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Germany should accelerate its renewable energy transition

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Germany's energy transition relies on variable renewables and electricity use across sectors, and it needs to accelerate. We argue that consistent policy commitments to proven technologies, such as wind and solar power, heat pumps and electric cars are needed.

Germany is the European Union's largest greenhouse gas emitter and has set ambitious transition targets to achieve climate neutrality by 2045. With the adoption of the Renewable Energy Sources Act in 2000, Germany laid the groundwork for a transition to renewables and electrification, also known as the *Energiewende*.

Germany's renewable energy supply relies primarily on variable wind and solar energy: the country lacks significant potential for geothermal or hydropower and has, after decades of controversies, given up the use of nuclear power. Lacking public acceptance, the option of fossil-fuel-based electricity generation with carbon capture and storage has been ruled out so far – but is now under discussion again. On the consumption side, widespread electrification is Germany's main strategy to decarbonise heating, transport and industry.

Today, Germany ranks among the countries with the highest per capita capacity of wind and solar power[1]. The share of renewables in German electricity consumption has steadily increased from 6% in 2000 to 54% in 2024. At the same time, greenhouse gas emissions in the energy sector have come down by 53%. The latest revision of the Renewable Energy Sources Act, entering into force in 2023, stipulates that renewables have to cover at least 80% of gross electricity demand by 2030. This target includes the additional load of electric vehicles, heat pumps and hydrogen production by electrolysis. After the coal-phase out, to be completed by 2038 according to current laws, the German electricity sector is planned to become carbon-neutral. The 2021-2024 government has further introduced ambitious specific targets for key technologies such as wind and solar power, electric cars and heat pumps that are largely in line with up-to-date energy system scenarios that reach net-zero greenhouse gas emissions by 2045[2] (Table 1). A new government assumed office in May 2025 and has indicated to downsize some of these targets with the intention to reduce the costs of the transition[3]. The policy shift of the new German government to prioritize competitiveness and cost reduction over decarbonisation can also be observed in several European countries and institutions.

Here, we advocate that German policymakers should not slow down the renewable energy transition. Rather, an additional acceleration is needed to put the country on the right track towards a low-carbon future and to reap related environmental and economic benefits. Based on open data provided on the Open Energy Tracker[4], we argue that two key signposts are needed at this junction. First, stick to the ambitious targets that will make solar and wind technology the backbone of Germany's energy future. Second, provide firm guidance and support for heat pumps and electric cars, as opposed to hoping for alternative solutions such as e-fuels.

Accelerated expansion of solar and wind energy

Solar photovoltaics capacity has expanded rapidly in Germany, with record capacity additions in 2023 and 2024 (Fig. 1a), primarily from small rooftop systems that account for around two thirds of new as well as existing installations. The combination of a sharp rise in electricity prices in the aftermath of the 2022 energy crisis and decreasing photovoltaics module prices made owning rooftop photovoltaics much more profitable for households and businesses.

Onshore wind power has been growing at a slower rate, hampered by long planning processes and less ambitious targets before 2021. With the current trend, the 2030 target would be missed by far (Fig. 1b). However, an acceleration is already on the horizon: Policy measures to fast-track wind power expansion have led to record-level approvals of 14 GW in 2024 and 10 GW in the first eight months of 2025[5] and pave the way for future growth.

Offshore wind power capacity has grown even less in recent years (Fig. 1c). Here, lead times for new projects are even longer than for onshore wind, and the newly set ambitions will take a few years to materialize. Yet, the framework conditions for strong future growth have recently improved: in 2023 and 2024, nearly double the previously existing offshore wind capacity was successfully tendered[6]. In addition, the federal government, coastal federal states, and grid operators have agreed to realize a grid connection capacity of 30 GW by 2030[7].

All in all, solar and wind energy show promise for meeting the government goals, provided the current trajectory is continued and not slowed down again.

Electrification of end uses lags behind

In sectors such as transport or heating, fossil fuels and associated greenhouse gas emissions can be substituted by the direct use of renewable electricity via battery-electric vehicles or heat pumps, or indirectly by means of electricity-based synthetic fuels. This cross-sectoral integration, referred to as sector coupling, is a matter of urgency. Renewable shares in heating and transport have been largely stagnating for more than ten years in Germany[8], and greenhouse gas emissions trends in these sectors are not in line with achieving climate neutrality by 2045[9].

In the residential sector, Germany's 2021-2024 government set the target of six million heat pumps installed by 2030, compared to a current overall number of heat pumps of around two million (Fig. 2a). Worryingly, installations of new gas or oil heating systems surpassed those of heat pumps in 2023 and 2024, likely as a result of economic and regulatory uncertainty as well as limited experience with this technology among homeowners. Nevertheless, heat pump installations could pick up over the coming years: the current law requires an extensive use of renewable energy sources for newly installed heating systems, for which heat pumps are often the most viable option. However, the new German government has highlighted the idea of technology neutrality and shows no interest in accelerating the heat pump rollout[3,10].

Around 1.9 million pure battery-electric cars are currently registered in Germany, and current growth rates are clearly too low to achieve the target of 15 million electric cars by 2030 (Fig. 2b). In fact, the annual average share of battery-electric vehicles in new car registrations has even been declining from 18.4% in 2023 to 13.5% in 2024, but recently recovered again. Supply of affordable electric car models is still limited and purchase subsidies ended abruptly at the end of 2023. Even if purchase subsidies were reintroduced, the 2030 target would likely remain out of reach. A lack of public charging points is often cited as another reason for the slow take-up of electric cars in Germany (Fig. 2c). Yet, this argument hardly seems valid anymore: averaging over the whole country, the number of electric cars per public fast-charging point has fallen from around 68 at the end of 2022 to around 44 recently. Despite the sluggish offtake of battery-electric cars, the new German government is not pushing for acceleration. On the contrary, the chancellor recently questioned the European regulation to ban the sale of cars with carbon emissions after 2035. The prolongation of the discussion around the ban risks adding new uncertainty for car producers and consumers alike, which could delay technological innovation and risk the long-run competitiveness of the entire sector.

Of the 10 GW electrolysis capacity to produce green hydrogen targeted for 2030, less than two percent is currently in operation. The overall capacity of announced projects would meet the target, but a large proportion of these projects are still at a conceptual planning stage, and their implementation is uncertain. The new government has recently declared its intention to soften this target[3]. The hydrogen demand side and the transport infrastructure are also at very early stages. Measures include the planning and financing of a core network of hydrogen pipelines, public support and de-risking for hydrogen imports, and subsidies for converting selected energy-intensive industrial processes to hydrogen.

Table 1 | Energy transition targets

	Targets for 2030		Targets for 2040	
Government coalition	**2018–2021**	**2021–2024**	**2018–2021**	**2021–2024**
Solar photovoltaics (GW)	100	215	—	400
Onshore wind power (GW)	71	115	—	160
Offshore wind power (GW)	20	30	40	55
Heat pumps (millions)	—	6	—	—
Electric cars (millions)	7–10	15	—	—
Electrolysis (GW)	5	10	—	—

Germany's targets for renewable energy capacity and electrification technologies have increased substantially between the Conservative/Social Democrat coalition of 2018–2021 and the Social Democrat/Green Party/Liberal coalition of 2021–2024.

Stay the course while addressing challenges

While we argue that both renewable expansion and electrification should be pushed forward in Germany, emerging challenges need to be addressed[11]. Two ingredients are required to support the 2030 targets. First, renewable energy sources must be integrated into grids and markets more efficiently, especially small-scale solar photovoltaics. This necessitates dynamic pricing to steer demand according to supply and expanding the grid to remove bottlenecks. Secondly, to enhance resilience, flexible and reliable capacity is needed to ensure security of supply, which also includes long-duration storage for prolonged periods of low renewable energy supply.

Integration of rooftop photovoltaics. The strong expansion of small rooftop photovoltaics systems is often regarded as a positive element of the *Energiewende* as it involves citizens directly. Yet, overall investment costs are higher compared to utility-scale photovoltaics systems, and their integration into electricity markets and grids is currently inefficient. Most households with solar-battery systems do not align self-consumption, storage operation or grid feed-in with the overall system needs: because neither feed-in nor retail tariffs reflect the varying price signals of the wholesale electricity market, there is simply no incentive for a system-oriented operation. In addition, grid operators often lack the technical and regulatory requirements to control the feed-in of small-scale solar

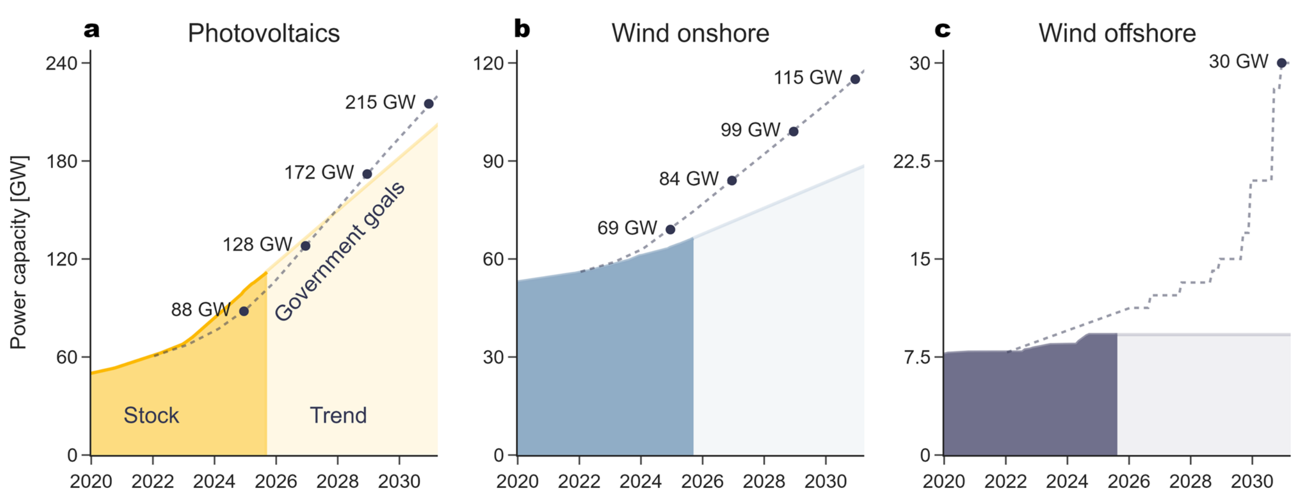

Fig. 1 | Stock, trend and goals for Germany's renewable energy capacity. Photovoltaics (**a**) track above government goals for 2030, whereas onshore (**b**) and offshore (**c**) wind energy trail behind targets. Darker colours depict evolution of stock, lighter colours denote an extrapolation of the trend over the past 12 months. Dotted lines signify current government goals. Data from the Open Energy Tracker[4].

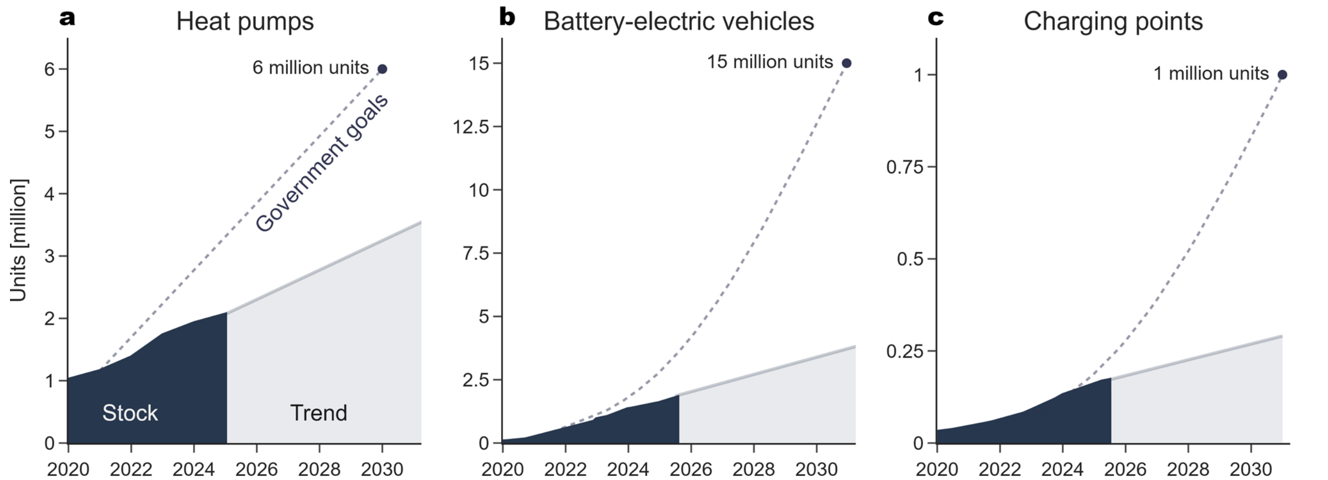

Fig. 2 | Stock, trend and goals for Germany's renewable energy capacity. Photovoltaics (**a**), battery-electric vehicles (**b**) and public charging points (**c**) in Germany. All substantially lag behind government goals. Darker colours depict evolution of stock, lighter colours denote an extrapolation of the trend over the past 5 years (**a**) or past 12 months (**b**, **c**). Dotted lines signify current government goals. Data from the Open Energy Tracker[4]. For battery-electric vehicles (**b**) and charging points (**c**), we assume a logistic target path between 2022 and 2030, as the government did not specify an annual path.

installations. Either rooftop photovoltaics systems need to be integrated better into the market or the future expansion needs to focus more on the deployment of utility-scale photovoltaics systems, which are already exposed to fluctuating market prices.

Flexible consumption. A lack of wholesale market price signals applies to most German electricity consumers. The still widespread use of time-invariant tariffs means that consumers lack the incentive to align their consumption with available supply. Consumption needs to be shifted away from periods with low availability of variable renewables and towards periods with high availability. This helps to avoid critical peak loads and high price volatility, to maintain the security of supply, and to ensure low-cost renewable integration. To improve the situation, tariffs that reflect variable wholesale price signals, metering and communications infrastructure, as well as different types of energy storage[12] are all needed. Prices should further reflect the value of electricity at a given location, putting the single German price zone into question.

Grid expansion. Transmission and distribution grids must absorb increasing amounts of electricity from variable renewable sources whose locations differ from legacy grid layouts. Due to political decisions in the past and recent material cost increases, very high costs are estimated for future grid expansions[11]. To minimize grid expansion, the location of future consumers could be optimised, such as electrolysers placed close to offshore wind power farms, in combination with regional pricing[2].

Security of supply. Some type of capacity mechanism appears necessary to ensure the security of supply and to contain excessive price spikes in the electricity market. In Germany, a small capacity reserve and a grid reserve are currently in place; however, they are unlikely to be sufficient. Because of an uncertain economic environment, long planning horizons, and the expectation of future subsidies, investors have shown little interest in building new firm power plants without financial support. While the introduction of a capacity mechanism could resolve this, it should not focus on conventional power plants only, because these would crowd out storage and demand-side flexibility options that are needed to efficiently integrate variable renewables. A centralized capacity market, as proposed by the current German government[3], however, tends to discriminate against such flexibility technologies[13].

Weather-resilience. For a future German energy system to be weather-resilient, it must also be able to cope with prolonged periods of scarcity in variable renewable energy supply[14]. Long-duration hydrogen storage is likely to play a key role here. Because of substantial uncertainties surrounding future quantities and prices of both hydrogen and electricity, it is unlikely that long-duration storage will be adequately ramped up by market actors alone. The construction of hydrogen caverns requires long lead times, therefore, developments should start early, supported by public policies.

Conclusions for policy and research

The German *Energiewende* has made progress, but its full extent has yet to materialize as recently introduced measures take effect. There is still a long way to go for all key technologies. Instead of slowing down the renewable energy transition, policy makers should stay the course. This requires long-term political commitments and enduring support. Based on the experience in Germany, we make recommendations for policy and research, in Germany and beyond.

Variable renewables are the backbone. Germany's energy future is based on variable renewables. Wind and solar power can be at the heart of energy supply for all demand sectors using sector coupling. Research shows that such a strategy is feasible[15,16]. By contrast, unproven options like nuclear fusion are far from ready, and traditional nuclear power is not an option in Germany for political reasons.

We argue that a political consensus is needed to push an ambitious energy transition that is largely based on variable renewables, capitalizing on the recently much-improved conditions for their expansion and leveraging their potential for further cost savings[17]. This transition can also bring a range of environmental co-benefits beyond greenhouse gas emission reductions such as lower local air pollution[18]. Watering down current targets, as now discussed in Germany[3], would conversely endanger long-run expansion plans and investments into supply chains.

Sector coupling requires technology clarity. Sector coupling technologies such as heat pumps and electric vehicles are well-established and proven decarbonization strategies[19–22]. Risking a delay in their adoption because of a political desire to keep technological options open (*Technologieoffenheit*[3]) does not appear to be a cost-efficient strategy. We argue that a clear focus on battery-electric vehicles, including trucks, and heat pumps, instead of perpetuating hopes for hydrogen and e-fuels, can create a thriving environment for respective investment decisions of business and citizens. We believe that technology clarity is more helpful than technology neutrality at this stage. In addition, policy makers should address the issue of high end-user electricity prices, such that electrification becomes economically viable.

A role for research. Research is fundamental for tackling the challenges discussed above. Considering that the energy transition cannot only rely on electrification but also needs strategies to promote energy efficiency and sufficiency. Energy transition research should encompass various disciplines such as energy system analysis, economics, engineering, environmental science, political science, and sociology.

Beyond pure research, researchers should become more active in communicating their findings and the state of knowledge to counter misinformation. Neither should they shy away from pointing out existing and upcoming challenges and potential solutions, nor from highlighting success stories and societal benefits of renewable energy transitions.

The international context. In the short term, concerns about economic competitiveness, distributional effects, and social acceptance pose great challenges for the German renewable energy transition, and the current global outlook is challenging for ambitious climate and energy policies.

We argue that in the long run, the transition to renewable energy sources is likely to offer both an economic and environmental dividend, as it increases Europe's energy security, sovereignty and resilience by reducing its dependence on fossil fuel imports, but can also contribute to its long-term competitiveness. We encourage policymakers not to slow down the transition but to focus on a continued expansion of low-cost renewables, an acceleration of sector coupling, and efficient system integration. A successful and effective renewable energy transition in Germany may well bring about technological, regulatory, political, and social learning that can, in turn, help other countries implement their own energy transitions and foster a virtuous circle.

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References

1. IEA. Renewables 2024. https://www.iea.org/reports/renewables-2024 (2024).
2. Luderer, G. et al. Die Energiewende kosteneffizient gestalten: Szenarien zur Klimaneutralität 2045. Kopernikus-Projekt Ariadne, Potsdam. https://doi.org/10.48485/pik.2025.003 (2025).
3. Federal Ministry for Economic Affairs and Energy. Klimaneutral werden - wettbewerbsfähig bleiben. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Downloads/J-L/klimaneutral-werden-wettbewerbsfaehig-bleiben.pdf (2025).
4. Roth, A. & Schill, W.-P. Open Energy Tracker: An open data platform to monitor energy policy targets. https://openenergytracker.org/en/ (2022).
5. Fachagentur Wind und Solar. Genehmigungen. https://www.fachagentur-wind-solar.de/veroeffentlichungen/wind-und-solar-monitor/genehmigungen-wind#c835 (2025).
6. Bundesnetzagentur. Ausschreibungen für EE- und KWK-Anlagen. https://www.bundesnetzagentur.de/DE/Fachthemen/ElektrizitaetundGas/Ausschreibungen/start.html (2025).
7. Federal Ministry for Economic Affairs and Climate Action. Mehr Windenergie auf See. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Downloads/neue-offshore-realisierungsvereinbarung-30-gw-bis-2030pdf.html (2022).
8. Federal Ministry for Economic Affairs and Climate Action. Time series for the development of renewable energy sources in Germany. Status: February 2025. https://www.bmwk.de/Redaktion/DE/Downloads/Energie/zeitreihen-zur-entwicklung-der-erneuerbaren-energien-in-deutschland-1990-2024-en.pdf (2025).
9. Wehnemann, K. et al. Treibhausgas-Projektionen 2025 – Ergebnisse kompakt. Umweltbundesamt. https://doi.org/10.60810/openumwelt-7821 (2025).
10. CDU, CSU, SPD. Verantwortung für Deutschland, Koalitionsvertrag zwischen CDU, CSU und SPD, 21. Legislaturperiode. https://www.koalitionsvertrag2025.de/ (2025).
11. EWI & BET. Energiewende. Effizient. Machen. – Monitoringbericht zum Start der 21. Legislaturperiode. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Publikationen/Energie/energiewende-effizient-machen.html (2025).
12. Roth, A. et al. Power sector benefits of flexible heat pumps in 2030 scenarios. *Communications Earth & Environment* **5**, 718 (2024).
13. Klaucke, F. et al. An advanced reliability reserve incentivizes flexibility investments while safeguarding the electricity market. https://arxiv.org/abs/2506.14664 (2025).
14. Ohlendorf, N. & Schill, W.-P. Frequency and duration of low-wind-power events in Germany. *Environmental Research Letters* **15**, 084045 (2020).
15. Brown, T. et al. Response to 'Burden of proof: A comprehensive review of the feasibility of 100% renewable-electricity systems'. *Renewable and Sustainable Energy Reviews* **92**, 834–847 (2018).
16. Pickering, B. et al. Diversity of options to eliminate fossil fuels and reach carbon neutrality across the entire European energy system. *Joule* **6**, 1253–1276 (2022).
17. Way, R. et al. Empirically grounded technology forecasts and the energy transition. *Joule* **6**, 2057–2082 (2022).
18. Luderer, G. et al. Environmental co-benefits and adverse side-effects of alternative power sector decarbonization strategies. *Nature Communications* **10**, 5229 (2019).
19. Šimaitis, J. et al. Battery electric vehicles show the lowest carbon footprints among passenger cars across 1.5–3.0 °C energy decarbonisation pathways. *Communications Earth & Environment* **6**, 476 (2025).
20. Van Heerden, R. et al. Demand-side strategies enable rapid and deep cuts in buildings and transport emissions to 2050. *Nature Energy* **10**, 380–394 (2025).
21. Rosenow, J. A meta-review of 54 studies on hydrogen heating. *Cell Reports Sustainability* **1**, 100010 (2024).
22. van der Zwaan, B. et al. Electricity- and hydrogen-driven energy system sector-coupling in net-zero CO2 emission pathways. *Nature Communications* **16**, 1368 (2025).

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W.S. wrote the initial draft of the manuscript, co-developed the underlying Open Energy Tracker and secured research funding. A.G. revised and edited the manuscript and helped maintain the underlying Open Energy Tracker. A.R. revised and edited the manuscript, produced the graphs and developed the underlying Open Energy Tracker. F.S. revised and edited the manuscript and helped maintain the underlying Open Energy Tracker.

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