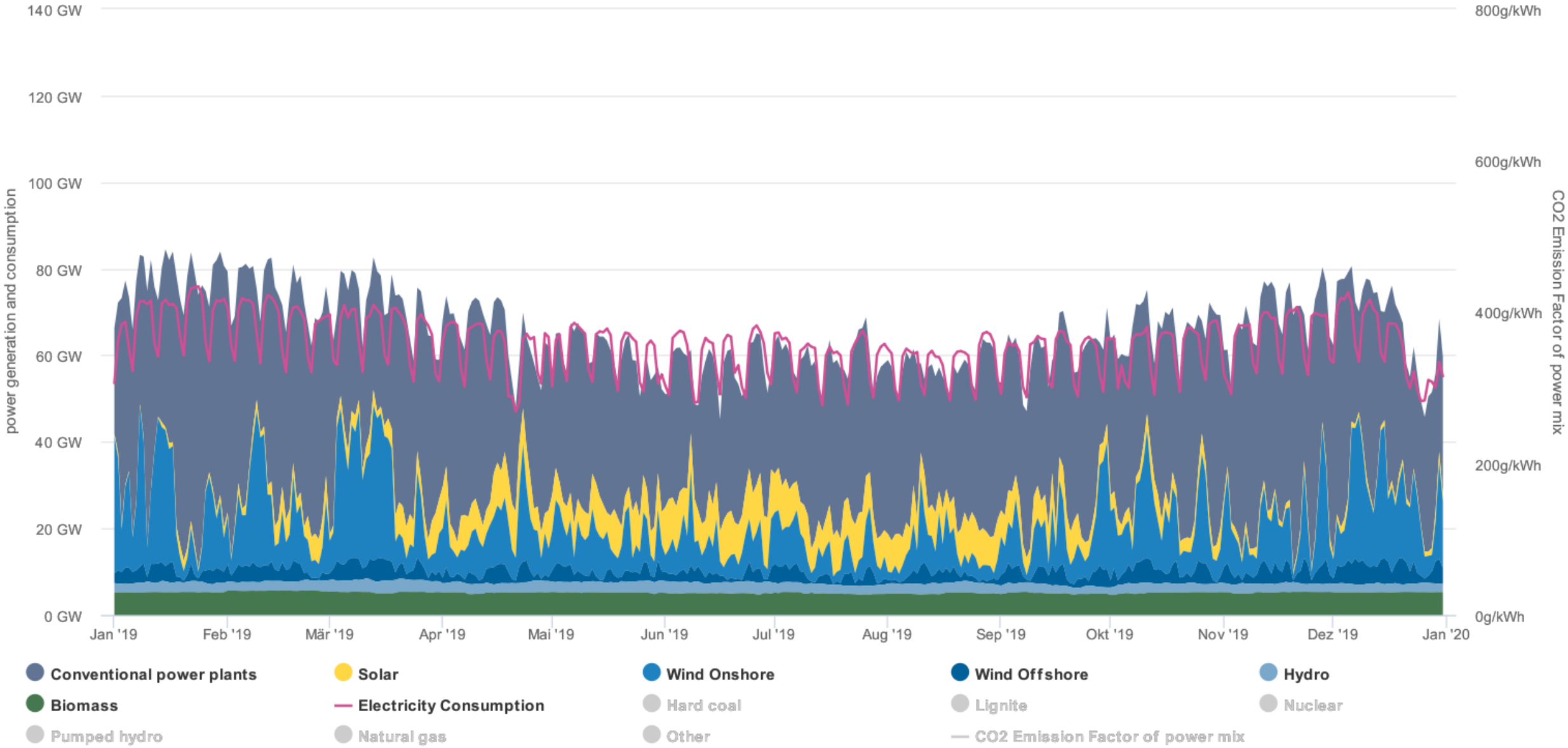
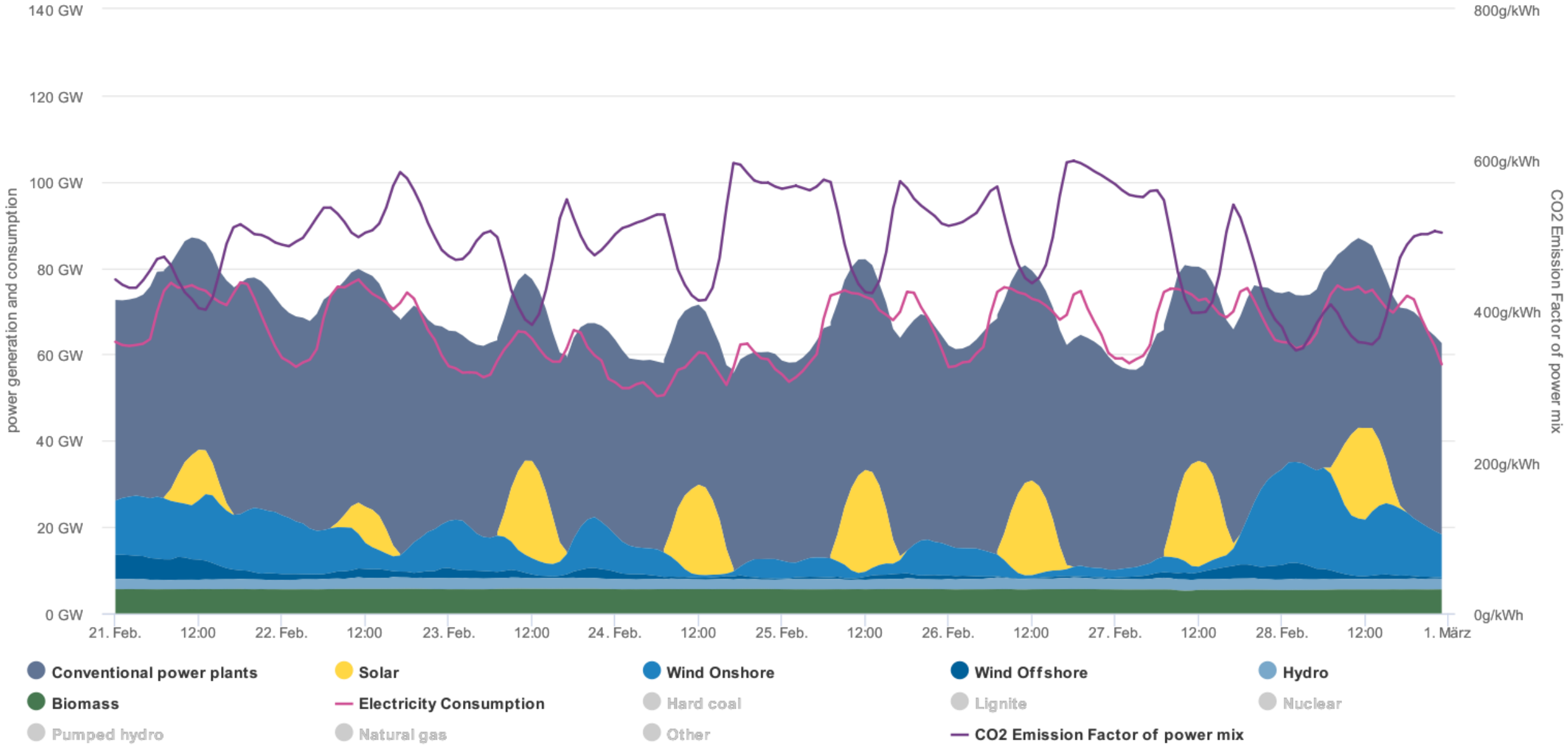
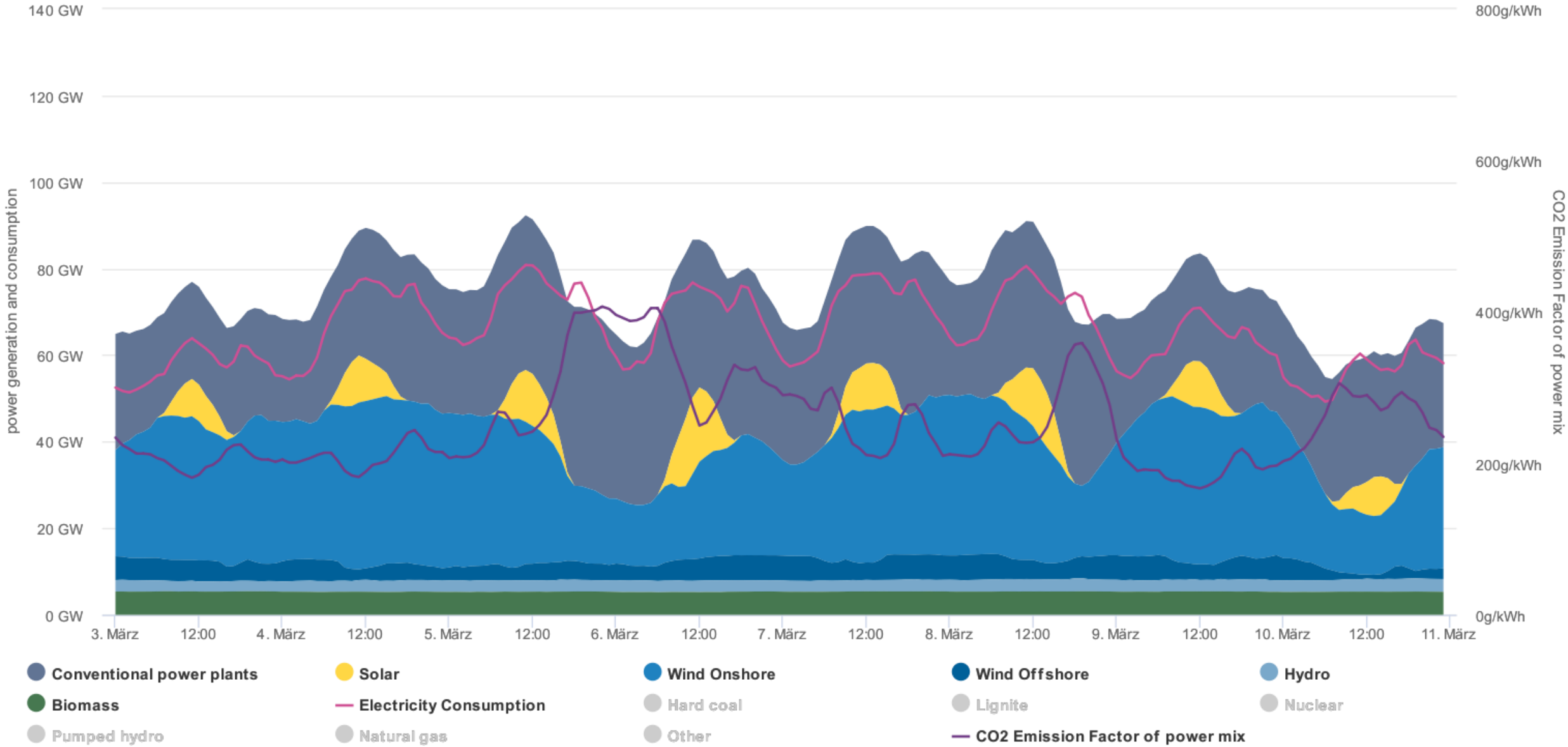
Renewable energy and grids



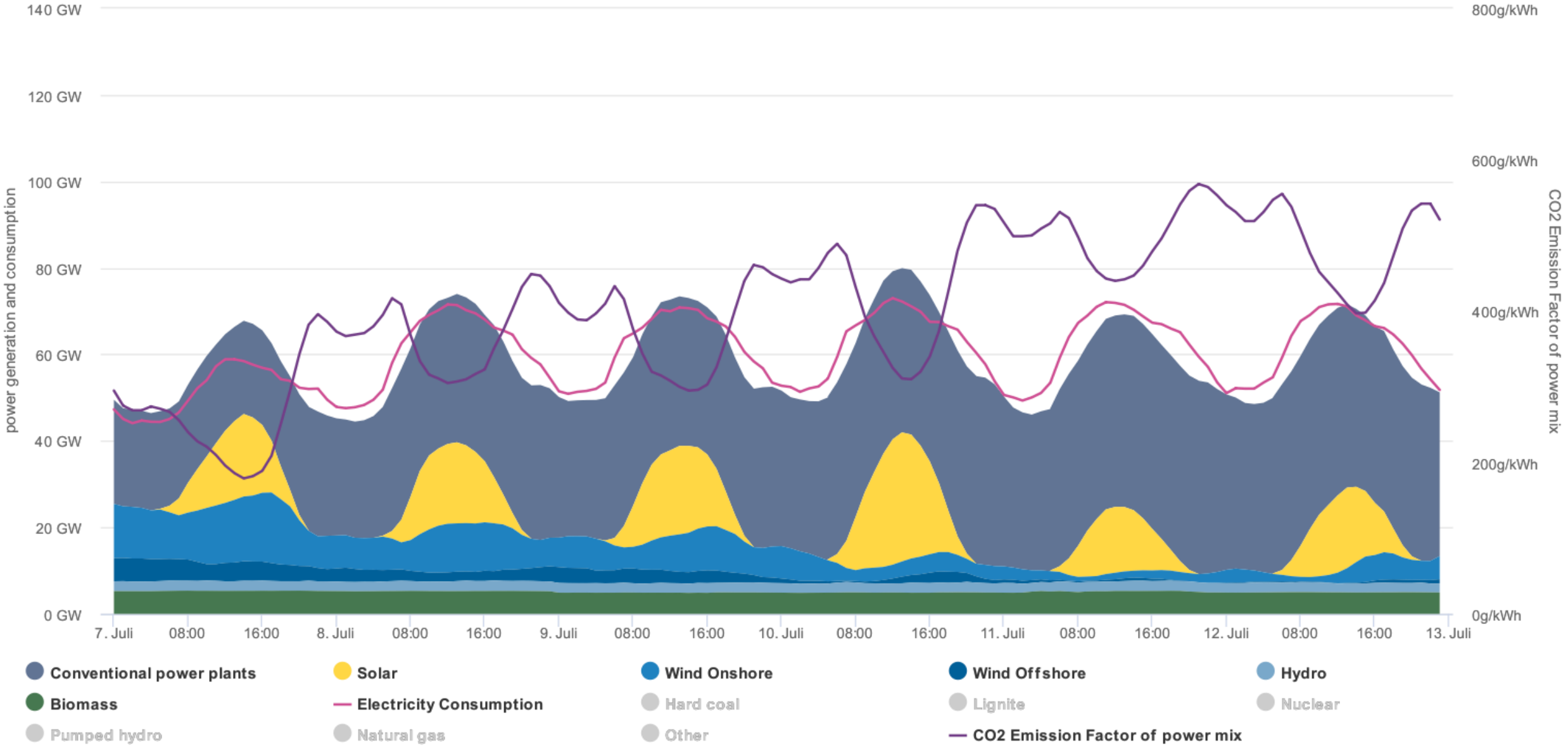
Electricity generation in Germany by source (2019): RES at ~40% of consumption


140 GW
120 GW
100 GW
80 GW
60 GW
40 GW
20 GW
0 GW
power generation and consumption
800g/kWh
600g/kWh
400g/kWh
200g/kWh
0g/kWh
CO2 Emission Factor of power mix
21. Feb.
12:00
22. Feb.
12:00
23. Feb.
12:00
24. Feb.
12:00
25. Feb.
12:00
26. Feb.
12:00
27. Feb.
12:00
28. Feb.
12:00
1. März
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

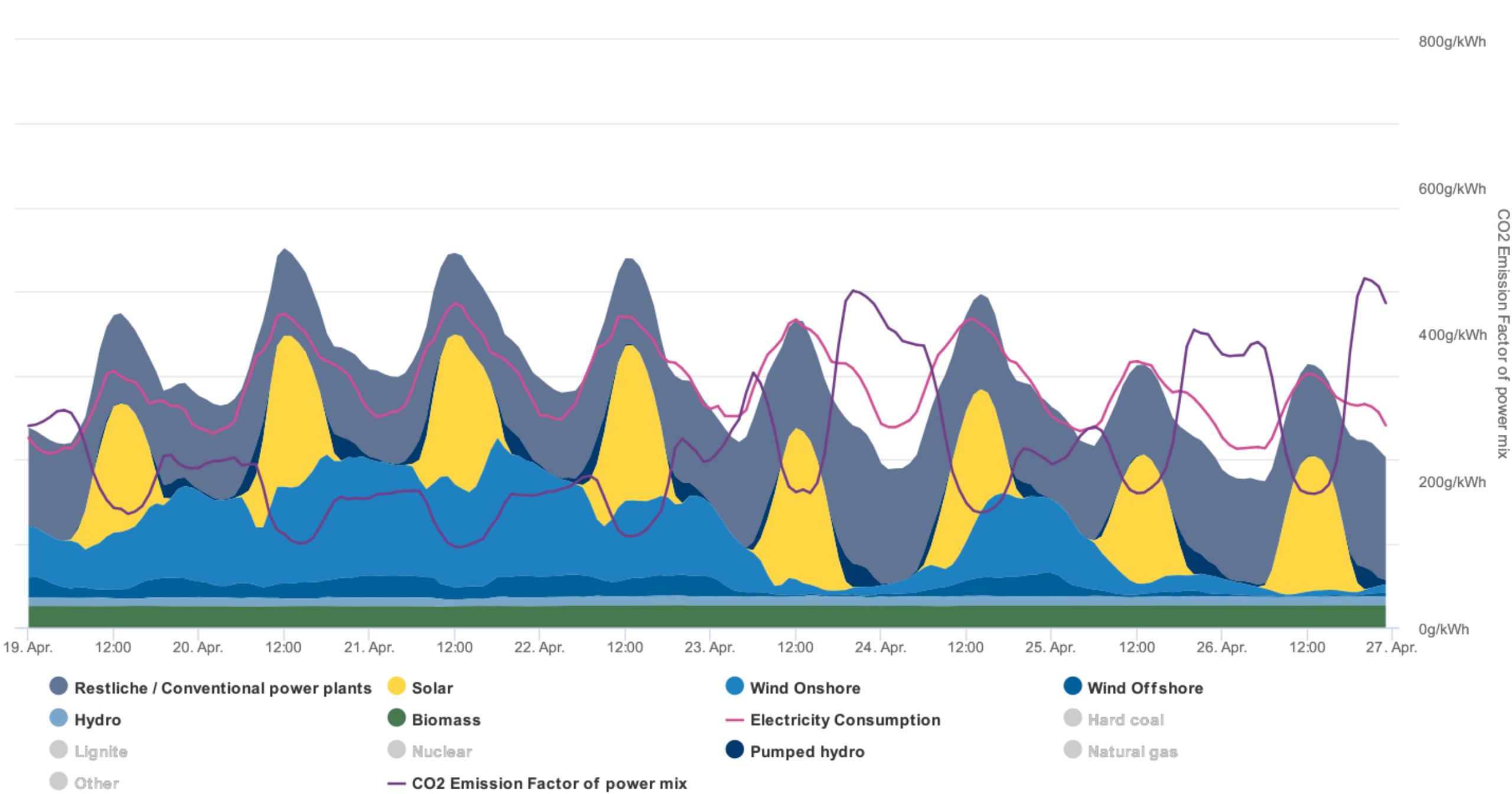
2019


140 GW
120 GW
100 GW
80 GW
60 GW
40 GW
20 GW
0 GW
power generation and consumption
800g/kWh
600g/kWh
400g/kWh
200g/kWh
0g/kWh
CO2 Emission Factor of power mix
3. März
12:00
4. März
12:00
5. März
12:00
6. März
12:00
7. März
12:00
8. März
12:00
9. März
12:00
10. März
12:00
11. März
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

2019


140 GW
120 GW
100 GW
80 GW
60 GW
40 GW
20 GW
0 GW
power generation and consumption
800g/kWh
600g/kWh
400g/kWh
200g/kWh
0g/kWh
CO2 Emission Factor of power mix
7. Juli
08:00
16:00
8. Juli
08:00
16:00
9. Juli
08:00
16:00
10. Juli
08:00
16:00
11. Juli
08:00
16:00
12. Juli
08:00
16:00
13. Juli
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

2019

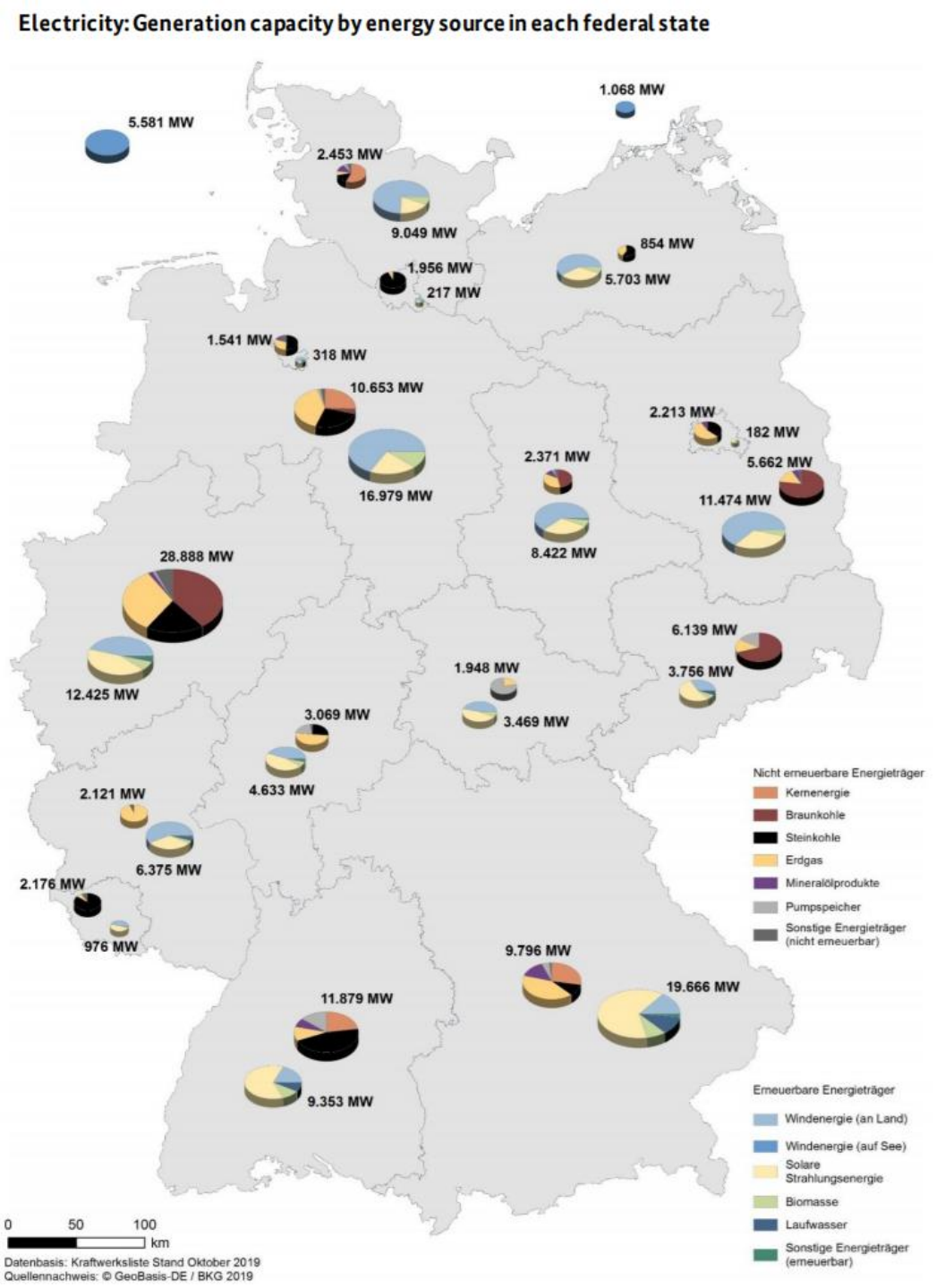

800g/kWh
600g/kWh
400g/kWh
200g/kWh
0g/kWh
CO2 Emission Factor of power mix
19. Apr.
12:00
20. Apr.
12:00
21. Apr.
12:00
22. Apr.
12:00
23. Apr.
12:00
24. Apr.
12:00
25. Apr.
12:00
26. Apr.
12:00
27. Apr.
Restliche / Conventional power plants
Solar
Wind Onshore
Wind Offshore
Hydro
Biomass
Electricity Consumption
Hard coal
Lignite
Nuclear
Pumped hydro
Natural gas
Other
CO2 Emission Factor of power mix

2020

Challenges

- Not enough or too much power
- Congestions
- Legacy grid topography

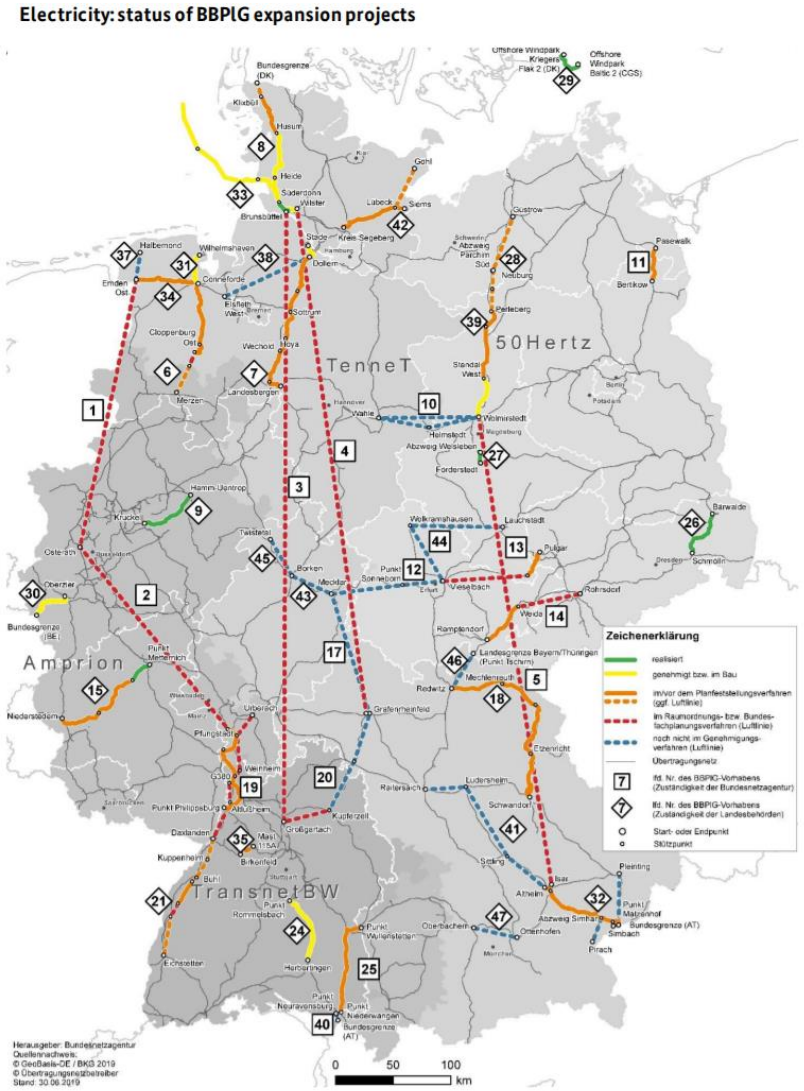
	Typical availability (load factor)
Conventional technologies (nuclear, coal, gas)	0.85
Wind onshore	0.2
Wind offshore	0.4
Solar	0.1

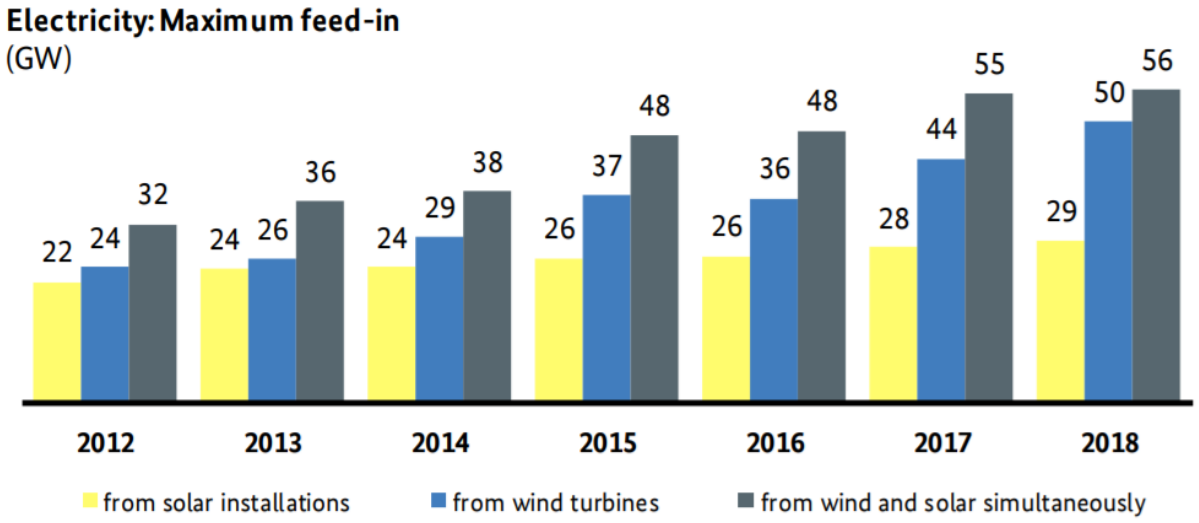


Solutions

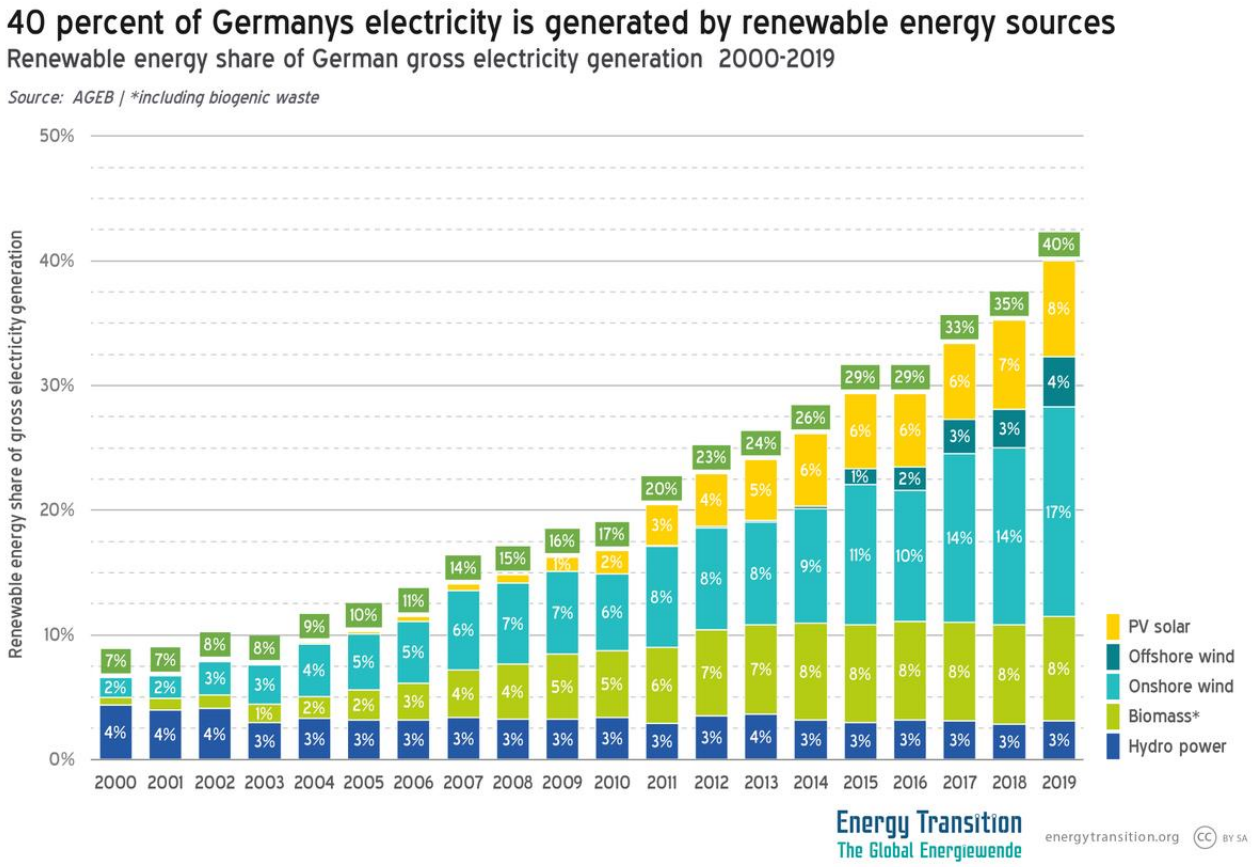
- Adjusting RES development to grid conditions
- More grids, more interconnections
- Grid upgrades
- Increasing flexibility of non-RES supply and demand
- Sector coupling
- Storage

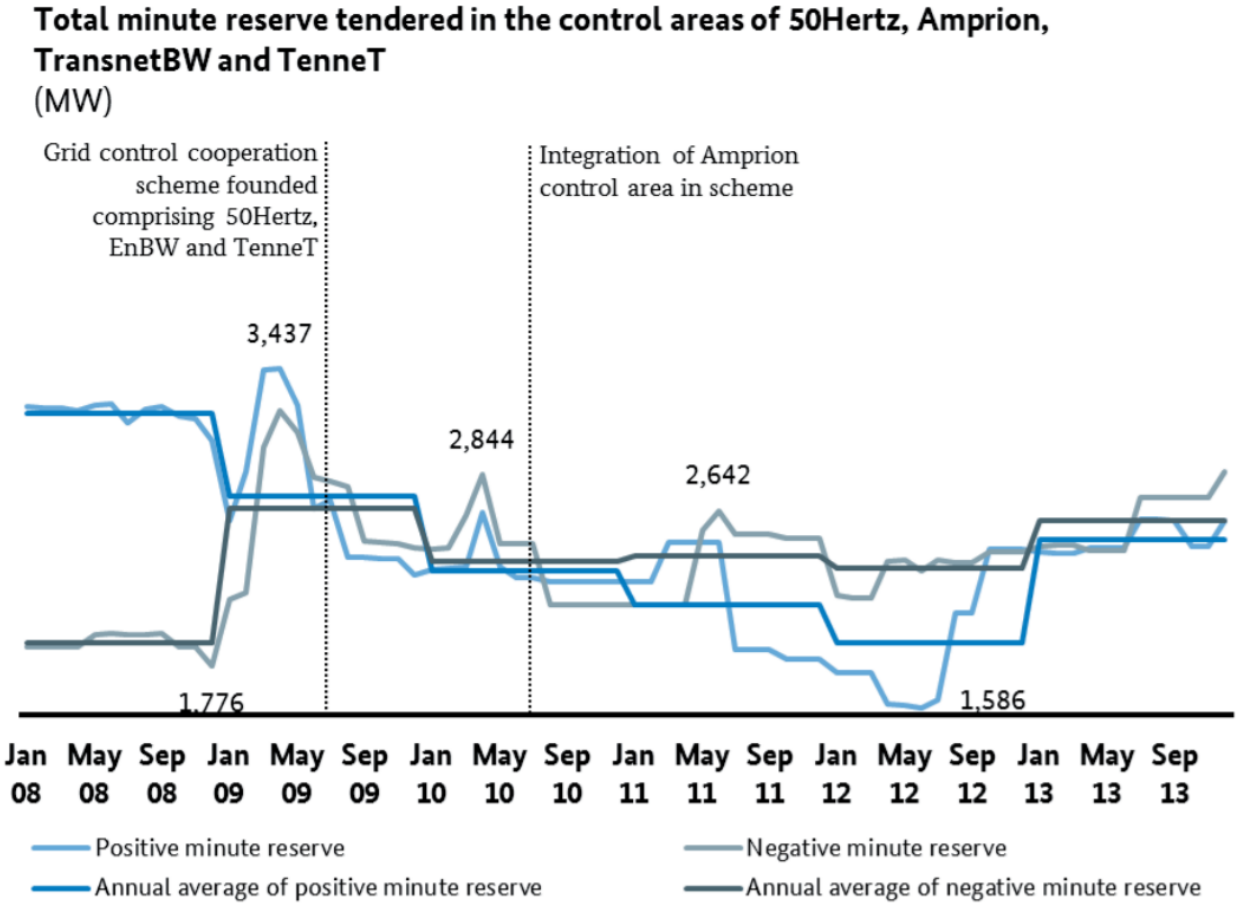
Adjusting RES: location restrictions and hybrid plants





More grids

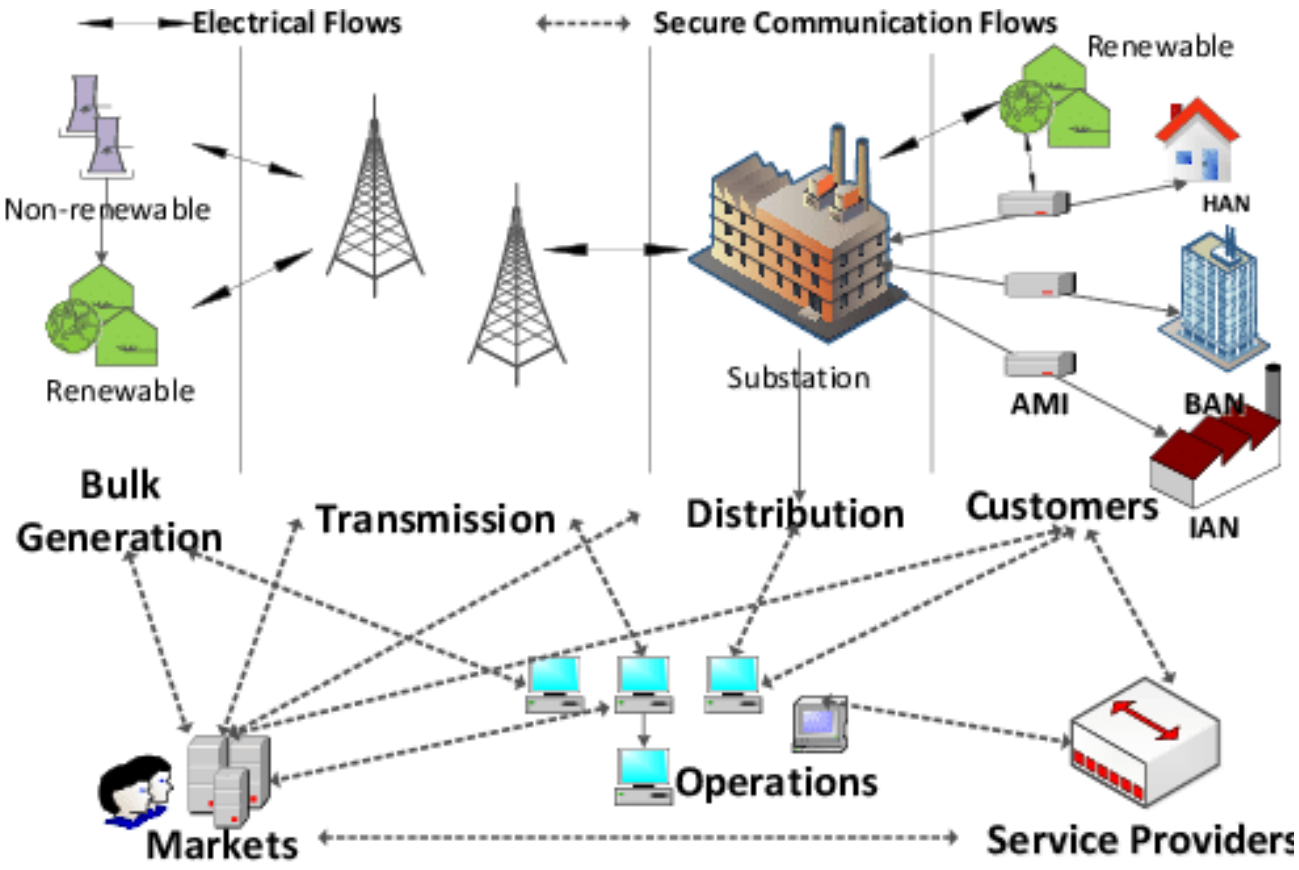




2009-2012: vRES production increased by 59% while balancing energy demand dropped by 37%

Grid upgrades

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

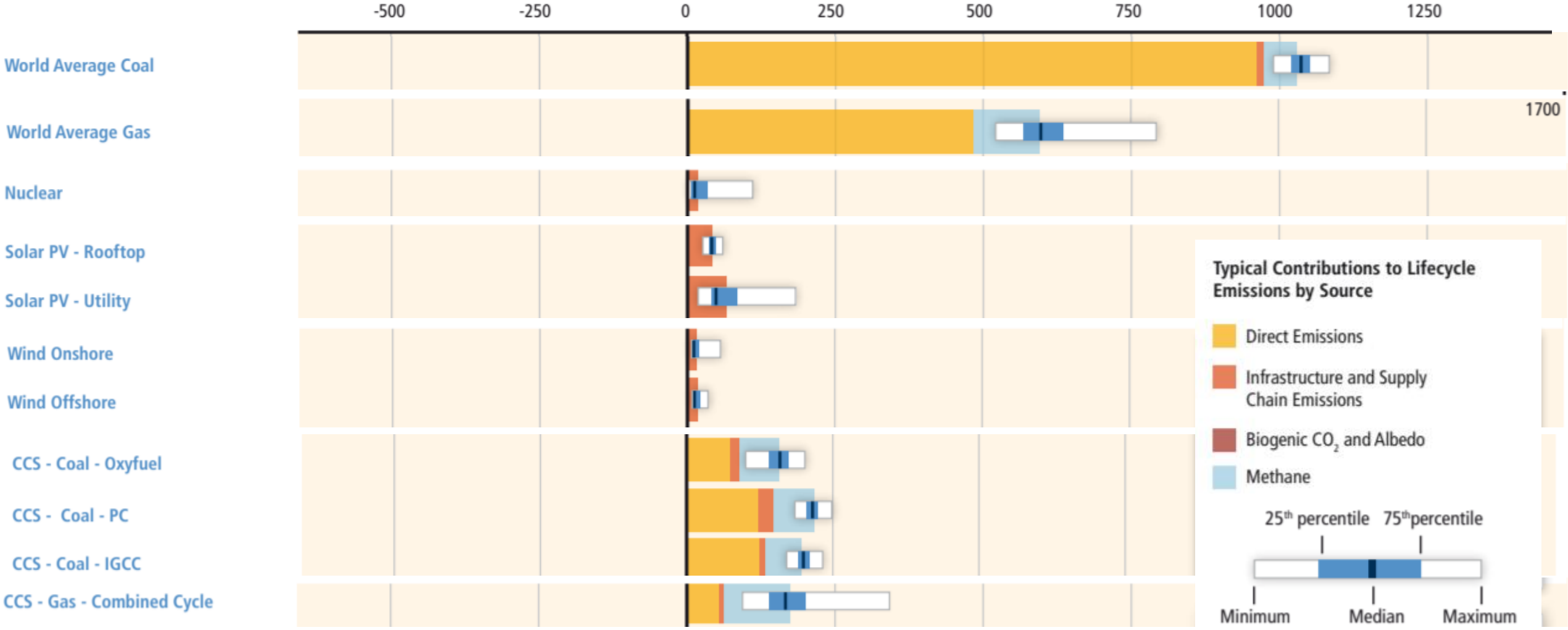


Flexibility of conventional technologies

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

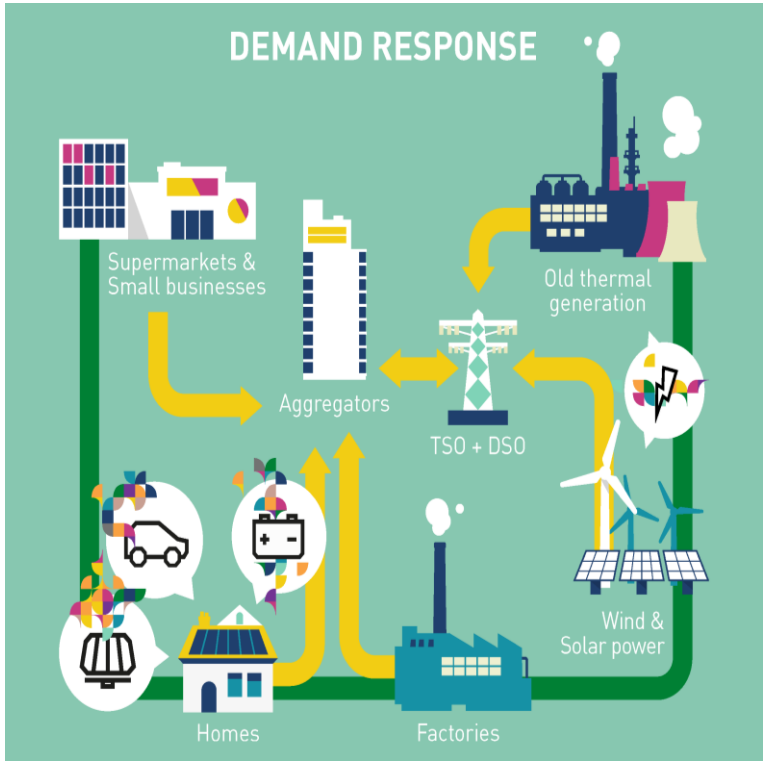
Sources: (Gagné, 2014; Gonzalez-Salazar et al., 2018)

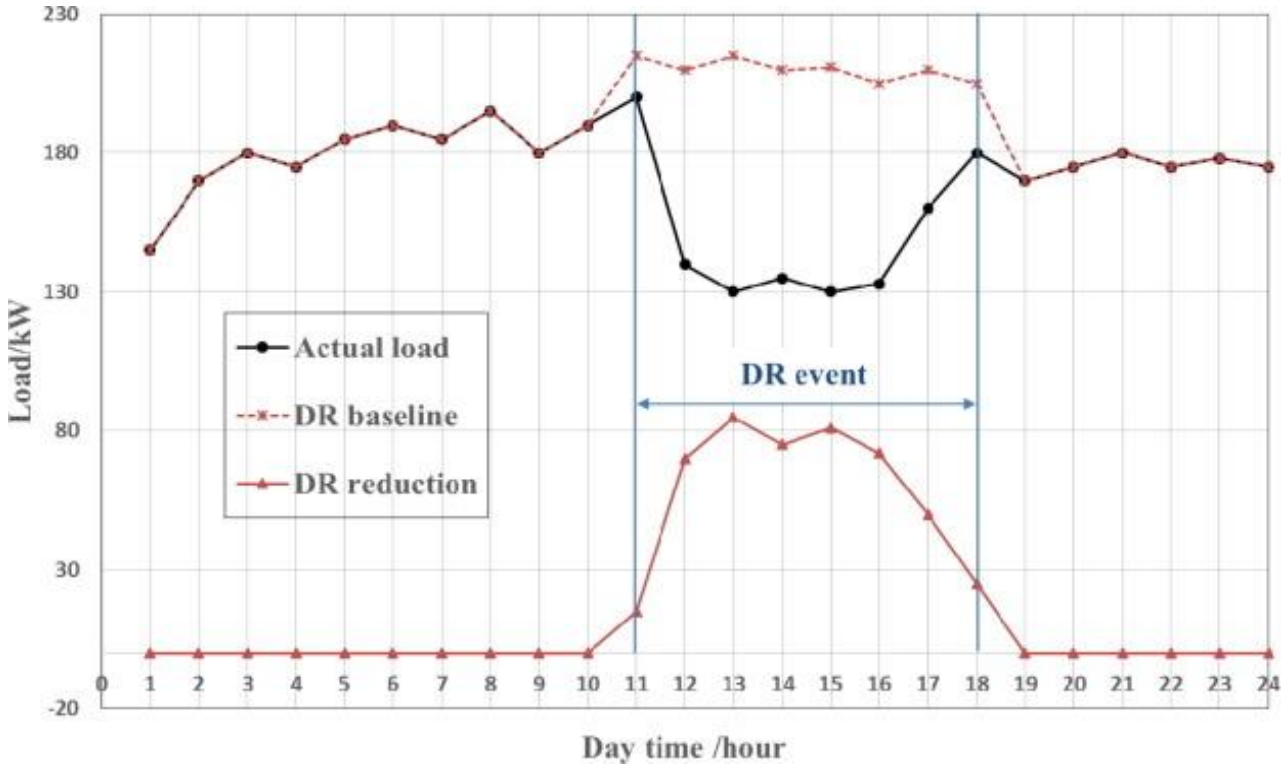
Carbon intensity (gCO2 eq/kWh)



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

Flexibility of demand (demand response)





Sector coupling (electrification)

- Transport
- Residential heating
- Industrial heating
- Long-distance energy transportation (syngas, hydrogen)

Storage

		Description	Use Cases[1]					
			Wholesale	Transmission & Distribution	Wholesale (PV + S)	Commercial (Standalone)	Commercial (PV + S)	Residential (PV + S)
Wholesale	Demand Response—Wholesale	• Manages high wholesale price or emergency conditions on the grid by calling on users to reduce or shift electricity demand				✓	✓	✓
	Energy Arbitrage	• Storage of inexpensive electricity to sell later at higher prices (only evaluated in the context of a wholesale market)	✓	✓	✓			
	Frequency Regulation	• Provides immediate (four-second) power to maintain generation-load balance and prevent frequency fluctuations	✓	✓	✓	✓	✓	
	Resource Adequacy	• Provides capacity to meet generation requirements at peak loading	✓	✓	✓	✓	✓	
	Spinning/ Non-Spinning Reserves	• 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	• Provides extra capacity to meet projected load growth for the purpose of delaying, reducing or avoiding distribution system investment		✓				
	Transmission Deferral	• Provides extra capacity to meet projected load growth for the purpose of delaying, reducing or avoiding transmission system investment		✓				
	Demand Response—Utility	• Manages high wholesale price or emergency conditions on the grid by calling on users to reduce or shift electricity demand				✓	✓	✓
Customer	Bill Management	• 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	• Provides backup power for use by Residential and Commercial customers during grid outages				✓	✓	✓

Source: Lazard and Roland Berger.

(1) Represents the universe of potential revenue streams available to the various use cases. Does not represent the use cases analyzed in the Value Snapshots.

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