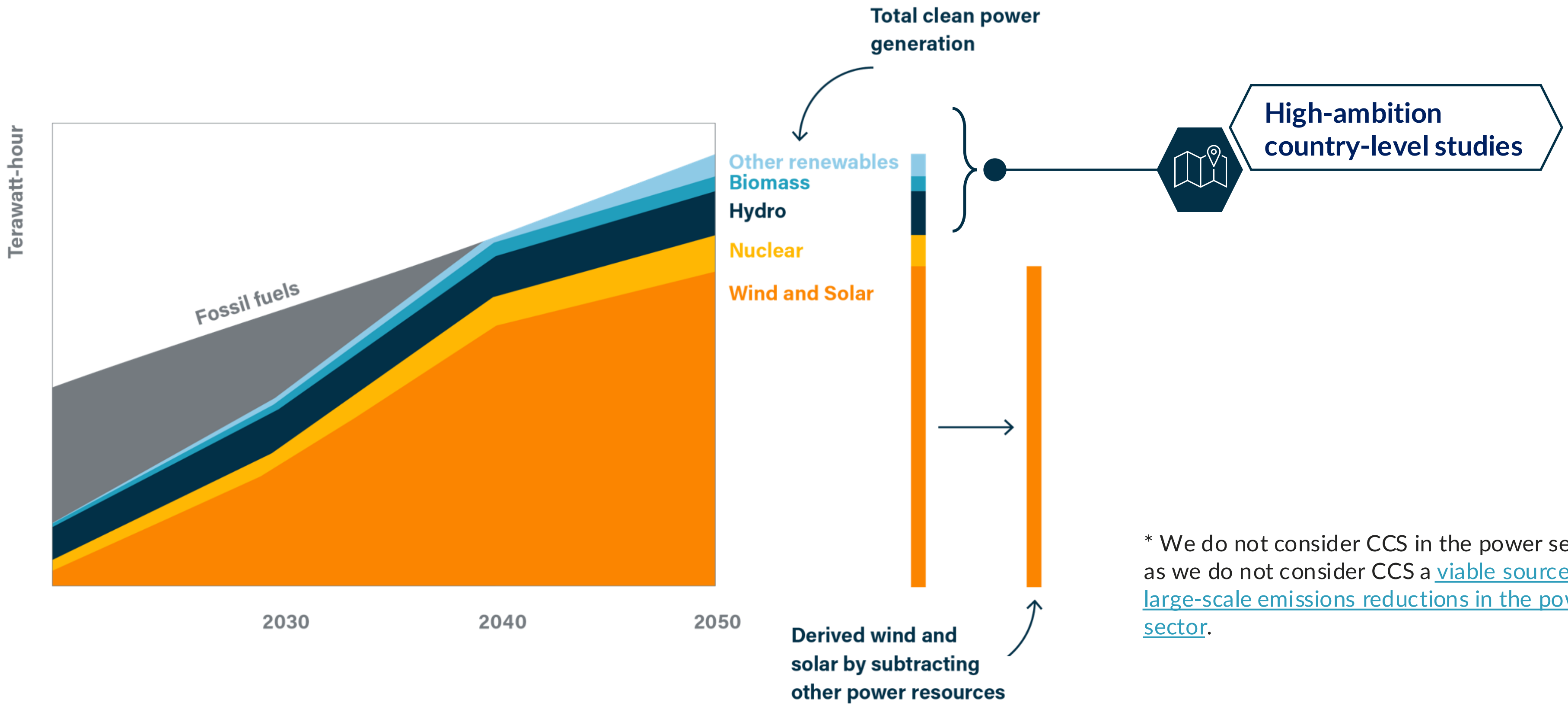
2 Fossil fuel phase-out

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.



Total clean power generation

High-ambition country-level studies

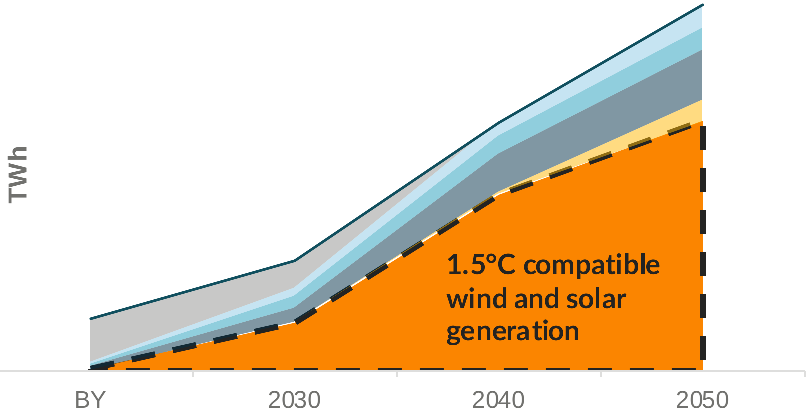
Derived wind and solar by subtracting other power resources

* 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.

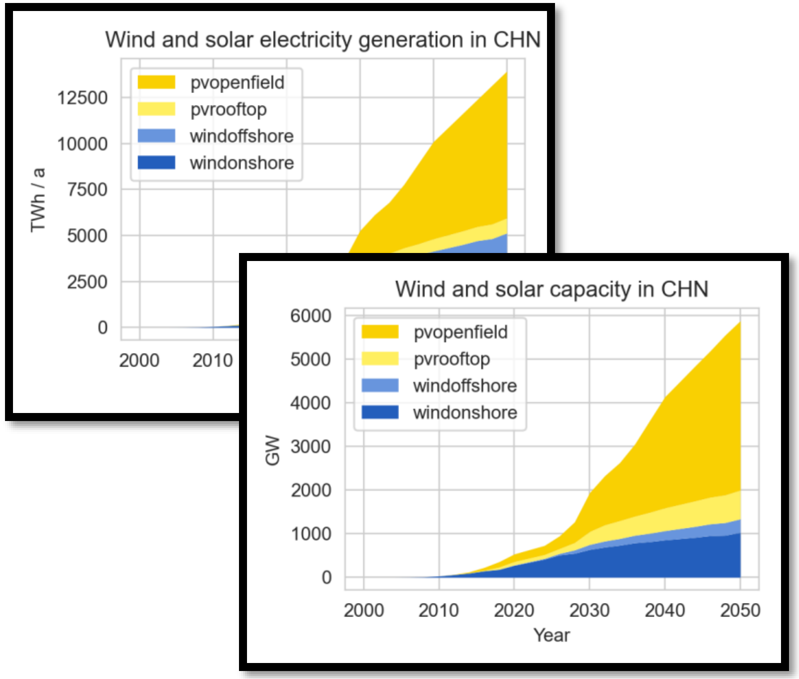
5 Wind and solar breakdown

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)



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.