A Climate-Neutral Power System in Germany in 2035

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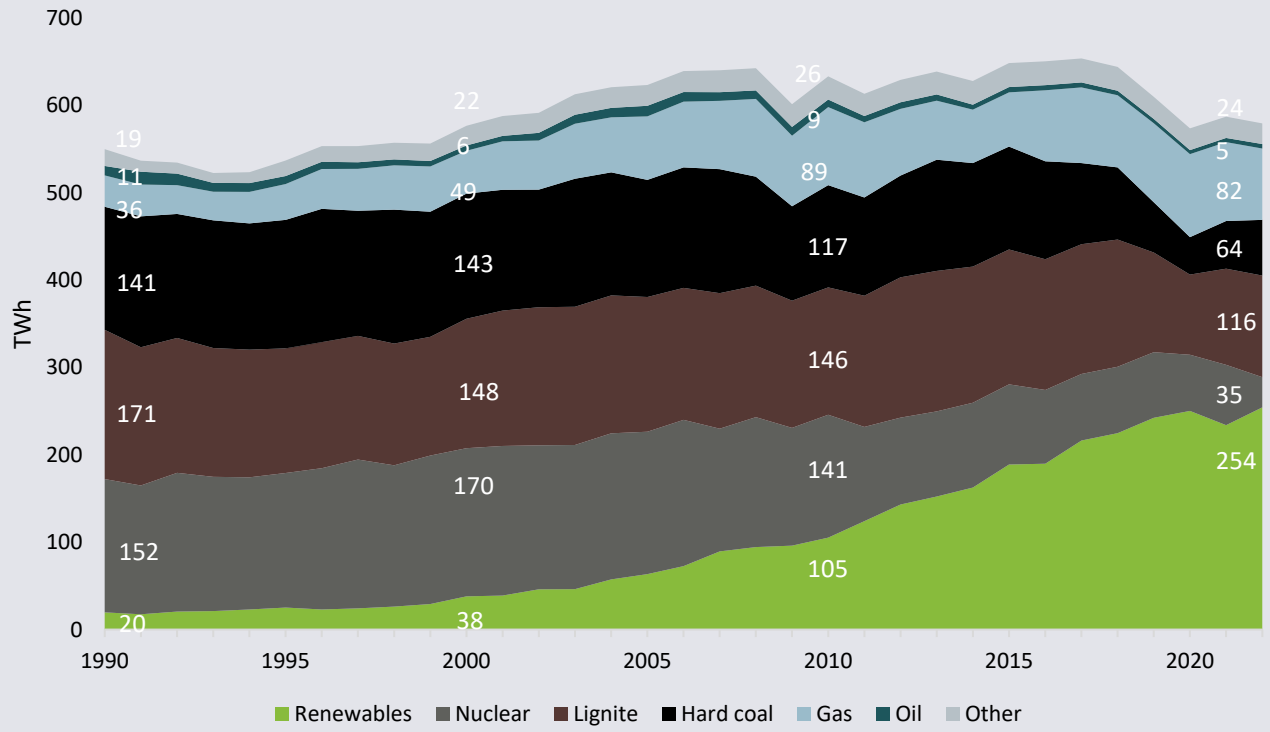
Agora Energiewende

- **Think Tank** and **Policy Lab**
- **~150 energy transition experts**
- **Independent** and non-partisan with diverse financing structure
- **Our vision:** a prosperous and **carbon-neutral global economy** by 2050
- **Science-based solutions and policy advice** to deliver **clean power, heat, industries, and agriculture** – in Germany, Europe, and globally
- **Programs in ~20 countries**, with offices in Berlin, Brussels, Beijing and Bangkok

The expansion of renewables has substituted nuclear, lignite and hard coal, while gas consumption has also been growing

Power generation by source in Germany, 1990 - 2021

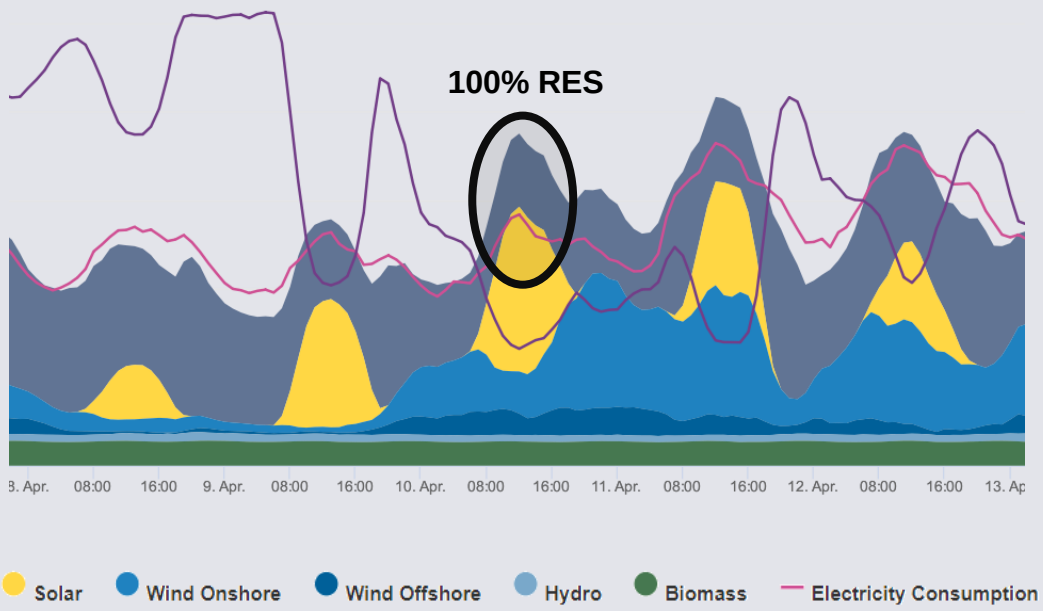


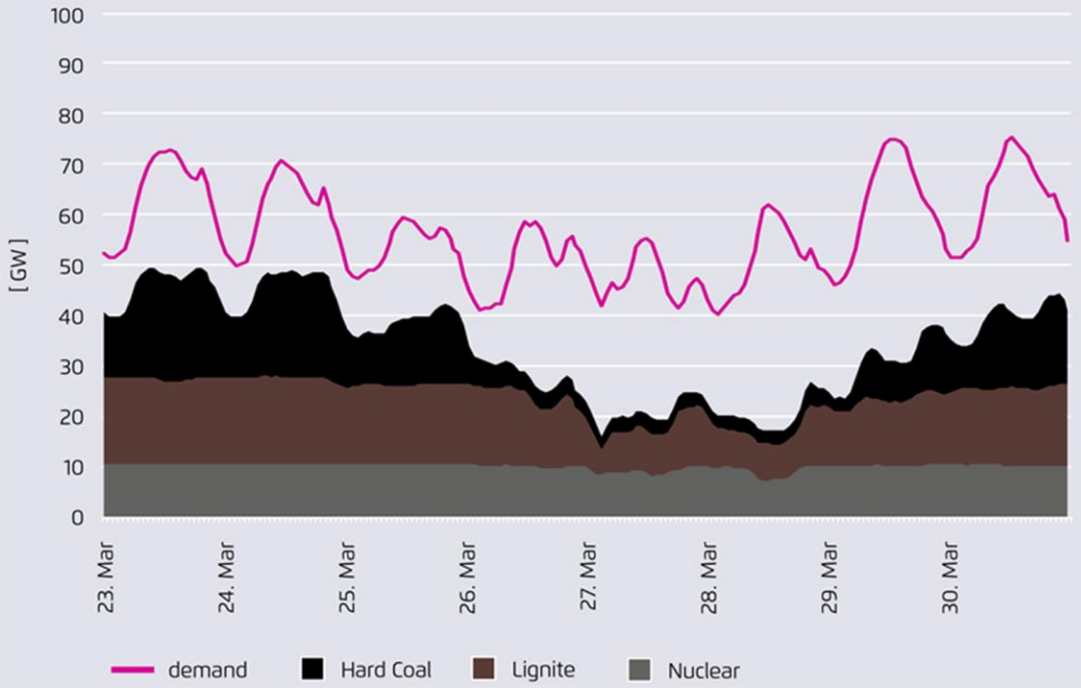
AG Energiebilanzen (2022)

- In 2022, **Renewables' share in electricity production reached 43%**, mainly driven by wind and solar power
- **Lignite and hard coal together account for 31%** of the electricity generation. Germany aims at shutting down all coal-fired power plants if possible by the end of 2030*
- **In April 2023, the last nuclear power plants were shut down.**
- **Secure power supply**: in the context of the energy crisis, up to 10 GW of old oil and coal-fired power plants were hold in the system (up to March 2024)

The German power system can accommodate 100% renewables - Flexibility is the new paradigm, baseload is an obsolete concept!

Electricity generation in Germany 30.4-2.05.2018 (links); Power generation from nuclear, hard coal and lignite power plants and demand in Germany, 29.04-06.04.2018 (right)

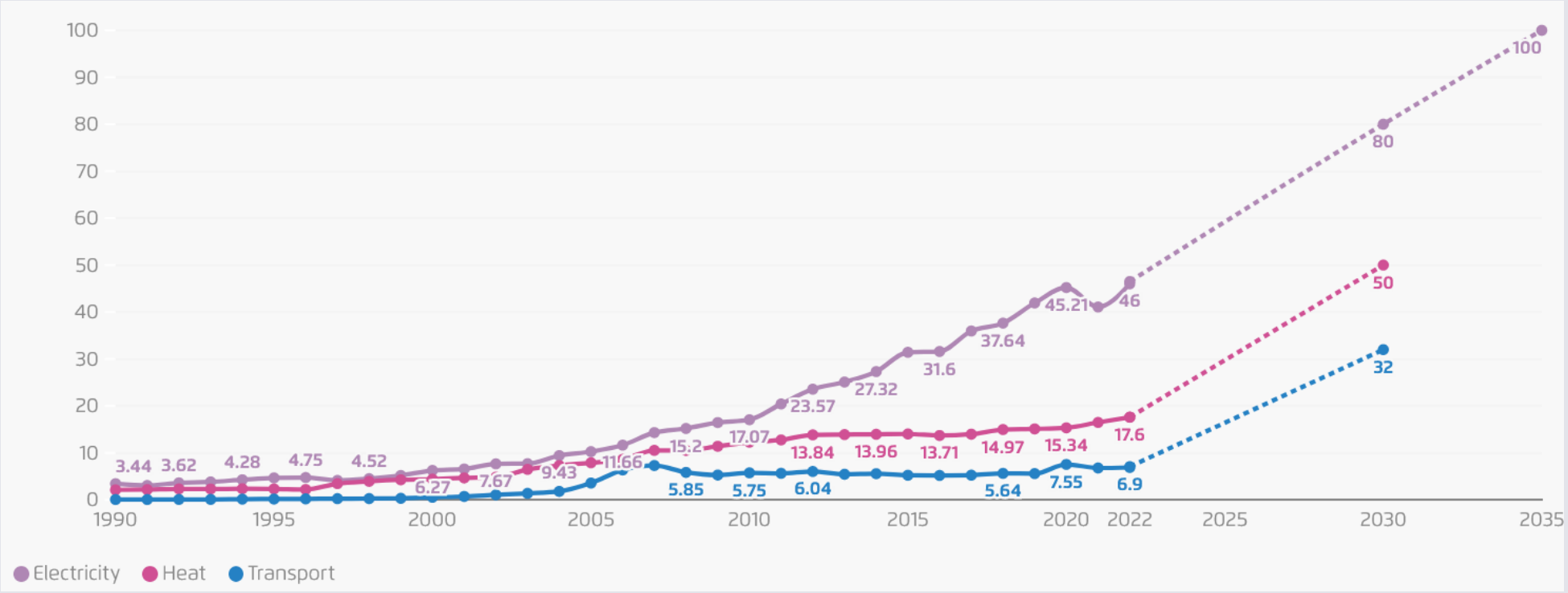




Agorameter - Agora Energiewende (2018)

Germany aims at reaching 80% renewables in the power sector by 2030. To be in track with net zero commitments, the power sector should be carbon neutral by 2035.

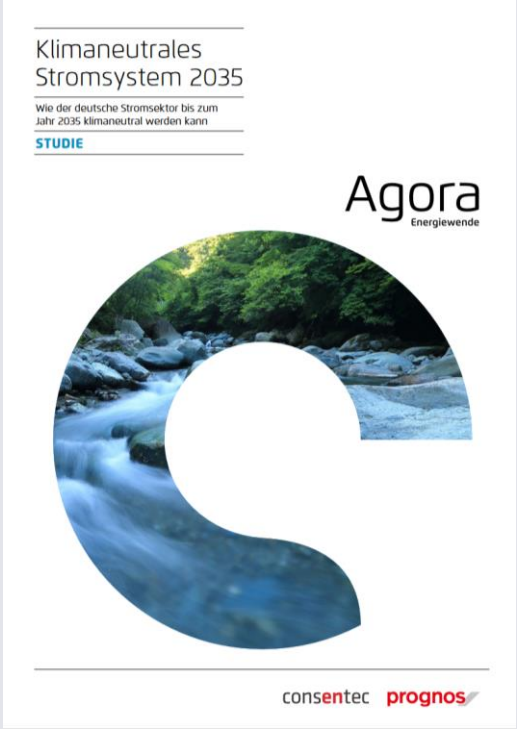
Renewables share in power, heating and transport



Agora Energiewende (2023) based on AGEB (2022a/b), AGEE Stat (2022) • 2022: preliminary data

The study „Climate Neutral Electricity System 2035“ investigates what is needed to fully decarbonize Germany‘s power system over the next twelve years.

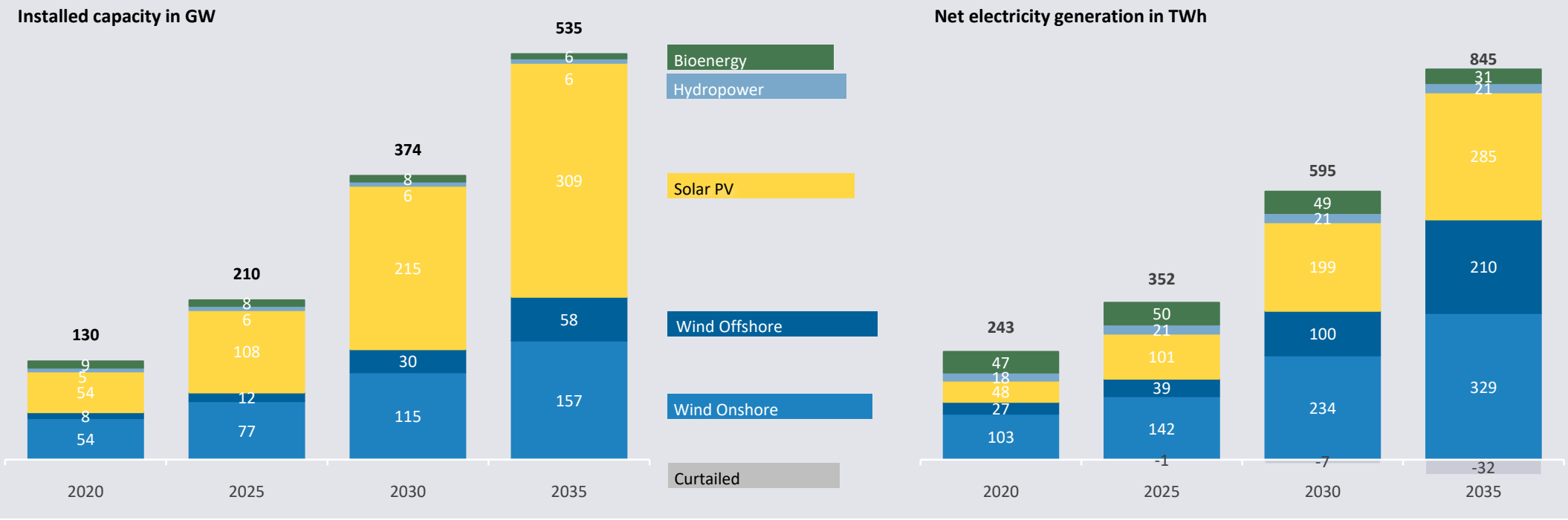
KNS2035 is based on the "Climate Neutral Germany 2045" study



Agora Energiewende (2021), Agora Energiewende (2022)

Wind and solar power are the pillars of the climate-neutral electricity system in 2035.

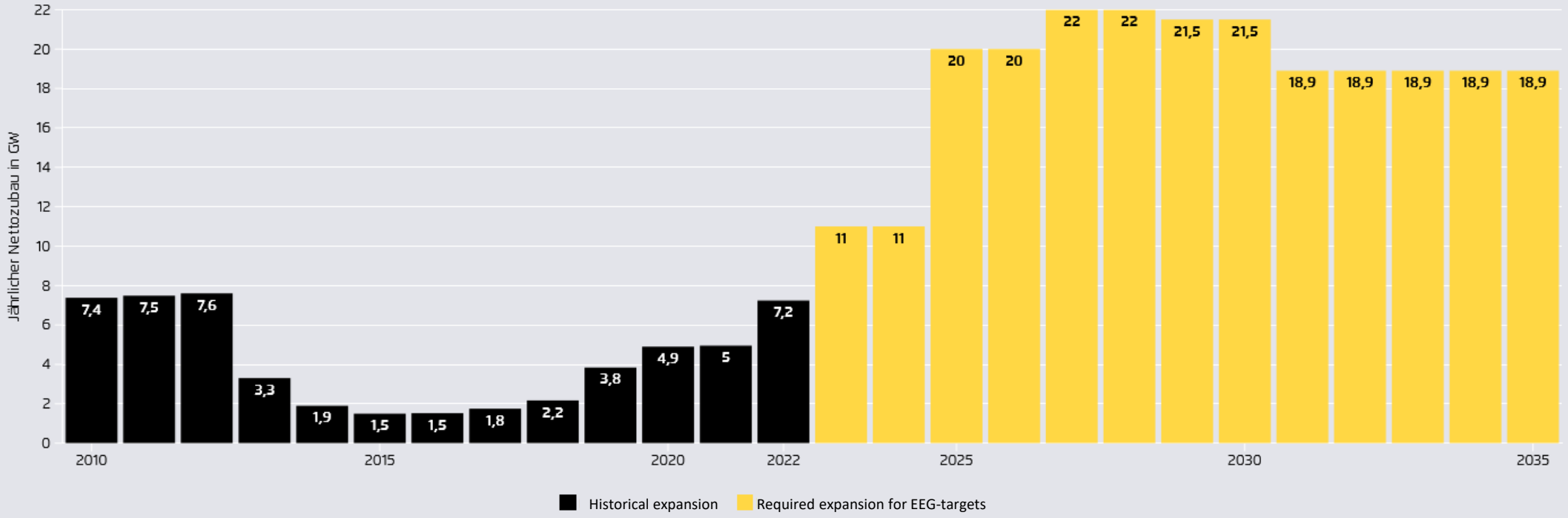
Renewable energies in scenario for a climate neutral power sector 2035 (Agora Energiewende 2022)



Prognos (2022)

While the solar PV is steadily recovering from the expansion crisis, yearly capacity expansion must be multiplied by three to reach a carbon neutral power system in 2035.

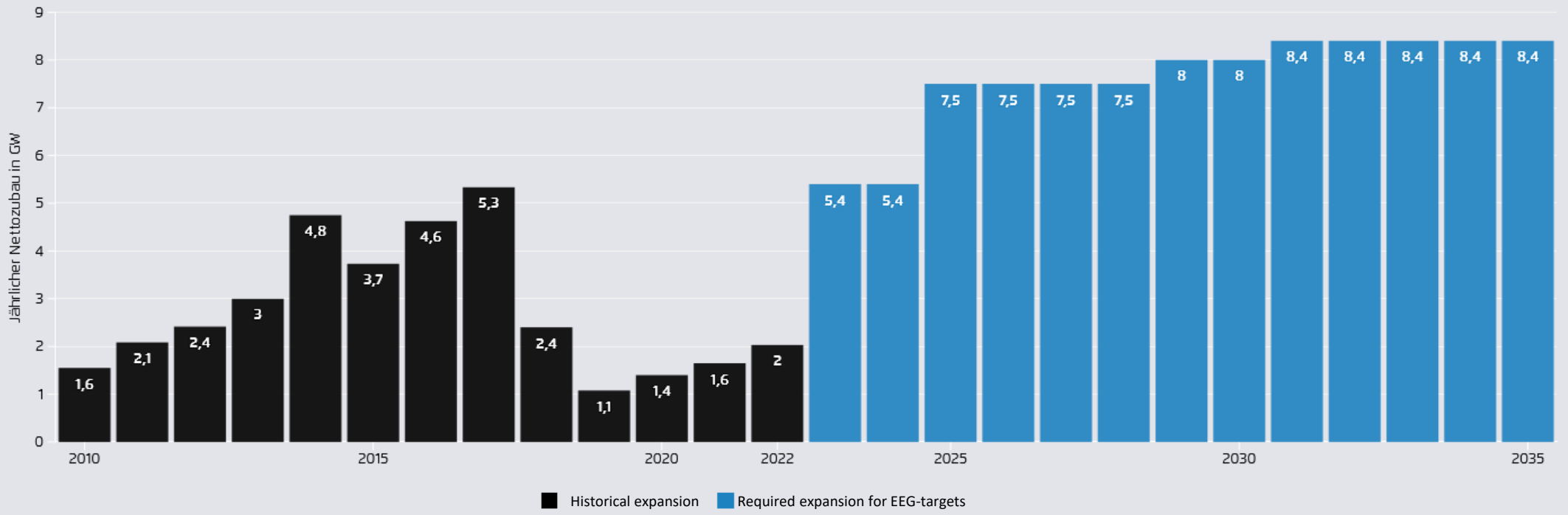
Historical and future required photovoltaic additions for EEG targets



Agora Energiewende (2023) - The EEG 2023 sets expansion targets for 2024, 2026, 2028, 2030, 2035 and 2040. The chart shows the corresponding average expansion required per year.

While an end of the onshore wind investment crisis is still not in sight, yearly capacity addition needs to be multiplied by three to four until 2030.

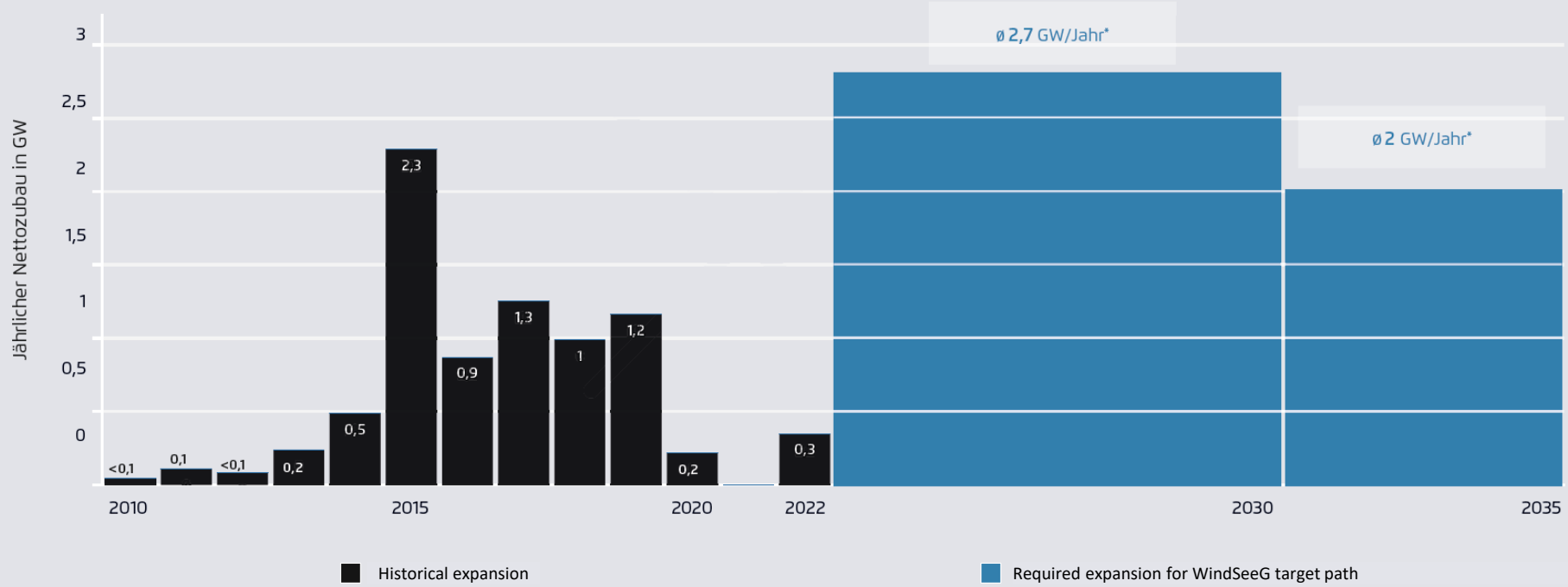
Historic and future wind-onland additions needed for EEG targets



Agora Energiewende (2023) - The EEG 2023 sets expansion targets for 2024, 2026, 2028, 2030, 2035 and 2040. The chart shows the corresponding average expansion required per year.

With only 300 MW capacity added in 2022, offshore wind expansion are at critically low levels. Average annual additions until 2030 must increase almost tenfold from 2023 onwards.

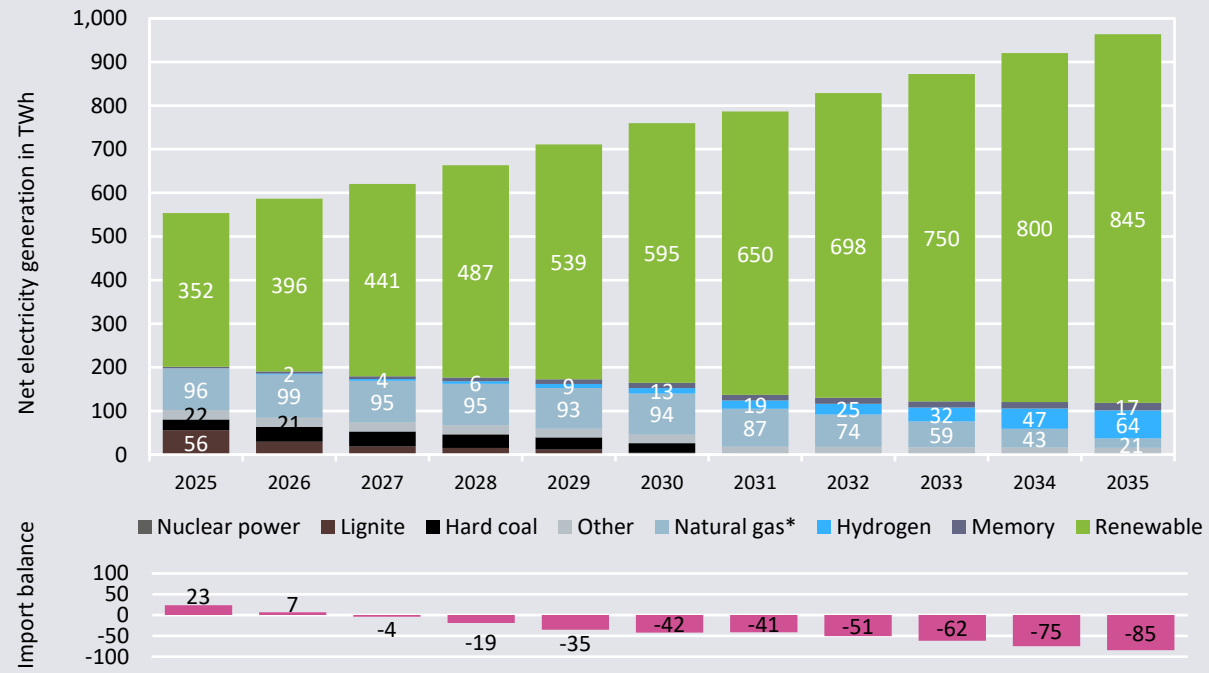
Historical and future wind offshore expansion required to meet WindSeeG expansion targets.



Climate-neutral electricity system 2035, Agora Energiewende (2022) - WindSeeG sets expansion targets for 2030, 2035 and 2045.
*Annual expansion strongly time-delayed due to long project duration of wind-on-sea plants and grid connections.

More renewable electricity and gas-fired power plants increasingly powered by green hydrogen secure the coal phase-out by 2030 and enable a climate-neutral electricity system by 2035.

Net electricity generation



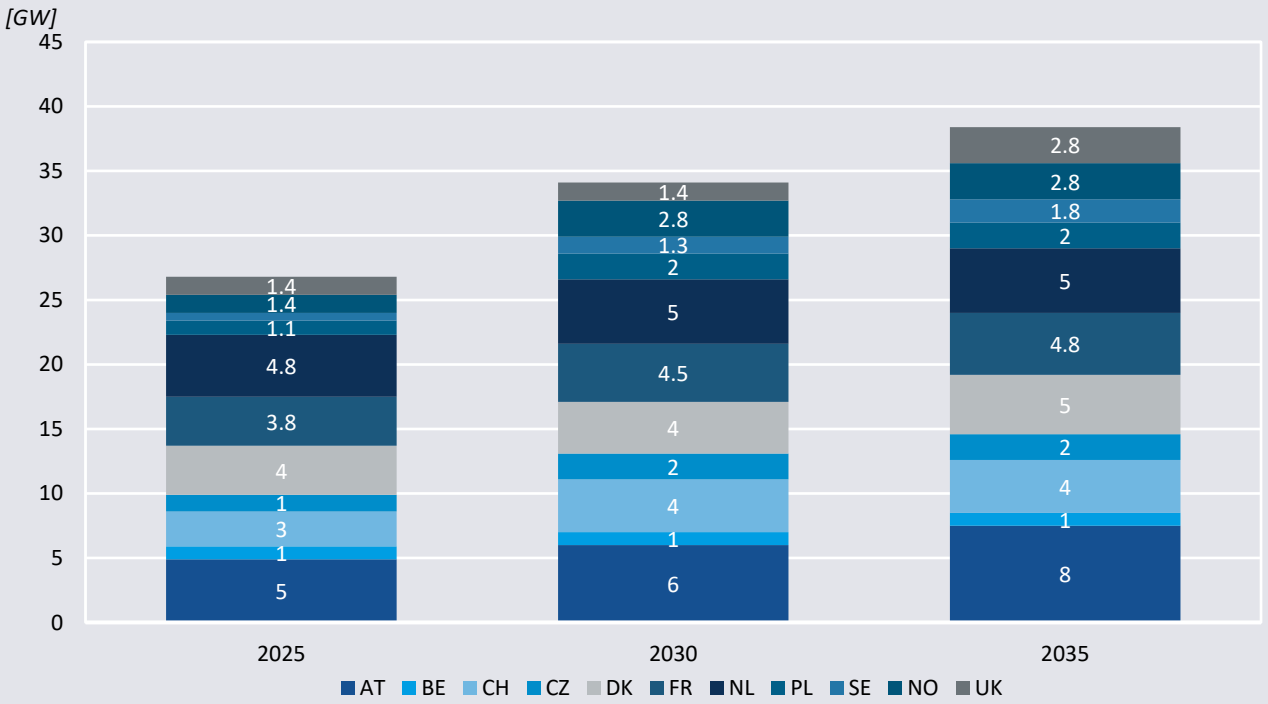
*Electricity generation from natural gas, which can lead to further GHG savings when replaced by electricity-based energy sources.

Prognos AG (2022)

- Rapid renewables development compensates for the coal phase out and the gradual electrification of end-use sectors (EV, heat pumps, industrial heat)
- Controllable gas-fired power plants are used to cover the residual load in time with no (or few) wind and solar in-feeds.
- A rapid switch to hydrogen in the gas-fired power plants reduces natural gas consumption and emissions.
- A rapid RE expansion helps Germany to remain a net power exporter in the long-run.

Exchange of electricity within Europe facilitates the integration of high renewable shares.

Import and export capacities

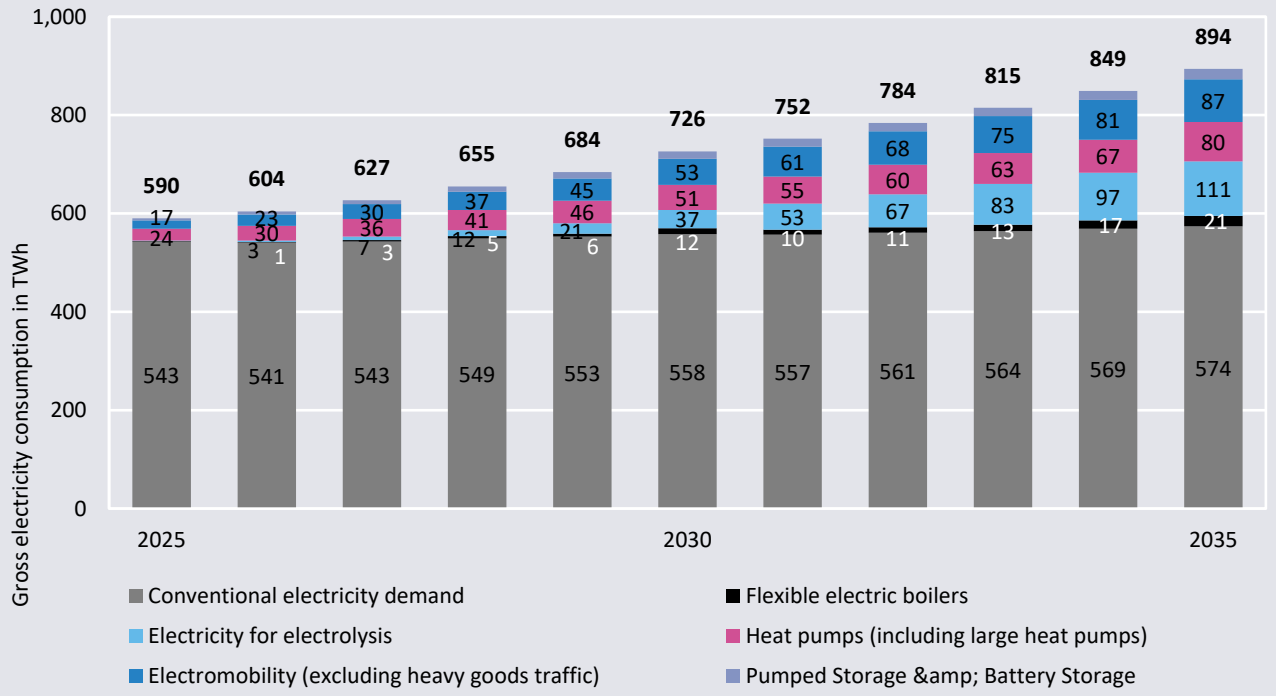


Prognos AG (2022)

- By the mid-2020s, Germany becomes a net importer of electricity (with high CO2 prices, coal-fired generation is less competitive than gas-fired generation from neighboring countries).
- By 2027, due to faster RE expansion compared to other countries, Germany becomes again a net exporter of electricity.
- To materialize cross-European integration benefits, additional interconnectors between Germany and its neighbors of about 15 GW are needed in the next twelve years.

Electrolysers, electric vehicles, heat pumps and electrode boilers increase the demand for electricity. Their flexibility potential must be increased in order to use wind and solar power efficiently.

Gross electricity consumption in the KNS2035 scenario



Prognos (2022)

- The level of future electricity demand is a key driver for RE expansion. It is crucial that electricity is used efficiently and, where possible, flexibly.
- The increasing electrification of heat generation, industry and transport as well as hydrogen production will increase electricity demand to around 726 TWh by 2030.
- Conventional electricity consumption stagnates as efficiency gains and more consumers offset each other.
- New consumers offer considerable flexibility potential. These must be mobilised comprehensively in order to efficiently match supply and demand.

The balance between supply and demand is guaranteed by adjustable power plants, storage facilities, flexible consumers and electricity exchange with EU neighbours

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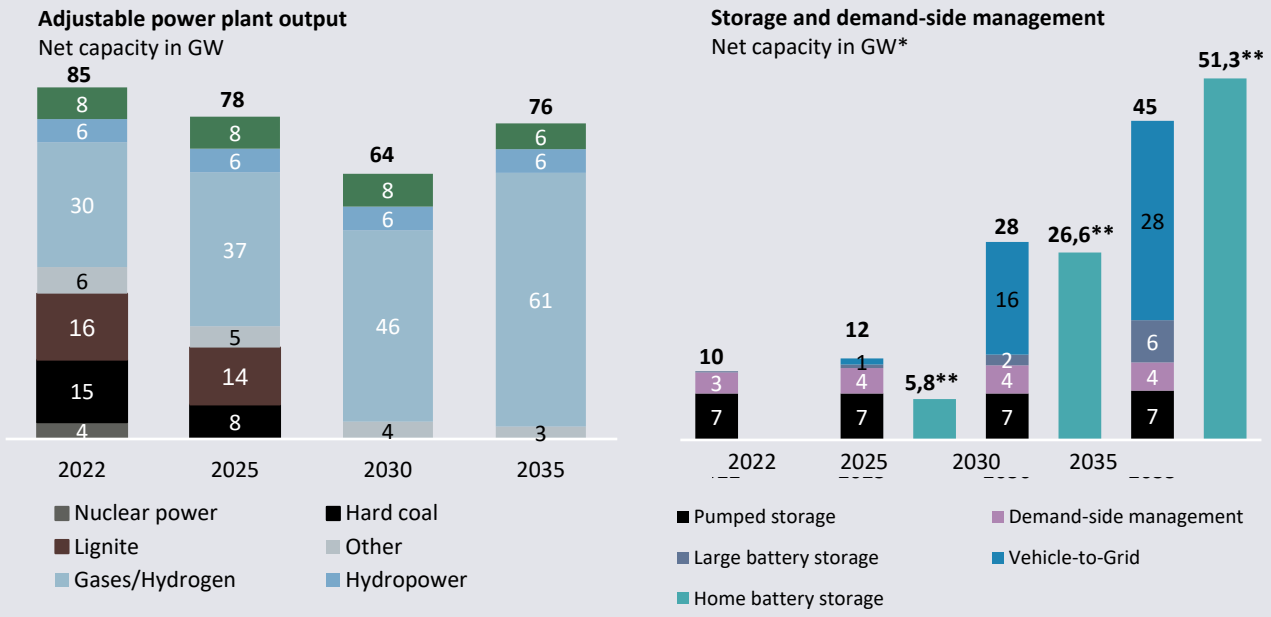
Adjustable power



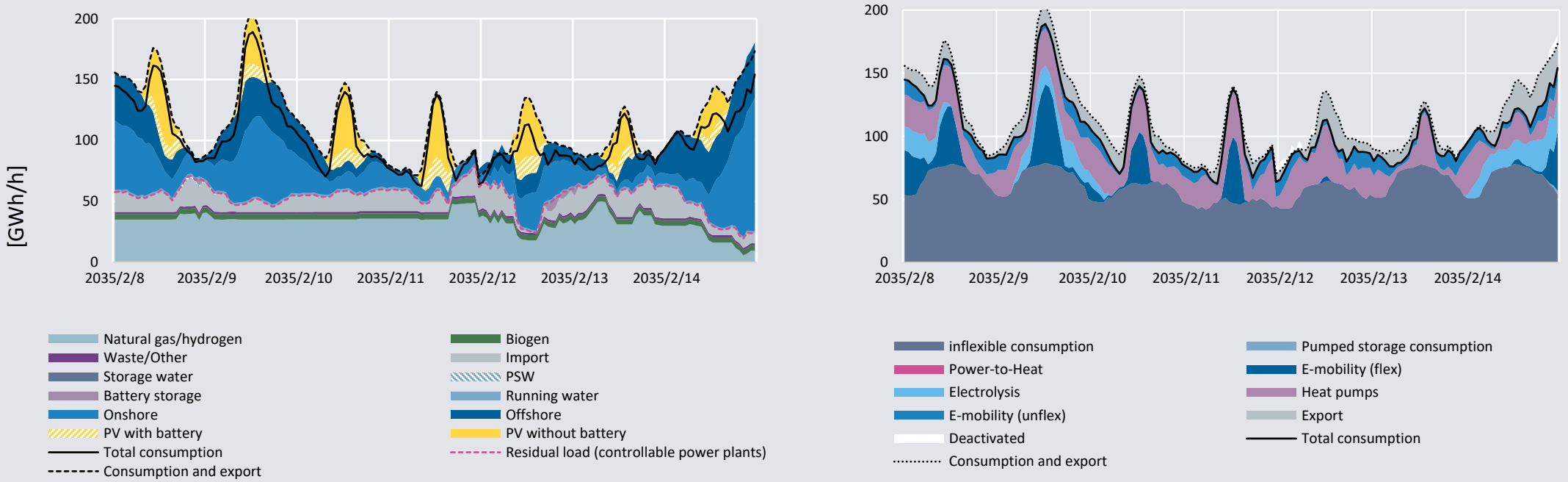
*Average storage capacity: battery storage 1 hour, pumped storage 8 hours | Demand-side management (DSM) = short-term load shifting potential in industry | Vehicle-to-grid: battery-electric vehicles that can also feed into the electricity grid from their battery. ** Home storage systems are partly operated for self-consumption.

Prognos AG (2022)

- By 2035, gas capacity in Germany will need to double (from 30 GW in 2022 to 61 GW in 2035). New gas-fired power plants must be 100 per cent H_2 -ready today.
- Flexible consumers (vehicle to grids, heat pumps, electrolysers) contribute to short-term balancing and thus to the efficient use of renewables.
- Home battery storage plays an important role in best utilizing renewable resources

Security of supply is guaranteed at all times. Thanks to the flexible shares of e-mobility, heat pumps and electrolysers, demand can follow supply to a certain extent.

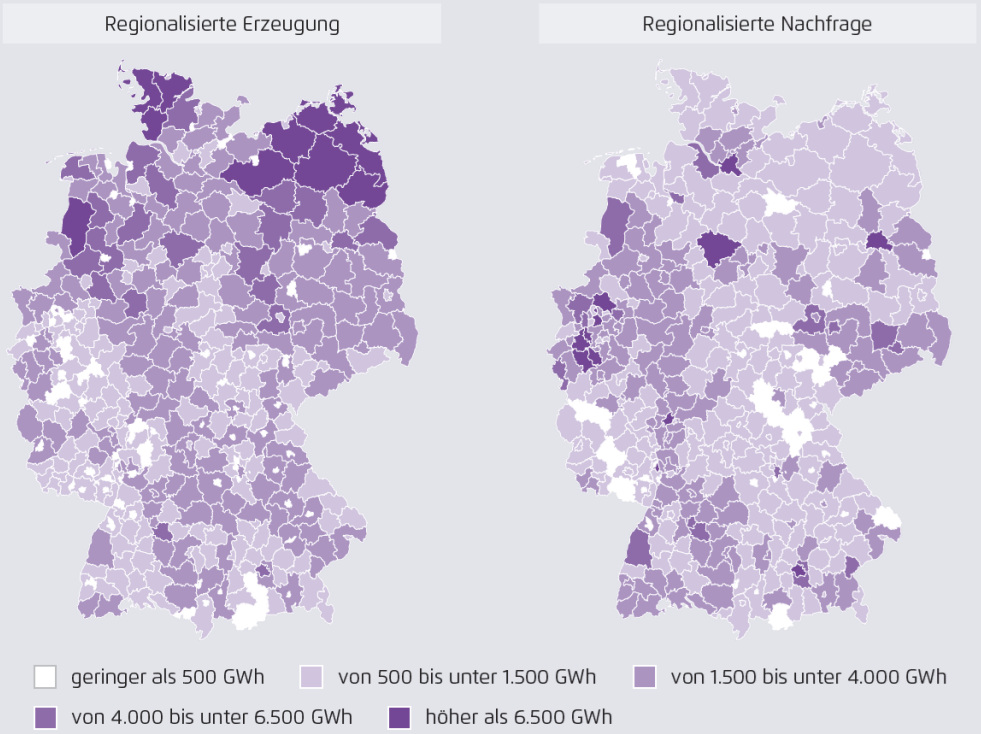
Generation and demand of a winter week with low RES-E generation



Prognos AG (2022)

A detailed load-flow modelling of the power system provides insights on the grid transformation needs

Regionalised electricity generation and demand in the KNS2035 scenario



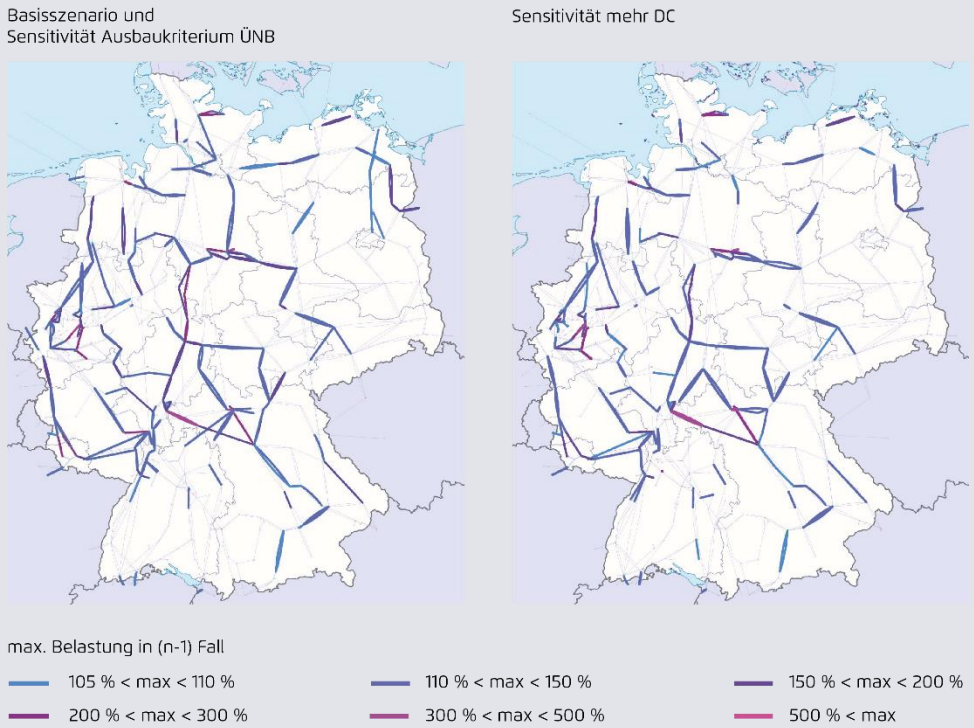
Prognos AG (2022)

The network modelling, performed by Consentec GmbH was carried in three steps:

1. **Regionalization** of electricity generation and storage facilities as well as electricity demand

A detailed load-flow modelling of the power system provides insights on the grid transformation needs

Maximum (n-1) grid loads in the AC grid starting from the starting grid incl. added HVDC, PST and grid booster



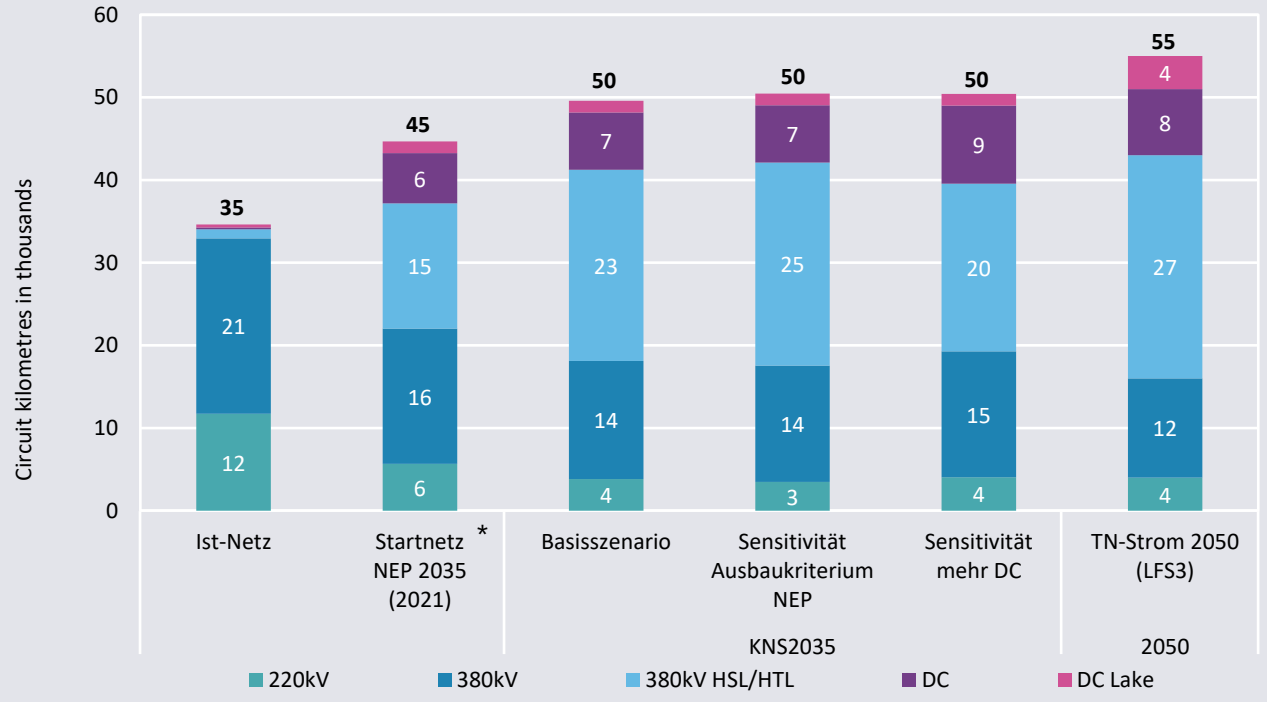
Consentec GmbH (2022) - HVDC: High Voltage Direct Current Transmission, PST: Phase Shifting Transformers

The network modelling, performed by Consentec GmbH was carried in three steps:

1. **Regionalization** of electricity generation and storage facilities as well as electricity demand
2. **Load flow and (n-1) failure simulation**, which successively map the failure of one operating resource each and analyze the resulting load flows
3. **Determination of cost-minimal grid expansion** and reinforcement measures following the GORE principle: Grid Optimization, Reinforcement and Expansion

A climate-neutral electricity grid in 2035 requires a considerably faster grid expansion of about 15‘000 additional kilometers.

Grid quantity structures of the German transmission grid



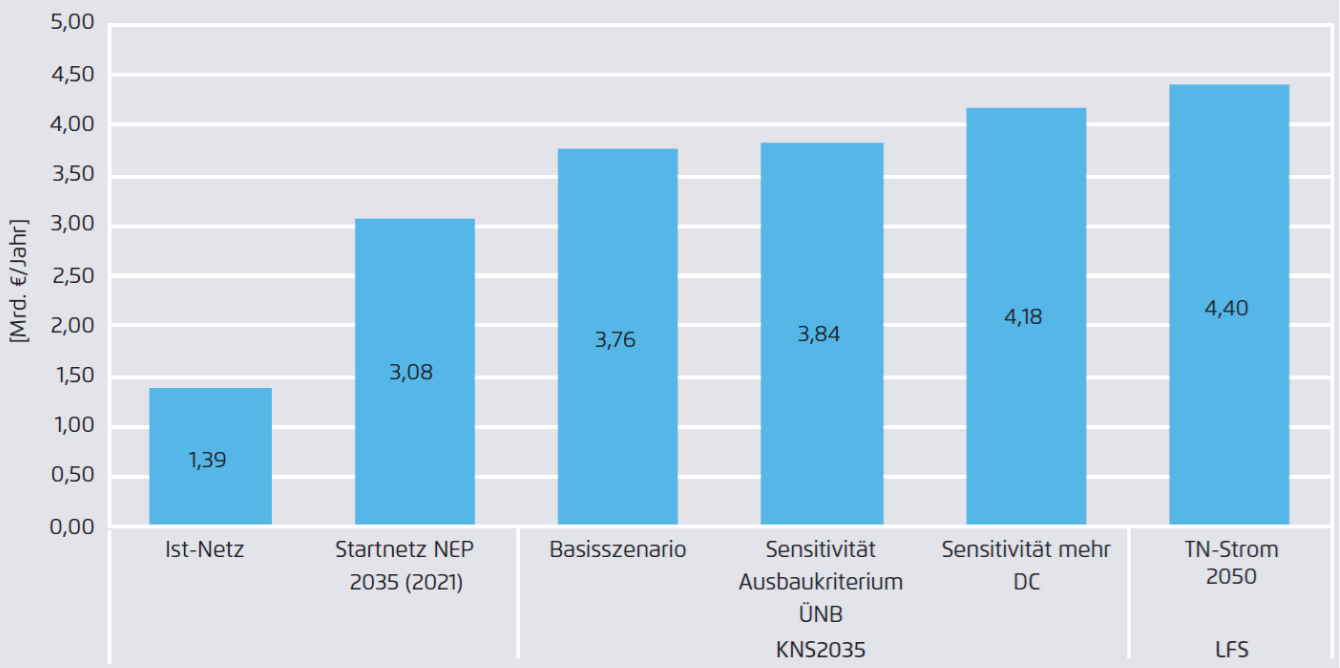
Consentec GmbH (2022)

- The total length of the German transmission grid need to grow from approx. 35,000 km today to approx. 50,000 km in 2035 - in all sensitivity scenarios.
- The expansion of renewable energies and grid expansion must continue beyond 2035 to meet the increase in electricity demand and the rising demand for European electricity exchange.
- Forward-looking and integrated planning of the electricity, gas and heat grids is necessary to guarantee the economic and speedy grid expansion and conversion of the entire German energy infrastructure

* For the assumed initial grid 2035, only grid expansion projects that are already under construction today or whose implementation is legally anchored are assumed as safely implemented (NEP 2035, TYNDP 2020).

Grid development leads to a substantial increase in grid costs

Annuity grid costs of the German transmission grid



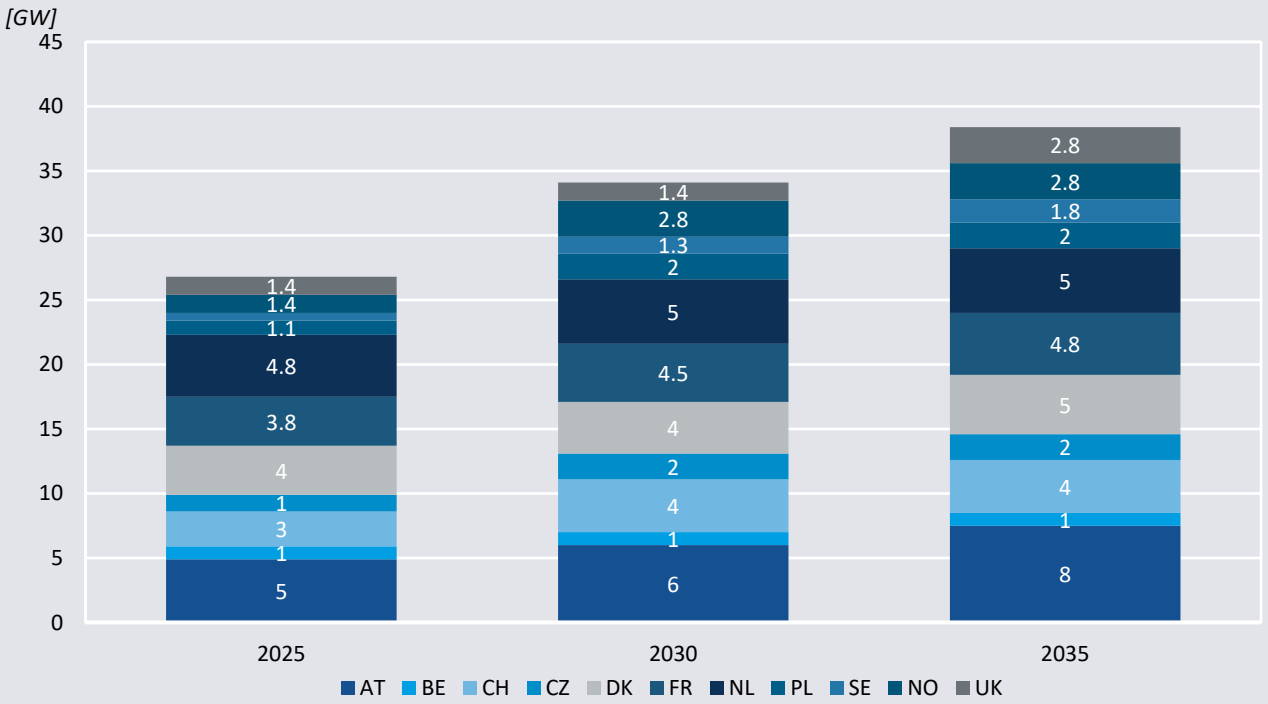
Consentec (2022)

NEP - Network Development Plan, TSO - Transmission System Operator, DC - direct current, LFS - long-term scenario

- The grid costs increase up to 3 times compared to todays values (interest rate assumptions of 2 % p.a.).
- This development could lead to an increase of household electricity price by about 8-10% in the next twelve years.
- "more HVDC scenarios“ drive costs up.
- Due to the further electrification of the other sectors, the annuity grid costs for the German transmission grid continue to rise after 2035.

Exchange of electricity within Europe facilitates the integration of high renewable shares.

Import and export capacities



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- To materialize cross-European integration benefits, additional interconnectors between Germany and its neighbors of about 15 GW are needed in the next twelve years.

System operators will need to rely on new ancillary service resources to ensure grid stability.

Contribution of various technologies to ancillary services

		Traditional resources			New resources		
	Service	**Thermal**	**Hydro/ Pumping**	**Compensators**	**VRES**	**Load**	**Battery**
Frequency control	Fast reserve	✓	✗	✗	✓⇩	✓⇧	✓
	Frequency containment (FCR)	✓	✓	✗	✗	✗	✓
	Frequency restoration (aFFR/mFFR)	✓	✓	✗	✓⇩	✓⇧	✓
Voltage Control	Primary voltage control	✓	✓	✓	✓	✗	✓
	Secondary voltage control	✓	✓	✓	✓	✗	✓
System management	Congestion management	✓	✓	✗	✓⇩	✓⇧	✓
	Interruptibility	✗	✓	✗	✗	✓	✓
	Overgeneration management	✗	✓	✗	✗	✗	✓

✓ fully capable

✓ capable with limitations

✗ not capable

⇧⇩ only up or down regulation

Terna

Conclusion

- A 100% renewables power system is technically possible. It requires an unprecedented grid expansion and optimization plan.
- Due to the long implementation deadlines, all grid projects must be brought into implementation in the coming years: approval procedures must be speed-up and acceptance policies reinforced (including compensation mechanisms for impacted consumers)
- The switch to green electricity in all-end use sectors must follow a system-serving paradigm from the start. This requires a swift reform of grid charges, smarter distribution grid operation and a consistent smart meter rollout.
- Securing electricity grid operation with 100 percent renewables requires a broad technology portfolio for the provision of system services and the efficient handling of grid bottlenecks.

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Thanks for your attention!

Any questions?
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