Germany seems to underestimate the challenges of the green transition

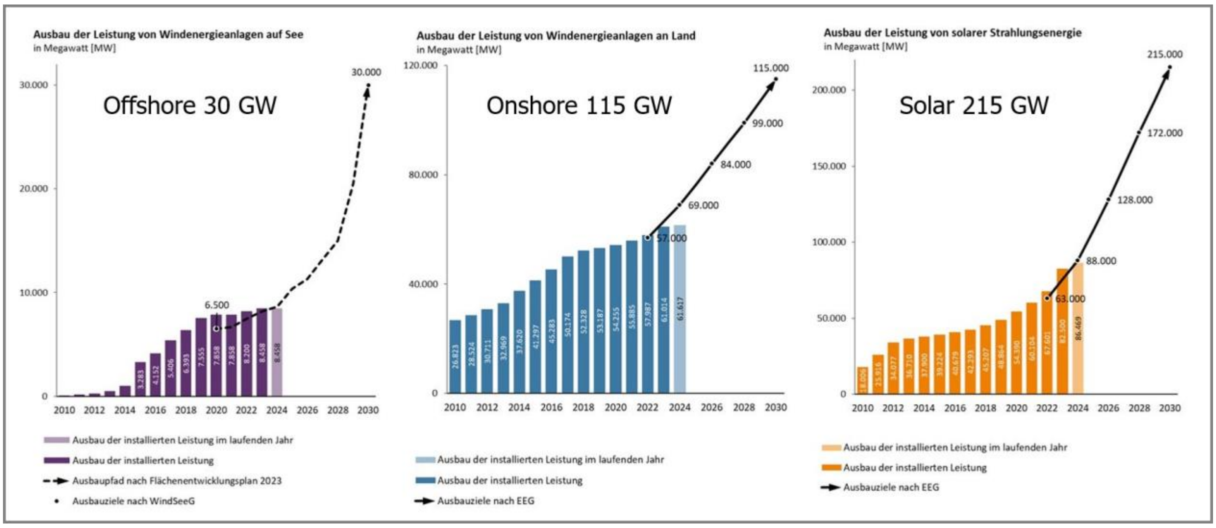

Fig. 1 - German wind and solar power in 2030. Source: Bundesnetzagentur (Federal Grid Agency) – Marktstammdatenregister[1]

This figure puzzles me. Is it right? How do you imagine running 360 GW of fluctuating production in a system where the biggest consumption so far has been below 100 GW?

I found the targets confirmed by the German Federal Ministry for Economic Affairs and Climate Action:[2]

> *By 2030, there should be at least 215 gigawatts (GW) of photovoltaic power on the grid, 115 GW of onshore wind energy and 30 GW of offshore wind energy. In addition, biomass and hydropower make a valuable contribution to sustainable energy supply.*

Summary

- The German think tank Agora Energiewende has published the results of analysing a scenario for a climate-neutral power system in 2035.
- The report recommends:
  - Geographical signals in the German electricity market. This is the same as dividing the German electricity market into price zones, which would be a clear break with current German market policy.
  - New network tariffs in order to encourage customers to adapt their use of the system to the situation at any given time.
  - An intelligent distribution network operation and a significantly faster smart meter rollout.

  The recommendations identify unresolved issues, which need political decisions and development efforts.
- 372 GW new wind and solar power capacity from 2023 to 2035 is supposed to provide 476 TWh new green electrical energy.
- The power system is balanced by flexible supply and demand facilities, including a hydrogen system and international exchanges.

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[1] https://www.bundesnetzagentur.de/DE/Fachthemen/Datenportal/2_Energie/ErneuerbareEnergien/start.html
[2] https://www.bmwk.de/Redaktion/DE/Dossier/erneuerbare-energien.html

- For 1200 hours there is an overflow of electricity in the simulation for 2035. The energy content of the overflow is 32 TWh.
- The plan requires significant grid reinforcements beyond what was already decided. The report finds that network costs will grow by between 22% and 36% compared to the current network plan.
- The new hydrogen system includes hydrogen production, hydrogen-capable power plants and hydrogen infrastructure. In the load dispatch, the natural gas price is adjusted so that hydrogen becomes competitive.
- With 35% solar energy and 65% wind energy in 2035 will the marginal utilisation of new solar cells be low. Unreliable forecasts for solar power are already now putting pressure on regulating power markets. Other solutions should be evaluated for comparison. Eg. can 100 GW of solar power be replaced by 7 GW of nuclear power.
- The report does not discuss, how system control can be developed for handling the new operational risks and challenges.
- The report presents a solution, which can be simulated on a computer, but which in practical operation will be very problematic. Is it time to update German energy policy?

German Wind and solar power in 2023 and 2030

Hourly time series[3] for 2023 are used in an attempt to understand the adaptation of the fluctuating production in Germany (table 1).

2023	Load factors	Sum GWh	Max GW	Min GW	Inst GW
Solar	15,5%	55.236	40,7	0,000	82,5
Offshore	35,2%	23.518	7,6	0,000	8,5
Onshore	27,9%	118.671	48,5	0,146	61,0
Combined	37,8%	197.425	59,7	0,559	152,0

Table 1 - Max combined output was only 39% of installed capacity

The energy output is in good agreement with other sources.
The installed capacities are from fig. 1 above. Using the installed capacity can be problematic because it changes over the time period considered.

It is nevertheless noteworthy that **the maximum combined output is only 39% of the installed capacity**. The combined output varied between 0.6 GW and 59.7 GW in 2023. The electricity demand varied between 30.9 and 72.2 GW.

In an appropriate mix, solar and wind energy complement each other so that the combined load factor is higher than for each of the three sub-elements. In 2023, 28% of the fluctuating production was solar energy. The maximum combined load factor is achieved at approx. 22%, but it is a rather flat optimum.

After scaling up to the 2030 data, we have installed 360 GW fluctuating power as in fig. 1. However, the maximum combined output will be only 136 GW (table 2).

2030	Load factors	Sum GWh	Max GW	Min GW	Inst GW
Solar	15,5%	144.166	106,2	0,000	215,3
Offshore	35,2%	83.489	27,1	0,000	30,0
Onshore	27,9%	223.102	91,1	0,274	114,7
Combined	37,7%	450.757	136,4	1,051	360,1

Table 2 - Scaling up to 2030

[3] Source: Entso-e Transparency Platform

A climate-neutral power system in 2035

The German think tank Agora Energiewende has published the results of an analysis of a scenario for a climate-neutral power system in 2035.[4] [5]

The German power system in 2035 is assumed to be composed of traditional electricity consumption, weather-dependent production of solar and wind power as well as a number of flexible elements on both the supply and demand side.

The system becomes more complex than now. The core of the report is a computer simulation which shows that it is possible to piece together the puzzle for all hours of the year. However, this does not solve the practical problems. The Agora Energiewende report is to be commended for discussing some of the unresolved issues.

Three recommendations are quoted below.

- *Even if the expansion of the network is significantly accelerated, structural bottlenecks will remain in the transmission network. The introduction of geographical signals in the electricity market is therefore unavoidable.*

This is interesting. Germany's insistence on the same electricity price throughout the country has been unshakable. The proposal from Agora Energiewende in 2023 has been noticed in several media, but, as far as is known, has not led to political debate or initiative.

- *The current network tariff structure is a serious obstacle to flexibility. An immediate reform of network charges is indispensable in order to leverage the necessary flexibility potential.*

The current network tariffs are favourable for even electricity consumption, but less favourable for flexibly varying consumption. There is a need for incentives which promote the adaptation of electricity consumption to the needs of the system.

- *The intelligent control of decentralized flexibility is a key pillar in a renewable electricity system. An intelligent distribution network operation and a significantly faster smart meter rollout are required for this.*

The new flexible measures in local networks will increase the loads in these networks. The intelligent solutions may spare undersized networks, but this will undermine the contribution to balancing the entire system. Therefore, there is no way around reinforcing the distribution networks where necessary.

Discussions are not the same as solutions. The three recommendations represent issues, which need new political decisions and a concentrated development effort. Both will take time and should therefore be initiated soon.

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[4] Agora Energiewende: Klimaneutrales Stromsystem 2035, Studie, April 2023 (in German)
[5] Agora Energiewende: Climate-neutral power system 2035, Executive summary, April 2023 (in English)

A simulation for the years until 2035

Annahmen zum Ausbau der Erneuerbaren Energien in KNS2035 und KNDE2045* — Tabelle 1

	KNS2035				KNDE2045		
	2020	2025	2030	2035	2025	2030	2035
Wind Onshore	54	77	115	157	65	80	104
Wind Offshore	8	12	30	58	11	25	41
Photovoltaik	54	108	215	309	91	150	234
Wasserkraft	5	6	6	6	6	6	6
Bioenergie	9	8	8	6	7	7	3
Summe	**130**	**211**	**374**	**535**	**179**	**268**	**390**

* Angaben in Gigawatt installierter elektrischer Leistung

Prognos (2022)

Source: Agora Energiewende: Klimaneutrales Stromsystem 2035 - Version 1.3, April 2023

Table 3 - Data for scenario KNS2035 are in full agreement with the 2030 data in fig. 1

372 GW new wind and solar power capacity from 2023 to 2035 is supposed to provide 476 TWh new green electrical energy.

2035	Load factors	Sum GWh	Max GW	Min GW	Inst GW
Solar	15,5%	207.135	152,5	0,000	309,4
Offshore	35,2%	161.333	52,4	0,000	58,0
Onshore	27,9%	304.985	124,6	0,374	156,8
Combined	38,2%	673.454	201,0	1,437	524,2

Table 4 - 524 GW installed wind and solar power in 2035

Traditional electricity consumption in Germany is assumed to be 574 TWh in 2035.

The balance between production and consumption is assumed at any time made possible by 101 TWh dispatchable production and 310 TWh flexible demand.

"Renewable" in table 5 is consisting of 329 TWh onshore wind, 210 TWh offshore wind, 285 TWh solar, 21 TWh hydropower and 31 TWh bioenergy.

The simulated capacity factor of electrolysis in 2035 is 40% (3500 full load hours). Investors in P2X plants probably hope for a higher utilisation.

DE 2035	Energy balance		
Supply	TWh	TWh	Demand
Renewable	845	574	Traditional
Storage	17	21	Storage
Hydrogen	64	111	Electrolysis
Gas	21	70	Heatpumps
Other	16	87	Electric transport
Net import	-79	21	Electric boilers
Total	884	884	Total
Source: Agora Energiewende 2035 Fig. A and B			

Table 5 - 310 TWh flexible demand

Fig. 14 in the report shows a total German import capacity of 38 GW. The report does not specify if the simulation assumes that there is always import available up to this limit. Calm winds can affect large parts of Europe at the same time, and then all countries cannot count on support from outside.

32 TWh overflow

According to the simulation, there will be an overflow of electricity for 1200 hours of the year, which it does not pay to use. The energy content of this overflow will be 32 TWh, of which 75% occurs in non-consecutive hours. The magnitude of the overflow peak could be about 100 GW. The level of curtailment is based on an estimate. It could be different depending on profitability analyses for the flexible measures.

The transmission grid must be reinforced

It must be assumed that the very large production peaks cause heavy loads in the network. Therefore, extensive network analyses have been carried out to get an estimate of which network reinforcements will be necessary in addition to those already decided.

Grid expansions are based on alternative criteria and overhead AC lines. An extension with HVDC links has also been investigated.

The report says that the procedure does not represent explicit network planning, as is the case, for example, in the context of the network development plan of the German transmission system operators, but serves in particular to comparatively evaluate the basic expansion calculation of the scenario and sensitivities with regard to its impact on the electricity grids.

In comparison with already decided grid expansion the total annual grid cost will increase by between 22% and 36% depending on sensitivity case.

An extensive hydrogen infrastructure

The German government has decided to build 10 GW of gas or hydrogen-fired power plants. According to table 5, the gas-fired power plants must deliver 85 TWh in 2035. Of this, 64 TWh must be fired with green hydrogen so that the climate targets can be met. Quote:

- *For the successful implementation of the energy transition, three paths are crucial for the hydrogen sector, and they must be initiated today: hydrogen production, hydrogen-capable power plants and hydrogen infrastructure.*

The hydrogen grid connects the sites of domestic production, feed-in points for imports and the consumption sites in industry, chemicals, the transformation sector and other consumption sectors.

The simulation assumes that hydrogen and natural gas are equal fuels in the load dispatch. This may require a correction of variable costs due to CO2 emissions. The additional cost is unknown.

Hydrogen infrastructure encompasses a transmission network with storage facilities. There is a storage facility in the network. Reports indicate that this could store approx. 500 GWh of energy when the average pressure is raised from 40 to 80 bar. Hydrogen storage quantities in the order of several TWh can only be provided via underground storage in salt caverns. Germany has around 200 TWh of storage capacity for natural gas, some of which could be converted to hydrogen. It connects the locations of domestic production, entry points for imports and the consumption locations in industry and other consumption sectors.

System control - an unnoticed challenge

It requires an advanced and robust system control to maintain the balance between consumption and production in an AC system every second around the clock. It can end in a blackout if the system operator loses control of the system.

Fortunately, blackouts are rare. A main reason is an international exchange of lessons learned from blackouts over decades. The transmission system operators have collected the experiences in a continuous improvement of their operational strategies.

The fluctuating production from solar and wind power is difficult to forecast and therefore creates new problems for the system operators. It is felt in the form of a growing need for manual adjustments to maintain the necessary reserves to meet sudden events.

Front-runners in the green transition will meet the challenges first. They are therefore forced into the most extensive development work of their system control to avoid power outages.

In order to spread that risk, an international harmonization of the green transition could be appropriate. Political decision makers want to be ambitious and therefore rarely consider this perspective.

Low utilization of new solar energy

As mentioned above, solar energy in Germany is assumed to be expanded beyond what is normally considered the optimal share.

I have previously mentioned that solar cells and wind turbines can complement each other. I have in other works found the best composition around 20% solar energy and 80% wind energy.

With higher proportions of solar power, the overflow of electricity increases, so that an increasing proportion of the new solar energy cannot be utilized.

The 35% share of solar energy indicates a composition that is quite far from optimal (fig. 2).

If the last 100 GW of solar energy is not installed, production in 2035 will be 69 TWh lower. Only 50 TWh of the 69 TWh could be utilized. The overflow is thus reduced from 32 TWh to 13 TWh.

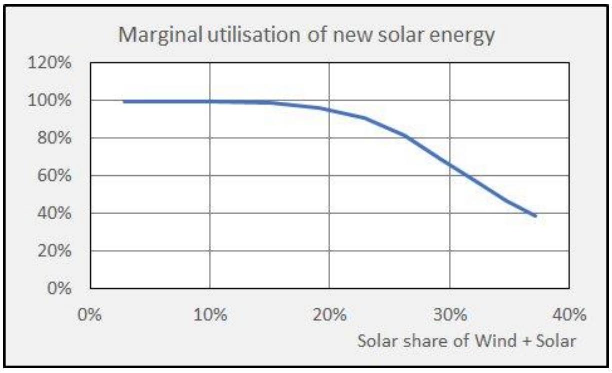

Fig. 2 - The scenario KNS2035 has 35% solar energy and 65% wind energy in 2035

A nuclear alternative?

The 50 TWh is less than the nuclear production that has been decommissioned since 2017. With a conservative assumption of a capacity factor of 80% for new nuclear power, 7 GW of installed nuclear power could deliver 50 TWh.

One must assume that replacing 100 GW of solar power with 7 GW of nuclear power could provide a simpler and cheaper infrastructure.

These figures are based on loose estimates. I think that the authorities owe to consumers and voters to evaluate the chosen policy against more traditional solutions and present analyzes with true and fair information on complexity, economy and security of supply.

Is there reason to update German energy policy?

The German energy policy seems to have led the Agora Energiewende into a non-optimal solution, which can be simulated on a computer, but which in practical operation will be very problematic.

Unreliable forecasts for solar power are already putting pressure on the regulating power markets. Montel News reports that the German intraday market on June 3, 2024 hit the price ceiling of EUR 9,999/MWh, while *"the price of balancing energy in Germany's automatic Frequency Restoration Reserve (aFRR) hit a peak of EUR 14,978/MWh for the 15- minute bloc starting at 09:00"*.

Against this background, it should be obvious that the 35%/65% distribution between solar and wind energy is far outside a siutable range of solutions.

This should give reason to consider whether the time has come to update German energy policy.