The Future is Flexibility

Role of flexible grids in more flexible operation of entire power system

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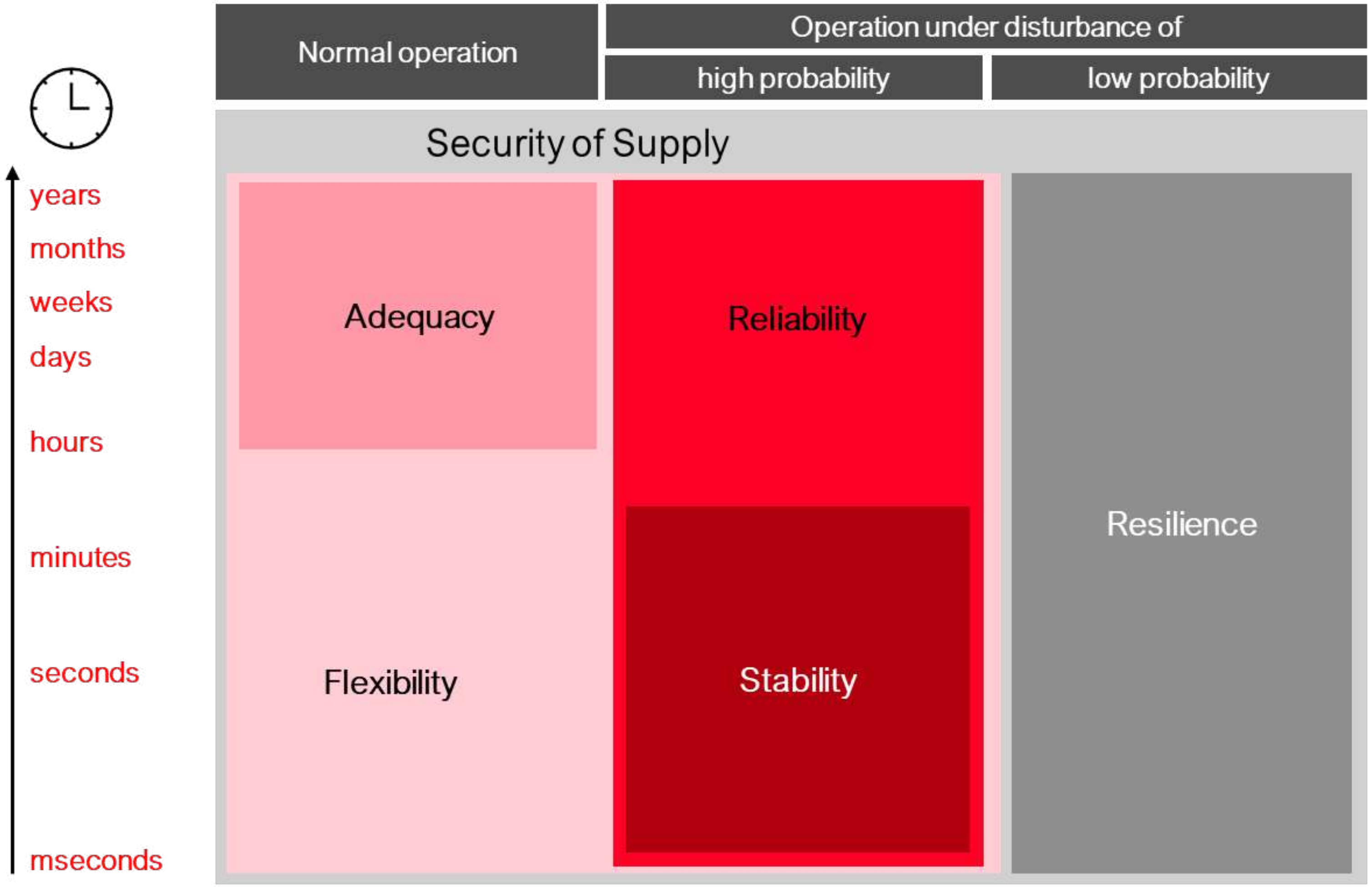
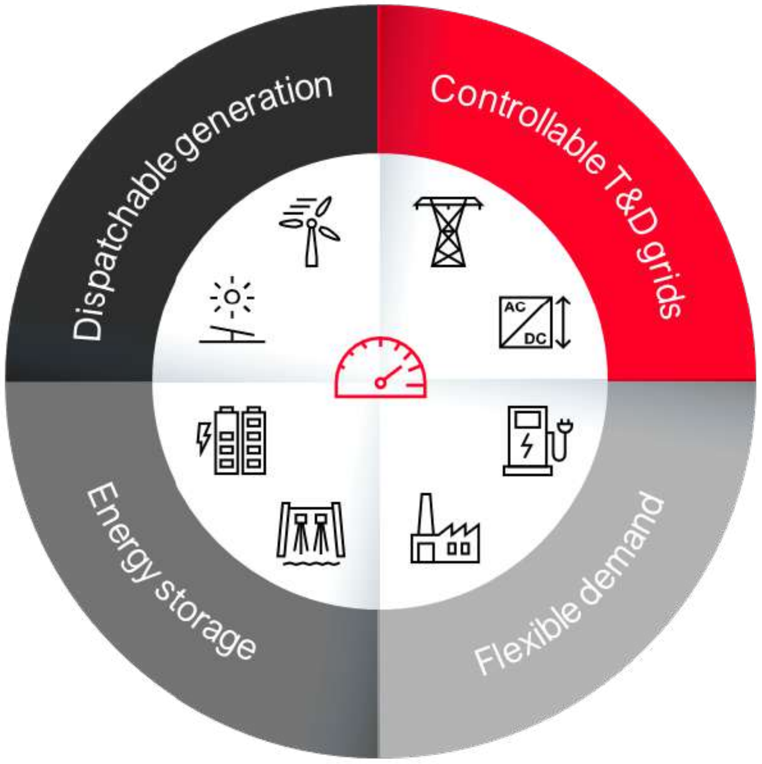
Flexibility and other power system characteristics



4 dimensions of Flexibility



Term of “Flexibility” is commonly used as an umbrella covering various needs and aspects of power systems operation and planning

How to measure power system's flexibility needs?

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Net load ramp rates

Net load (NL) is calculated by subtracting the available generation by variable renewable energy sources[1] (VRES) from the total load of power system.

$$NL = Total\ load - VRES\ generation$$

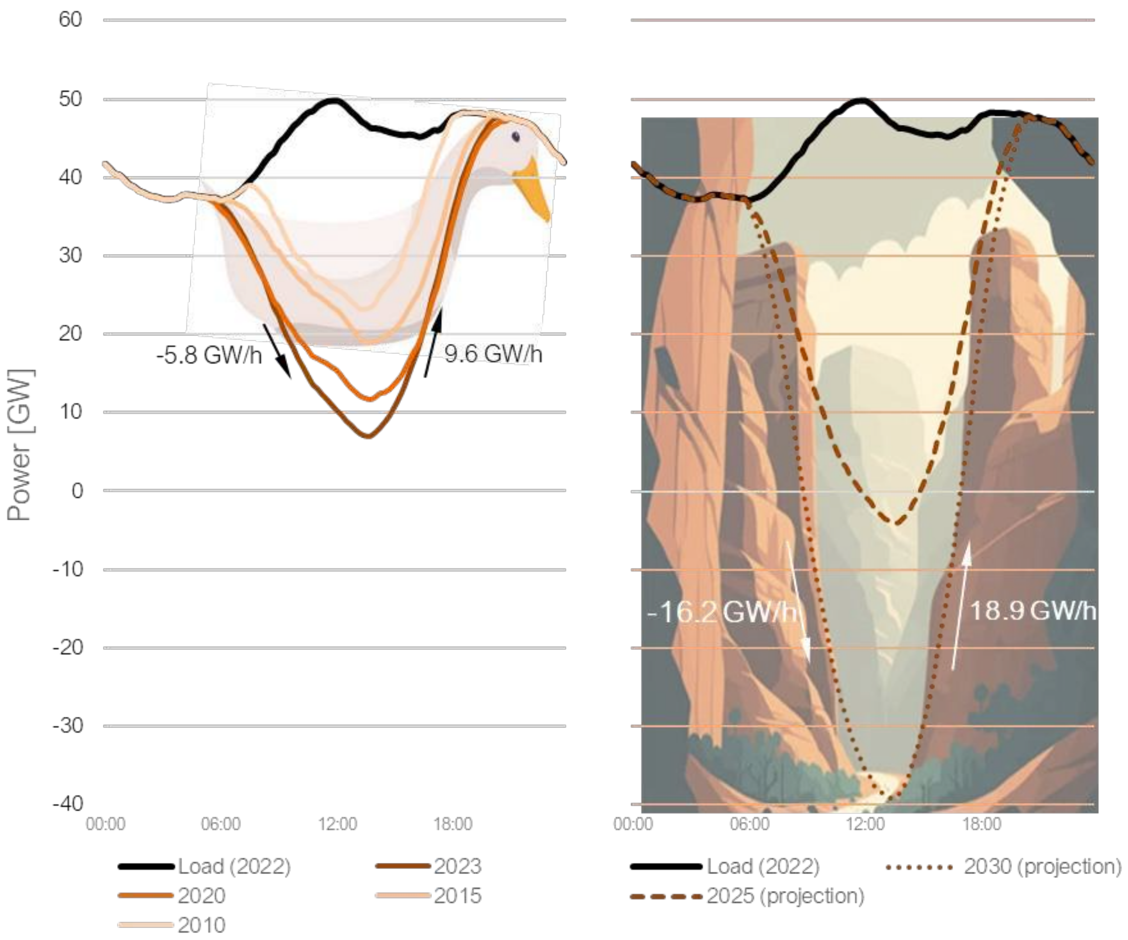
Net load ramp (NLR) refers to the rate at which the NL changes over time. It reflects how quickly the system needs to adjust to changes in electricity supply-demand balance.

$$NLR = \frac{dNL}{dt}$$

Usually, NLR is calculated on the hourly base, i.e., dt=1h. Increasing time resolution to a 15-min or less time scale may potentially result in higher ramping rate peaks.

Analyzing NL and NLR trends over time can help to identify and prepare for specific periods where power systems may have higher flexibility needs.

NL profile evolution in DE from duck to canyon curve in 15 years



Internal

1. Weather dependent wind and solar generation

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Flexible power and energy

Two important characteristics of the net load to be served are the **power and energy** requirements which must be met by flexible generation, storage, demand and/or power exchange.

The **required power** (P_{req}) is defined as the absolute maximum value of the NL profile over a specific period.

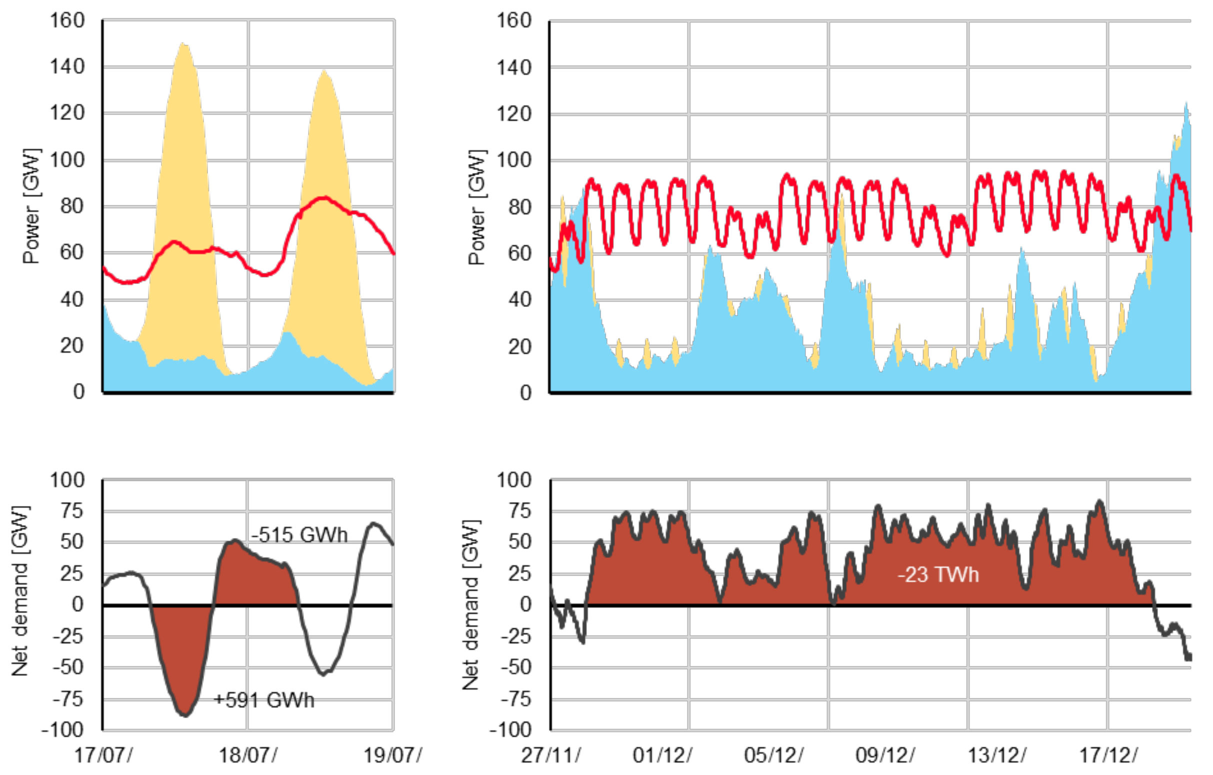
$$\boxed{P_{req} = \max|NL(t)|}$$

The **required energy** (E_{req}) is defined as the area under the net load curve. The limits are commonly defined when the NL curve crosses the zero line. If this is not the case, the limits have to be defined according to the custom requirements of the study.

$$\boxed{E_{req} = \int_{t_{NL=0}} NL(t) \cdot dt}$$

VRES supply, demand and net demand in Germany

Example of hypothetical 100% VRES supply case by 2040



How to measure power system’s flexibility needs?

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Grid flexibility

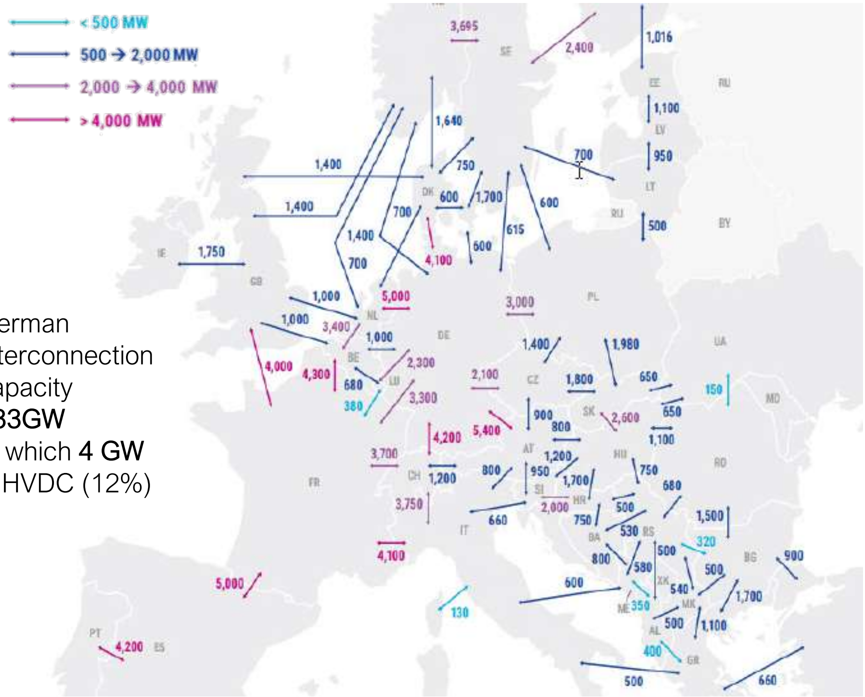
The **Cross-Border Capacity Ratio (CBR)** describes the ratio between the total interconnection capacity of a country with all its neighbors and the local power generation installed capacity.

$$\boldsymbol{CBR = \frac{Interconnection\ Capacity}{Installed\ Generation\ Capacity}}$$

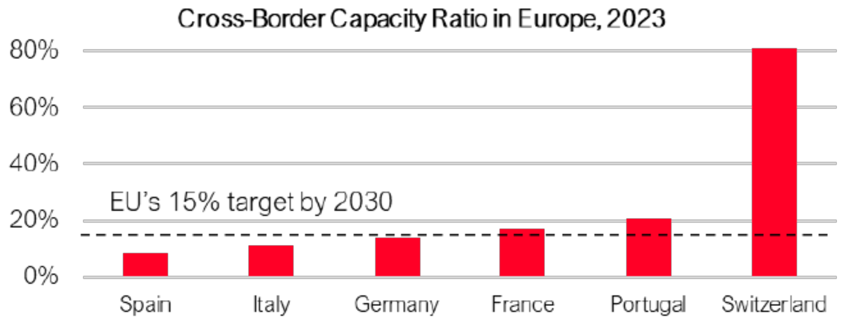
It identifies the capability of a country to export excess generation, when the VRES production exceeds the local demand. The EU has set an interconnection target of **at least 15% by 2030** to encourage EU countries to interconnect their installed electricity production capacity.

Future grid operation will require the ability to control the power flows between different countries, requiring the deployment and use of HVDC links or FACTS devices in the cross-border connections. The **Level of Controllability (LC)** can be defined as the ratio between controllable and total interconnection capacity.

$$\boldsymbol{LC = \frac{Controllable\ Interconnection\ Capacity}{Total\ Interconnection\ Capacity}}$$



German interconnection capacity **~33GW** of which **4 GW** is HVDC (12%)



Source: ENTSO-E Transparency Platform, ENTSO-E TYNDP 2022

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The grid of the future demands flexible and controllable energy flows

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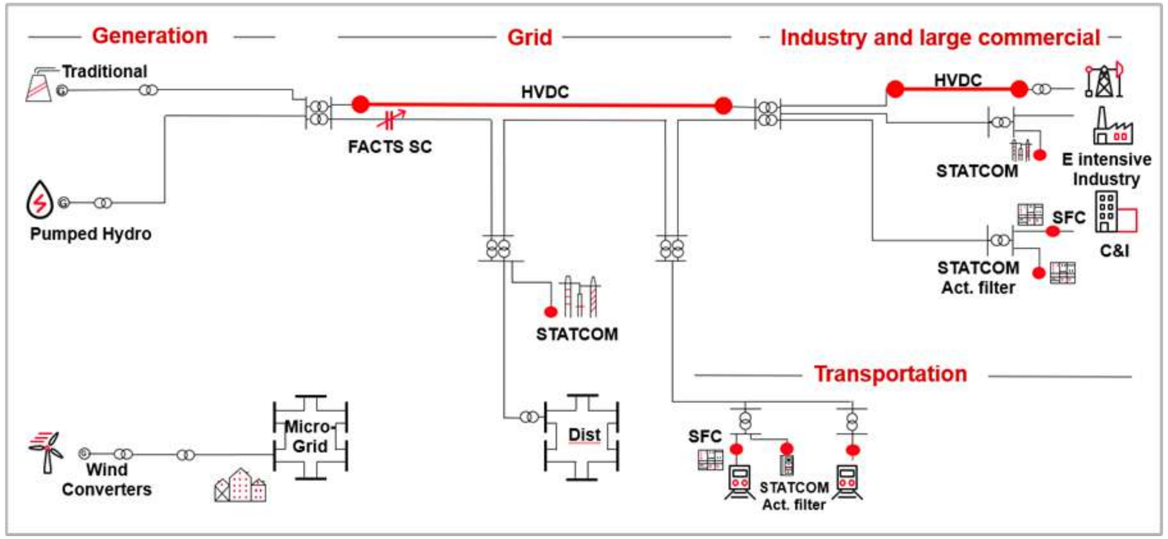
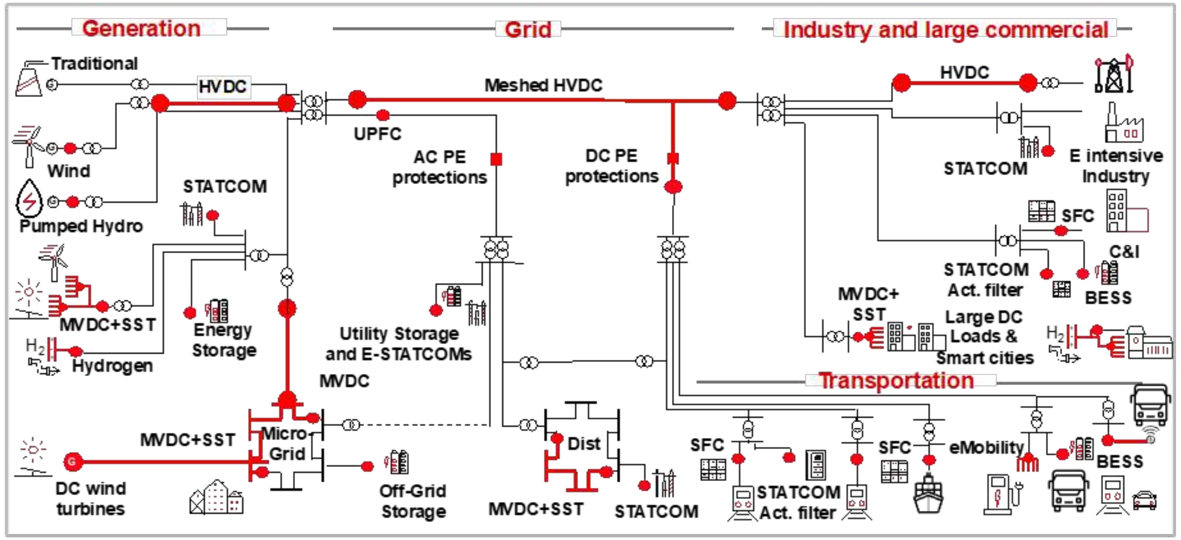
The grid today



Fossil dependable power generation plays a crucial role for grid stability while renewable power emerges

The grid of the future



Power conversation systems will interface all new assets with the grid, enabling energy system stability and flexibility

The complexity of the grid of the future will be managed by power electronics and digital technologies

Power conversion systems

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Complementarity in weather patterns encourage transmission

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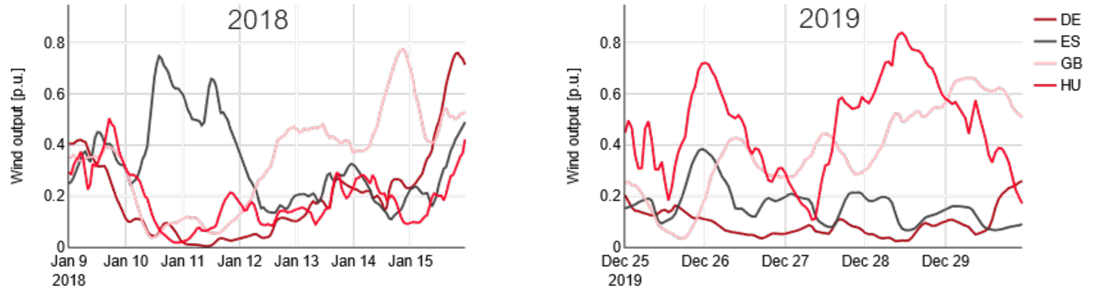
Are low output events happening at the same time?

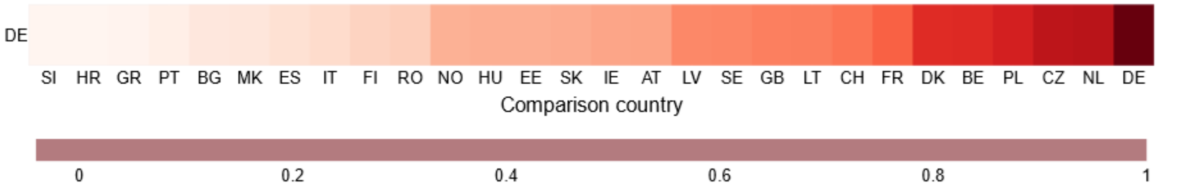
Wind patterns across Europe do not follow one same pattern. Germany may have a certain correlation with its neighbors, but most of the European countries do not show a correlation with the wind profile from Germany. This means that there may be available wind resources when in Germany they are low.

Germany will not always be complemented by the same country in periods of time when there is little VRES output, e.g., while in 2018 Spain could complement Germany, in 2019 Hungary would be a better option.

Dunkelflaute periods in Germany



Correlation of onshore wind profile of Germany with other European countries
1980 - 2019

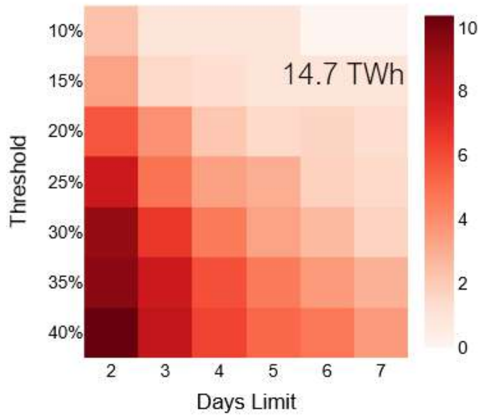


How often do low VRES output events occur?

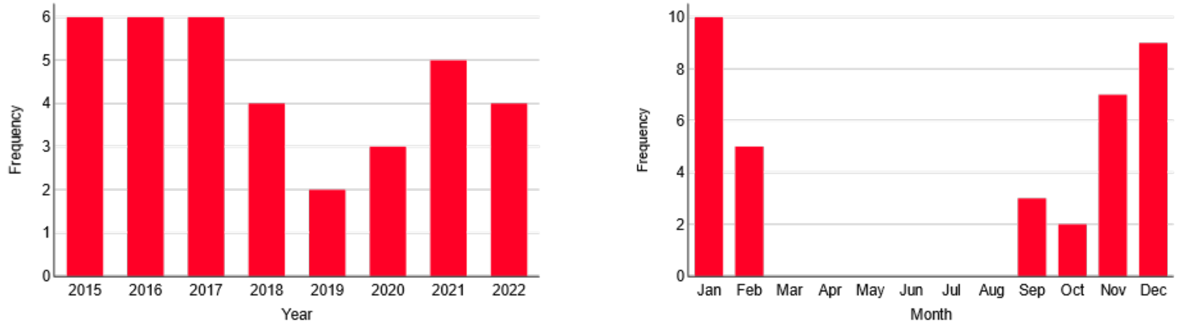
The prolonged low VRES output events e.g., Dunkelflaute in Germany, are present on an annual basis mainly in the late fall and winter season between November and February.

Assuming an output lower than 15% of the daily electricity consumption is enough to detect low VRES output events that can last up to 7 days.

Average annual frequency
of low VRES output events



Frequency of low V-RES output events in Germany
Assuming an output lower than 20% of the daily electricity consumption over at least 3 days



Source: Renewables Ninja (Reanalysis), Energy Charts Germany (Historical)

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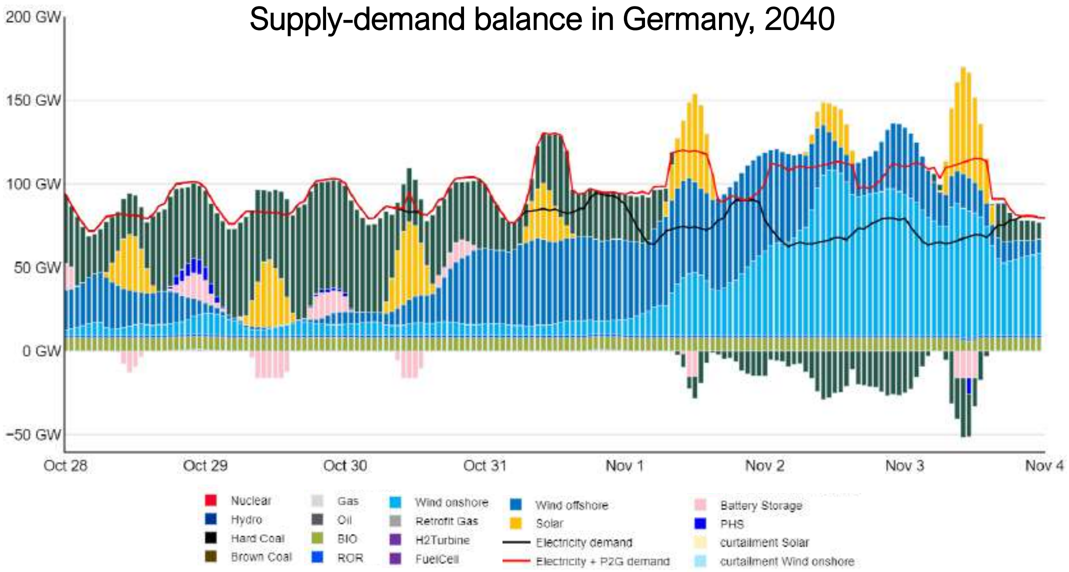
Dynamically controlled T grids enable more flexible operation

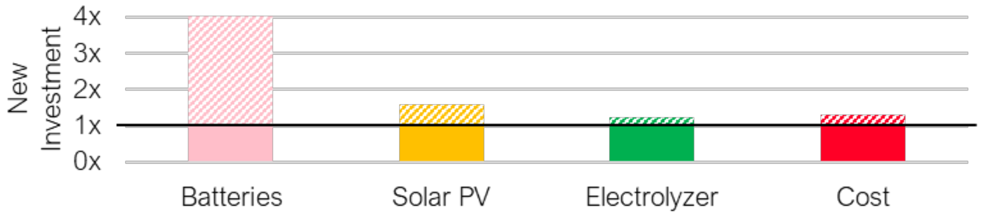
When the optimal investment decisions are implemented, Germany can take advantage of electricity imports from other European countries.

If the investment in grid expansion is not allowed, the required investment in other technologies would increase.

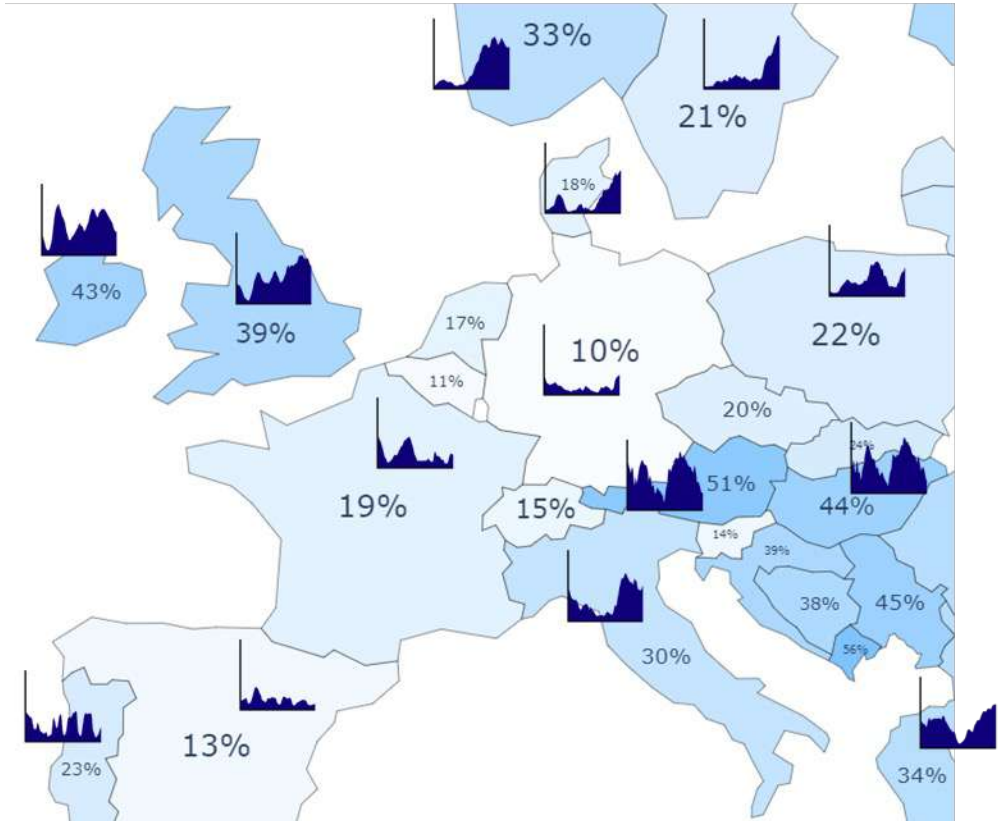
With enough interconnection capacity, the complementarity between the VRES resources across Europe can be fully exploited.



Required additional investments when no grid expansion is possible



Onshore Wind Power Capacity Factor (5-day period)



Source: renewables.ninja, Hitachi Energy analysis

Dynamically controlled D grids enable more flexible operation

Paradigm shift towards more interconnected D grids

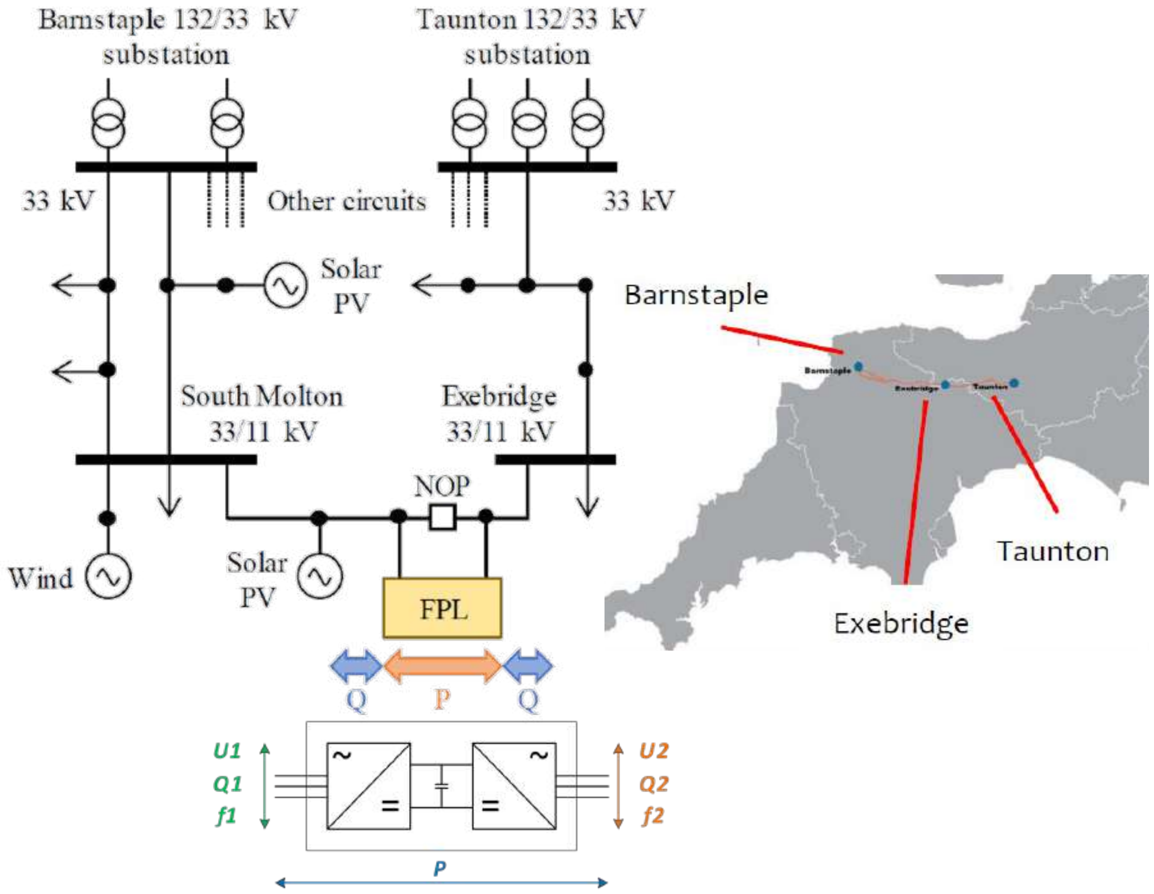
Urbanization and electrification of transport and thermal loads result in a significant increase of electricity demand at the edge of the grid.

At the same time, in an increasing number of cases the distribution grid reinforcement options are either prohibitively expensive or it takes multiple years to plan and construct.

Applying DC technology in distribution networks allows full control of power flows and optimized voltage system settings to unlock additional network capacity of existing grids.

There are several cases where MVDC technologies are proposed to use as back-to-back flexible bi-directional power flow controller between the adjacent distribution grid clusters with a complementary structure which would normally run isolated from each other.

For example, the Flexible Power Link (FPL) installed in a 33-kV grid of Western Power Distribution in UK and allowed up to 20 MW power exchange between two distribution grids supplied by different HV grid supply points.



Dynamically controlled distribution grids by means of power electronics allow a better balancing and utilization of existing infrastructure

Dynamically controlled D grids enable more flexible operation

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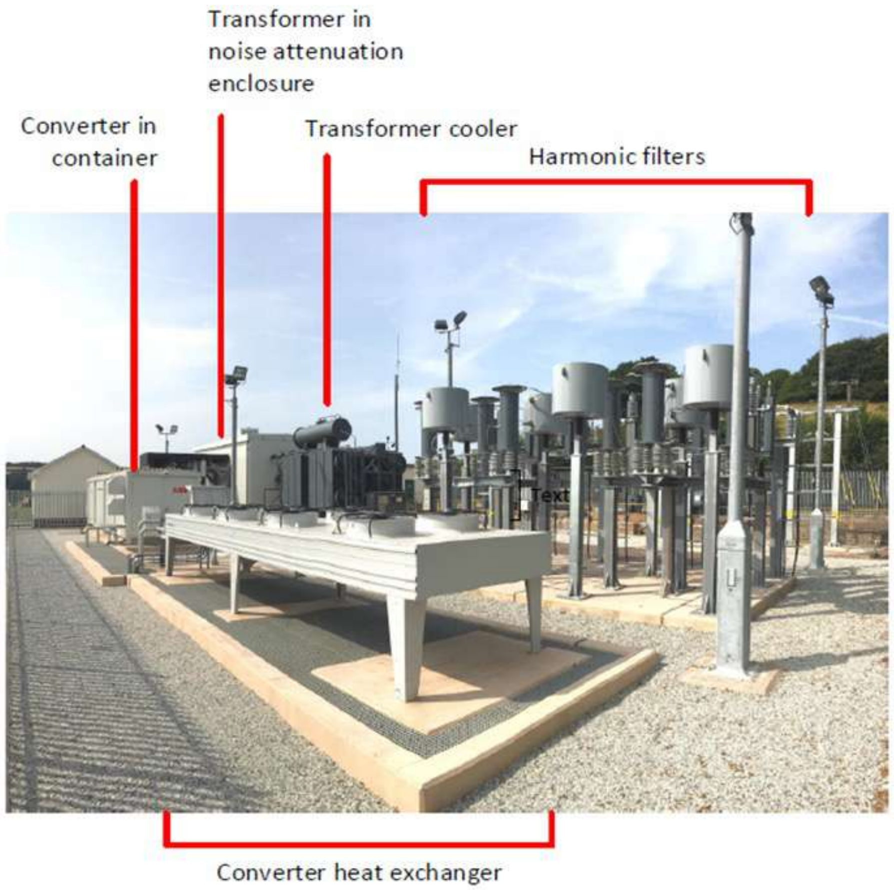

Dynamically controlled distribution grids by means of power electronics allow a better balancing and utilization of existing infrastructure

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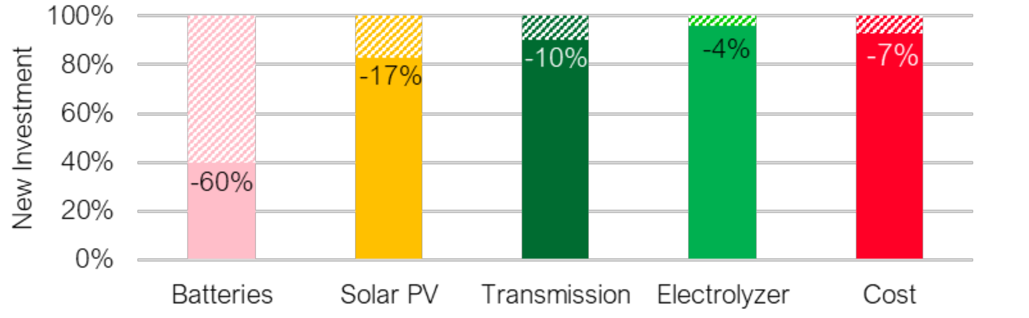
The role of demand flexibility

Demand flexibility allows to shift electrical demand to hours where the electricity generation is cheaper due to a higher availability of renewable generation.

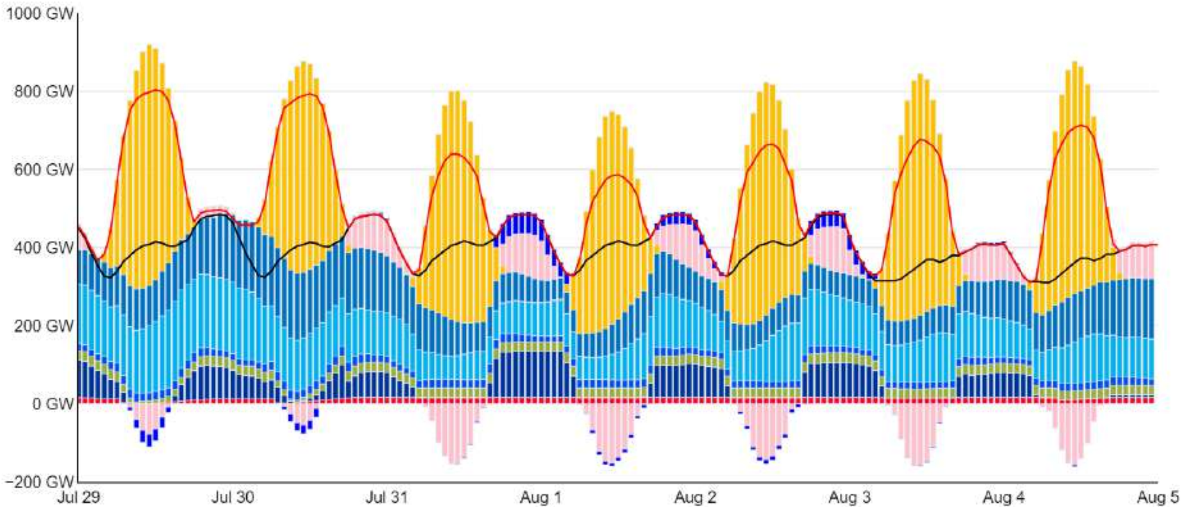
All energy sectors can contribute to demand flexibility: smart charging of EV, thermal loads as heat pumps and industry processes that can be easily controlled.

In the sensitivity analysis, demand flexibility is enabled, allowing a shifting of up to 10% of the instantaneous electricity demand in a range of ±12 hours.

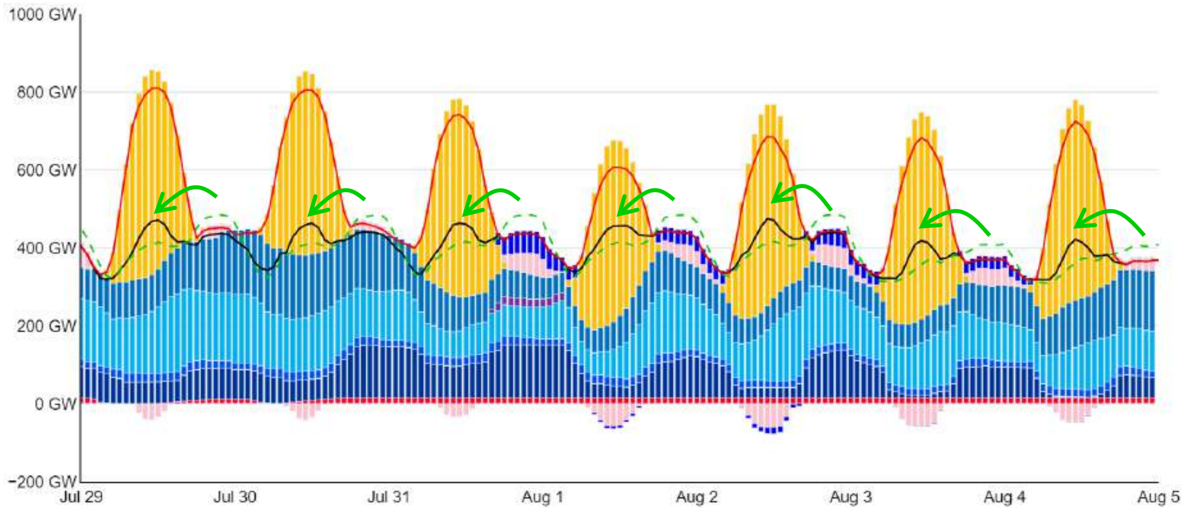
Required additional investments variation when demand flexibility is allowed



Base case, Europe 2040



Sensitivity case



Nuclear, Hydro, Hard coal, Brown coal, Gas, Oil, Biomass, Run of river, Wind onshore, Wind offshore, Solar, Retrofit gas, H_2 turbine, Fuel cell

Battery storage, PHS, Curtailment solar, Curtailment wind onshore, Electricity demand, Electricity demand + P2G, Old electricity demand

Combined T&D capacity expansion planning

TSOs and DSOs plan their grids independently

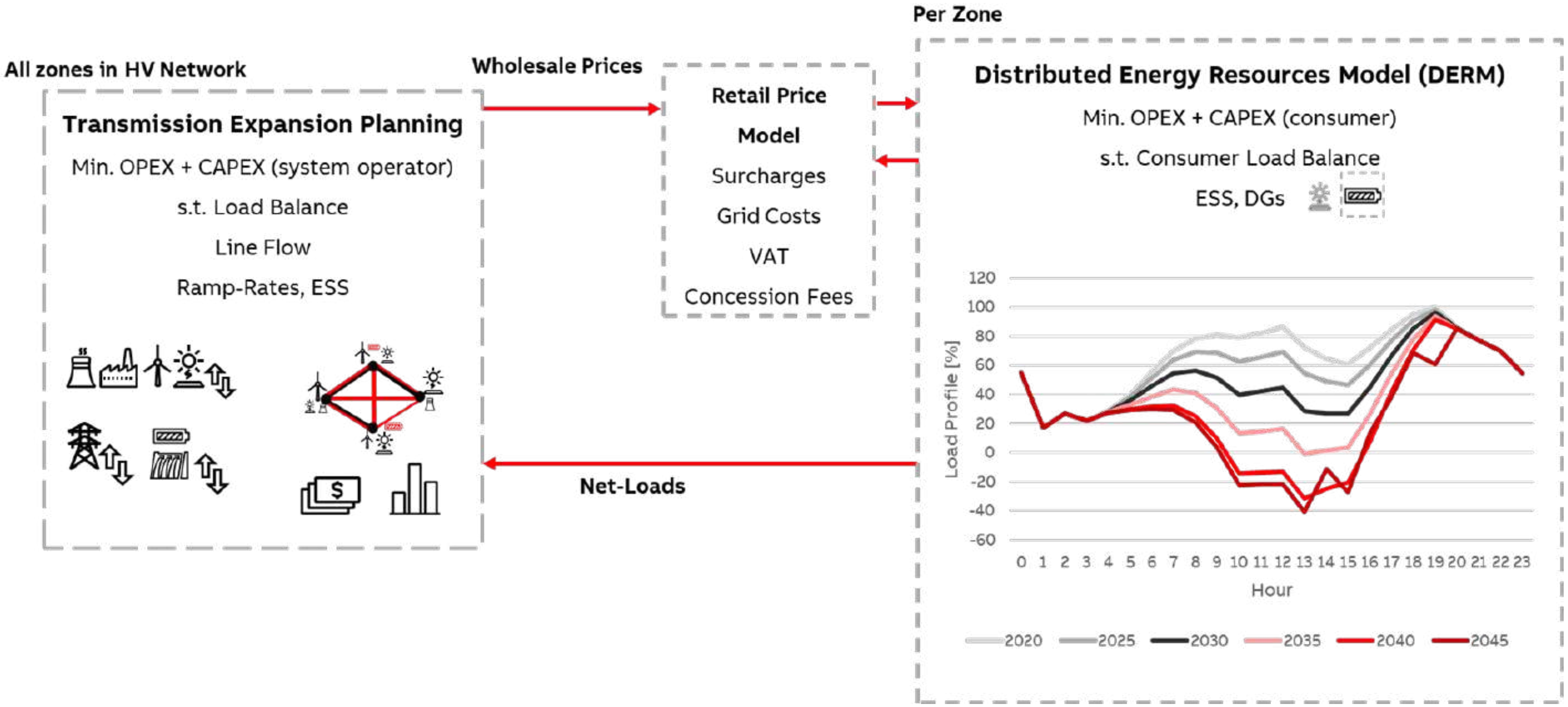
Simultaneous optimization of all voltage levels is computationally complex → Introduced iterative, two-level optimization framework

Level 1: Wholesale energy market model for transmission system expansion planning

Level 2: Retail market model which considers distribution grid expansion planning under DER penetration, and development of retail electricity price parallel to Level 1 timeline

Roof-top solar PV and battery adoption is modelled to be proportional to their economic benefit

Use OPF to assess distribution grid capacity expansion costs under high DER scenarios



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Key take away messages

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Why do power systems need flexibility?

- Power systems have always needed flexibility to balance varying demand and to deal with unexpected failures
- Rapid growth of variable renewables and electrification of demand call for more flexible power system

How to measure power system's flexibility needs?

- Flexibility is the ability of power systems to cope with variability and uncertainty over all relevant timeframes
- Flexibility requirements can be quantified in terms of net load dynamics and spatial distribution of flexibility sources

Which flexibility solutions will play a major role in the future net-zero energy systems?

- Future net-zero energy systems will need to harness flexibility across all levels
- Dynamically controlled T&D power grids will play increasingly important role in facilitating more flexible operation of the entire power system

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