The impact of weather in a high renewables power system

How high is scarcity during *Kalte Dunkelflaute* events – and how can it be bridged?

Weather impacts power markets in all its dimensions: power production, power demand and commodities

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Weather change

- Irradiance
- Wind speed
- Precipitation
- Temperature

Power market impact

- Solar load factors
- Onshore wind load factors
- Offshore wind load factors
- Hydro load factors
- Heat demand
- Commodity prices

Production level and volatility

Demand level and volatility

Merit order of thermal assets

Asset impact

Production

Capture prices

Profitability

Sources: Aurora Energy Research

With a growing share of renewables and increasing electrification of heat, weather effects on power are amplified

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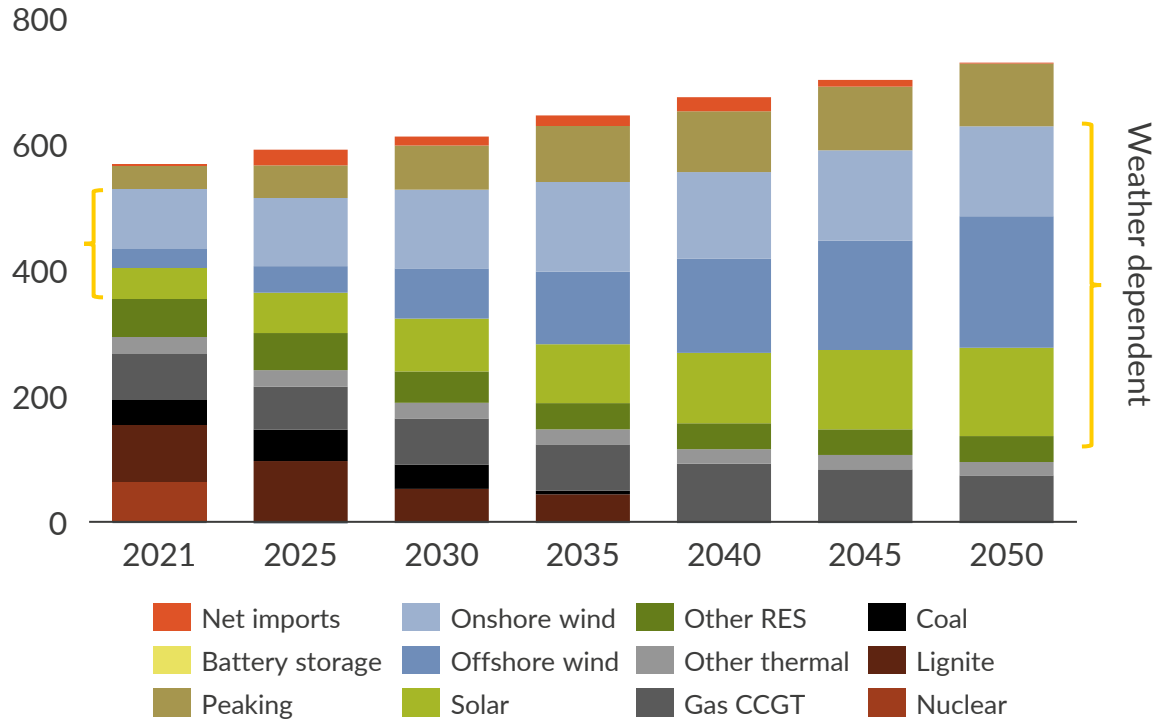
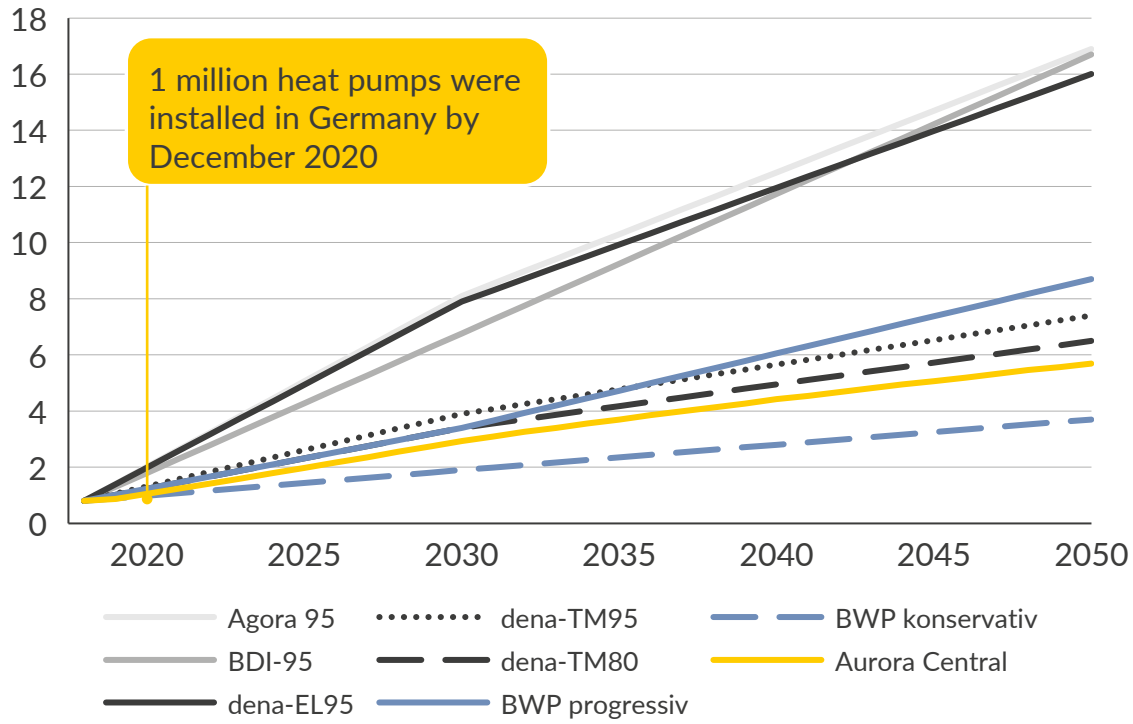
Electricity production in Aurora Central
TWh



Heat pumps installed
million



- In this report, we analyze the effects of weather on Aurora Central, i.e. the scenario that represents our view on the most likely development of the German Power market until 2050, given the current policy regime
- In our Net Zero scenario, which is not part of the report, we expect weather to have far more drastic effects as the share of renewables in generation and the number of heat pumps on the system both would be higher

Sources: Aurora Energy Research, Bundesverband Wärmepumpe e.V.

Extreme weather years require flexible capacities that are significantly higher than what would be used in average years

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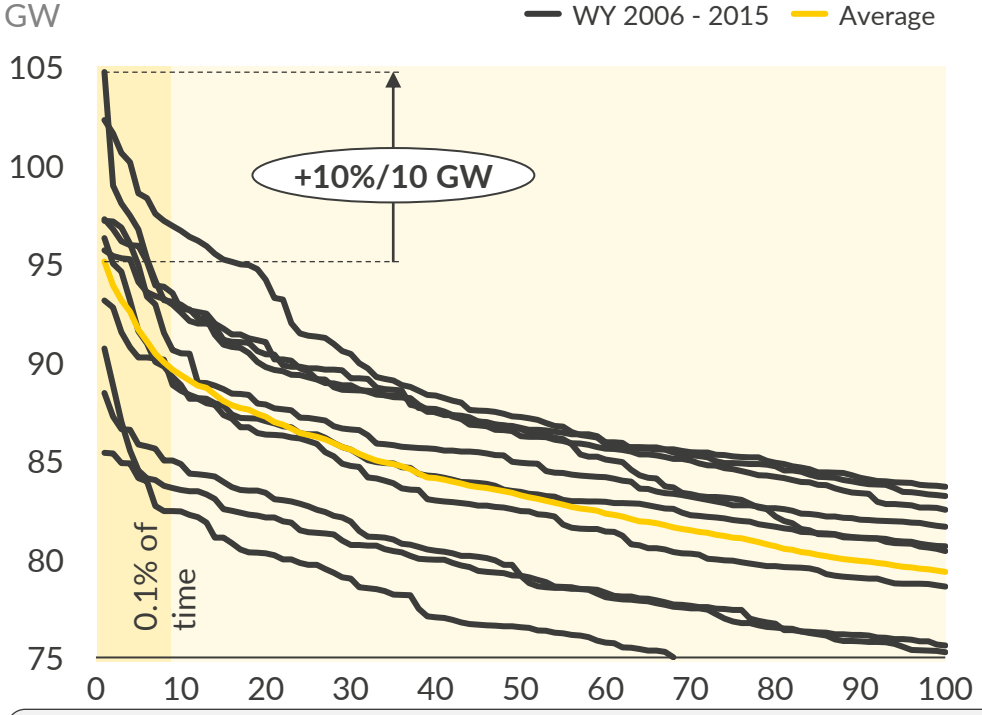
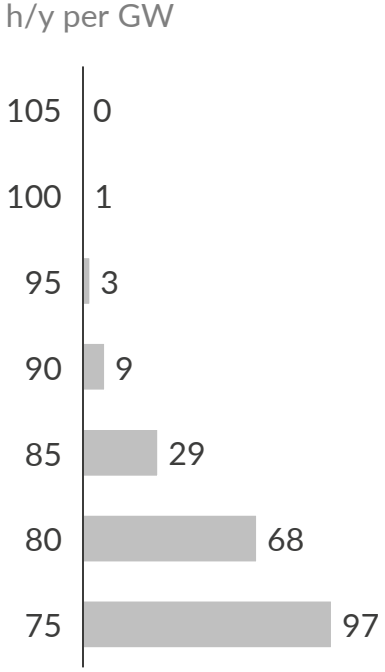
1 Up to 10 GW more capacity is needed in extreme weather years compared to an average weather year…

Residual load duration curves (tightest hours) in 2050



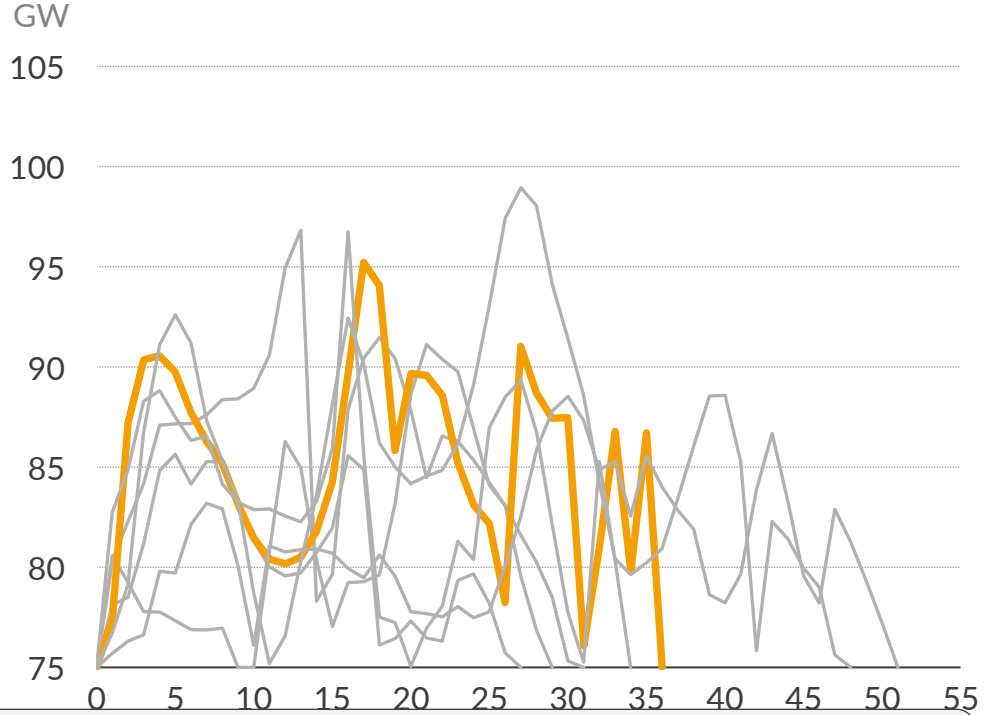
2 … the last 20 GW are rarely used …

Avg. dispatch



3 … still, the flexibility is required for sustained periods of time: E.g. in 2007, residual load is close to 90 GW for over 30h

Sample of events with residual load above 75 GW in 2050



This raises several questions:

- What capacities and technologies will provide the required flexibility? How can these capacities be financed given their rare operation?
- How far can we expect the market to make precautions for rare events? How much capacity does the state need to keep as reserves for events that are too rare for the market to account for?

2007 — examples from other years

Source: Aurora Energy Research

For this supply gap to be addressed within the current market design, market participants need to believe in four key assumptions

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Current market design

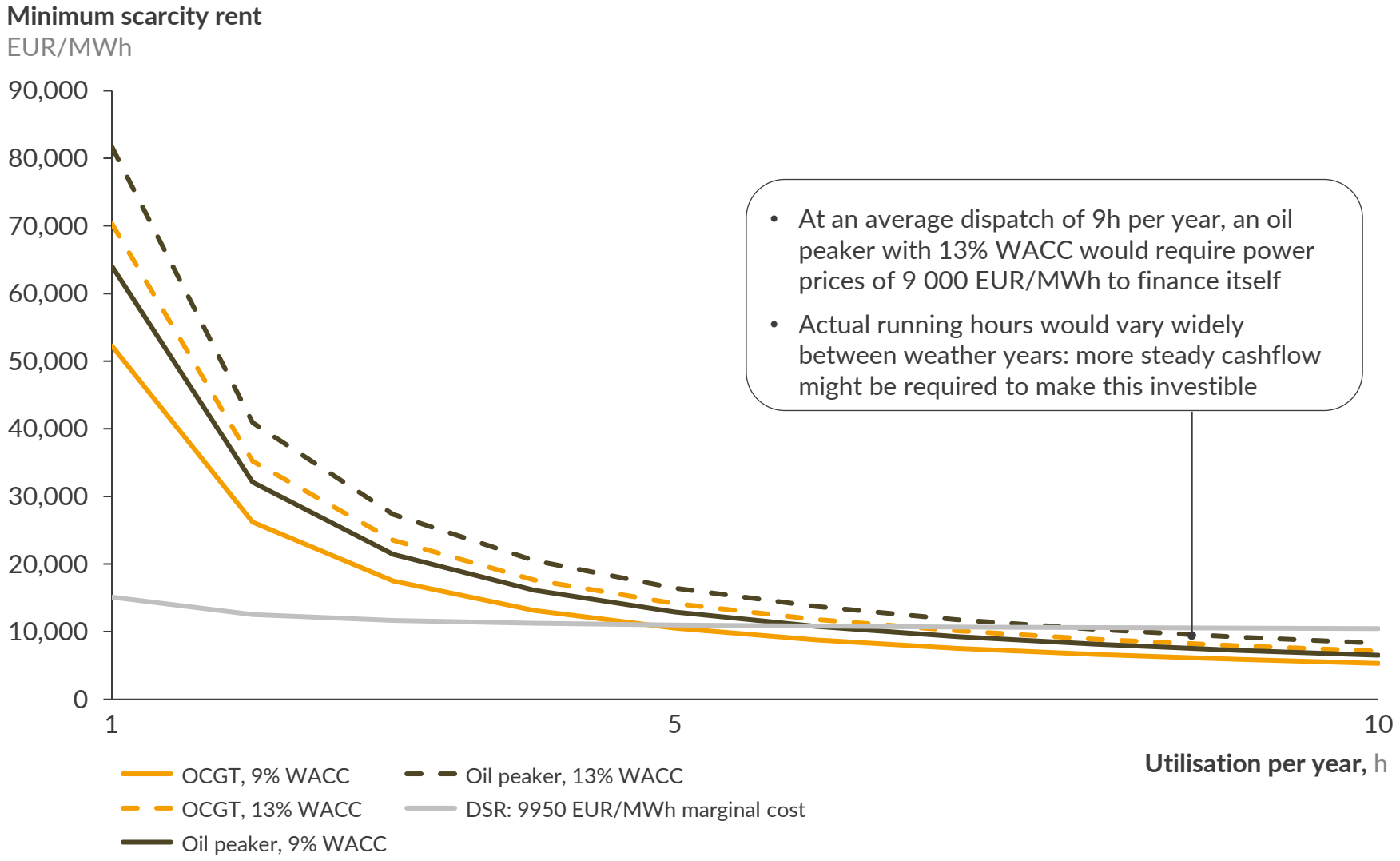
- The energy only market (EOM) is expected to find the economically optimal solution to meet supply and demand by pure market logic
- Additionally, the government procures a capacity reserve, which is activated if the day-ahead market does not clear
- Parties responsible for the activation are charged an extremely high penalty, set at double the maximum intraday price, i.e. (currently) 20,000 EUR/MWh
- Plants in the capacity reserve are not allowed to participate in the wholesale market
- This design mitigates security of supply concerns without removing investment incentives from scarcity pricing

Key assumption	Criticality	Likelihood	Main insight
A **EU market integration reduces residual load peak**	!	✓	Market integration reduces peak demand by 10% or more, but does not solve the problem as weather patterns are highly correlated
B **Electrification of heat, transport and hydrogen production will make demand more flexible**	!	✓	About 19% of demand will be flexible and shift peaks to periods of high renewables production
C **Industrial demand side response enters the market at scale**	!	?	Due to short duration of DSR, more than 18 GW[2] would be required to cover rare peak periods – investment incentives unclear
D **Market framework makes generation capacity for rare peaks investible**	! !	? ?	For peaking plants to be investible, market players need to be able to trust in availability of scarcity events and thus steadiness of the EOM design

1) BMWi Monitoringbericht zur Versorgungssicherheit; 2) Assuming shedding of 2 h

Sources: Aurora Energy Research

Peaking capacity is dependent on rare scarcity payments; steady cashflow from capacity contracts can de-risk investment



- At an average dispatch of 9h per year, an oil peaker with 13% WACC would require power prices of 9 000 EUR/MWh to finance itself
- Actual running hours would vary widely between weather years: more steady cashflow might be required to make this investible

Source: Aurora Energy Research

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Issue

Assuming a pure energy only market, how can assets relying on rare scarcity revenues be financed and enter the market?

Importance

Given the short run-time of demand side response, peaking capacities are necessary to ensure security of supply and can be profitable, but investments are associated with high risk

Potential solutions

- Industry can hedge via baseload futures, to which utilities would have to provide capacity
- Utilities can hedge via cap futures translating price spikes into continuous investible cashflows, or build capacities on balance sheet
- Tighter regulatory controls and more transparency on how much capacity was contracted vs how much would be required in extreme events

Weather variations will have a greater bearing on energy market margins of thermal assets than of renewables

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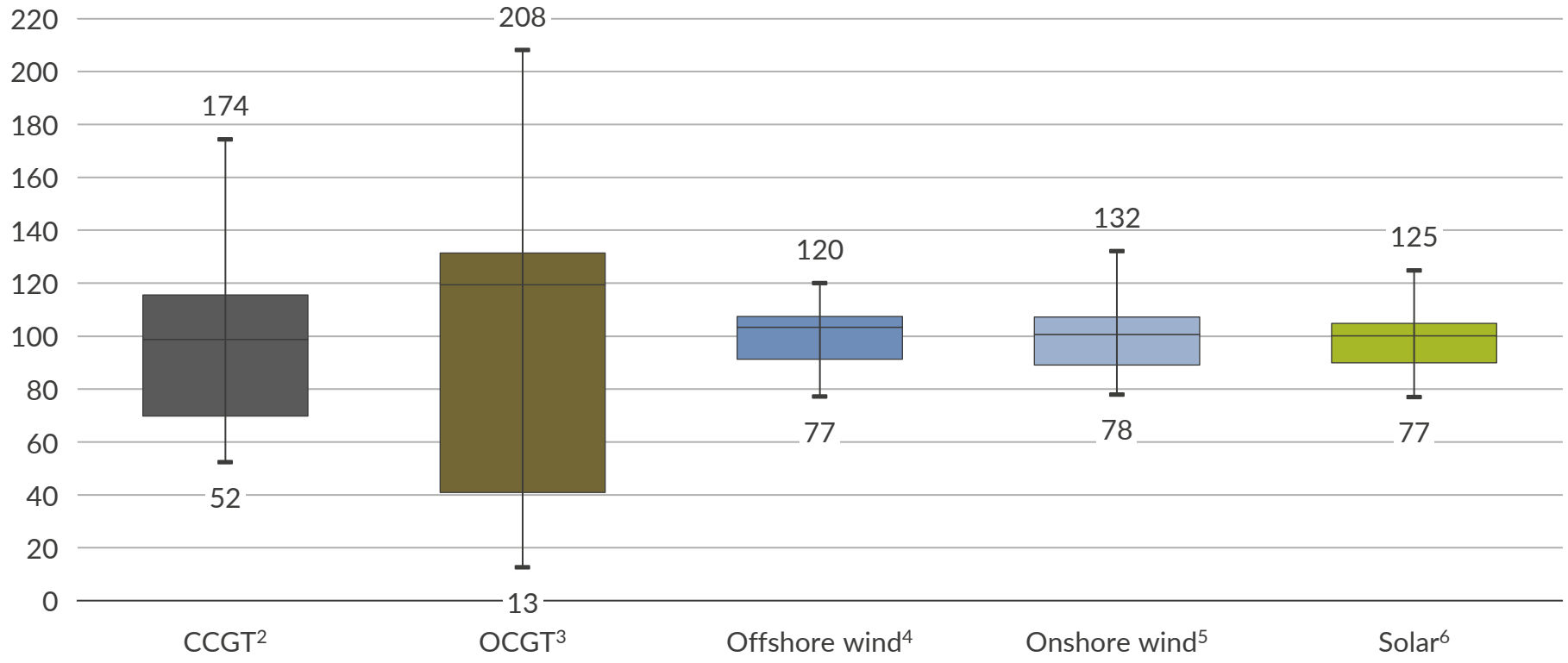
Annual gross margins in 2050[1]
% relative to average of 10 weather years



Standard deviation,
K EUR/MW

CCGT[2]	OCGT[3]	Offshore wind[4]	Onshore wind[5]	Solar[6]
14	7	28	16	6

Asset economics will see greater volatility in the future from fluctuations in weather. However, the impact for individual technologies could differ:

1. Thermal assets see significant swings as a low renewable production year allows for higher levels of thermal production and power prices
2. By comparison, renewables see smaller swings as a high production year is typically coupled with lower power prices

Source: Aurora Energy Research

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Agenda

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I. Appendix

Timing of about 19% of power demand will be flexible and shift peaks to periods of high renewable production

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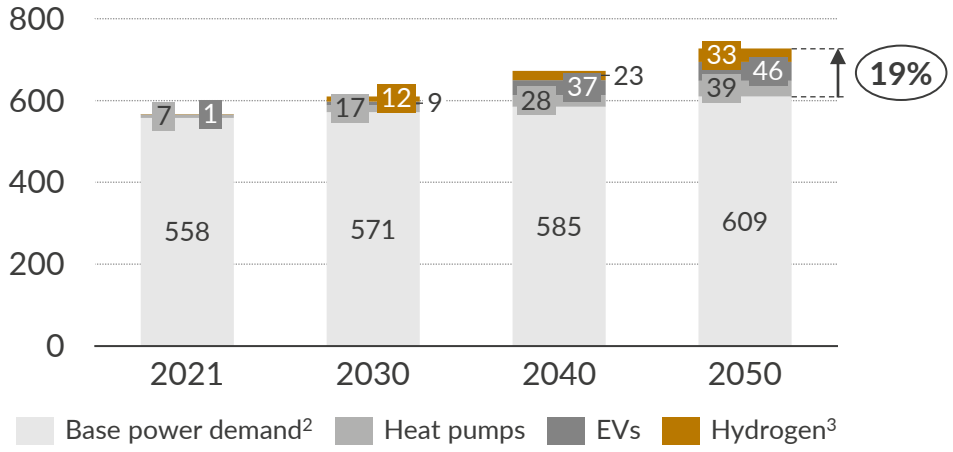
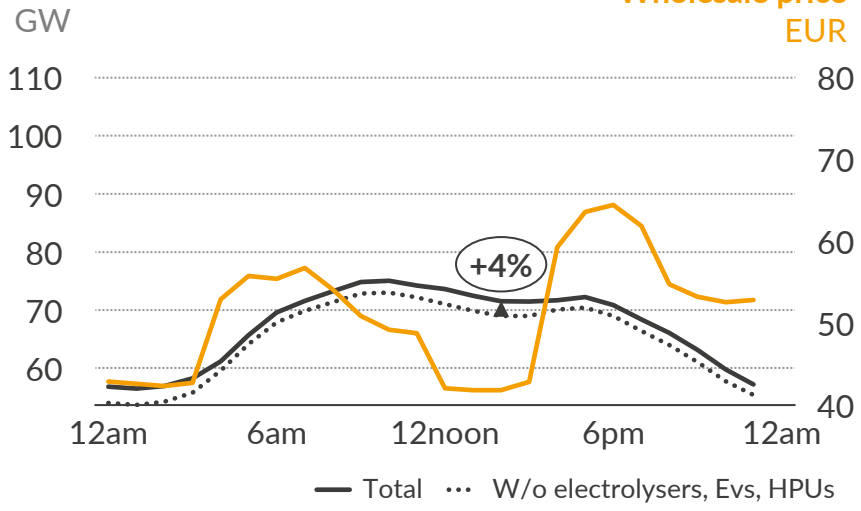
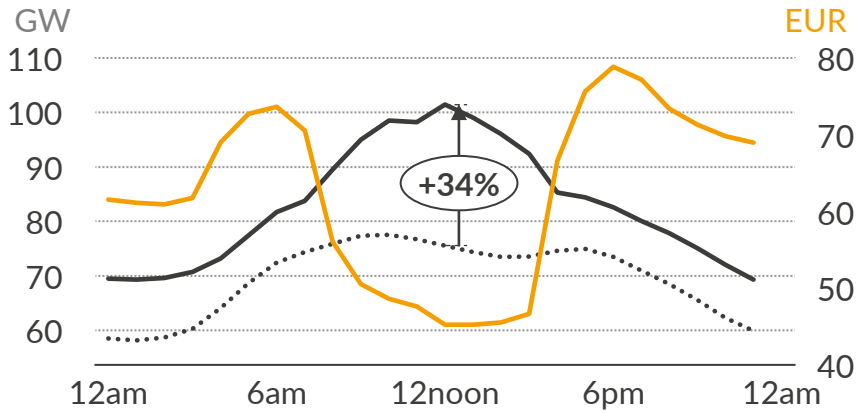
Net electricity demand[1]



Average daily demand in 2025



Average daily demand in 2050



- Assumed flexible heat pumps that react to scarcity without incurring costs, ability to switch off for 4h
- Electric vehicles will become increasingly smart, with the share of smart EVs reaching 90% from 2040, meaning they charge when wholesale prices are lowest
- Electrolysers are required to meet a growing share of projected hydrogen demand, but can shift their production freely to the cheapest times

Issue

How can private consumers be incentivized to accept flexibilization, e.g. of EV charging and heat pumps?

Importance

Potential for storage via EVs and demand side response (DSR) via heat pumps is enormous (20% of peak demand) and could significantly mitigate stress on generation and grids

Potential solutions

- Besides technical requirements, regulation like the withdrawn SteuVerG[4] law is needed to facilitate flexible solutions
- Aggregators and utilities can create business models attractive also to end customer, e.g. power providers already offer lower tariffs for the permission to switch off heat pumps

1) Includes sectoral demand (i.e. industry, commerce, transport and households) as well as transmission losses, but excludes power plant self-consumption and demand from efficiency losses of storage. 2) Underlying demand excluding heat pumps and EVs. 3) Demand for hydrogen production from electrolysis; 4) Steuerbare-Verbrauchseinrichtungen-Gesetz

Sources: Aurora Energy Research

DSR can bridge peaks in residual load, but due to its short duration it would not suffice to entirely avoid loss of load in periods of scarcity

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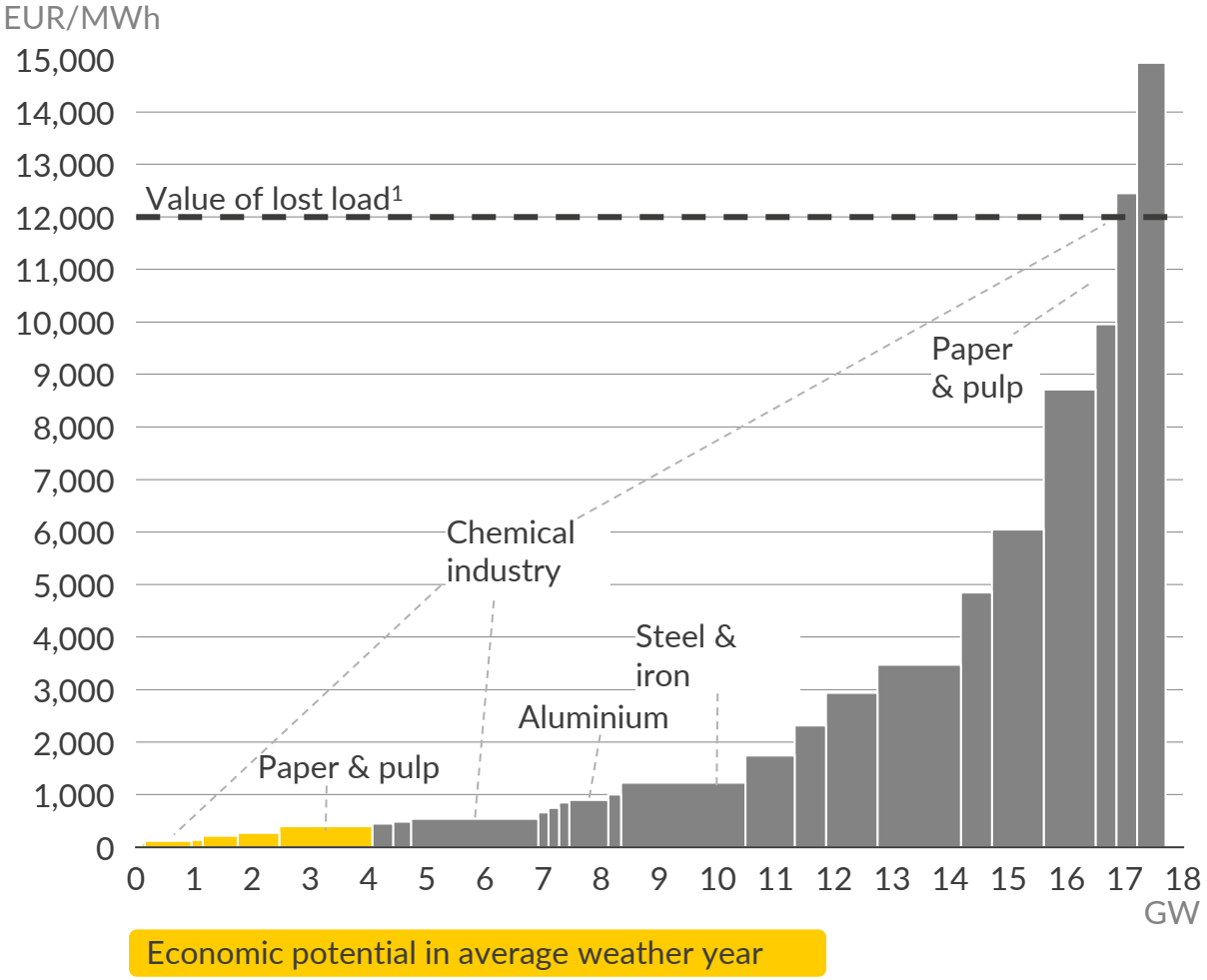
- Depending on industry and process, demand side response (DSR) can be utilised for periods between 15 minutes and 4 hours – we assume an average of 2 hours in our model
- Hence, to cover above-average peak load of 42 GWh in the weather year 2012, 17 GW of DSR would have to switch off completely and 8 GWh would still be missing
- Similarly, variable costs of DSR differ greatly between industrial processes (factor 50 between lowest and highest cost processes in chemical industry)
- Additional DSR potential could be found in the commercial and residential sector, e.g. in cooling and heating as they get more electrified

Demand side response potential and variable costs in industry



Issue

Currently, industrial capacities are incentivised to run baseload[2] – will DSR potential be tapped fast enough to be in place for tight periods? Will flexibility be extended to cover long enough periods?

Importance

Given the comparatively low CAPEX of DSR, making demand flexible is a far more economic solution than the installation of peaking capacities

Potential solutions

- Regulator can increase visibility of scarcity via monitoring reports
- Big industrials are balancing responsible parties, so avoiding price risk by use of DSR is in their interest
- For smaller players, utilities or aggregators need to structure contracts accordingly

1) Conservative estimate for the entire economy, based on ACER; 2) StromNeV § 19 Abs. 2

Sources: Aurora Energy Research; BMWi, ACER

Market players need to have confidence in steadiness of the Energy-only Market, otherwise their distrust might turn into a self-fulfilling prophecy

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Danger of …	Description	Solutions	Feasibility of solutions
… changes/ intervention in regulatory framework	Ambiguity on if and how the government will intervene in the Energy-only Market (EOM) creates uncertainty on whether sufficiently high peak prices can be realized:		
	▪ High scarcity pricing might raise suspicion of market abuse, with the risk of market intervention like price caps[1]	▪ Transparent criteria for market interventions to be defined ex ante – but can hardly be comprehensive	
	▪ Scarcity might lead to political pressure for politicians to fund additional capacity, and has led to intervention in other markets	▪ Government could guarantee the continuation of EOM for a minimum number of years and cover losses caused by abandoning the EOM	
… market participants holding back their investments	Capacity instruments might become necessary if neither incumbents nor new players are willing to build capacity in the EOM:		
	▪ Large players might strategically decide not to invest in expectation of capacity mechanisms	▪ Energy markets must keep low barriers for new entrants with higher risk appetite, such as financial investors	
	▪ Market players might not build because last few GW not attractive, financing not available	▪ The capacity reserve should be prolonged to decrease pressure on politicians	

1) As happened in reserve markets in 2017

Sources: Aurora Energy Research

Capacities to cover rare times of extremely high residual load are required, but they are expensive and hard to finance - two questions arise:

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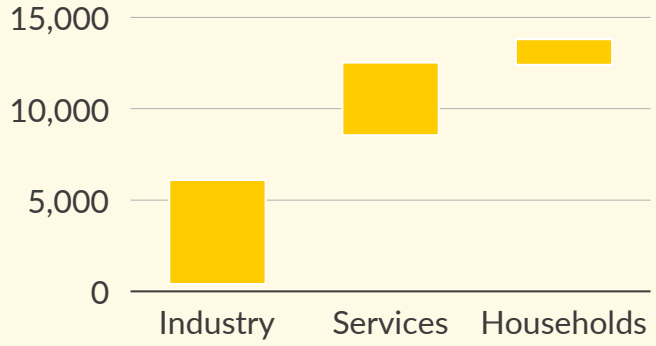
1. How much loss of load should be accepted?

- Loss of load (LOL) is most economic solution for rare residual load peaks
- Currently, ministry accepts loss of load expectation (LOLE) of 5 h p.a., which reflects cost and surveyed value of loss load to households
- Picking the right level of LOLE is difficult:
  - Will even 5 h be accepted?
  - On the other hand – is the value of lost load really as high as surveys present?
  - Which capacity margin achieves this?

Value of loss of load in Germany
EUR/MWh

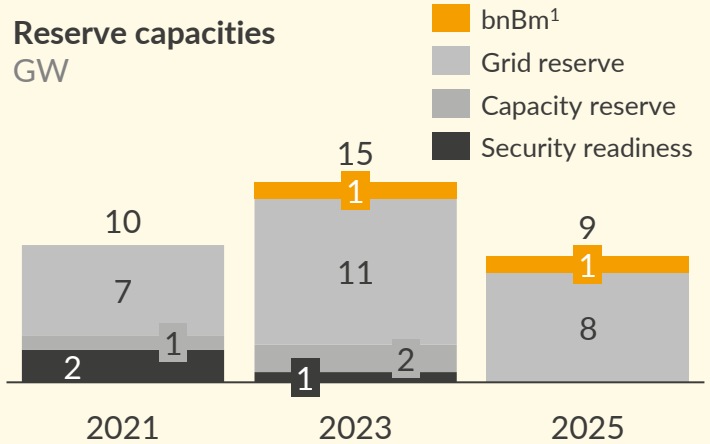


2. To what degree should the state provide capacities for hard-to-foresee events – using what framework?

Keeping the Energy Only Market

- EOM trusts decentral market decision to find the optimal demand and supply balance & mix
- For the EOM to work, continued strong political commitment is necessary, including acceptance of high scarcity pricing – as well as forward looking behaviour of market participants
- Paired with a capacity reserve, the EOM still allows regulator to guarantee security of supply at a chosen level

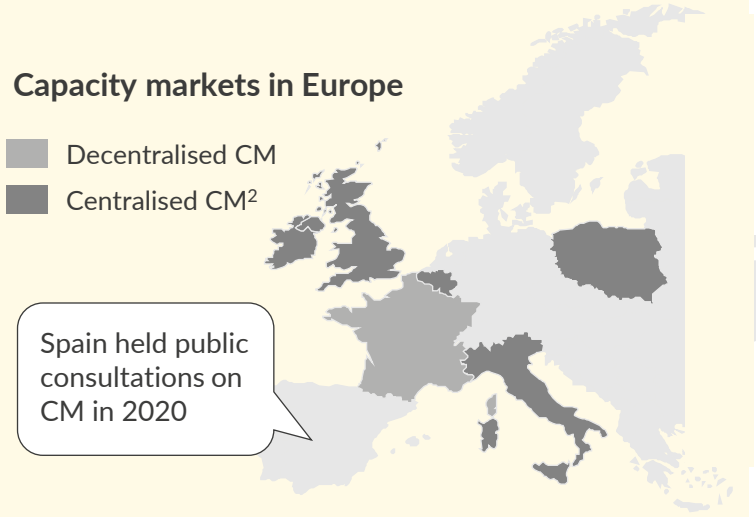
Reserve capacities
GW



Creation of a Capacity Market

- Capacity markets were introduced in several European countries in the last decade
- Seemingly "the easiest solution" to guarantee security of supply, it requires detailed market knowledge of the regulator and first attempts (e.g. in the UK) did not necessarily work as expected

Capacity markets in Europe



1) "Besondere netztechnische Betriebsmittel" are another type of grid stability reserve, 2) Belgium's capacity market is currently under review by EU Commission

Source: Aurora Energy Research, ACER, Growitsch et al; BMWi; ENTSO-E, BNetzA

Details and disclaimer

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Date
12th March 2021

Prepared by
Kora Stycz
(kora.stycz@auroraer.com)
Eva Zimmermann
(eva.zimmermann@auroraer.com)
David Taylor
(david.taylor@auroraer.com)
Gero Roser
(gero.roser@auroraer.com)

Approved by
Lukas Bunsen
(lukas.bunsen@auroraer.com)