

# Wind and solar benchmarks for a 1.5°C world

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

---

**Türkiye**

**NEW  
CLI/ATE**  
INSTITUTE

 **CLIMATE  
ANALYTICS**



# Executive Summary

---

## Context

- Türkiye became the second largest coal-fired power generator in Europe in 2023. While there is abundant potential for wind and solar deployment in Türkiye, further action will be necessary to transform the Turkish electricity system into one powered predominantly by renewables.
- Türkiye's transition to wind and solar slowed in 2023, with wind generation falling for the first time, and Poland overtaking Türkiye in the share of solar in the electricity mix.
- In this report, we explore the level of wind and solar that Türkiye 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

- There is no room for complacency in the transition to wind and solar. Wind and solar generation in Türkiye needs to grow three to four times by 2030, reaching 160–215 TWh in 2030, up from 50 TWh in 2022.
- This would require just over 90 GW of wind and solar to be installed by 2030 (60 GW of solar, 30 GW of wind).
- This would be equivalent to achieving the wind and solar capacity targets set by the National Electricity Plan for 2035 five years early.
- Türkiye needs to update its renewables targets, and drive the acceleration of the energy transition needed to deliver on them.

# Context

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

Wind and solar deployment is accelerating around the world. However, expected wind and solar capacity deployment under current policies falls short, and is concentrated mainly in a few regions.

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

This project aims at answering the following questions:

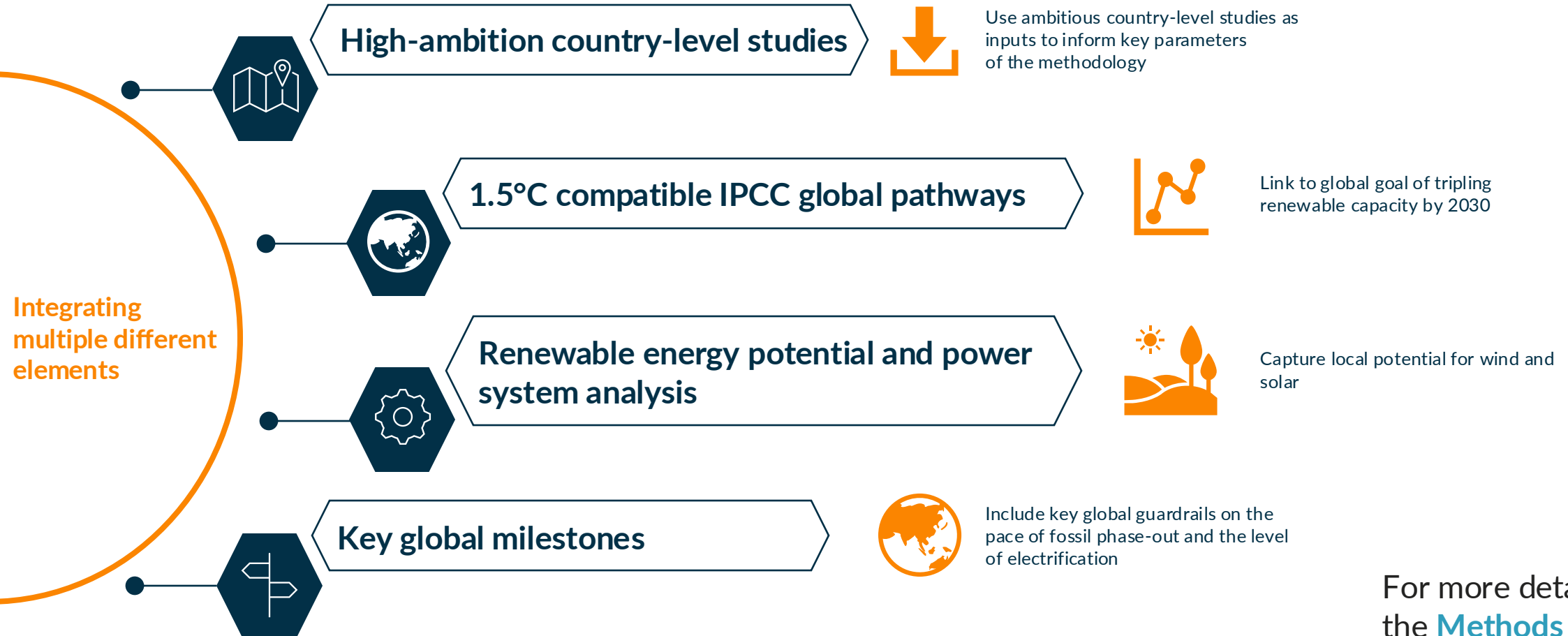
- **How much wind and solar generation is needed (TWh) at the national level?**
- **How much wind and solar needs to be built (GW of capacity)?**
- **When does it need to be built by?**

# Summary of our method

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

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

# Our method is focused on including multiple different analytical elements



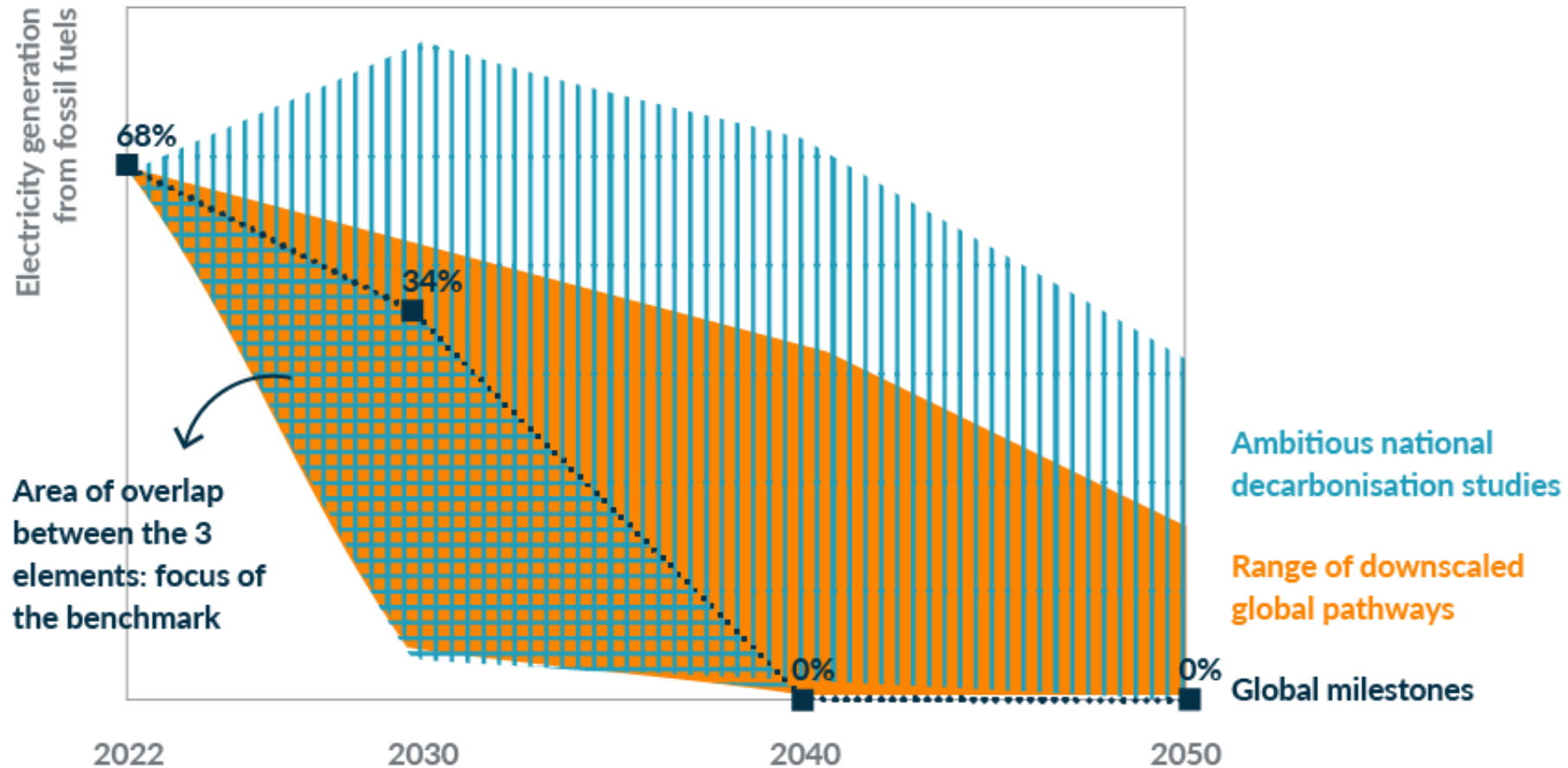
For more details see the [Methods Annex](#)

# Overlap of different elements

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

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

# Overlapping multiple analytical elements can provide more robust benchmarks



# National enabling factors

Key enabling factors for ambitious wind and solar rollout include:

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



# Policy context

Türkiye's current NDC is to cut emissions by 41% below a business-as-usual projection in 2030, to reach **695 MtCO<sub>2</sub>e**. This still allows emissions to almost double relative to 2010 levels. In 2021, Türkiye announced a net zero by 2053 target.

Türkiye's current renewable targets are to reach **33 GW of solar and 18 GW of wind by 2030**, as of the National Energy Plan published in 2022.

Under current policies and market conditions, the IEA estimates that **solar capacity will reach 39 GW in 2028**, up from 11 GW of solar in 2022. Meanwhile, **wind capacity is projected to reach 18 GW in 2028**, up from 11 GW in 2022. Türkiye is therefore on track to overachieve its current wind and solar targets.



# Results

---

# Future electricity demand

Electricity demand is taken from [Shura's](#) study exploring net zero by 2053 pathways for Türkiye, and the implications for the electricity sector.

In this study, total electricity generation in Türkiye triples by 2050 relative to 2022 levels, reaching almost 1000 TWh. This is driven by strong 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 770 TWh to 1620 TWh. This would affect the necessary growth of wind and solar significantly. Our demand projection is at the lower end of the literature studies assessed.

# 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 Türkiye achieves a clean power system by 2045.

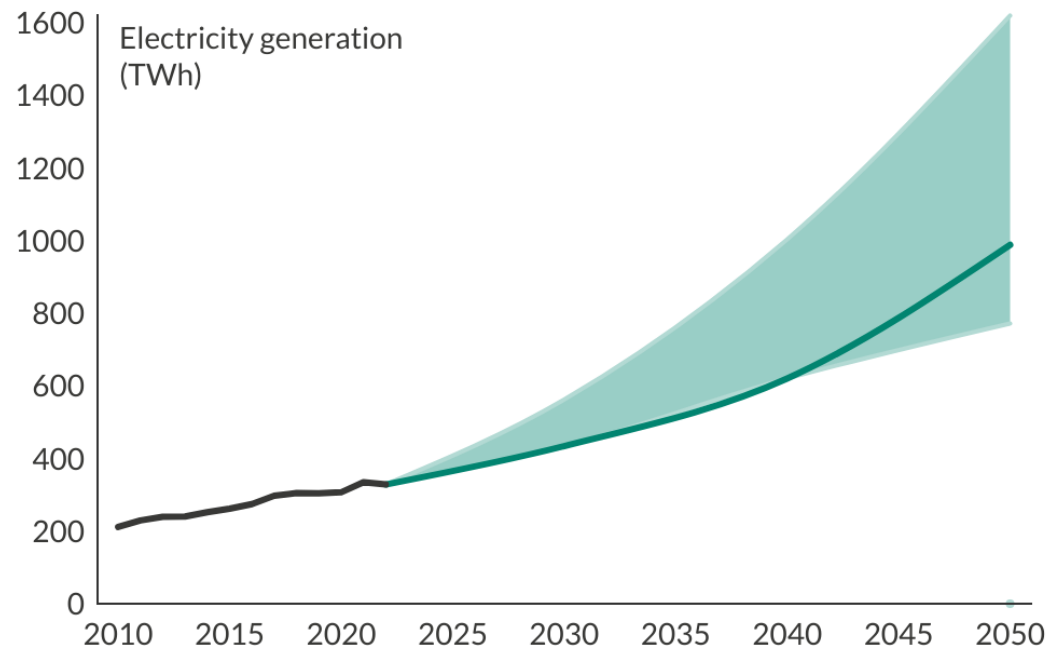
To align with 1.5°C, fossil fuels must exit the Turkish power sector before 2045.

Fossil fuel generation falls by 41 to 70% between 2022 and 2030.

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

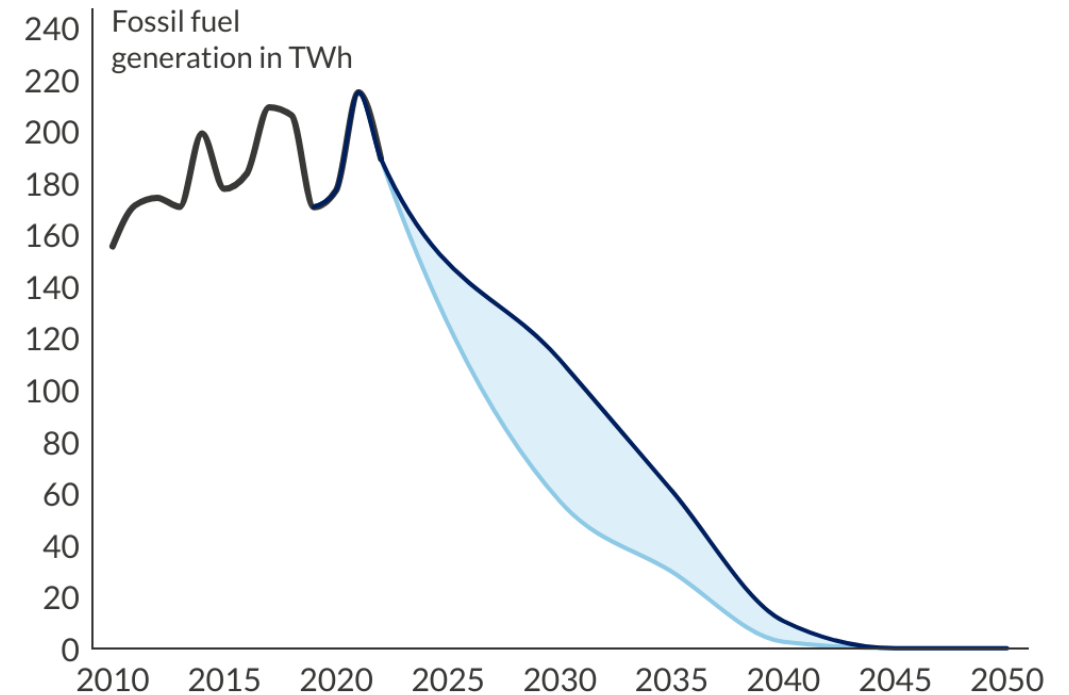
## Electricity generation triples in Türkiye over 2022–2050

— Historic — Electricity generation assumed in this work — Range of electricity generation in the reviewed studies



## Türkiye would need to achieve clean electricity by 2045

— Maximum ambition — Minimum ambition — Historic



# 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 Türkiye would reach 160 TWh by 2030 and over 200 TWh by 2050. This is provided by a mix of hydropower (which provides on average almost 100 TWh of generation by 2050 in the reviewed national studies), biomass (over 50 TWh by 2050), other renewables such as geothermal and solar CSP (30 TWh by 2050) and a small amount of nuclear (30 TWh by 2050).

\* 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.

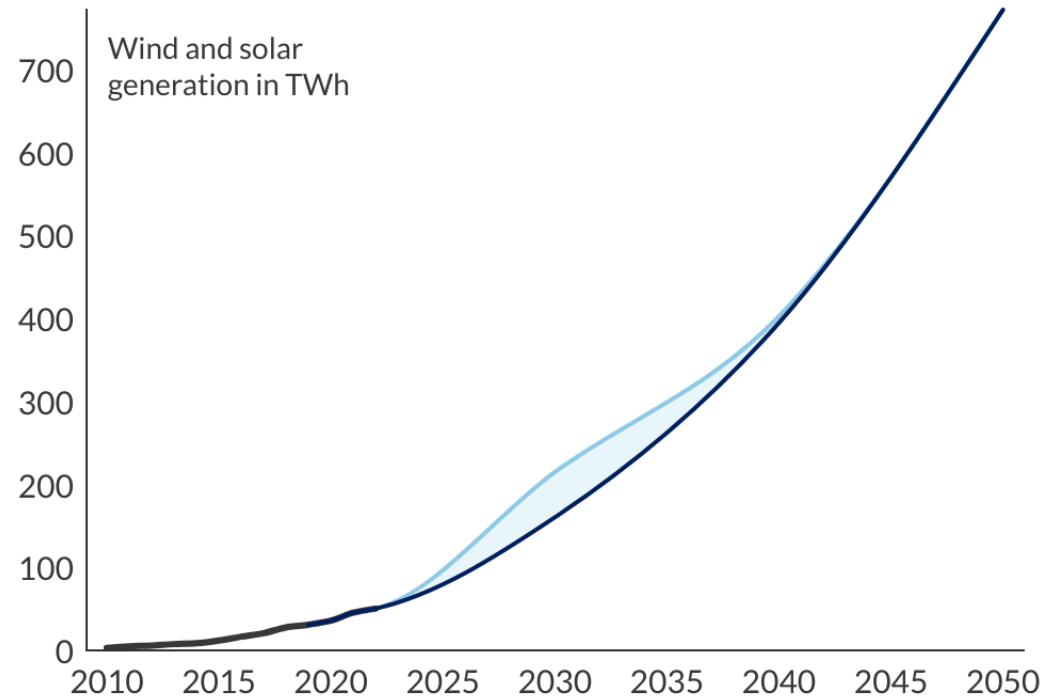
To align with 1.5°C, wind and solar generation in Turkey would need to reach between 160-215 TWh by 2030. Generation in 2022 was 50 TWh. This is therefore a 3 to 4-fold growth in wind and solar.

Wind and solar provides 37–50% of overall electricity generation in 2030, and 78% of overall generation in 2050.

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

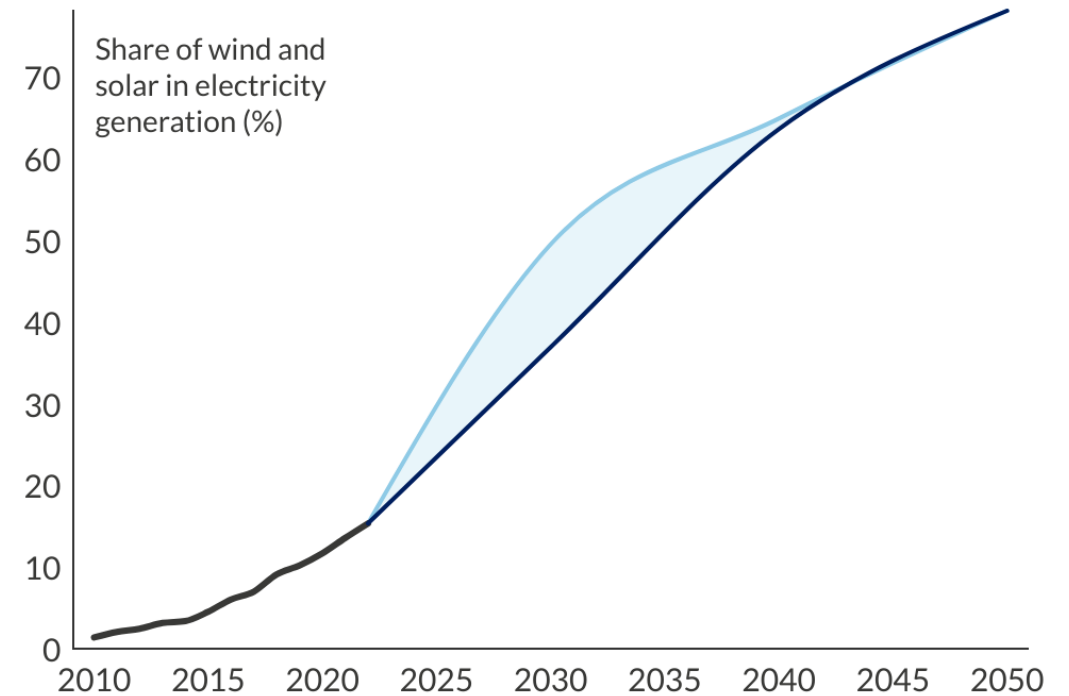
## Wind and solar generation needs to grow 3-4x by 2030 relative to 2022 in Türkiye

— Historic — Maximum ambition — Minimum ambition



## Wind and solar would need to provide around 80% of electricity in Türkiye by 2050

— Historic — Maximum ambition — Minimum ambition





# 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](#)), reflected on a range of possible future generation mixes between wind and solar.

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

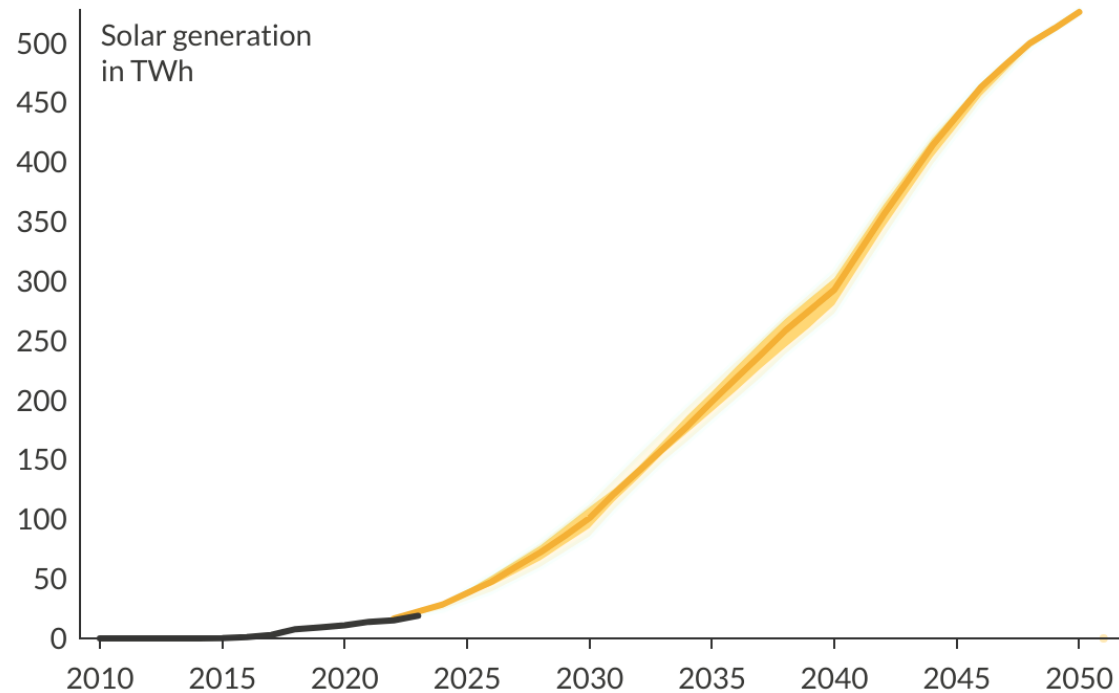
In Türkiye, the level of uncertainty seen in our benchmarks across wind and solar costs is small. This does not mean that there is no uncertainty in the possible split of wind and solar, as a range of other uncertainties could also impact on the split, including grid capacity, supply chains, national policies and more.

In this scenario, **wind and solar capacity in Türkiye would need to reach around 90 GW of by 2030, and 150 GW by 2035**. By 2050, total wind and solar capacity would need to reach towards 400 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 Türkiye

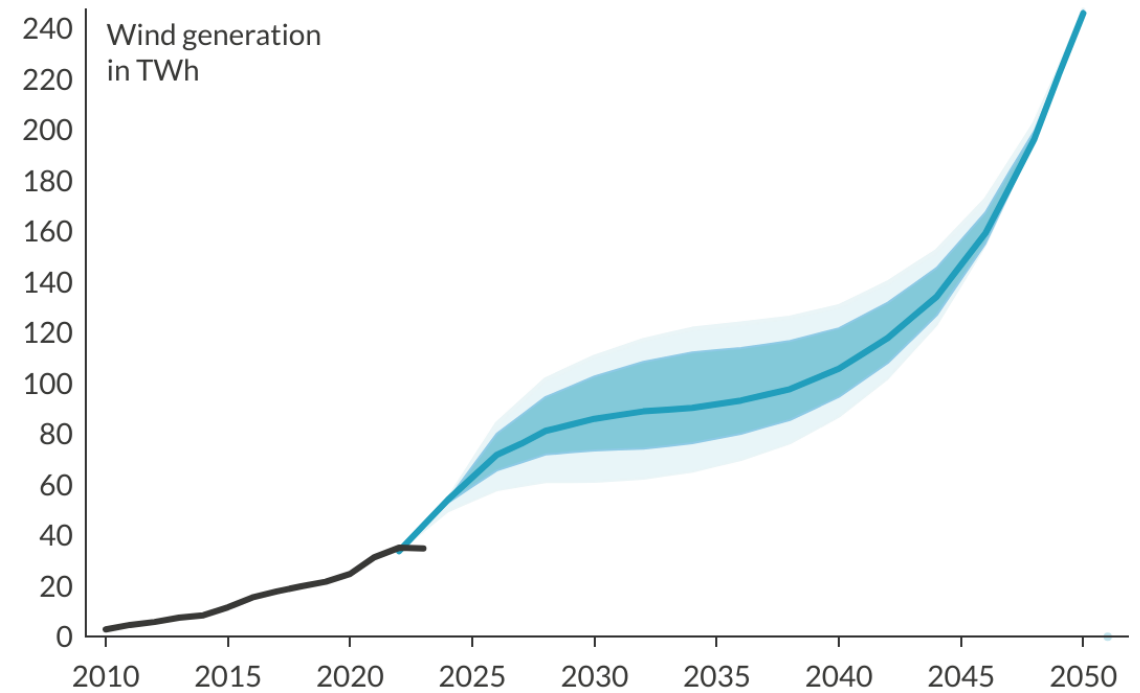
## Solar generation in Türkiye would reach over 500 TWh by 2050 in a 1.5°C-aligned transition

— Historic — Central benchmark — Interquartile range — 90th percentile range



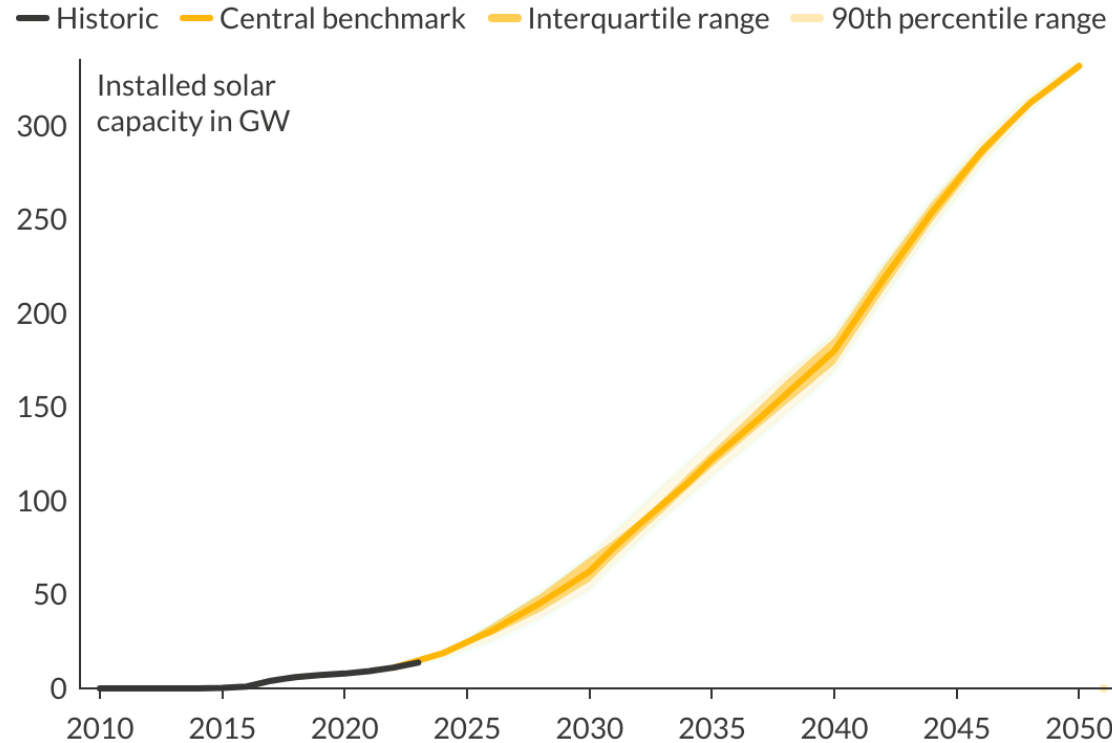
## Wind generation in Türkiye would reach almost 250 TWh by 2050 in a 1.5°C-aligned transition

— Historic — Central benchmark — Interquartile range — 90th percentile range

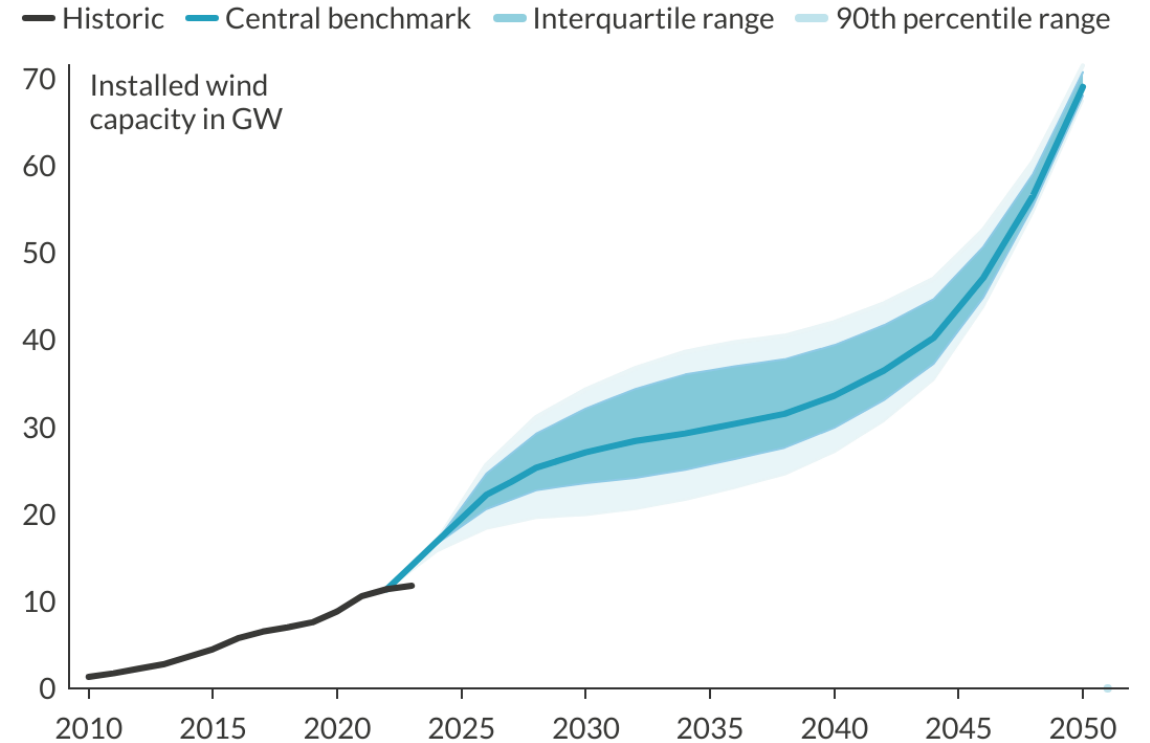


# Türkiye needs to install around 90 GW of wind and solar by 2030 to align with 1.5°C

## Solar capacity would reach 62 GW in Türkiye by 2030 in a 1.5°C-aligned scenario



## Wind capacity would reach 27 GW in Türkiye by 2030 in a 1.5°C-aligned scenario



# Comparison to current rollout

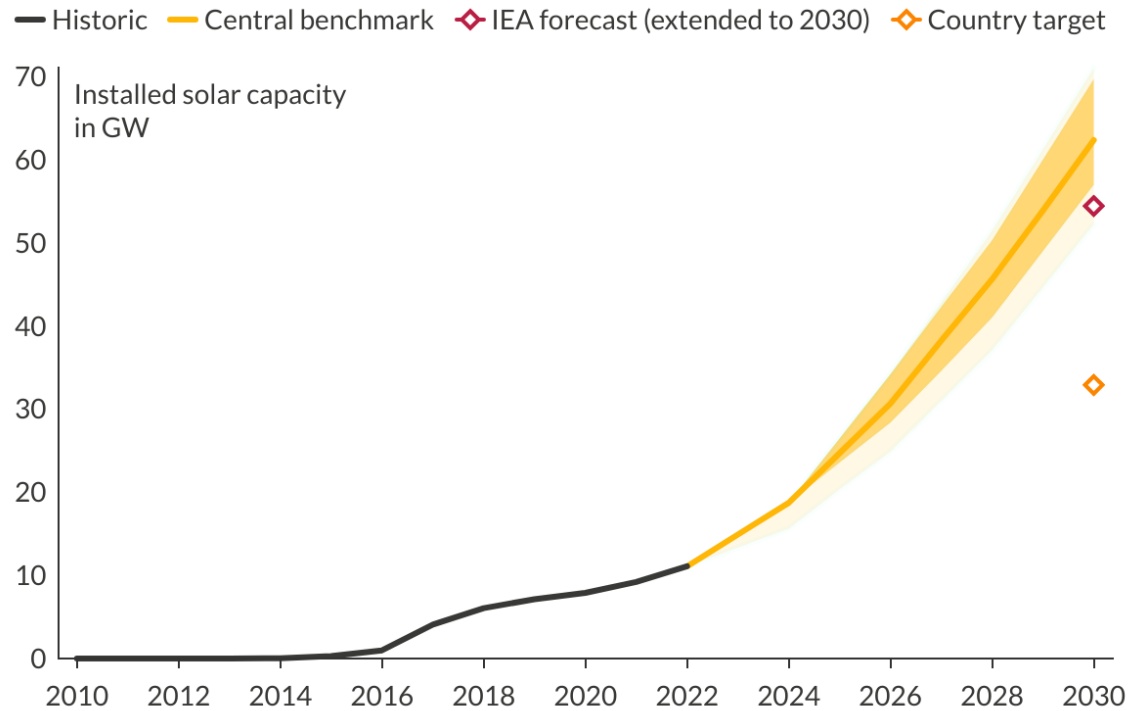
We extend the [IEA's capacity forecast](#) for wind and solar (which is provided out to 2028) to 2030 and compare to the benchmarks presented in this report.

Under current policies and market conditions, deployment of wind and solar come close to aligning with the benchmarks set out here, although there remains a gap of around 9 GW of solar and 4 GW of wind that would need to be closed.

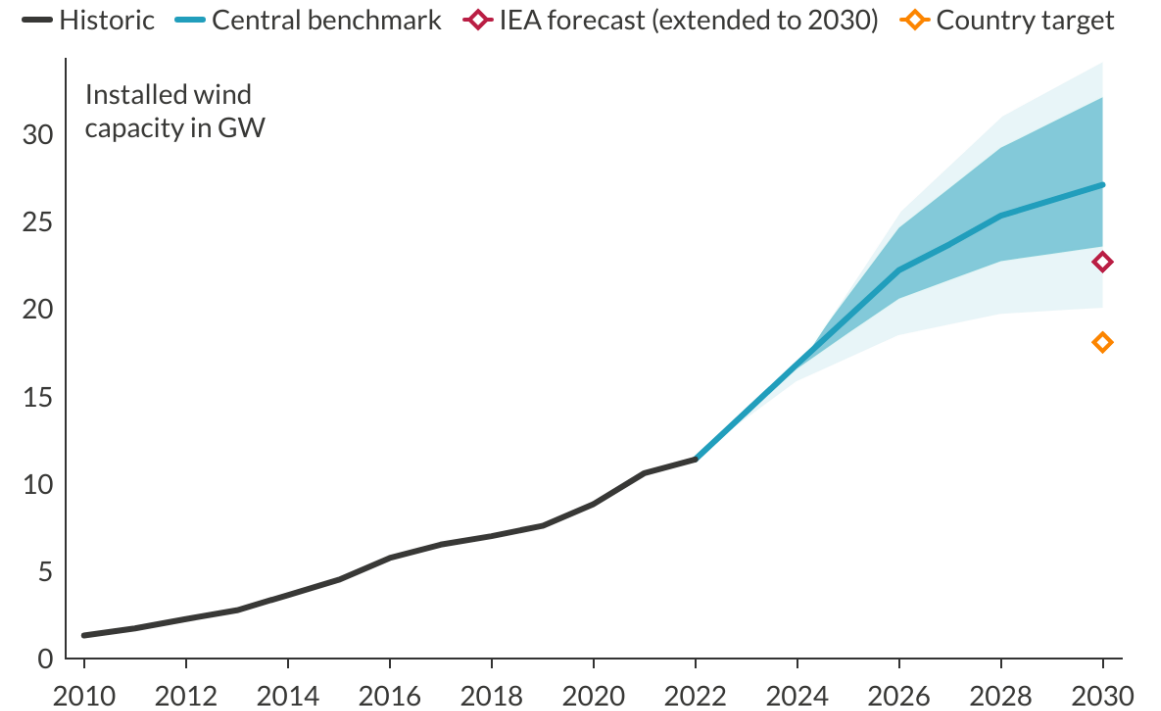
Meanwhile, the targets announced in the [2022 National Energy Plan](#) are not ambitious enough to align with 1.5°C and should be updated.

# Türkiye's rollout of wind and solar come close to alignment with 1.5°C, but targets need updating

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

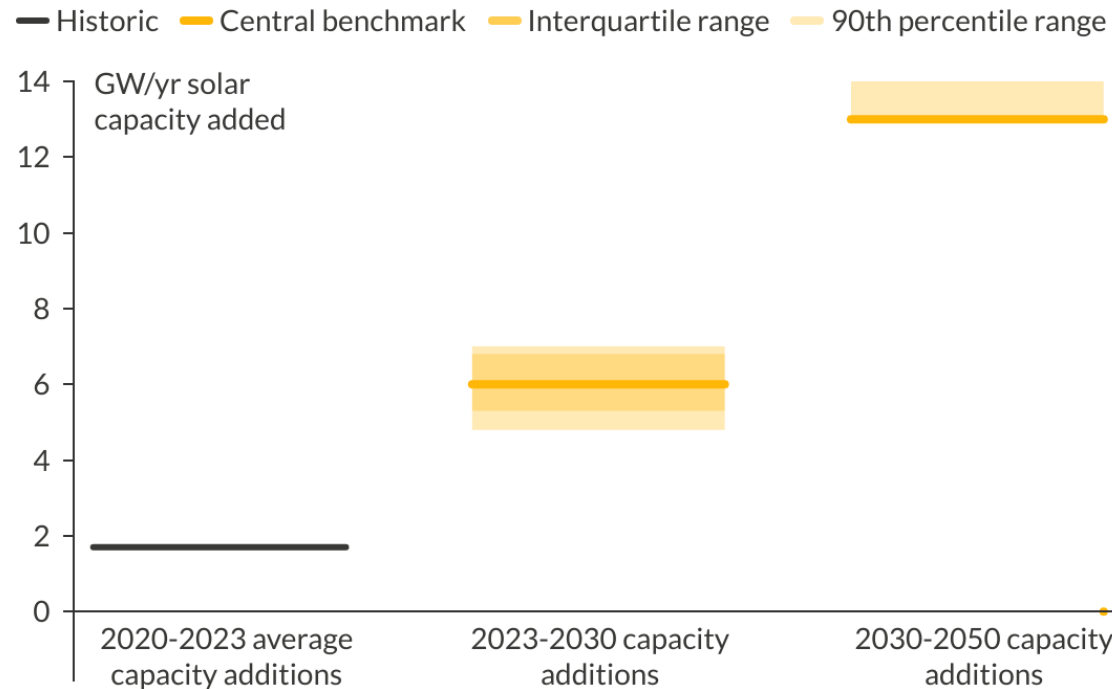


## Current rollout of wind in Türkiye comes close to aligning with 1.5°C, but targets need updating

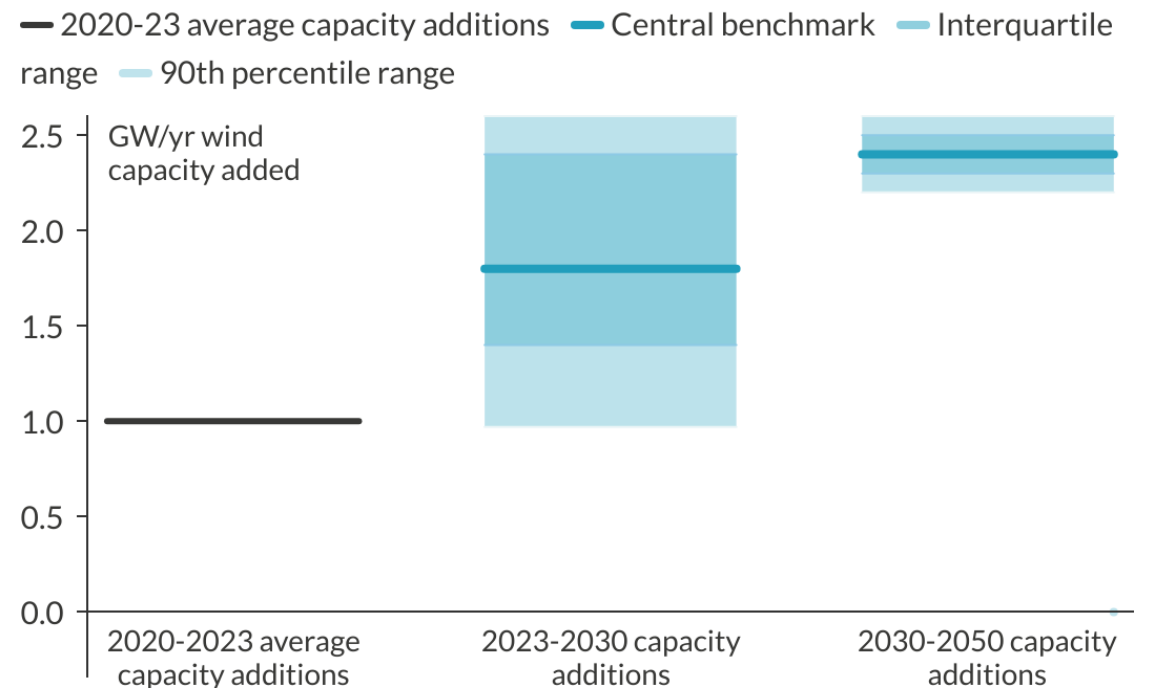


# Wind and solar capacity additions in Türkiye need to accelerate to align with 1.5°C

Türkiye would need to add on average 6.0 GW/yr of solar capacity until 2030, and 13.0 GW/yr by over 2030–2050.



Türkiye would need to add on average 1.8 GW/yr of wind capacity until 2030, and 2.4 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 [Shura's](#) study exploring net zero by 2053 pathways for Türkiye's power sector.

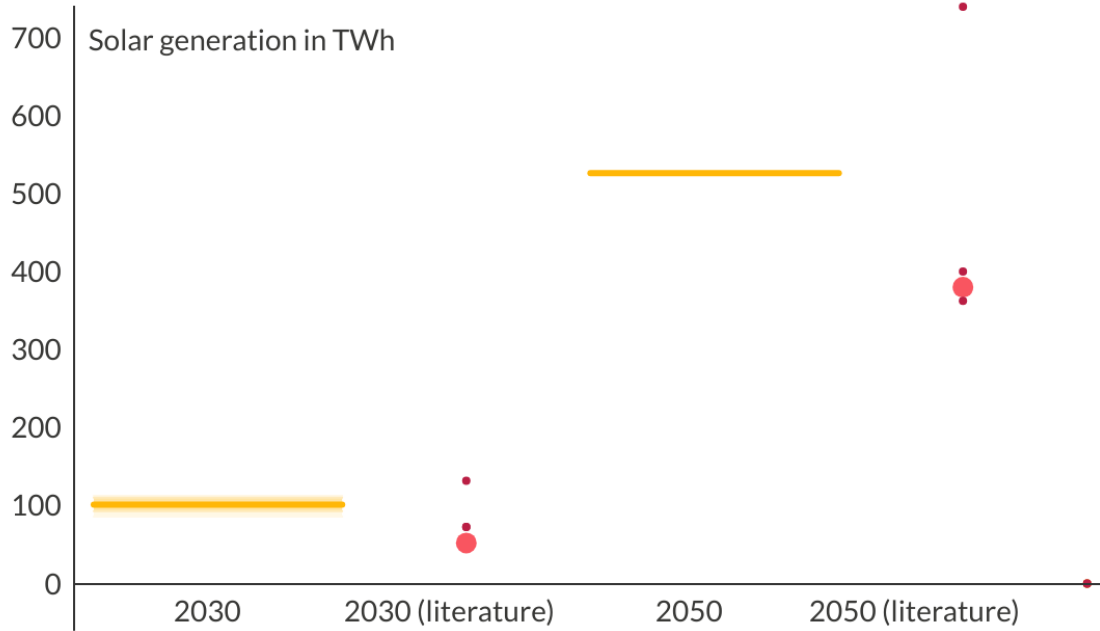
We see that the wind and solar generation that our method produces is broadly within the range of the national literature in 2030. In 2050, our model generally deploys more solar generation than the national studies reviewed, while it remains in the center for wind generation (two studies reporting higher generation, two reporting lower).

In 2050, our analysis deploys more solar and less wind than the study highlighted from Shura.

# In 2050, our benchmarks show higher solar and less wind than the net zero roadmap from Shura

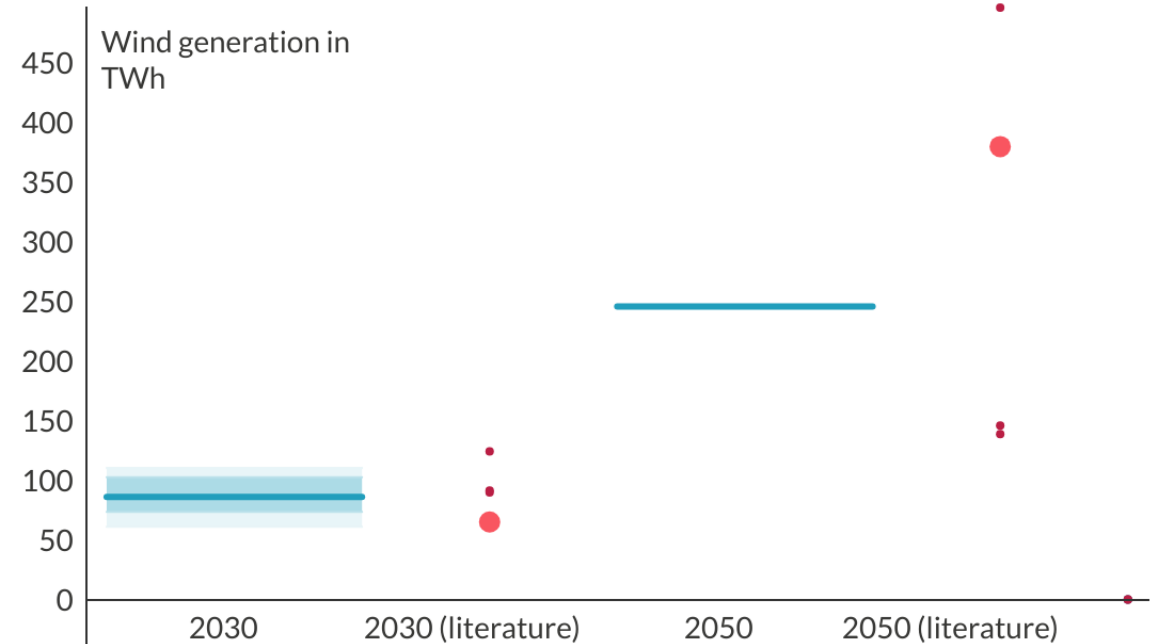
## Electricity generation from solar: comparison with literature in Türkiye

Central benchmark Interquartile range 90th percentile range  
Literature studies Shura, 2023



## Electricity generation from wind: comparison with literature in Türkiye

Central benchmark Interquartile range 90th percentile range  
Literature studies Shura, 2023



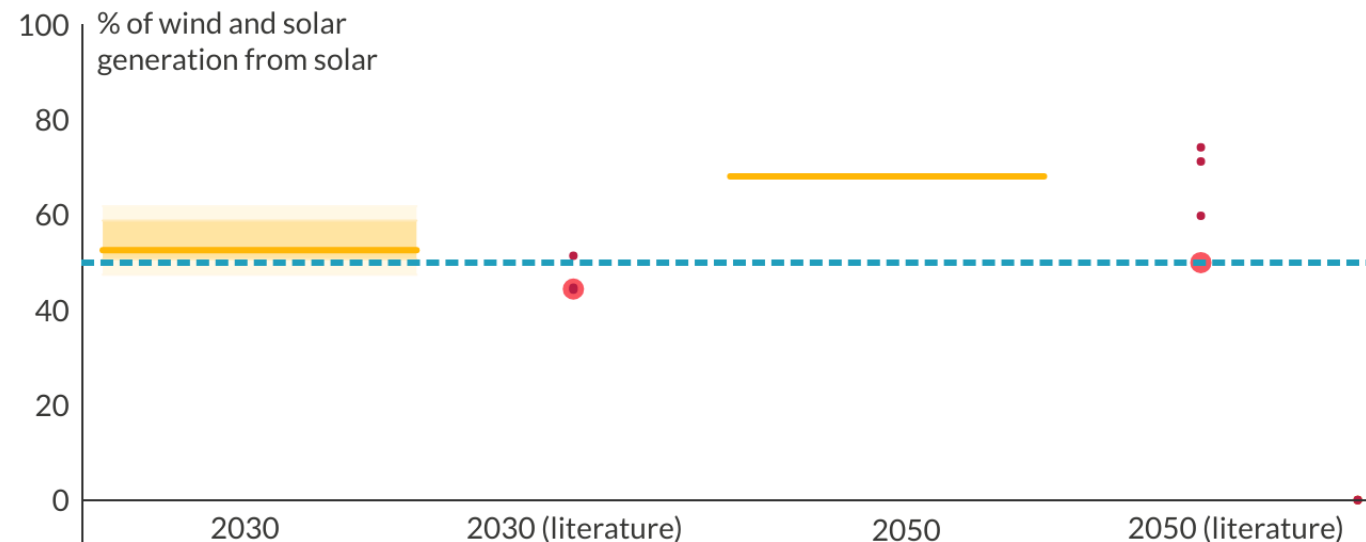


# In Türkiye, our benchmarks generally suggest that solar will provide more generation than wind

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

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

Central benchmark Interquartile range 90th percentile range Literature studies  
Shura, 2023



# 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	17	100	200	290	530
Central 1.5°C benchmark	Wind generation	TWh	34	90	92	110	250
Central 1.5°C benchmark	Solar capacity	GW	11	62	120	180	330
Central 1.5°C benchmark	Wind capacity	GW	11	27	30	34	69



# 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
<a href="#">Shura, 2023</a>	Net Zero by 2053: A Roadmap for the Turkish Electricity Sector	Net Zero 2053
<a href="#">Teske et al., 2023</a>	Net-zero 1.5°C sectorial pathways for G20 countries: energy and emissions data to inform science-based decarbonization targets	1.5 °C
<a href="#">Sahin et al., , 2023</a>	Turkey's decarbonization pathways - Net zero in 2050	<ul style="list-style-type: none"> <li>• Net-Zero Scenario (NZS)</li> <li>• Nuclear-Free NZS</li> </ul>

# Global milestones

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

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





# Annex 2

---

Step-by-step method

# Summary of our method

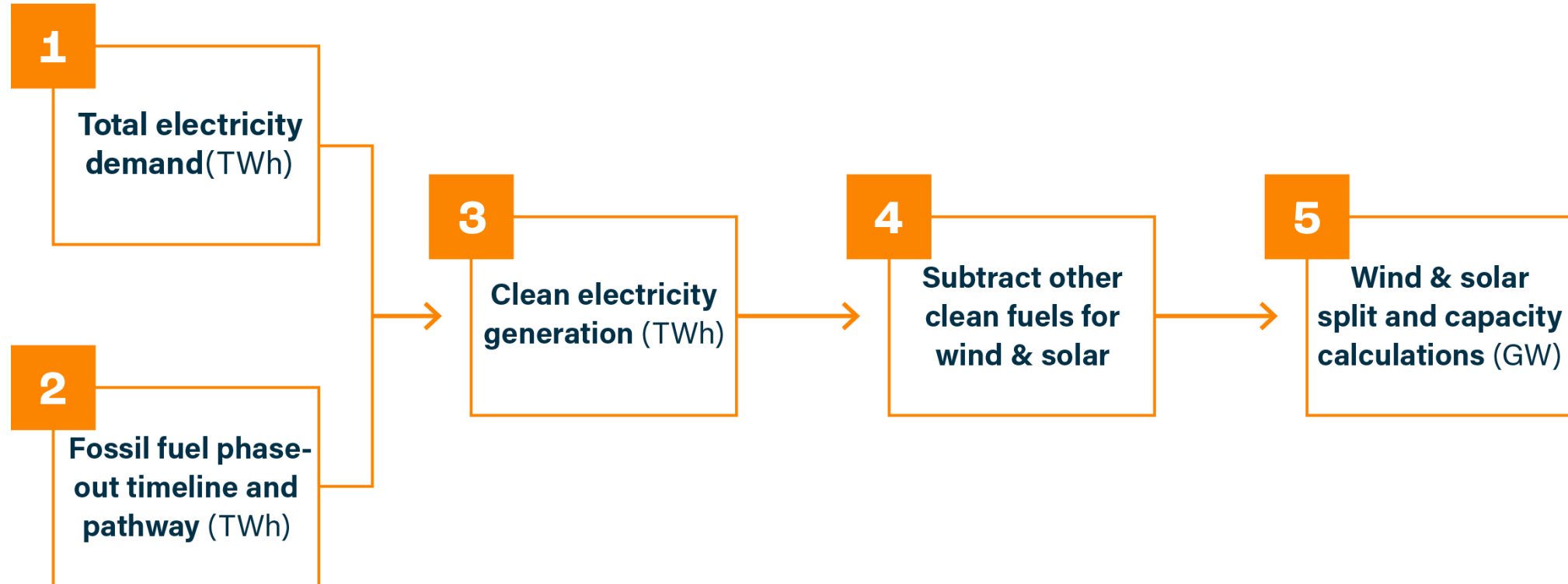
Our method takes a series of steps to calculate the wind and solar generation needed for 1.5°C, and the resulting capacity deployment.

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

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

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

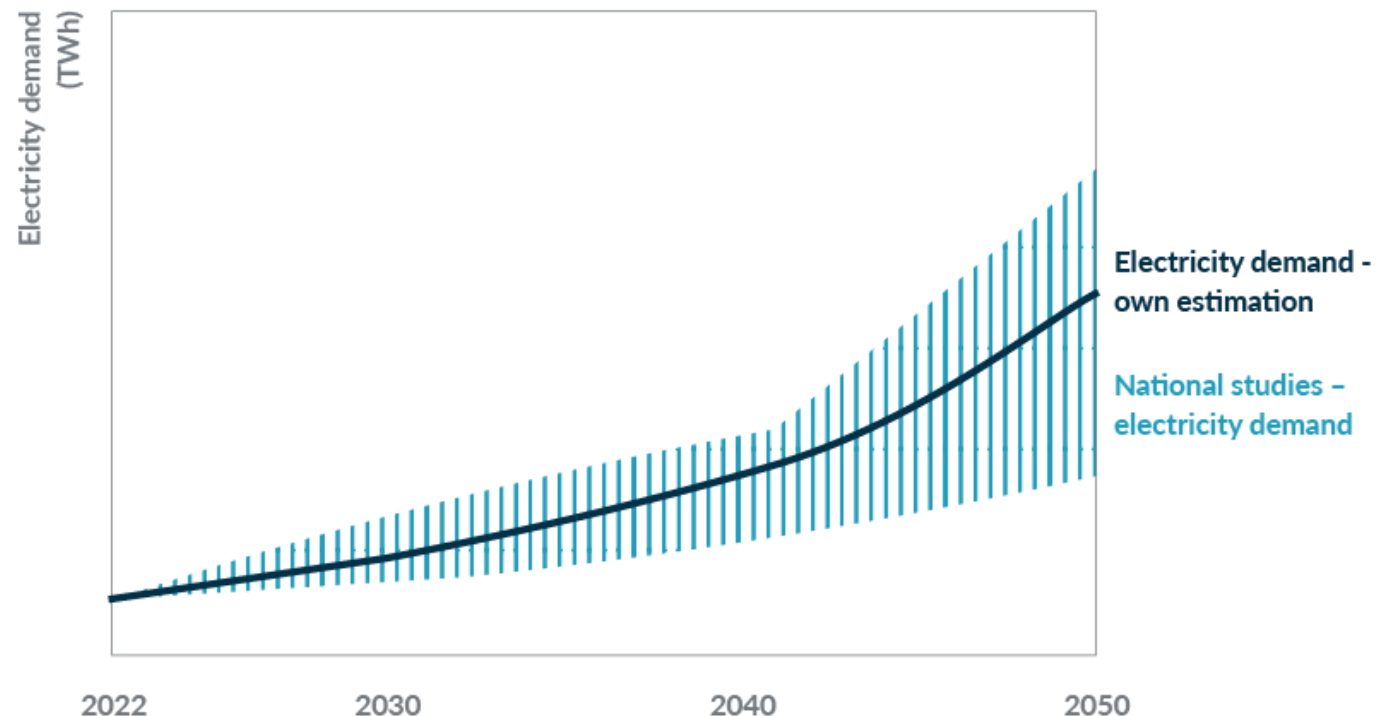
# We use a step-by-step method to calculate our benchmarks



For more details see the [Methods Annex](#)

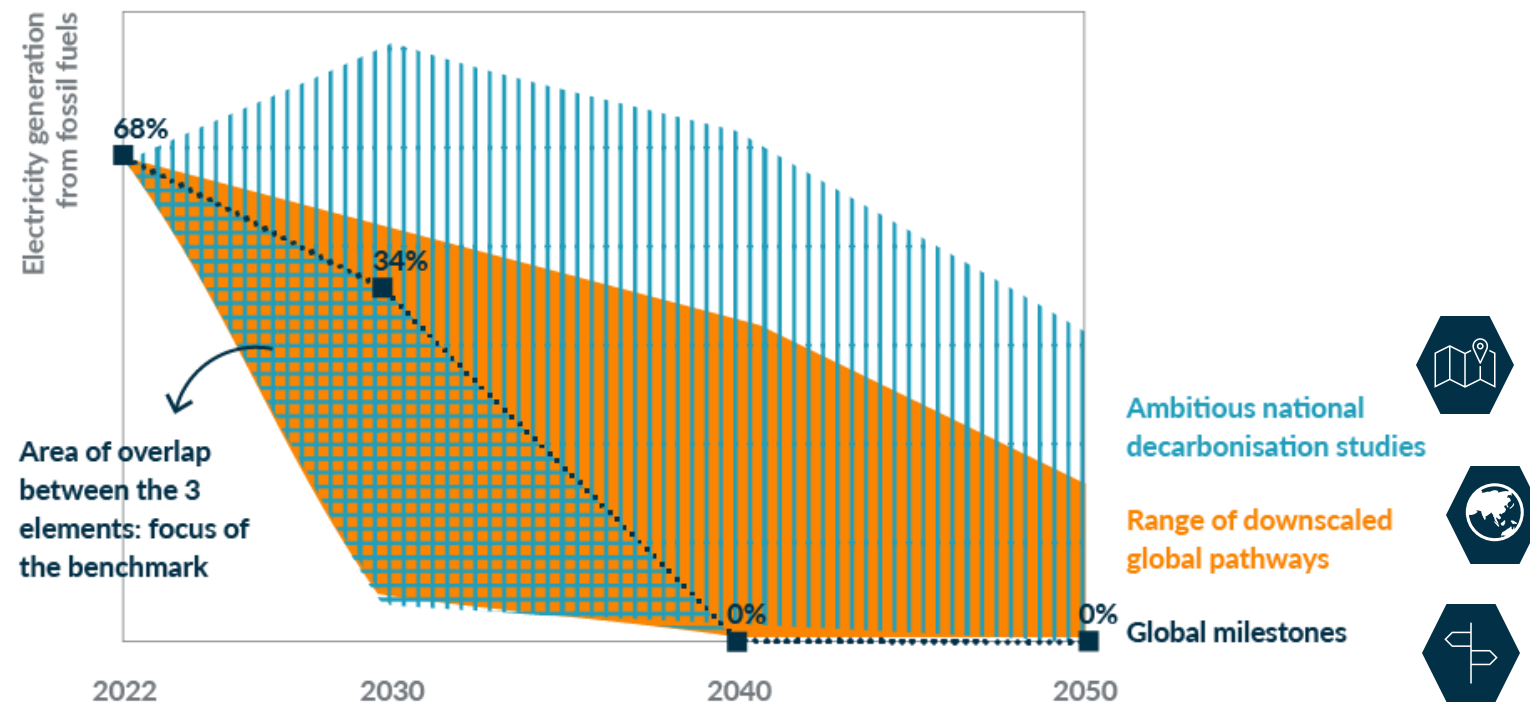
# 1 Total electricity generation

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



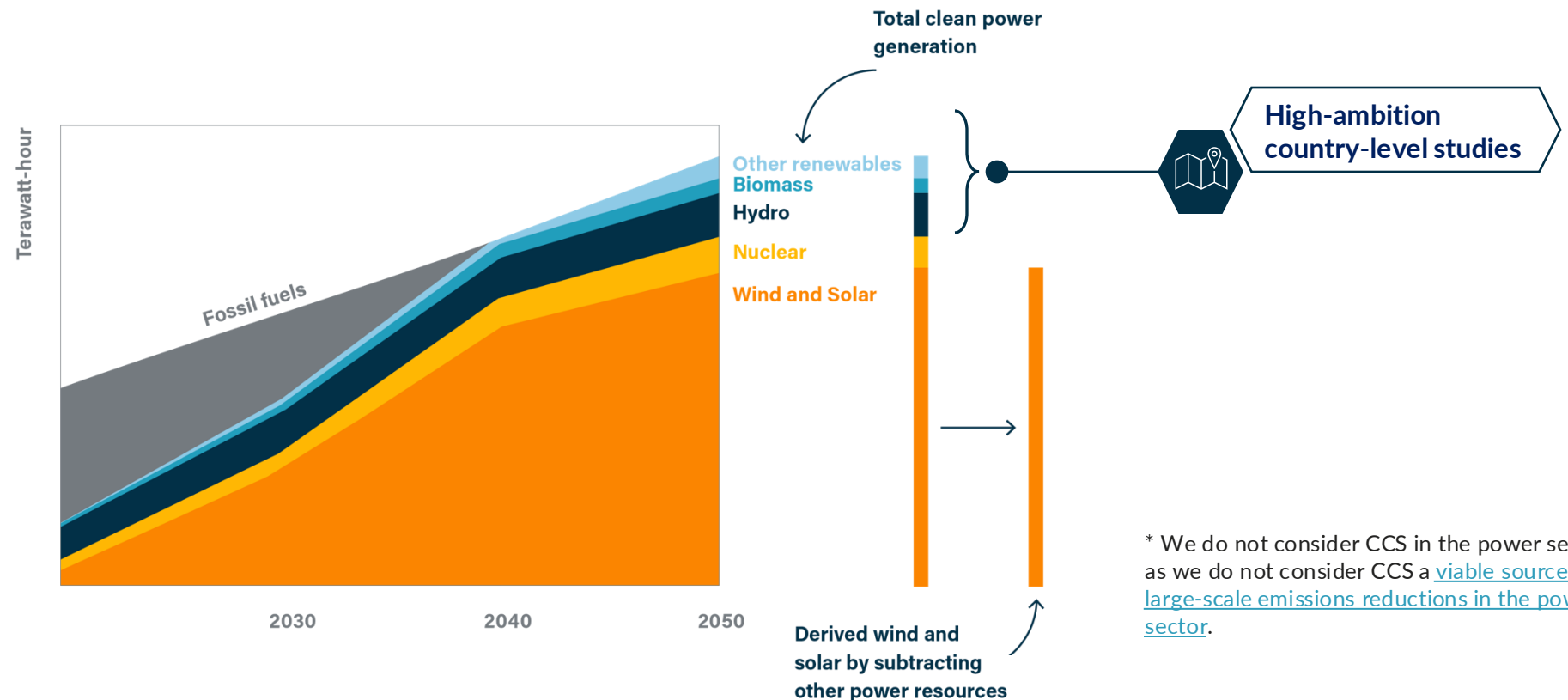
## 2 Fossil fuel phase-out

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



# 3 4 Calculate wind and solar generation

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

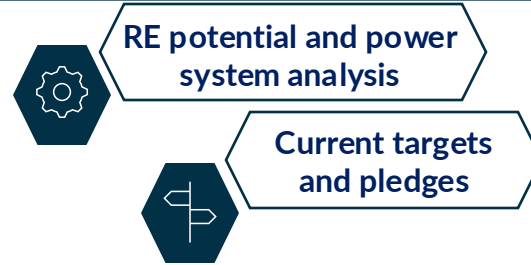


\* We do not consider CCS in the power sector, as we do not consider CCS a [viable source of large-scale emissions reductions in the power sector](#).

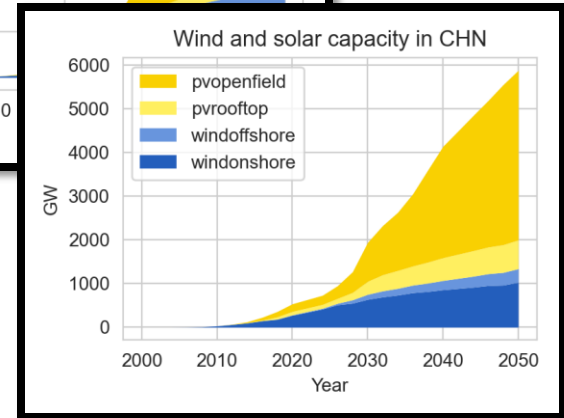
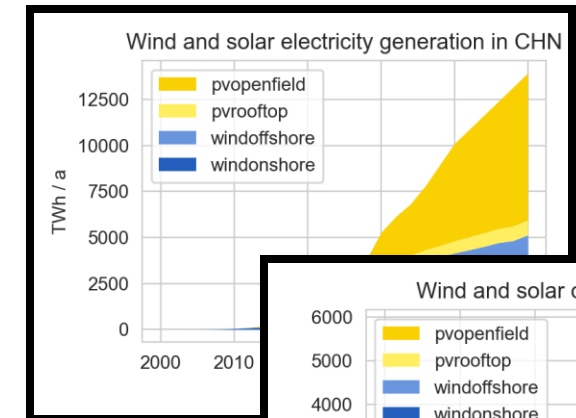
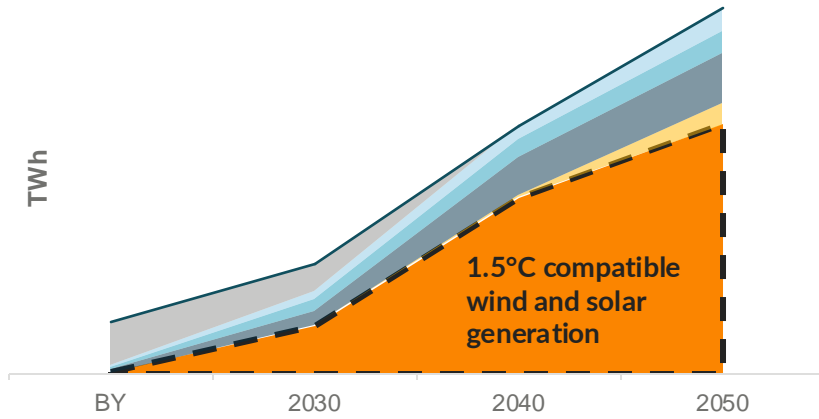
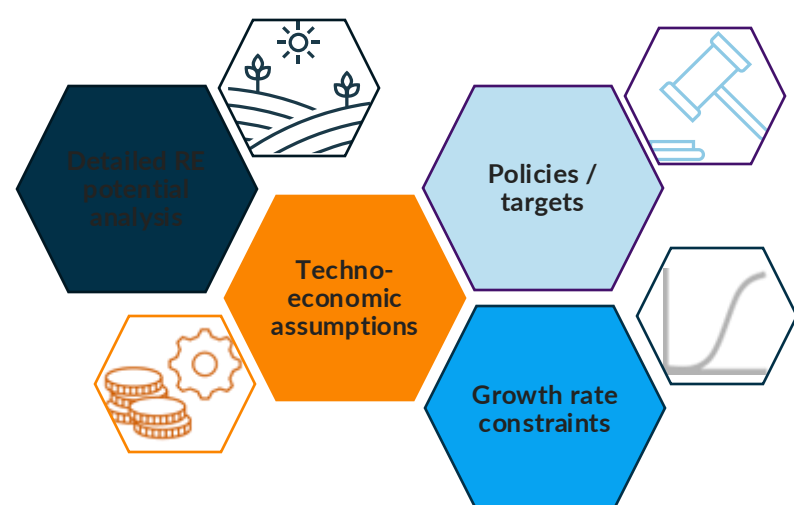
# 5 Wind and solar breakdown

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)



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	<p>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</p> <ul style="list-style-type: none"><li>• Wind = 16% per year</li><li>• Solar = 33% per year</li></ul> <p>These constraints are applied to both total capacity and capacity additions.</p>
Adequacy factor	<p>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.</p>
Wind and solar costs	<p>We produce a range of different cost curves for wind and solar in each country, based on IRENA data. For more details see the <a href="#">technical annex</a>.</p>