# Beyond the Tipping Point

## Flexibility gaps in future high-renewable energy systems in the U.K., Germany and Nordics

A Bloomberg New Energy Finance study commissioned by Eaton in partnership with the Renewable Energy Association

Presentation for CEER, March 1, 2018

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| Bloomberg | Bloomberg New Energy Finance |
|---|---|
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| Generating 5,000 news stories a day from 150 bureaus | Generating over 700 Insight reports annually |
| 320,000 global clients | 2,500+ global clients |

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Wind
Storage
Decentralized Energy
Frontier Power
Impact on Power & Utilities

## Advanced Transport

Electrified Transport
Autonomous Driving
Shared Mobility
Impact on Transport
Impact on Oil & Power

## Commodities

LNG & Gas
Oil & Products
Power
Carbon

## Emerging Technologies

Internet of Things
Machine Learning & Analytics
Advanced Materials
Impact on Industrials and Energy

# Beyond the Tipping Point: summary findings

## Tipping Points

- Rapid cost reductions in wind and solar power make them the cheapest sources of electricity in Germany and the U.K., driving the shift to high-renewable power systems

## Flexibility Requirements

- Short-term volatility and hourly/daily variations will necessitate much greater flexibility in the power system in both U.K. and Germany
- Seasonal gaps mean dispatchable sources will continue to be needed for back-up capacity. However, significant drops in their utilisation will harm them economically
- Spare flexibility in the Nordic markets present an opportunity for its export via increased interconnections with the rest of Europe

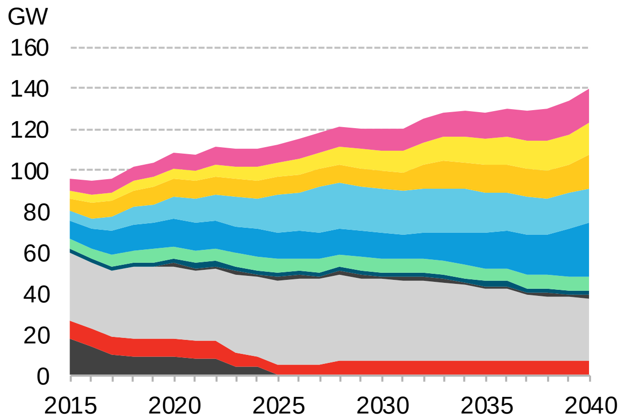
# Forecasts used in this study

## Extracts from BNEF's New Energy Outlook

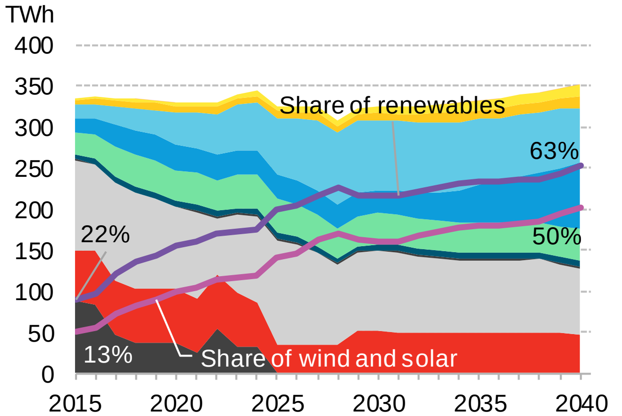
# Forecasts for U.K., Germany and Nordics

## United Kingdom

### Cumulative installed capacity

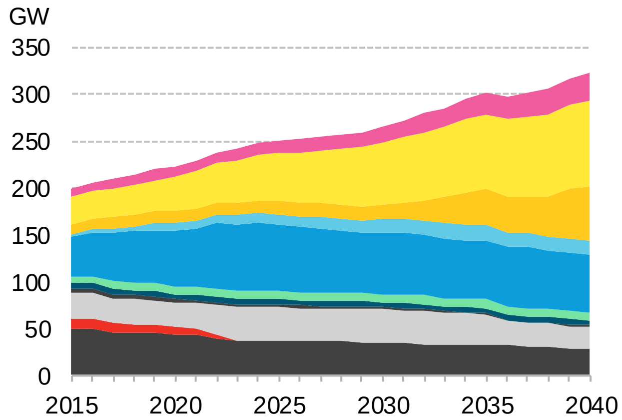



### Electricity generation

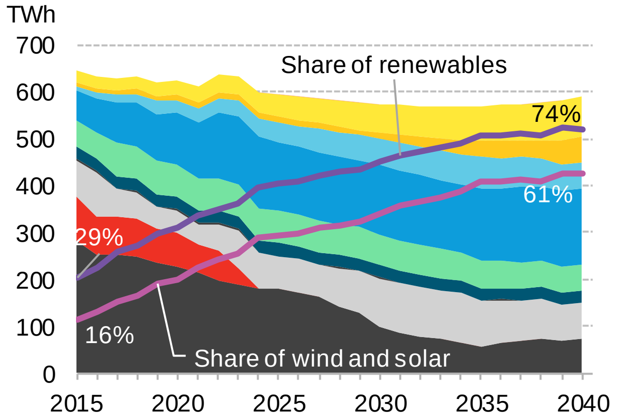



## Germany

### Cumulative installed capacity

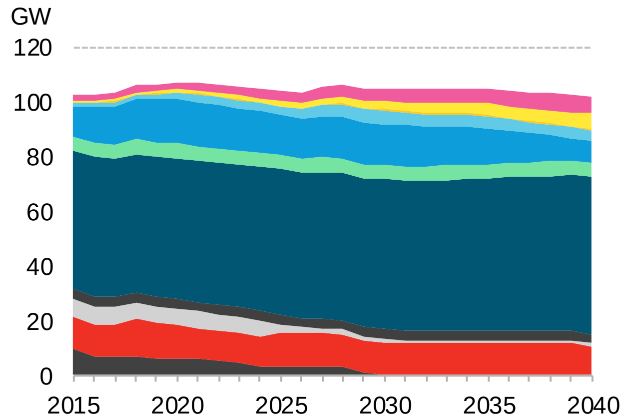



### Electricity generation

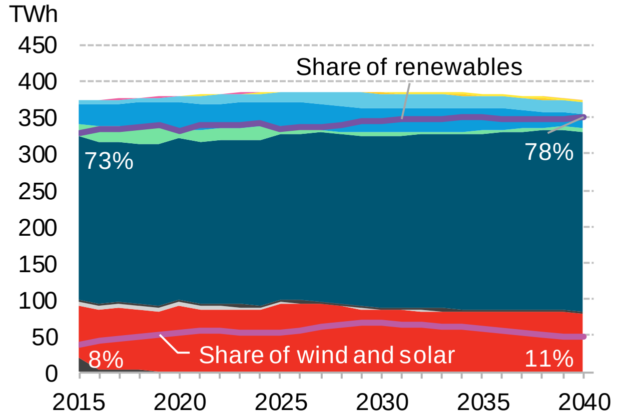



## Nordics

### Cumulative installed capacity




### Electricity generation

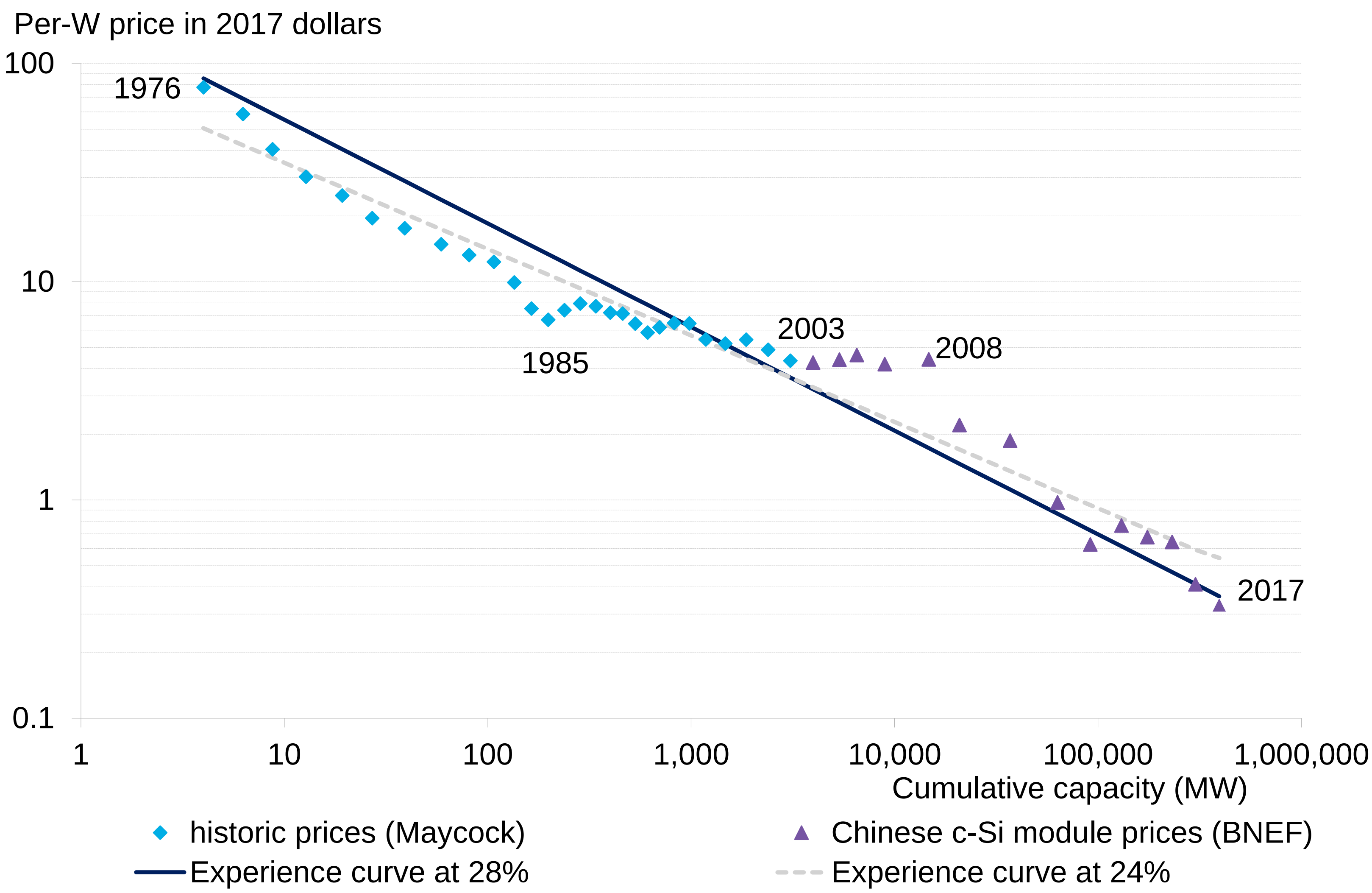



Coal · Nuclear · Gas · Oil · Other · Hydro · Biomass · Onshore wind · Offshore wind · Utility-scale PV · Small-scale PV · Flex

# Future costs of wind, solar, and storage

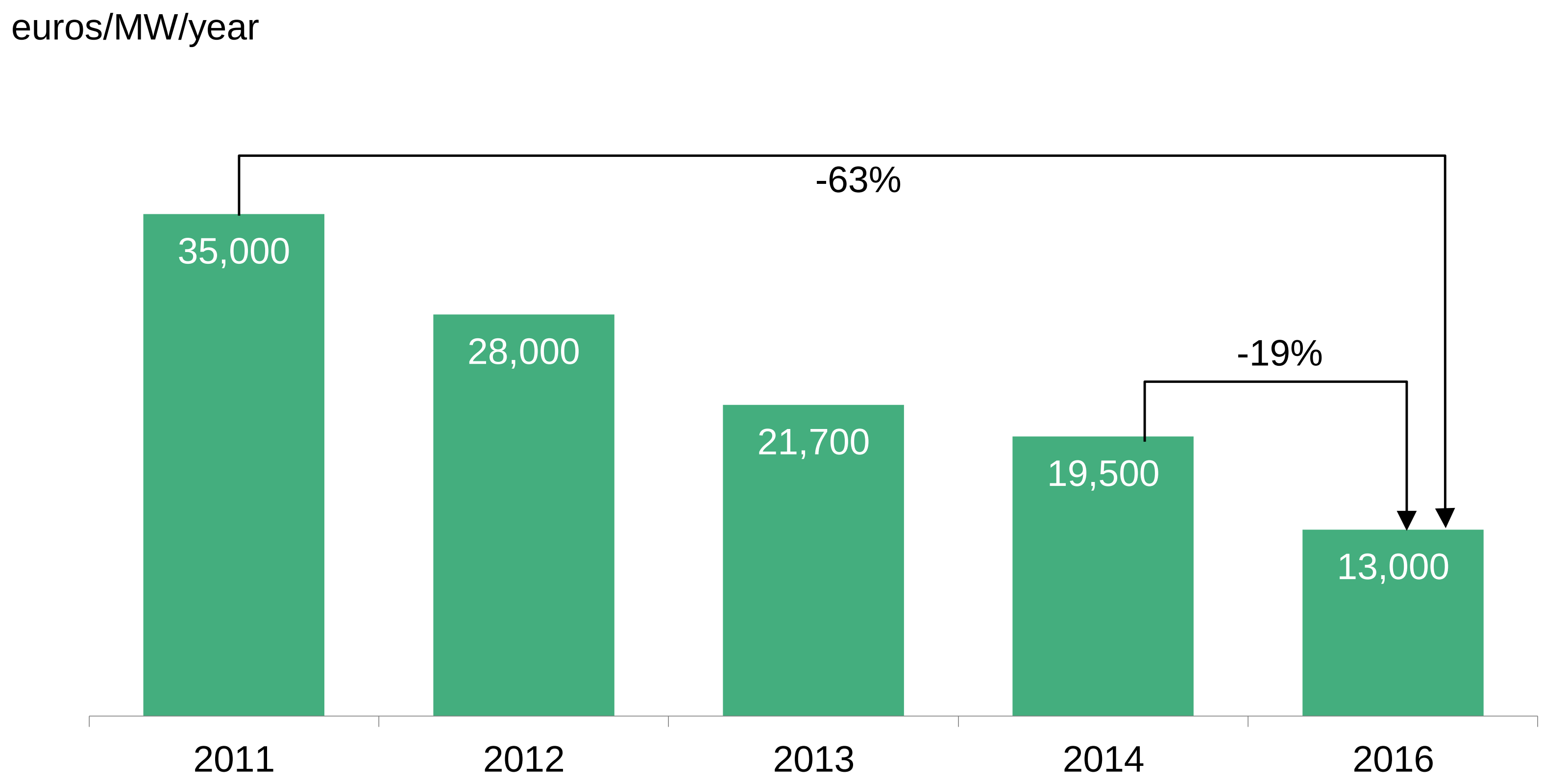
## Historical and future cost drivers

# Experience curve for crystalline silicon PV modules



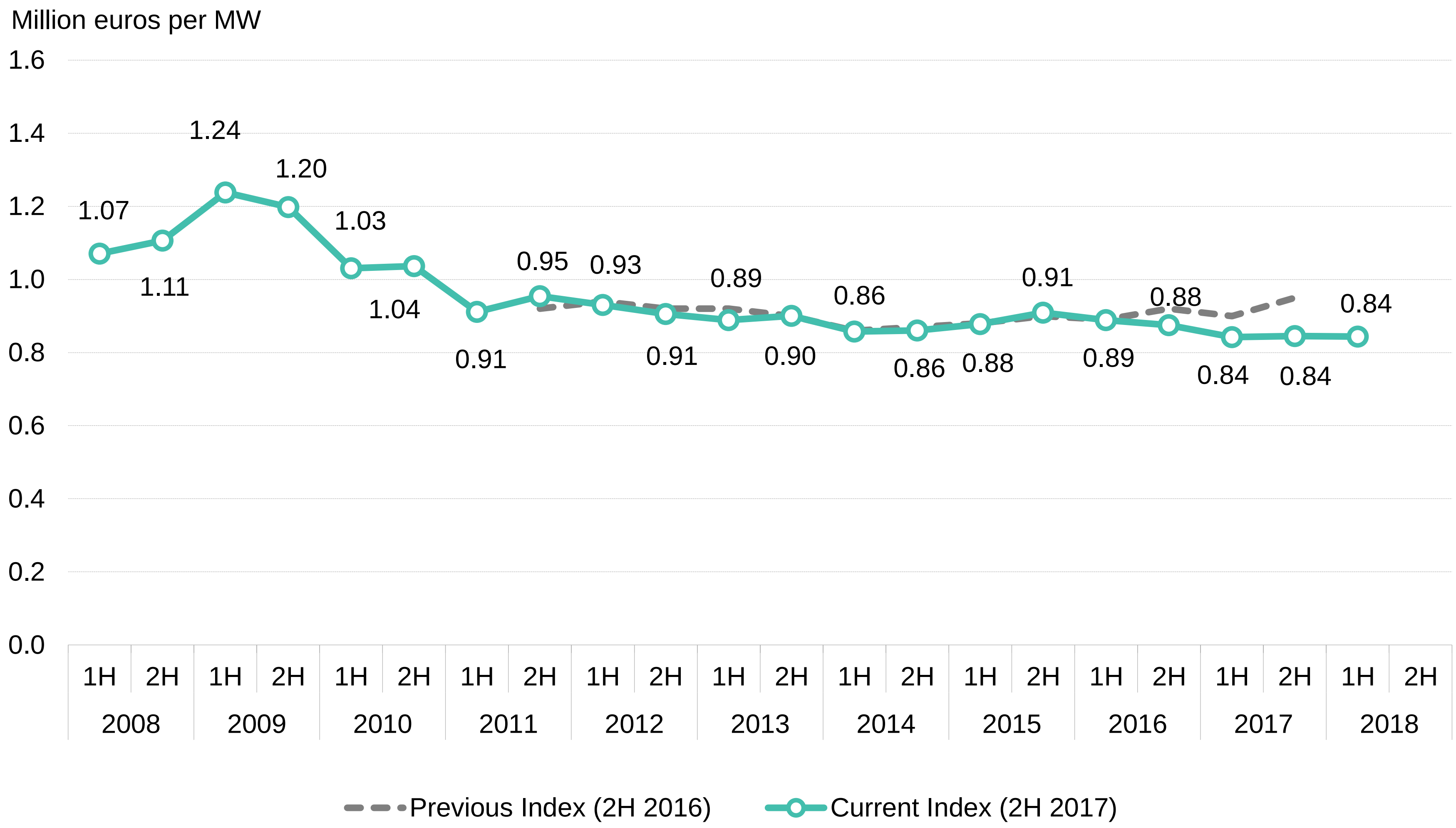

*Source: Bloomberg New Energy Finance, Paul Maycock*

# Average price for solar operations and maintenance contracts, Europe



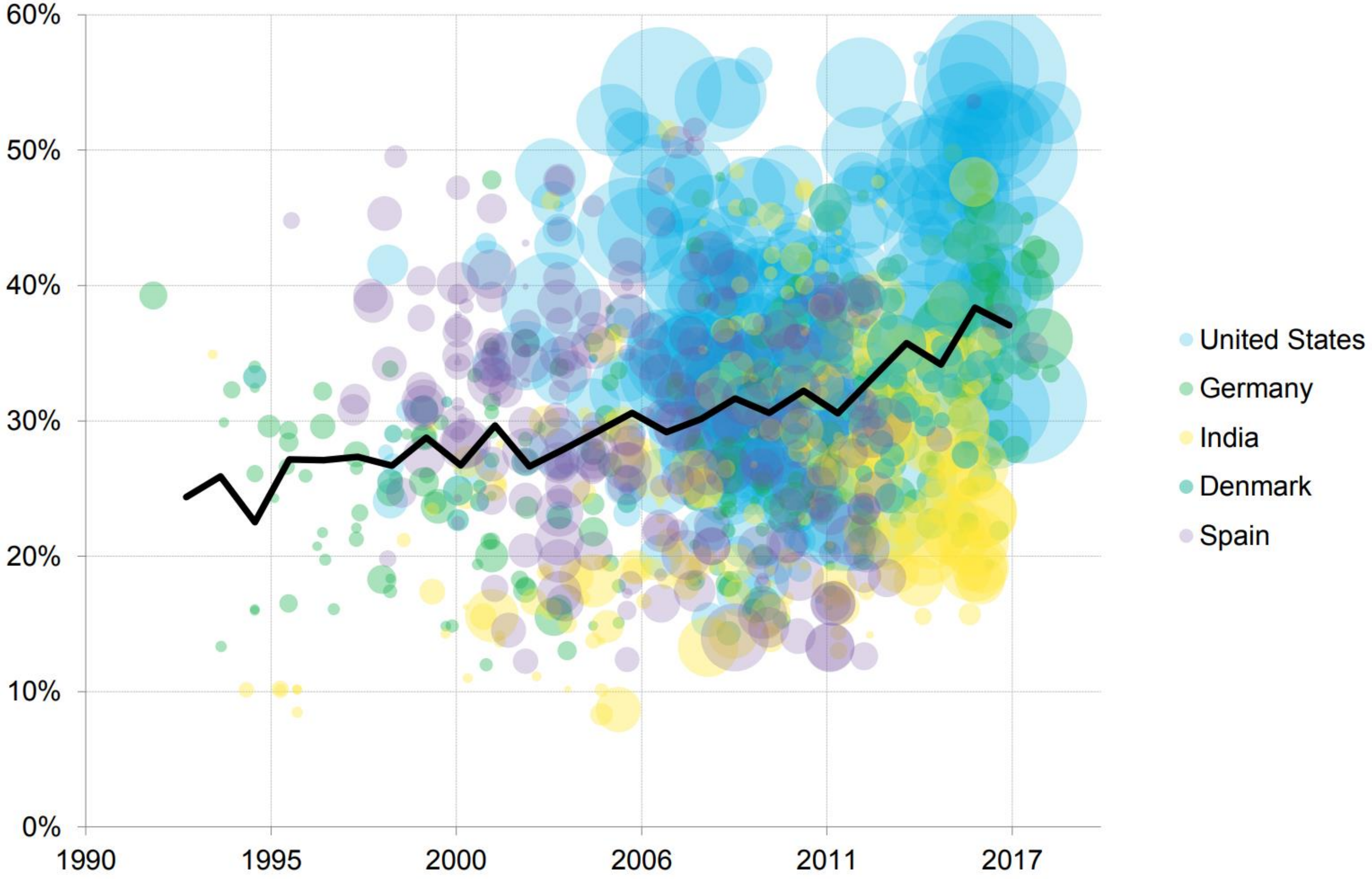

*Source: Bloomberg New Energy Finance. Note: Full-scope O&M for utility-scale projects.*

# Onshore wind turbine price by delivery date

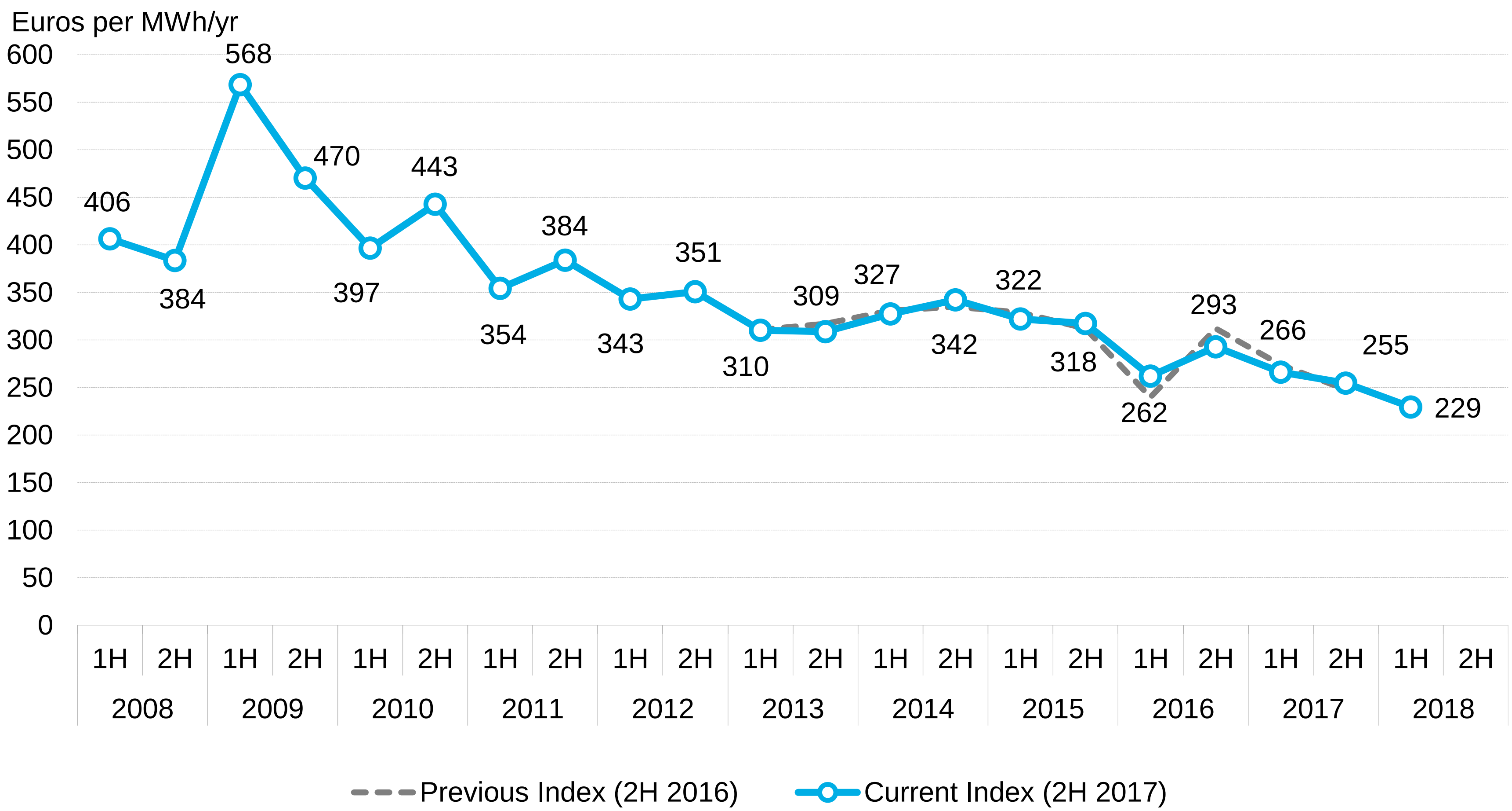



*Bloomberg New Energy Finance*

# Onshore wind capacity factors



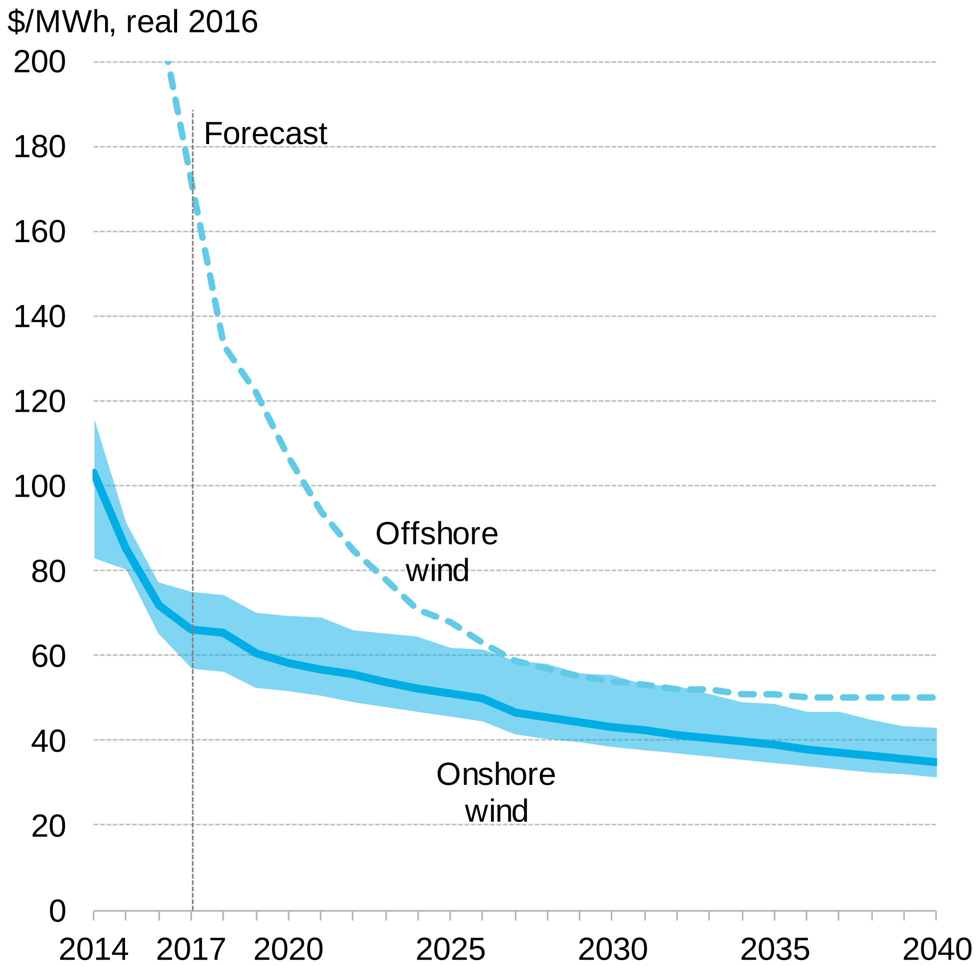
# Turbine price by delivery date – per MWh



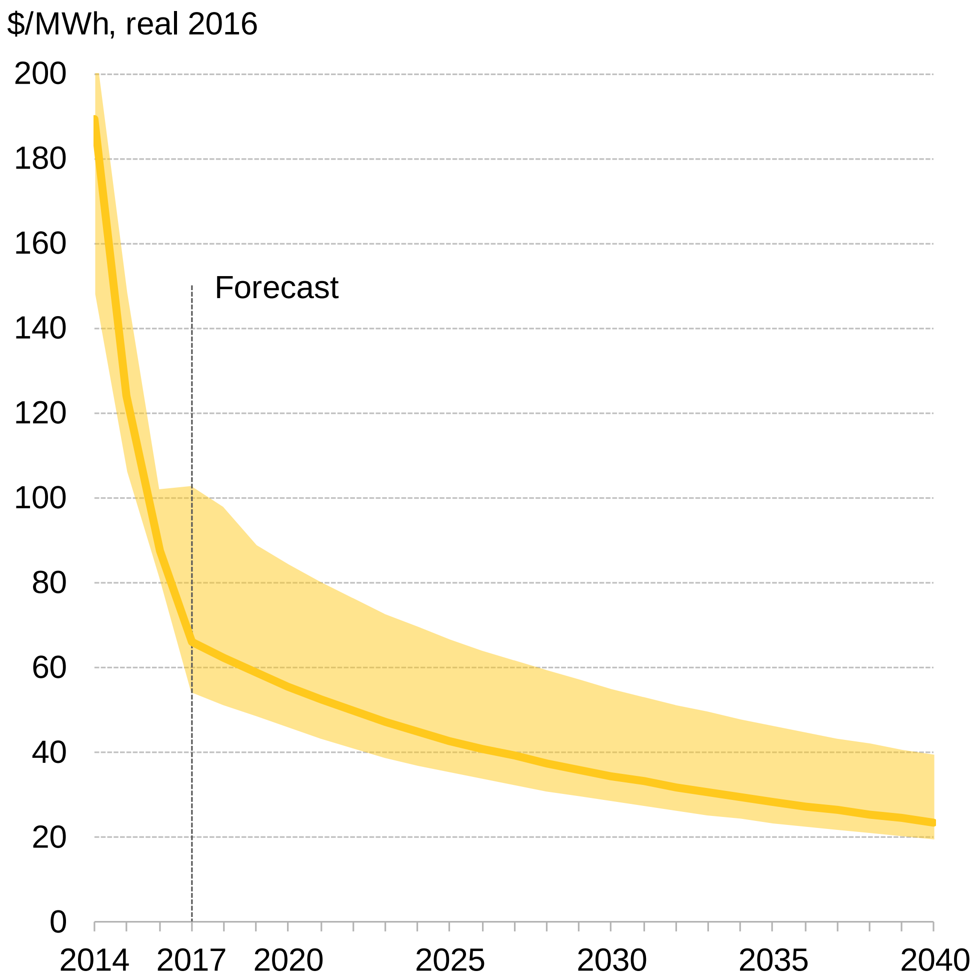

*Bloomberg New Energy Finance*

# Wind and solar LCOE forecasts, Europe ranges

## Onshore and offshore wind

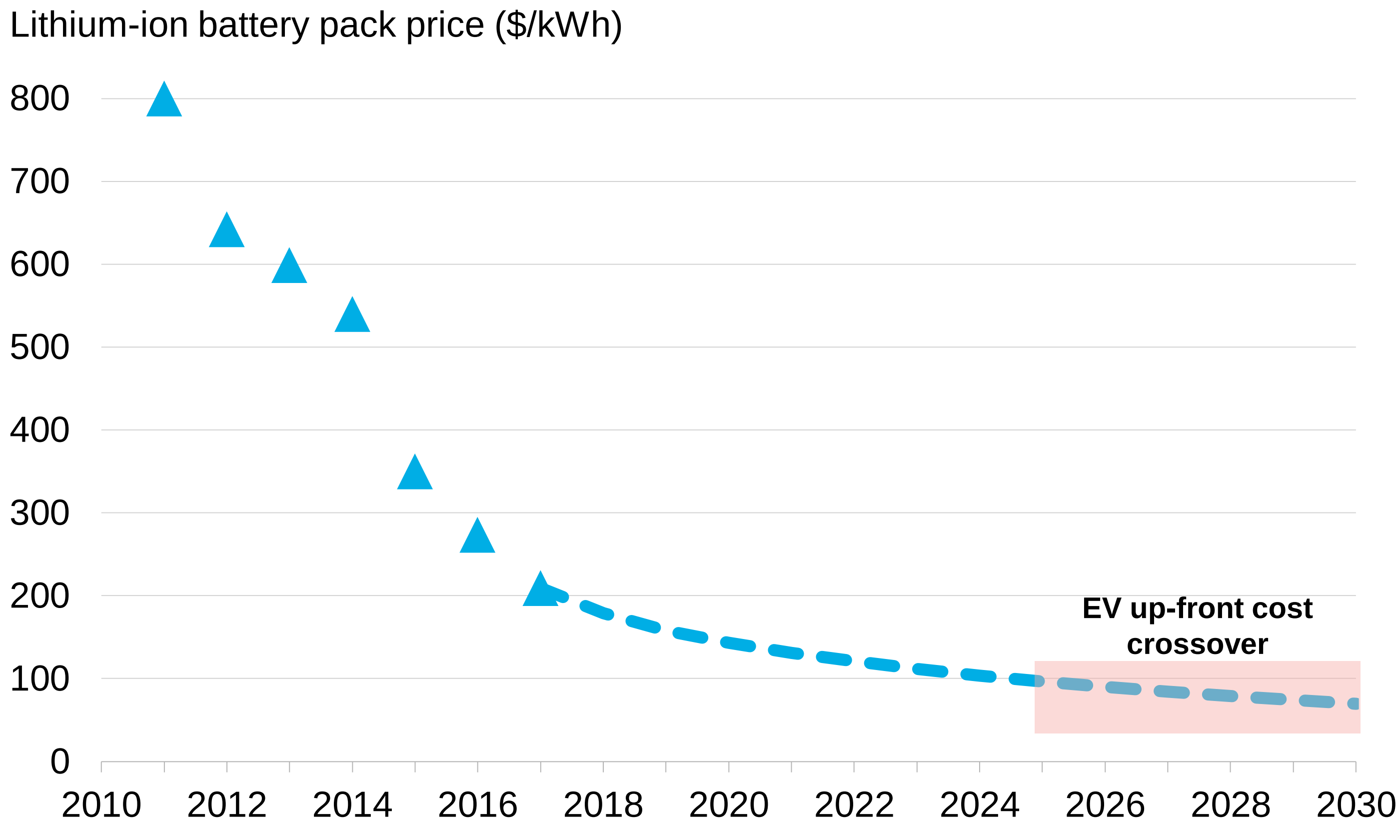



## Utility-scale PV




*Source: Bloomberg New Energy Finance*

# Battery price forecast ($/kWh)



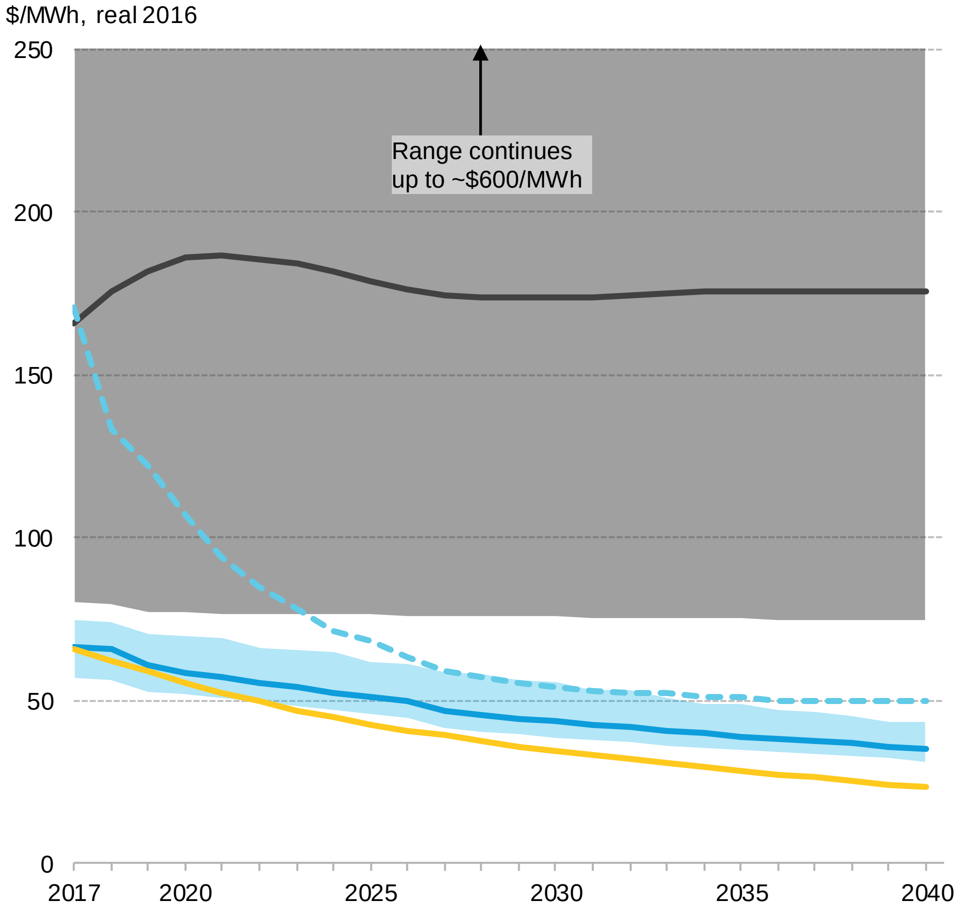

*Source: Bloomberg New Energy Finance. Note: Triangles are observed values, the dashed line is our forecast. All forecast values are in real 2017 $.*

# Cost tipping points

## When do renewables become cheapest?

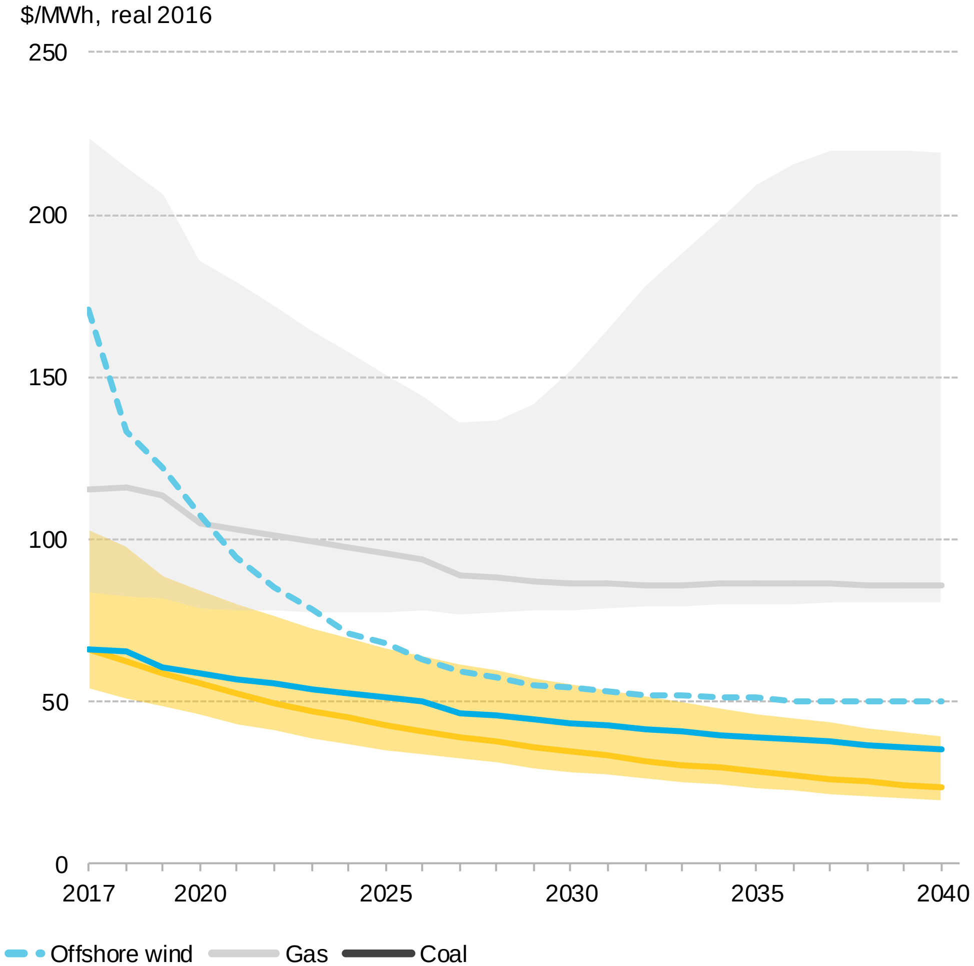
# Tipping point 1: when new-build renewables beat new-build gas and coal

## LCOE forecast range for new-build coal, onshore and offshore wind, and utility-scale PV in Europe




*Source: Bloomberg New Energy Finance*

## LCOE forecast range for new-build gas, onshore and offshore wind, and utility-scale PV in Europe




*Source: Bloomberg New Energy Finance*



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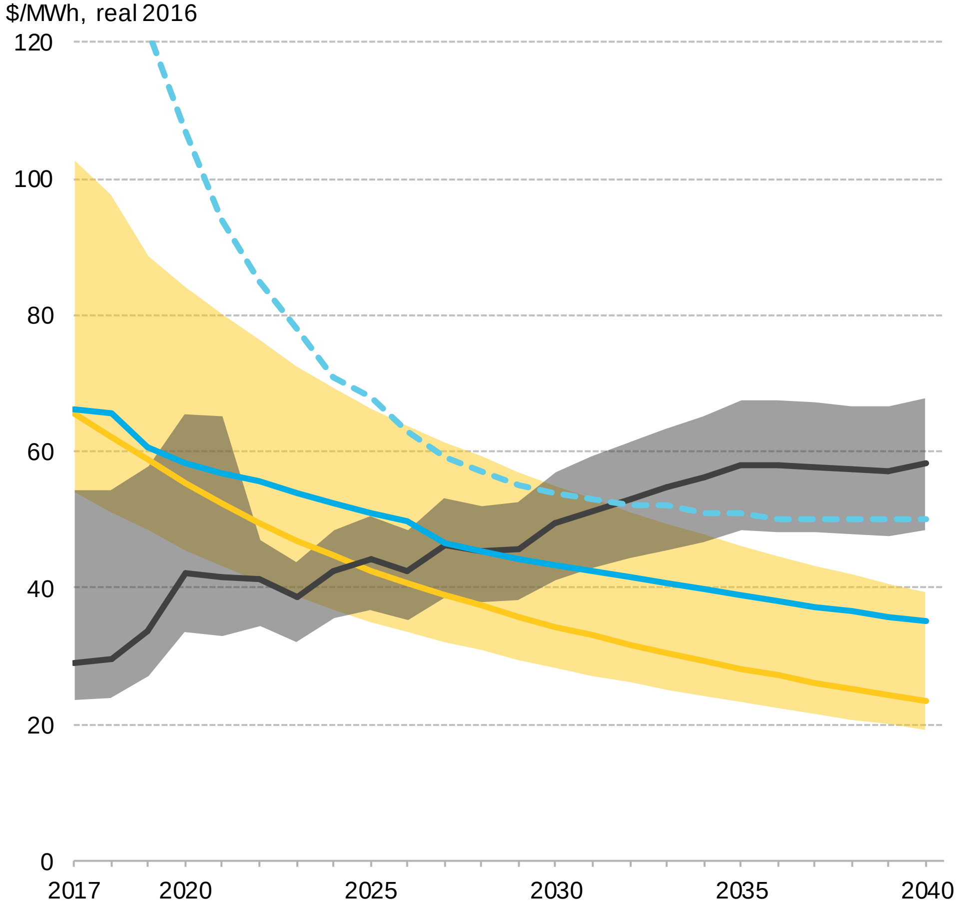
Cost tipping points

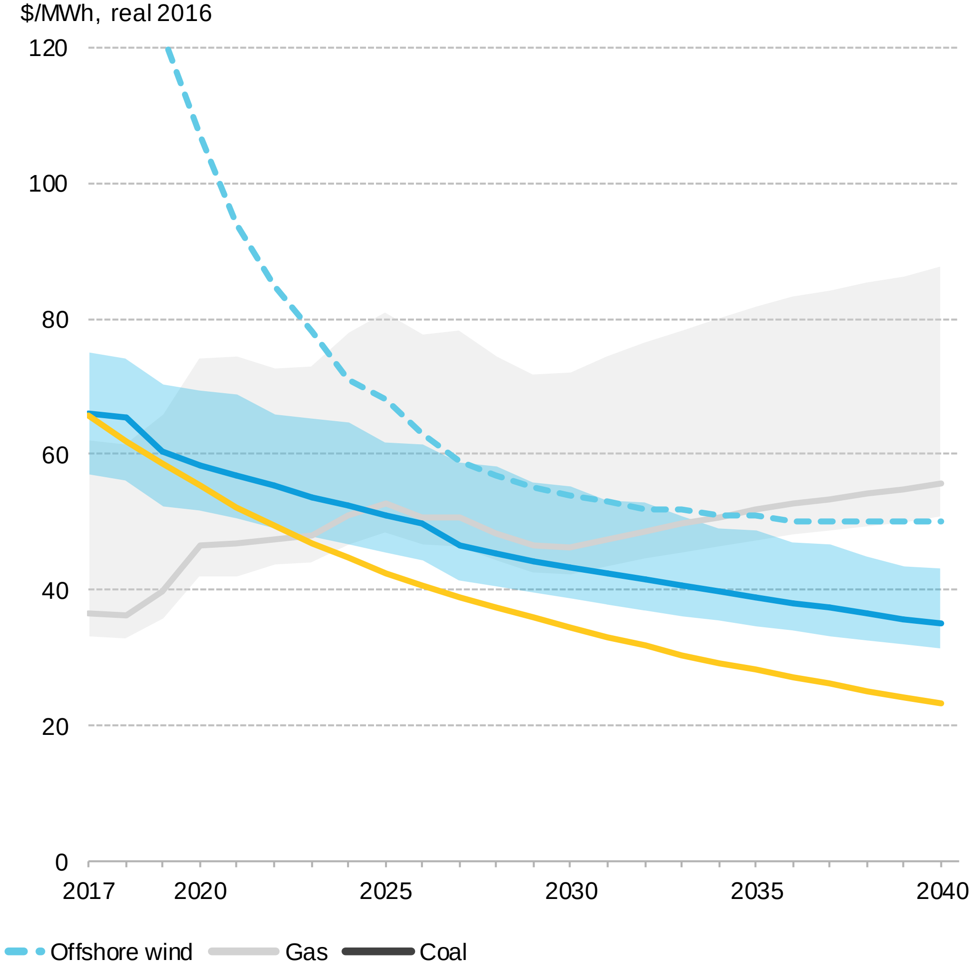
# Tipping point 2: when new-build renewables beat existing gas and coal

## LCOE forecast for wind and PV, and generation cost range of existing coal in Europe




*Source: Bloomberg New Energy Finance*

## LCOE forecast for wind and PV, and generation cost range of existing gas in Europe




*Source: Bloomberg New Energy Finance*



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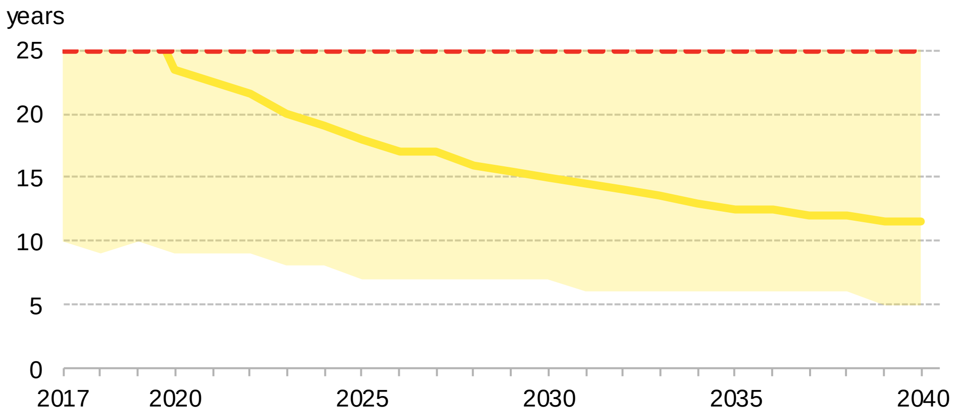
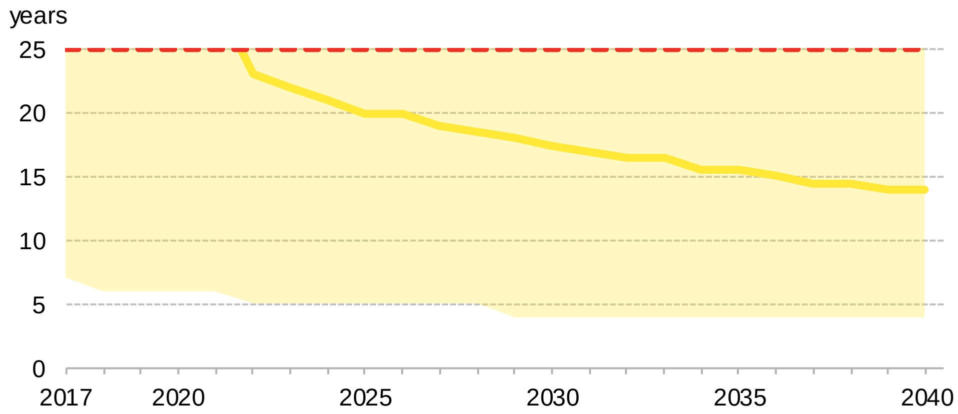
# Tipping point 3: when small-scale PV becomes cheaper than retail

## Payback period for residential small-scale PV systems in Europe

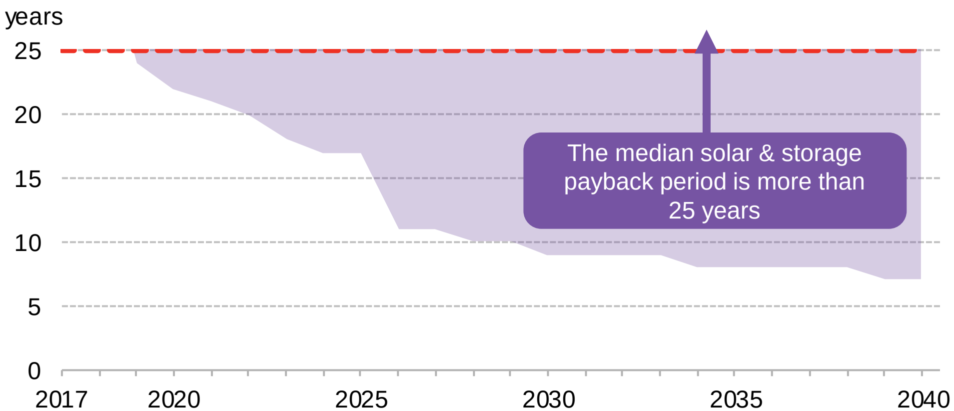



## Payback period for commercial small-scale PV systems in Europe

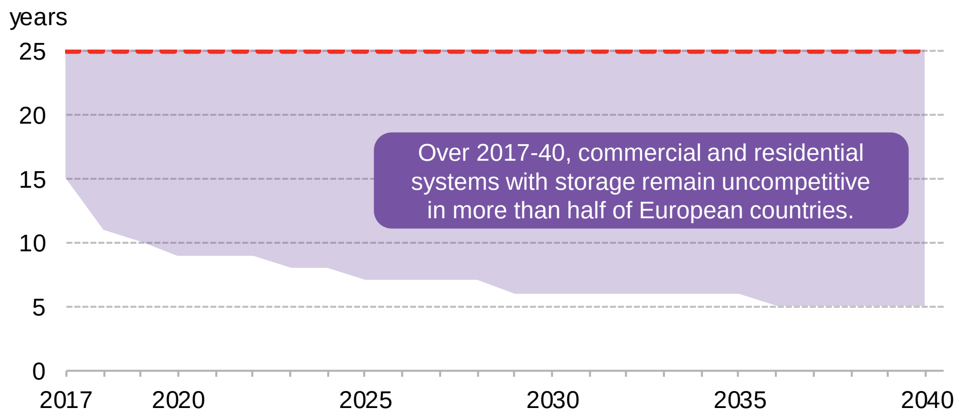



Min-max range for solar only | Min-max range for solar & storage | Median for solar only | Technical lifetime

## Payback period for residential small-scale PV systems with storage in Europe




## Payback period for commercial small-scale PV systems with storage in Europe



# Modelling assumptions

## What else goes into the New Energy Outlook forecast?

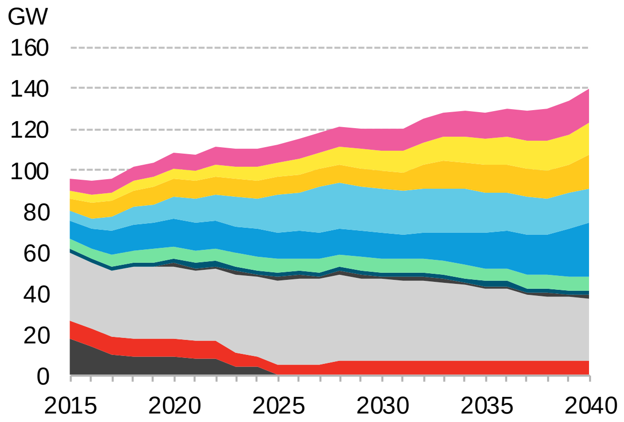
- Peak demand must be met!
- Distributed energy: 280GW of rooftop PV installed across Europe by 2040, and 46GW of small-scale batteries
- Electric vehicle forecast >50% of sales by 2040, providing extra power demand…
  - …But power demand forecast is broadly stagnant to 2040
- Commodity prices:
  - Coal prices flat
  - Gas prices rising to ~$8/mmBtu by 2040
  - Carbon prices recovering through $30/ton after 2030

Modeling assumptions

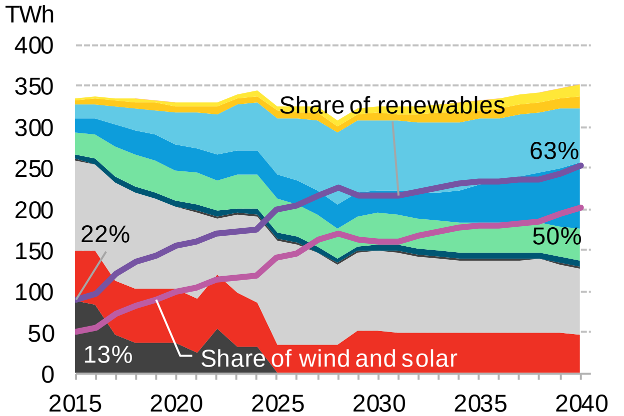
# Forecasts for U.K., Germany and Nordics

## United Kingdom

### Cumulative installed capacity

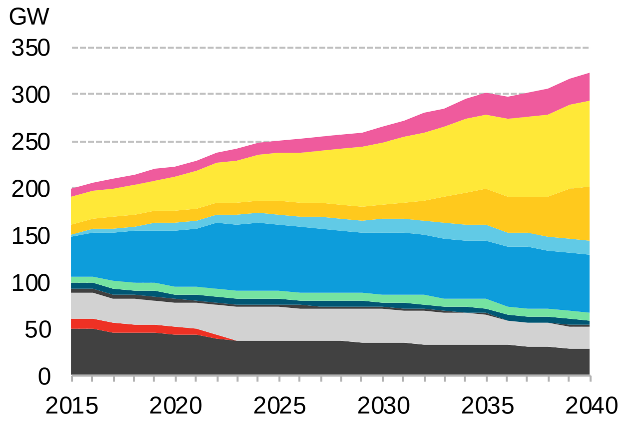



### Electricity generation

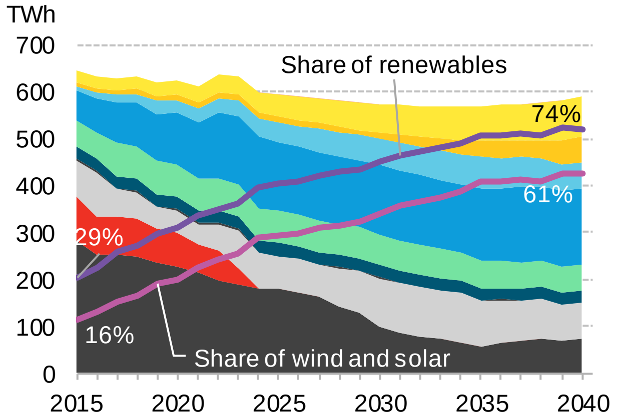



## Germany

### Cumulative installed capacity

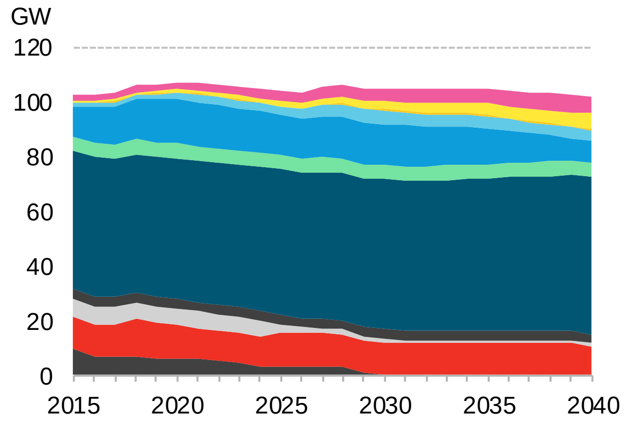



### Electricity generation

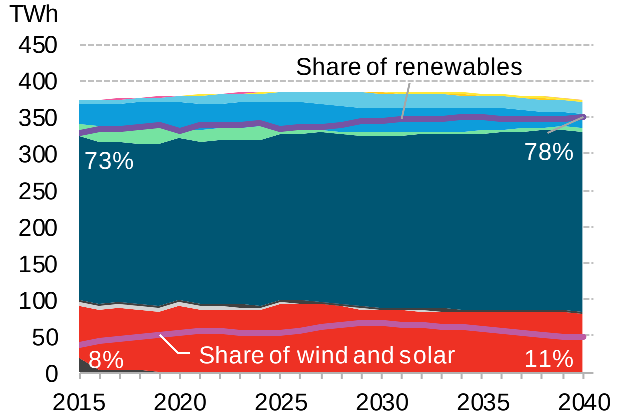



## Nordics

### Cumulative installed capacity



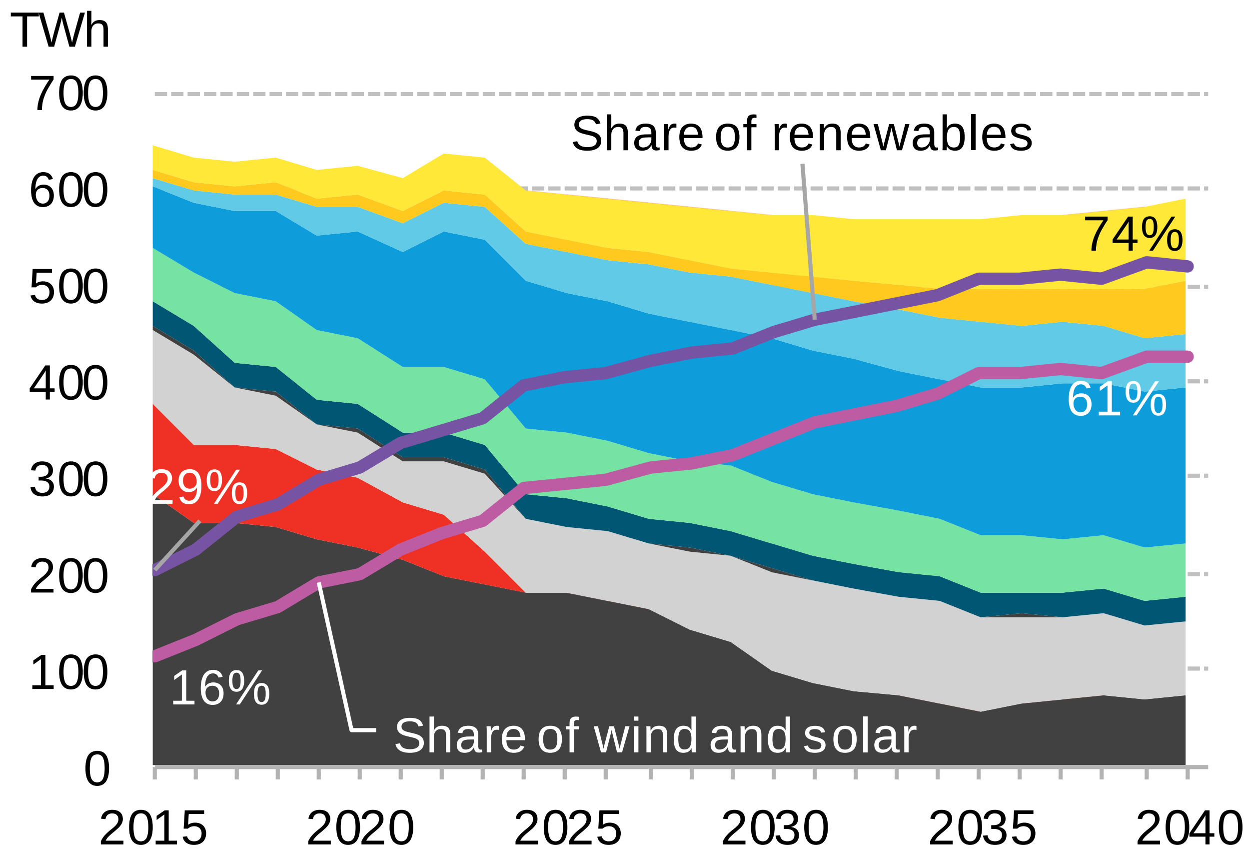

### Electricity generation




■ Coal ■ Nuclear ■ Gas ■ Oil ■ Other ■ Hydro ■ Biomass ■ Onshore wind ■ Offshore wind ■ Utility-scale PV ■ Small-scale PV ■ Flex

# Germany: overview of scenarios and issues

# Four scenarios used for analysis




?

| **Share of demand met by wind and solar:** | **2017** | **2030** | **2040** | **And an extreme scenario:** |
|---|---|---|---|---|
| | 25% | 49% | 61% | 100% |

*Source: Bloomberg New Energy Finance.*

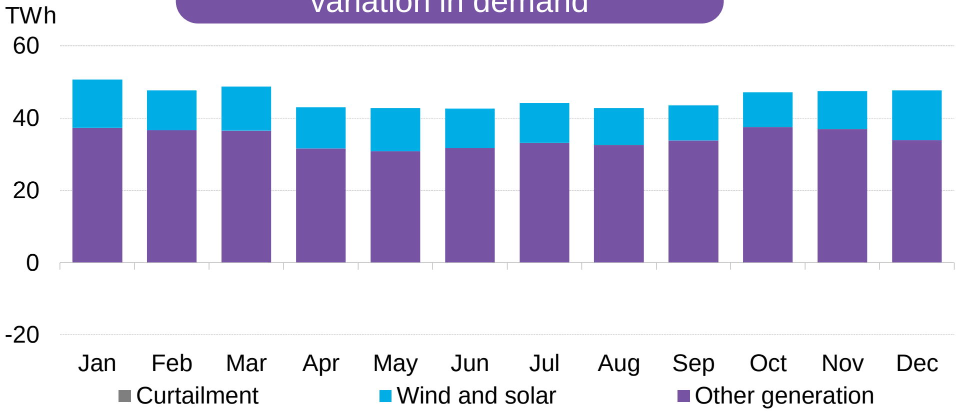
# Some considerations

- In all scenarios, there is enough dispatchable capacity to meet peak demand
- We used five years of weather and demand data in each scenario – to capture extremes
- Grid constraints and interconnectors are not modelled
- No demand shifting is assumed
- 100% scenario is an exception – not economically modelled

# Monthly generation

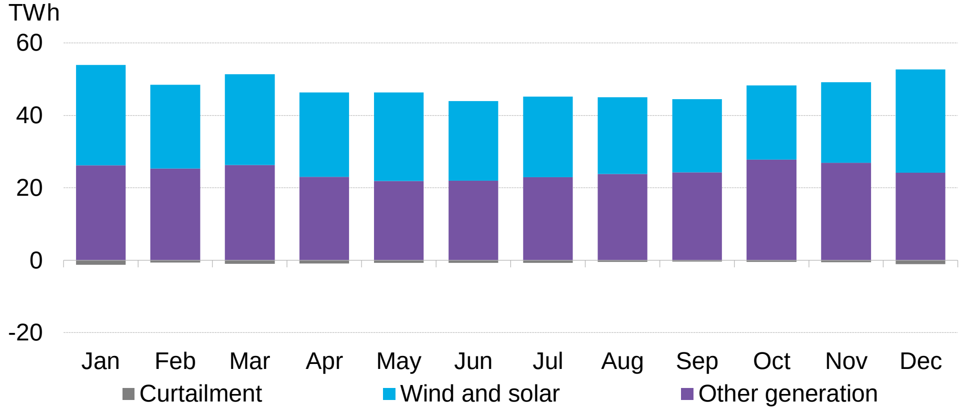
## 2017

Seasonal variations in 'other generation' are explained by variation in demand



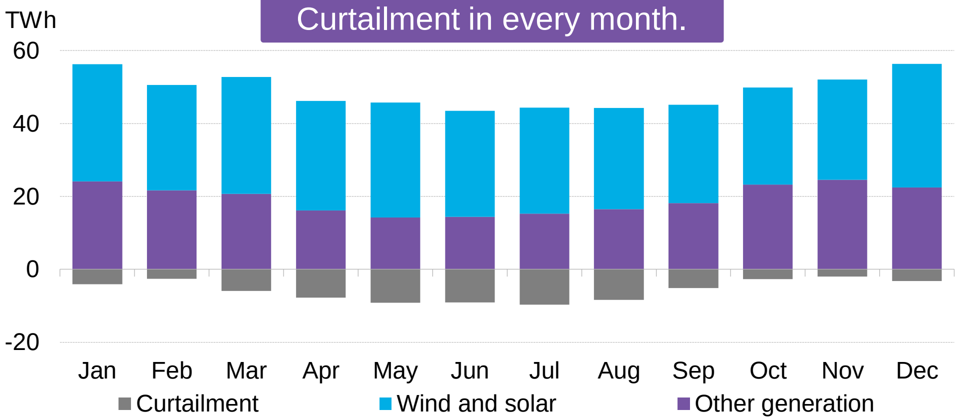

## 2030

First instances of curtailment appear



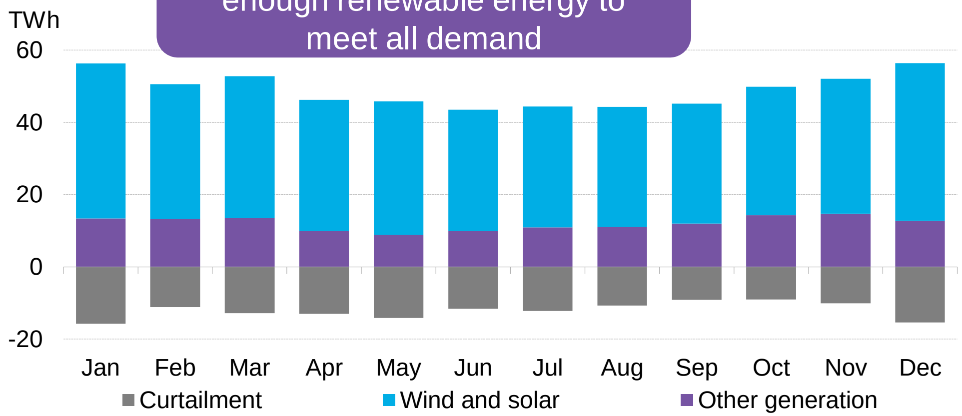

## 2040

Wind and solar now supply the majority of energy. Curtailment in every month.




## 100%

Entire calendar months have enough renewable energy to meet all demand

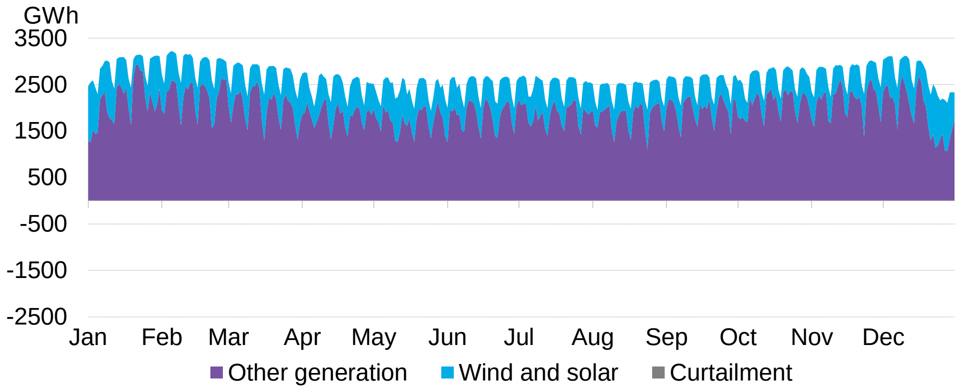



*Note: other generation includes all form of generation besides wind and solar, and can also be interpreted as 'net demand' – total demand net of wind and solar generation.*

Germany: overview of scenarios and issues

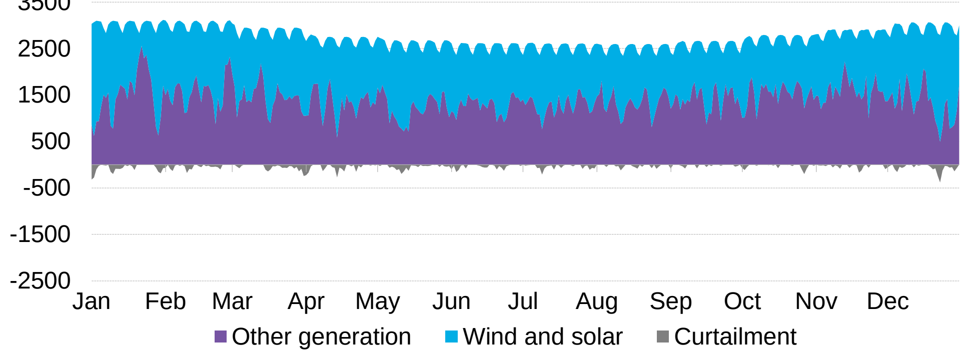
# Daily generation

## 2017



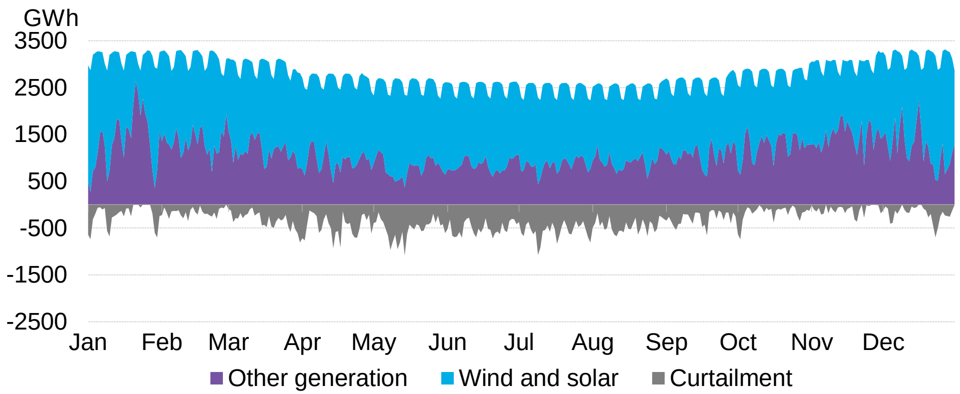

## 2030

Generation from other sources starts to vary significantly

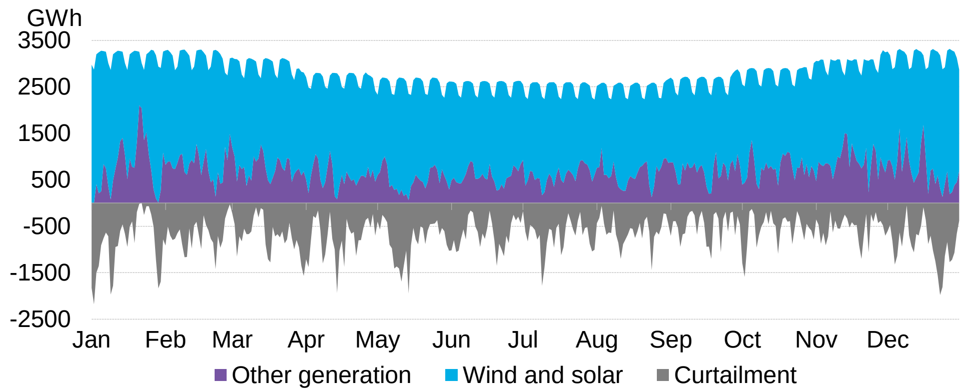



## 2040

Almost every day is dominated by renewables.

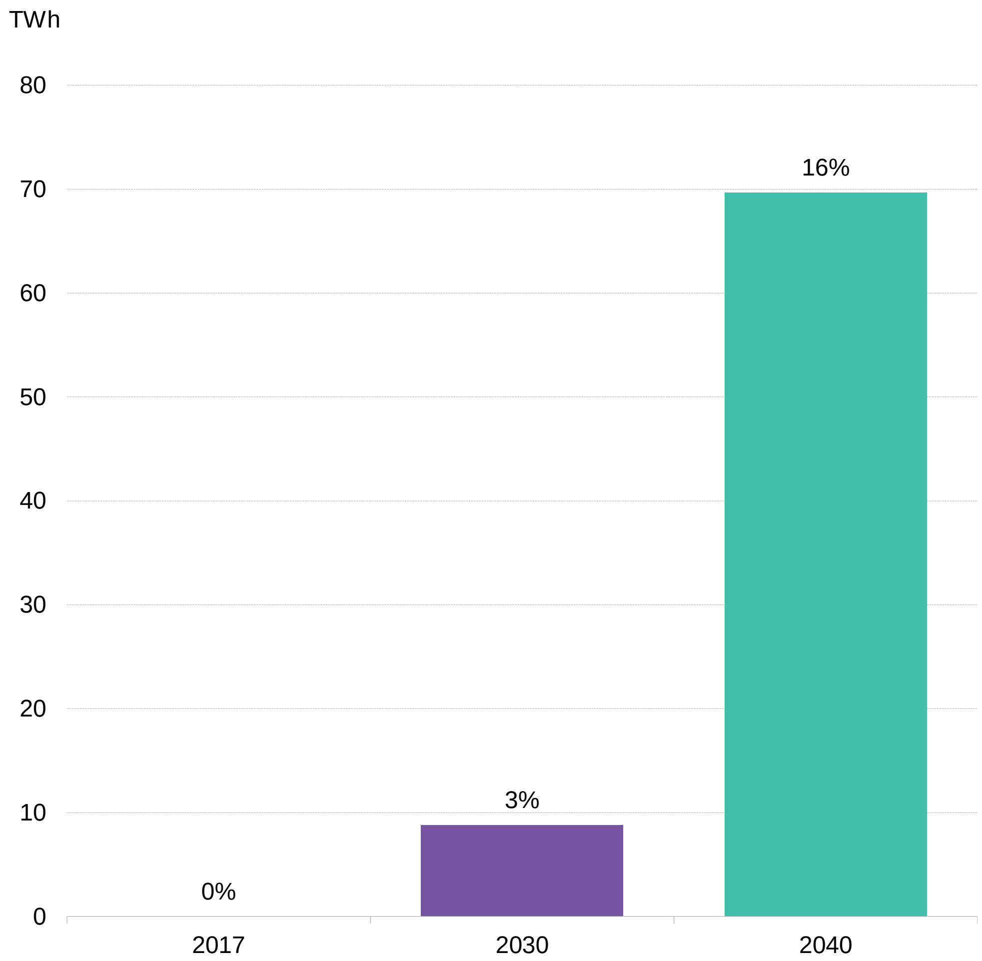



## 100%



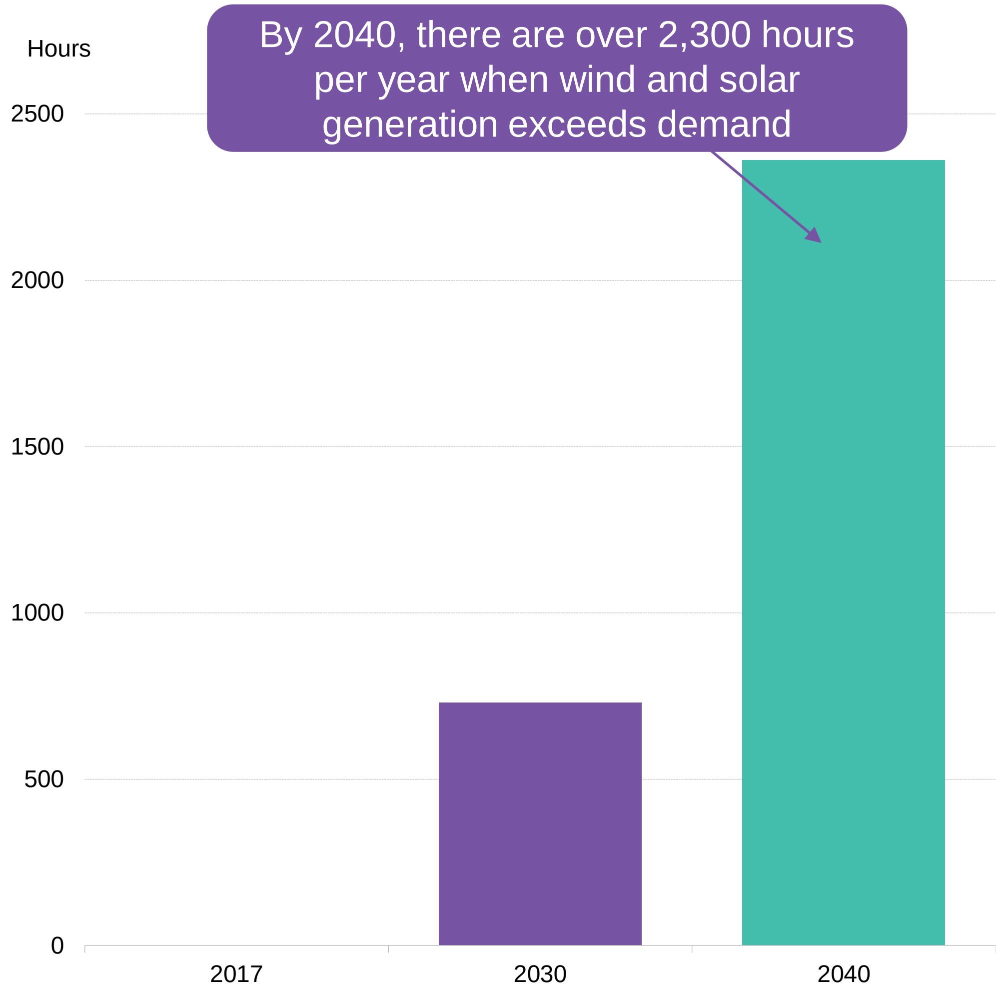
# Curtailment of wind and solar generation

## Wind and solar energy curtailed by scenario




*Source: Bloomberg New Energy Finance*

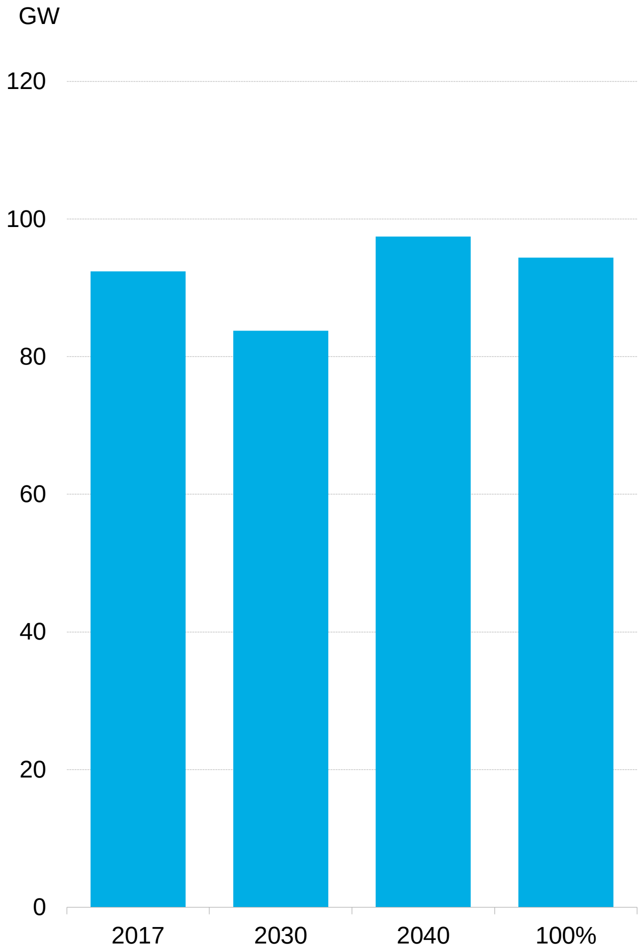
## Hours of wind and solar curtailment by scenario



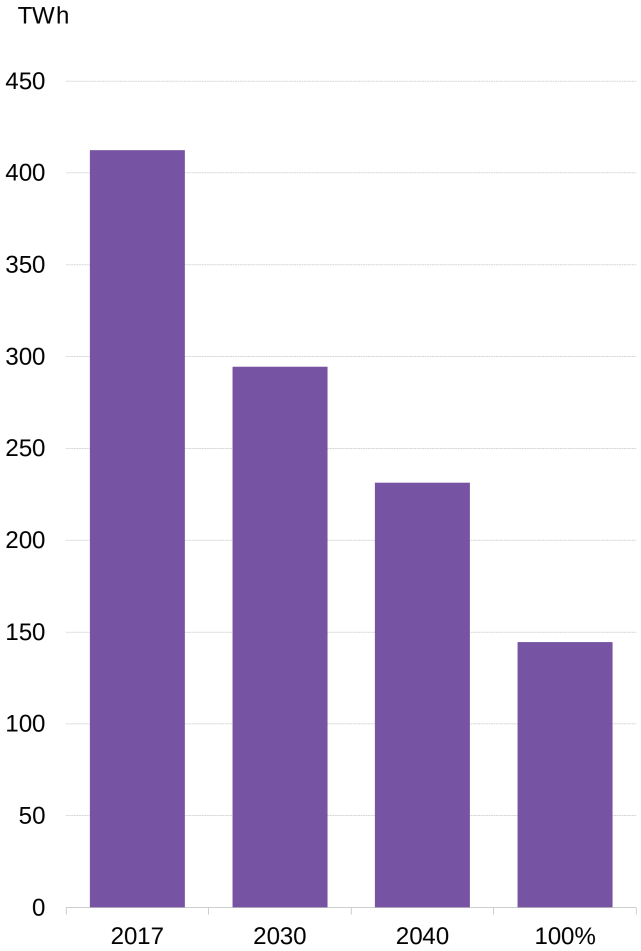

*Source: Bloomberg New Energy Finance*

# Back-up capacity & declining utilisation

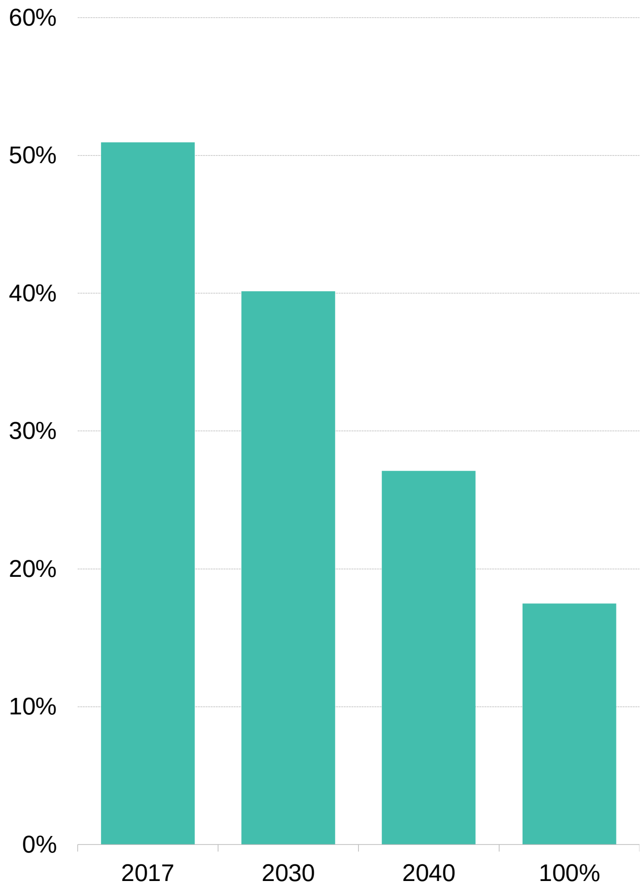
## Peak output of ‘other generators’




## Energy generated by ‘other generators’




## Utilisation of ‘other generators’



# Growing system volatility

## Distribution of hourly ramp rates across the year

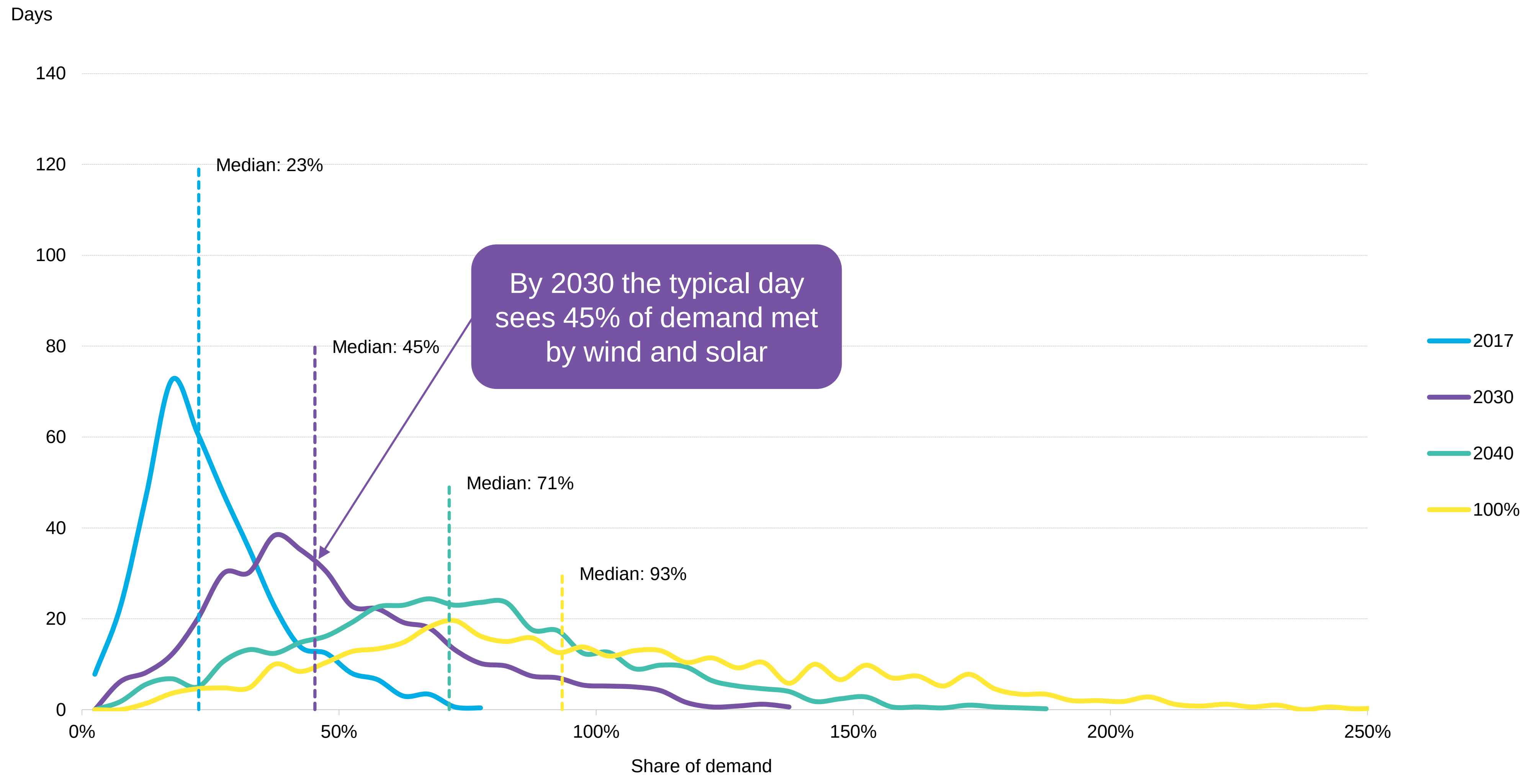
# Germany: hourly and daily variability

## Analyzing hourly and daily issues

Germany: hourly and daily variability

# Variable renewable generation distribution

## Number of days for which renewable generation makes up X% of demand

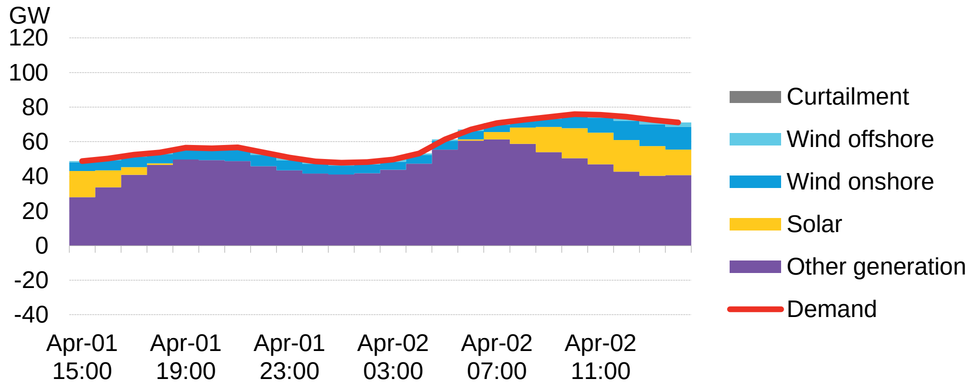



*Source: Bloomberg New Energy Finance*

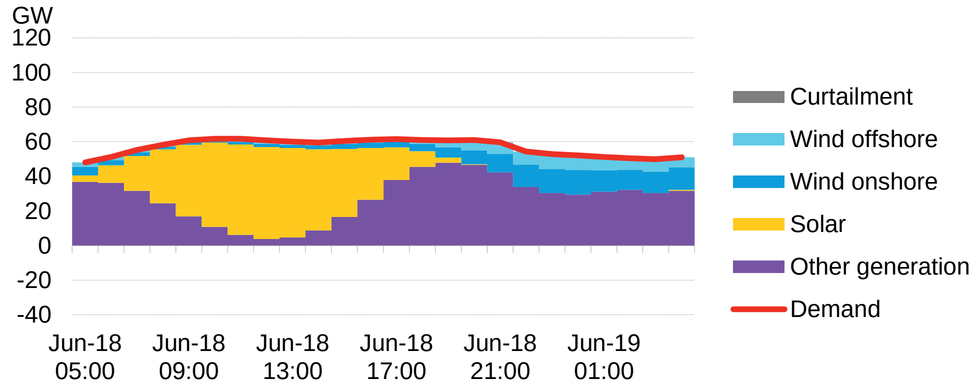
Germany: hourly and daily variability

# Median wind and solar 24-hour period

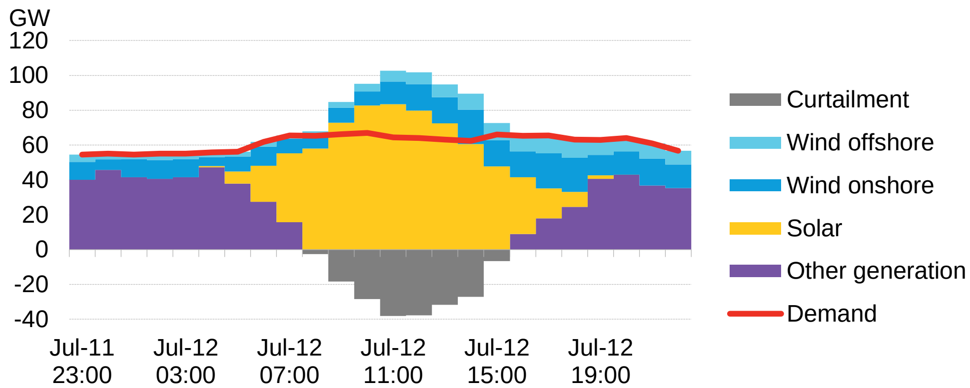
## 2017



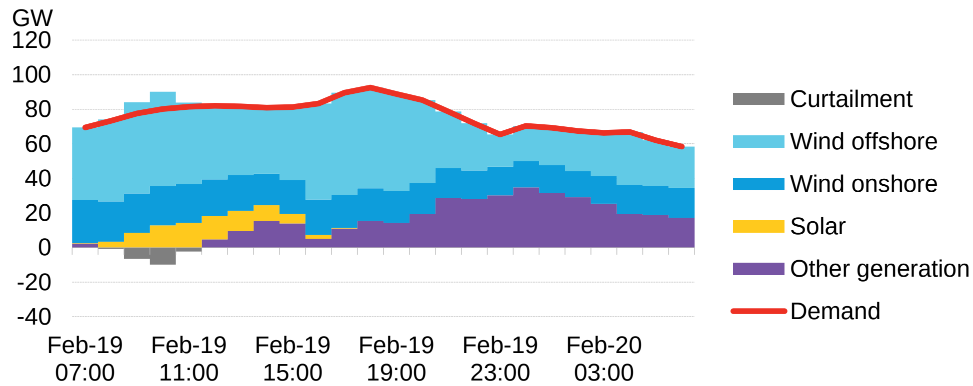

## 2030




## 2040




## 100%

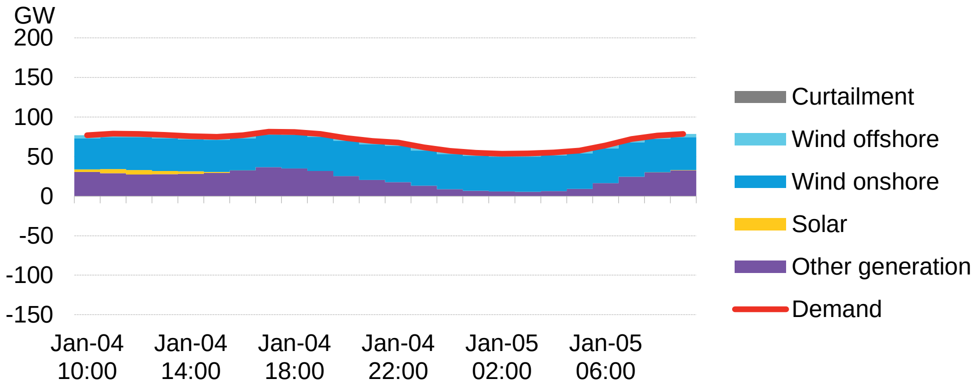



*Note: definition of the median renewable 24 hour period: 50% of 24-hour periods in the year have a higher share of renewable generation and 50% of 24-hour periods in the year have a lower share of renewable generation. These are 24-hour periods, not calendar days – so there are 8,736 24-hour periods in a year.*

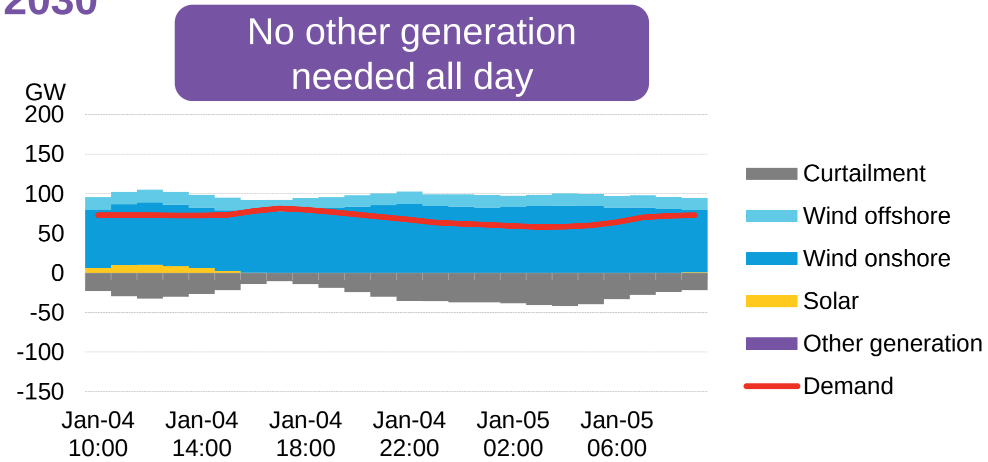
Germany: hourly and daily variability

# Highest wind and solar 24-hour period

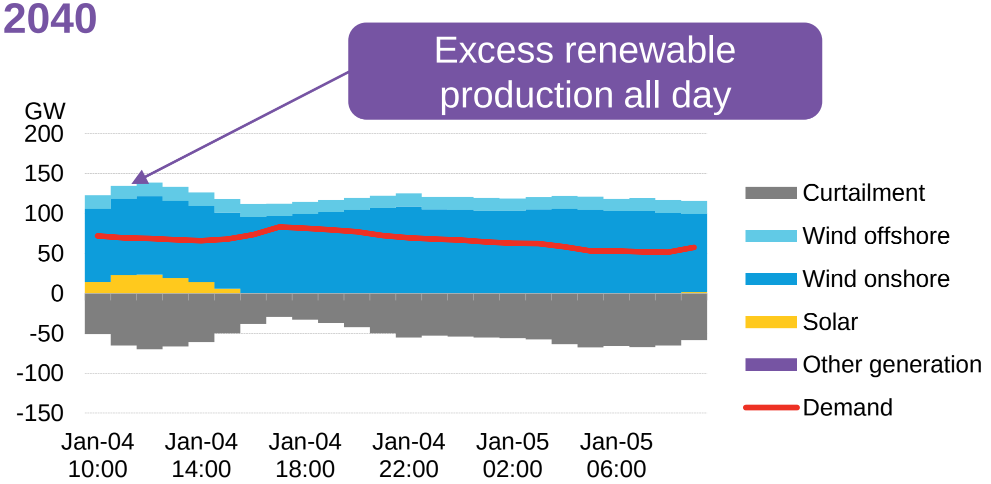
## 2017



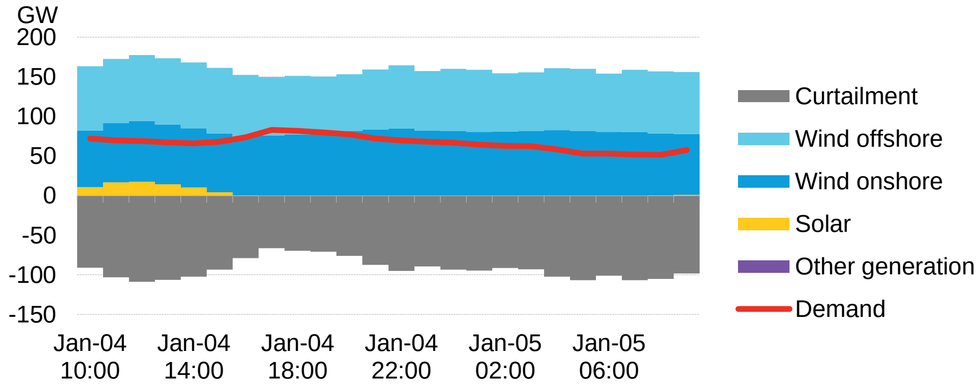

## 2030




## 2040




## 100%

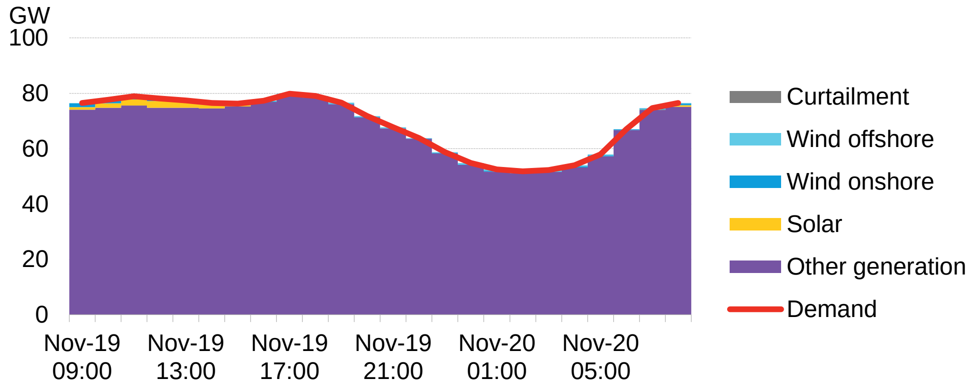



*Note: 24-hour periods where wind and solar account for the highest share of demand in the year. These are 24-hour periods, not calendar days – so there are 8,736 24-hour periods in a year.*

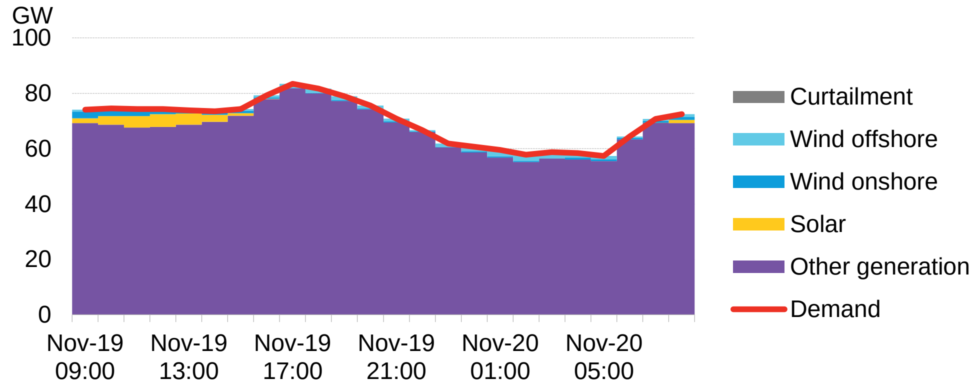
Germany: hourly and daily variability

# Lowest wind and solar 24-hour period

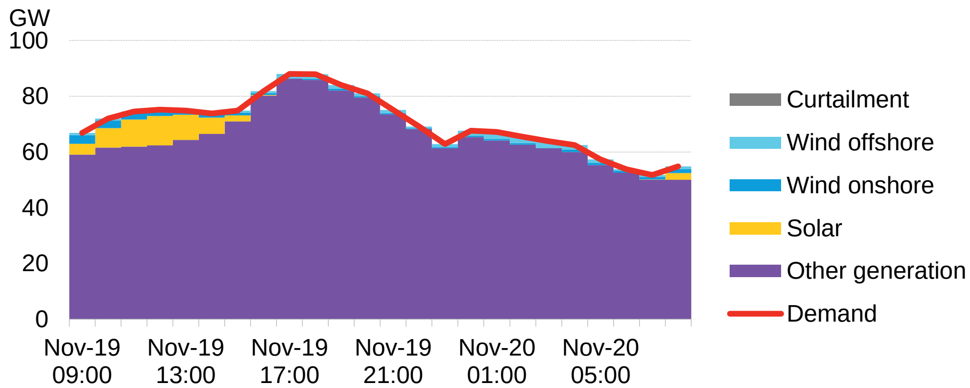
## 2017



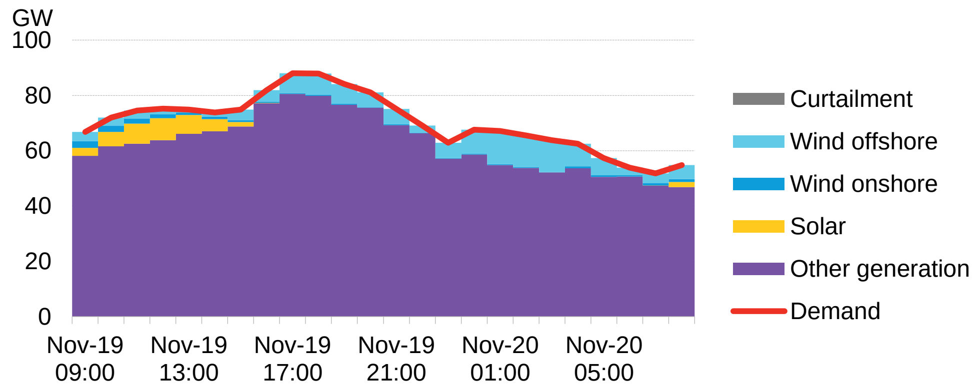

## 2030




## 2040



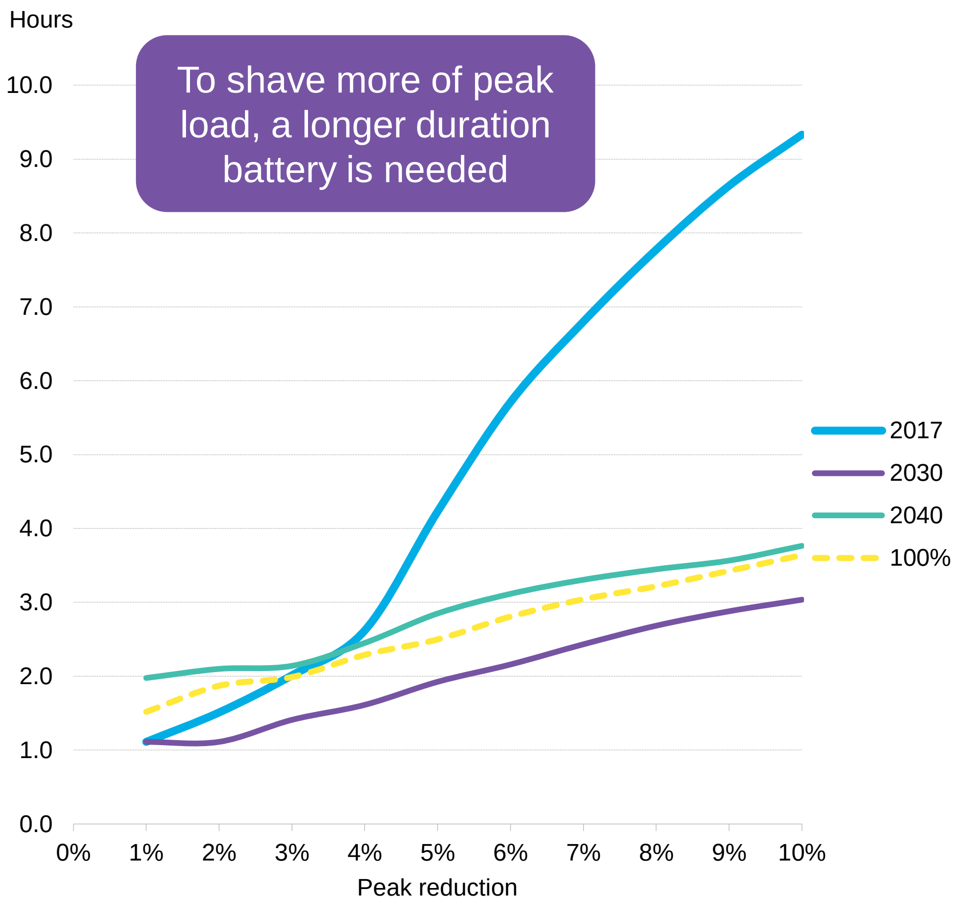

## 100%



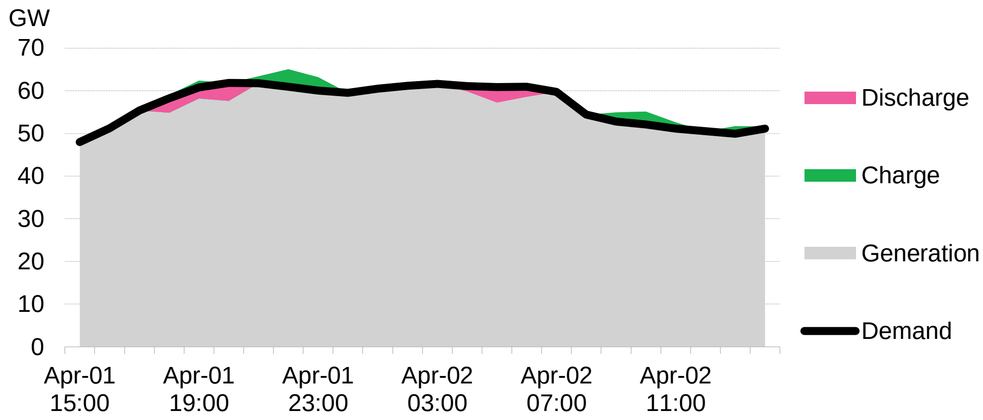

*Note: 24-hour periods where wind and solar account for the lowest share of demand in the year. These are 24-hour periods, not calendar days – so there are 8,736 24-hour periods in a year.*

# Case study: batteries to manage hourly peaks

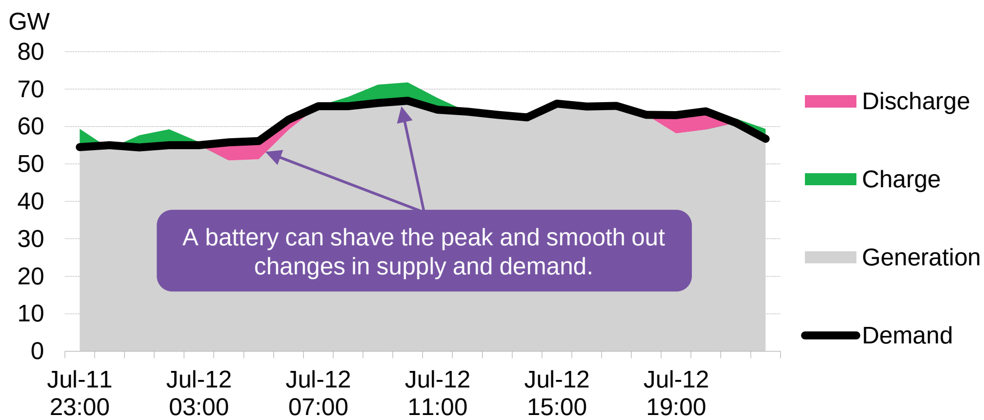
## Peak shaving (size of battery based on desired peak reduction)




## 5% peak reduction with battery, 2030




## 5% peak reduction with battery, 2040

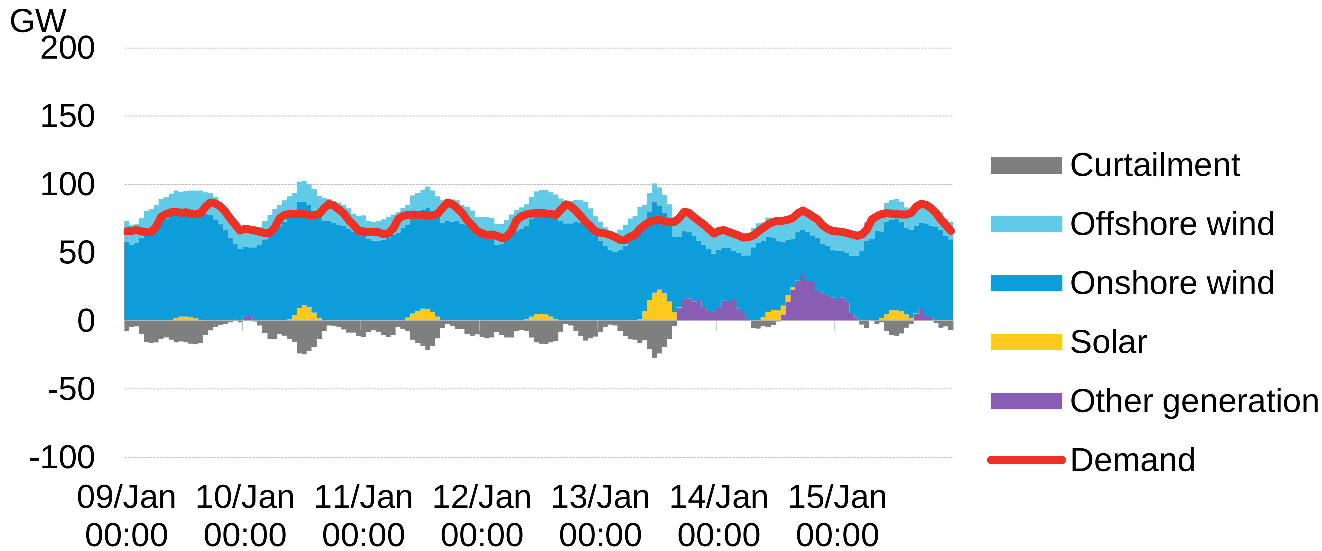


# Germany: weekly, monthly and seasonal variability

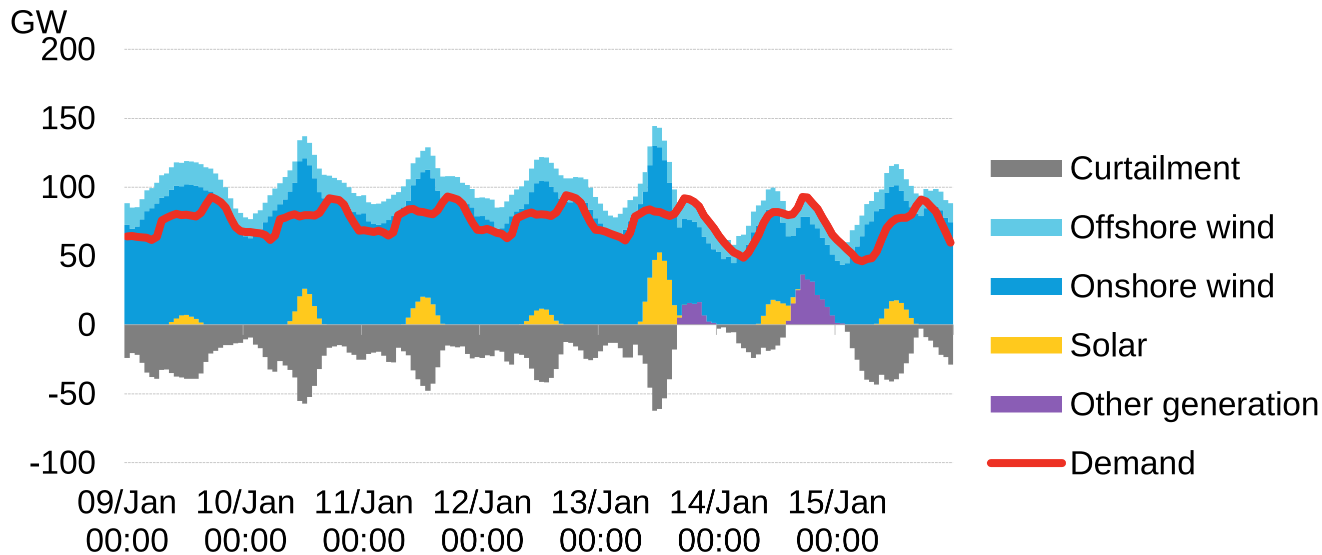
## Analyzing weekly to seasonal issues

# Highest wind and solar output week

2030



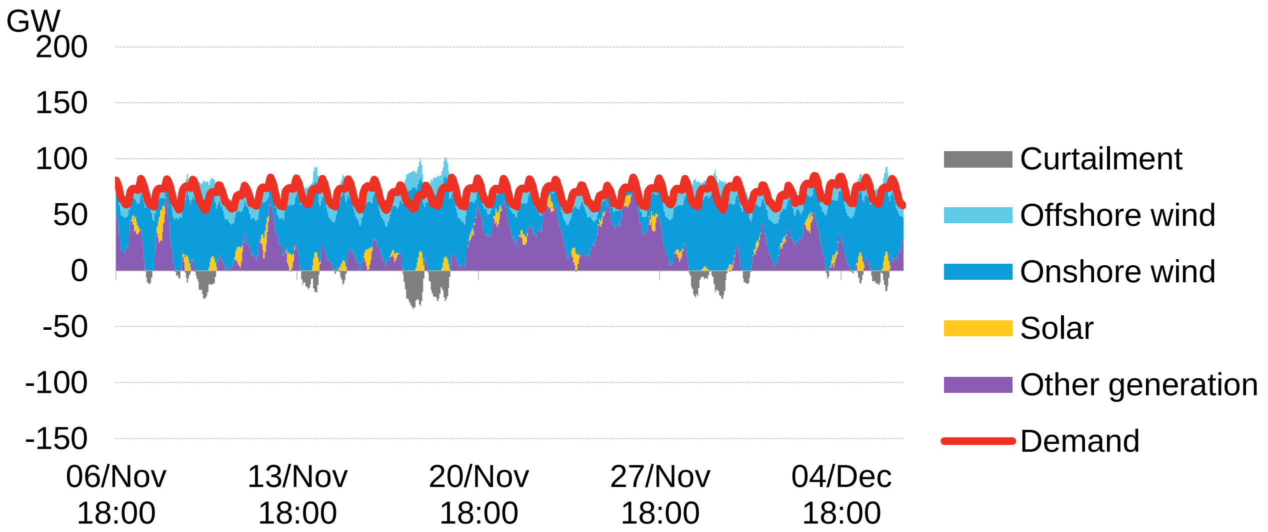

2040



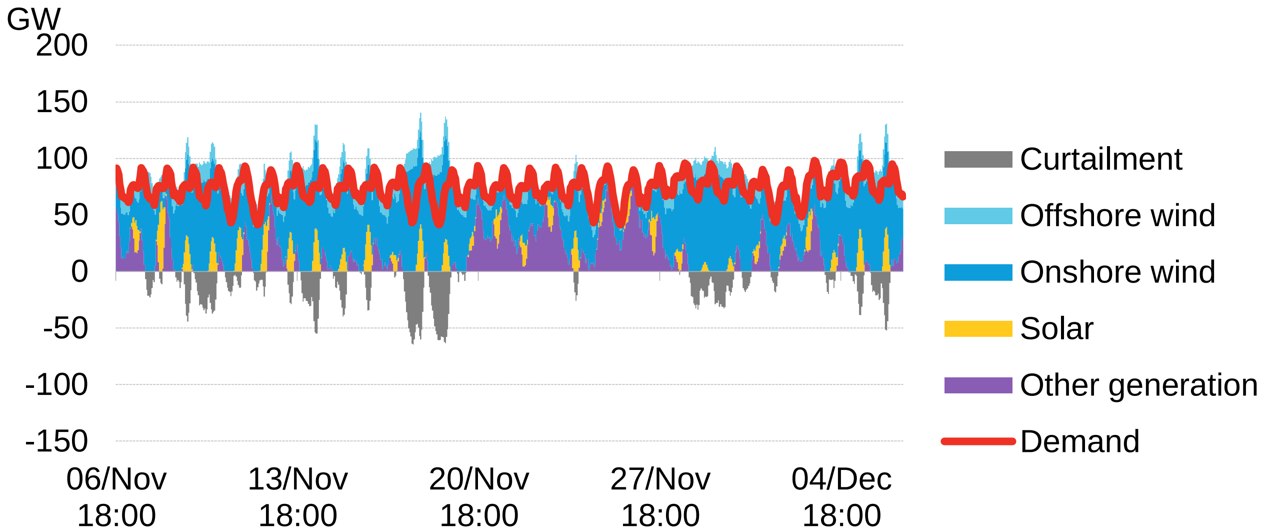

*Note: a week is defined as a 168 hour period, not a calendar week.*

# Highest wind and solar output month

2030



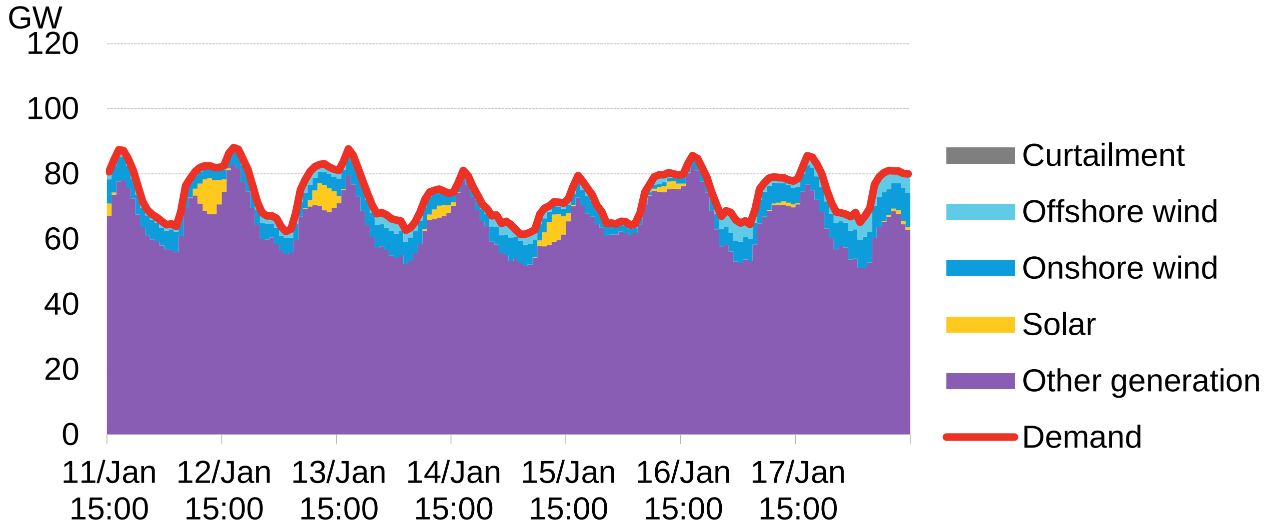

2040



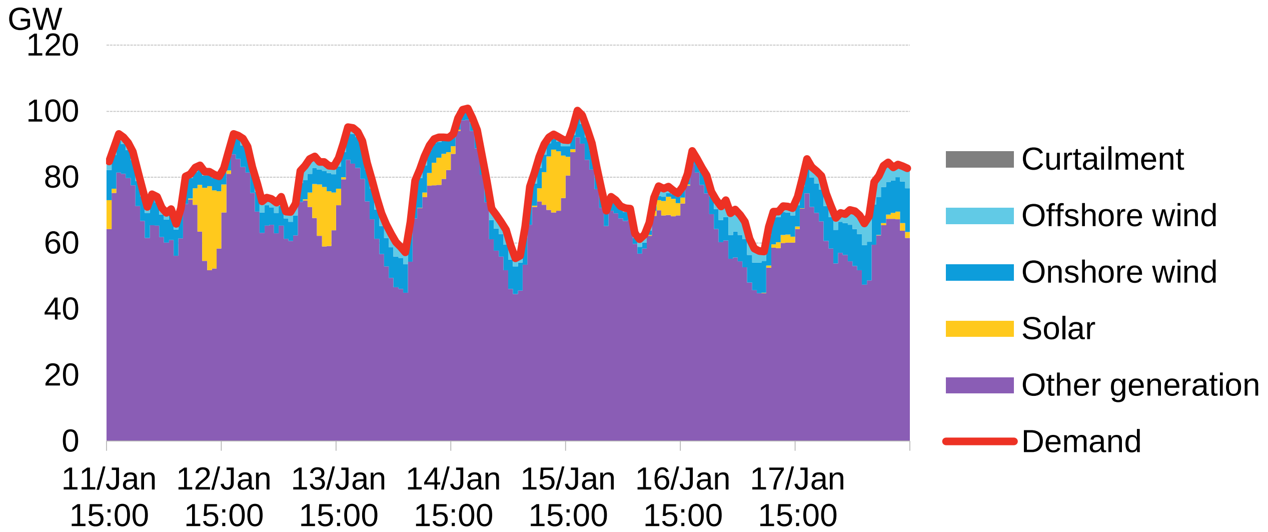

*Note: a month is defined as a 730 hour period, not a calendar month.*

# Lowest wind and solar output week

2030




2040

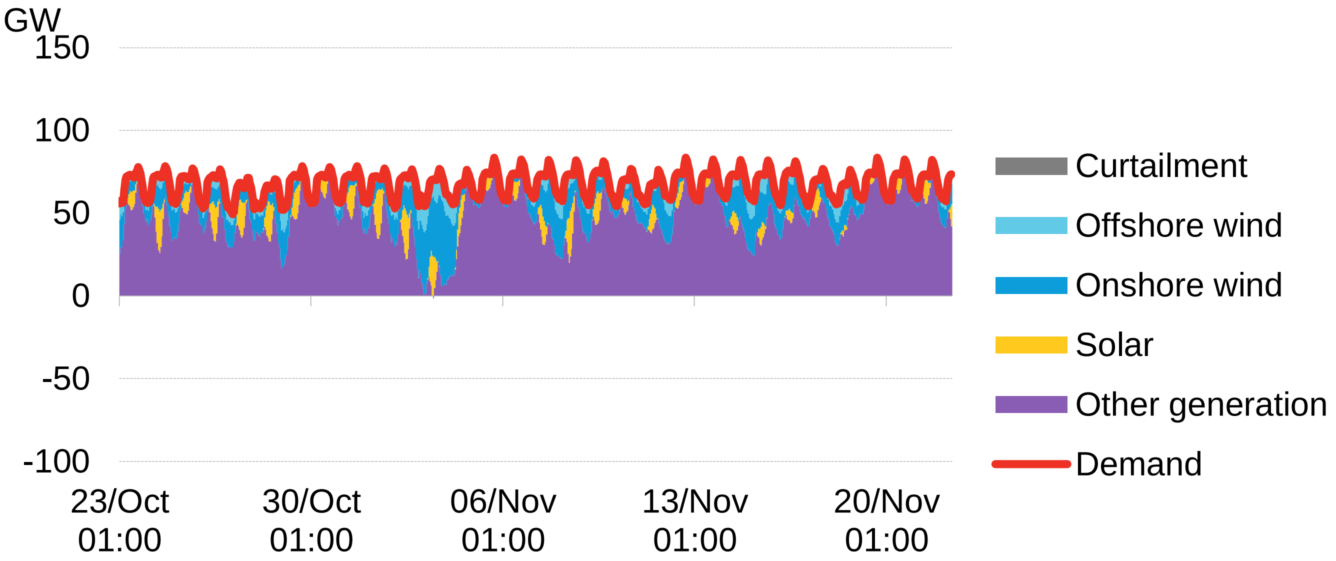



*Note: a week is defined as a 168 hour period, not a calendar week.*

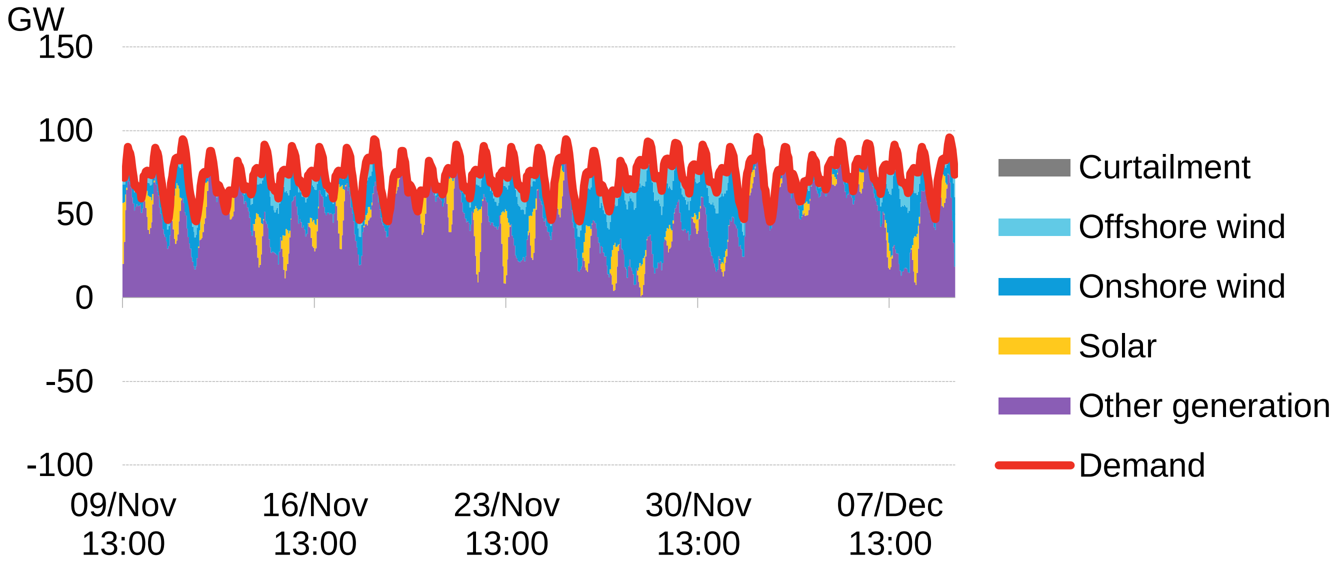
Germany: weekly, monthly and seasonal variability

# Lowest wind and solar output month

2030




2040

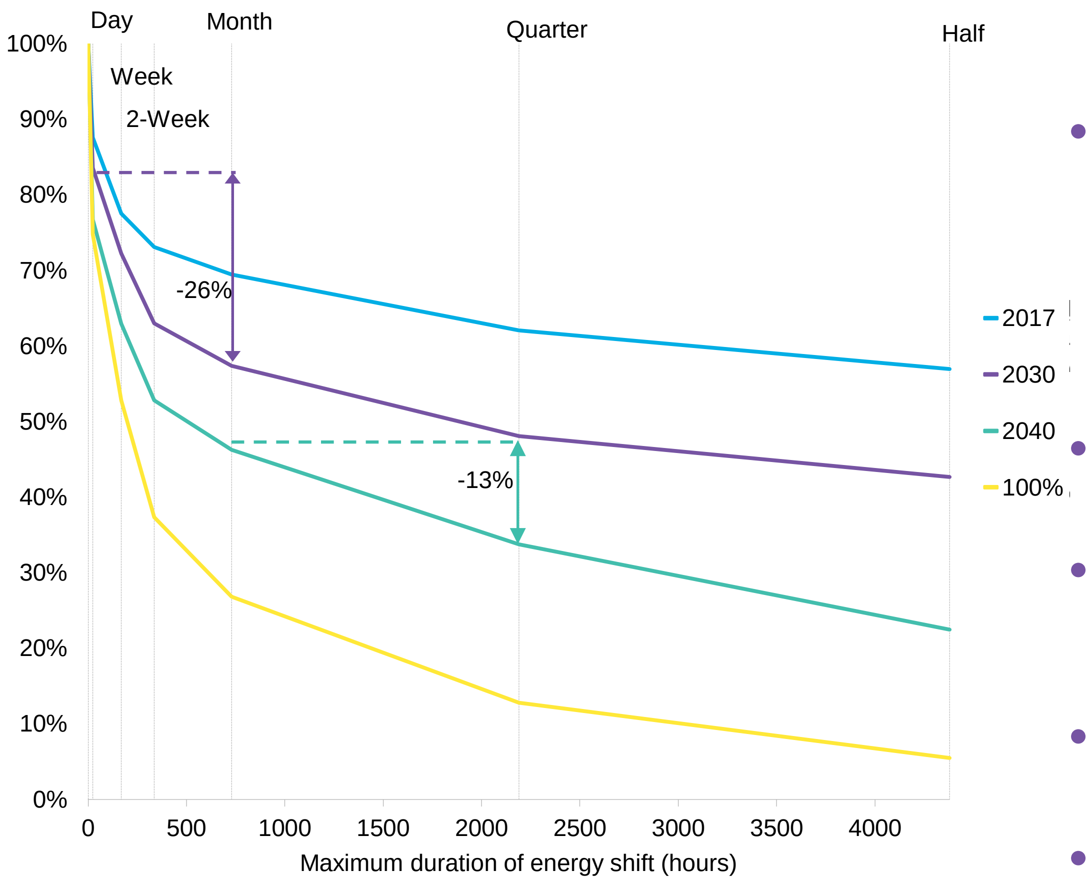



*Note: a month is defined as a 730 hour period, not a calendar month.*

# Opportunities for long-term energy shifting

## Opportunity to reduce back-up generating capacity

Percentage of peak net load




*Source: Bloomberg New Energy Finance*

## Interpretation

- Chart shows how long you have to store energy for, to reduce the need for back-up
- Eg in 2030 (**purple line**):
  - If you can shift energy by a whole day, you can reduce back-up requirements by 17%
  - If you can shift by a whole month, you can reduce back-up requirements by 43% in total
- Curves flatten to the right = diminishing returns
- Curves get lower in future years = it gets easier (but sill difficult!)
- Very, very hard to get to zero back-up
- Reducing back-up capacity also raises utilisation rates for all remaining back-up. 19% utilisation improvement improvement in the 2030 example above.

# Final thoughts

# Summary of flexibility challenges and opportunities *at the 50-60% VRE level*

## Short-run (days and hours)

- ‘Typical’ days will see much greater share of demand met by RE
  - In 2030 and 2040, there is still need for other resources, but they will need to be flexible!
- ‘Highest’ RE days will see significant excess production of wind and solar
- Lowest RE days still require almost all demand to be met by non-variable resources
- There will be an opportunity for batteries – as well as flexible demand – to manage daily peaks

## Long-run (weeks and months)

- There will be whole weeks (and longer) dominated by renewable energy
  - ‘Other resources’ will have to be flexible
- But there will be whole weeks (and longer) where ‘other resources’ will need to fill the gap
  - But utilisation of these resources will be low over the year
- Interconnection will help!
- Long-run energy shifting could reduce the need for back-up, and raise the utilisation of dispatchable generators
  - But not yet commercially viable
  - For deeper decarbonisation (beyond ~60% VRE), long-term storage or clean dispatchable generation will be needed

# What about the U.K. and Nordics?

The full study provides the same analysis for the U.K. market and the Nordics, and can be found here: **www.eaton.com/tippingpoints**

## U.K. summary

- The U.K. results are similar to Germany:
  - Greater system volatility
  - More extreme days, weeks, months
  - Little room for inflexible generators
  - Opportunities for storage, flexible demand, interconnectors, flexible generators
- The main differences are:
  - Dominated by wind, less solar
  - Slightly lower penetration of renewables
  - Less curtailment (3% vs. 16%)

## Nordics summary

- The Nordics achieve high levels of decarbonisation through hydropower
- Growth of wind and solar is limited
- Nordics have more than enough flexibility to manage variable renewables, and have an opportunity to export their flexibility

*Note: Nordics = Denmark, Finland, Norway and Sweden, analysed as one market.*

# What next?

- New Energy Outlook 2018 (due this summer) will continue to explore power system economics and flexibility needs in greater detail
- BNEF recently published a white paper on *Power Market Design for a Renewable Future* – including discussion of DSO-TSO cooperation models. Copies available on request.
- We're currently scoping a follow-up study on ***flexibility solutions*** – speak to us if interested!

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# Thank you!


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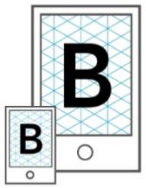

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