Power Grid planning and operation with growing shares of wind and solar electricity

Welcome and Introduction

Philipp Godron
Stephanie Ropenus

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Agora Energiewende – Who are we?

Think Tank with more than 40 Experts

Independent and non-partisan

Project duration 2012 – 2021

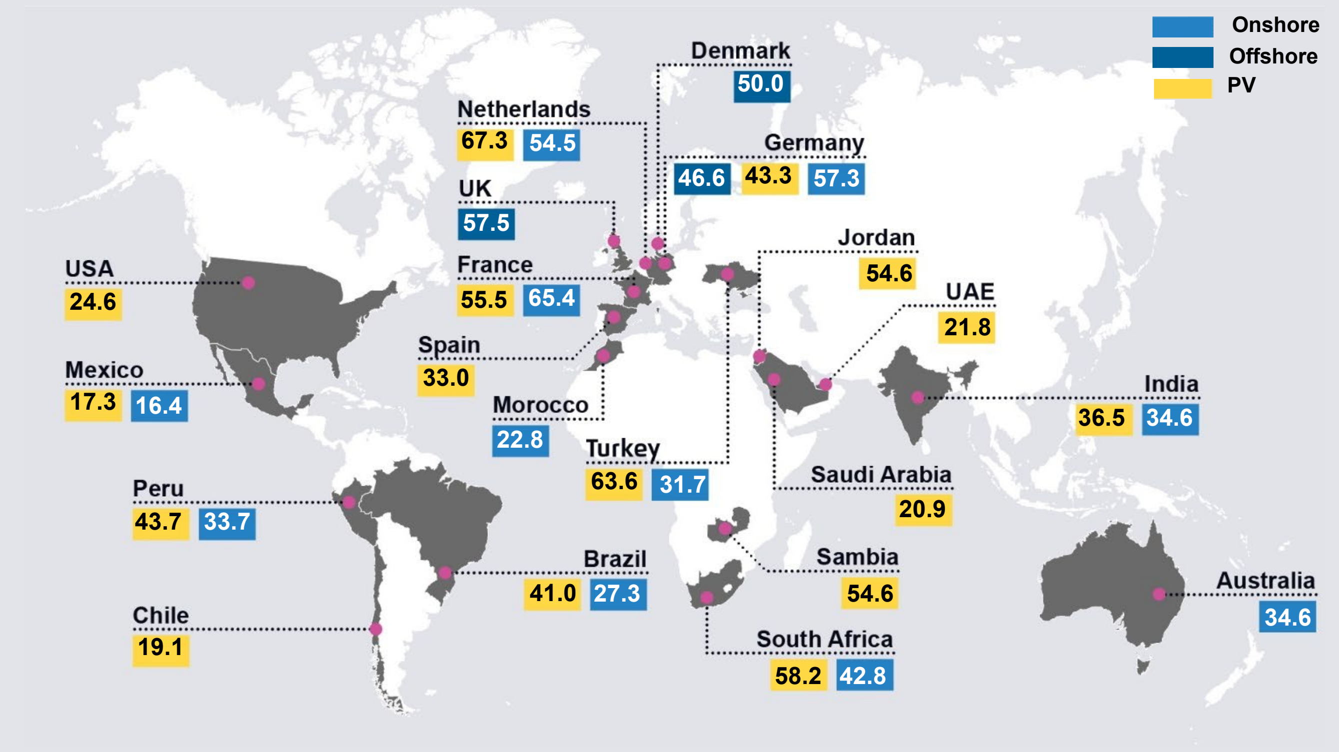
Financed by Mercator Foundation & European Climate Foundation

Mission: Make the energy transition a success story: in Germany, and worldwide

Methods: Analyzing, assessing, understanding, discussing, putting forward proposals, Council of Agora

Cheap renewables are a global phenomenon by now, wherever the market design is right

Auction results/PPA 2016/17/18 in €/MWh



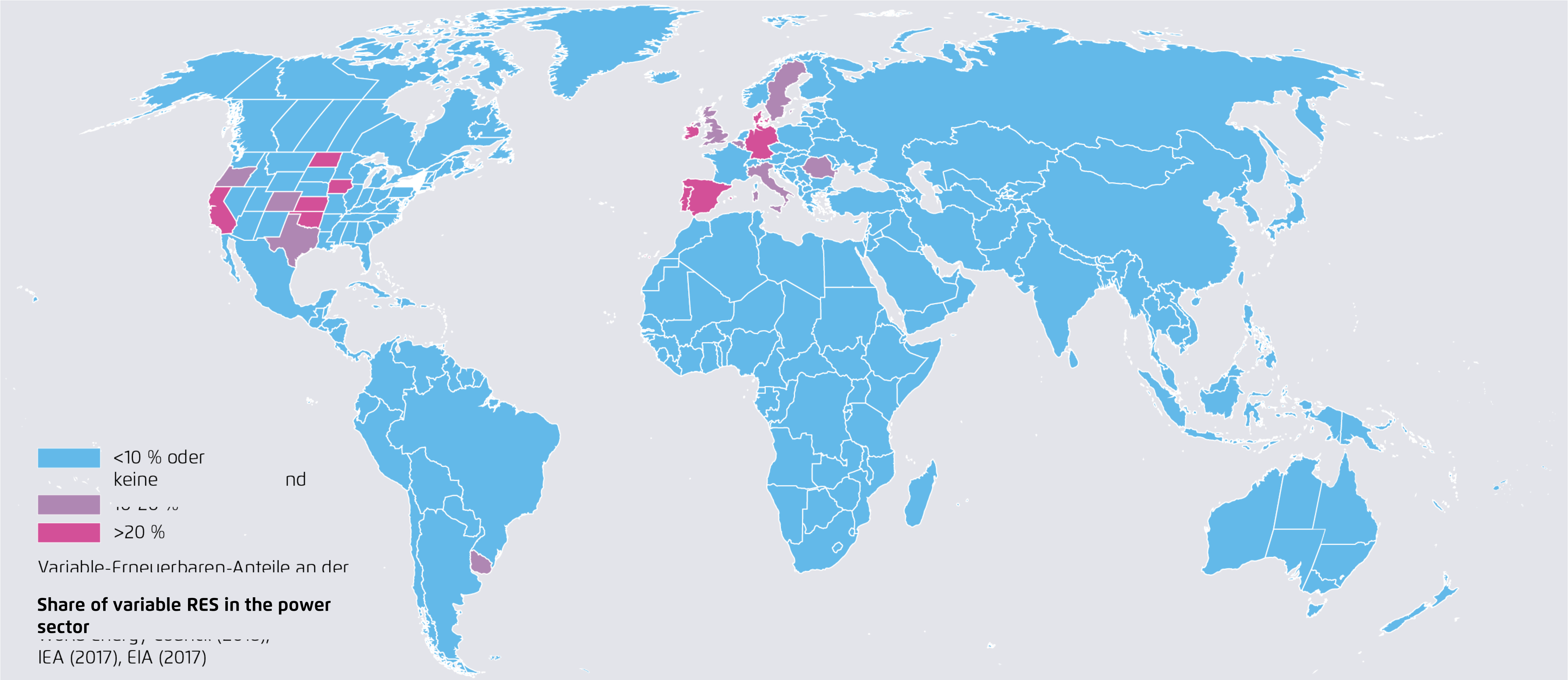
Own illustration based on BMWi, BNetzA, etc.; PPA or lowest/ average, volume weighted awarded bid values (Europe)

→ The results of single countries cannot be compared directly with each other due to differing underlying conditions, like e.g. regulatory frameworks, specific costs, etc.

→ Nevertheless, decreasing auction results mirror the steep cost digression trend, driven by

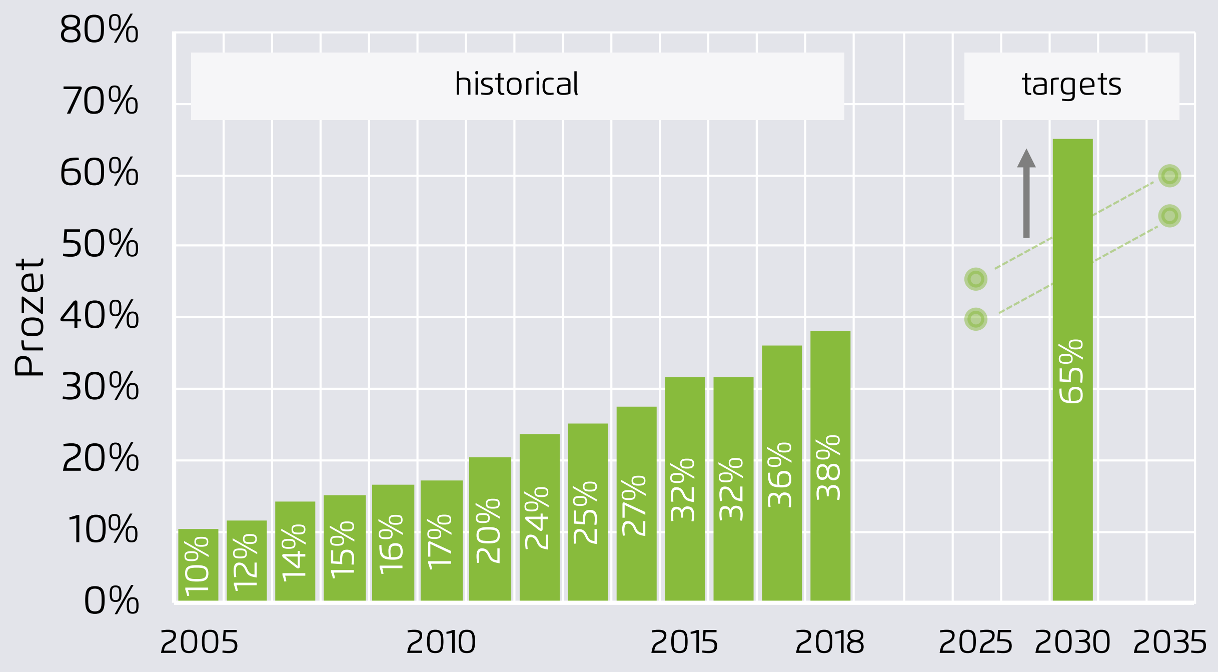
- decreasing technology costs,
- increased competition,
- better financing opportunities, etc.

Growing interest in experiences of countries with wind and solar shares at double-digit numbers



Germany has committed to continue growing its share of renewable energy in the power sector to 65% in 2030

Share of renewable energy in the power sector, 2010 – 2018, target 2030

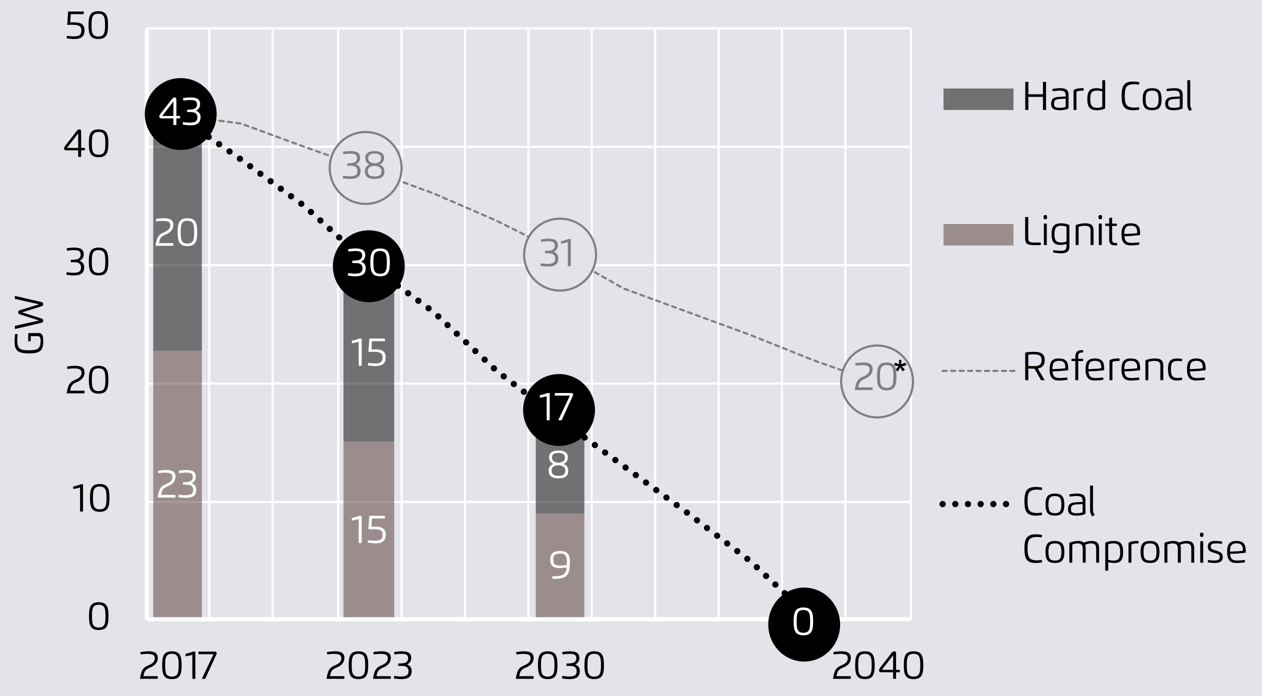


AG Energiebilanzen (2019)

- → The increase of the renewables target to 65% until has already been part of the coalition treaty.
- → However, up to now the economic ministry has not started an implementation process on that. The current renewable-energy-framework still foresees capacity additions in line with the old target corridor of 40-45% in 2025 and 55-60% in 2035.

According to the phase out plan of Germany's "coal commission", coal capacity will go down to 17 GW by 2030

Coal capacities 2018, 2023, 2030 and 2040



Aurora Energy Research (2019), Commission

Step by step reduction of coal capacity in the market:

→ from 23 GW lignite and 20 GW hard coal in 2017

→ to 15 GW lignite and 15 GW hard coal in 2022

→ to 9 GW lignite and 8 GW hard coal in 2030

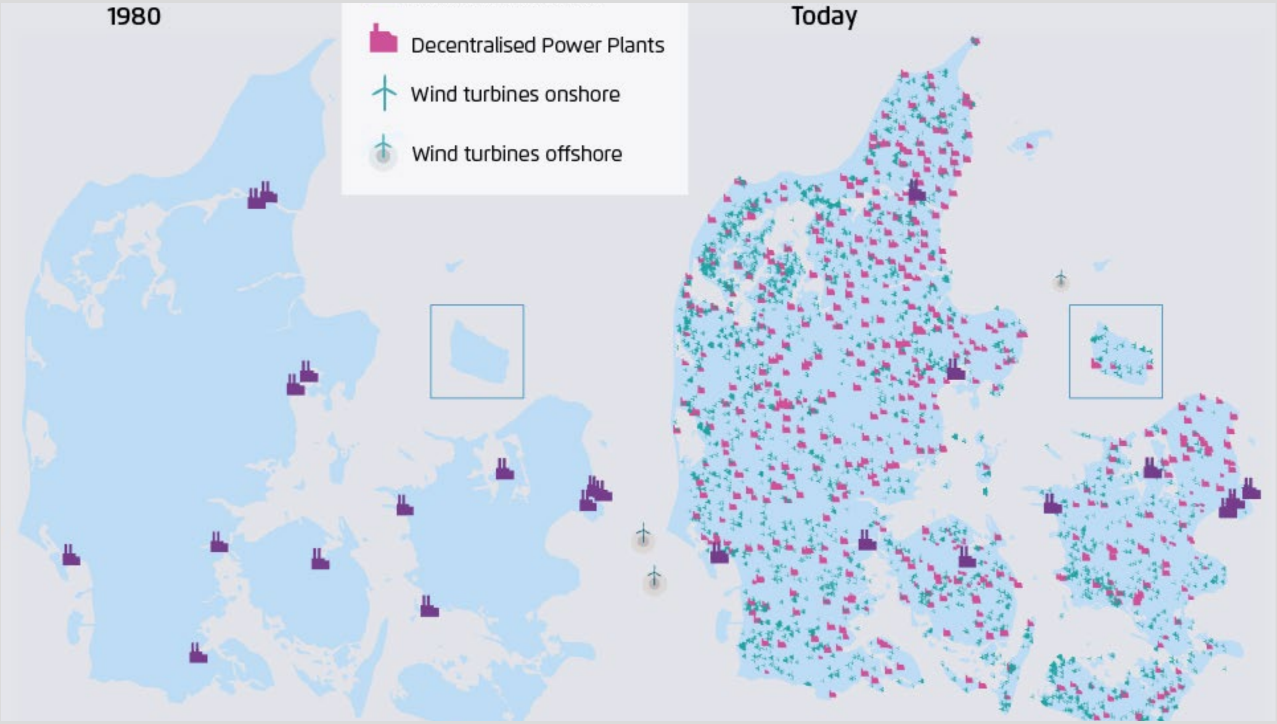
→ And finally phasing out the latest until 2038; thereby reviewing in 2032, if 2035 is doable

** own estimate based on average lifespans*

What are the key challenges from rising shares of wind and solar?

Power systems are no longer dominated by few large thermal power plants, but rather by many small, decentralised power stations – based on renewable energy

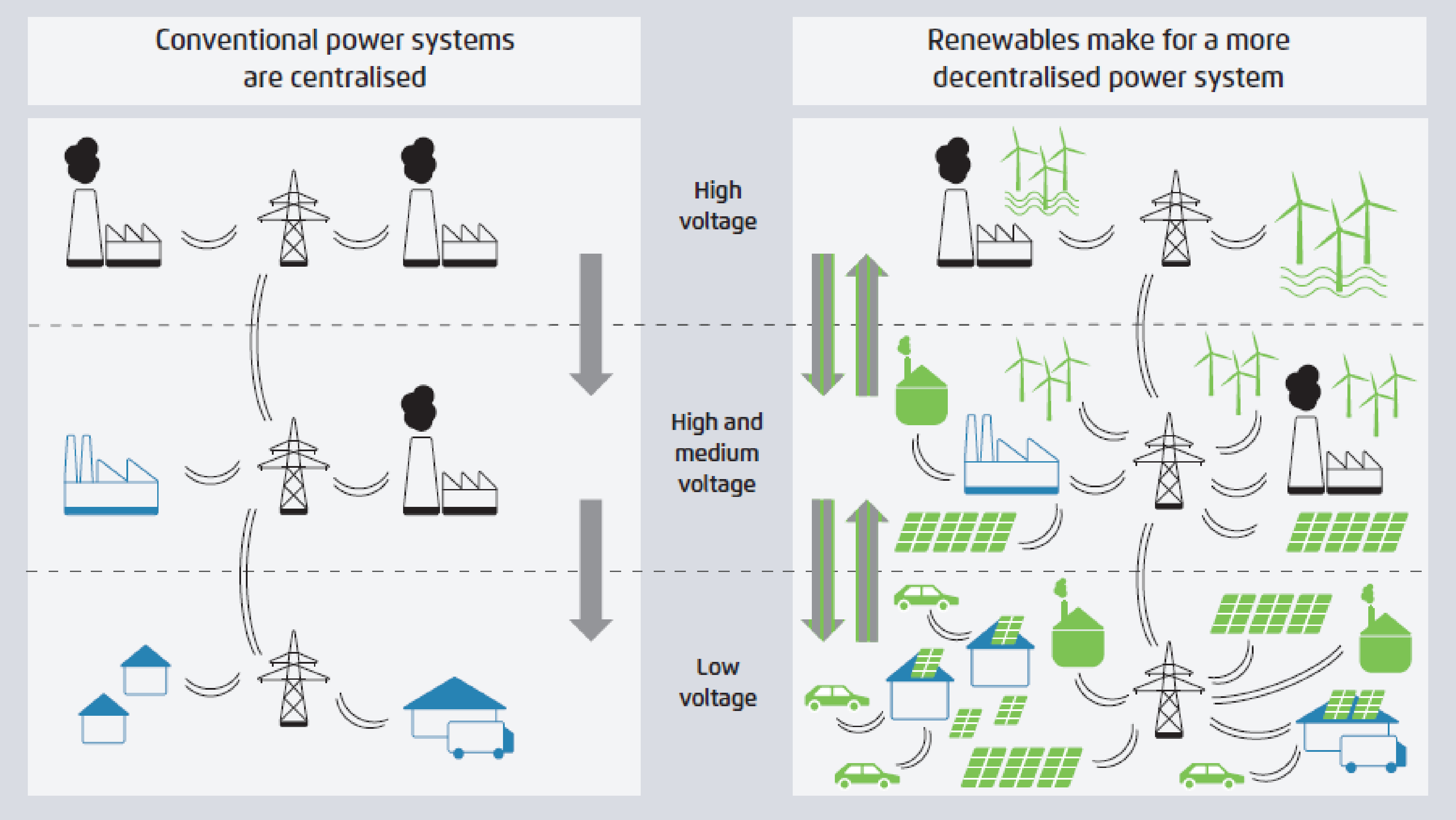
Example Denmark: from centralized to decentralized generation



Energinet.dk

- In Denmark the electricity system has changed from a centralised power system towards a more decentralised system, inlcuding onshore wind energy and combined heat and power. Also, there is a lot of offshore wind energy.
- Denmark had a 41% wind energy share in electricity consumption in 2018 (record in 2017: 43%).
- In Germany, the number of PV installations is above 1.5 million and nearly 30,000 wind turbines (RES share: 38% of electricity consumption in 2018).
- Emergence of new actors such as prosumers.

The electricity system is becoming more complex, with bi-directional power flows



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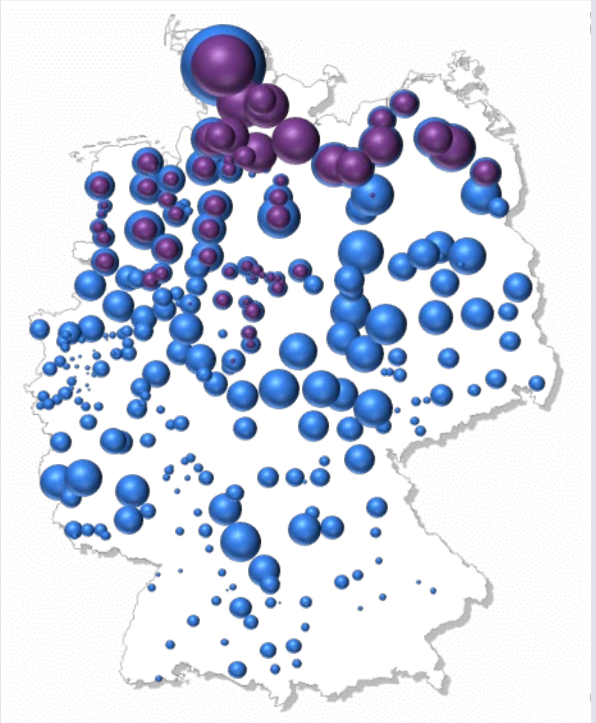
- The number of power sources on the supply side and the number of electric-powered devices on the demand side (e.g., electric vehicles, heat pumps) are increasing.
- Renewables feed for the most part directly into the distribution grid. There are bidirectional power flows.
- The new technologies lead to changing roles in the energy system, and a stronger need for coordination.

Wind and solar generation tends to be located where resources are best, rather than where demand is

Installed wind capacity (103 GW, Scenario „Best Sites“) 2033

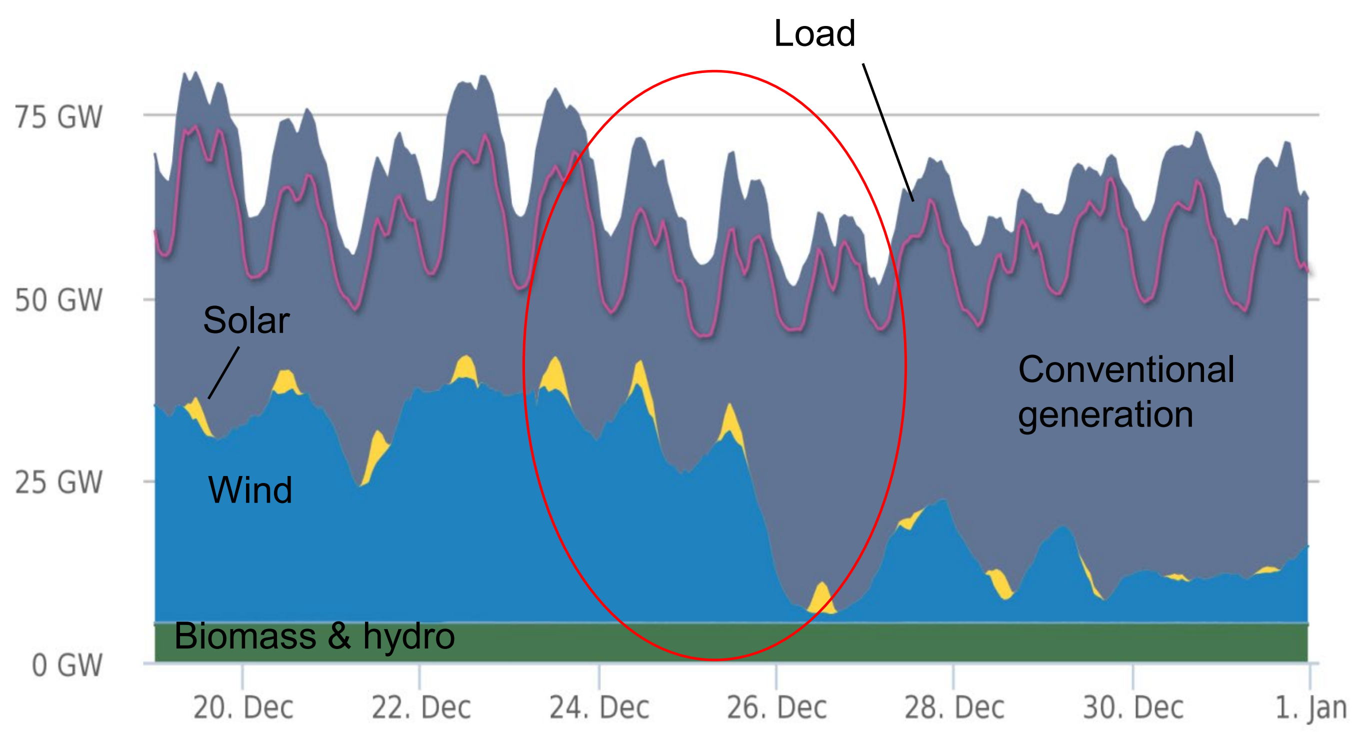


Fraunhofer IWES (2013)

- → **Good site conditions** play a major role for the installation of wind turbines: a lot of onshore wind is installed in areas where the energy yield is high.
- → For example, in Germany the bulk of wind energy is installed in the Northern part of the country.
- → **Load centres** may be located elsewhere. For example, Germany they are rather in the middle or Southern part of the country.
- → **Grid expansion** becomes necessary in order to transport electricity produced by wind turbines to load centres.

Rapid changes in supply and demand lead to steeper ramp rates

Electricity generation and demand in Germany 20th to 31st December 2014



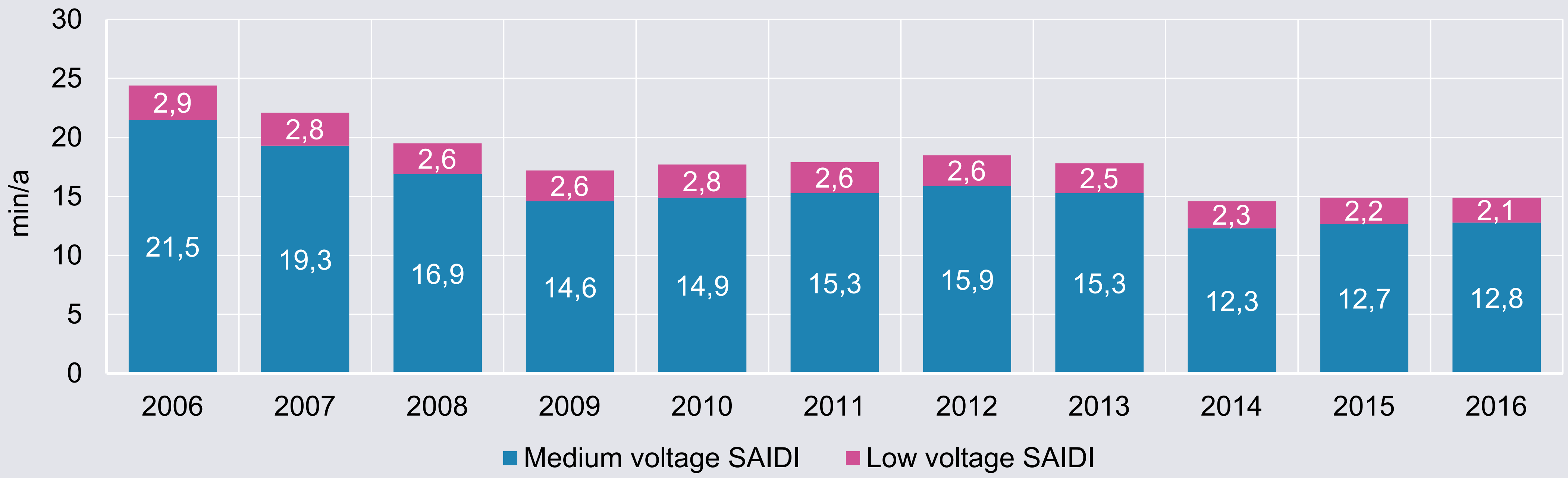
Agorameter

- High generation from wind on 24/25 December
- Low demand on 24/25 December due to Christmas holidays (minimum load 44.5 GW)
- Drastic drop of electricity generation from wind at night 25/26 December

→ In the future, ramps may be caused both by rapid changes in RE generation or demand (electric vehicles, heat pumps)

The good news: system reliability can remain high while the share of variable renewables increases

SAIDI (System Average Interruption Duration Index) Germany 2010 - 2016



BNetzA

But how?

Planning modern grids

Philipp Godron
Stephanie Ropenus

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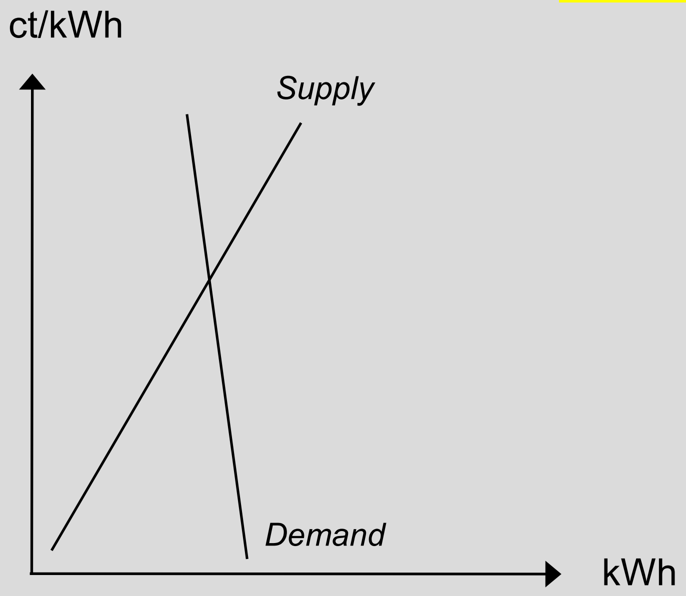
Adequate grid planning helps avoid grid congestions and allows operators to dispatch power based on least cost

The power market ("financial") and actual operation of the grid ("physical")

Power market: "copper plate"



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Grid operation

- Bottlenecks in distribution and transmission grid: no more "copper plate" in real time. Local congestions may occur.
- Avoid exceeding limit values (current, frequency, voltage).
- Provision of ancillary services in order to ensure grid stability and reliability.

Own illustration

Grid planning

→ If there are delays in grid expansion (e.g., in regions with high RES-E deployment), grid bottlenecks may occur.

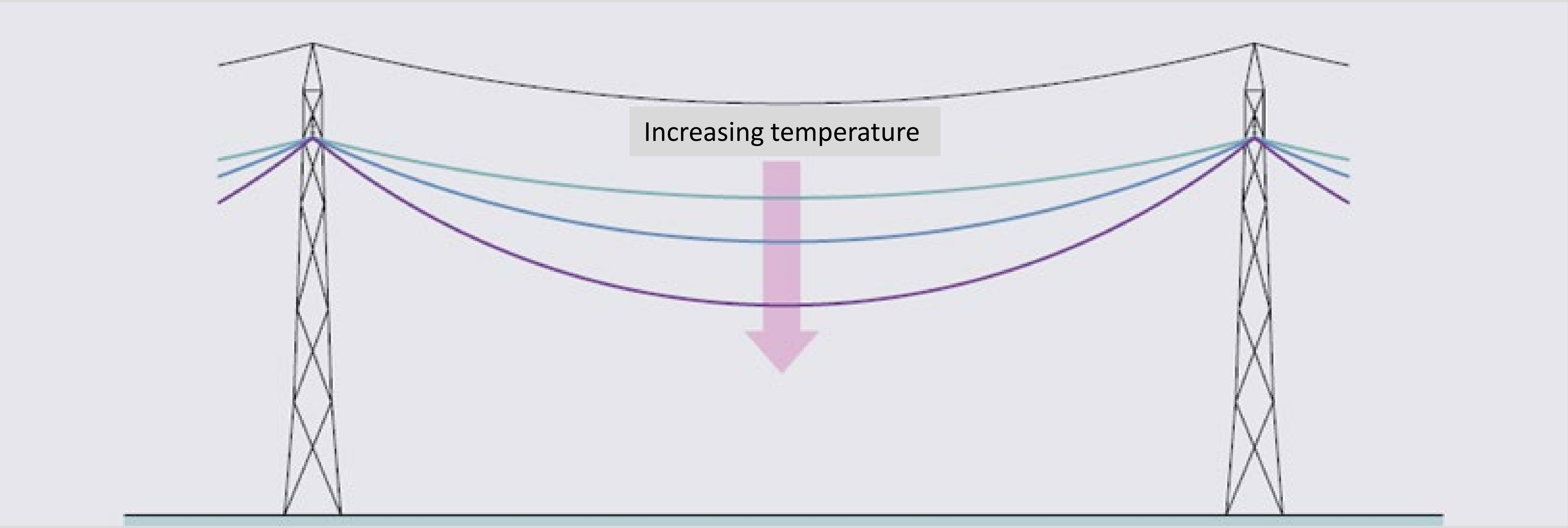
Grid operation

→ In case of congestion grid operators may have to curtail generation to ensure system stability.

- First: redispatch of conventional power plants.
- Curtailment of RES-E as measure of last resort.

What does grid congestion actually mean?
Operating temperature exceeds the thermal limit of the transmission line or transformer

Stylized illustration: sag of an overhead transmission line



Own illustration by Energynautics GmbH, in: Agora Energiewende und Energynautics GmbH (2018)

GORE Principle
Grid Optimisation prior to grid Reinforcement prior to grid Expansion

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- The "GORE Principle" prioritises "low-hanging fruits" before constructing new transmission lines
- Low-hanging fruits include the opimisation and reinforcement of the exisiting transmission grid infrastructure
- New transmission lines are built if optimisation and reinforcement measures have been exhausted.
- Notably, grid expansion is still necessary. It is not an "or", but rather an "and": grid optimisation and reinforcement and expansion.

GORE Principle
Dynamic line rating – an “ideal partner“ for wind energy

© Erwin Wodicka, Fotolia

- **Objective**: to safely increase the utilisation of the transport capacity of existing transmission and distribution lines.
- **Dynamic line rating**: monitor real conditions in which power lines operate (actual atmospheric conditions) rather than deterministic or probabilistic methods (static line rating).
- Wind power feed-in and ambient temperature of power lines are “ideal partners.“
- Prerequisite: continuous measuring of temperature of overhead transmission lines by means of sensors or infrared cameras so as to avoid violation of thermal limits.
- Increasing thermal limits of transmission lines.
- Different variants are already applied by German transmission system operators.

GORE Principle
High Temperature Low Sag (HTLS)

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- **Objective**: to increase transport capacity by retrofitting power lines in the existing transmission or distribution grid.
- **High temperature low sag power line conductors (HTLS):** transmission of larger current in existing structures by upgrading existing lines with composite cored conductors (annealed aluminium or aluminium alloy conductors). This allows for higher operating temperatures and for a larger current to be transmitted.
- Account for: statics of electrical towers, exposure of environment to increased electric and magnetic fields (may impact parallel infrastructure, such as gas pipelines), possibly increase in line losses.
- When thermal limits are increased, there is still the question of stability limits.

GORE Principle
Grid operation: power flow controlling devices

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- **Objective**: improving the efficiency of already existing AC grids and preventing overloads on specific transmission lines by means of active power flow control.
- **Power flow control** (e.g., phase shifting transformers (PSTs)): control of the amount of active power that can flow in a transmission line. “Re-routing“ power flows to parallel transmission lines or network sections that are not operated close to their thermal limits.
- PSTs as a new short-term measure (to be implemented by 2023) as part of German Network Development Plan in order to reduce redispatch and curtailment. In the long-term: implementation may also help to reduce grid expansion.
- Coordination between adjacent TSOs is vital.

Streamlining grid planning procedures and keeping track of progress in grid expansion and optimisation

Streamlining grid planning procedures:

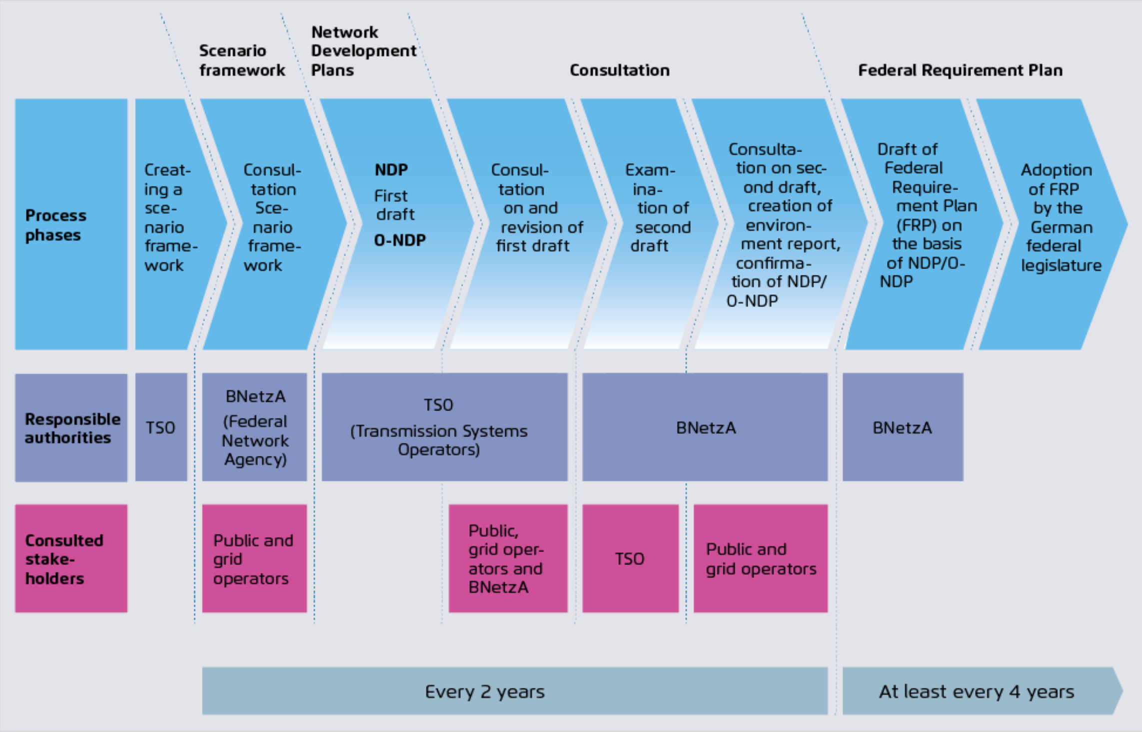
- → How large or neglible is the impact of the new transmission project:
  - → Only modification of existing power line?
  - → Impact on transmission tower, electric and magnetic fields, noise, environment?
- → Streamlining of planning and permitting procedures if criteria for minor impact are fulfilled ("simplified permitting procedure").

Keeping track of implementation:

- → Regular review of implementation of GORE principle by regulatory authority
- → Transparency on progress in grid expansion
- → Identification of barriers and development of solutions based on "lessons learned" in other grid projects

German regulation foresees well-defined process that involves TSOs, regulatory authority and broader public

Network Development Plan and Federal Requirement Plan.



50Hertz et. al. (2017), p. 3

Scenario Framework:

- → TSOs need to take into account at least 3 scenarios of how supply and demand develop in a 10-year-horizon
- → One scenario looking at next 15-20 years

Biannual **Network Development Plan**:

- → Plan covers grid optimisation, reinforcement and expansion measures for the next 10-15 years
- → Proposed by TSOs, followed by comprehensive public consultation, approved by regulator

Federal Requirement Plan:

- → Makes high-priority grid expansion projects legally binding

The traditional planning approach: Grid follows supply (and demand)

Example: Germany

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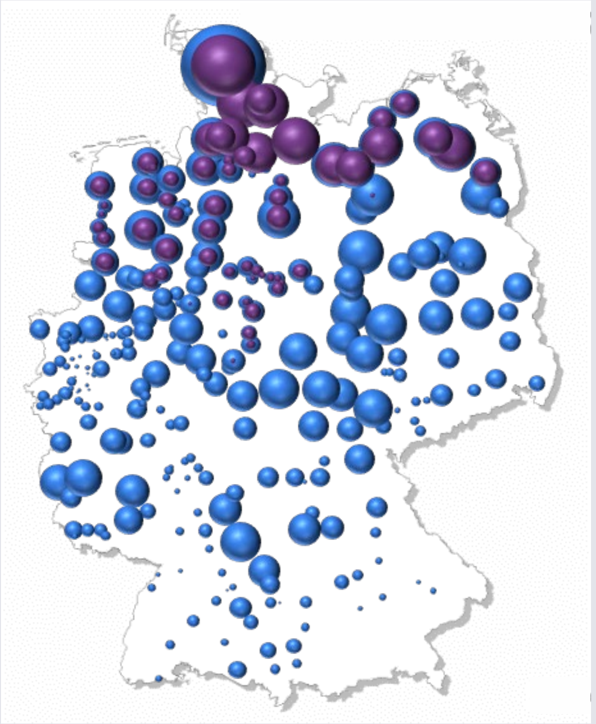
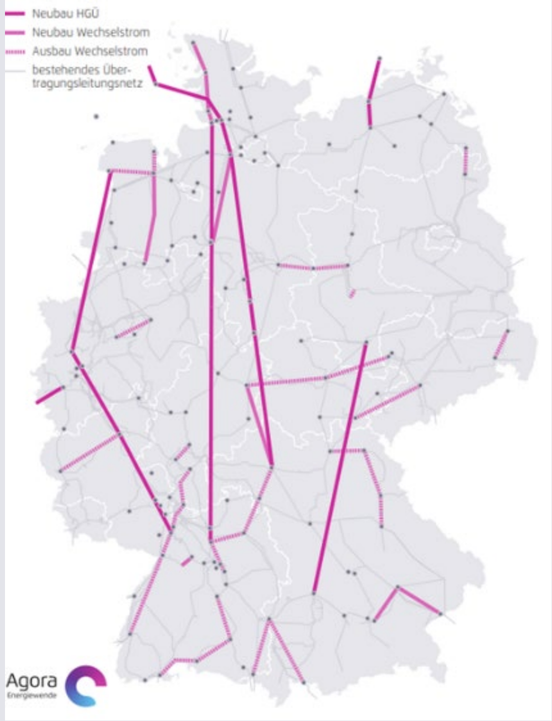
Installed wind capacity (103 GW, Scenario „Best Sites“) 2033



Fraunhofer IWES (2013)

Planned transmission grid extensions until 2022



Bundesbedarfsplangesetz (2013)

Wind power will be installed mainly near the coast in the North of Germany, but key consumptions centers are located in the South. Additional power lines are necessary to transport wind electricity from North to South (4 HVDC corridors).

Innovations to align RE and grids:

→ **Peak shaving in grid planning:** up to three percent of annually forecasted generation. This eliminates the need to build new lines to cover a very limited number of hours during the year

→ **“Grid-friendly” placement of new vRES:** restrict the installation of new onshore wind turbines in areas where the transmission network is already overloaded (known as grid expansion regions) until additional grid capacity becomes available.

Texas Renewable Energy Zone (REZ) Transmission Planning Process help close time lag between RE and transmission invest

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
PROCESS DESIGN & VISION STATEMENT	RENEWABLE ENERGY RESOURCE ASSESSMENT	CANDIDATE ZONES SELECTION	TRANSMISSION OPTIONS DEVELOPMENT	FINAL TRANSMISSION PLAN DESIGNATION	TRANSMISSION SYSTEM UPGRADE
	Summary: Select areas with highest potential **Output:** Study areas map and supply curves	**Summary:** Identify zones with highest probability of development **Output:** Candidate zone map and supply curves (one per area)	**Summary:** bundle candidate zones and analyse options **Output:** Cost, benefit and reliability impacts for each alternative	**Summary:** Select transmission option according to pre-set criteria **Output:** Final transmission order	

Source: Lee, N. et al. (2017

Addresses the challenge of transmission investment requiring longer lead times than Renewables

Main characteristic: transmission planning is based on an in-depth solar and wind resource assessment of the country or region in order to identify so-called Renewable Energy Zones

Requires strong stakeholder involvement

Developed in Texas, US, adopted in several other countries, i.e. South Africa, parts of India, etc.

“Menu card“ for integrating renewables (non-exhaustive): no one-size-fits-all solution, but variety of measures

Grid related		Interplay Grid/Market	
Grid expansion	**Grid operation**	**Generation**	**Demand**
→ Classical grid expansion → Grid reinforcement (e.g., HTLS* on already existing transmission lines) → Increasing flexibility of planned transmission lines (empty ducts)	→ Grid congestion: redispatch, curtailment → Dynamic line rating → Power flow controlling devices, “grid boosters“ → Enhanced automatic control in grid operation → Increased coordination between TSO-DSO**	→ “Grid-friendly“ regional incentives for deployment of renewables (e.g., wind) → Reduction of must-run generation → Increasing flexibility of CHP***, heat pumps → Provision of ancillary services independent of conventional power generation	→ Incentives for increasing flexibility of demand → Power-to-heat in areas with grid constraints → Intelligent control of new types of demand (e.g., smart charging of electric vehicles; heat pumps)
	→ Smart markets: flexibility markets incentivizing grid-related flexibility		

* High Temperature Low Sag
** TSO – Transmission System Operator
** DSO – Distribution System Operator
*** Combined Heat and Power

Agora Energiewende
Anna-Louisa-Karsch-Str.2
10178 Berlin

T +49 (0)30 700 1435 - 000
F +49 (0)30 700 1435 - 129

www.agora-energiewende.de

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Questions or Comments? Feel free to contact me:

stephanie.ropenus@agora-energiewende.de
philipp.godron@agora-energiewende.de

Agora Energiewende is a joint initiative of the Mercator Foundation and the European Climate Foundation.