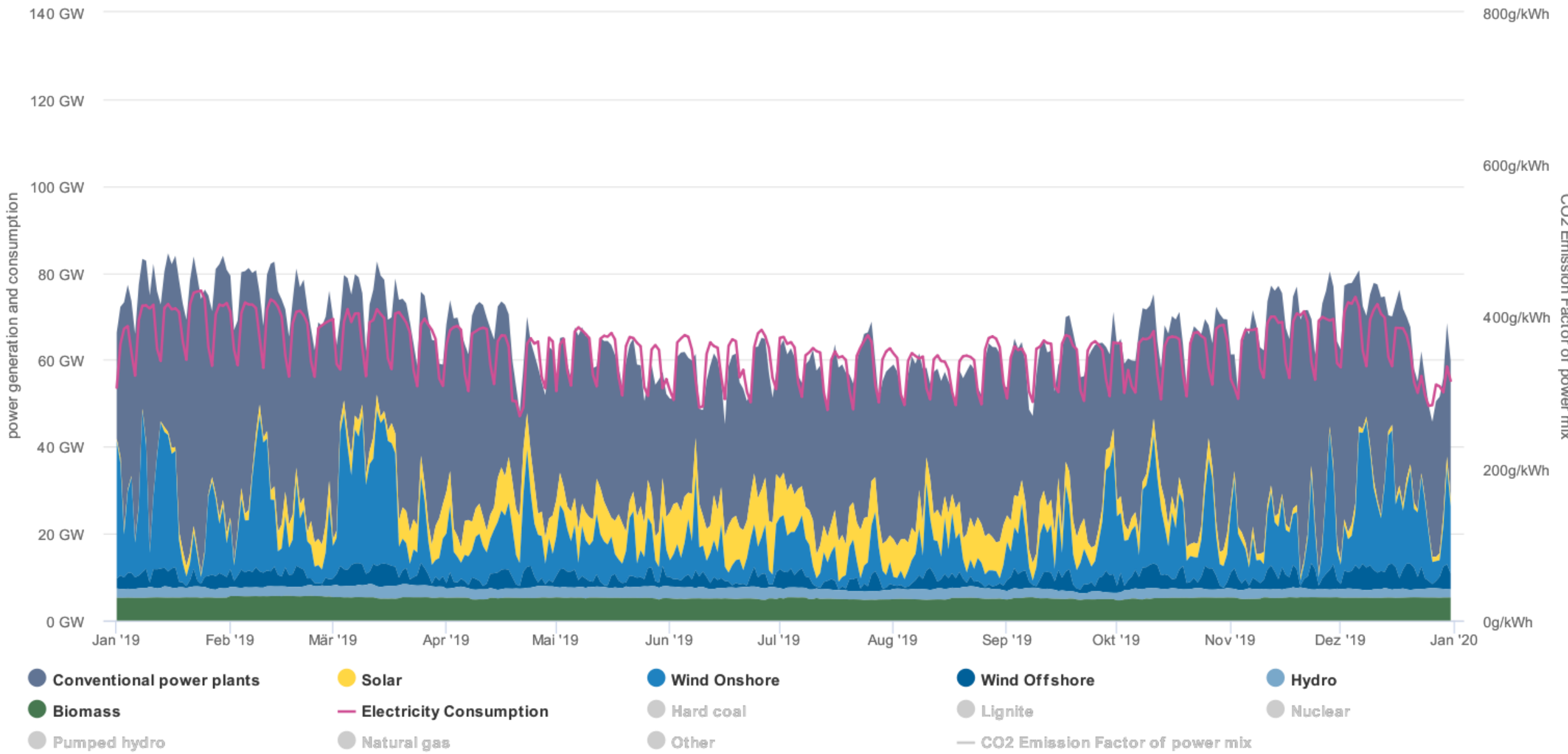
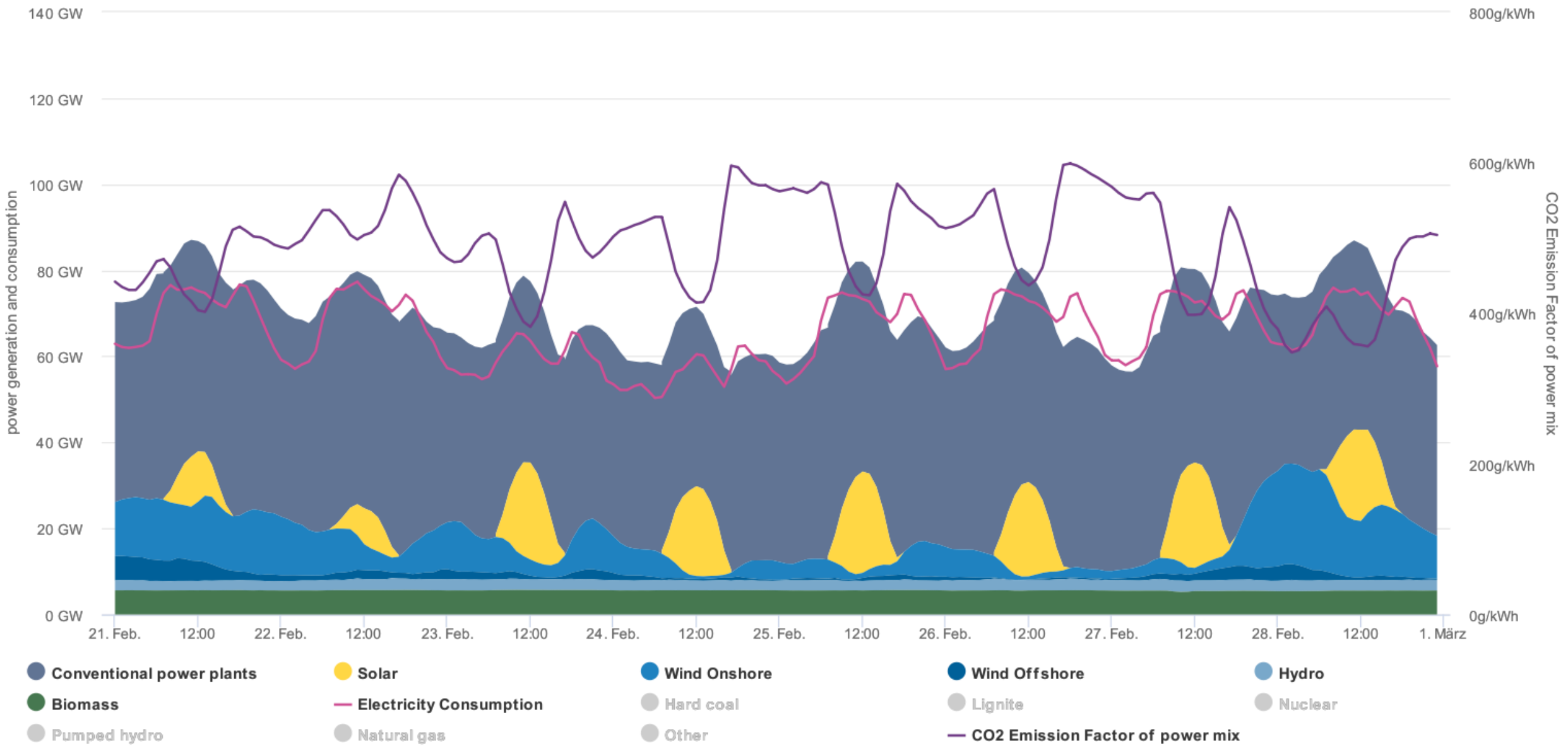


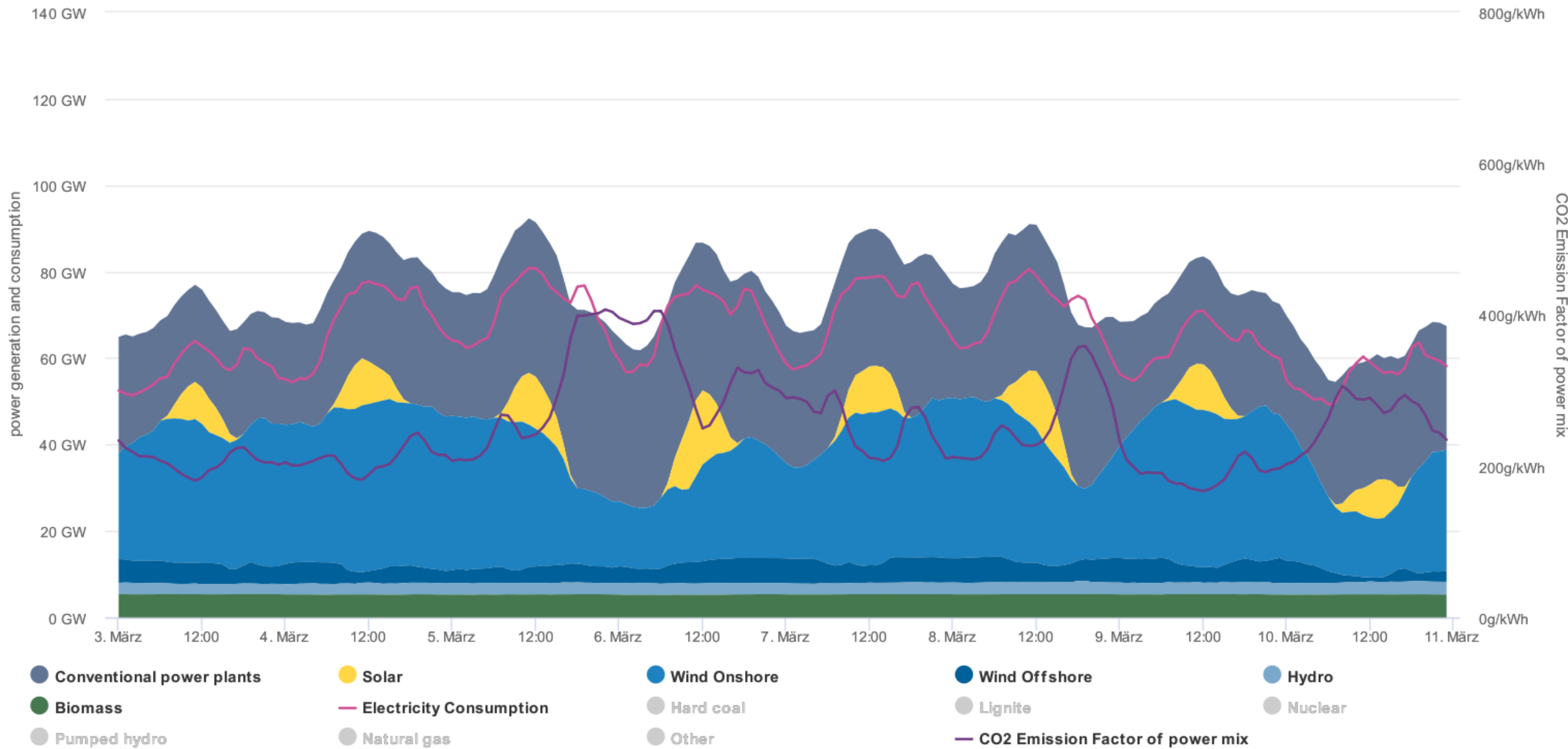
Renewable energy and grids



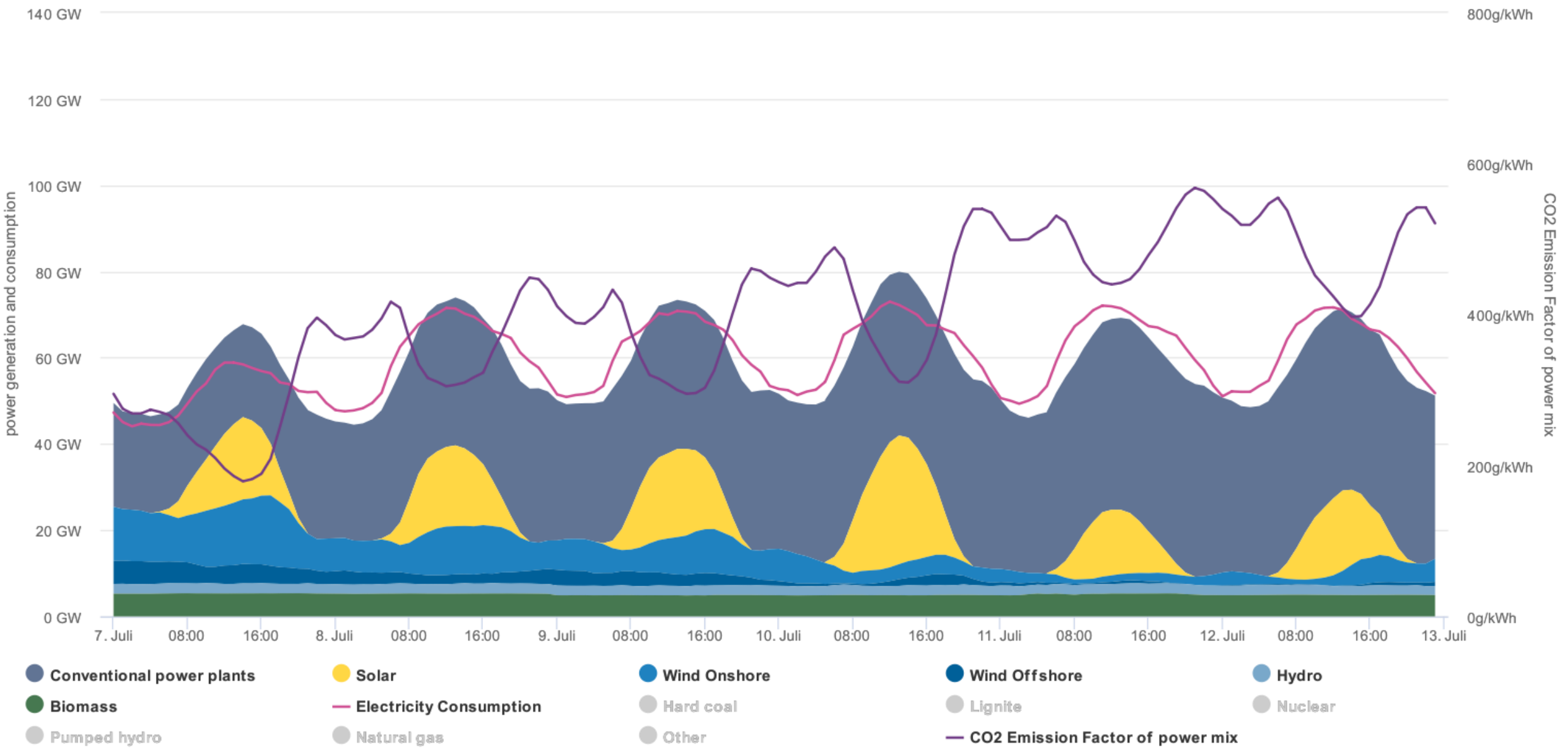
Electricity generation in Germany by source (2019): RES at ~40% of consumption



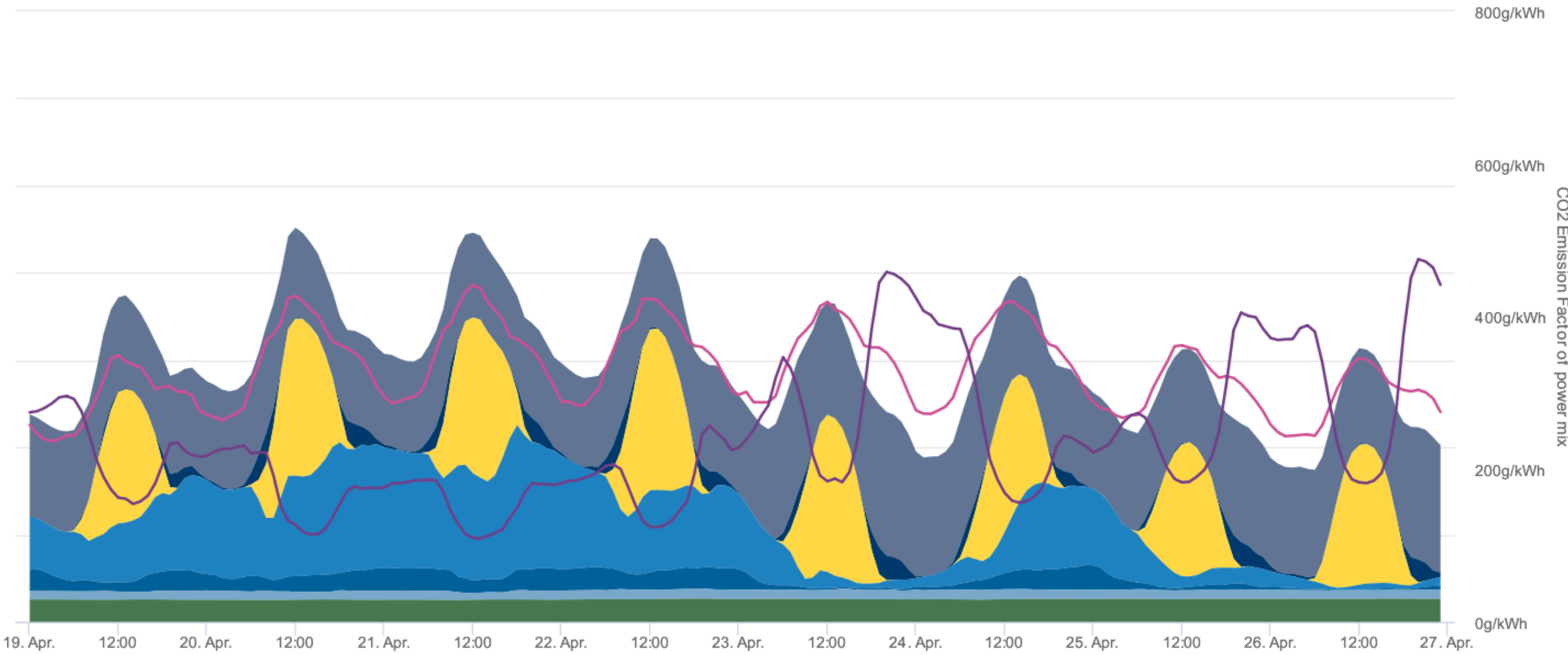
2019



2019



2019



Restliche / Conventional power plants

Solar

Wind Onshore

Wind Offshore

Hydro

Biomass

Electricity Consumption

Hard coal

Lignite

Nuclear

Pumped hydro

Natural gas

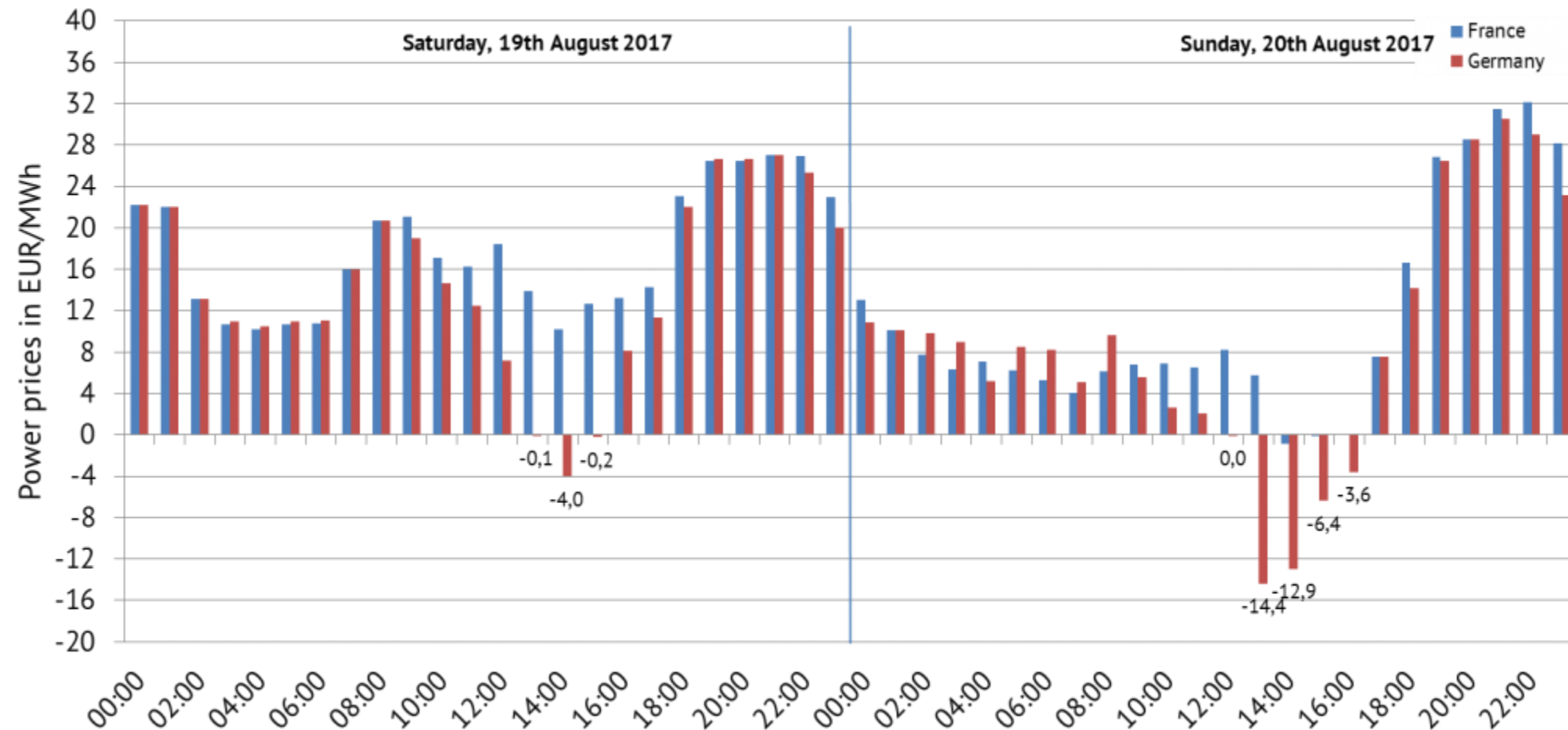
Other

CO2 Emission Factor of power mix

2020

Challenges

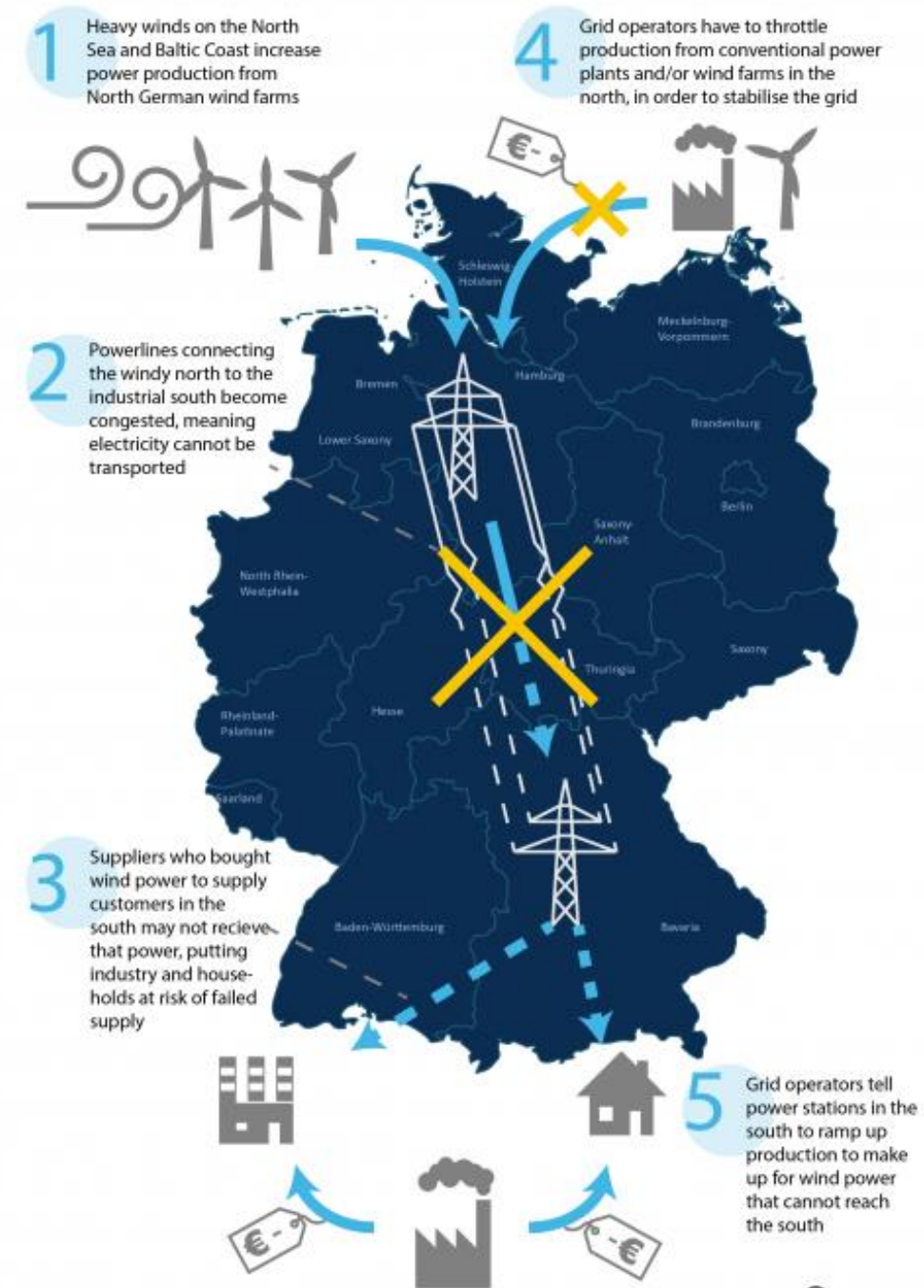
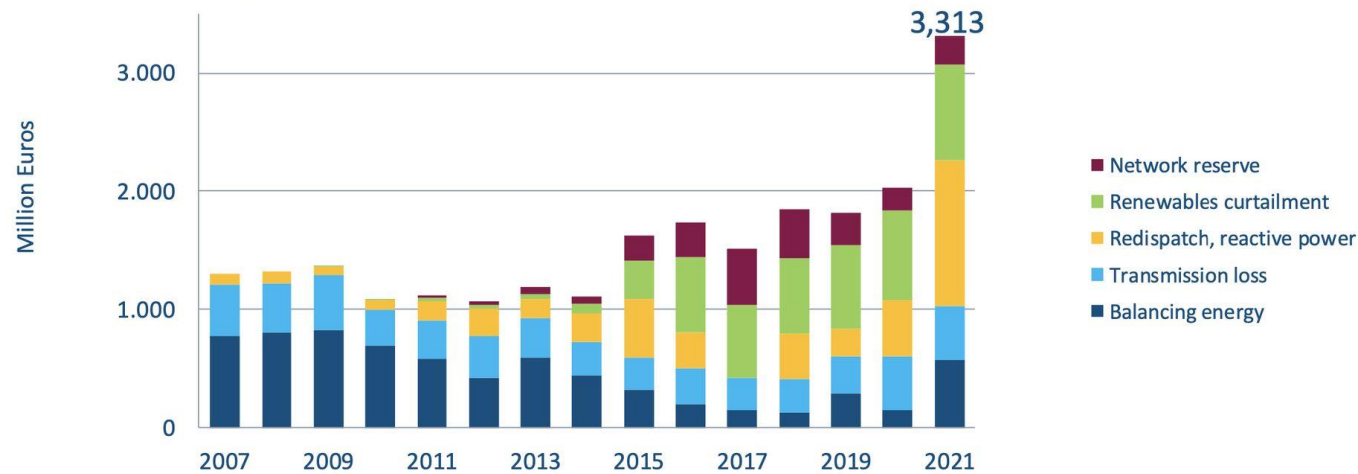
Not enough or too much power (volatility)



Congestions

System services ensure the high reliability of the German power system

Annual costs of system services for German transmission system operators



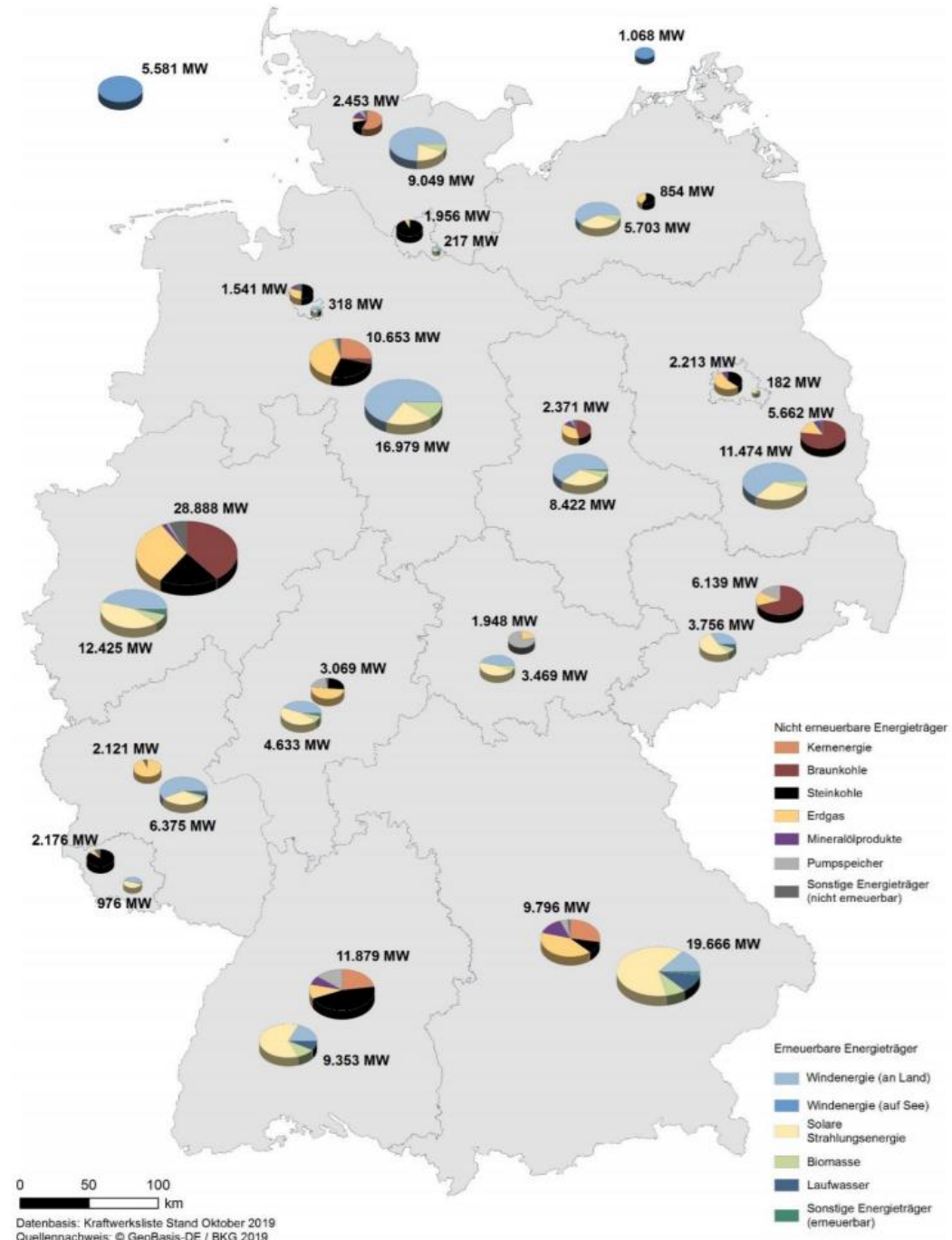
Source: Guidehouse, June 2023 based on BNetzA/BKartA 2022

Legacy grid topography

Year	Rated power (MW)	Thermal efficiency (%)	Price (USD1992/kWh)
1892		2.5	4.00
1907	12		1.56
1927	110	20	0.55
1947			0.19
1967	1,000	40	0.09

	Typical availability (load factor)
Conventional technologies	0.85
Wind onshore	0.2
Wind offshore	0.4
Solar	0.1

Electricity: Generation capacity by energy source in each federal state



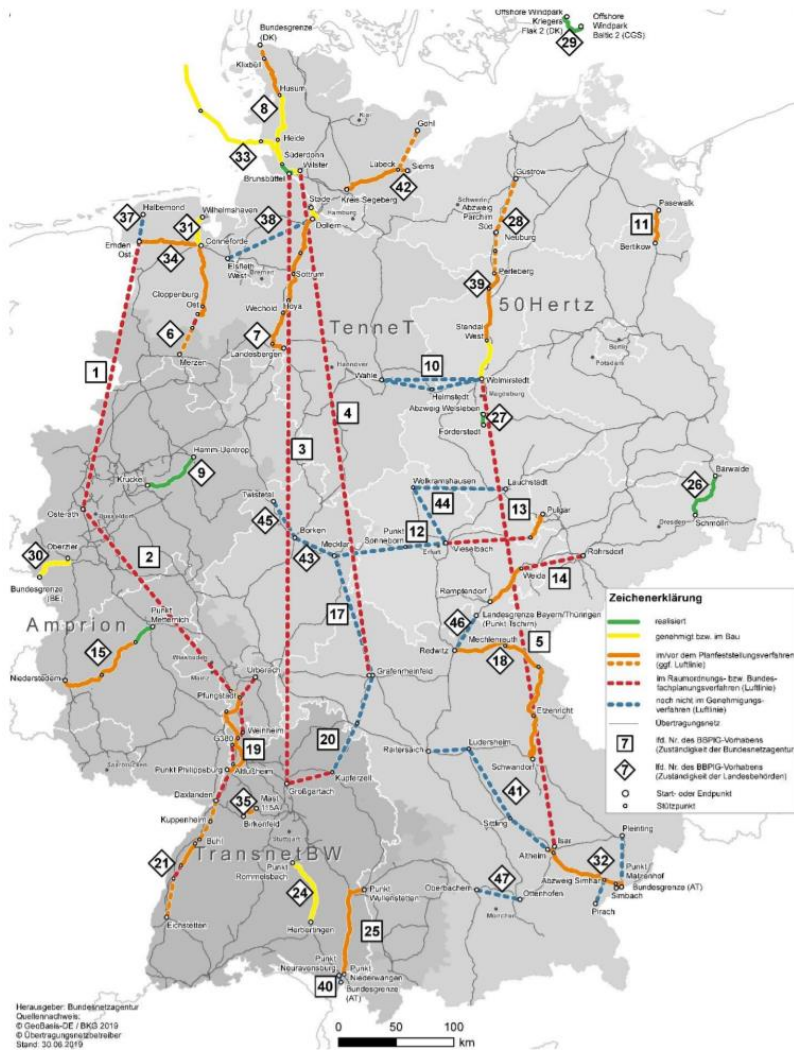
Solutions?

Solutions

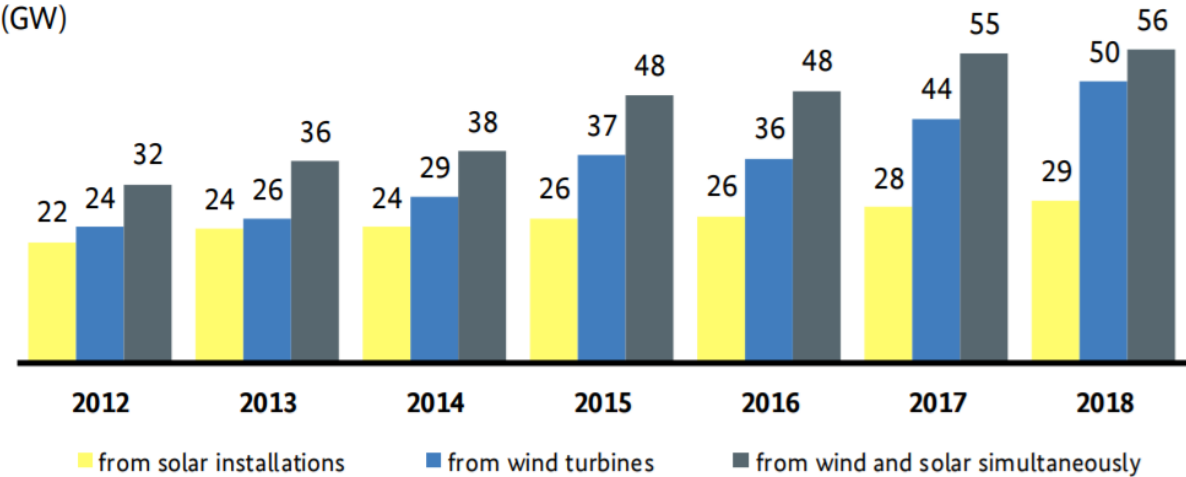
- Adjusting RES development to grid conditions
- More grids, more interconnections
- Grid upgrades
- Change in the market design
- Increasing flexibility of non-RES supply and demand
- Sector coupling
- Storage

Adjusting RES: location restrictions and hybrid plants

Electricity: status of BBPG expansion projects



Electricity: Maximum feed-in (GW)

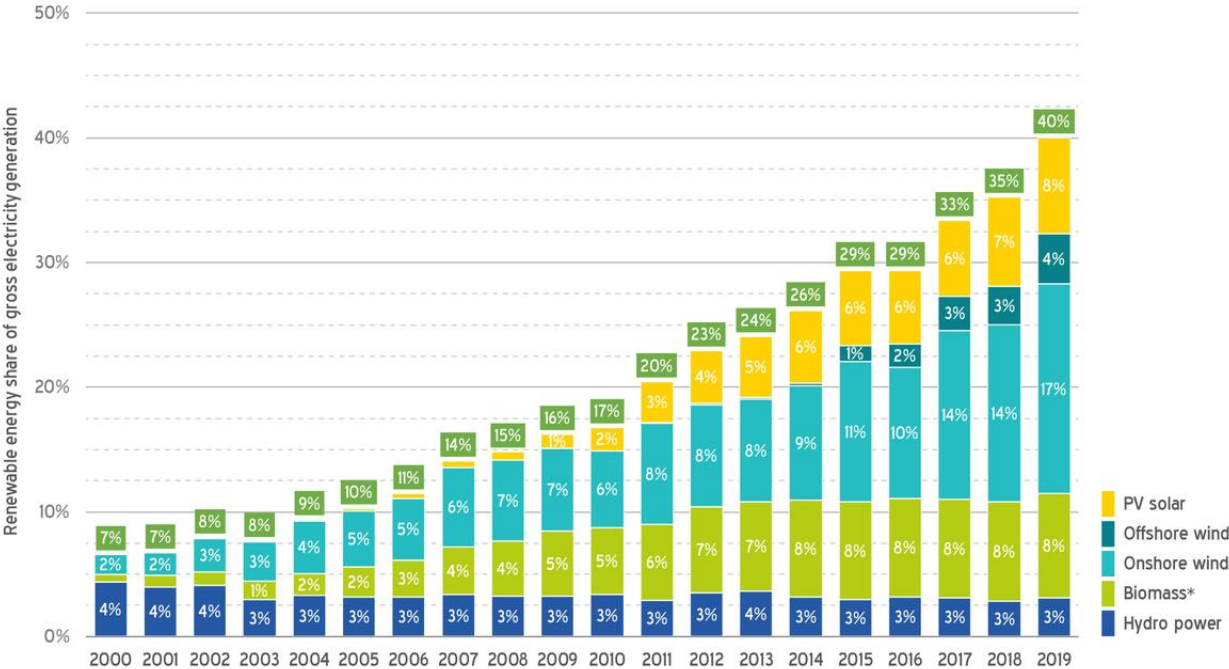


More grids

40 percent of Germany's electricity is generated by renewable energy sources

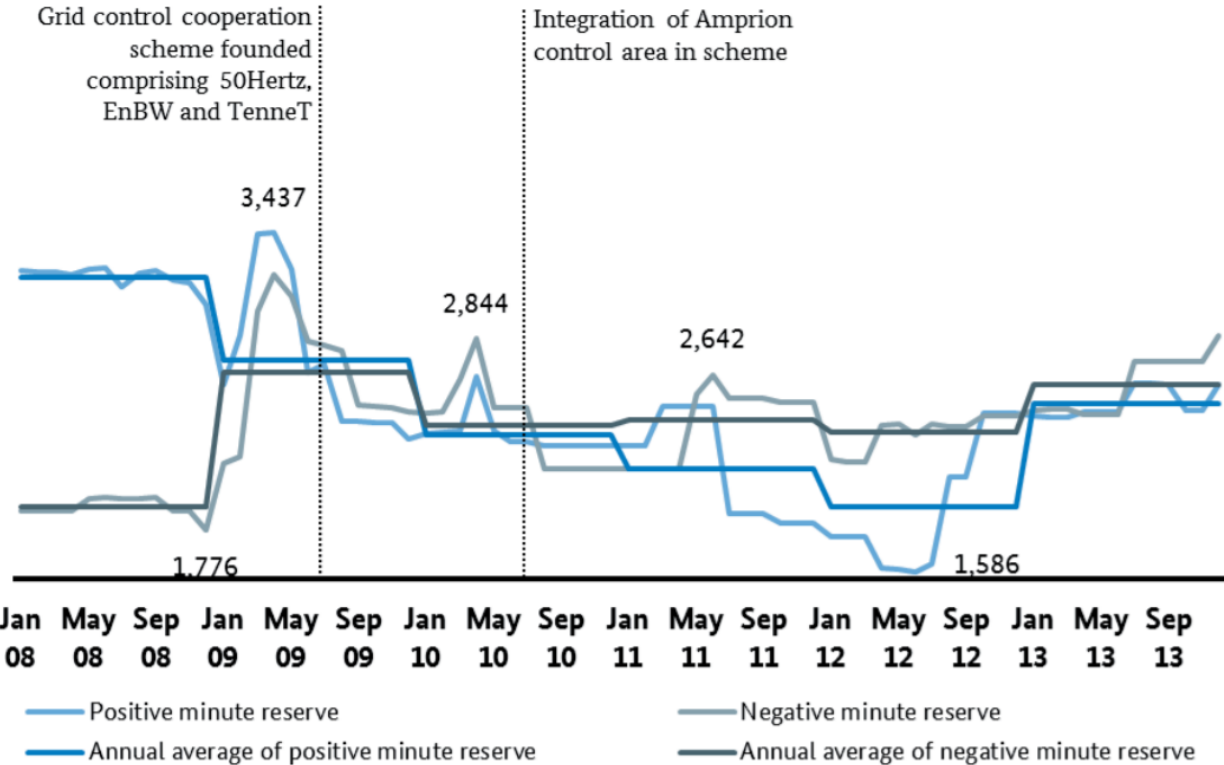
Renewable energy share of German gross electricity generation 2000-2019

Source: AGEB | *including biogenic waste



Energy Transition
The Global Energiewende
energytransition.org CC BY SA

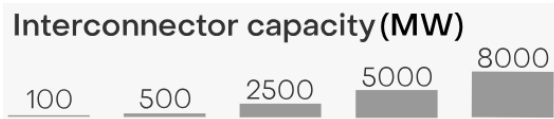
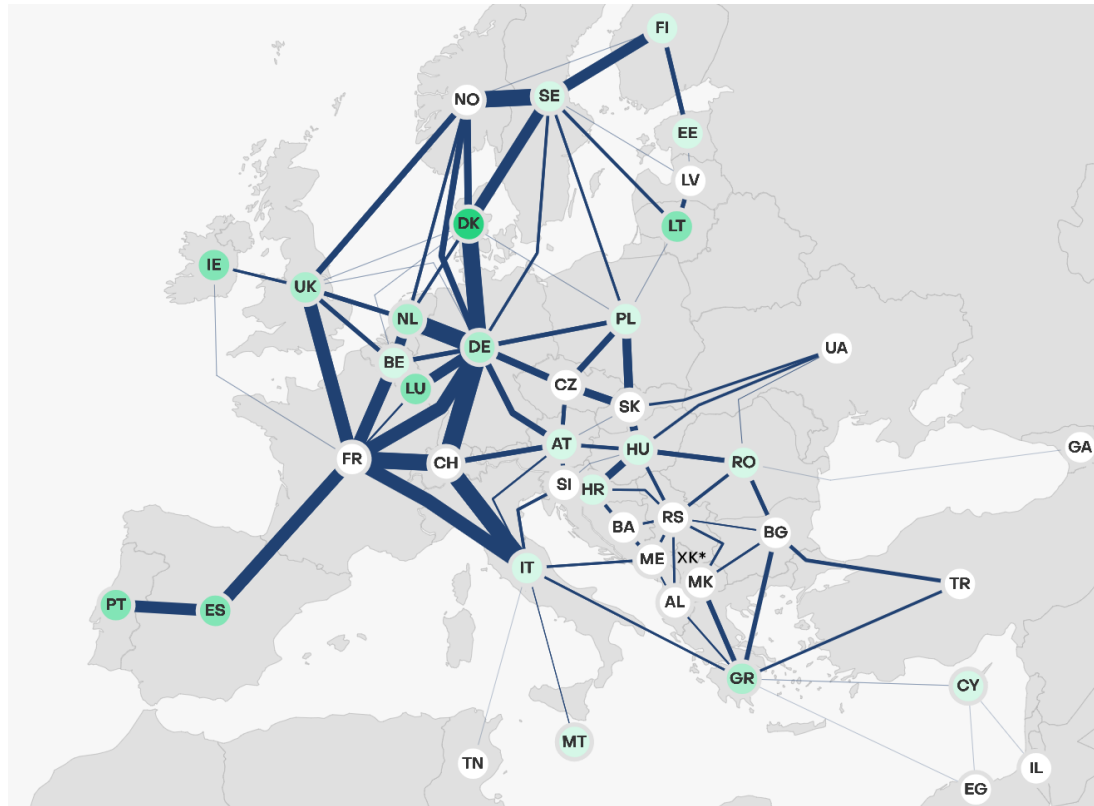
Total minute reserve tendered in the control areas of 50Hertz, Amprion, TransnetBW and TenneT (MW)



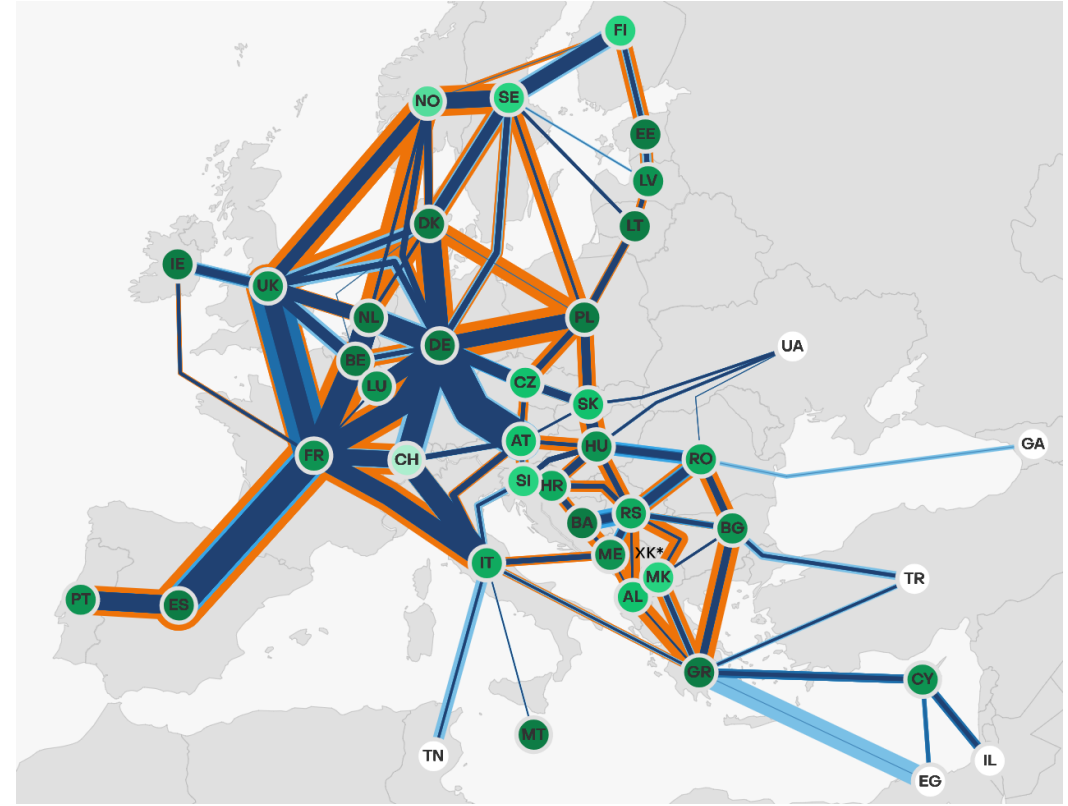
2009-2012: vRES production increased by 59% while balancing energy demand dropped by 37%

More interconnection: electric or P2G

2021



2040 ("Green Europe" Scenario)

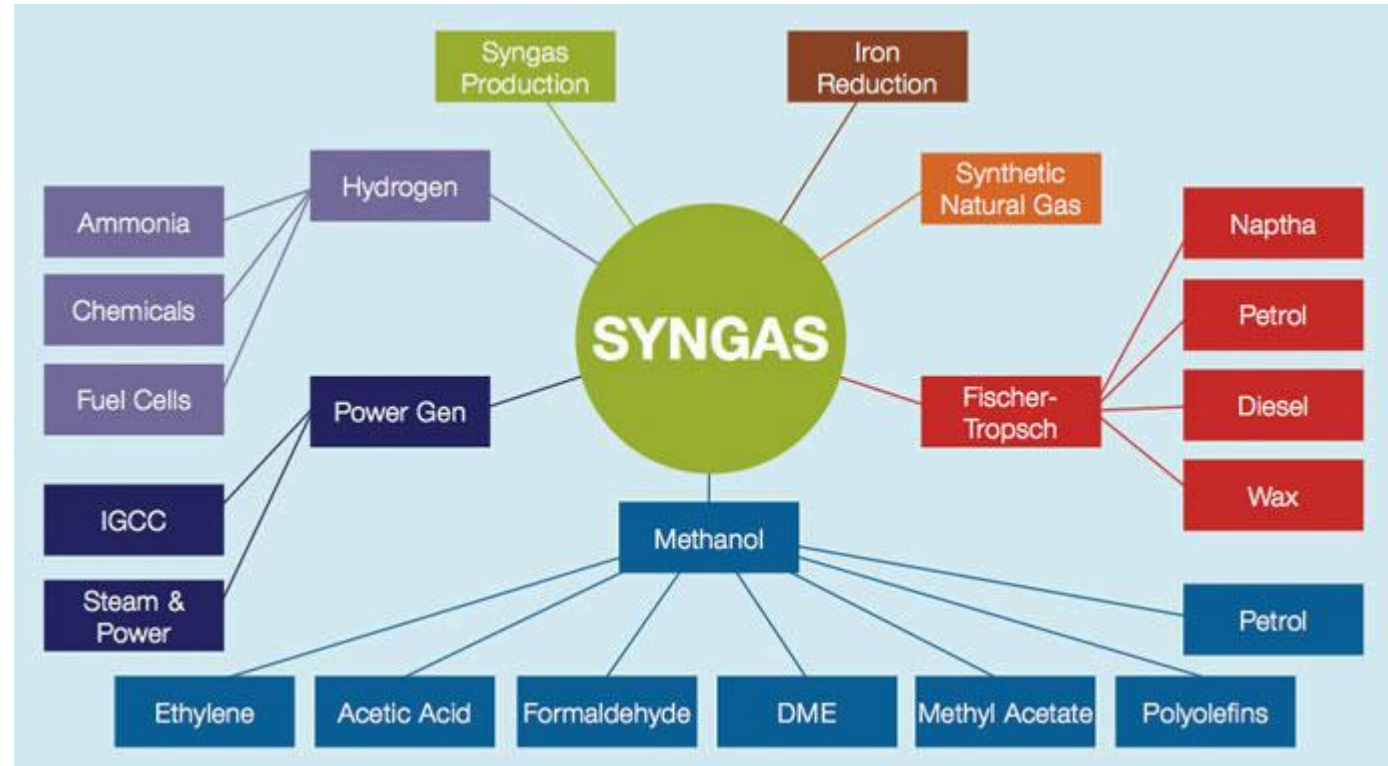


Meanwhile... 1,200 MW cable ~ 1 bcmy gas pipeline

Source: [Ember](#)

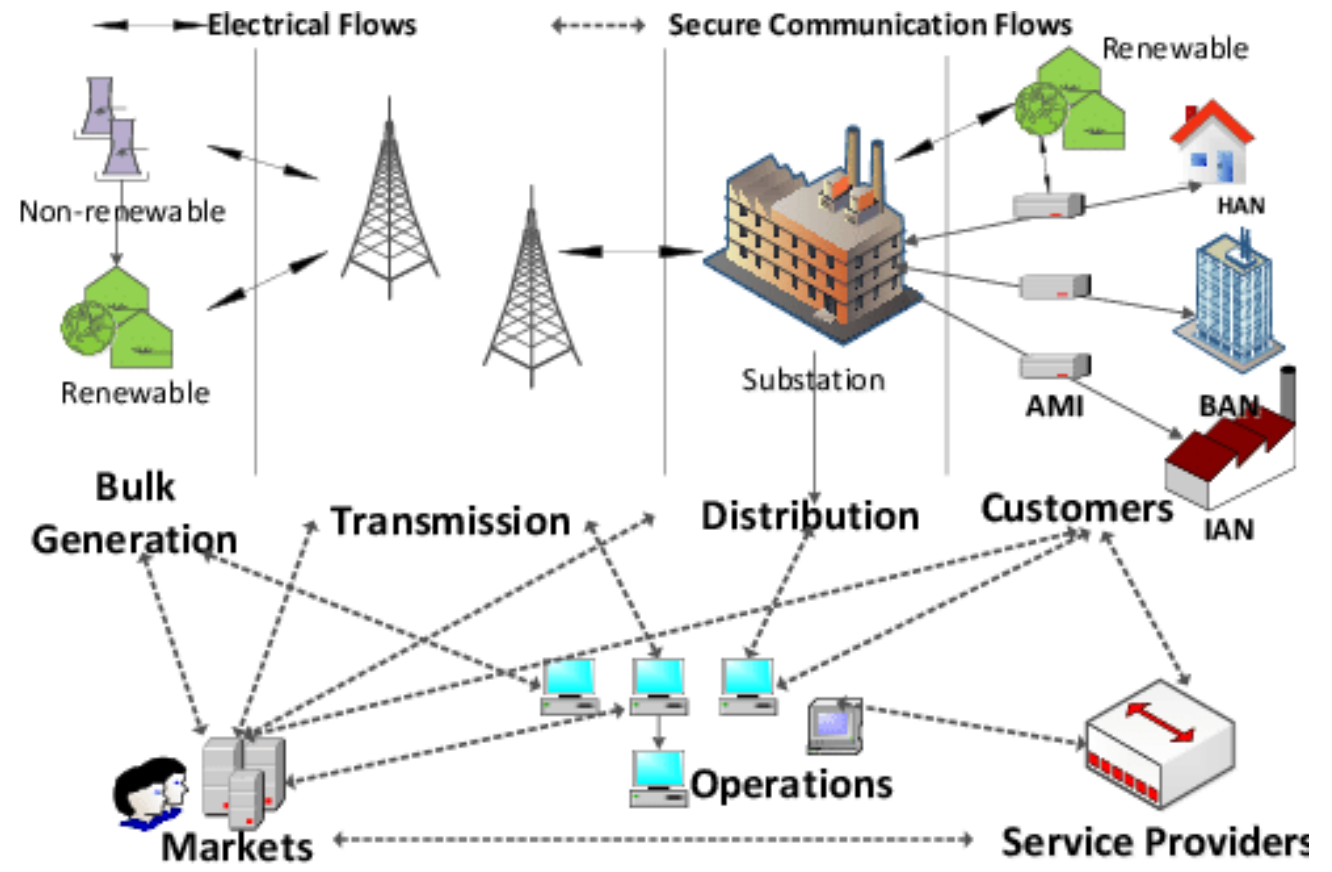
Sector coupling (electrification, P2X)

- Transport
- Residential heating
- Industrial heating



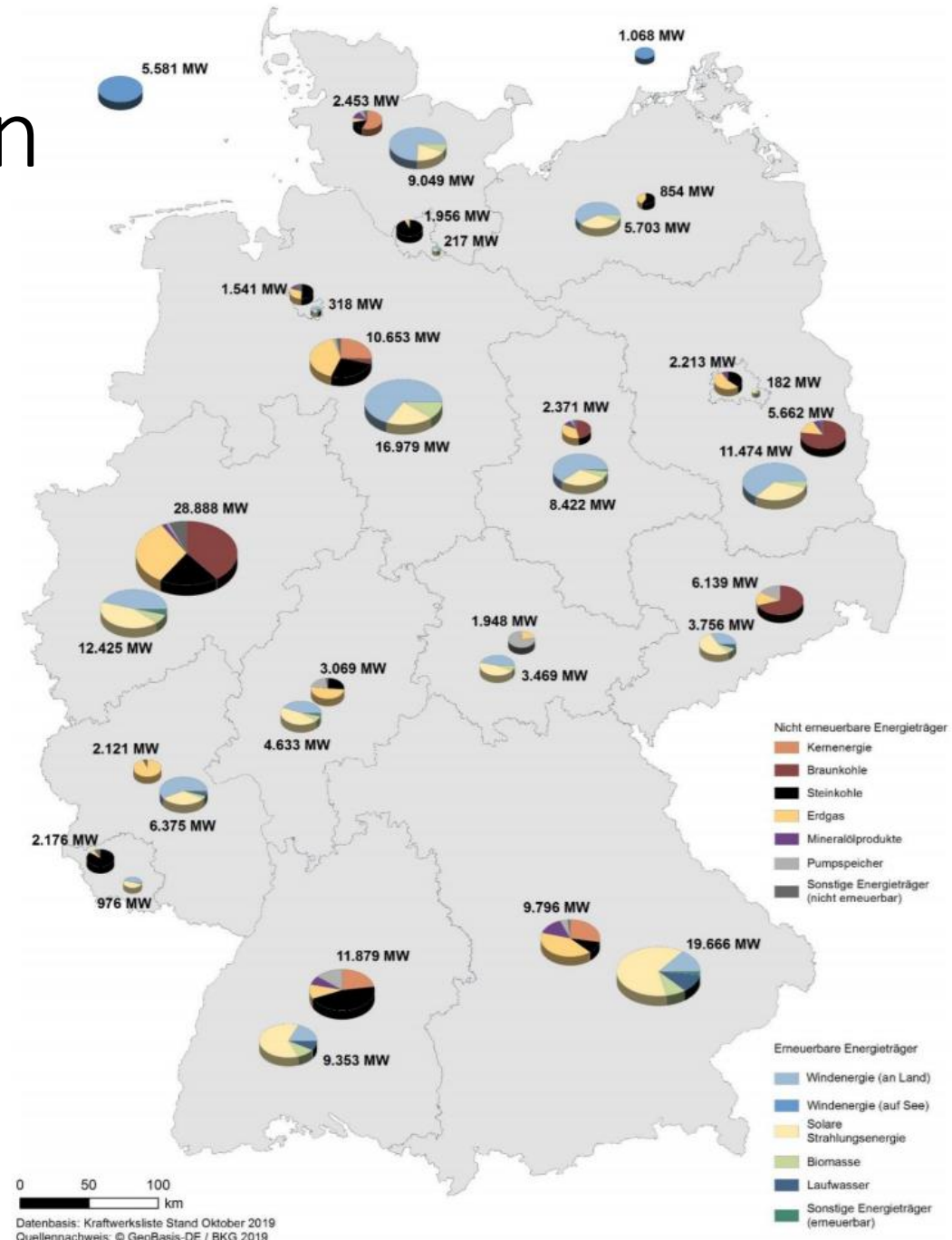
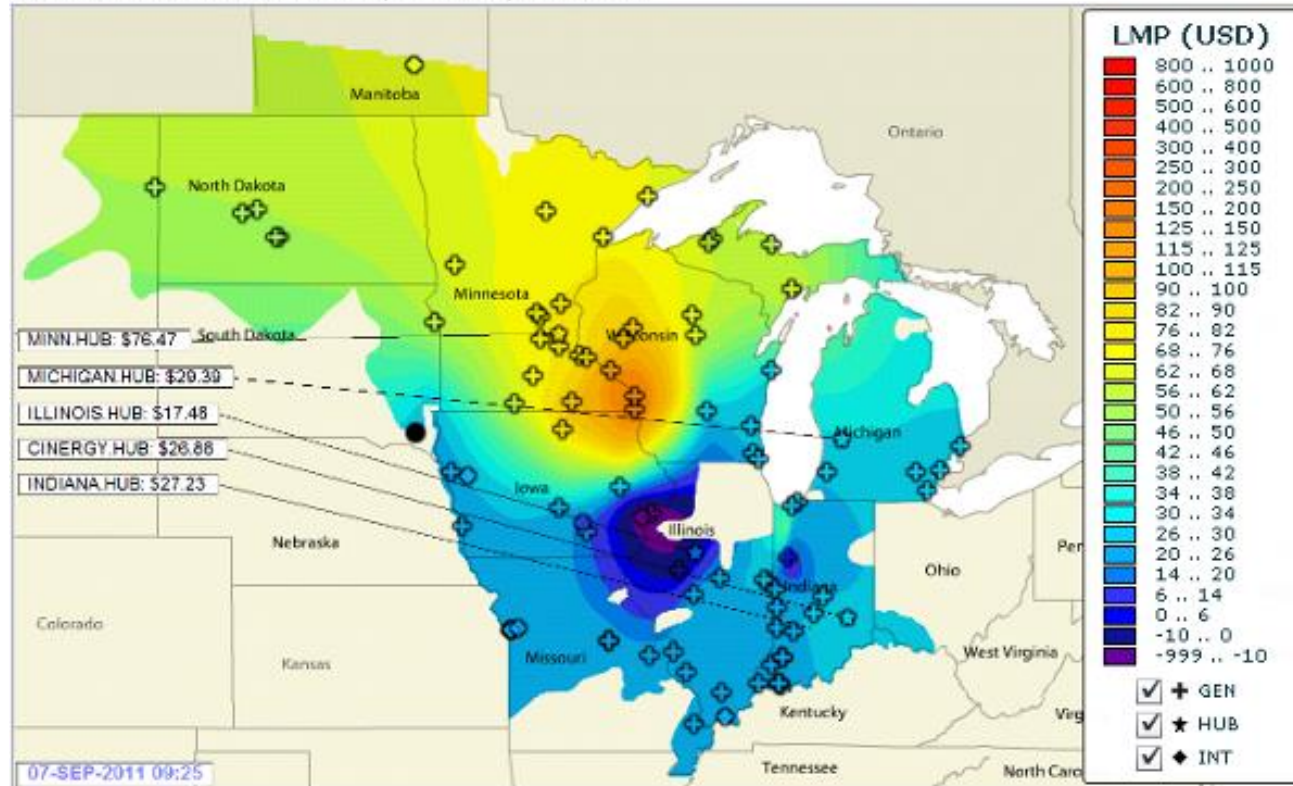
Grid upgrades

- Increased physical capacity
- Increased regulatory capacity (congestion management rules)
- TS-DS interaction
- Smart grids



Change in the market design

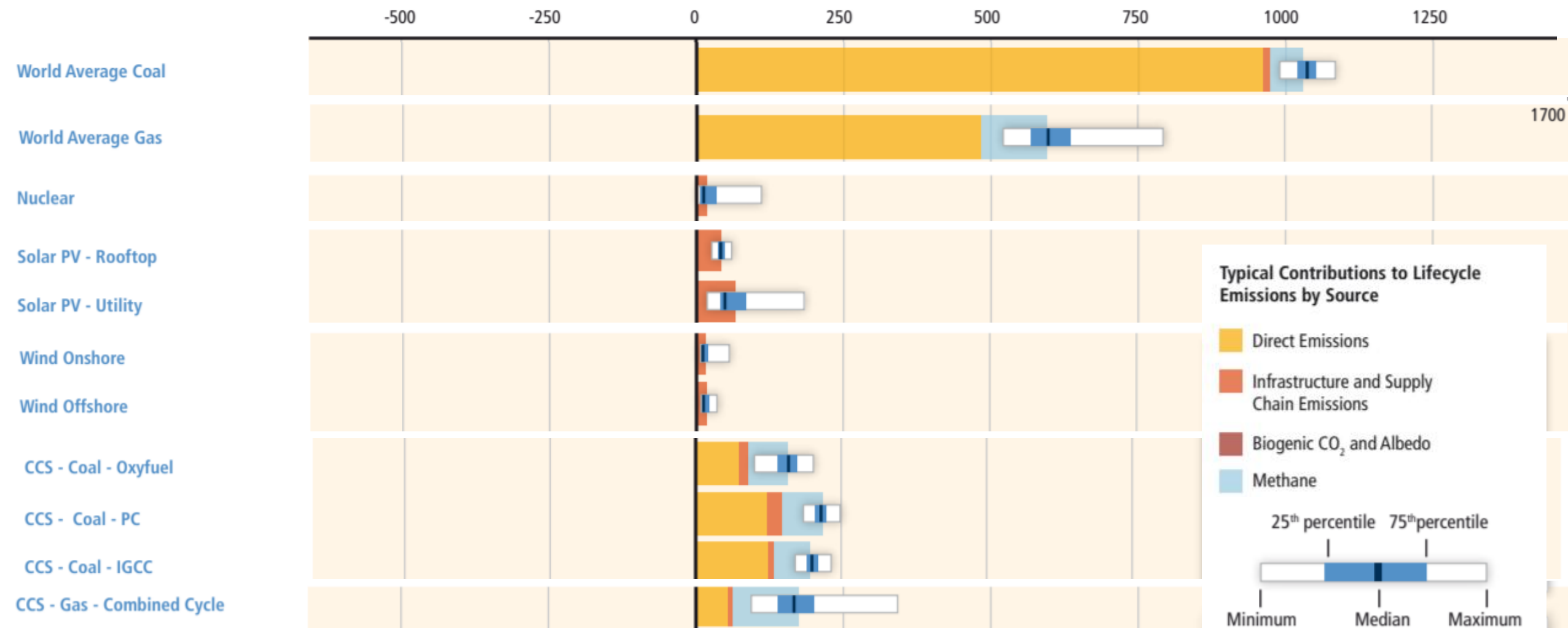
Midwest ISO real-time LMP, 9/7/2011, 9:25 a.m.



Deploy flexible conventional technologies

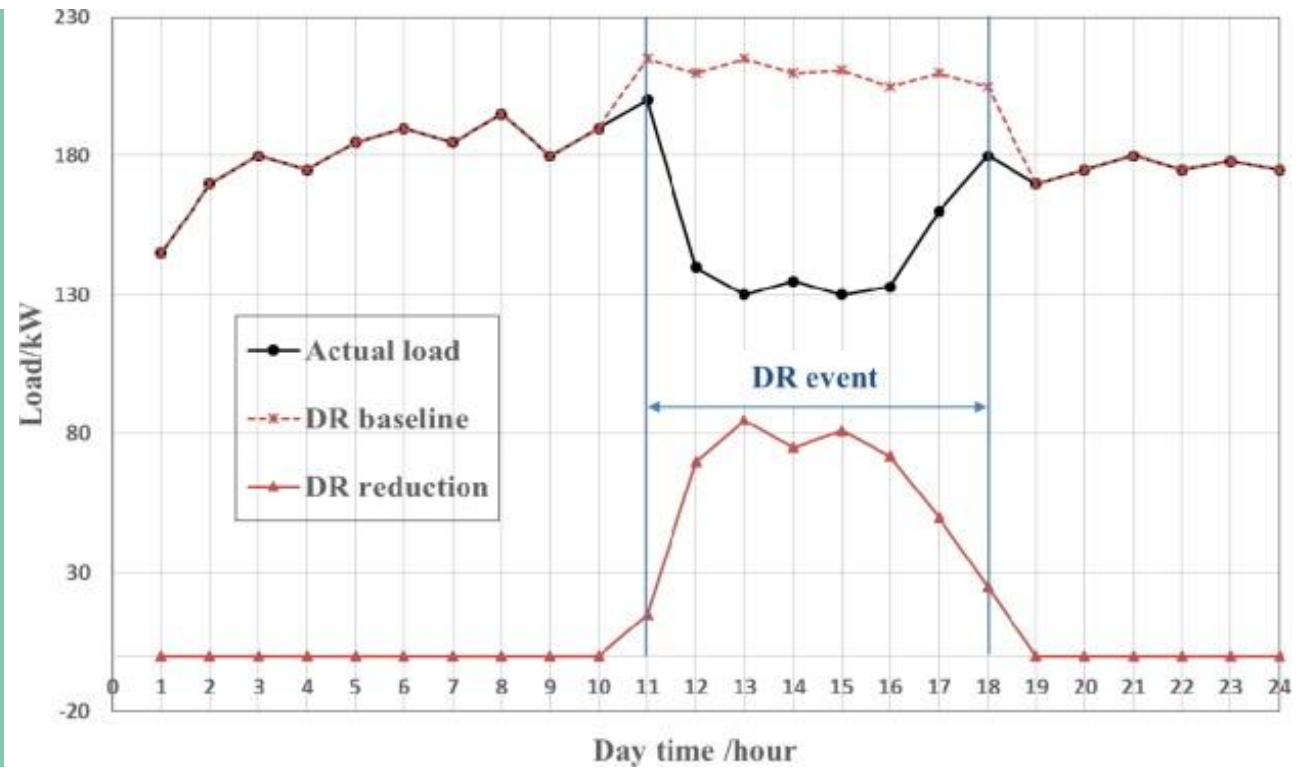
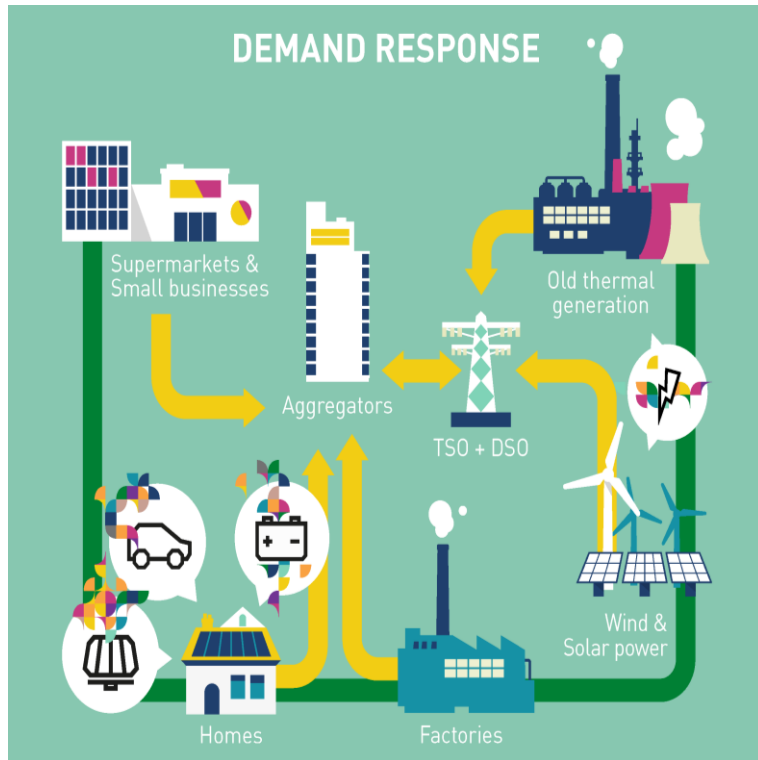
Technology	Minimum power (% of rated power)	Ramp rate (% of rated power per minute)	Hot start-up time (h)
Nuclear	50%	2%	24
Coal	30%	6%	3
Natural gas – CCGT	30%	8%	2
Natural gas – OCGT	20%	20%	0.16

Carbon intensity (gCO₂ eq/kWh)

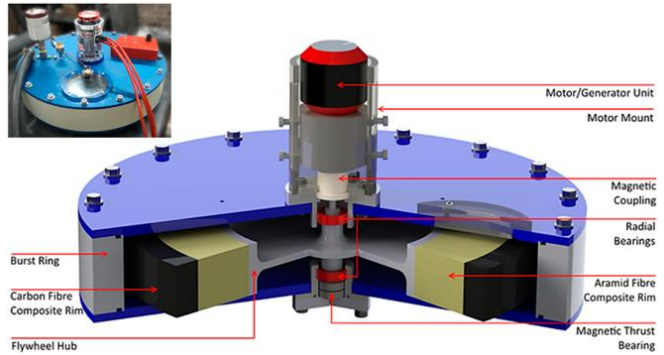
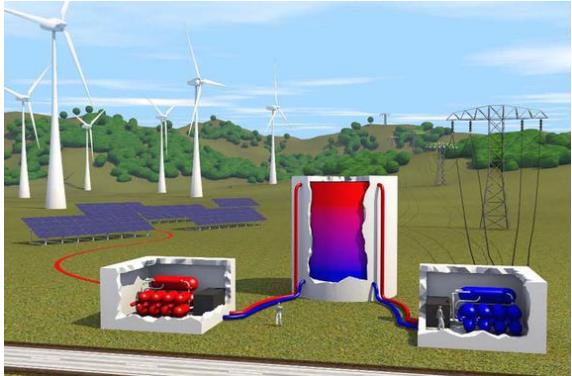


Source: IPCC 2018, p. 537 (https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter7.pdf)

Make demand flexible (demand response)



Storage

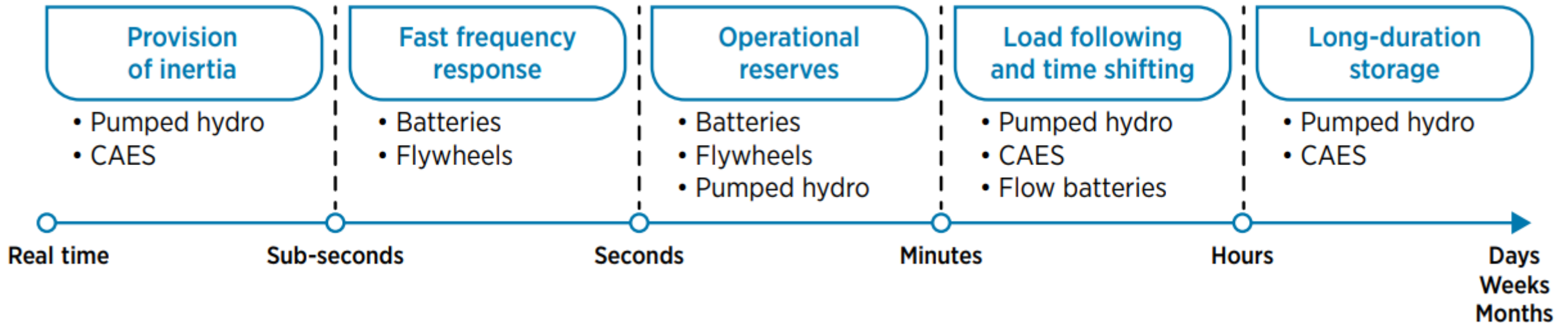


Storage

- Variety of tech: pumped hydro, battery, flow battery, capacitor, flywheel, hydrogen, compressed air, gravitational
- What we look at:
 - Power and capacity (MW and MWh)
 - Levelized costs of storage (€/MWh)
 - Operating costs
 - Round-trip efficiency
 - Construction time
 - Cycle life (cycles before capacity falls below 80%)
 - Space requirements and weight (power or energy per unit of mass or volume)
 - Depth of discharge
 - Level of technology maturity

Storage

- Variety of tech: pumped hydro, battery, flow battery, capacitor, flywheel, hydrogen, compressed air, gravitational



Storage

		Description	Use Cases ⁽¹⁾					
			Wholesale	Transmission & Distribution	Wholesale (PV + S)	Commercial (Standalone)	Commercial (PV + S)	Residential (PV + S)
Wholesale	Demand Response—Wholesale	<ul style="list-style-type: none"> Manages high wholesale price or emergency conditions on the grid by calling on users to reduce or shift electricity demand 				✓	✓	✓
	Energy Arbitrage	<ul style="list-style-type: none"> Storage of inexpensive electricity to sell later at higher prices (only evaluated in the context of a wholesale market) 	✓	✓	✓			
	Frequency Regulation	<ul style="list-style-type: none"> Provides immediate (four-second) power to maintain generation-load balance and prevent frequency fluctuations 	✓	✓	✓	✓	✓	
	Resource Adequacy	<ul style="list-style-type: none"> Provides capacity to meet generation requirements at peak loading 	✓	✓	✓	✓	✓	
	Spinning/Non-Spinning Reserves	<ul style="list-style-type: none"> Maintains electricity output during unexpected contingency events (e.g., outages) immediately (spinning reserve) or within a short period of time (non-spinning reserve) 	✓	✓	✓	✓	✓	
Utility	Distribution Deferral	<ul style="list-style-type: none"> Provides extra capacity to meet projected load growth for the purpose of delaying, reducing or avoiding distribution system investment 		✓				
	Transmission Deferral	<ul style="list-style-type: none"> Provides extra capacity to meet projected load growth for the purpose of delaying, reducing or avoiding transmission system investment 		✓				
	Demand Response—Utility	<ul style="list-style-type: none"> Manages high wholesale price or emergency conditions on the grid by calling on users to reduce or shift electricity demand 				✓	✓	✓
Customer	Bill Management	<ul style="list-style-type: none"> Allows reduction of demand charge using battery discharge and the daily storage of electricity for use when time of use rates are highest 				✓	✓	✓
	Backup Power	<ul style="list-style-type: none"> Provides backup power for use by Residential and Commercial customers during grid outages 				✓	✓	✓