"Impact of growing renewable energy generation onto thermal power plant operation in Germany"

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Motivation, Goals and Challenges
Transition to renewable energy sources

Motivation: → **Substitute the limited fossil fuels with unlimited renewable energy sources**

→ Massive reduction of the CO_2 emissions

→ **Stop the production of nuclear waste**

→ Eliminate the threat of nuclear accidents like Fukushima 2011

Goals: → **Reduce the CO_2 emissions up to 80% until 2050 in Germany**

→ **Nuclear phase-out planned until the end of 2022**

→ **Increase the total fraction of all renewables sources up to 45% of the electrical energy demand until 2025 and up to 80% until 2050**

Challenges: → **Use as much renewable power as possible <u>directly when it is produced</u>**

→ To achieve the highest efficiency of the potentials

→ Due to the high losses of storage systems store only as much as necessary

→ Problem of power transmission because of limitations of the transmission lines etc.

→ **Problem of balancing power of intermittent sources by thermal power plants**

→ Guarantee the safety of supply

Motivation, Goals and Challenges
Transition to renewable energy sources

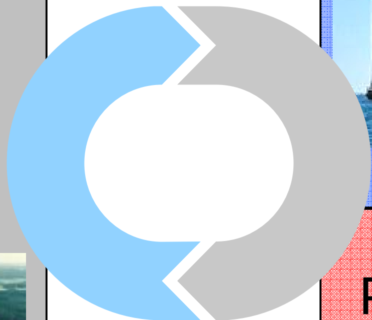
<u>controlled power production</u>

of fossil and (nuclear) power plants

with limited fuels, nuclear waste & high CO_2 emissions

fuel: lignite, hard coal, natural gas, Uranium

Power plant operation depends on intermittent feedin



Integration of intermittent feedin depends on flexibility of conv. Power plants

<u>uncontrolled power production</u>

of wind and photovoltaic systems

with intermittent feed-in (not reliable)

Wind turbines

<u>Situation 2014:</u>

34 GW

<u>expected 2020:</u>

50+ GW

Photovoltaic systems

<u>Situation 2014:</u>

36 GW

<u>expected 2020:</u>

50+ GW

<u>Goal:</u>
- **massive reduction of CO_2 emissions**
- **nuclear phase-out until 2022**

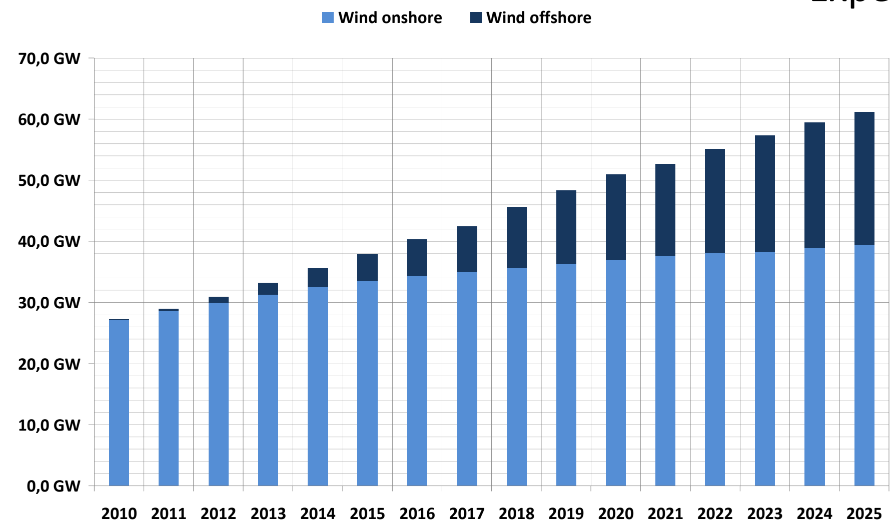
<u>Expected installed capacity until 2020:</u>

>100 GW (>33% of annual electricity demand)

Expected growth of installed capacities of German wind turbines & photovoltaic systems

Peak load in Germany: app. 80 GW (expected to remain constant)

Expected installed power until 2025

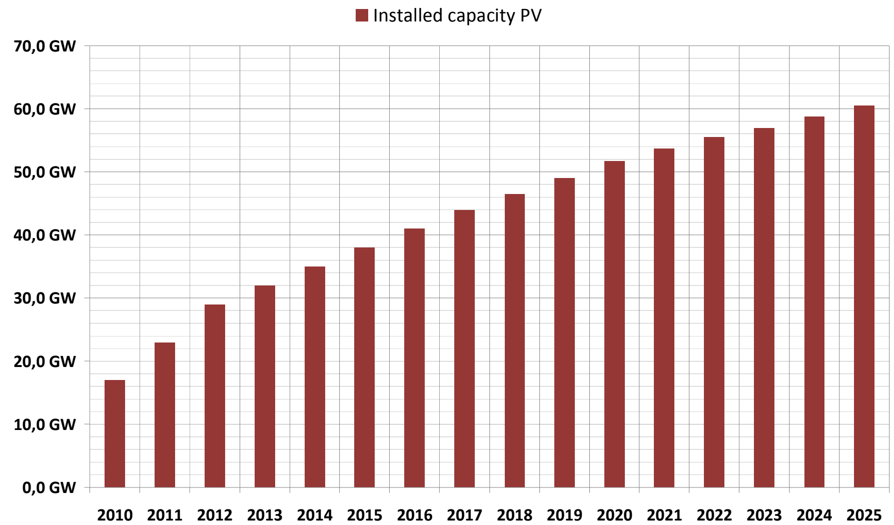


<u>Installed 2020:</u>

Wind PV

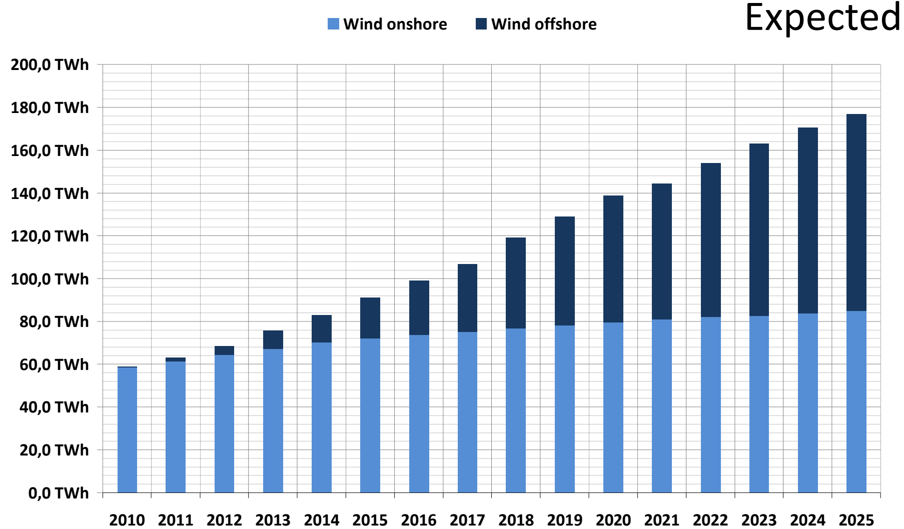
51,0 GW + 51,7 GW

Σ 102,7 GW



Consumption in Germany 2011: app. 600 TWh (expected to remain constant)

Expected energy to be “harvested” until 2025

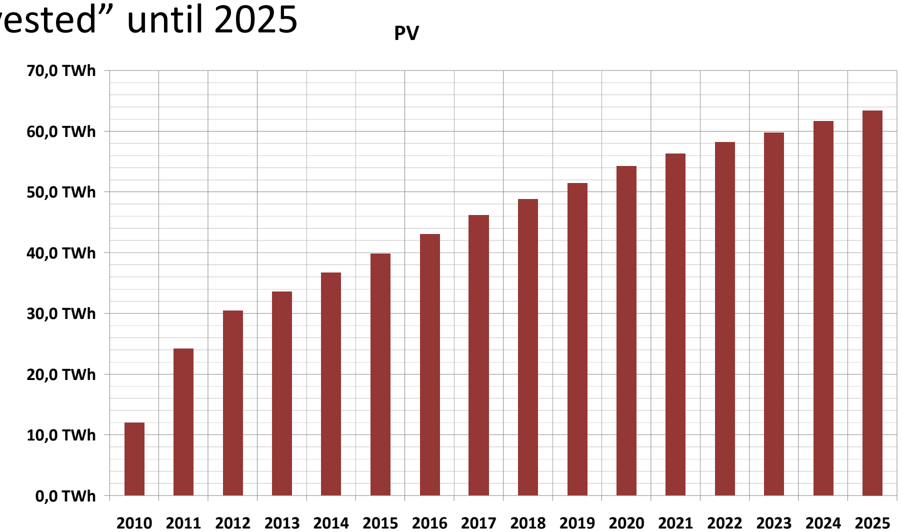


<u>Annual harvest 2020:</u>

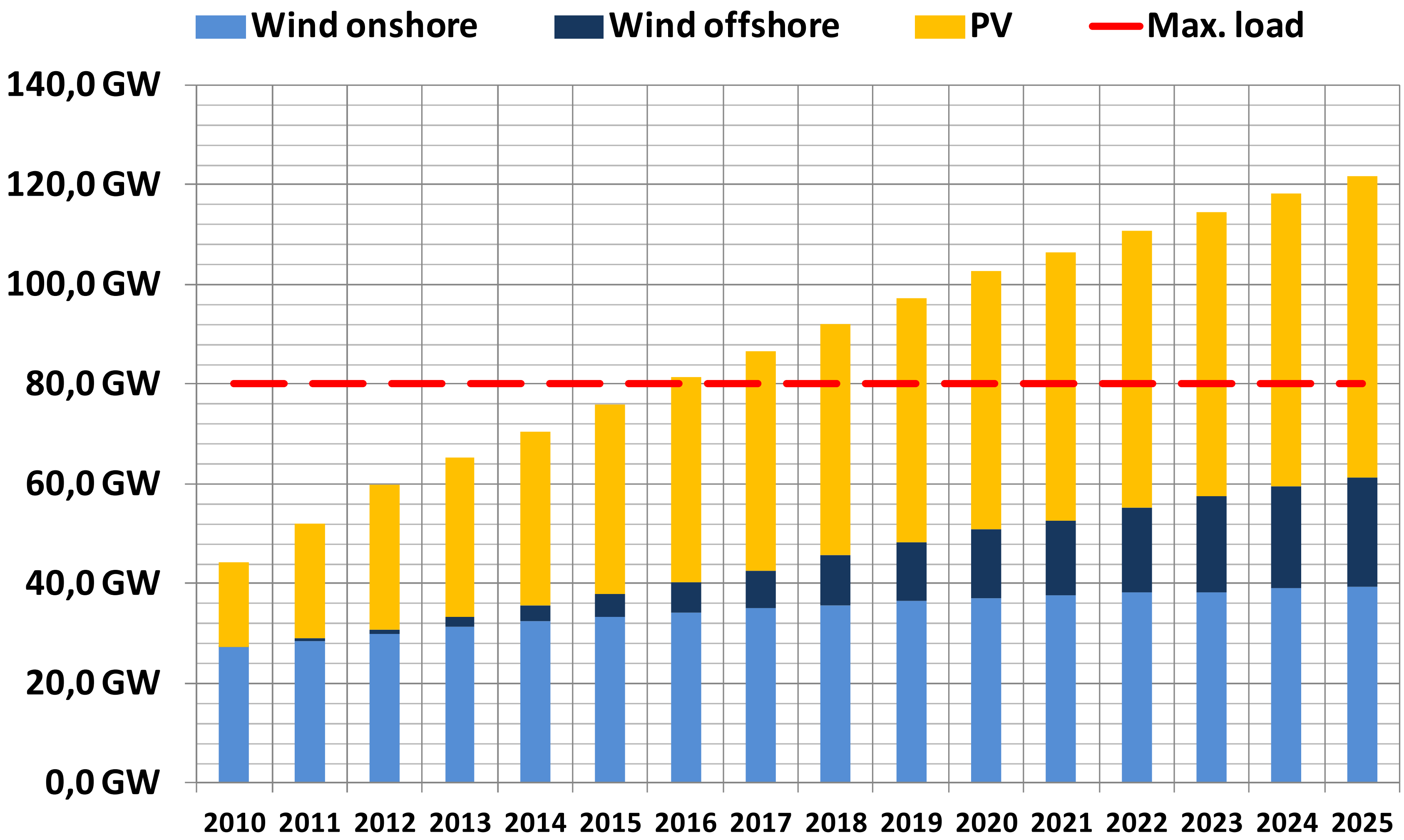
Wind PV

138,8 TWh + 54,2 TWh

Σ 193 TWh



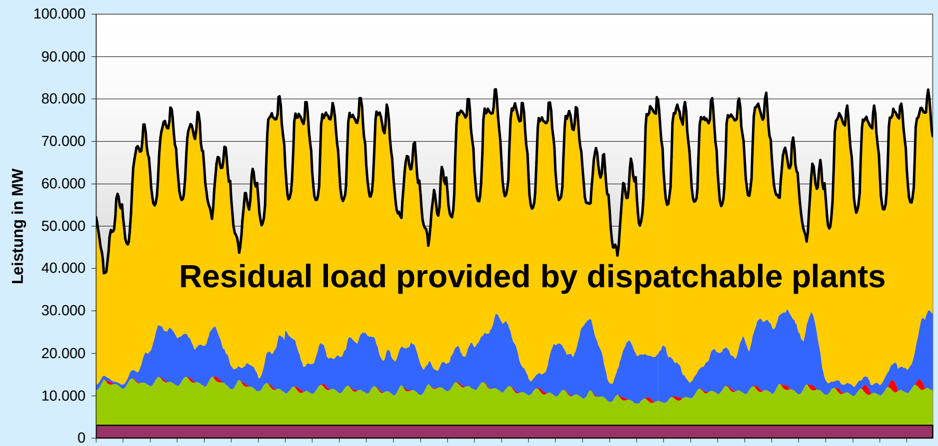
Capacities of renewable energy from wind and solar systems expected until 2025 in Germany

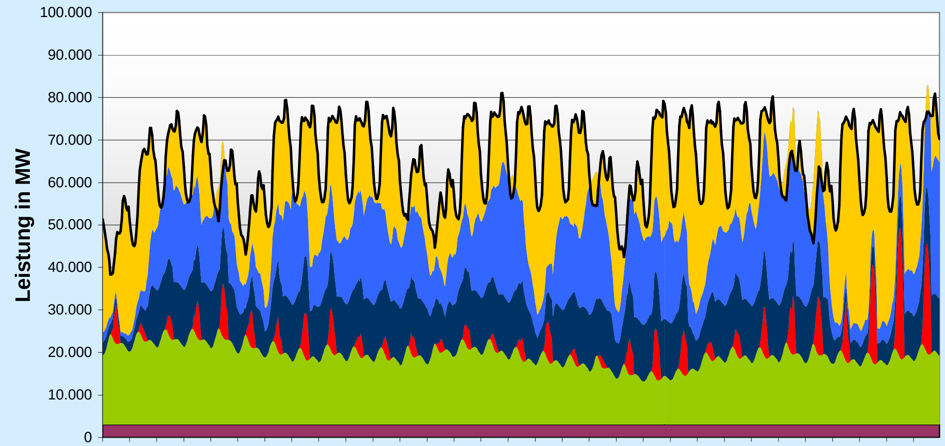


Combinations of different load and intermittent feed-in (non-dispatchable feed-in)

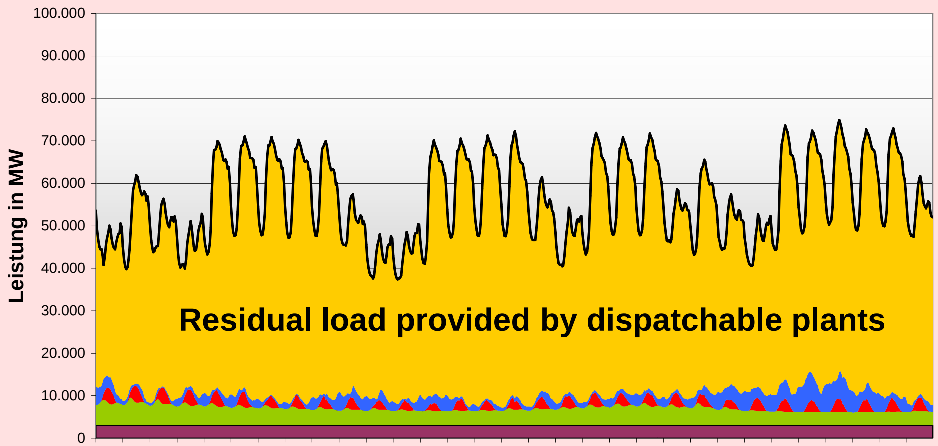
In the past (2008) | **In the Future (2020)**

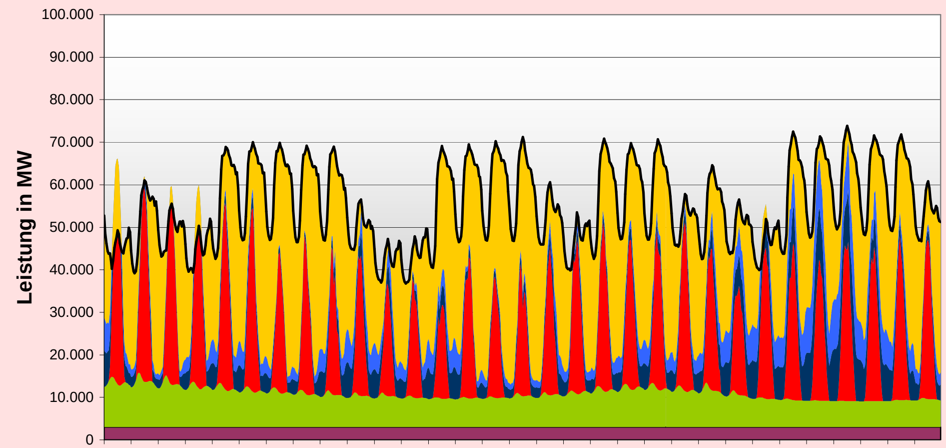
Winter period in January





Summer period in May/June

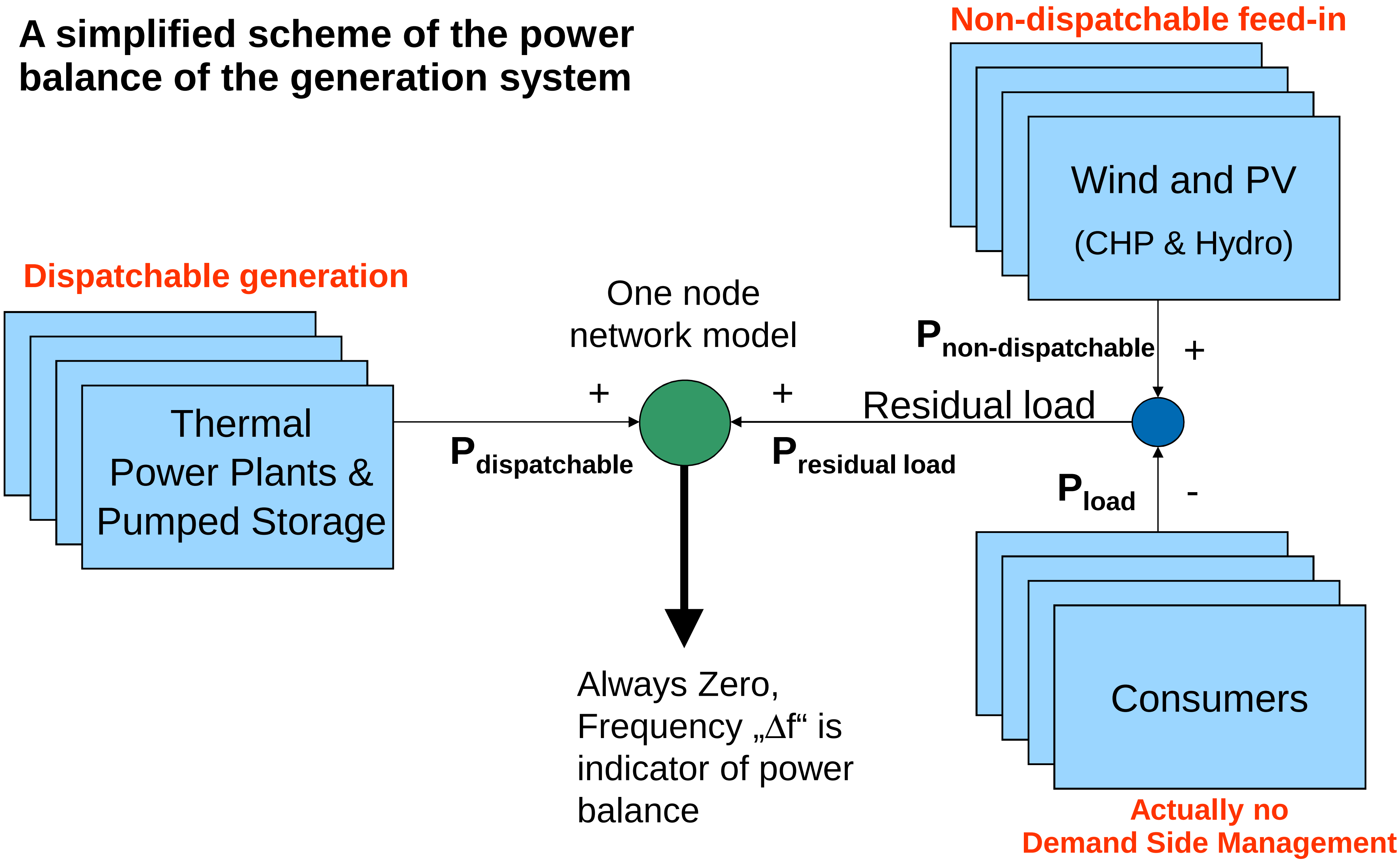




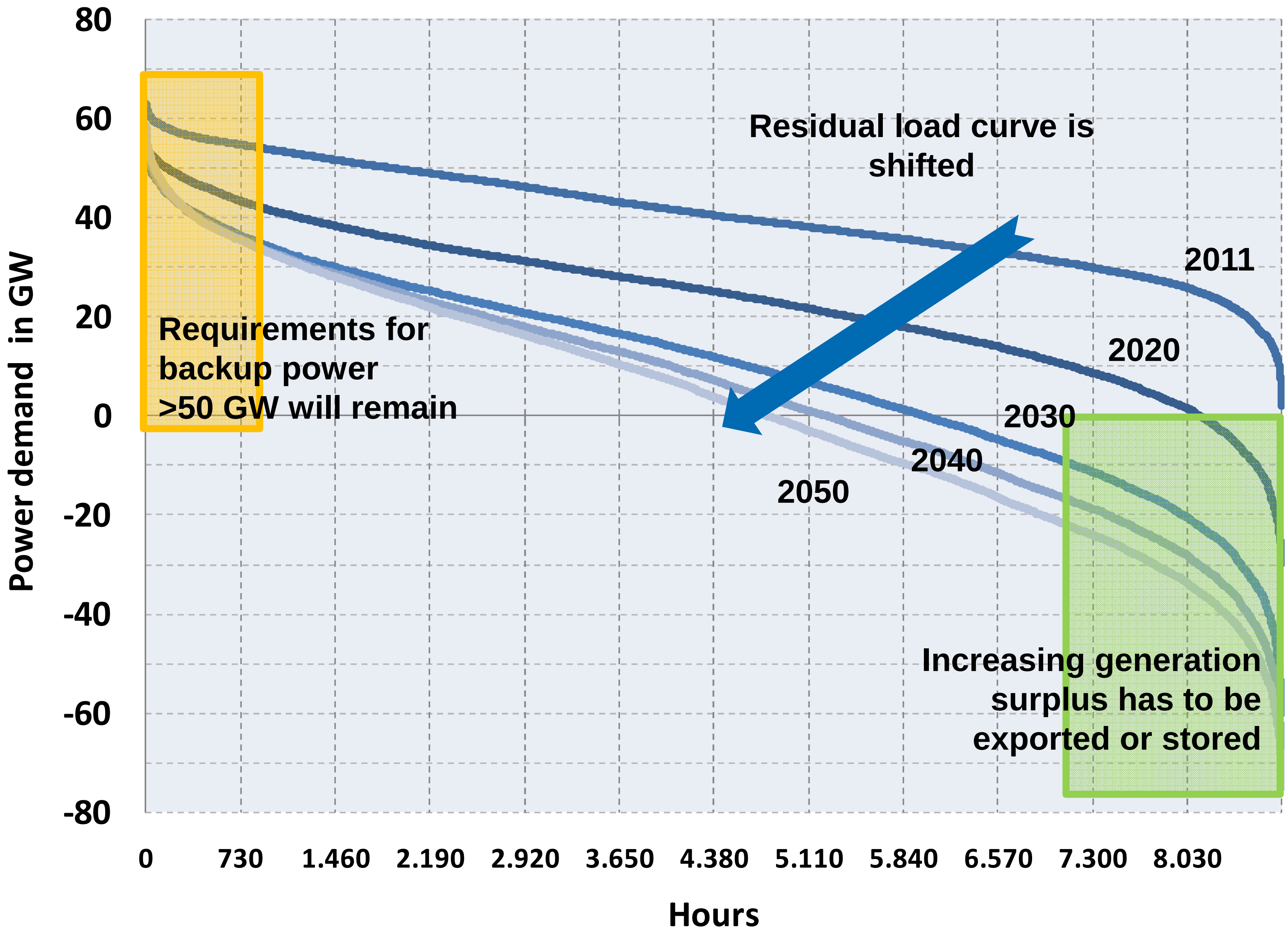
- Hydro (run-of-river)
- Combined-Heat&Power (CHP)
- Photovoltaic (PV)
- Offshore Wind
- Onshore Wind
- Residual Load
- Total demand (load)

Transition of the power system into a renewable system

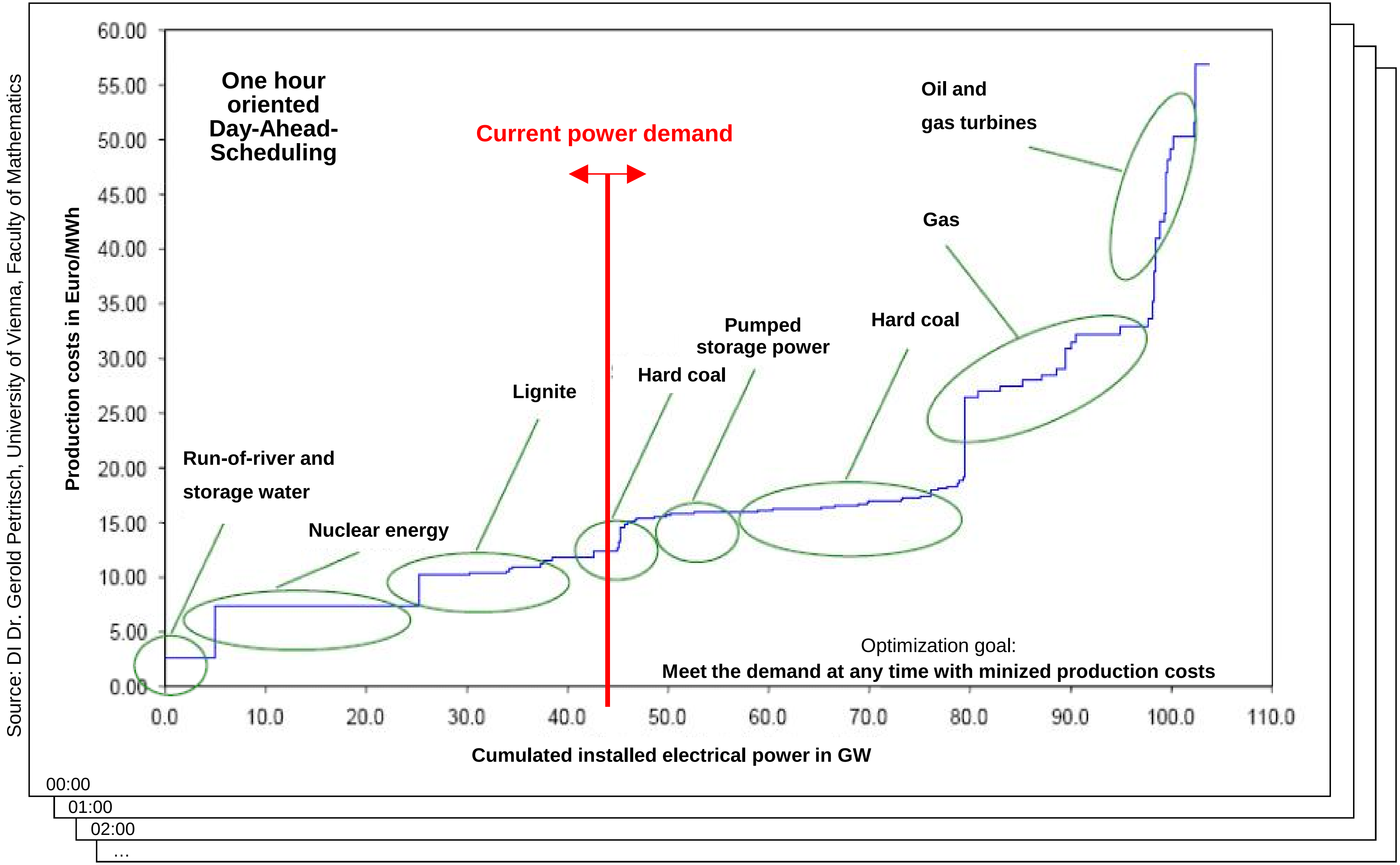
A simplified scheme of the power balance of the generation system



Resulting annual residual load curve

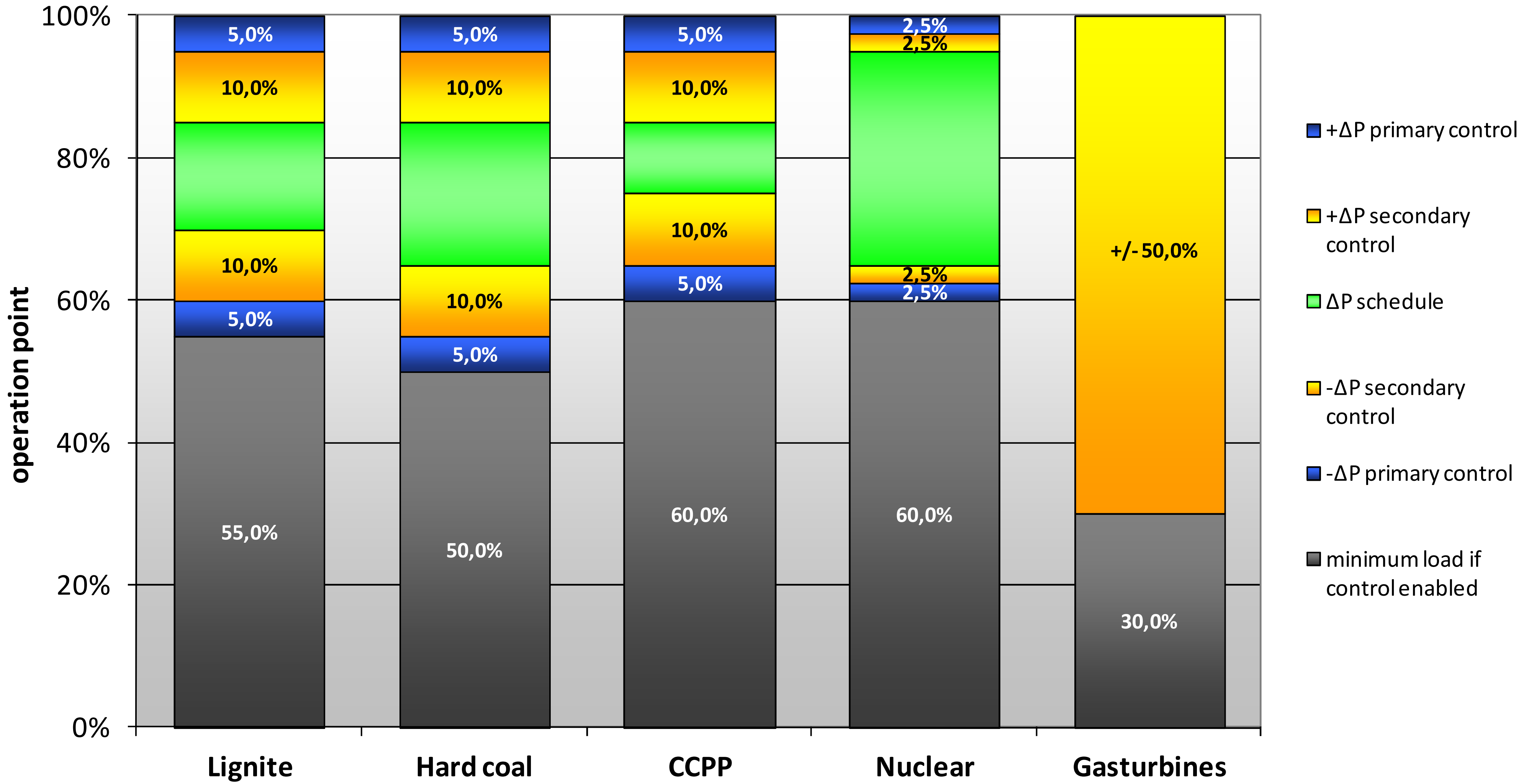


Merit Order Method (example prices)



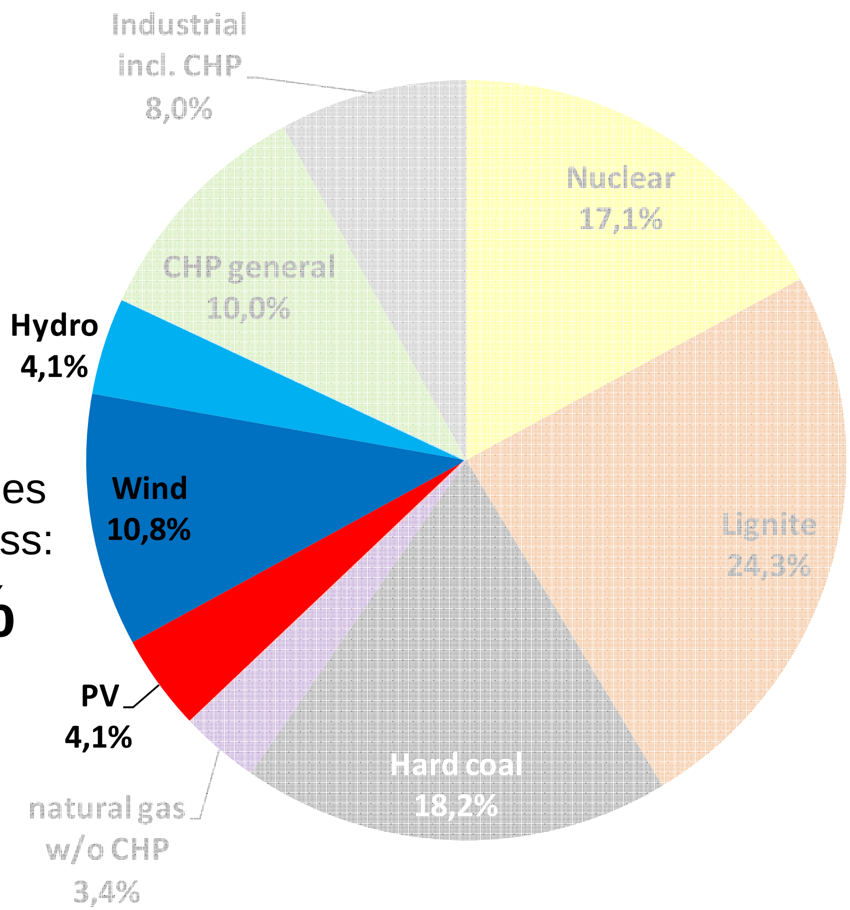
Flexibility assumptions for scenarios

of different thermal types (refers to the rated power)



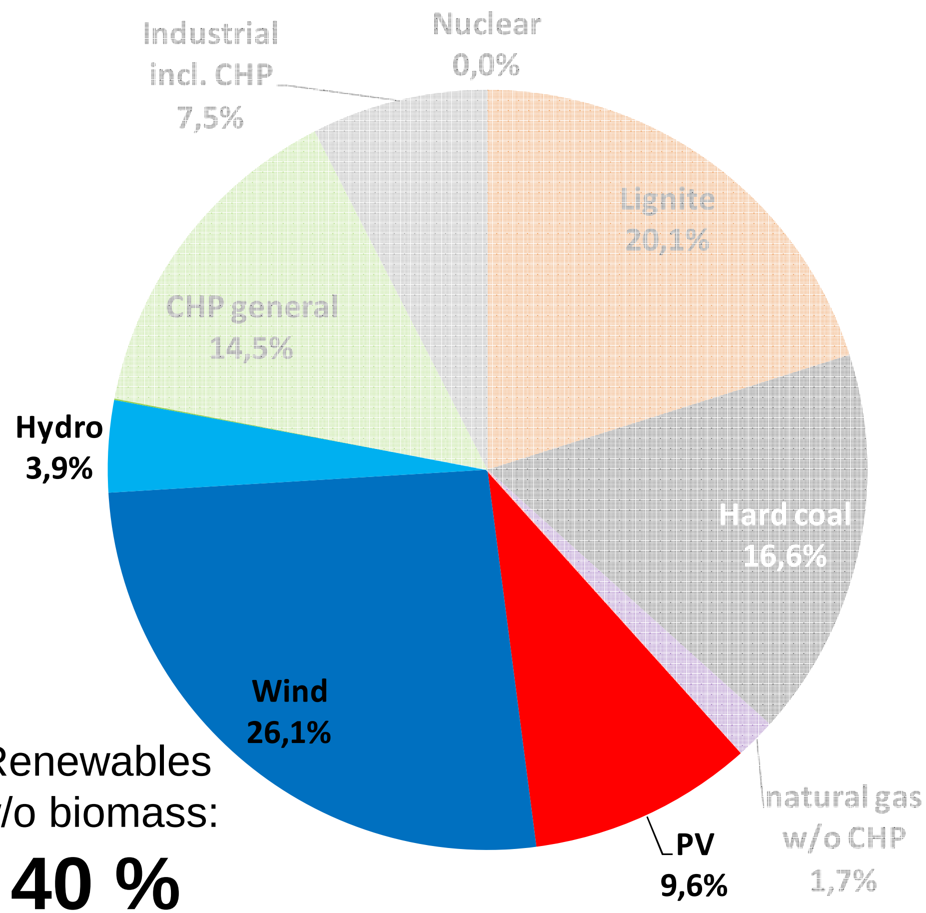
Resulting generation structure in Germany
Percentage basis referred to net electr. generation

Renewables w/o biomass:
19 %



2011

Net electr. generation:	**587,4 TWh**
--> thereof surplus:	**0 TWh**
--> thereof export:	**18,3 TWh**



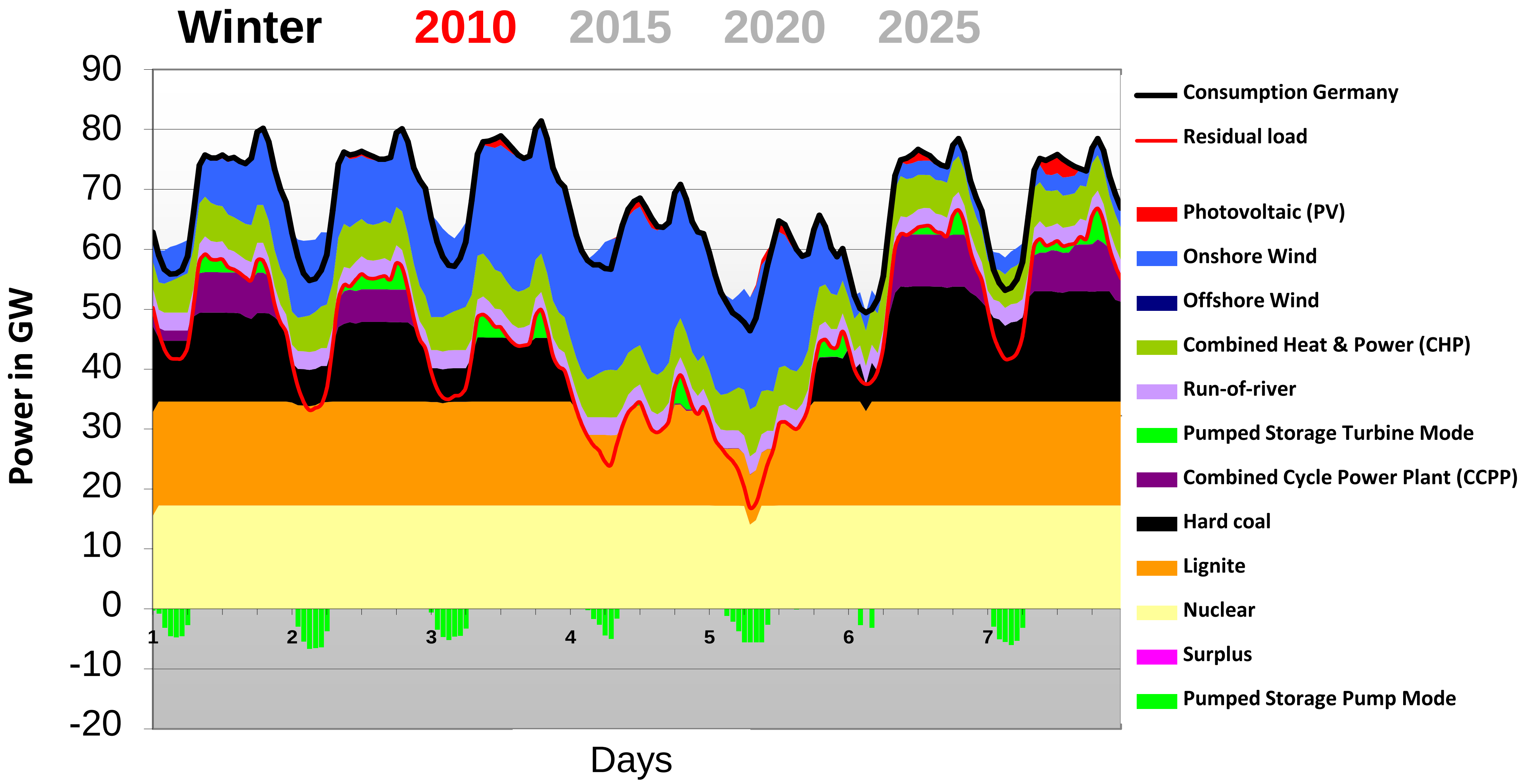
Renewables w/o biomass:
40 %

2023

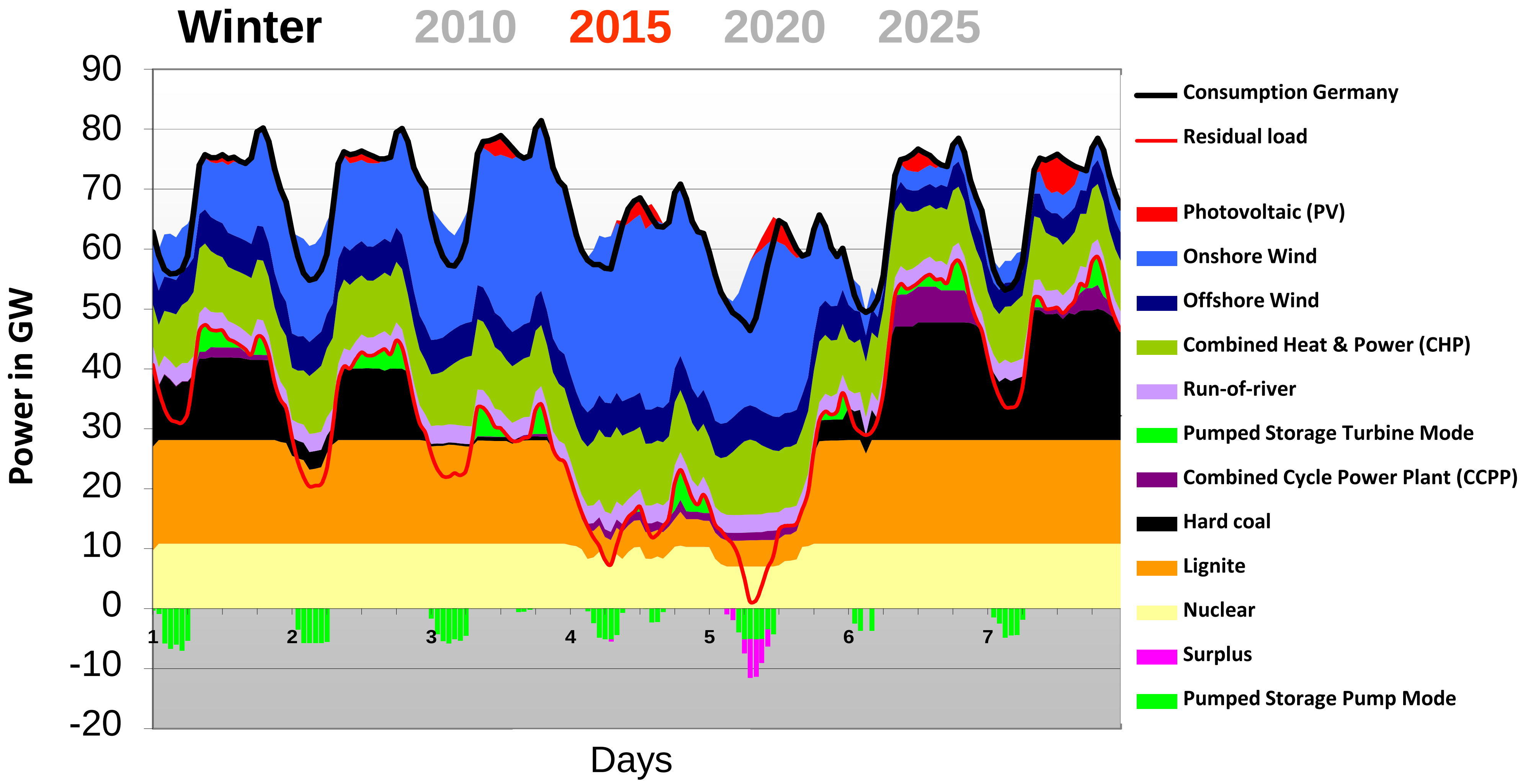
Net electr. generation:	**625,1 TWh**
--> thereof surplus:	**4,5 TWh**
--> thereof export:	**50,5 TWh**

Displacement of conventional power

Exemplary power plant scheduling for one week

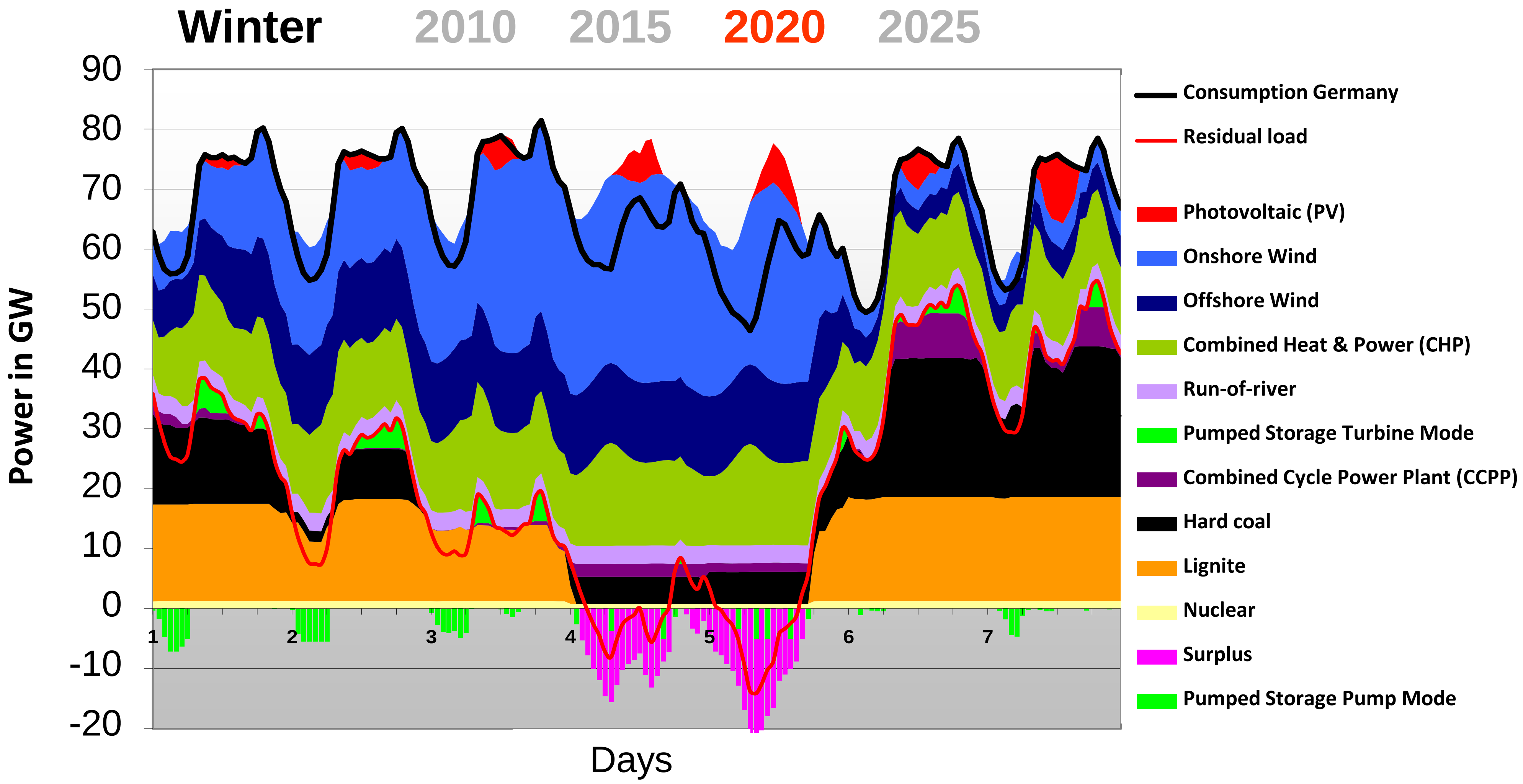


Displacement of conventional power
Exemplary power plant scheduling for one week

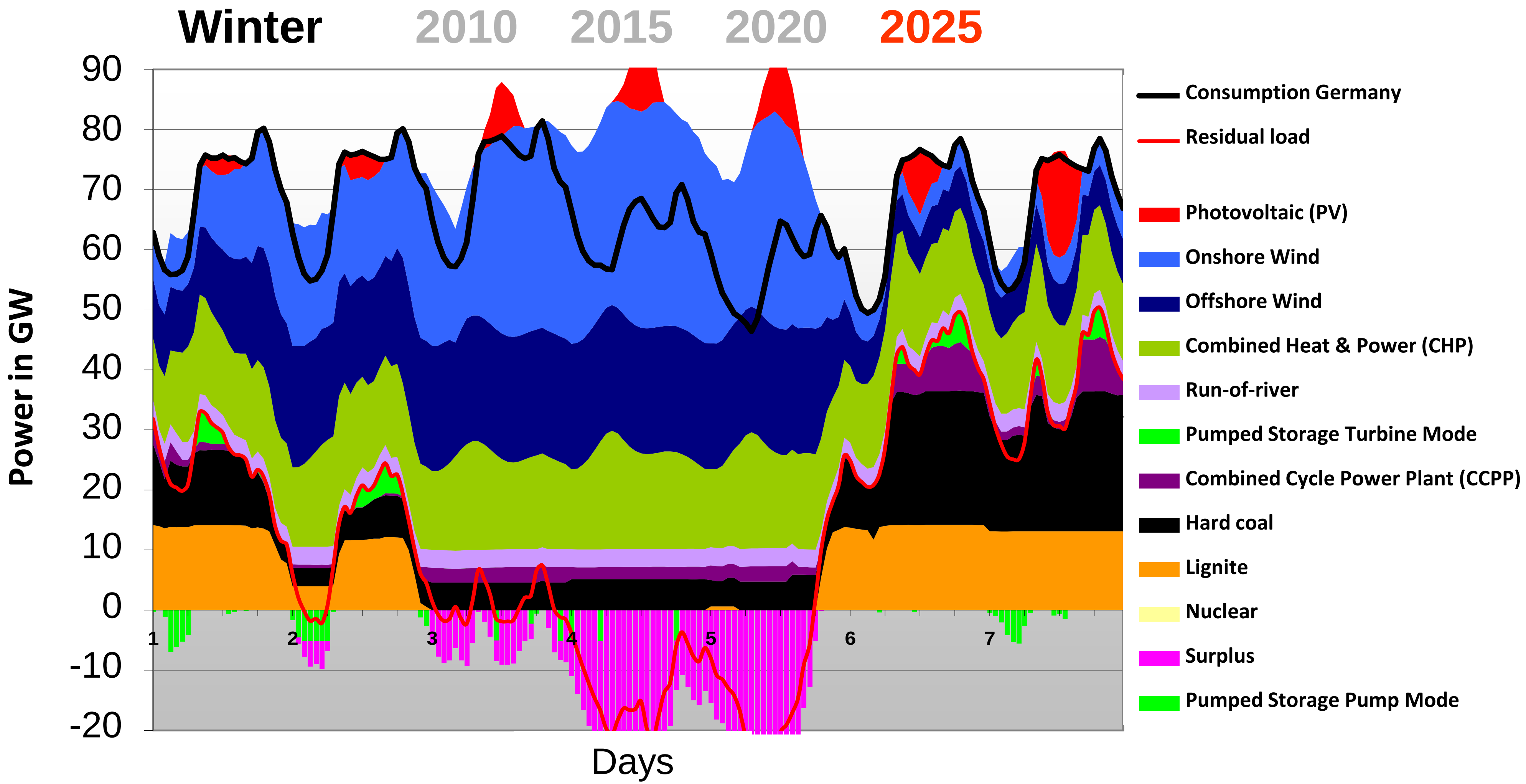


Displacement of conventional power

Exemplary power plant scheduling for one week



Displacement of conventional power
Exemplary power plant scheduling for one week



Displacement of conventional power
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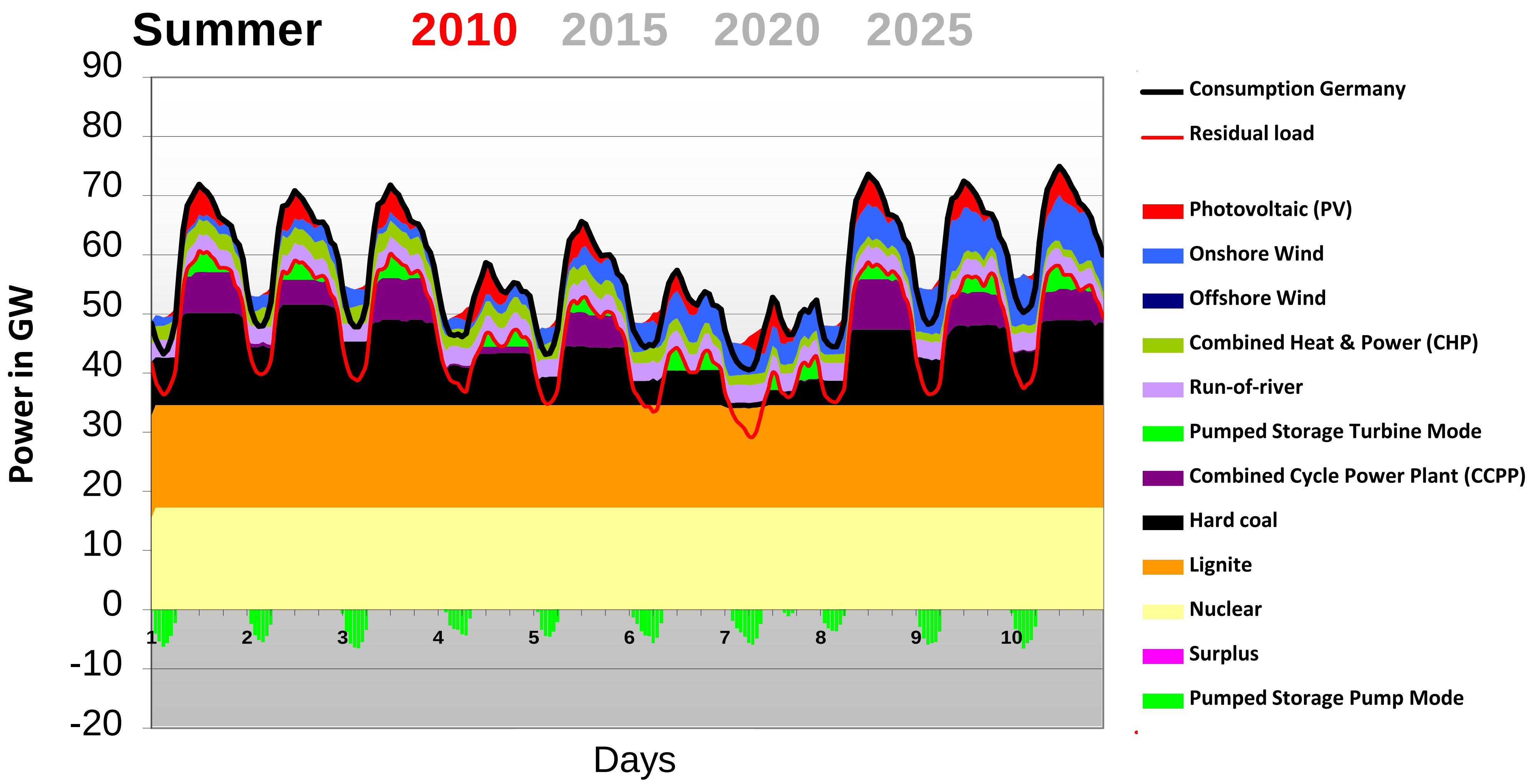
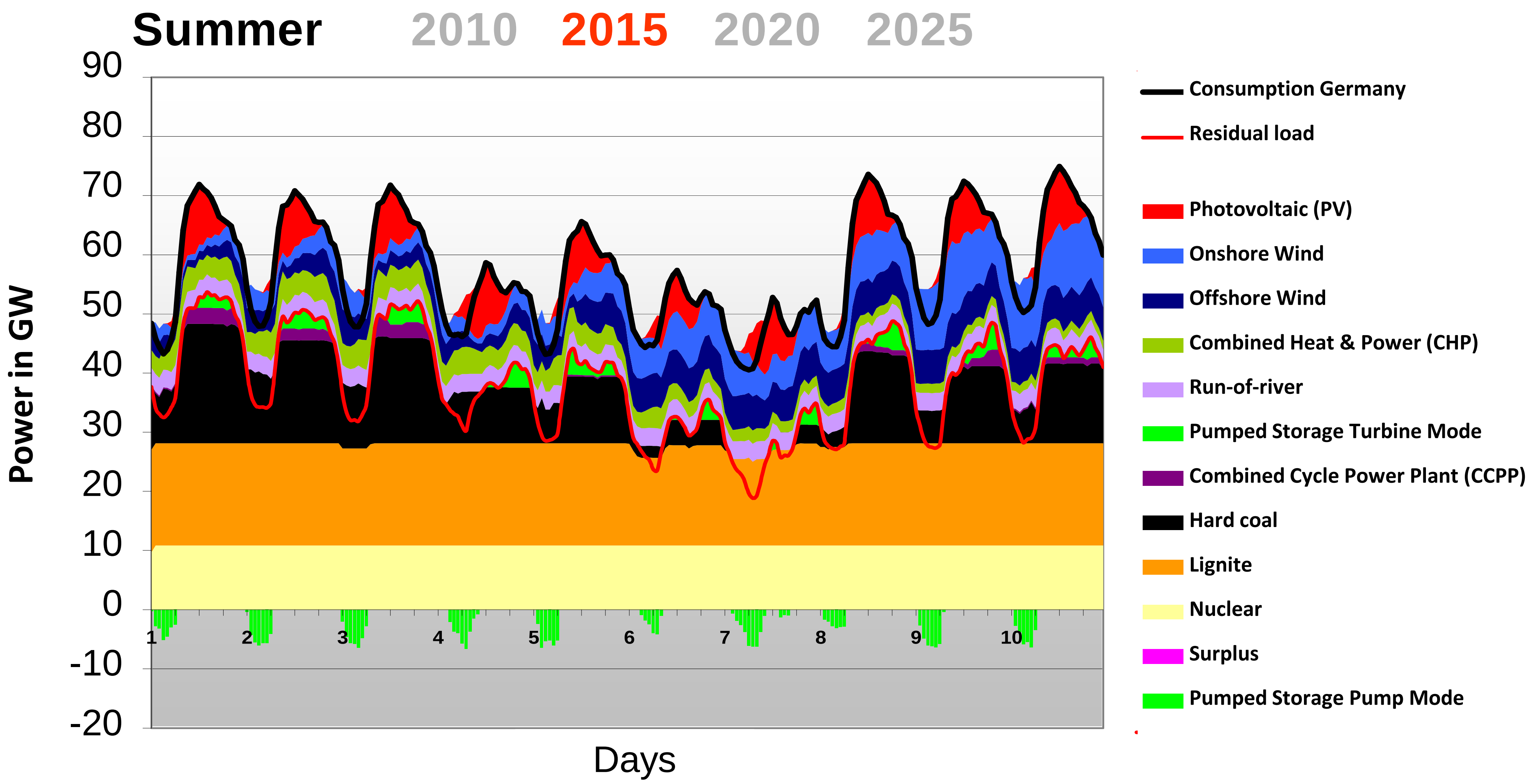
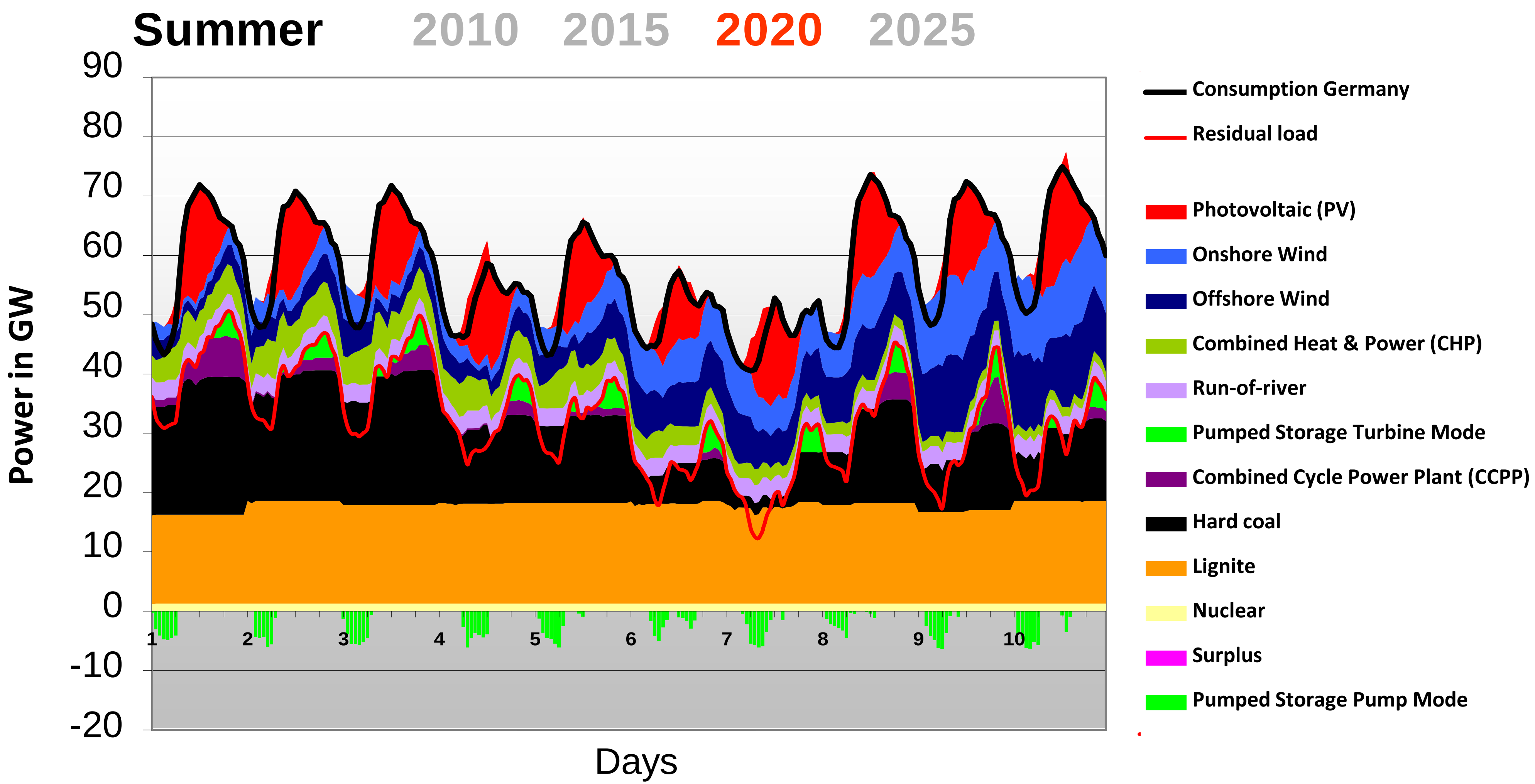


Displacement of conventional power

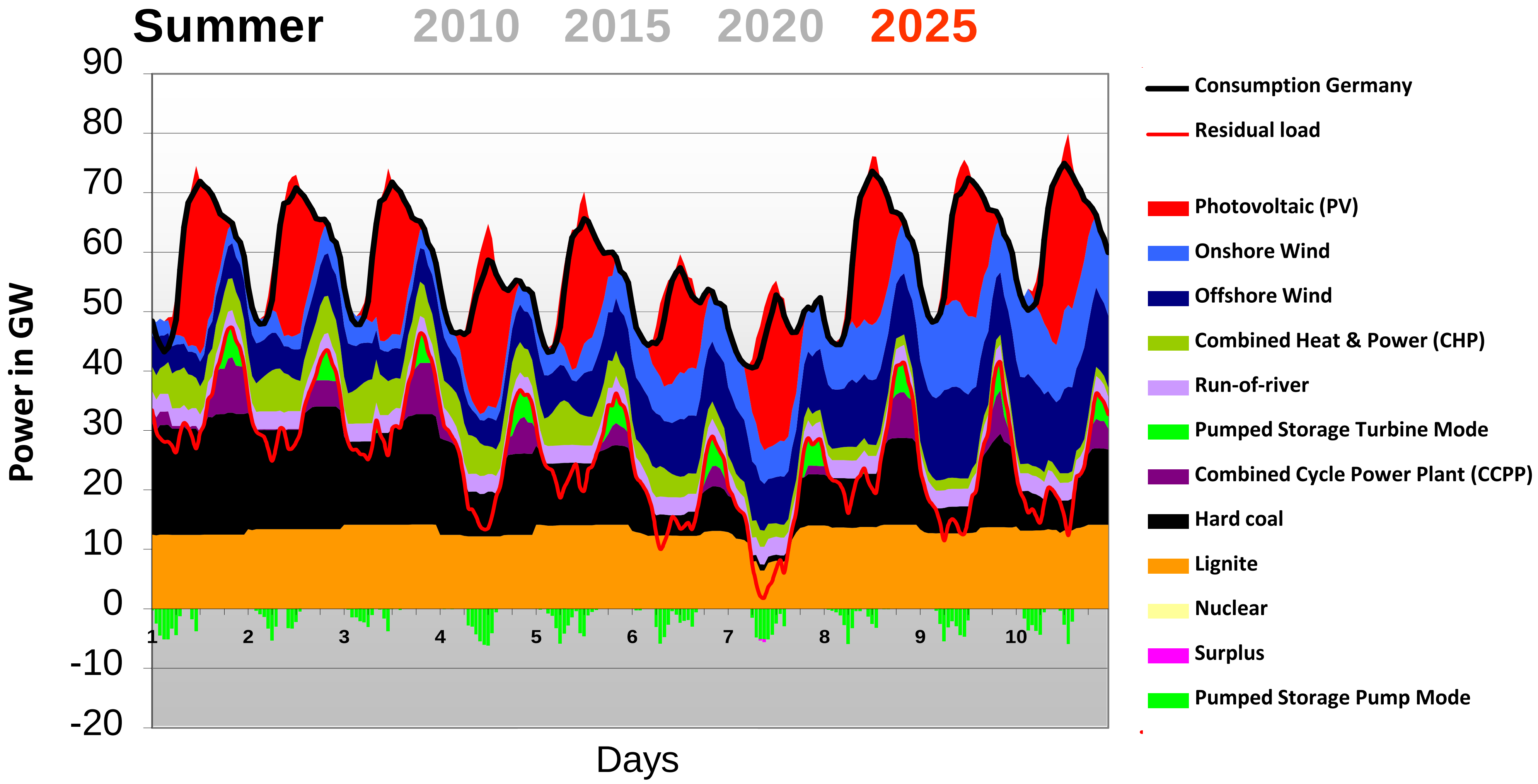
Exemplary power plant scheduling for one week



Displacement of conventional power
Exemplary power plant scheduling for one week



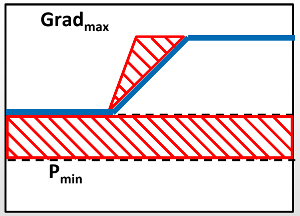
Displacement of conventional power
Exemplary power plant scheduling for one week



Increasing capacity of wind and solar generators: Change of single thermal power plant operation and utilization

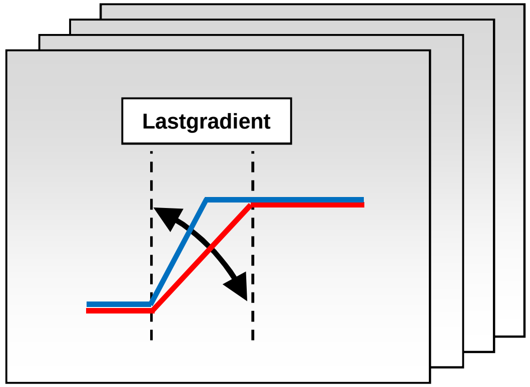
VGB RESEARCH
Project 333

Limits of a thermal power plant
Variation of different flexibility parameters

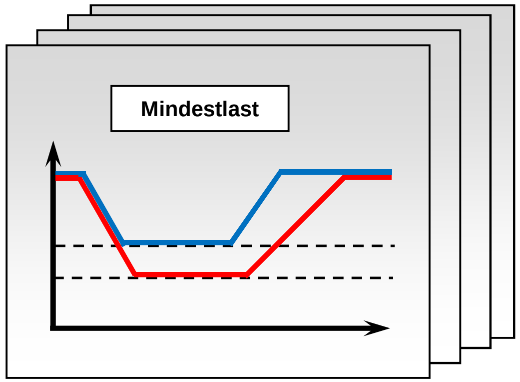


operation parameters

Load gradient Scenarios
2.5%, 4%, 6%



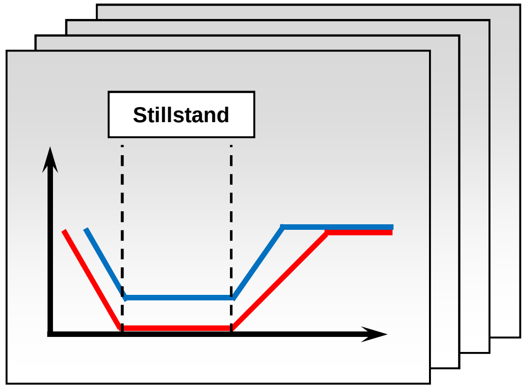
Min load scenarios
50%, 37.5%, 33%, 20 %



Simulate different operation modes

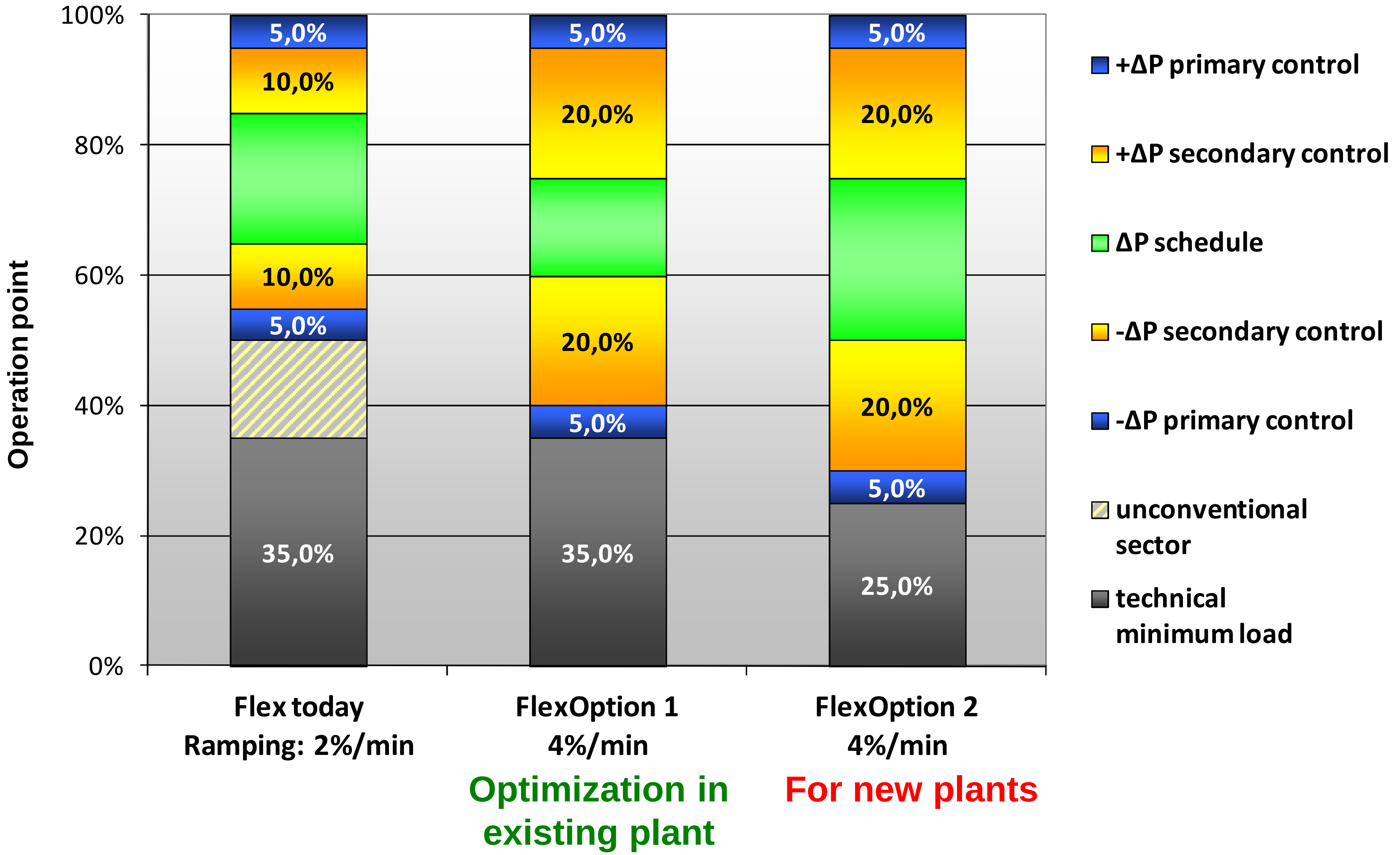
Simulation of critical load and intermittent scenarios under variation of load gradient, min load of PP Rostock or operation of the power plant in unconventional partial load

special operation modes
„shut down & restart“ (red)
„reduce to circulation mode“ (blue)



Compared Flexibility Options (TPP Rostock)

Pmax=500MW net, eta=43.2%, hard coal, comm. In 1994

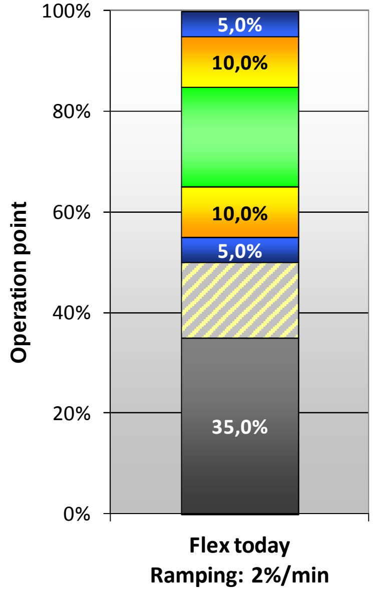


Unconventional sector: If primary and secondary control is used this operation point normally is not used due to coal mill switching

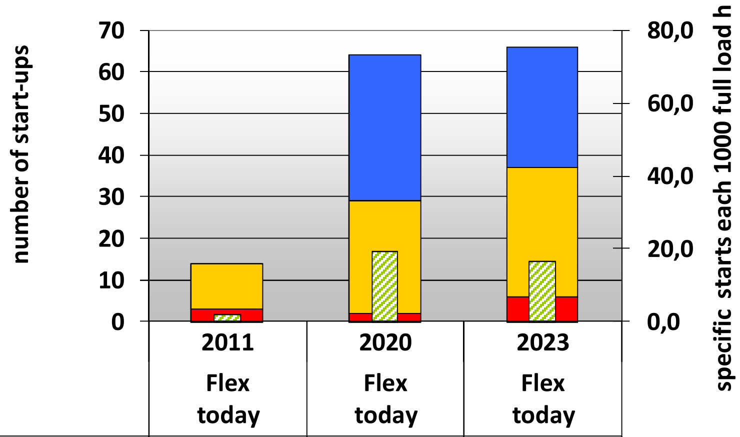
→ Potential for optimization to achieve higher flexibility

Results for „Flex today“
Without enhanced flexibility

Flexibility in this case

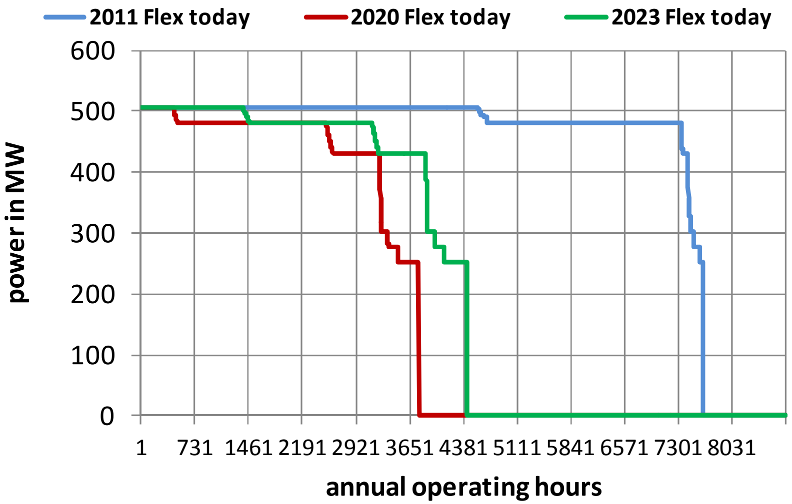


Annual start-up cycles

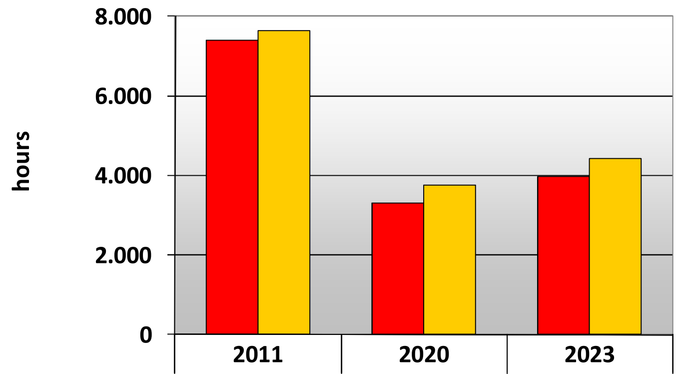


	2011 Flex today	2020 Flex today	2023 Flex today
cold start	0	35	29
warm start	11	27	31
hot start	3	2	6
specific	1,9	19,3	16,6

Annual partial load operation



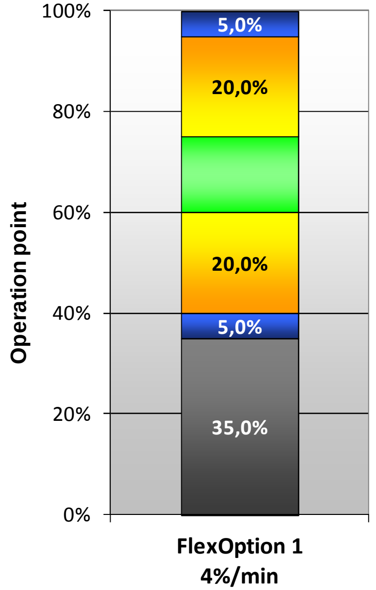
Annual full load and operating hours



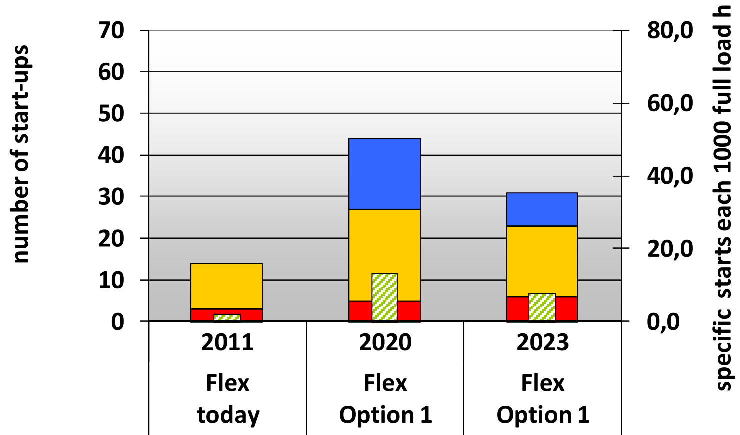
	2011 Flex today	2020 Flex today	2023 Flex today
full load hours	7399	3321	3977
operating hours	7629	3774	4423

Results for „Flex Option 1“
With enhancements in the existing plant

Flexibility in this case

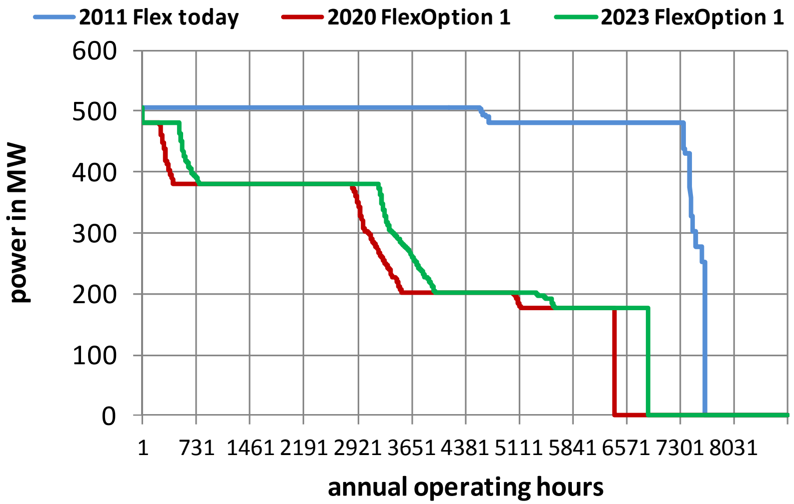


Annual start-up cycles

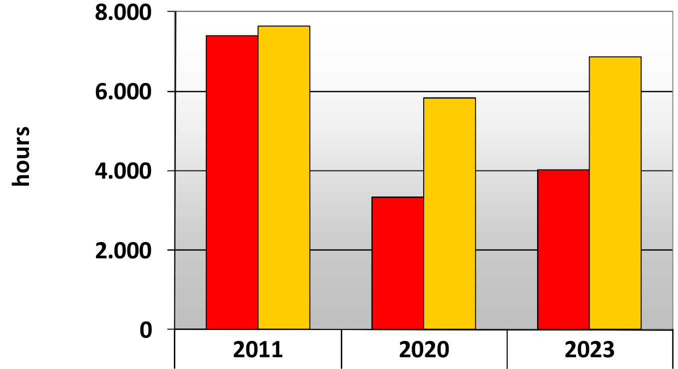


	2011 Flex today	2020 Flex Option 1	2023 Flex Option 1
cold start	0	17	8
warm start	11	22	17
hot start	3	5	6
specific	1,9	13,2	7,7

Annual partial load operation



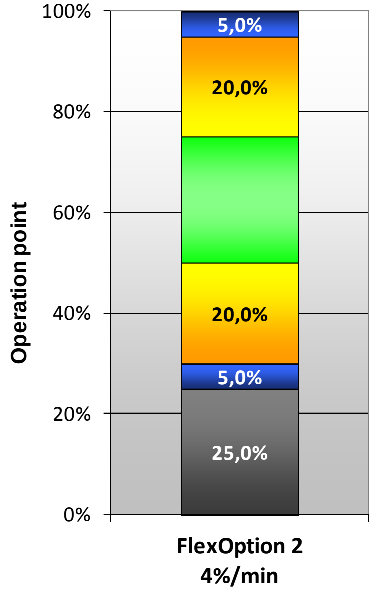
Annual full load and operating hours



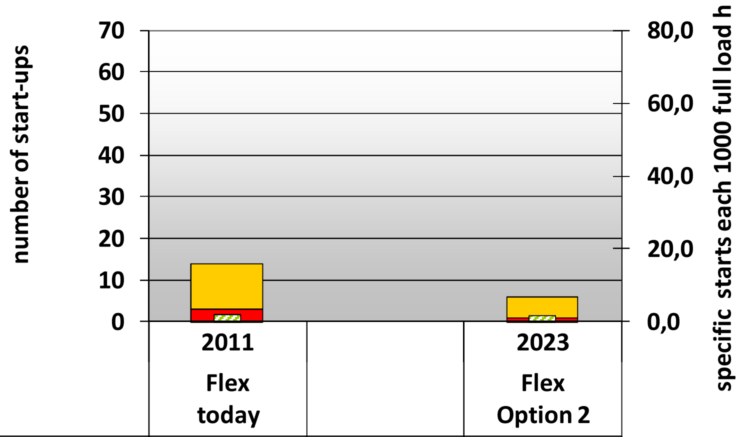
	2011 Flex today	2020 Flex Option 1	2023 Flex Option 1
full load hours	7399	3330	4024
operating hours	7629	5828	6860

Results for „Flex Option 2“
With enhanced design parameters for new plants

Flexibility in this case

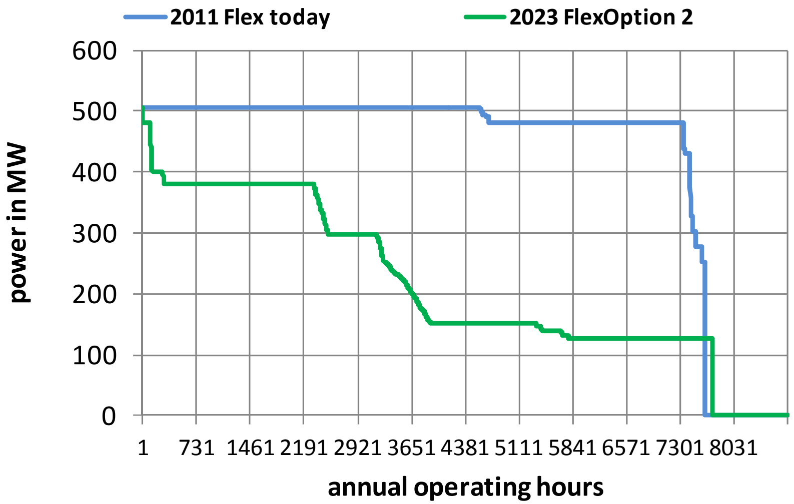


Annual start-up cycles

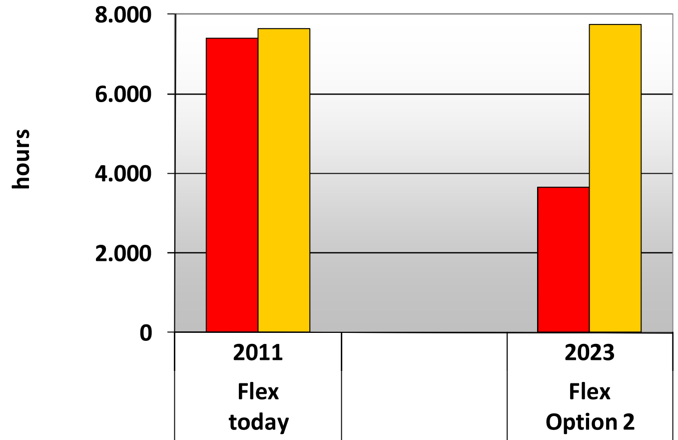


	2011 Flex today		2023 Flex Option 2
cold start	0		0
warm start	11		5
hot start	3		1
specific	1,9		1,6

Annual partial load operation



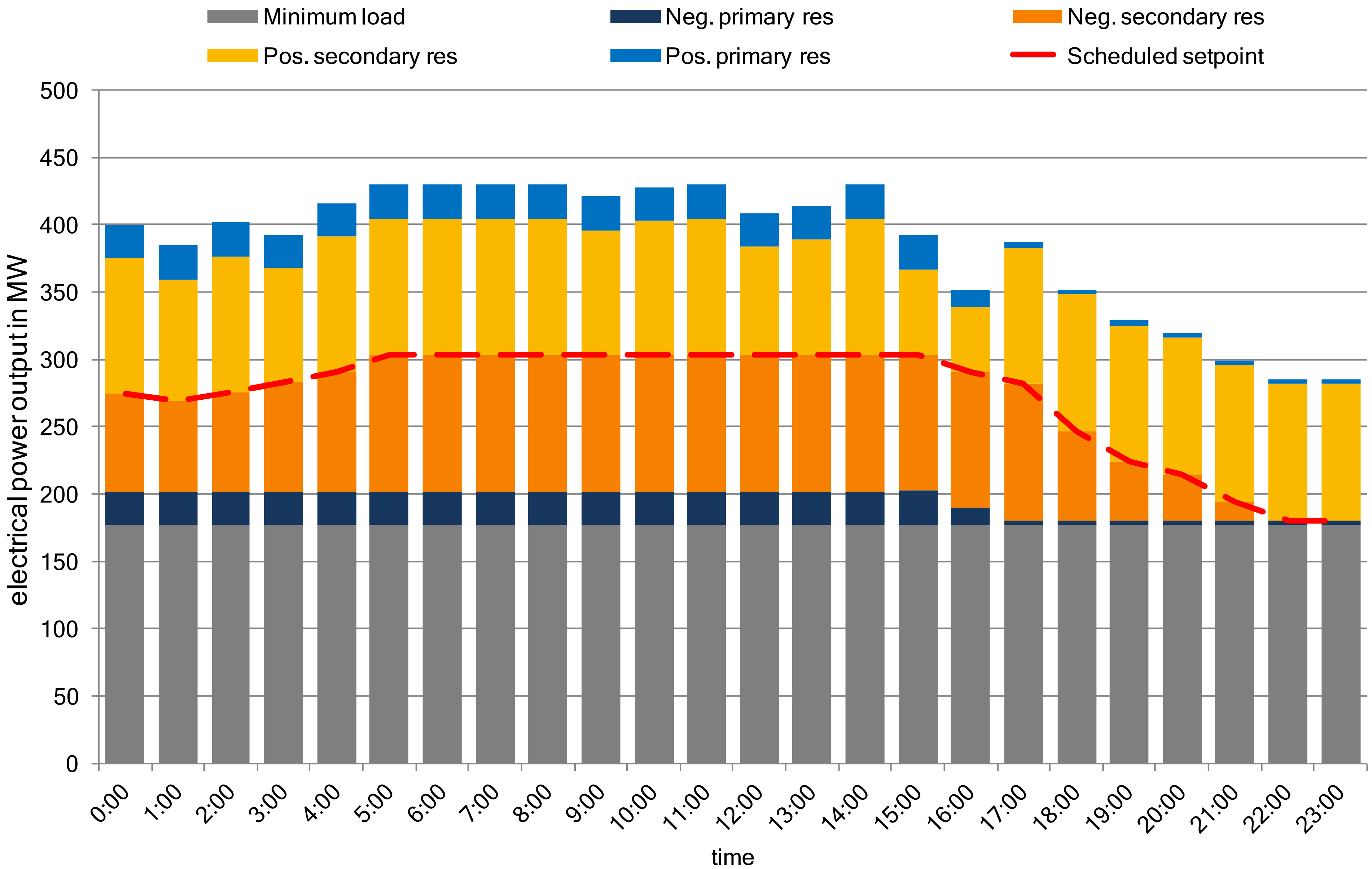
Annual full load and operating hours



	2011 Flex today		2023 Flex Option 2
full load hours	7399		3646
operating hours	7629		7738

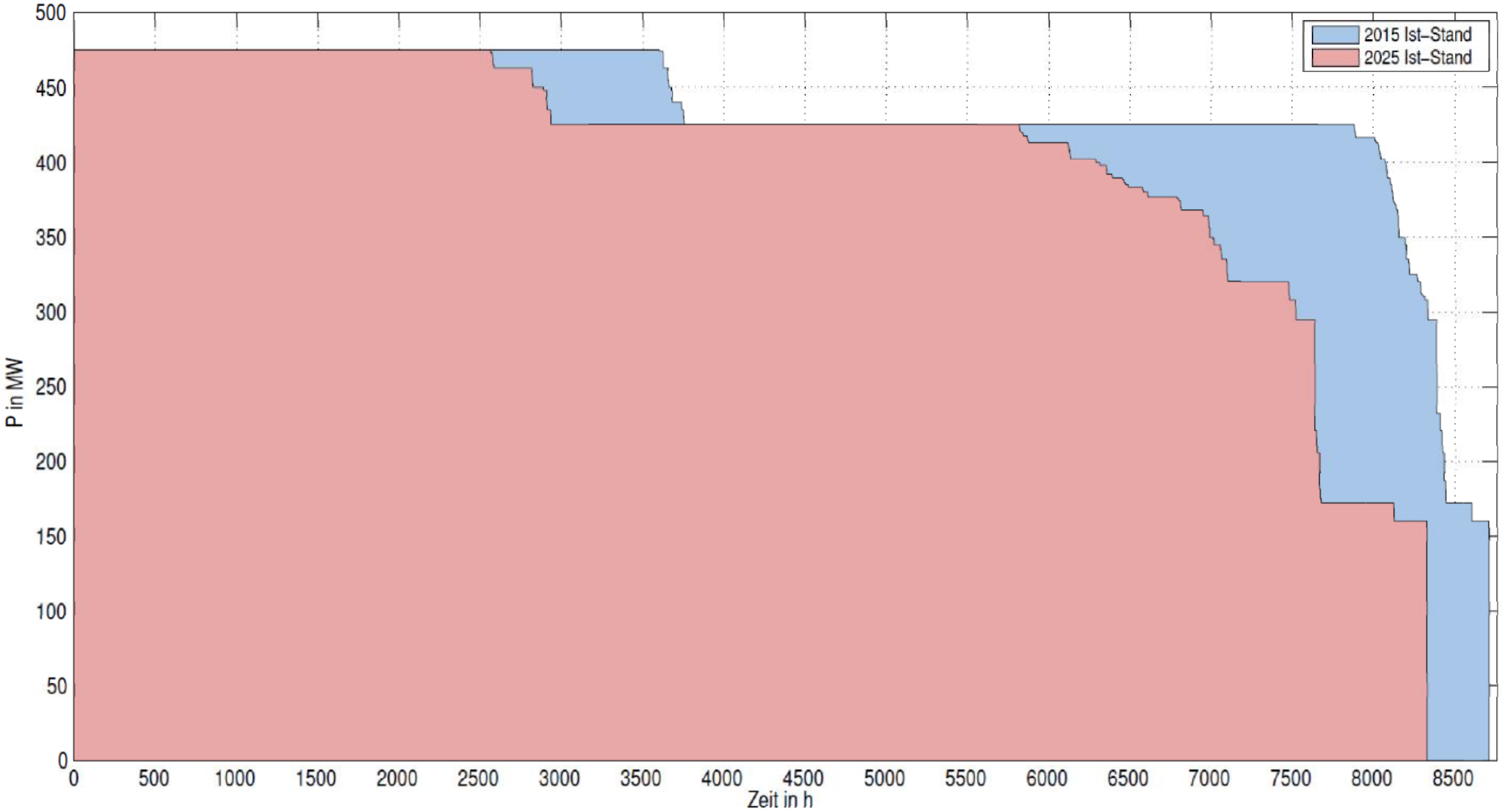
Investigation of power plant schedules

Hourly resolution (example Thermal Plant Rostock)

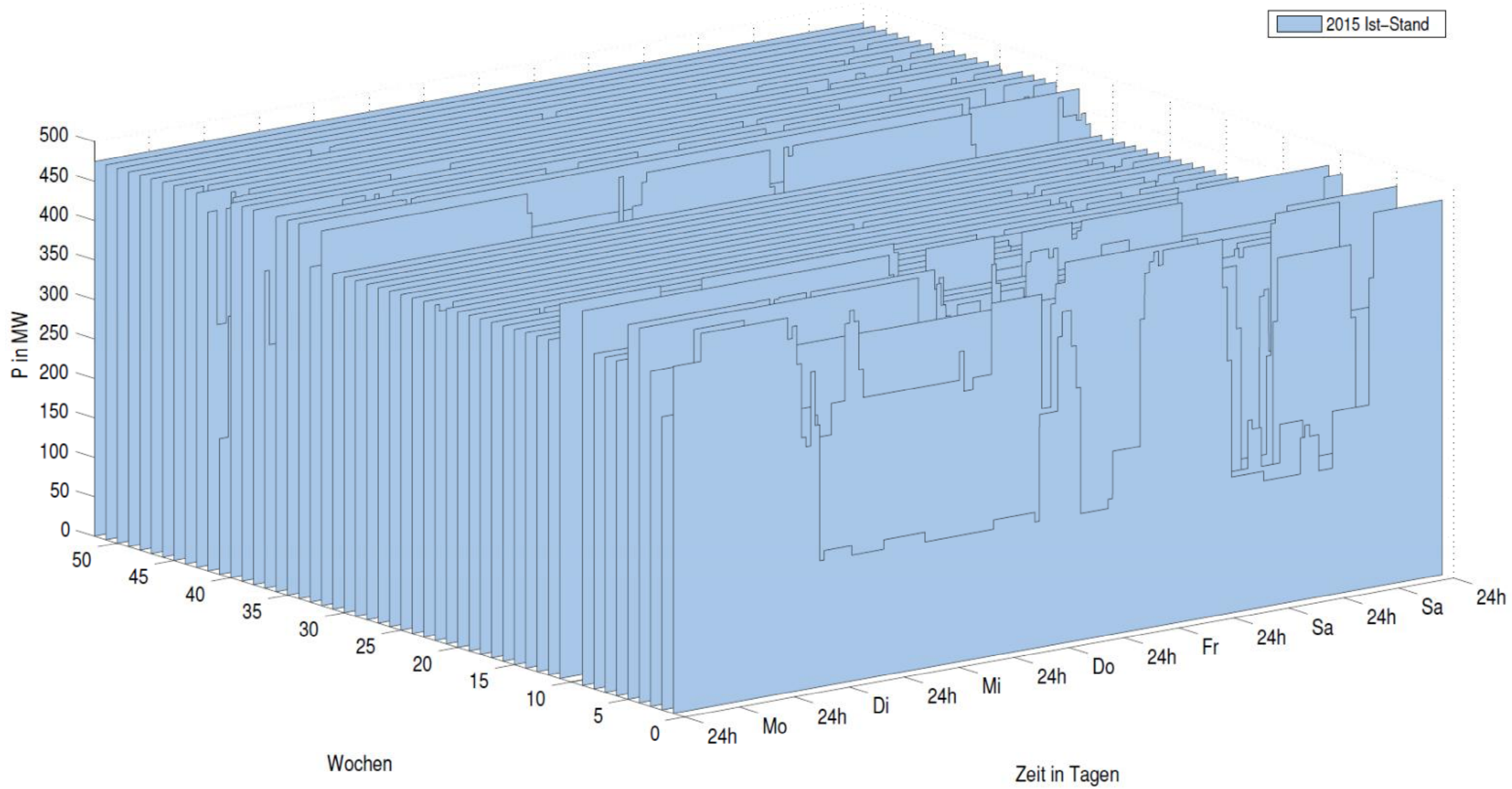


Results for annual ordered utilization

lignite fired power plant 2015/2025 –
No information for load step frequency evaluation in this figure type

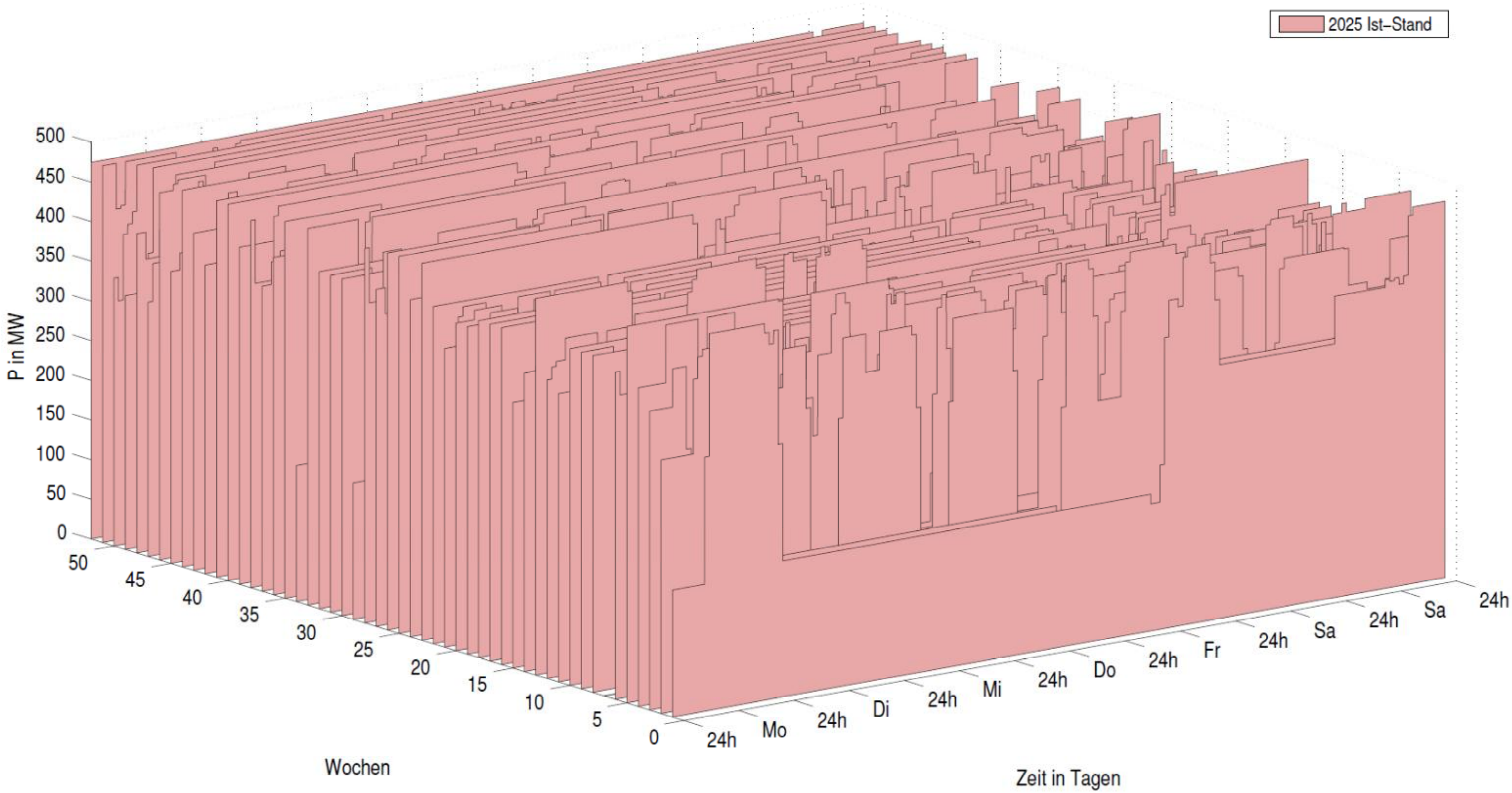


Results for annual utilization
Annually ordered load change steps (weeks over the year)

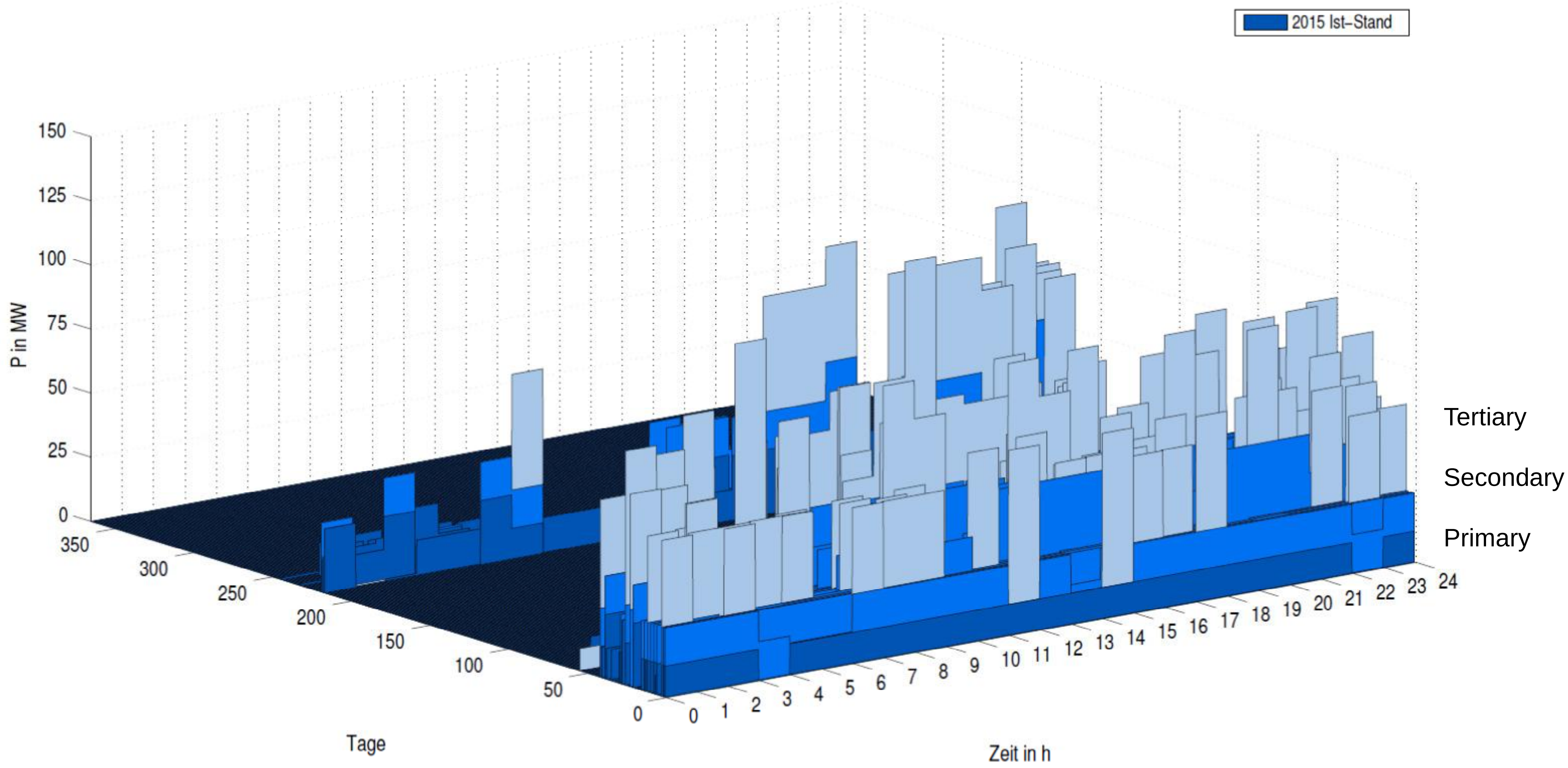


Results for annual utilization

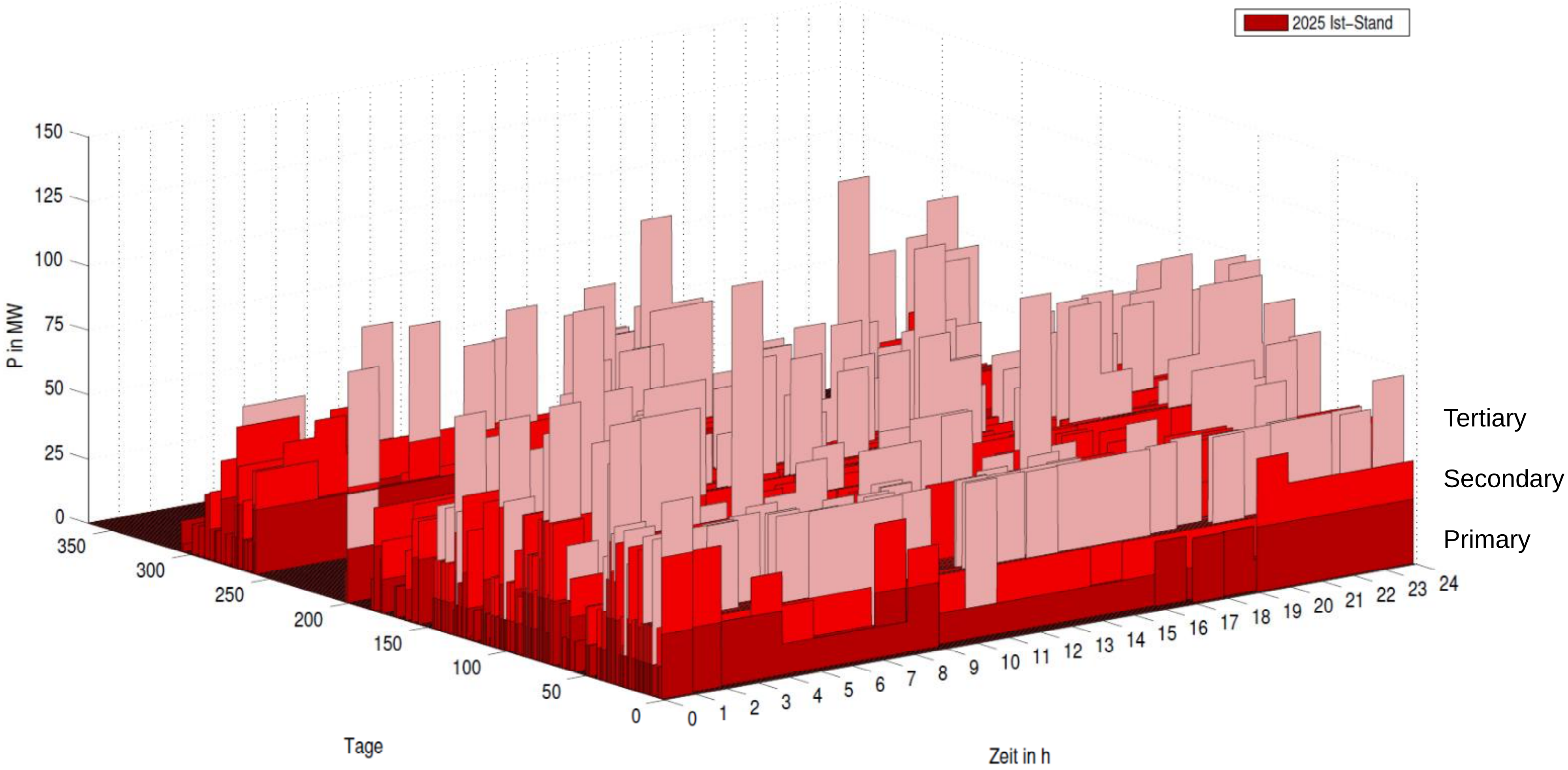
Annually ordered load change steps (weeks over the year)



Results for annual pos. Reserves
Annually ordered reserved power (weeks over the year)



Results for annual pos. Reserves
Annually ordered reserved power (weeks over the year)



Detection of Restrictions

overview

lowering minimum load

- 50%
  - Degradation of the regulating capabilities due to low mass flow rates
  - Shut down of coal mills
  - Low exhaust temperature prior DENOX
- 34%
  - Switch over to circulation mode
  - Life steam temperature decreases which cause thermal stress cycles
  - Low primary air temperatures in coal mills
  - Single feed water pump operation
- 20%

enhanced load gradient

- 4%
  - Pressure deviations in the furnace due to low regulation capabilities of the forced draft fan
  - Regulating capabilites of the coal mills is restrictive
  - Increasing fatigue due to temperature deviations
- 2%

Possible Optimizations

Identification & quantification

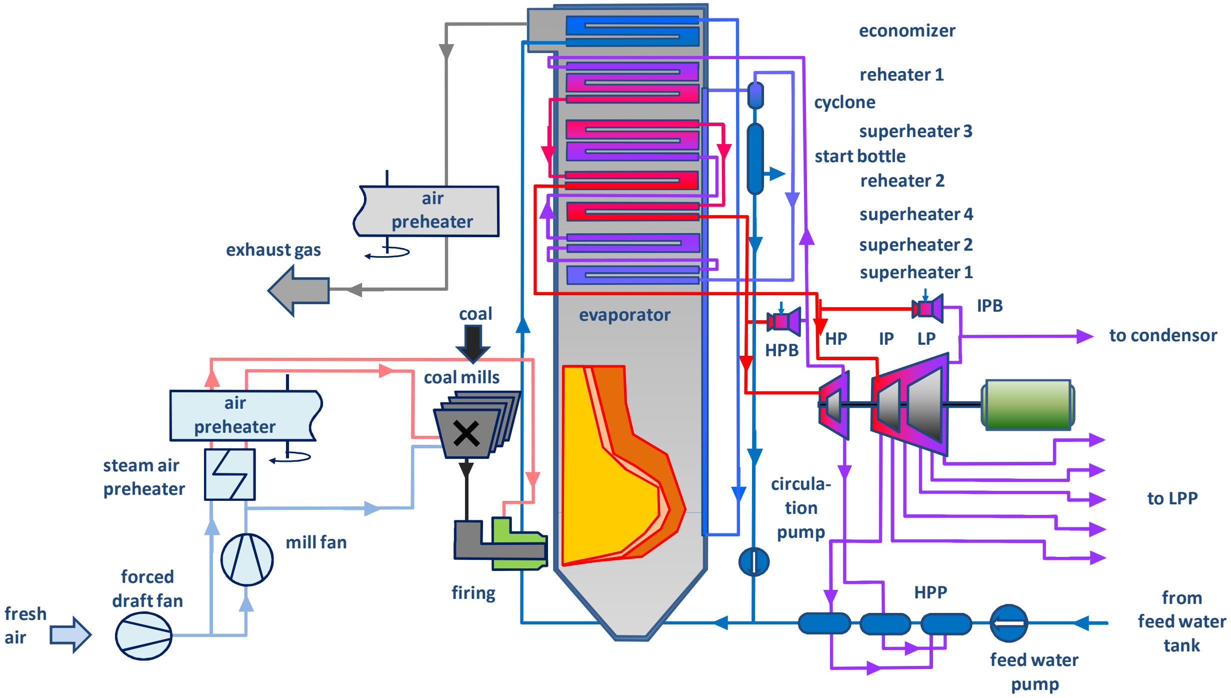
lowering minimum load (50% – 34% – 20%)

- Modified control parameters for low partial load
- Analysis of the potential of map based coal mill control and coal dust mass flow rate
- Optimization of the switch events (1/2 Pump operation, on/off switching of coal mills and change from circulation to Benson operation)
- Investigation of the circulation mode as an alternative operation to shut down and restart

enhanced load gradient (2% – 4%)

- potential by expanding the data basis, e.g. map based determination of heating value, measurement of coal dust mass flow
- Optimization of the control parameters, e.g. dynamic of the ratio fuel rate to feed water mass flow

Overview of dynamic power plant model



Structure of the power plant model

Scope of Power Plant Model

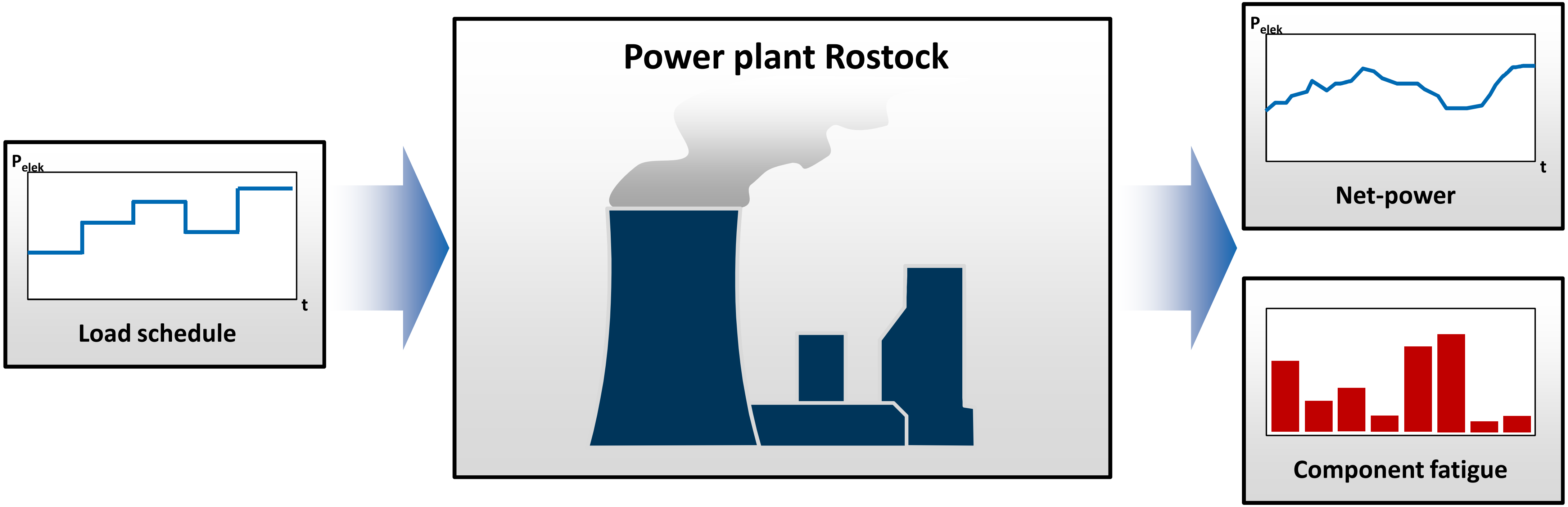
- Water steam cycle from feed watertank until condenser, including start up devices
- Air Duct from forced draft fan until air preheater exhaust gas outlet
- reproduction of the independent coal mills and of combustion with regard to the coal composition
- reduced copy of the Control system including control for fuel mass flow rate, feed water pump, spray attemporators, coal mills, circulation cycle, turbine bypass and forced draft and mill fan
- Can be operated with arbitrary load schedule

Modeling of:

- Temperature distribution in thick walled components → fatigue investigations
- Calculation of process parameters (e.g. DENOX-inlet temperature, efficiency, etc.)
- Modular structure enables model extension or substitution of components (e.g. simple Implementation of new control concepts)

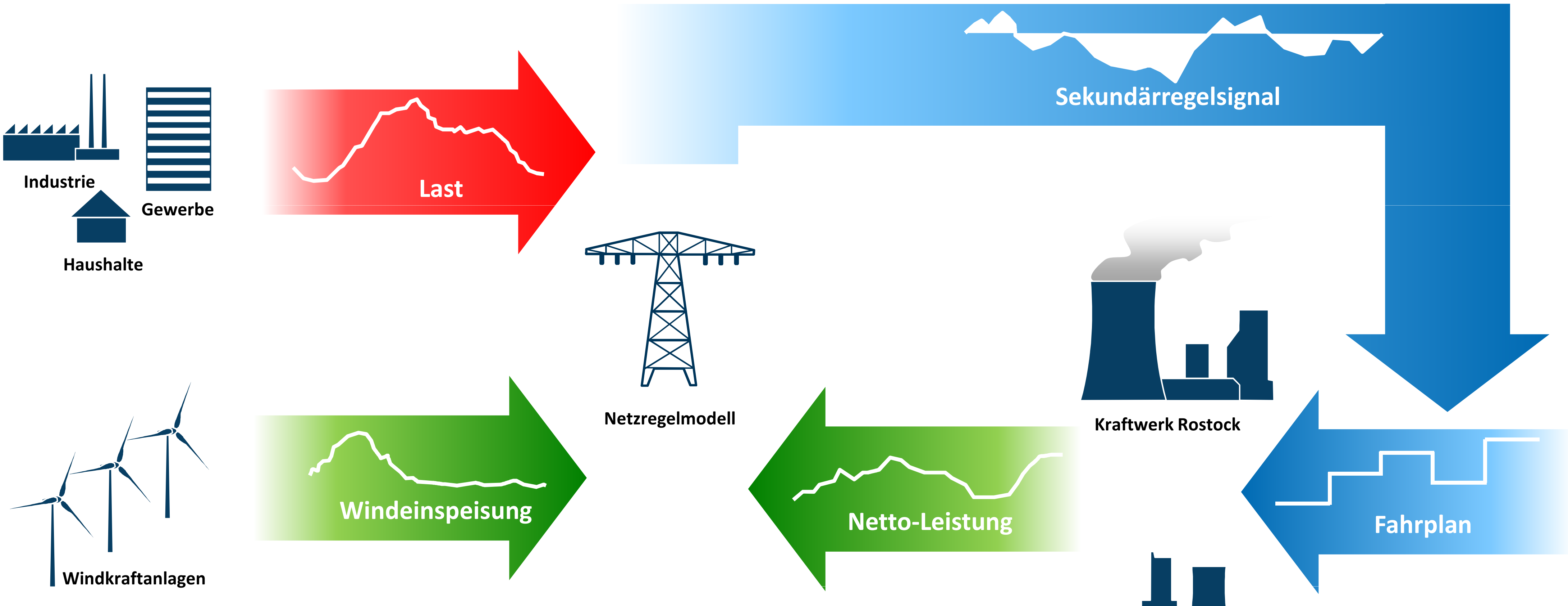
Demonstration scenario:
12 h of load schedule operation

Results of power plant simulation



- Creation of an fictitious load schedule with load set points between 37 % und 100% load
- Model calculates the resulting generator output
- Benchmark of the operation mode – evaluation of component fatigue for the corresponding basic operation , e.g. Start or schedule load change/step

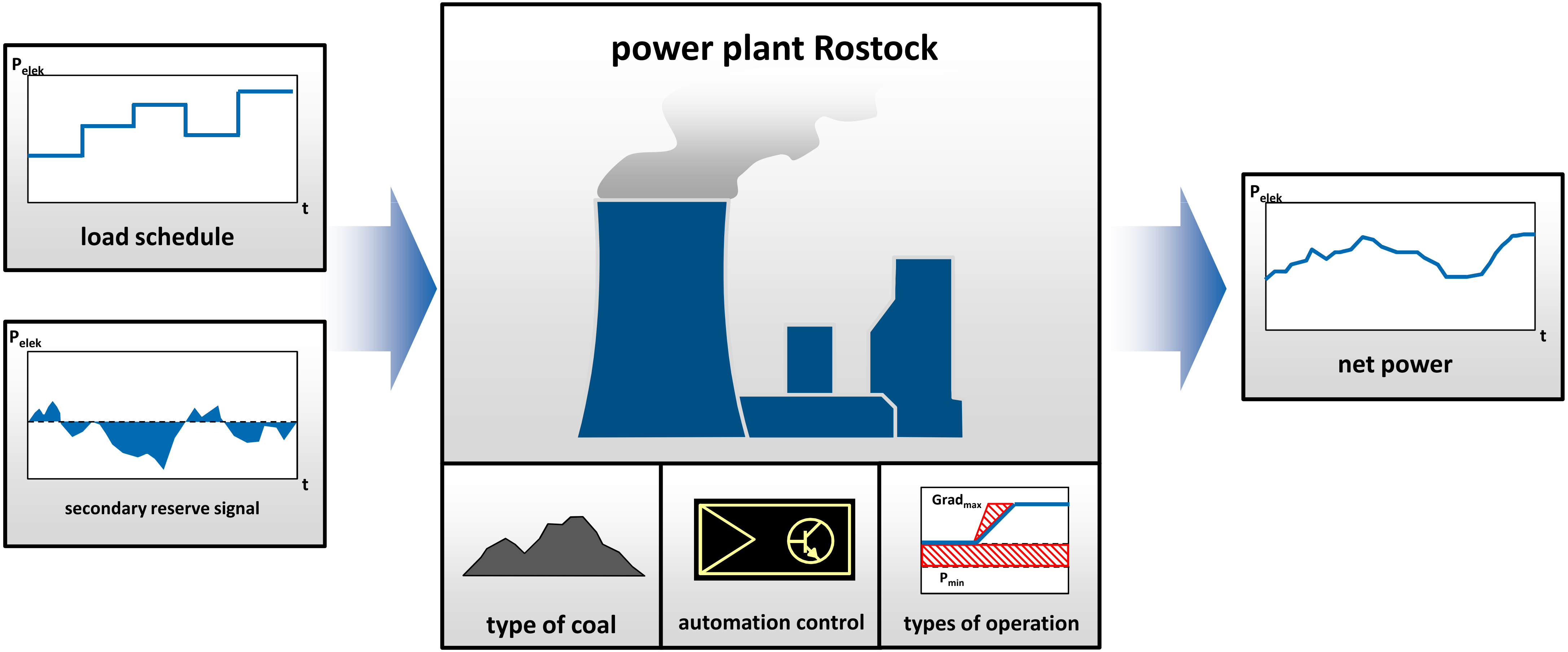
Presentation of the base scenario of the evaluation



Structure of Base scenario

- coupling of the detailed model of power plant Rostock with simplified model of the rest power plant fleet in the control area
- application of a load schedule (from power plant scheduling model)
- input of a critical load and wind scenario
- evaluation of secondary reserve demand from power difference in the control area

Derivation of compare scenario

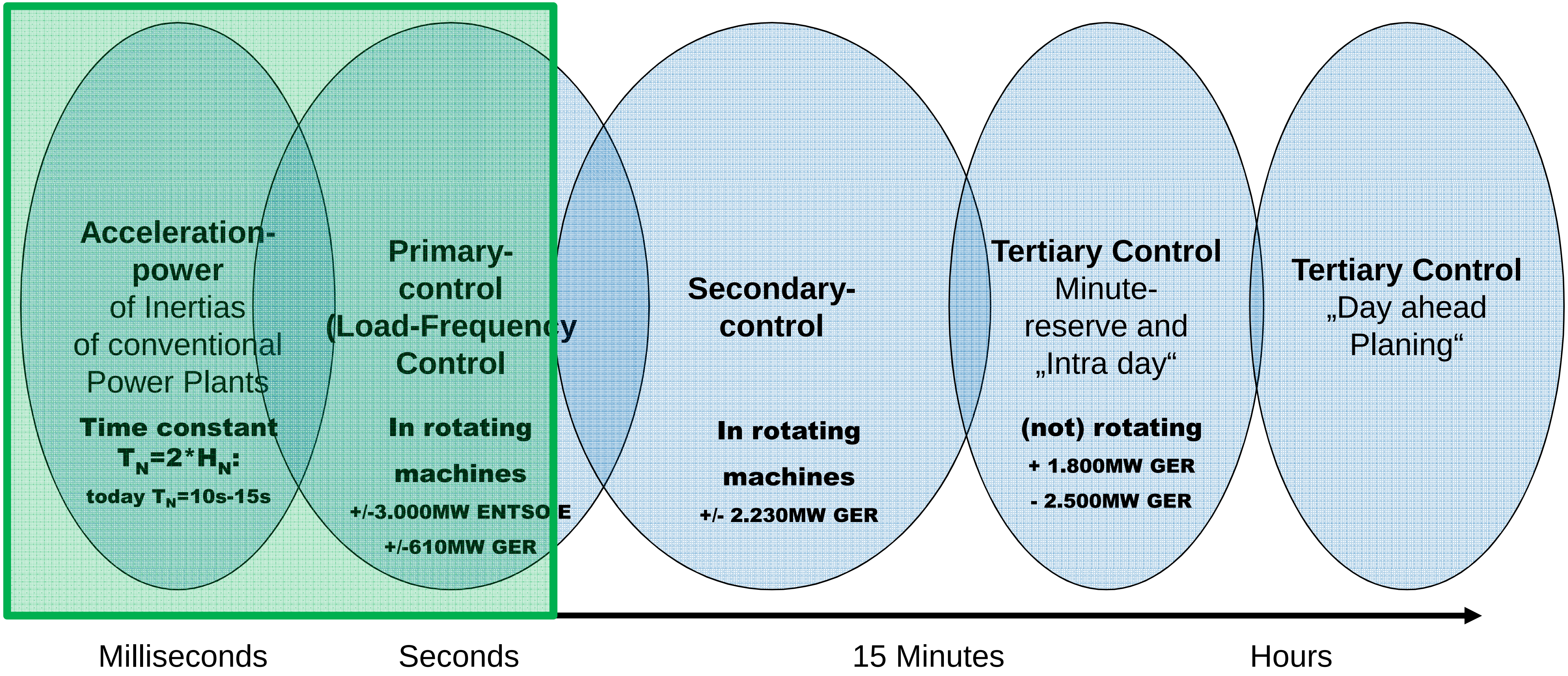


- Variation der used coal
- Implementation of optimized automation control
- usage of different operation parameters

Influence of decreasing inertia:
A short introduction into power system control

Project 345

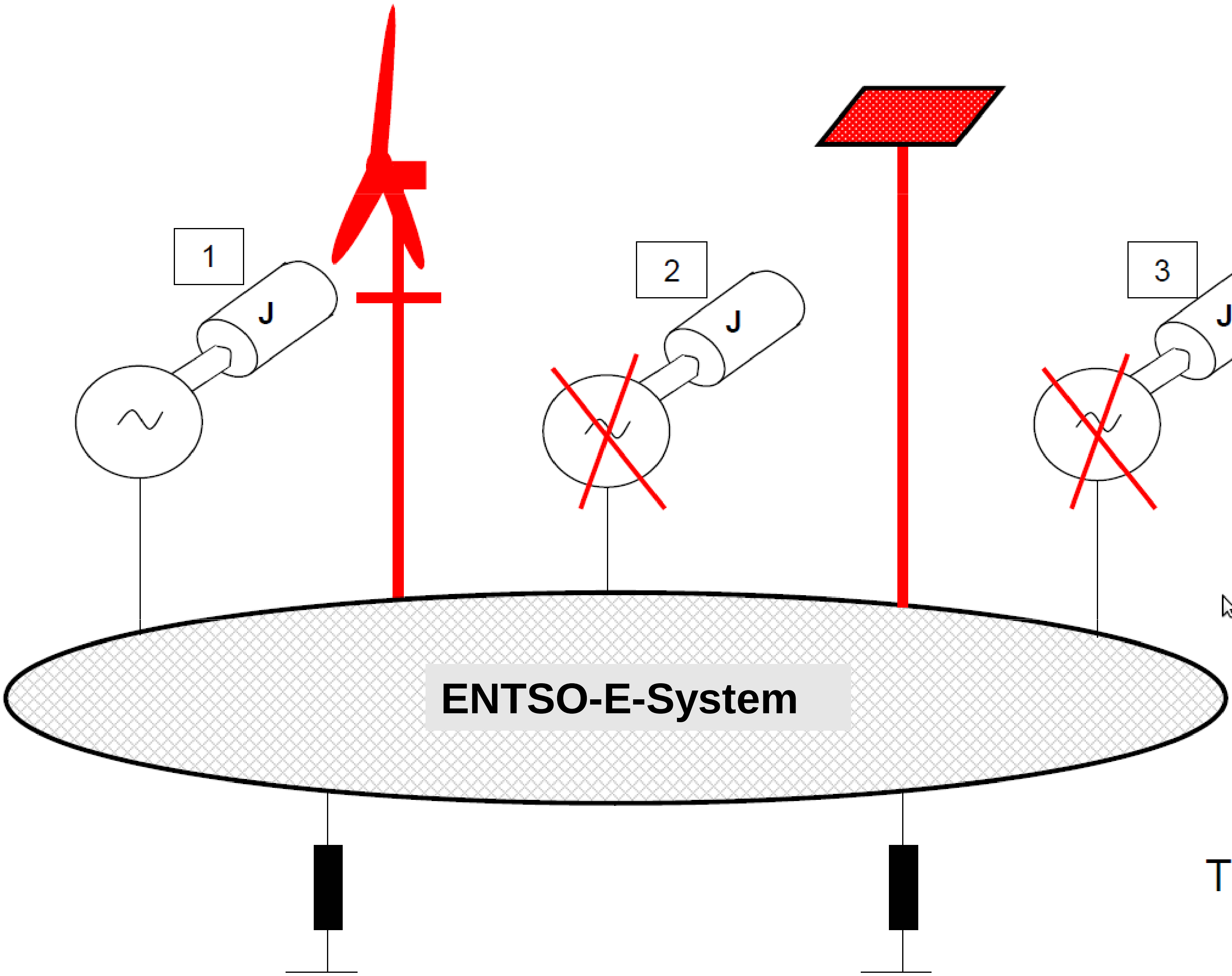
Control of Electrical Power Systems



Time frame

$$H_N = \frac{1}{2} \cdot \frac{J \cdot \Omega_N^{\ 2}}{P_N}$$

Development of the time constant T_N in the Entso-e-system



New World

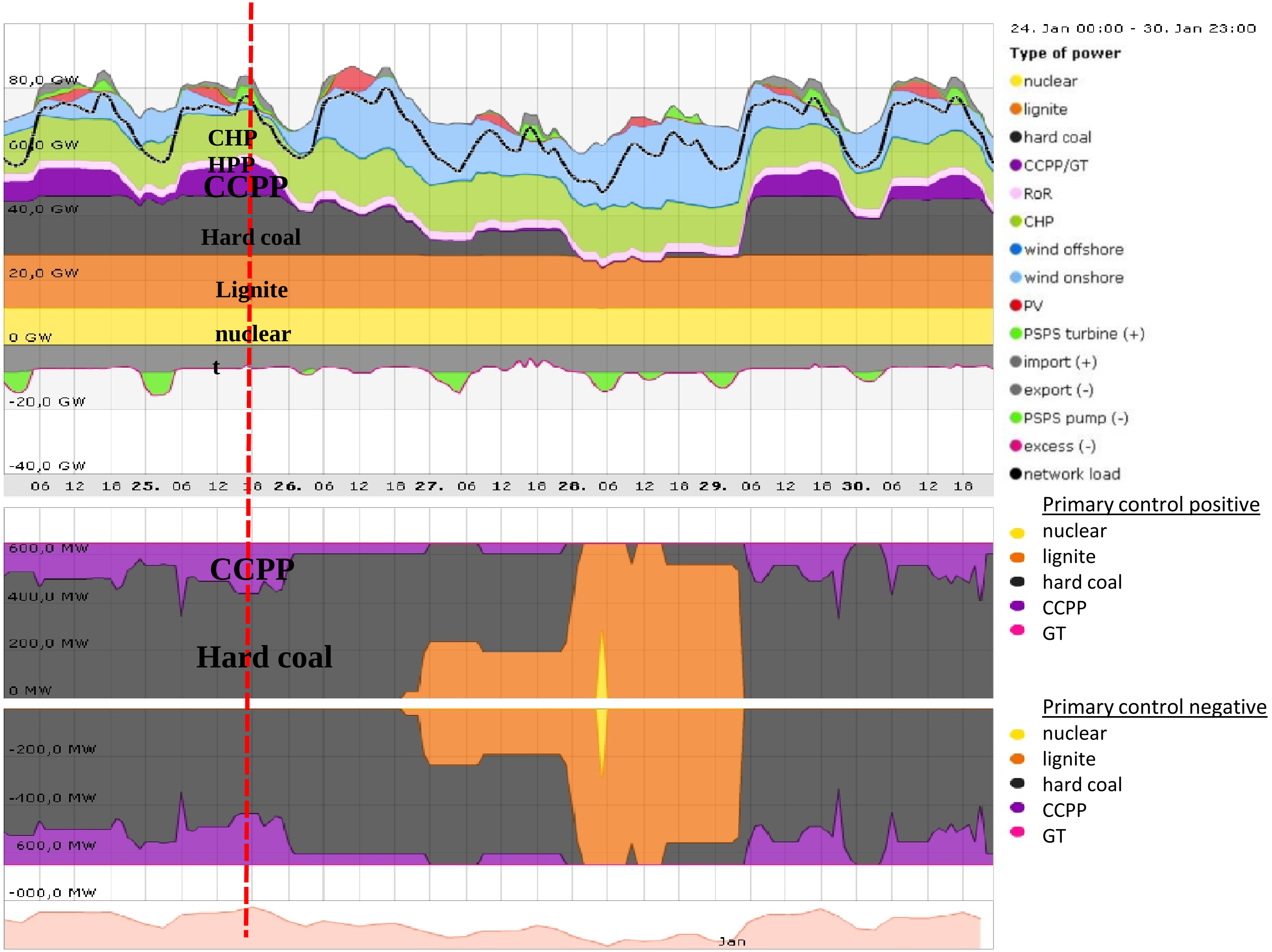
$$T_{G_i} = \frac{J_i * \Omega_N^2}{P_{G_i}}$$

Old World

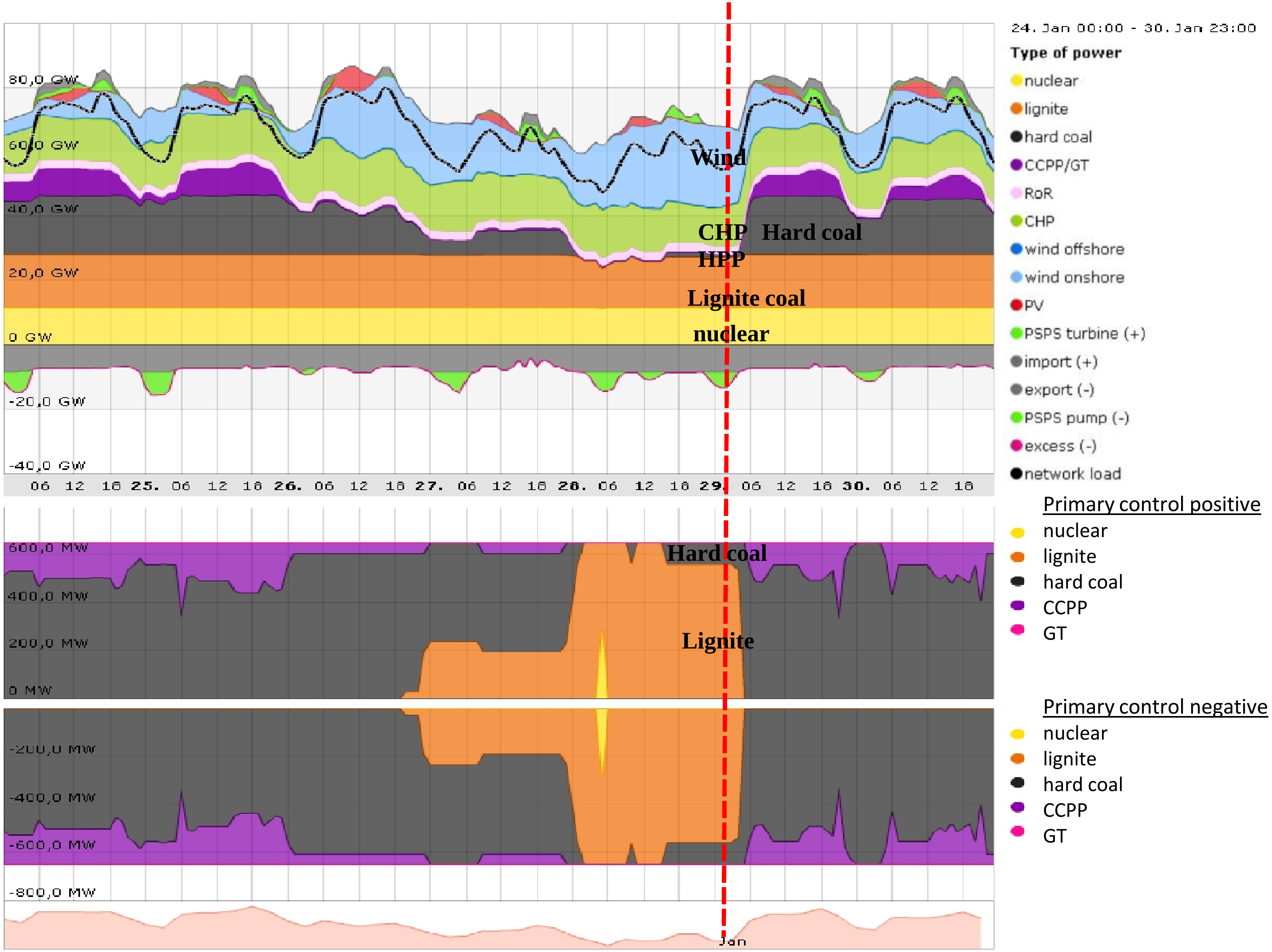
Network

$$T_N = \frac{\sum_{i=1}^{n} T_{G_i} * P_{G_i}}{P_N}$$

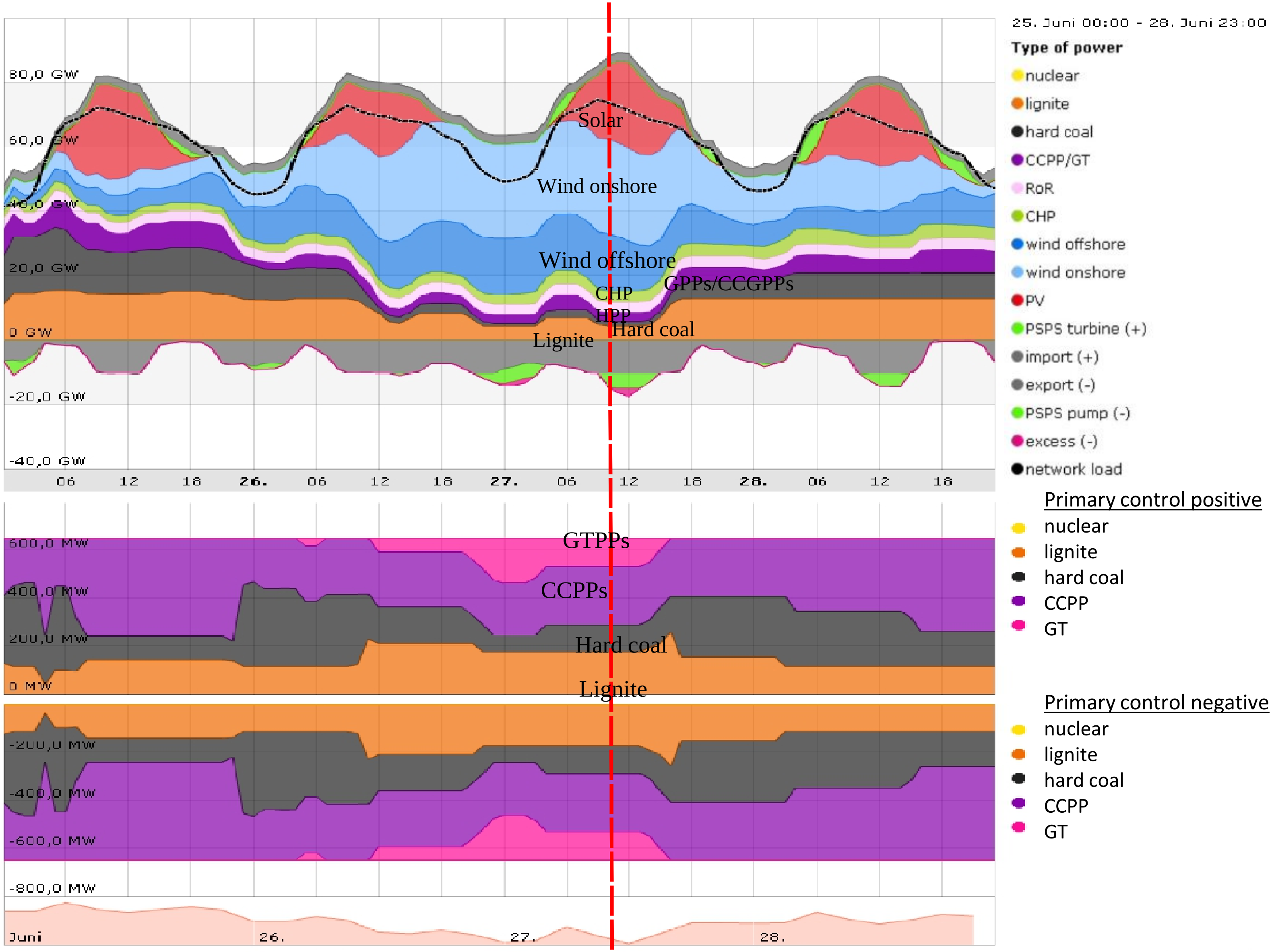
Case 1: Winter 2011 (0% Wind and PV)
TN = 10,6 s



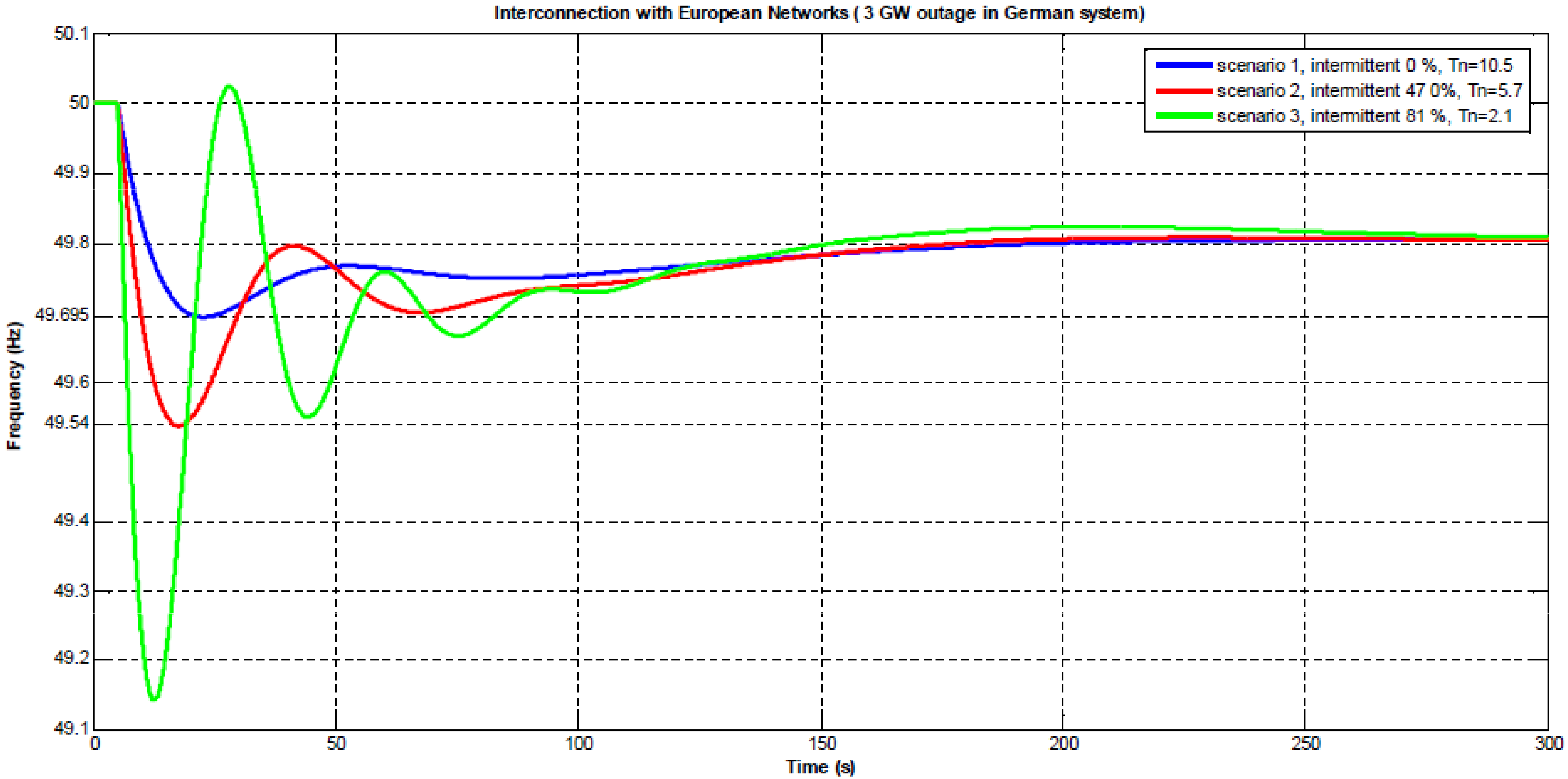
Case 2: Winter 2011 (47% Wind and PV)
TN = 5,7 s



Case 3: Sommer 2023 (81% Wind and PV)
TN = 2,1 s



Simulated Frequency Cases 1 - 3

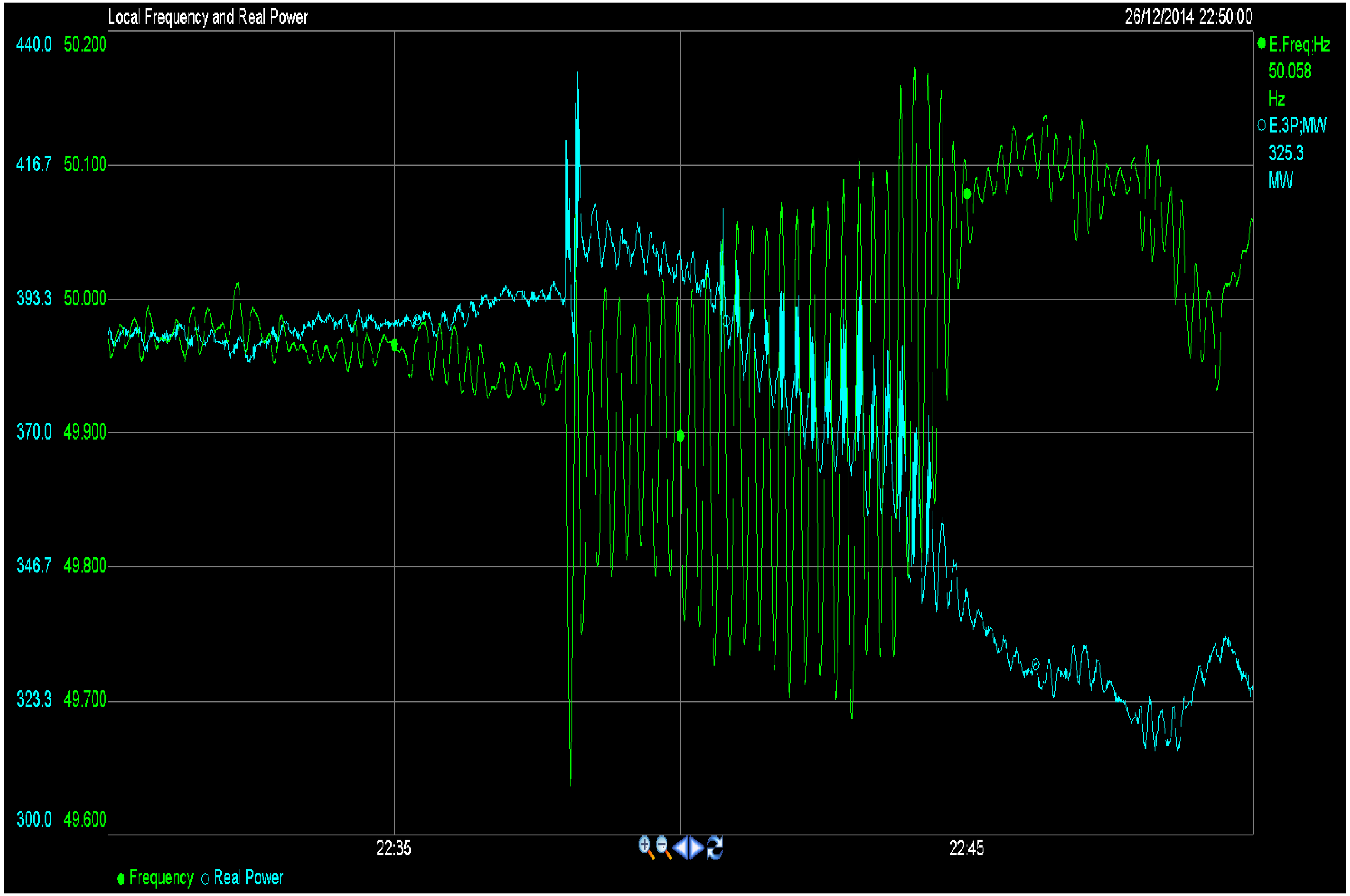


The frequency of interconnected model

- For scenario 3, the gas and nuclear power plants are shut down and replaced by intermittent renewable energy to increase to 81 %, and TN recalculated to 2.1s.
- As a result, the frequency deviation decreased to less than – 800 mHz with more oscillation . That means some of the protection devices will operate.

Measurements in the Irish Network
System frequency begins to oscillate due to reduced inertia
26 of December 2014 at 10:38 pm

Due to a changed strategy of power plant operation from partial load with several thermal power stations to only a few near full load, inertia was reduce to level that the systems startet to oscillate



Quelle: ESB, Electric Ireland

- Fraction of Wind 37%
- Only a few turbo-generators left

- Unit C30 Trip at 22:38
- MW; Hz
- 7 Min Oscillation
- Pk-Pk: ~0.3 – 0.4 Hz
- Period of Osc: 15 s (0.066 Hz)

Thank you for your attention!

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