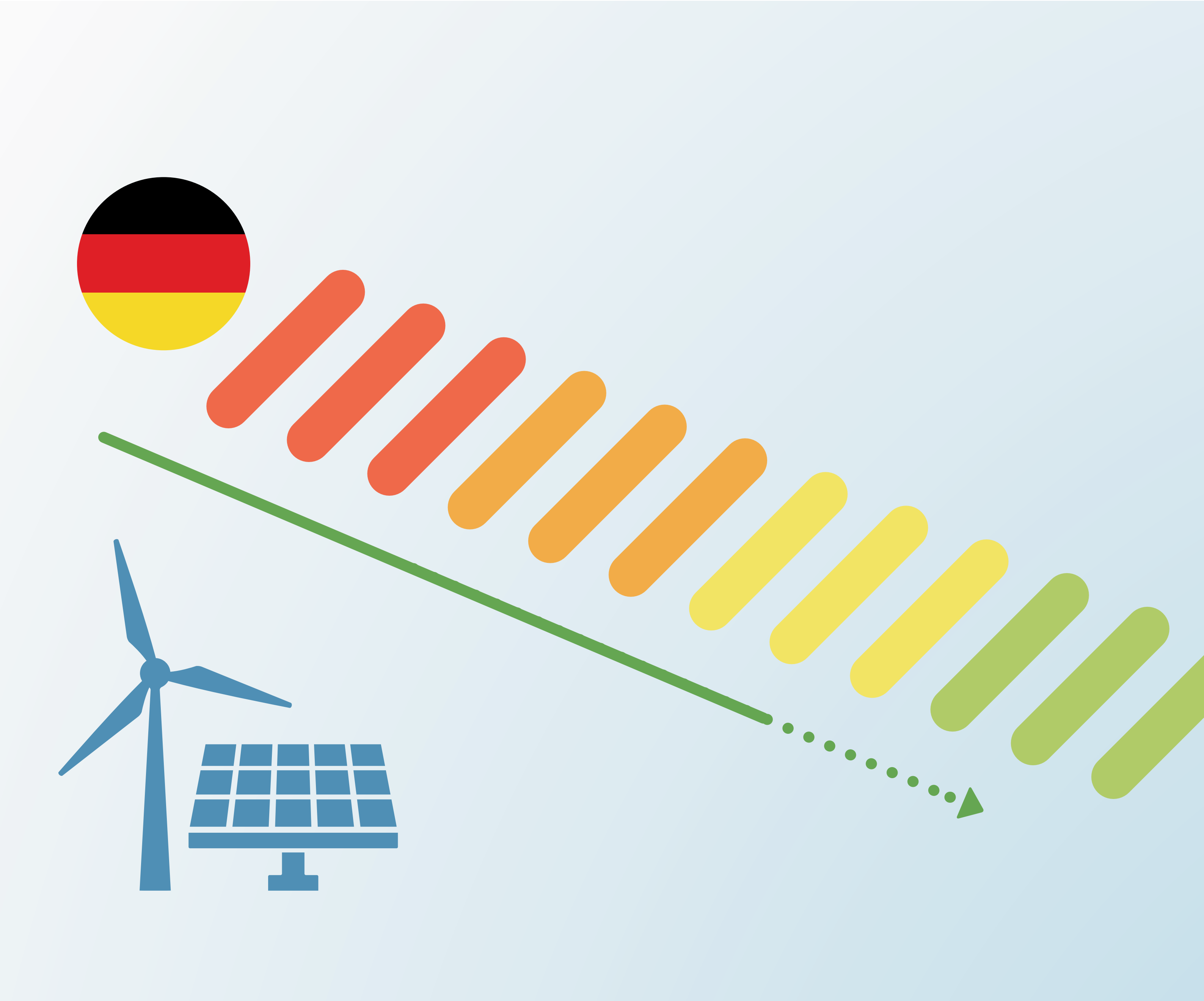


Climate Action Tracker

Wind and Solar benchmarks for a 1.5°C world

GERMANY

February 2026

CLIMATE ANALYTICS

NEW CLIMATE INSTITUTE

Executive Summary

Context

- In 2023, nearly half of Germany's electricity came from fossil fuels. Per capita emissions were above the global average.
- Wind (27%) became the largest single contributor to electricity generation, marginally surpassing coal (26%). The share of wind and solar (39%) is 3x that of the global average (13%).
- As part of its RE law, Germany aims to achieve more than 80% of electricity through renewables by 2030, and 100% by 2035. The country's Climate Law has set ambitious total net zero emissions target for 2045, which includes clearly defined annual build-out targets enshrined in law.
- This implies a complete phase-out of coal in the next decade, although the pace of fossil fuel phase-out is less clear and remains controversial.
- This report examines the wind and solar capacity installation Germany needs for a 1.5°C compatible pathway, aligning with the goal of tripling renewables by 2030.

Key findings

- By 2030, Germany's wind and solar generation must more than triple from 2022 levels, with wind capacity more than doubling and solar capacity almost quadrupling.
- Rollout projections show both solar and wind falling short of the 250 GW and 145 GW benchmarks, respectively.
- Germany's wind and solar 2030 targets broadly align with the 1.5°C benchmarks.
- Over the rest of this decade, annual capacity additions need to grow almost 5x on average for wind and almost triple for solar. The country has achieved comparable deployment rates in the past for wind, showing that these benchmarks are achievable.
- Despite a recent slowdown, our modelling predicts wind power will continue to generate more electricity than solar, consistent with country studies and government efforts to promote wind power.
- Fossil fuel phase-out in the next decade is crucial for meeting national targets and ensuring alignment with 1.5°C wind and solar benchmarks; our analysis suggests the share of fossil fuels must decrease by 68-76% by 2030.

Wind & solar
1.5°C benchmarks

Generation capacity in **2022**	Generation capacity in **2030**
133 GW	**400 GW**
66 GW Wind	**150 GW** Wind
67 GW Solar	**250 GW** Solar

Context

At COP28, governments agreed to triple global renewable capacity by 2030 globally to stay in line with 1.5°C. This report highlights the potential implications of this COP28 decision at the national level, focusing on **Germany**.

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 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, and how quickly?**

Policy context

Germany's current NDC is to reduce emissions to at least 65% below 1990 levels by 2030, **a 53% reduction on 2010 levels** excluding LULUCF. The country has a net zero target for 2045.

Germany's current renewable targets are to reach **215 GW of solar and 145 GW of wind by 2030**, as per the Renewable Energy Sources Act (EEG 2023) and the Windenergie-auf-See-Gesetz (WindSeeG), released by the German government. Build out targets are separated by year and technology (including on and offshore wind). In total the law aims for a minimum generation share of 80% from RE by 2030.

Under current policies and market conditions, the IEA estimates that **solar capacity will reach 212 GW in 2030**, up from 67 GW of solar in 2022. Meanwhile, **wind capacity is projected to reach 121 GW in 2030**, up from 66 GW in 2022.

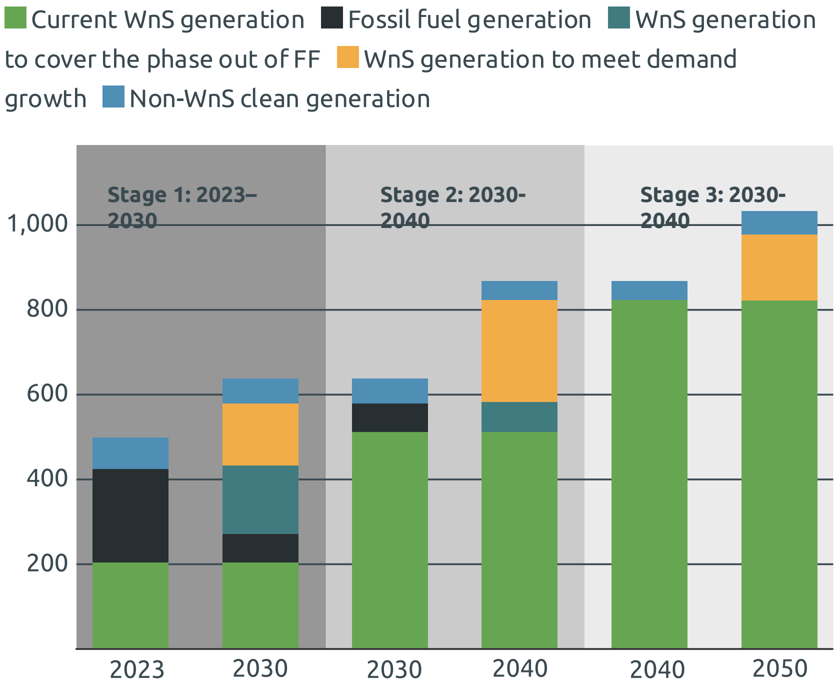
National enabling factors

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 fuel phase-out.** 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 adapted to RE-based systems that incentivise and mobilise investments to install renewable energy at the scale needed (e.g., minimise cost of capital, ensure revenue certainty, etc).

Results

Stages of power sector decarbonisation



The stages of the electricity system transition in Germany

WnS = Wind and Solar

Figure 1 – Electricity generation in each stage in TWh

In a 1.5°C pathway, countries must add solar, wind, and other clean technologies to meet rising power demand while replacing phased-out fossil fuels. The evolution of the power capacity mix over successive decades varies across countries.

From now until 2030, Germany would need to add 35 GW of wind and 82 GW of solar capacity to meet growing demand alone. Another 40 GW of wind and 90 GW of solar will be needed to displace the share of fossil fuels in the electricity generation mix.

Power sector transformation and the increasing participation of variable renewable energy (VRE) – mainly wind and solar – in a country's power mix gives rise to a set of technical challenges linked to the integration of VRE sources. Six phases can be distinguished here, from phase 0 (pre-development with negligible amount of VRE shares) to phase E (with over 80% VRE shares). More information about these phases can be found in Annex A.

Meeting the benchmarks for 2030 will put Germany in Phase D, with wind and solar making up 80% of the generation mix. Periods in which VRE availability exceeds demand occur more frequently than in earlier phases. Ensuring system stability while continuing to increase renewable penetration requires additional measures, such as expanded demand response, stronger interconnections and large-scale energy storage. Market design and regulatory frameworks become increasingly important to enable these solutions. Although particularly critical in this phase, many of these measures should begin in earlier phases (B and C) to provide long-term investment signals and facilitate a smoother system transformation.

Figure 1 and Table 1 both show the stages of the transition to a decarbonised power sector in terms of the volumes of existing wind and solar and what is needed to displace fossil fuels and meet demand increases. Figure 1 shows the stages in terms of electricity generation, and Table 1 shows it in terms of generation, capacity and share of the electricity mix.

Table 1: Stages of the electricity system transition detailing how much generation capacity of wind and solar will be needed to displace fossil fuels in the system and meet growing electricity demand

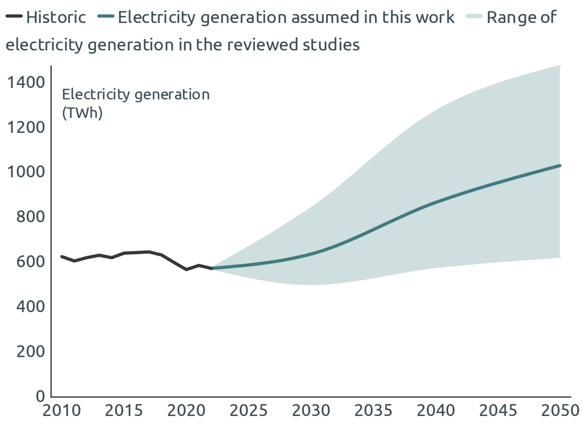
	2023		2030		2040		2050
Grid integration phase (share of variable renewable energy in total electricity generation)							
Phase	Phase C		Phase D		Phase E		Phase E
Share of VRE	**< 40%**		**< 70%**		**> 85%**		**> 85%**
Share of electricity generation							
Wind & Solar	**41 %**		**80 %**		**95 %**		**95 %**
Other renewables	15 %		9.1 %		5.2 %		5.3%
Fossil Fuels	**44 %**		**11 %**		**0 %**		**0 %**
Generation capacity							
To displace fossil fuels		**+130GW**		**+32 GW**		**+0 GW**	
Wind & Solar	**150 GW**	**+36 GW/yr**	**400 GW**	**+14 GW/yr**	**540 GW**	**+4 GW/yr**	**580 GW**
To meet demand increase		**+120 GW**		**+110 GW**		**+48 GW**	
Generation							
Total	**500 TWh**	28%	**640 TWh**	36%	**870 TWh**	15%	**1000 TWh**
Wind & Solar	200 TWh		510 TWh		820 TWh		980 TWh
Generation Capacity of VRE (variable renewable energy)							
To displace fossil fuels			40 GW		8 GW		0 GW
Wind capacity	**71 GW**		**150 GW**		**180 GW**		**230 GW**
To meet demand increase			35 GW		27 GW		48 GW
To displace fossil fuels			90 GW		24 GW		0 GW
Solar capacity	**81 GW**		**250 GW**		**360 GW**		**350 GW**
To meet demand increase			82 GW		82 GW		0 GW

Note: Numbers are rounded to two significant figures, which may contribute to minor differences in totals. The calculations assume that wind, solar, and other renewables contribute equally and proportionally to displacing fossil fuels and meeting demand growth.

Future electricity demand

Electricity demand is taken from the Szenarienvergleich der "Big 5" Klimaneutralitätsszenarien study comparing net zero pathways by 2045 for Germany, in line with the German net zero target. We take demand from the BMWK's LFS TN Strom pathway, which achieves net zero CO_2 emissions by 2045. Total electricity generation in Germany almost doubles by 2050 relative to 2020 levels, reaching 1,000 TWh. This is driven mainly by increased electrification.

Generally, studies in Germany that evaluate the 2045 targets tend to largely agree on the expected electricity generation in 2045 ranging from 910 TWh to 1,200 TWh, according to a comparison between the most relevant scenarios. The growth in electricity demand due to electrification drives the expected growth of RE significantly. Our demand estimate is in the middle of the presented range.



Electricity generation almost doubles in Germany over 2022–2050

The solid line shows the electricity generation projection used to develop the benchmarks

Figure 2 – Total electricity generation in TWh

Pace of fossil fuel phase-out needed

The rate of fossil fuel phase-out is set by the overlap between the bottom-up country-level studies and the downscaled 1.5°C compatible global pathways and the global milestones of the IEA's Net Zero roadmap, in which Germany achieves a clean power system by 2035.

To align with 1.5°C, fossil fuels must exit the German power sector during the 2030s.

The time frame until 2030 is critical. Fossil fuel generation needs to fall by 68-76% by 2030, compared to 2022 levels.

The fastest rate of fossil phase-out is set by the Fraunhofer et al. study (Langfristszenarien für die Transformation des Energiesystems in Deutschland).

To align with 1.5°C, fossil fuels must exit the power sector in Germany by 2035, while meeting growing electricity demand

Germany would need to achieve clean electricity by 2035

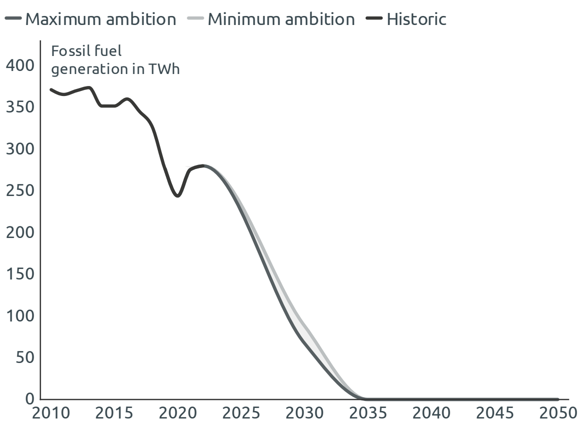


Figure 3 – Fossil fuel generation in TWh

Coal and gas phase-out in Germany

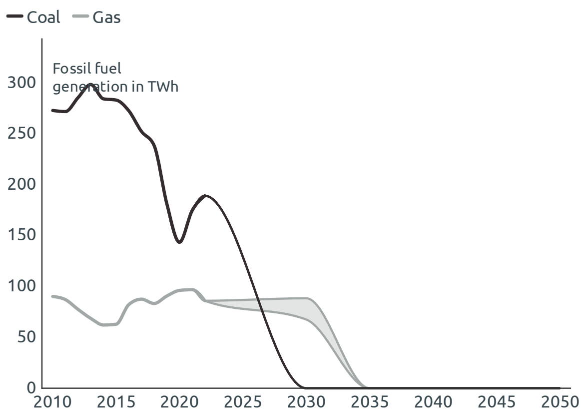


Figure 4 – Fossil fuel generation by fuel type in TWh

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. 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 clean technologies other than wind and solar in Germany would reach 45 TWh by 2030 and 55 TWh by 2050. This is provided by nuclear, hydrogen, biomass, and other renewable technologies.

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

Wind and solar is then needed to drive the phaseout of fossil fuels while meeting demand requirements due to higher electrification rates.

To align with 1.5°C, wind and solar generation in Germany would need to reach 600 TWh by 2030. Generation in 2022 was 186 TWh. This is therefore a greater than 3-fold growth in wind and solar.

Wind and solar provides 79-82% of overall electricity generation in 2030, and 95% of overall generation in 2050.

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

Wind and solar generation needs to almost triple by 2030 relative to 2022 in Germany

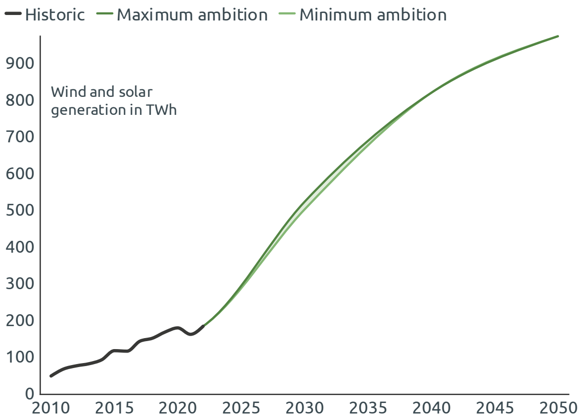


Figure 5 – Wind and solar electricity generation in TWh

Wind and solar would need to provide around 95% of electricity generation in Germany by 2050

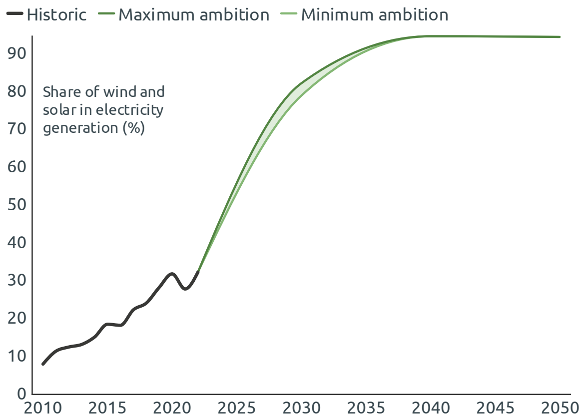


Figure 6 – Wind and solar electricity generation share (%)

* 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.

Possible splits between 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, **Germany would need to deploy around 400 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 towards **580 GW**. Due to its higher capacity factor, greater wind deployment would reduce total capacity requirements.

Germany needs to reach almost 400 GW of wind and solar installed capacity by 2030 to align with 1.5°C

Solar capacity would reach 250 GW in Germany by 2030 in a 1.5°C-aligned scenario

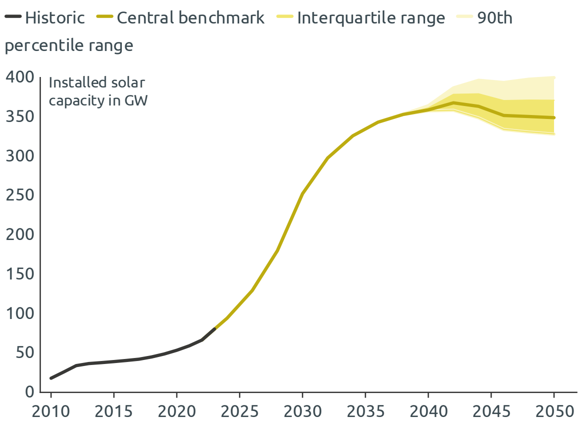


Figure 7 – 1.5°C compatible capacity benchmarks for solar in GW

Wind capacity would reach 140 GW in Germany by 2030 in a 1.5°C-aligned scenario

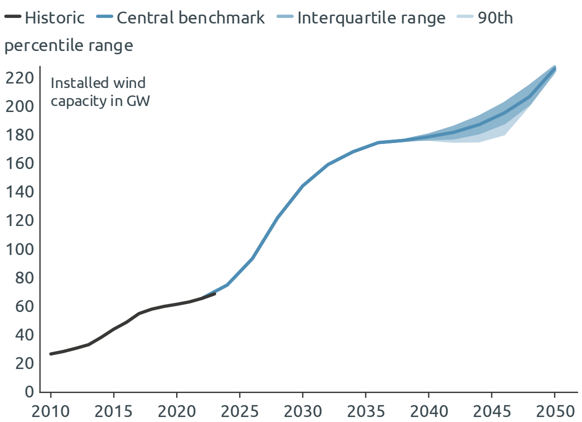


Figure 8 – 1.5°C compatible capacity benchmarks for wind in GW

Note: The benchmarks assume action from 2022.

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.

Table 2: Wind and solar electricity generation and capacity (2022–2050)

Scenario	Variable	Unit	2022	2030	2035	2040	2050
Central 1.5°Cbenchmark	Solar generation	TWh	62	270	360	370	350
Central 1.5°Cbenchmark	Wind generation	TWh	124	330	420	450	660
Central 1.5°Cbenchmark	Solar capacity	GW	67	250	340	360	350
Central 1.5°Cbenchmark	Wind capacity	GW	66	150	170	180	230

Table 3: Benchmarks translated into CAT format

Variable	Ambition	Unit	2030	2035	2040	2045	2050
Share of coal	Minimum	%	0	0	0	0	0
	Maximum	%	0	0	0	0	0
Share of gas	Minimum	%	14	0	0	0	0
	Maximum	%	11	0	0	0	0
Share of renewables	Minimum	%	86	100	100	100	100
	Maximum	%	89	100	100	100	100
Share of wind and solar	Minimum	%	77	94	95	95	95
	Maximum	%	80	94	95	95	95

Comparison to current rollout and country target

Under current policies and market conditions, the projected solar deployment in Germany is in line with the 1.5°C benchmark. This development exceeds the targets set out in law. In contrast, while the target for wind power is aligned with a 1.5°C buildout, the projected wind rollout for Germany by the IEA is below the wind benchmark outlined in our analysis by 2030. However, German law has a mechanism to correct for this misalignment. The largest risk in the country is a potential roll-back of the existing target under future governments.

To align with the 1.5°C target, the period until 2030 is critical. Despite recent progress, the country must substantially accelerate the pace of annual capacity installations over the remainder of the decade, compared to 2020–2023. Annual capacity additions need to grow almost five-fold on average for wind and almost triple for solar. However, Germany has done it in the past, where they were able to deliver on the buildout speed needed for wind.

There is strong support from businesses for high ambition from the government to phase out fossil fuels and transition the electricity system to be powered by renewables, with 98% of executives from Germany polled in the Global Business Poll in favour of and 71 % wanting to see this transition by 2035.

Germany's solar rollout broadly aligns with 1.5°C, while wind rollout needs accelerating in line with the buildout outlined by the law

Current rollout of solar in Germany comes close to aligning with 1.5°C

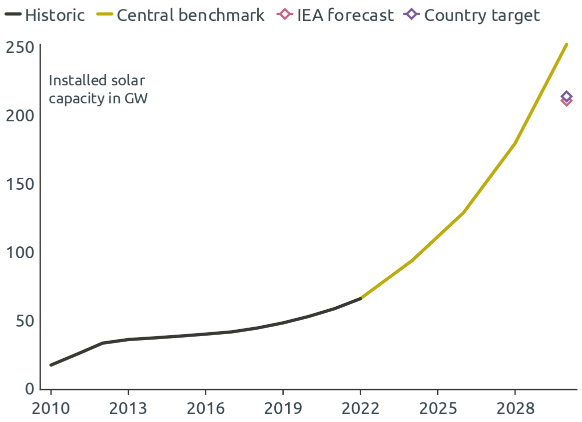


Figure 9 – Installed solar capacity in 2030 compared to targets and current policy projections in GW

The current wind capacity target in Germany aligns with 1.5°C, but current rollout needs accelerating

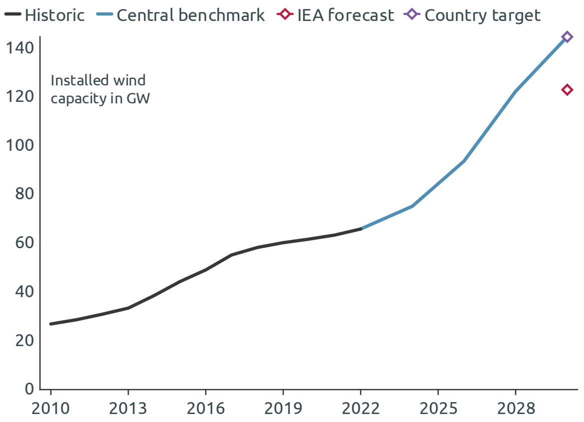


Figure 10 – Installed wind capacity in 2030 compared to targets and current policy projections in GW

Note: The target data was last pulled from Ember in January 2025. The current policies data was last pulled from the IEA in June 2025.

Solar additions in Germany must continue their exponential growth, while wind needs to return to its highest historical growth rates

Germany would need to add on average 22 GW/yr of solar capacity until 2030, and 9.1 GW/yr by over 2030–2050

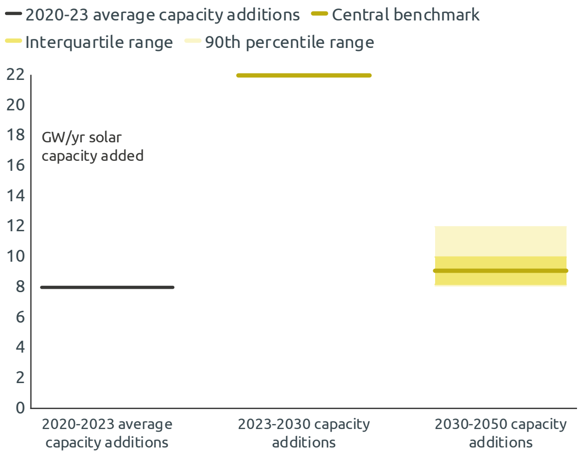


Figure 11 – Solar capacity additions per year in GW/y

Germany would need to add on average 11 GW/yr of wind capacity until 2030, and 7.2 GW/yr by over 2030–2050

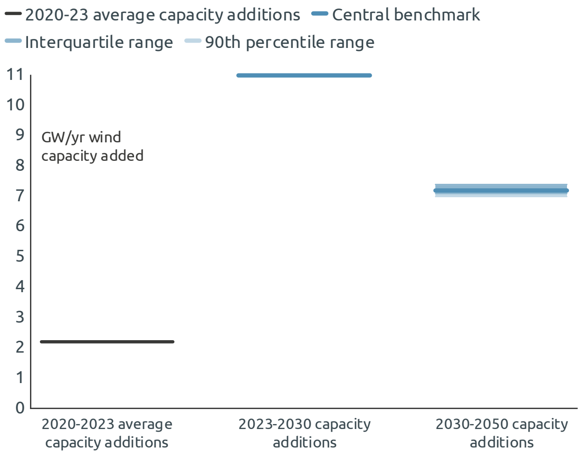


Figure 12 – Wind capacity additions per year in GW/y

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 Ariadne Projekt Big 5, exploring net zero pathways for Germany.

We see that the wind and solar generation that our method produces is broadly within the range of the national literature. Our analysis shows solar and wind generation at the higher end of the pathways in the study highlighted from the Ariadne Projekt Big 5, particularly by 2050.

Despite the recent slowdown in wind development, our modelling sees wind power generating more electricity than solar in 2030, 2040, and 2050, in-line with country-level studies and government efforts to promote wind development.

The increase in wind and solar generation in our benchmarks aligns with national literature

Electricity generation from solar: comparison with literature in Germany

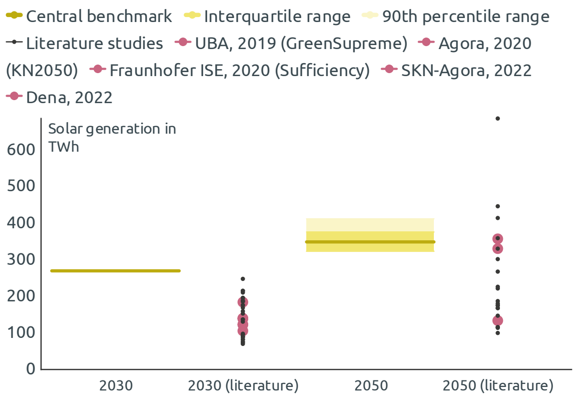


Figure 13 – Solar electricity generation in TWh

Electricity generation from wind: comparison with literature in Germany

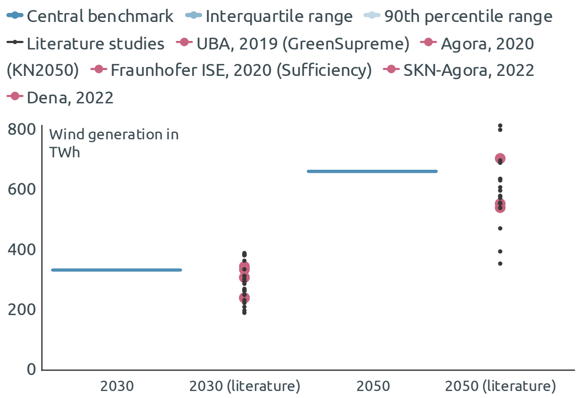


Figure 14 – Wind electricity generation in TWh

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

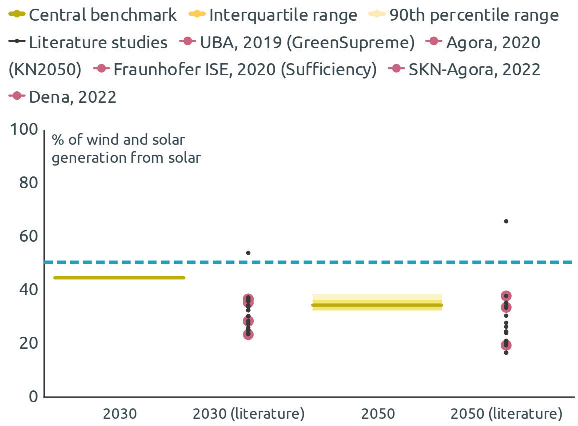


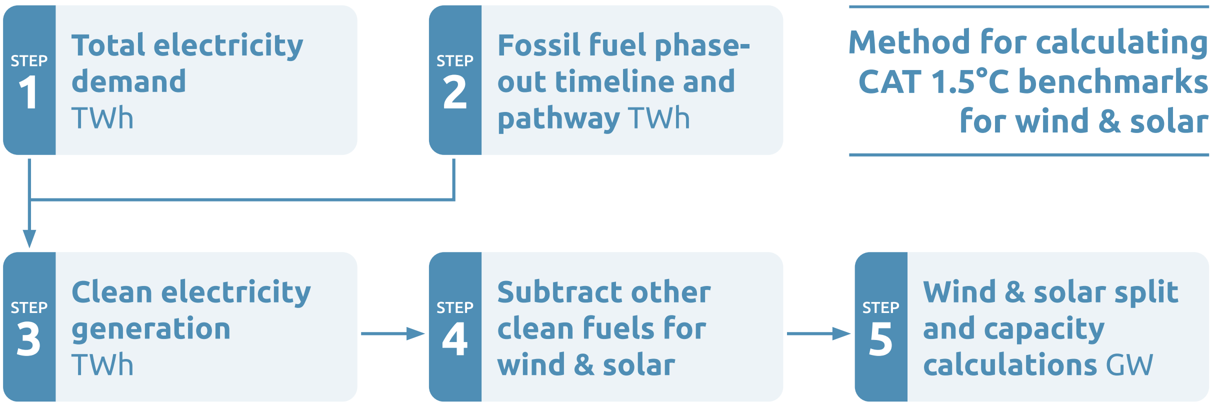
Figure 15 – Generation split between wind and solar (%)

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

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

Methodology

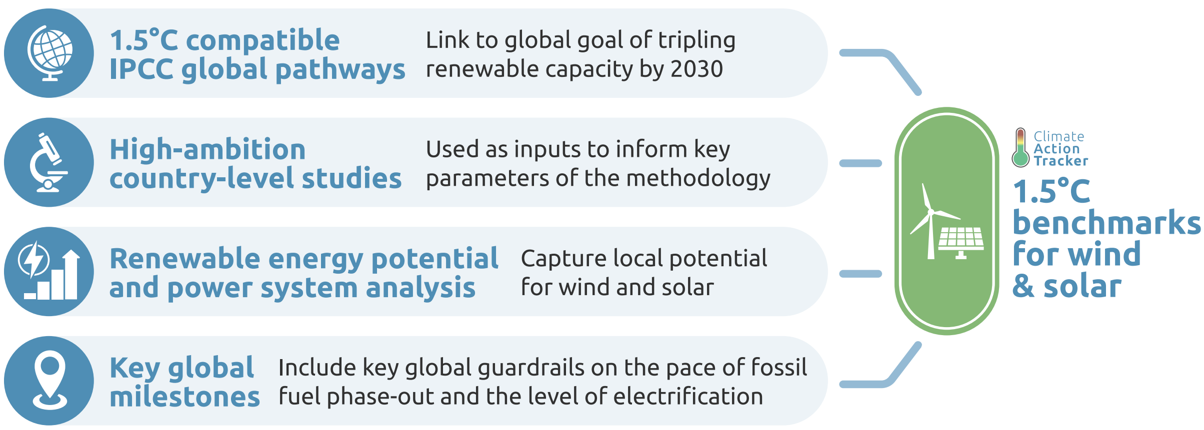
Summary of our method



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 (PyPSA), which calculates for a given set of cost assumptions around wind and solar, a split into wind versus solar and the associated capacity requirements.

Overlap of different elements



Our method focuses on the overlap between different elements. By looking at the range of fossil fuel phase-out which is outlined in both high ambition country-level studies and downscaled 1.5°Ccompatible 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.

For more details see the Methods Annex.

List of scenarios selected

Table 4: Country level studies for Germany

Study	Publication	Scenario selected
Agora Energiewende, 2020	Klimaneutrales Deutschland	• Climate-neutral 2050 (KN2050) • Klimaneutral Minimalvariante (KNmin)
Agora Energiewende, 2023	Climate neutral power system 2035	KNS2035
ARIADNE, 2019	Szenarienvergleich der "Big 5" Klimaneutralitätsszenarien	• REMIND Mix • REMod Mix • Times PANEU Mix
Bartholdsen *et al.*, 2019	Pathways for Germany's low-carbon energy transformation towards 2050	• Green Democracy (GD)BDI
Bundesverband der Deutschen Industrie (BDI), 2018	Klimapfade für Deutschland	• Global Climate Protection 80 • Global Climate Protection 95
BDI, 2022	Szenarienvergleich der "Big 5" Klimaneutralitätsszenarien	Klimapfade 2.0 Zielpfad
BMWK, 2022	Szenarienvergleich der "Big 5" Klimaneutralitätsszenarien	LFS TN Strom
Deutsche Energie-Agentur (dena), 2018	Integrierte Energiewende: Impulse für die Gestaltung des Energiesystems bis 2050	• Electrification95 • TechnologyMix9
Dena, 2022	Szenarienvergleich der "Big 5" Klimaneutralitätsszenarien	KN 100

Forschungszentrum Jülich (FZJ), 2020	Wege für die Energiewende	Scenario 95
Fraunhofer *et al.*, 2020	Langfristszenarien für die transformation des Energiesystems in Deutschland	
Fraunhofer *et al.*, 2023	Stromsystem Deutschland Leistung T45_var2023 / Electricity System Germany Capacity T45_var2023	T45-Strom*
Fraunhofer ISE, 2020	Wege zu einem klimaneutralen Energiesystem	• Reference • Persistence • Non-acceptance • Sufficiency
Joachim Nitsch, 2021	Was für einen erfolgreichen Klimaschutz erforderlich ist	KLIMA-21
SKN-Agora, 2022	Szenarienvergleich der "Big 5" Klimaneutralitätsszenarien	KNDE2045
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
UBA, 2019	Transformationsprozess zum treibhausgasneutralen und ressourcenschonenden deutschland	• GreenEe1 • GreenEe2 • GreenLate • GreenMe • GreenLife • GreenSupreme

Annex A

Phases of grid integration

The grid integration phase is adapted from a de Vivero et al. report detailing a qualitative assessment framework for power system transformation and an IEA report on integrating solar and wind. We use the share of VRE sources in electricity generation to classify countries into a phase. More information about the characteristics and key challenges of each phase can be found in the report.

Phase 0 (less than 5% annual VRE share): we assign this phase when wind and solar make up 0-5% of a country's electricity generation mix. Installed VRE capacity is limited, and the impact on power system operation is negligible. Integration does not require significant operational or structural changes.

Phase A (between 5% and 15% annual VRE share): we assign this phase when wind and solar make up 5-15% of a country's electricity generation mix. Conventional power system operation remains largely sufficient for day-to-day system management. However, system planning must anticipate higher future VRE shares. This includes improving forecasting tools, integrating forecasting into dispatch decisions and moving toward shorter scheduling intervals and more real-time system operation.

Phase B (between 15% and 25% of annual VRE share): we assign this phase when wind and solar make up 15-25% of a country's electricity generation mix. The contribution of VRE varies significantly over time, with periods of very low output and periods of high penetration. This variability increases the need for operational flexibility. Enhanced coordination between system operators, network operators, and distribution system operators becomes critical to maintain system efficiency and security.

Phase C (between 25% and 40% of annual VRE share): we assign this phase when wind and solar make up 25-45% of a country's electricity generation mix. Periods in which VRE dominates system behaviour become increasingly frequent. A key operational challenge is maintaining system stability during sudden disruptions in supply or demand. Curtailment of VRE may become necessary to preserve system security. Without structural adjustments, integration constraints of VRE into the system may slow further increases in renewable energy shares despite additional installed capacity.

Phase D (between 40% and 70% of annual VRE share): we assign this phase when wind and solar make up 45-80% of a country's electricity generation mix. Periods in which VRE availability exceeds demand occur more frequently than in earlier phases. Ensuring system stability while continuing to increase renewable penetration requires additional measures, such as expanded demand response, stronger interconnections and large-scale energy storage. Market design and regulatory frameworks become increasingly important to enable these solutions. Although particularly critical in this phase, many of these measures should begin in earlier phases (B and C) to provide long-term investment signals and facilitate a smoother system transformation.

Phase E (more than 70% share of annual VRE share): we assign this phase when wind and solar make up 80-100% of a country's electricity generation mix. The power system reaches very high VRE penetration. The primary challenge becomes ensuring adequacy during extended periods of low wind and solar availability. Addressing this requires long-duration energy storage, sector coupling allowing for export and import of power between economic sectors in the same country and extensive electricity trade both within regions and between countries.

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The Consortium

The Climate Action Tracker (CAT) is an independent scientific analysis produced by three research organisations tracking climate action since 2009. We track progress towards the globally agreed aim of holding warming well below 2°C, and pursuing efforts to limit warming to 1.5°C.

climateactiontracker.org

Climate Analytics is a non-profit institute leading research on climate science and policy in relation to the 1.5°Climit in the Paris Agreement. It has offices in Germany, the United States, Togo, Australia, Nepal and Trinidad and Tobago.

climateanalytics.org

NewClimate Institute is an independent non-profit organisation that develops solutions to tackle climate change and drives their implementation worldwide. Through research, policy advice and knowledge sharing, we aim to raise the ambition for climate action and support sustainable development.

newclimate.org