Germany's Energiewende – Current and imminent challenges for the Transmission System Operator in Germany

Jens Jacobs
Transmission System Operation Brauweiler
Budapest, 04 December 2014

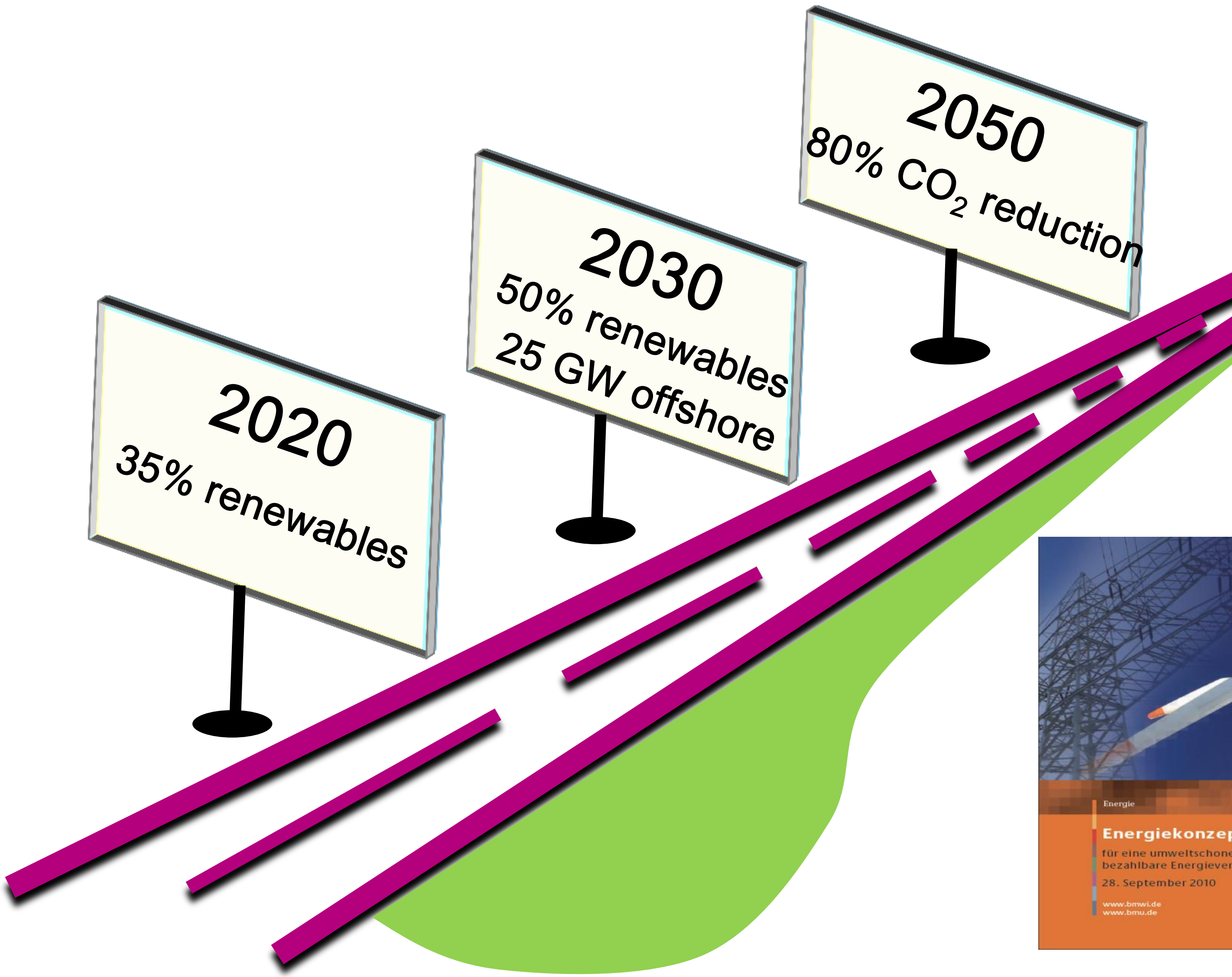
Agenda

- Germany’s Energiewende - Framework
- Transmission System Operation
- Major Challenge: Transition of the Electricity System due RES
- Impacts of RES on Conventional Generation and the Market
- Cooperation of TSO and DSO: Cascade in Generation Dispatching
- Outlook and Conclusion

Far-reaching changes due to the goals of the EU and the German Federal Government

- EU
  - Completion of the European internal electricity market
  - Integration of renewable energy sources (RES)
  - „EU 20-20-20“:
    -20% energy consumption; -20% greenhouse gas emission; +20% energy efficiency
  - European Legislation – Network Codes – to guarantee system security and establish harmonized market rules
- Federal Government Germany
  - Nuclear phase-out till 2022
  - 35% power generation from RES till 2020 (80% till 2050)
  - 40% reduction of greenhouse gases till 2020 (80% till 2050)
  - 20% reduction of primary energy consumption till 2020 (80% till 2050)

Germany, quo vadis?
Road to "Green Revolution"



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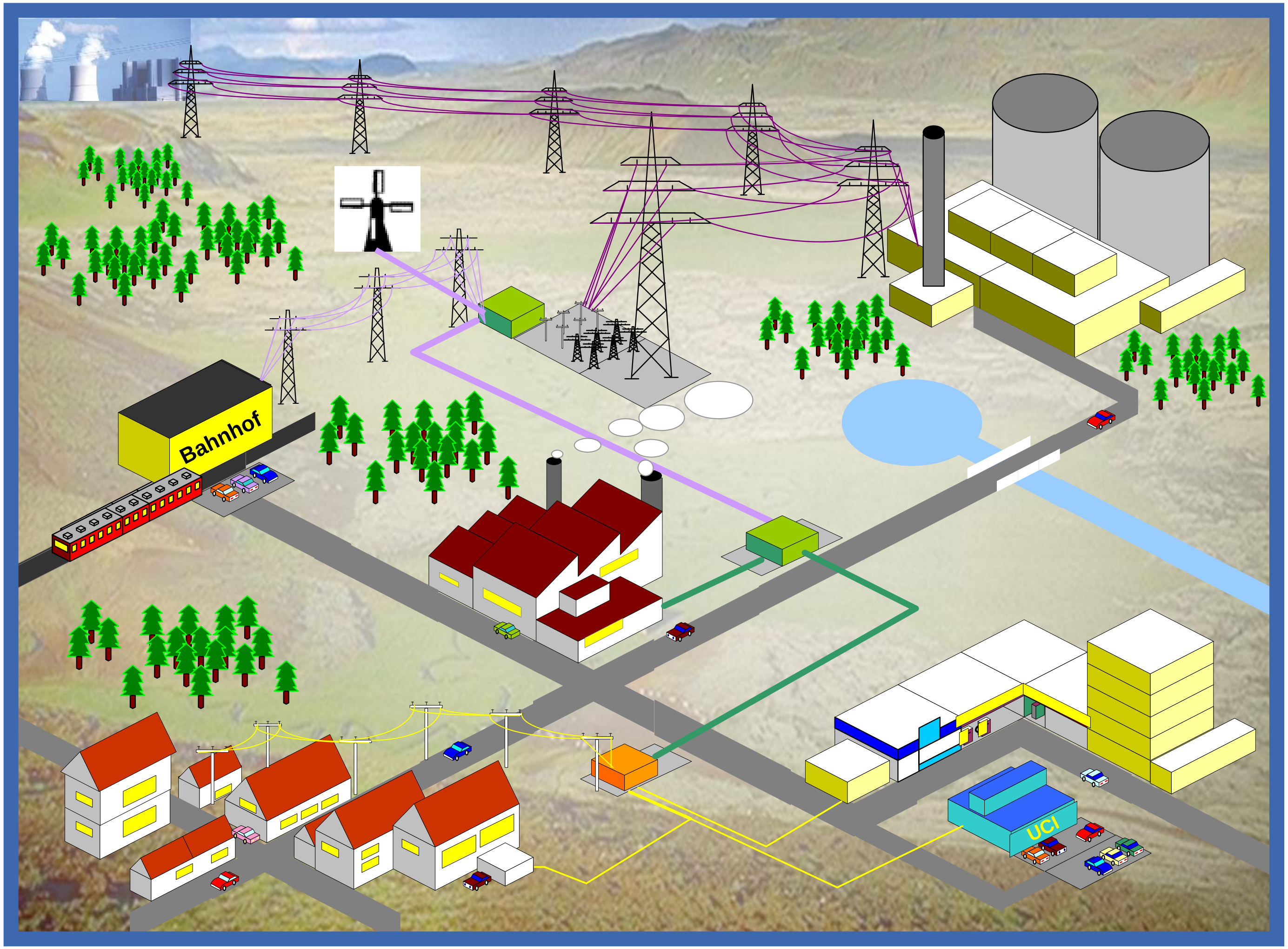
From power plant to households



380-kV / 220-kV:
- large-scale PPs
- transits

110-kV:
- Industry PPs
- Industry
- RES Infeed

Distribution level:
- cutomers
- distributed PPs

extra high voltage network 380 kV /220 kV
high voltage network 110 kV
medium voltage network 20 kV
low voltage network 0,4 kV

Substation
Transformer station

The Transmission Grid (380/220kV-Grid)

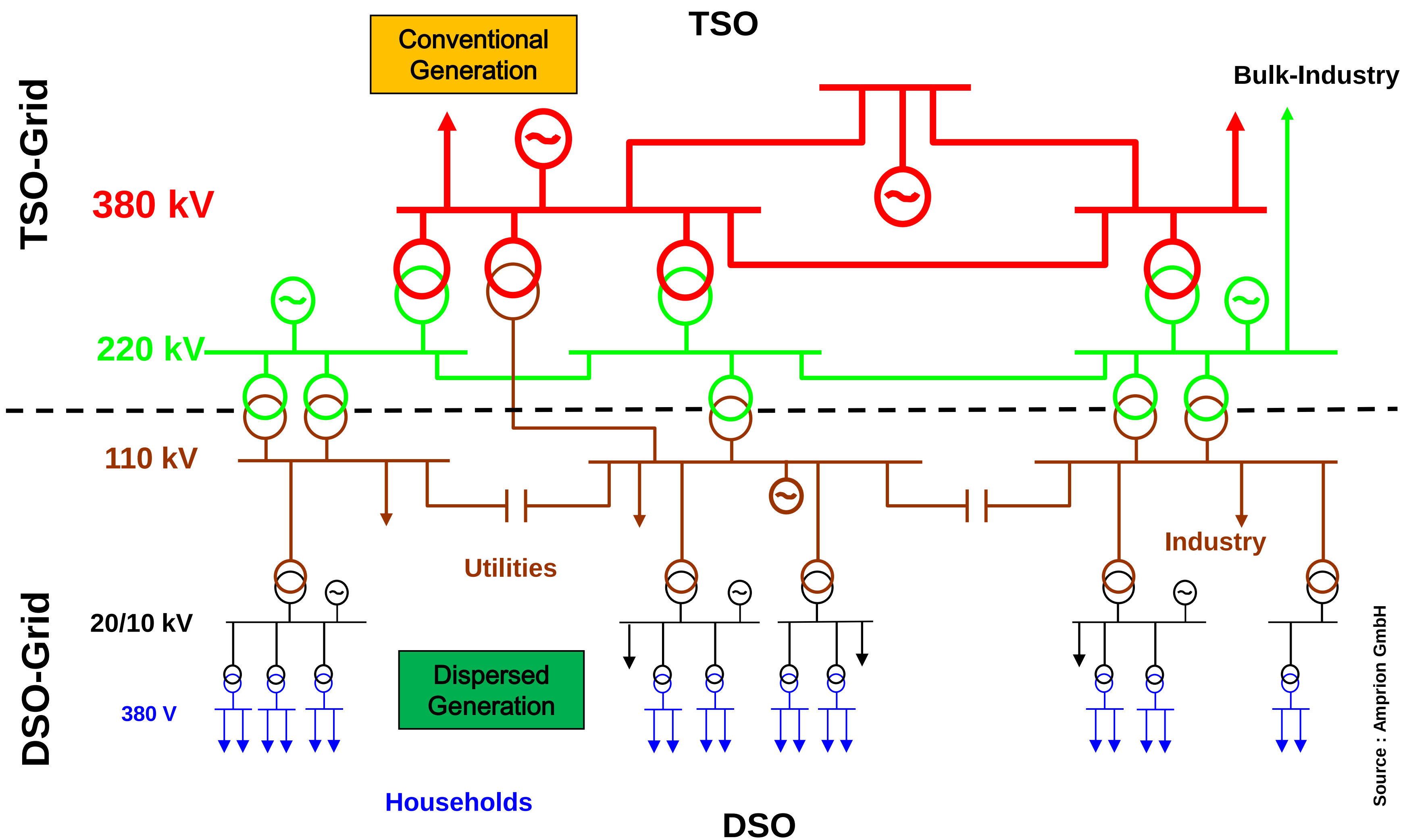
The electrical System “Transmission Grid”

- Physical Unit (Lines, Transformer, Substation, Power Plant, Consumer Installation, etc.)
- International meshed system

Sensitive “real time” - System

- Electrical Energy is **not directly storable**
- Production and Consumption have to be balanced **at any time**
- The Electrical System is operated in **Real time (24h/365d)**
- **EU Legislation and National laws (EnWG/EEG)** define the Market Rules and the legal framework
- The Transmission System Operator (TSO) is in charge of **security of supply** (§ 13 EnWG)

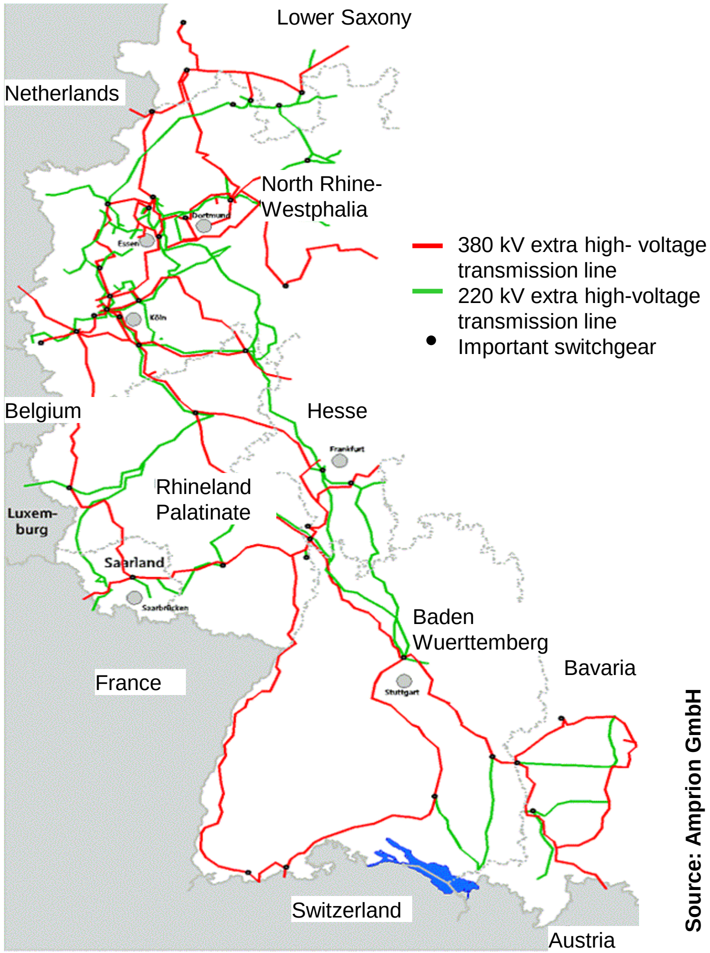
Structure of the German electrical power supply



Security of Supply: Backbone of Electricity Supply

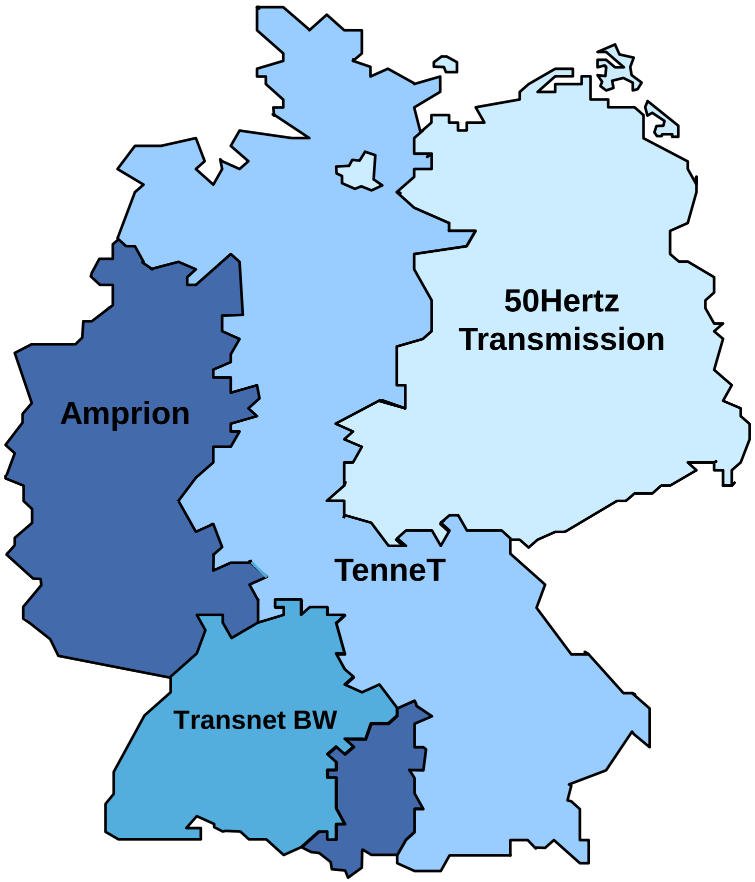
- Largest transmission system in Germany with a circuit length of approx. **12,000 km** at the 380/220 kV level and **165** substations
- Connects the generation units of the lignite-fired power plants on the lower Rhine with the hydroelectric stations in the Alps: installed capacity of power plants approx. **40 GW**
- Through its central position in Europe, Amprion's transmission system is an important hub for electricity trading between north and south as well as east and west: approx. **4,000 schedule** nominations per day
- Interconnectors to eight foreign transmission system operators in five countries (NL, L, F, CH, A) enables Amprion to meet the specific transmission requirements of European power traders at an utmost level of transmission reliability
- Amprion's electricity network is part of the European interconnected ENTSO-E system

380/220 kV Network of Amprion



Source: Amprion GmbH

Operational Areas of German Transmission System Operators



	Amprion	TenneT	50Hertz	Transnet BW
Network length [km] (380 kV)	5.300	5.800	6.870	1.970
Network length [km] (220 kV)	6.100	5.300	2.870	1.721
Served area [km²]*	73.100	140.000	109.000	34.600
Annual transmission [TWh]	27	20	18	11
Share load [%]**	35	32	19	14

Source : Amprion GmbH

* in Germany
** Renewable Energy Act load compensation 2005

Security first:

Transmission System Operation Amprion (I)

The main control room: system control and system management

- Tasks for Amprion (**TSO Responsibility**)
- Tasks for the German TSOs (**National Responsibility**)
- Coordination Center ENTSO-E RG CE North (**International Responsibility**)

Security first:
Transmission System Operation Amprion (II)

TSO Responsibility

- system control and system management of the transmission grid 380/220 kV
- disturbance management
- congestion management (preventive und curative)
- planning and acquisition of ancillary services
- Load-Frequency-Control and managing controlling power range of the Amprion control zone
- management of Wind and PV and prediction of system load
- system balancing
- process technology and –data management

Security first:

Transmission System Operation Amprion (III)

Nationale Responsibilities

- coordination of the power exchange programs between the German TSOs and with foreign TSOs
- pluralistic Load-Frequency-Control of the German control block
- national quantity balancing of the German control block

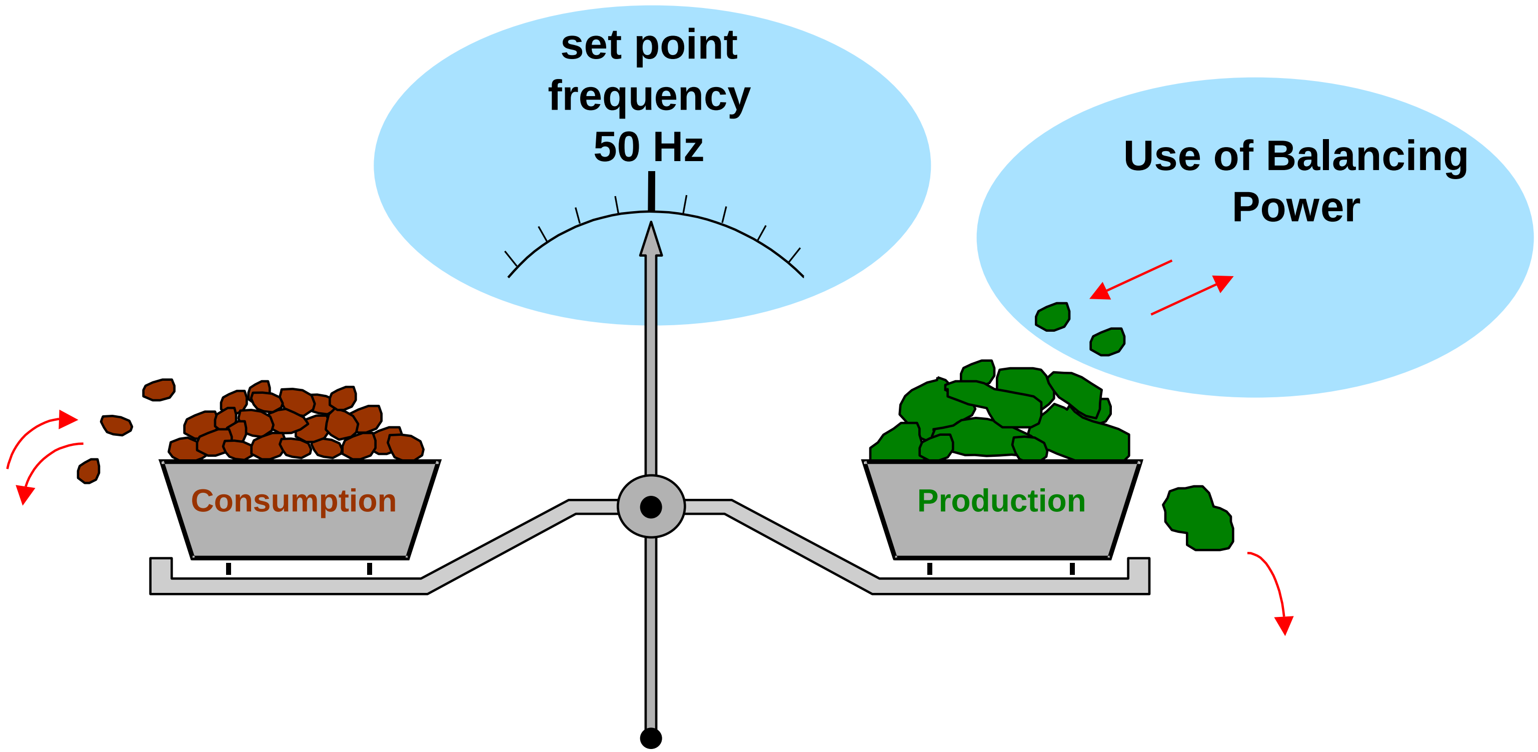
Security first:

Transmission System Operation Amprion (IV)

Internationale Responsibilities

- international coordination of the power exchange programs RG CE North / South with Swissgrid
- international quantity balancing of ENTSO-E RG CE North
- congestion forecast (DACF)
- Data management and clearance for the ENTSO-E ITC Process
- Hosting and server operation of process technology for CWE Market Coupling
- Hosting and server operation of process technology for international security analysis within TSC Security initiative (11 TSOs)
- Hosting of the Security Service Center (Germany / The Netherlands)

Load Frequency Control and Power Balance



Forecast deviation

Load interference

Tripped Load

Generation loss

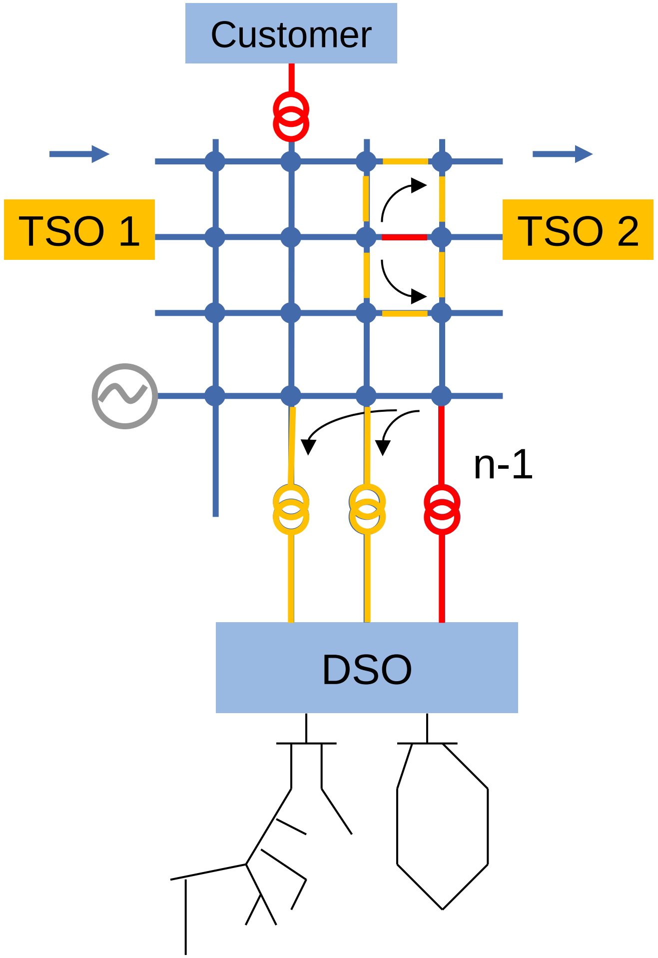
Forecast deviation (RES)

Security of Supply: the „(n-1) - Criterion“

"N-1" CRITERION:

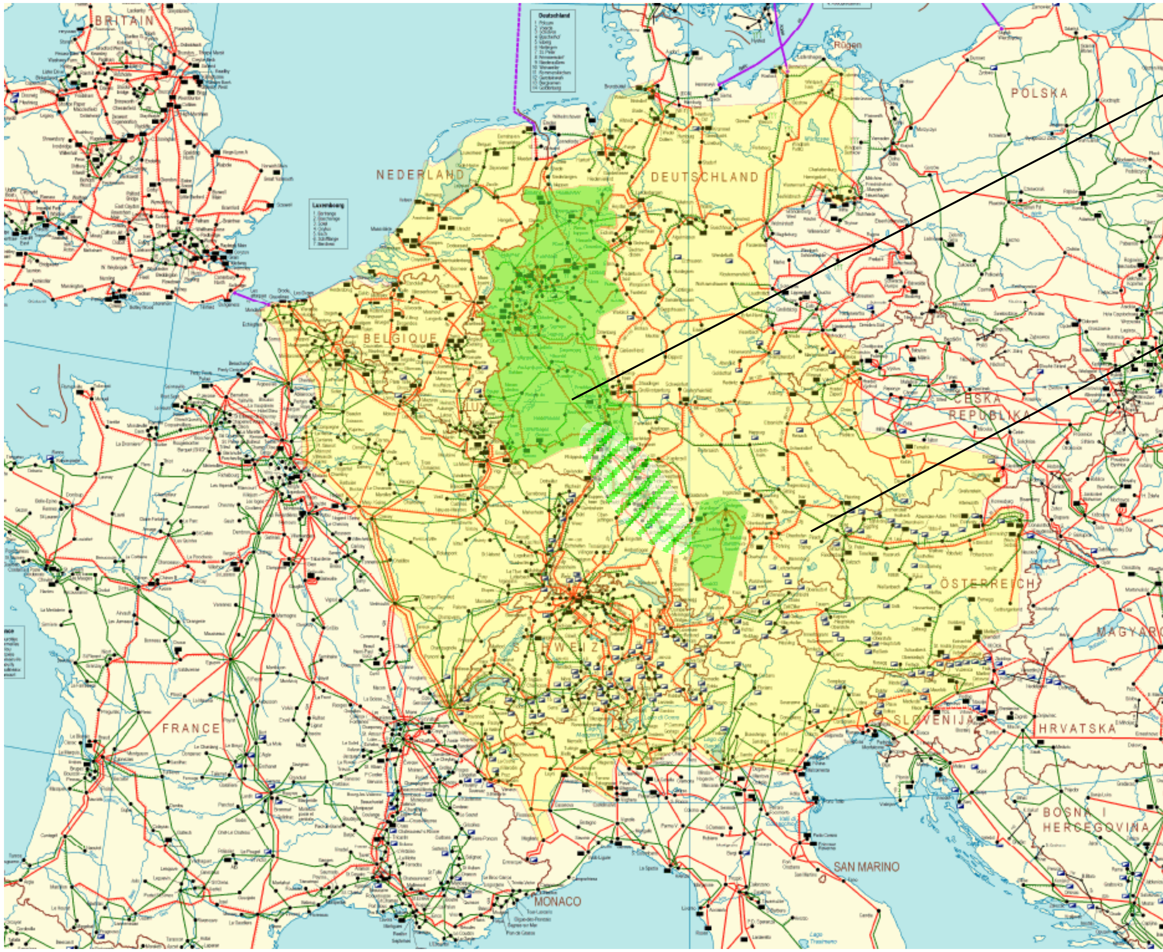
Any probable single event leading to a **loss of Power System elements** (generating set, transmission line, transformer, etc.) should **not** endanger the **security of interconnected operation**:

- Loss of Consumption
- Interconnected System Stability
- Violation of limit values (Current, Voltage, Frequency Deviation)
- Cascade of Tripping



“N-1” Security Criterion: Regional Approach

Observability area of Amprion



Source: Amprion GmbH

responsibility area (Amprion)

165 substations

observability area

435 substations

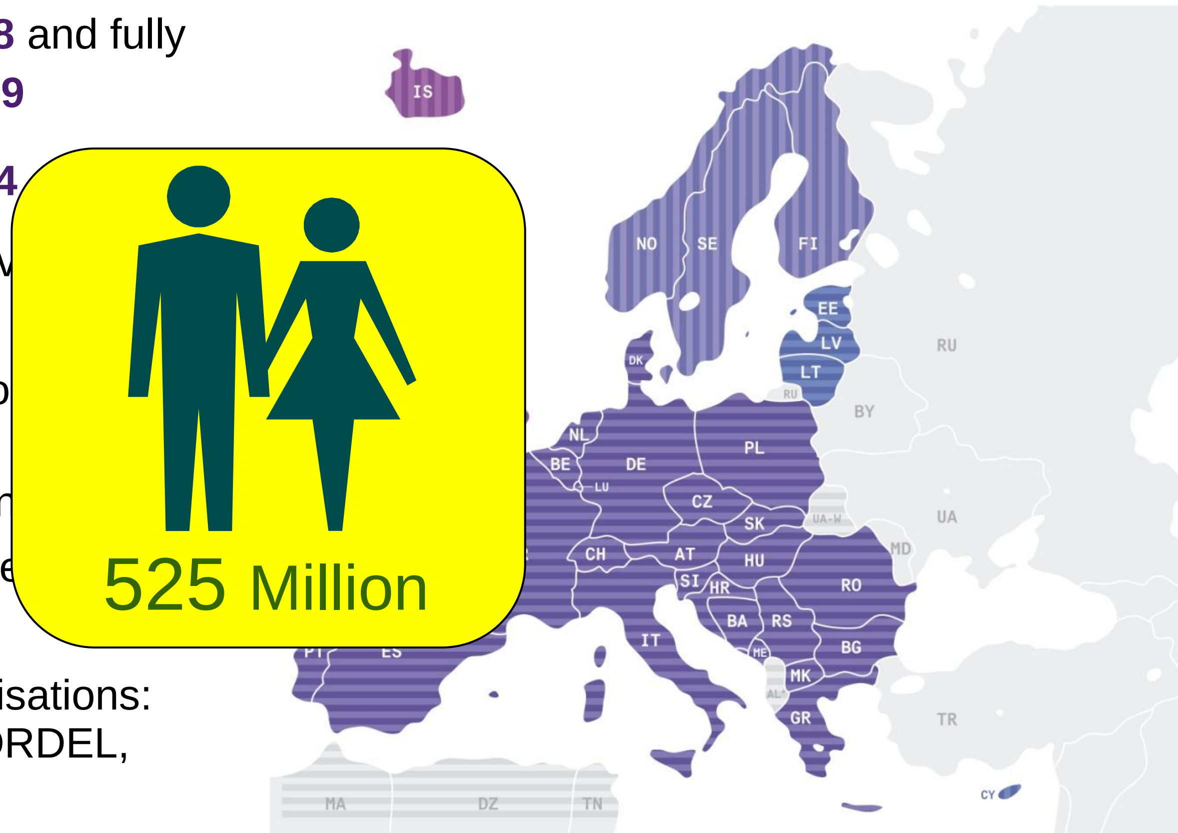
Dramatic extended data volume for

On-line Calculations

- Load flow Analysis
- (n-1)-Security Calculations

The European Interconnected System
ENTSO-E

- Founded **19 December 2008** and fully operational since **1 July 2009**
- Represents **42** TSOs from **34**
  - **525** million citizens serv
  - **828** GW generation
  - **305,000** km of transitio managed by the TSOs
  - **3,400** TWh/year deman
  - **400** TWh/year exchange
  - **5** synchronous areas
- Replaces former TSO organisations: ATSOI, BALTSO, ETSO, NORDEL, UCTE, UKTSOA



Source: ENTSO-E

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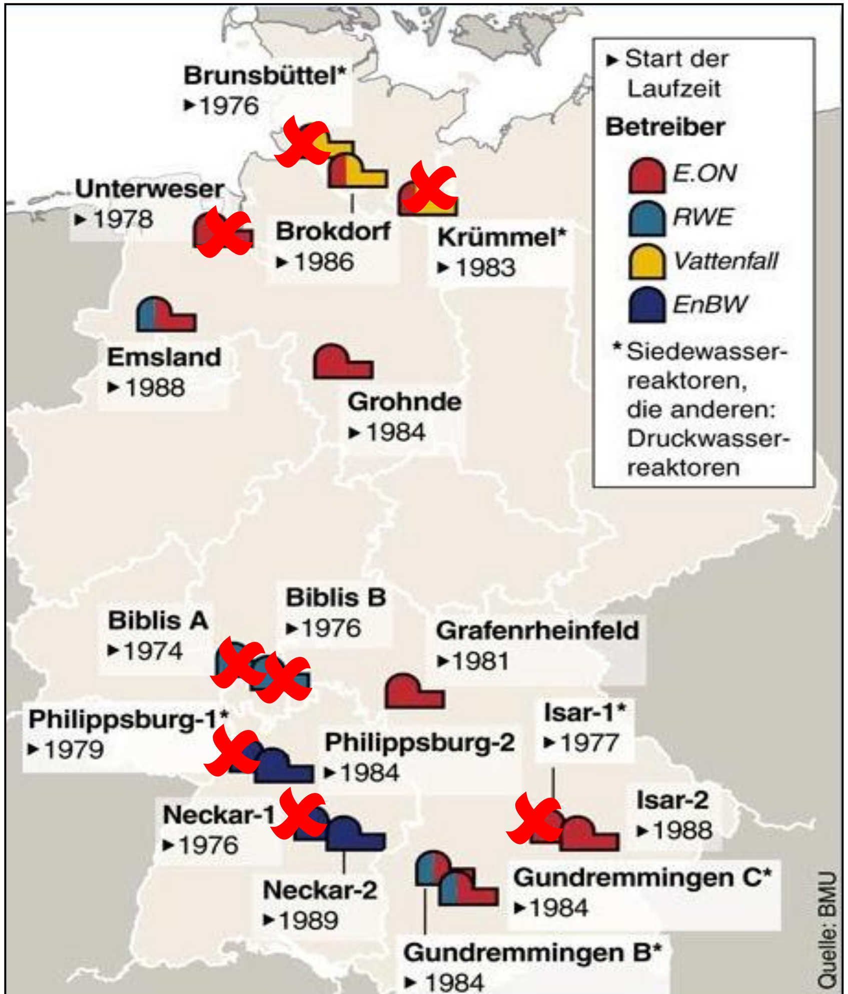
Nuclear phase out in Germany, March 2011

Nuclear power plants in Germany

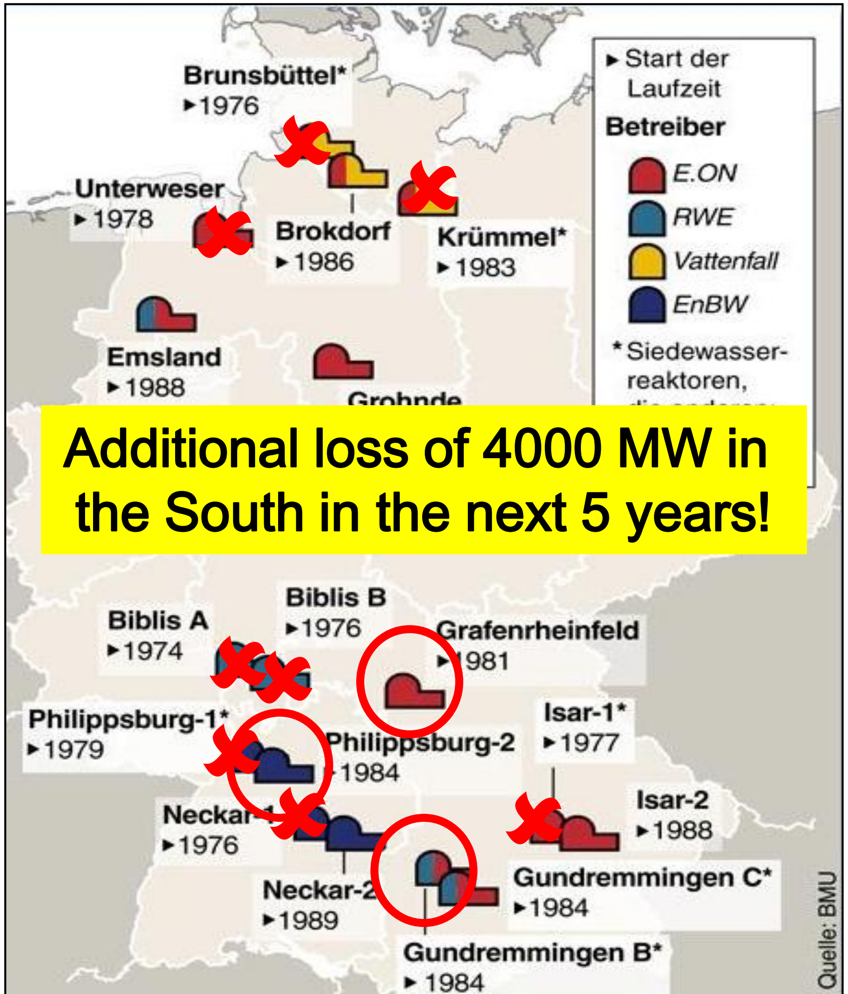


Directly Effected power plants

Biblis A	1167 MW
Neckarwestheim	645 MW
Philippsburg 1	890 MW
Unterweser	1345 MW
Isar 1	878 MW
Biblis B	1240 MW
Brunsbüttel	771 MW
Krümmel	1345 MW
Total	**8 281 MW**

Nuclear phase out in Germany till 2022

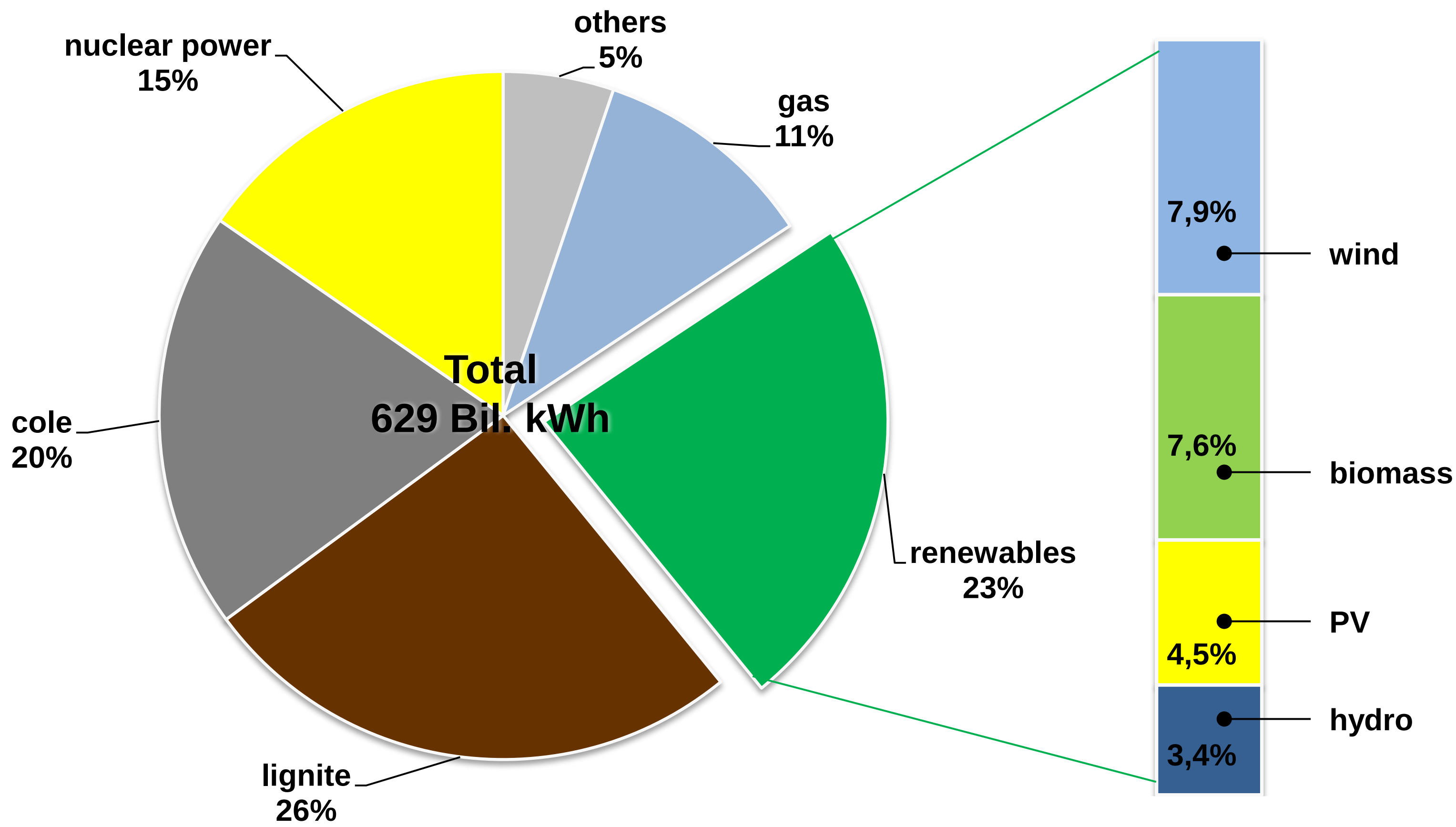
Nuclear power plants in Germany



2015:	
Grafenrheinfeld	1275 MW
2017:	
Gundremmingen B	1284 MW
2019:	
Philippsburg 2	1402 MW
2021:	
Brokdorf	1410 MW
Grohnde	1360 MW
Gundremmingen C	1288 MW
2022:	
Emsland	1329 MW
Isar 2	1410 MW
Neckarwestheim	1310 MW
Total	**12.068 MW**

Generation mix in Germany 2013

Share of renewable energy 23%

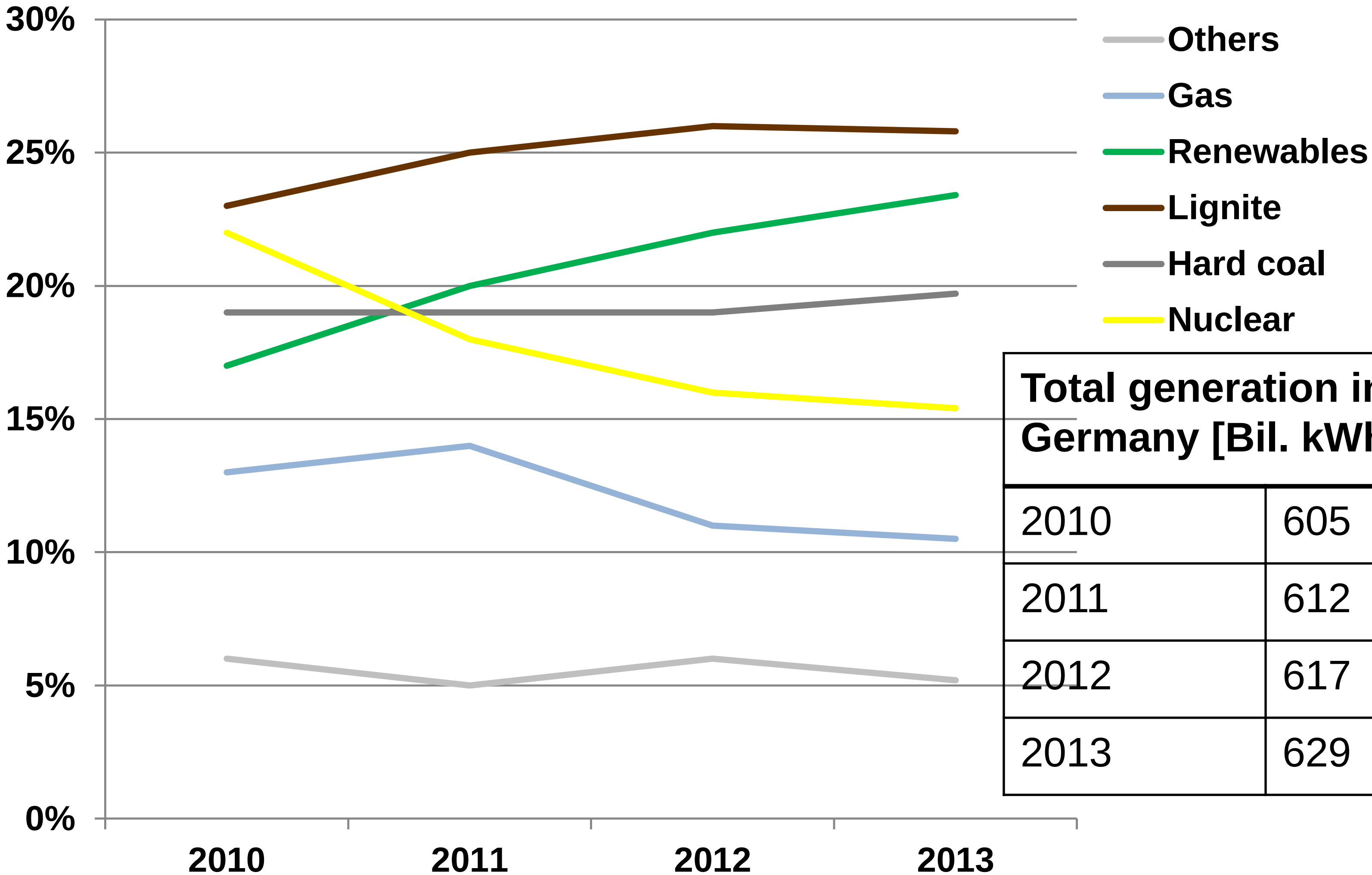


RES in Hungary: $\approx 7 - 8\%$

Source: BDEW 01/2014

Development of Generation Capacity in Germany

since 2010 (share of primary energy)



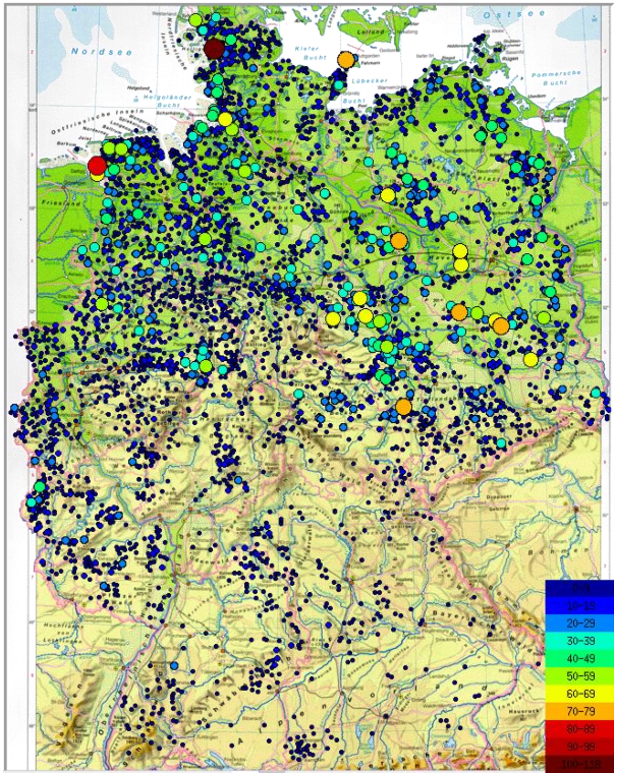
Total generation in Germany [Bil. kWh]:	
2010	605
2011	612
2012	617
2013	629

Source: Amprion GmbH

Impacts of Renewable Generation on Grid Security (1)

Renewable Generation leads to an inharmonic and unusual power flow in the Grid:

- In Germany Wind generation is installed in the northern and eastern part of the country
- High Wind power leads to bulk energy flows from North to South because most industry is concentrated in southern part of Germany



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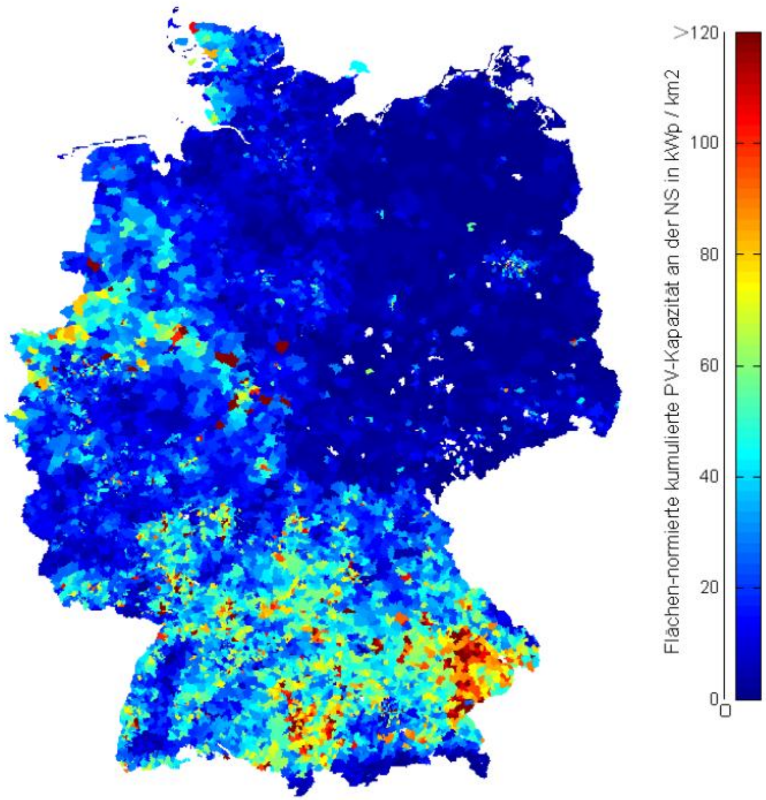
Impacts of Renewable Generation on Grid Security (2)

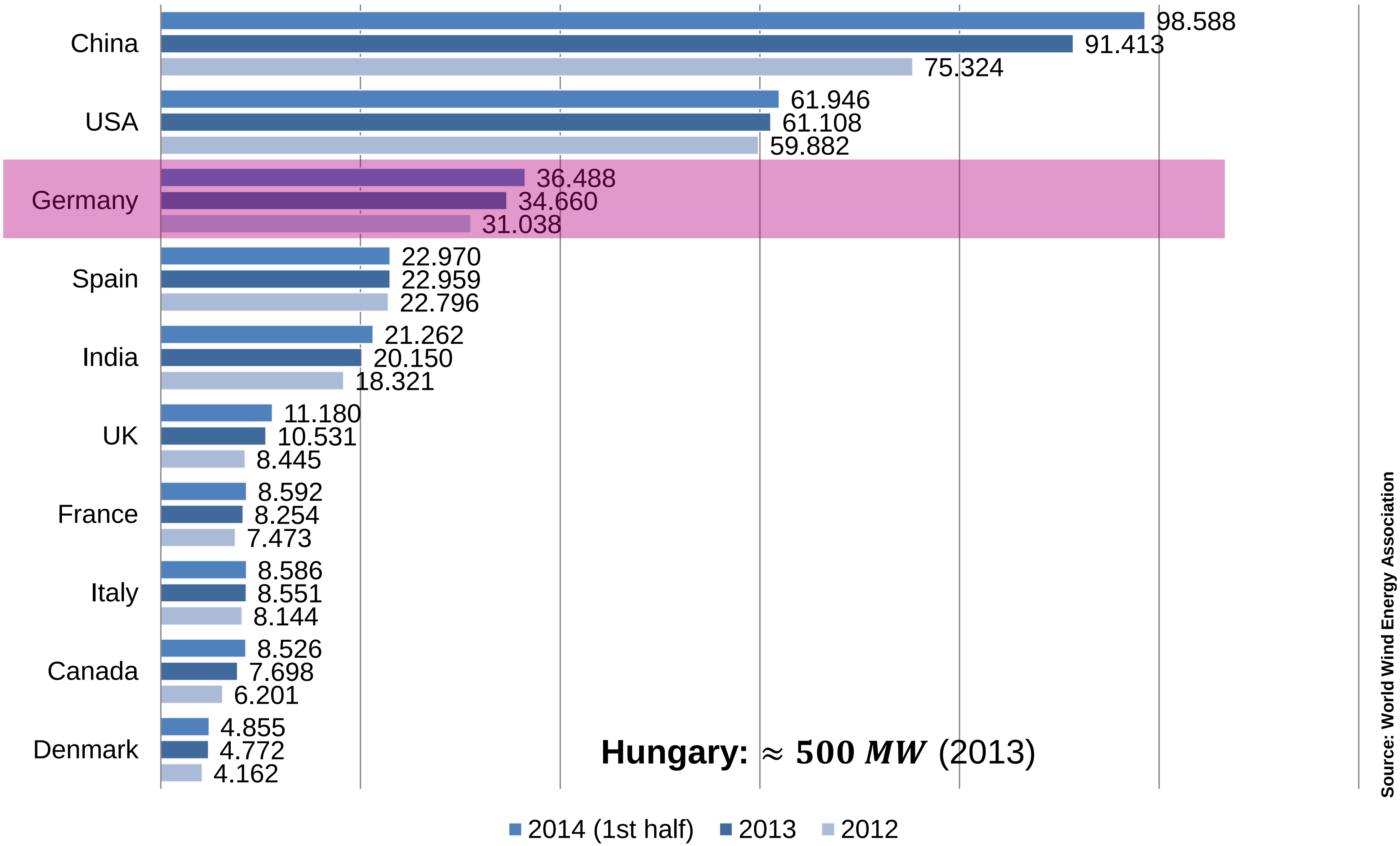
Renewable Generation leads to an inharmonic and unusual power flow in the Grid:

- In Germany <u>PV</u> generation is installed in the southern part of the country
- High PV power leads to bulk energy flow in DSO grid and from DSO to TSO

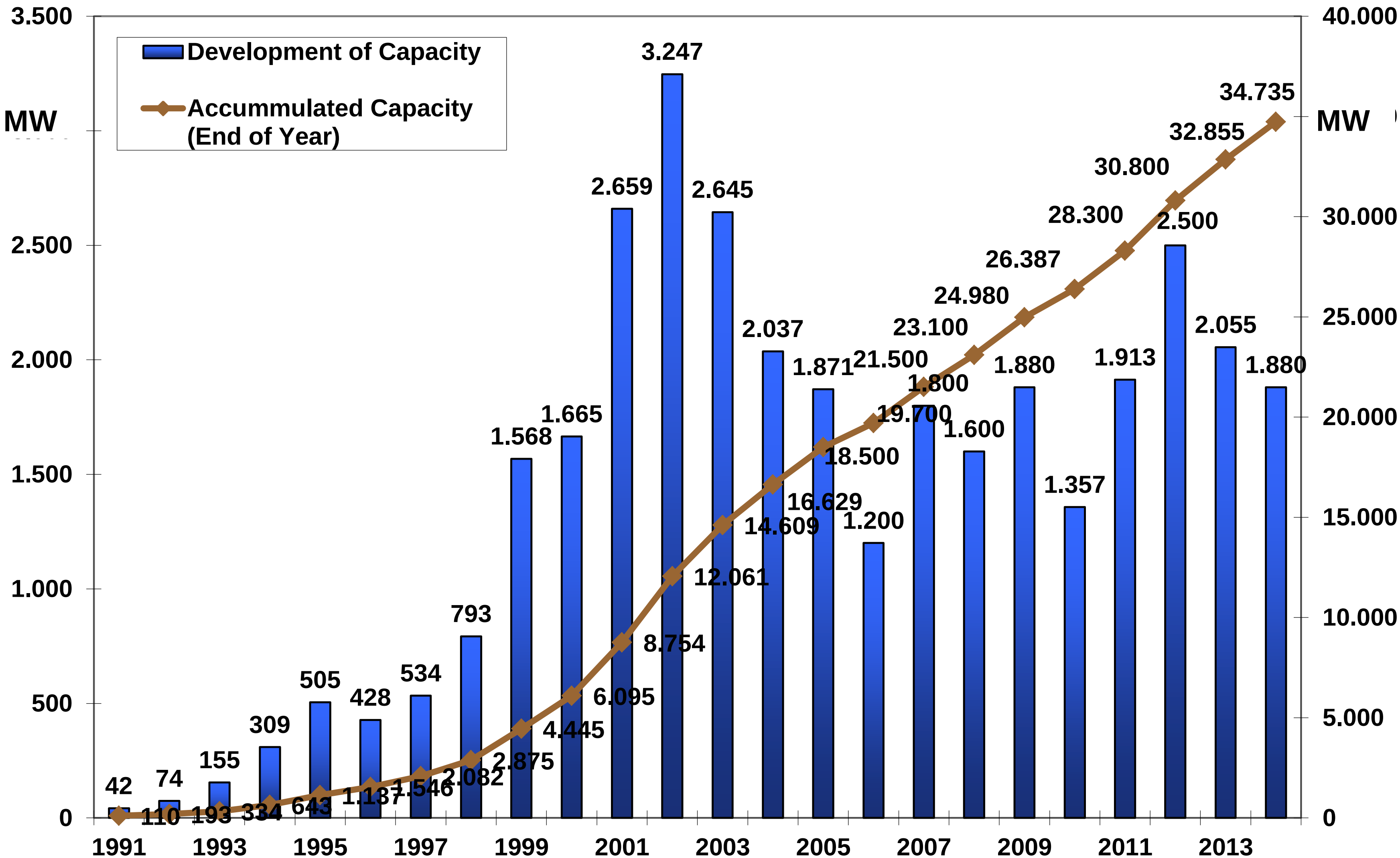


Top 10 Countries by Total Wind Capacity [MW]

2012 to 2014 (first half)



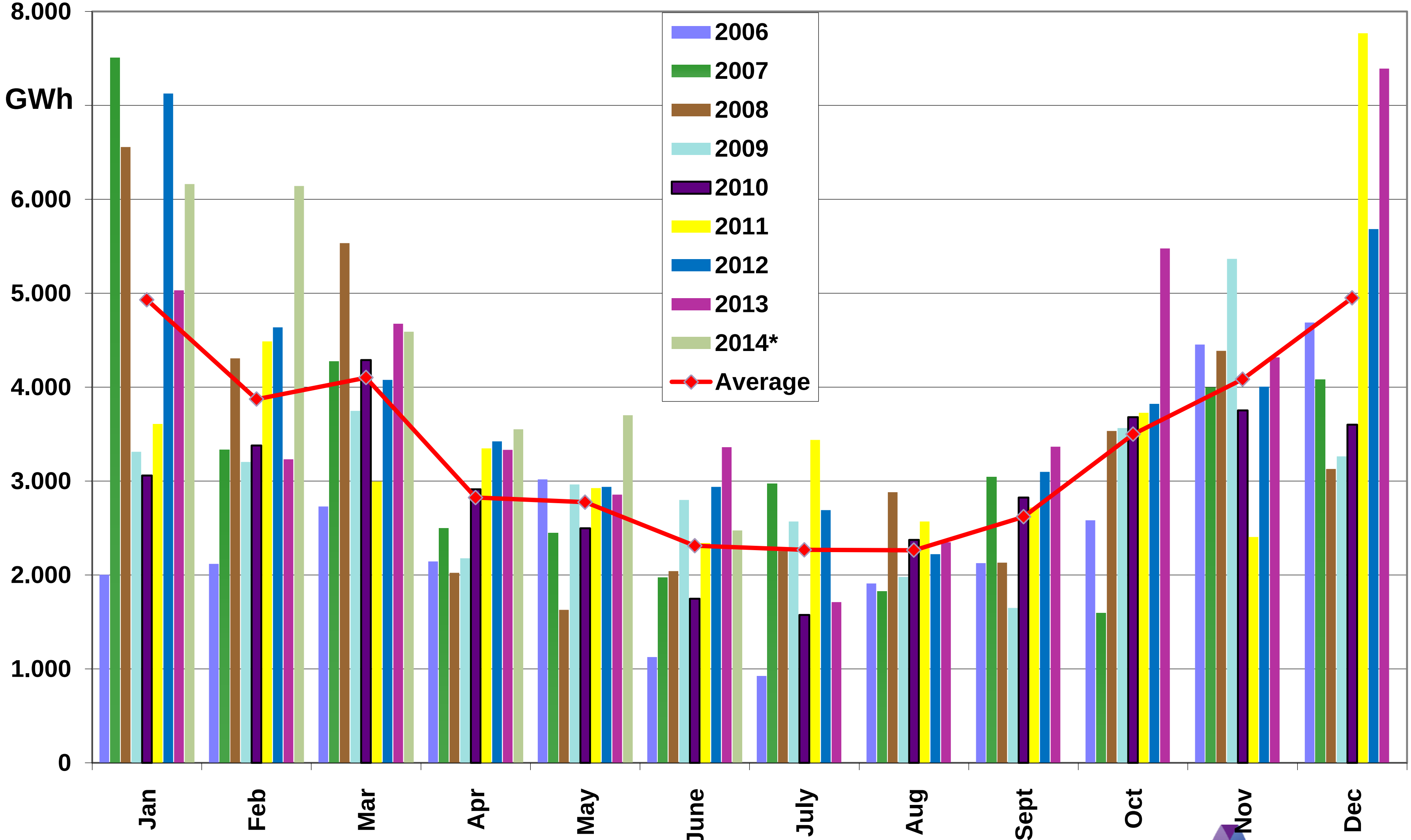
Wind Power Development in Germany



Source: IWES, TSOs

Monthly Production of Wind Energy in Germany

2006 to 2014 (1st half)

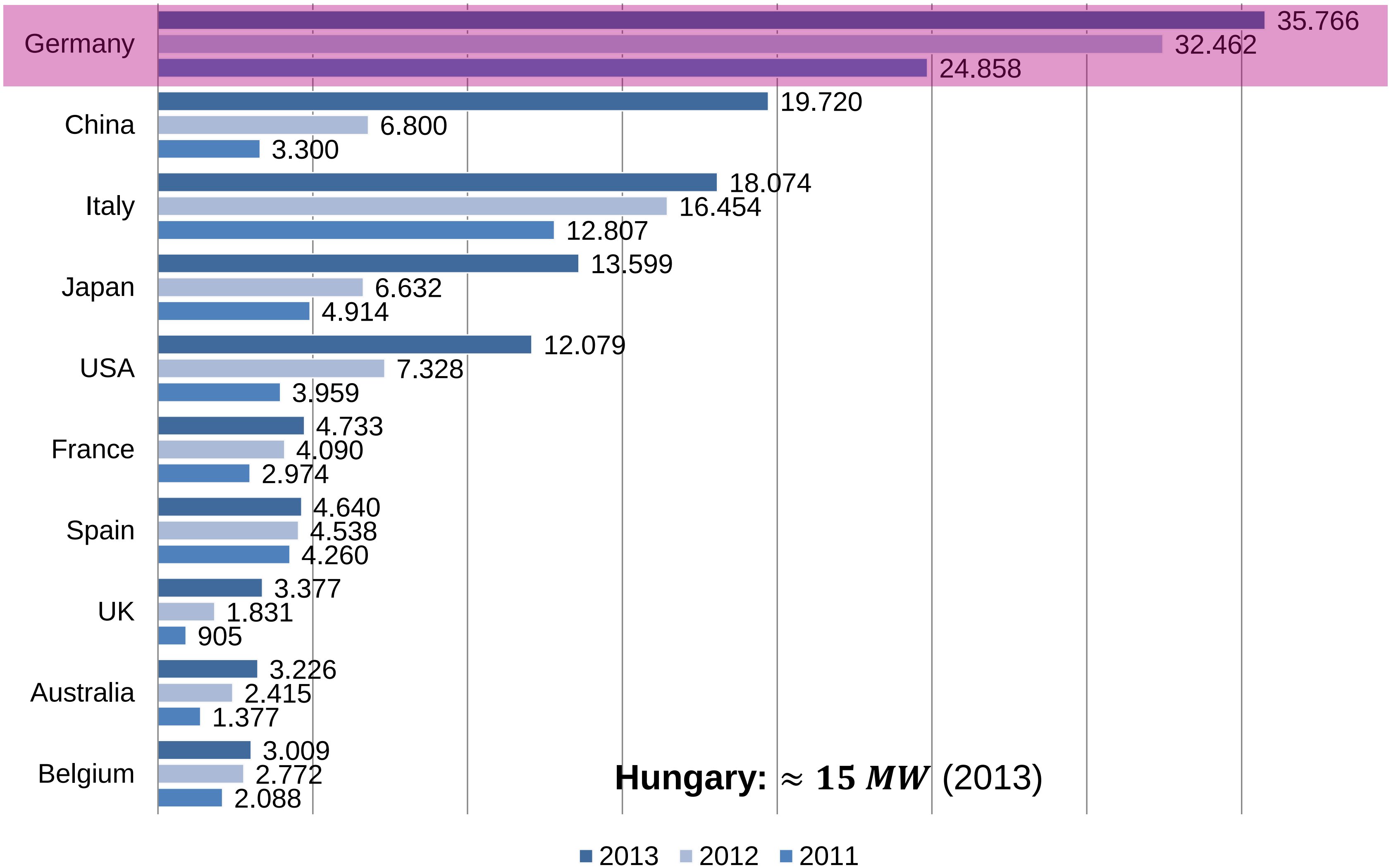


2014*: 1st half

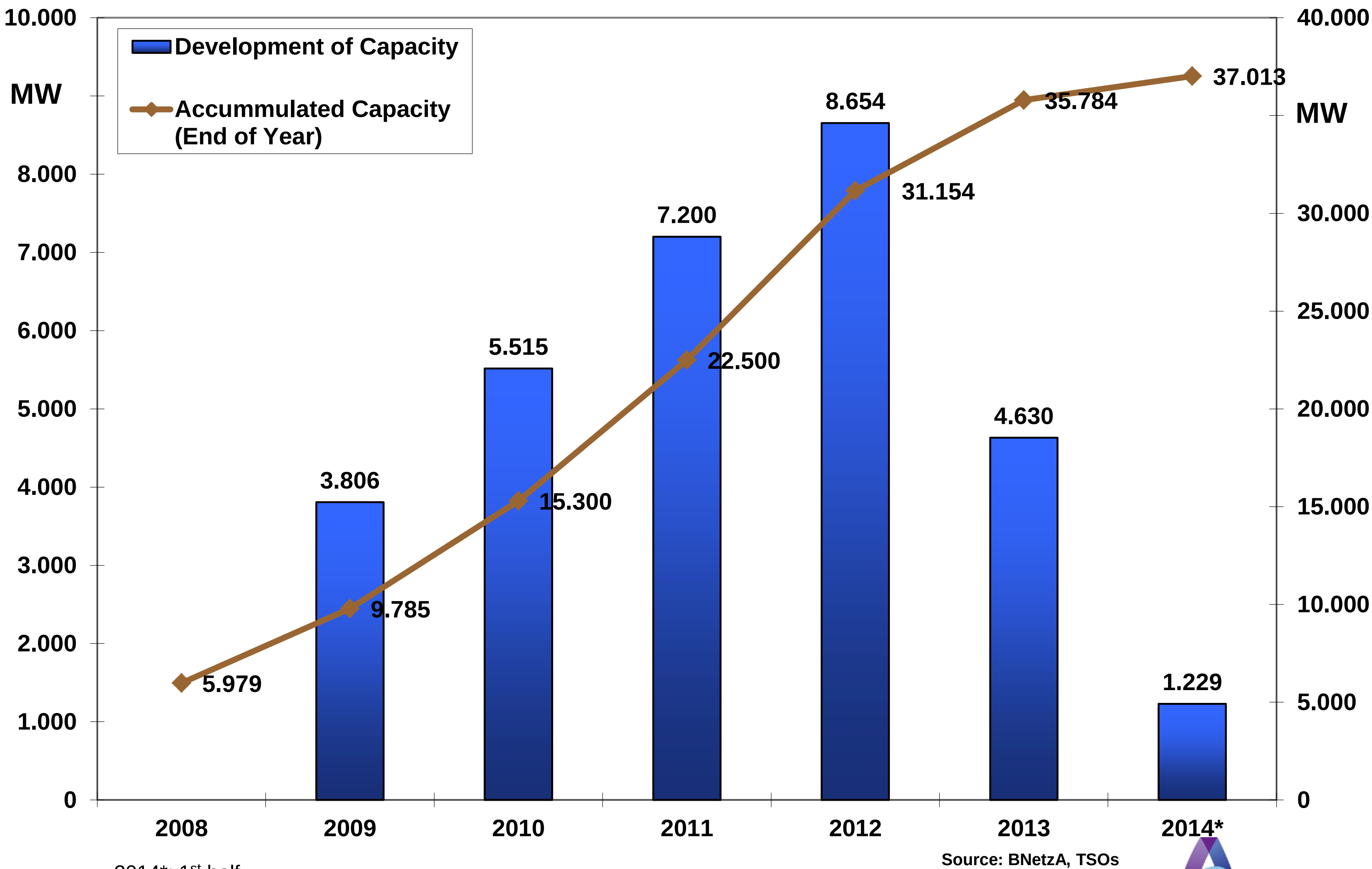
Source: Online Extrapolation German TSO

Top 10 Countries by Total PV Capacity [MW]

2011 to 2013



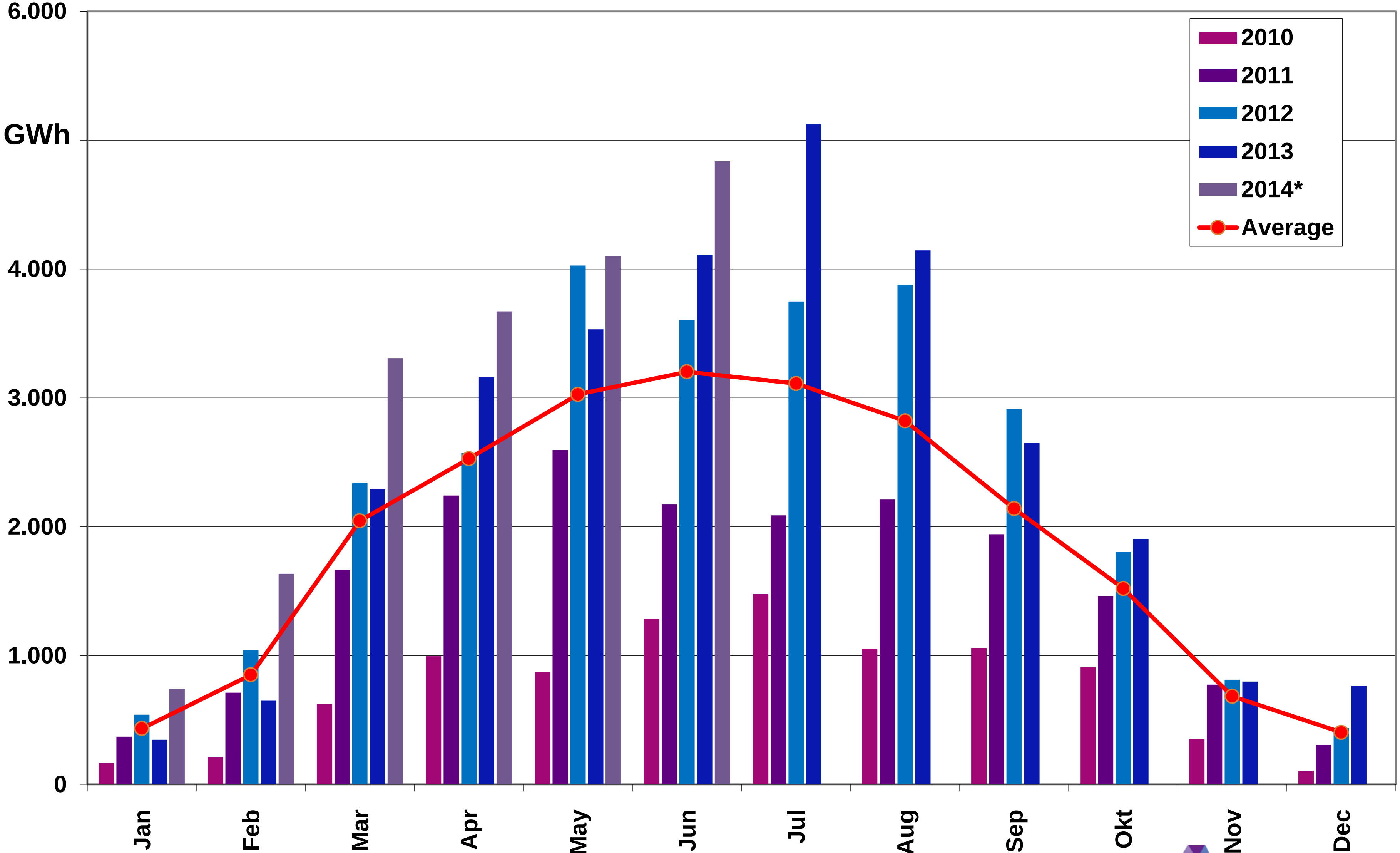
PV Development in Germany



2014*: 1st half

Monthly Production of PV Energy in Germany

2010 to 2014 (1st half)



Source: Online Extrapolation German TSO

2014*: 1st half

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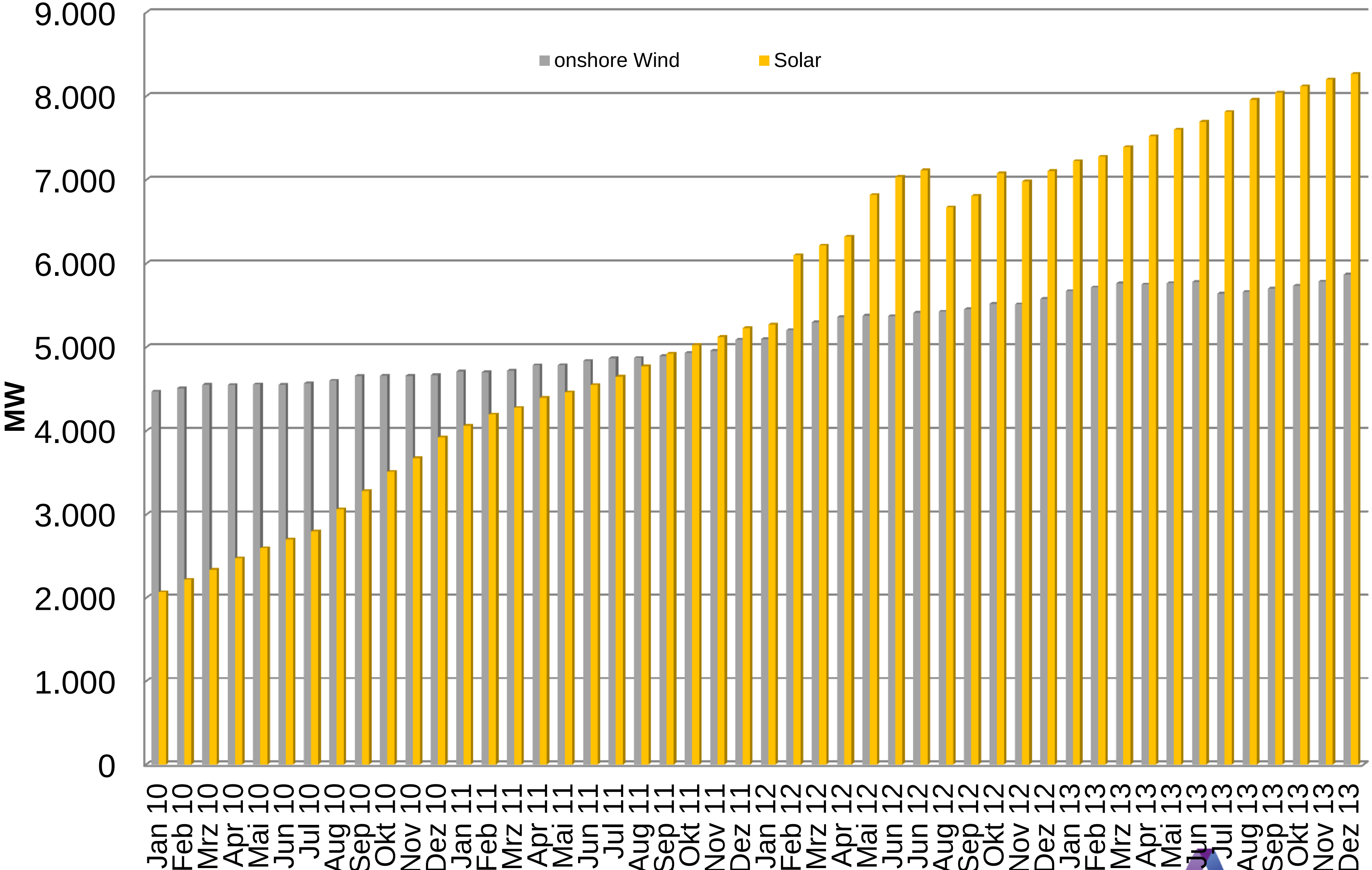
Wind / PV – installed capacity in Amprion grid



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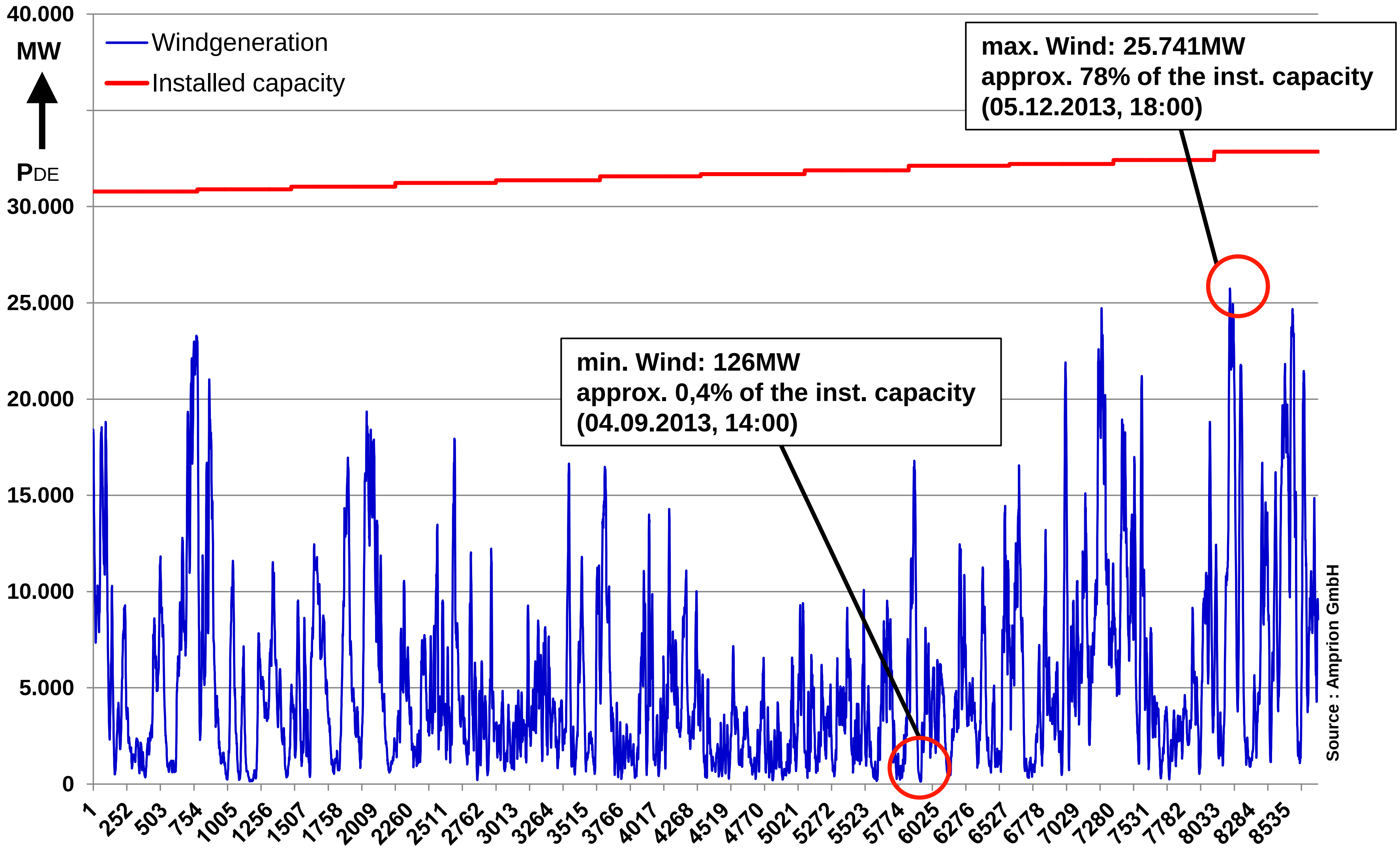
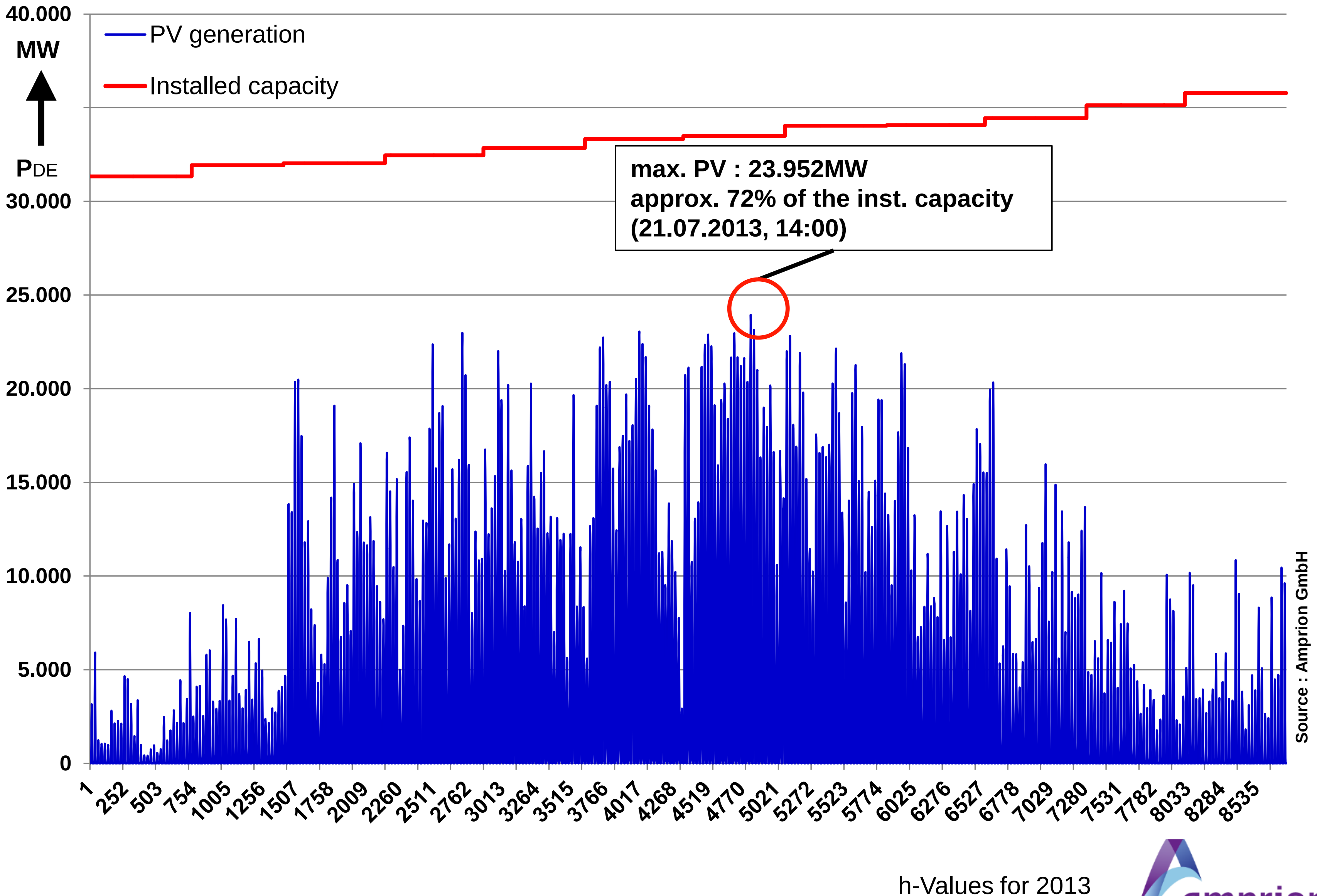
Wind Energy: Installed Capacity and Production (2013)

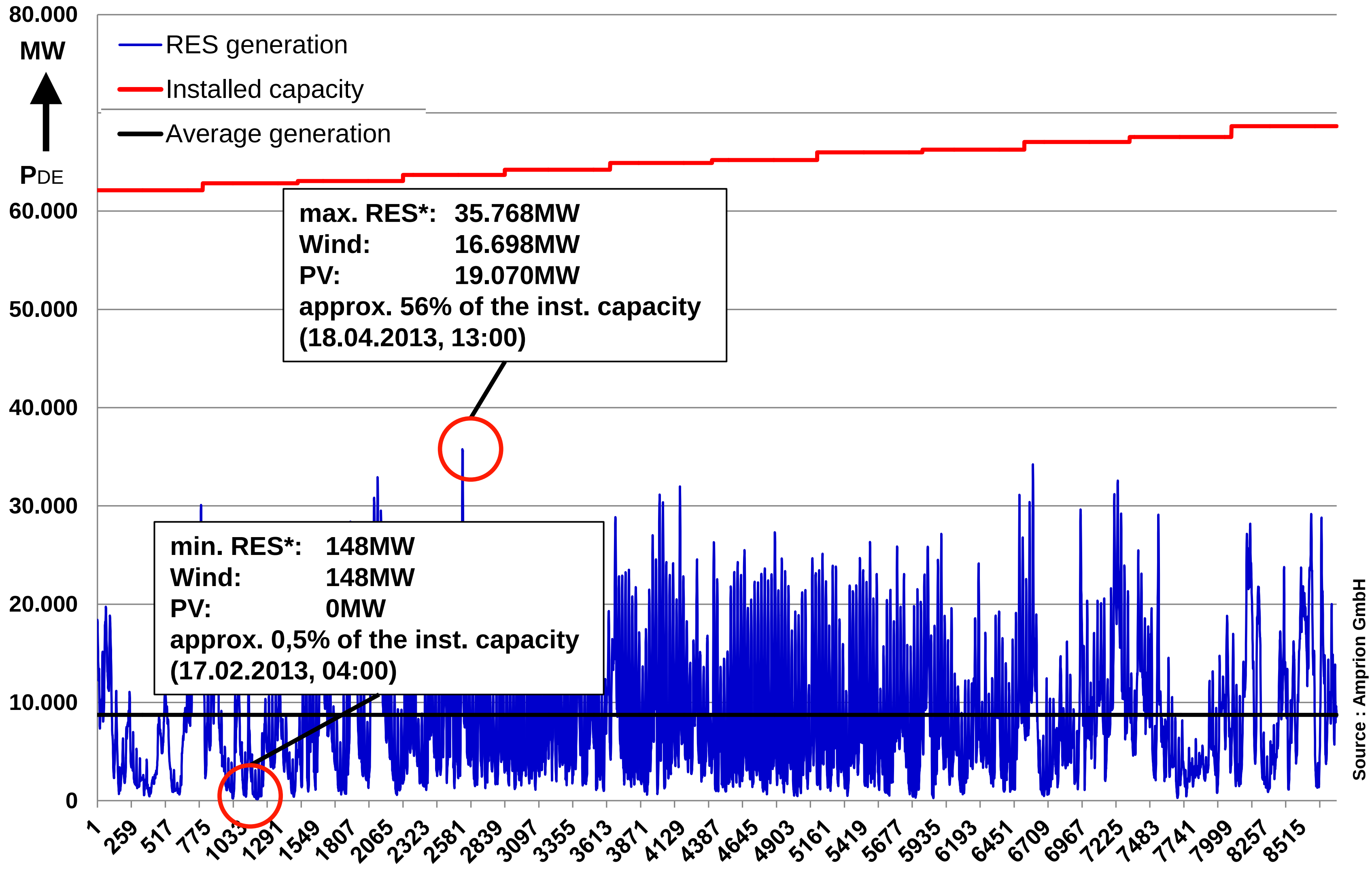


h-Values for 2013

PV Energy: Installed Capacity and Production (2013)

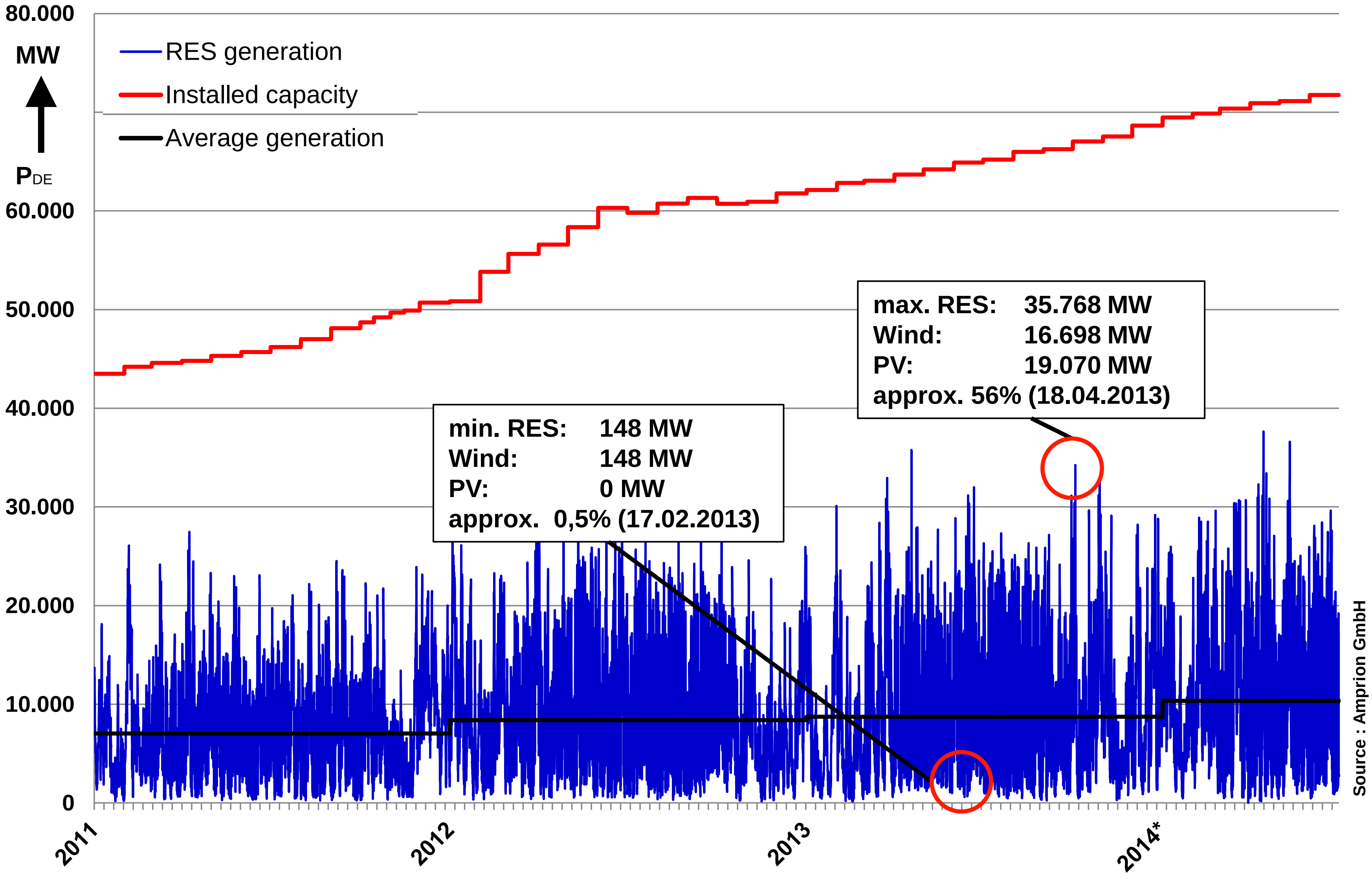


RES Energy: Installed Capacity and Production (2013)



h-Values for 2013

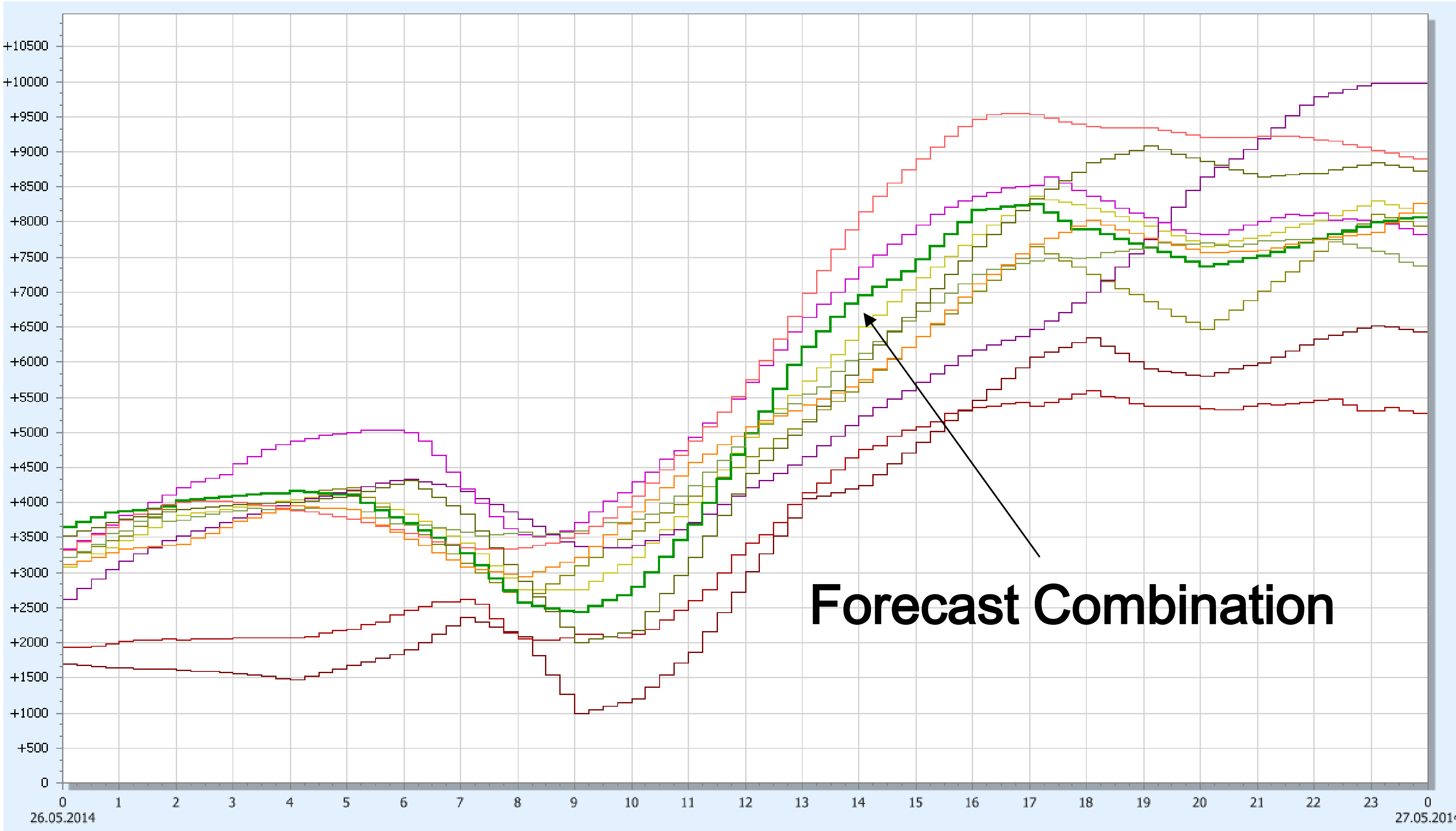
RES Energy: Installed Capacity and Production (since 2011)



2014*: 1st half

Wind Power Forecast Optimization (1/2)

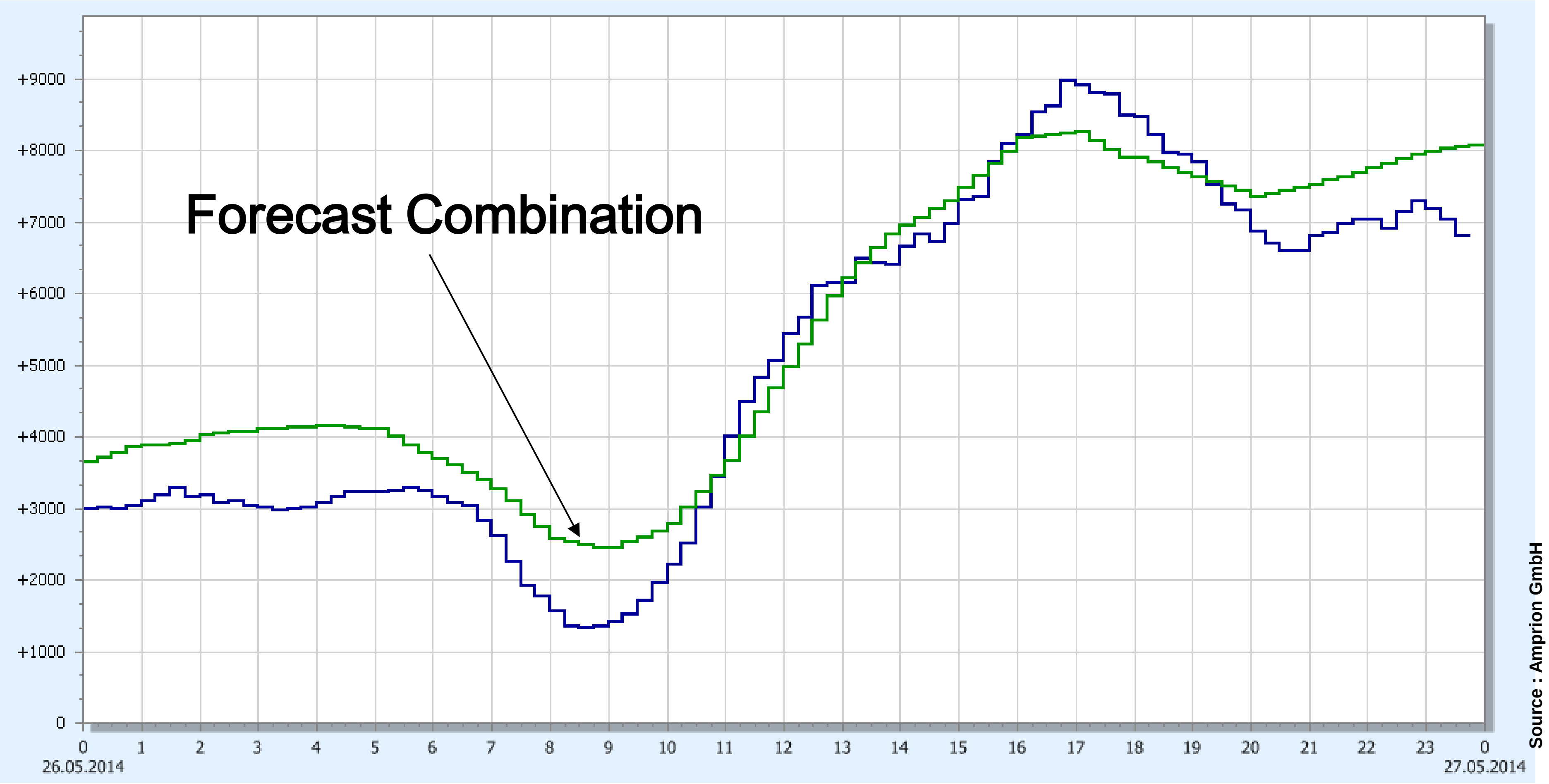
Example: 25.05.14 forecast of 26.05.14 – total German wind



Source : Amprion GmbH

Wind Power Forecast Optimization (2/2)

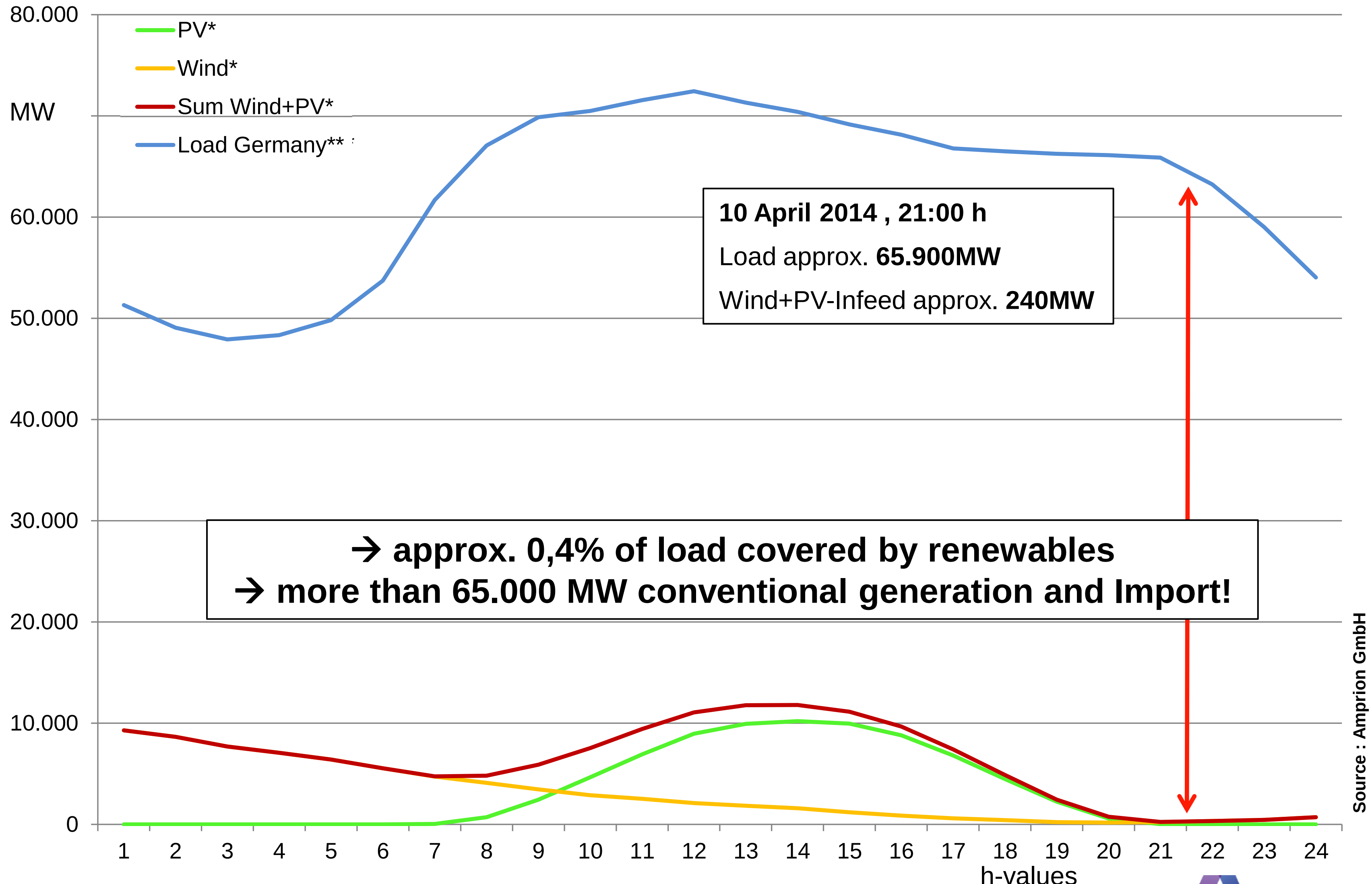
Example: 26.05.14 – total German wind



Source : Amprion GmbH

Wind and Solar Infeed vs. Load in Germany

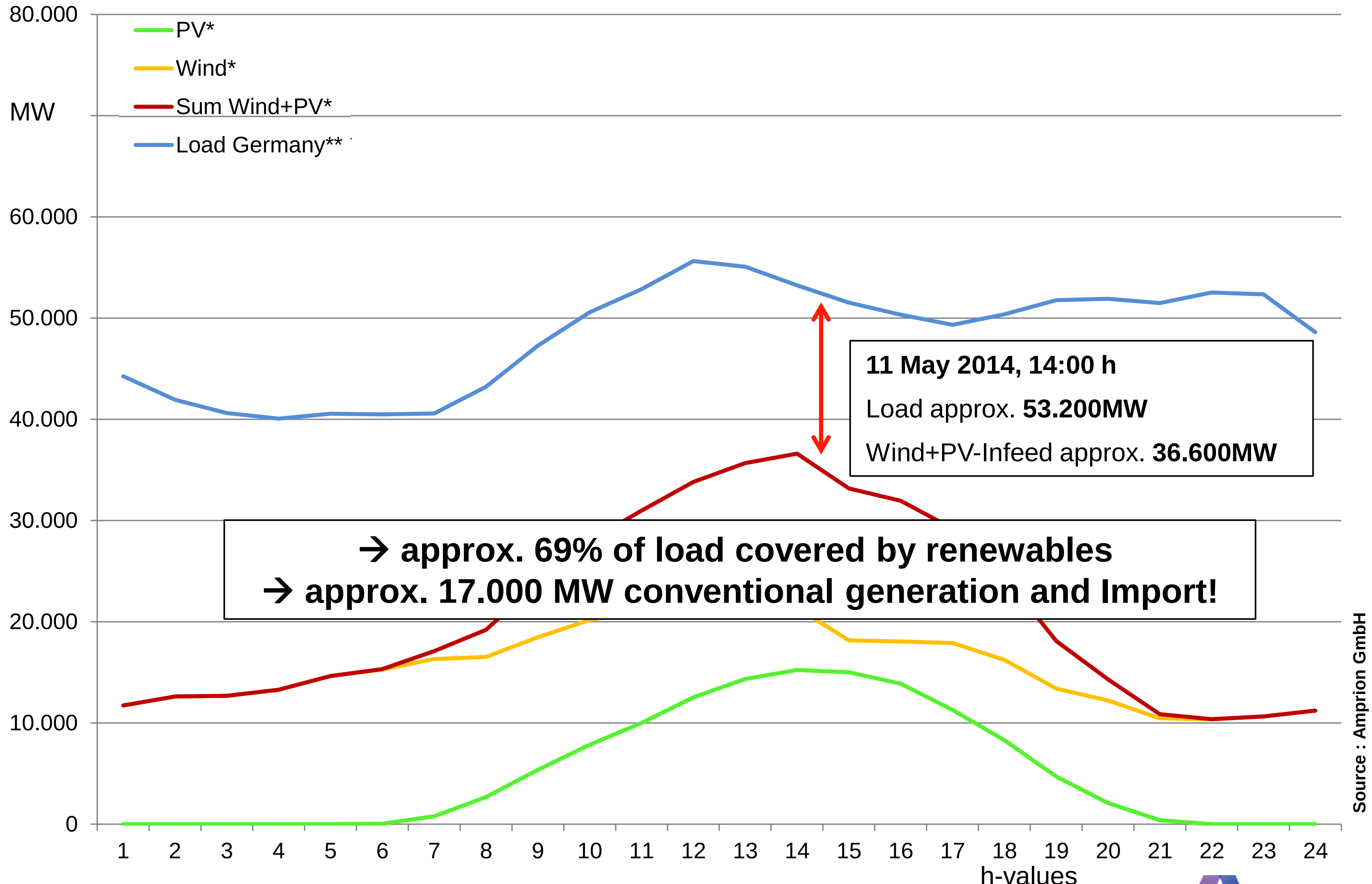
Time: Thursday, 10 April 2014 (day with lowest share of renewable energy covering load)



Data Source: * Netz-Transparenz ** ENTSO-E

Wind and Solar Infeed vs. Load in Germany

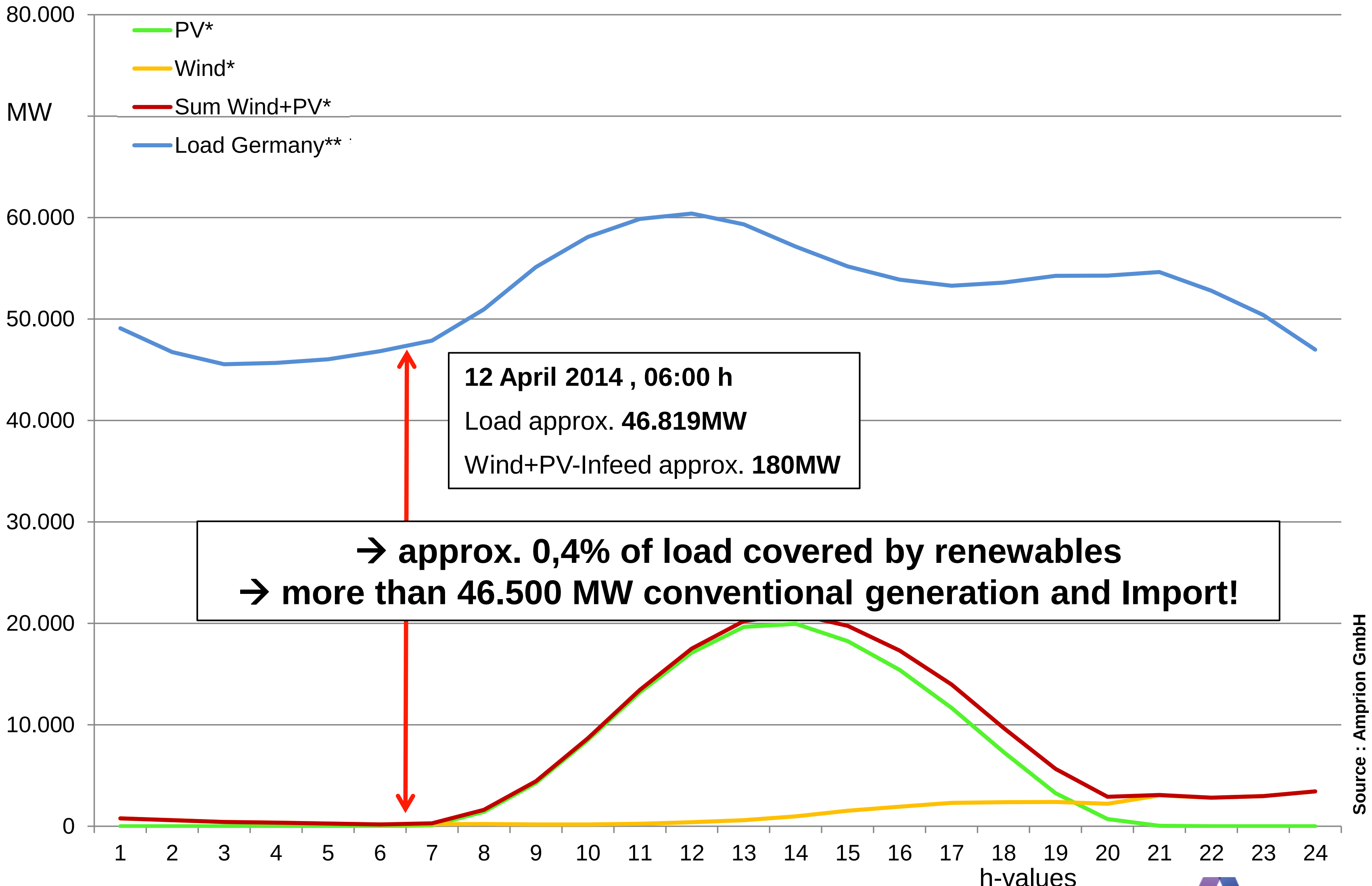
Time: Sunday, 11 May 2014 (day with highest share of renewable energy covering load)



Data Source: * Netz-Transparenz ** ENTSO-E

Wind and Solar Infeed vs. Load in Germany

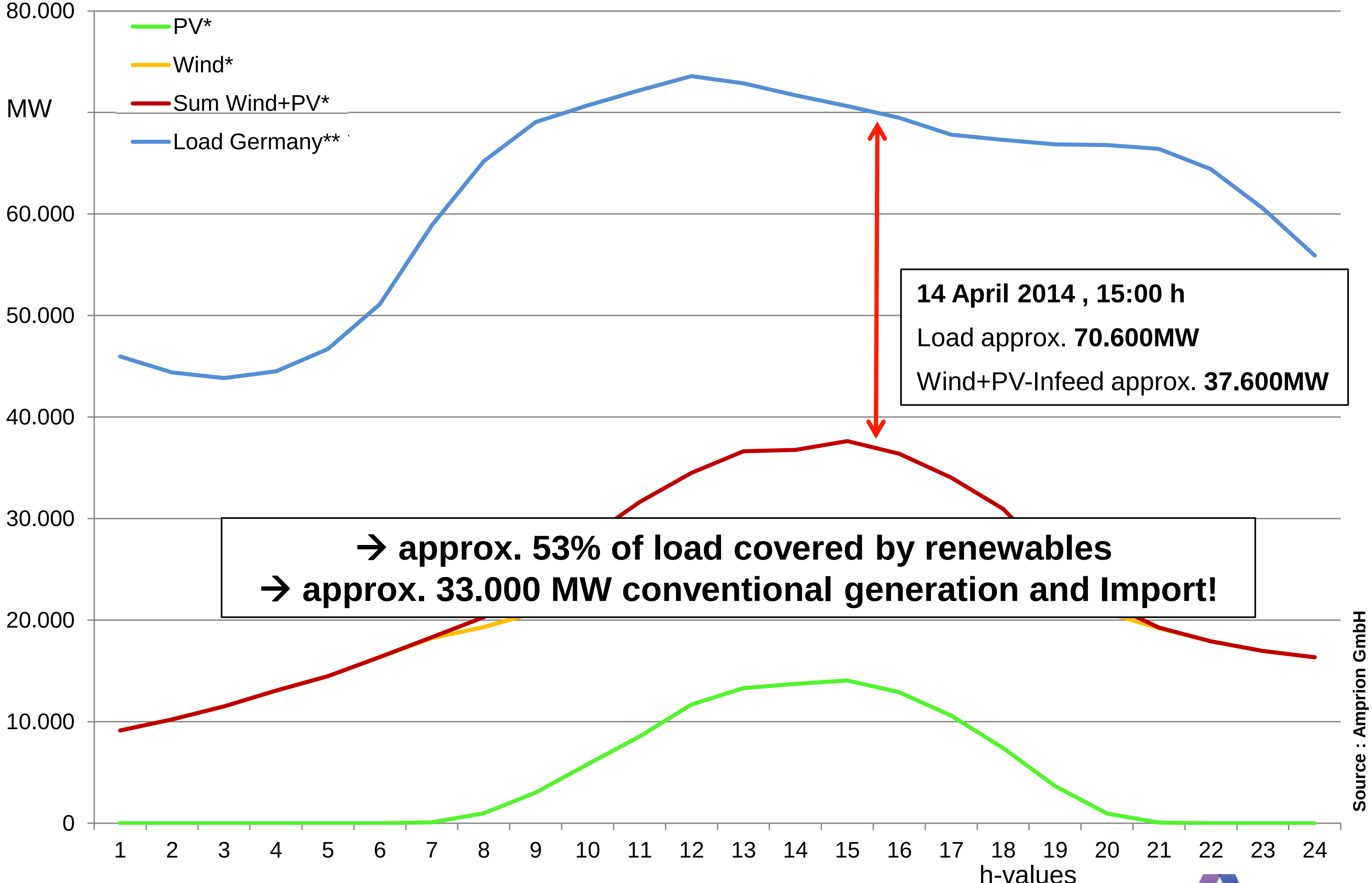
Time: Saturday, 12 April 2014 (day with lowest renewable infeed)



Data Source: * Netz-Transparenz ** ENTSO-E

Wind and Solar Infeed vs. Load in Germany

Time: Monday, 14 April 2014 (day with highest renewable infeed)



Data Source: * Netz-Transparenz ** ENTSO-E

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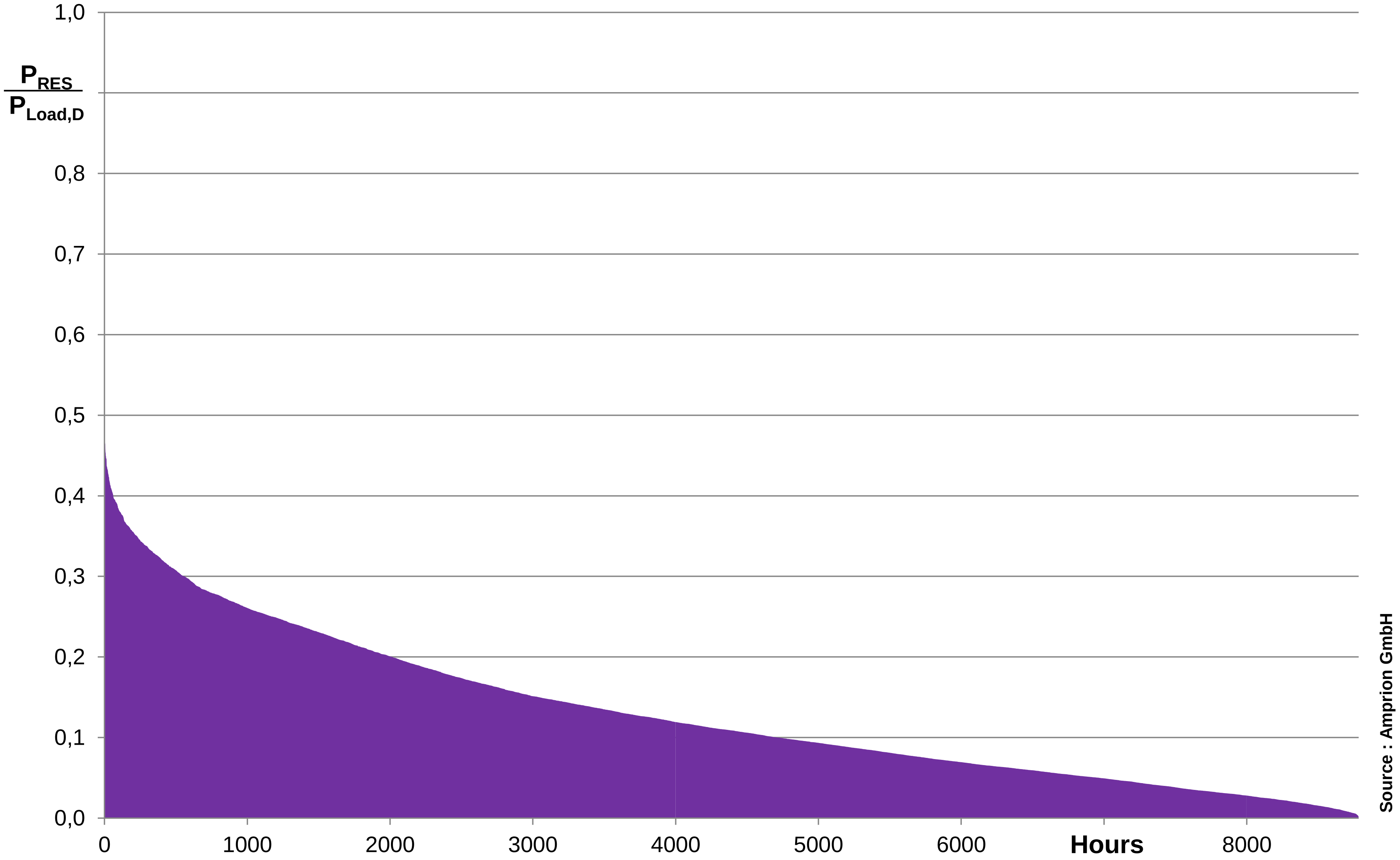
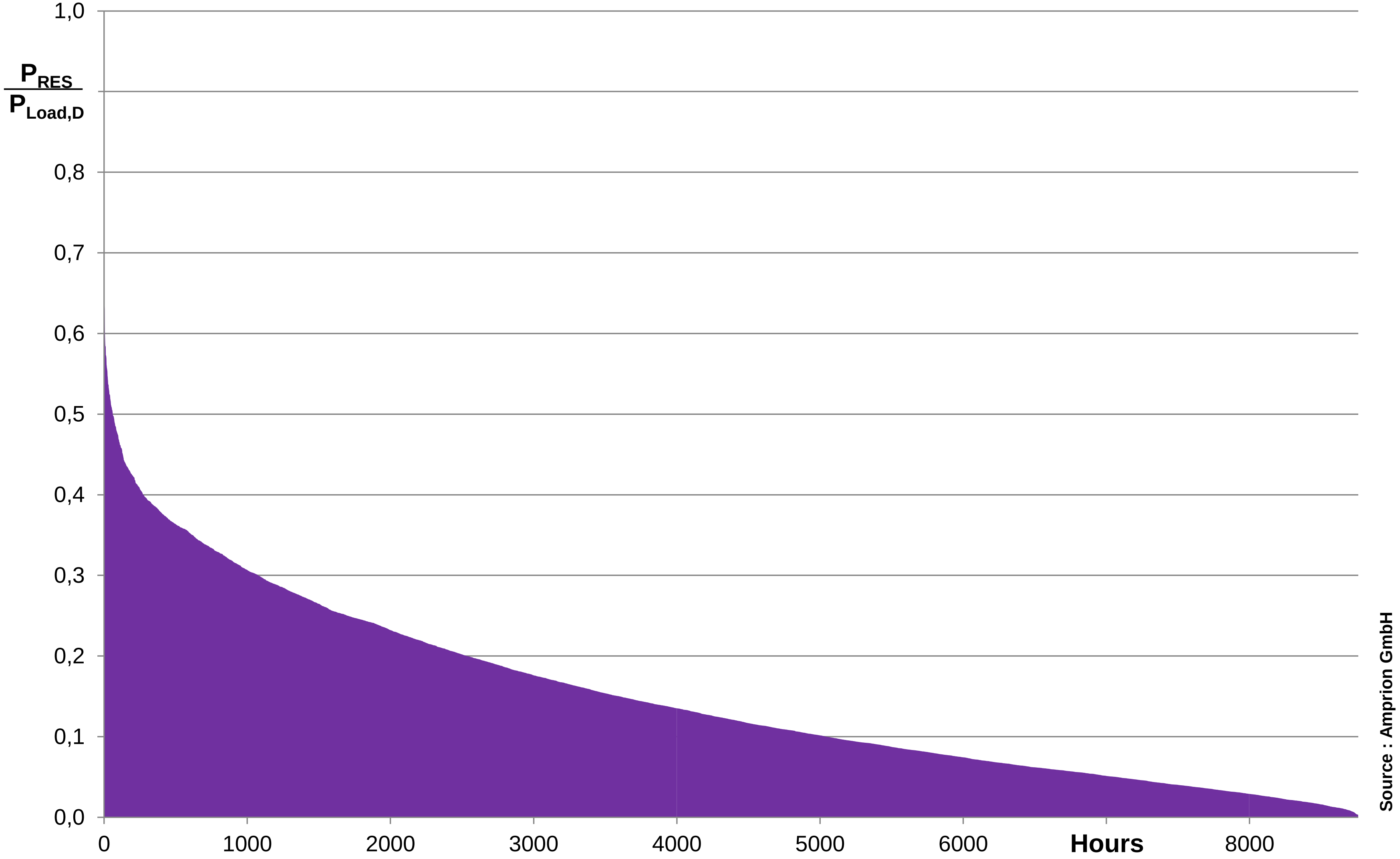
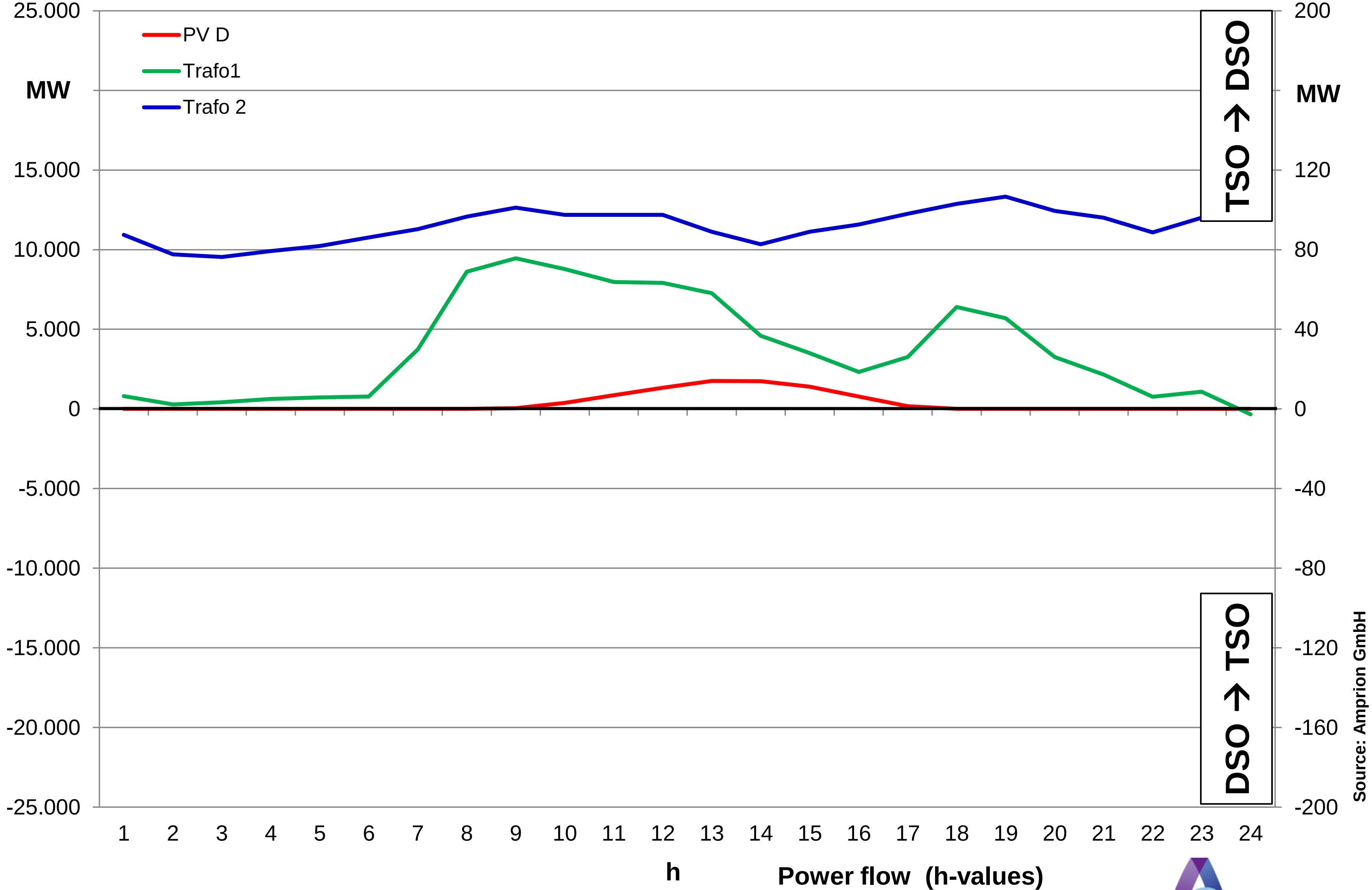
Duration curve of load covering with Wind und PV in 2012



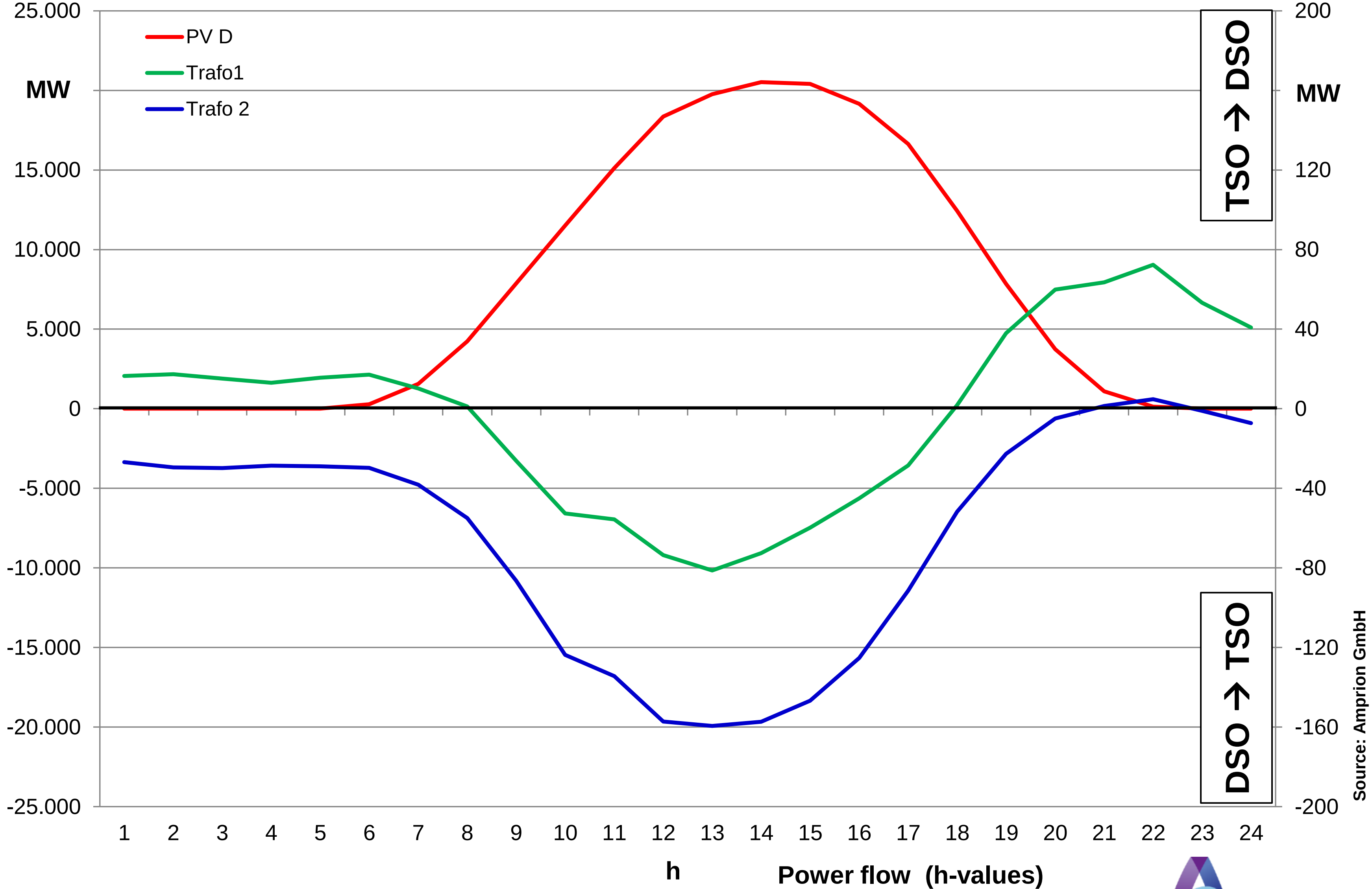
Duration curve of load covering with Wind und PV in 2013



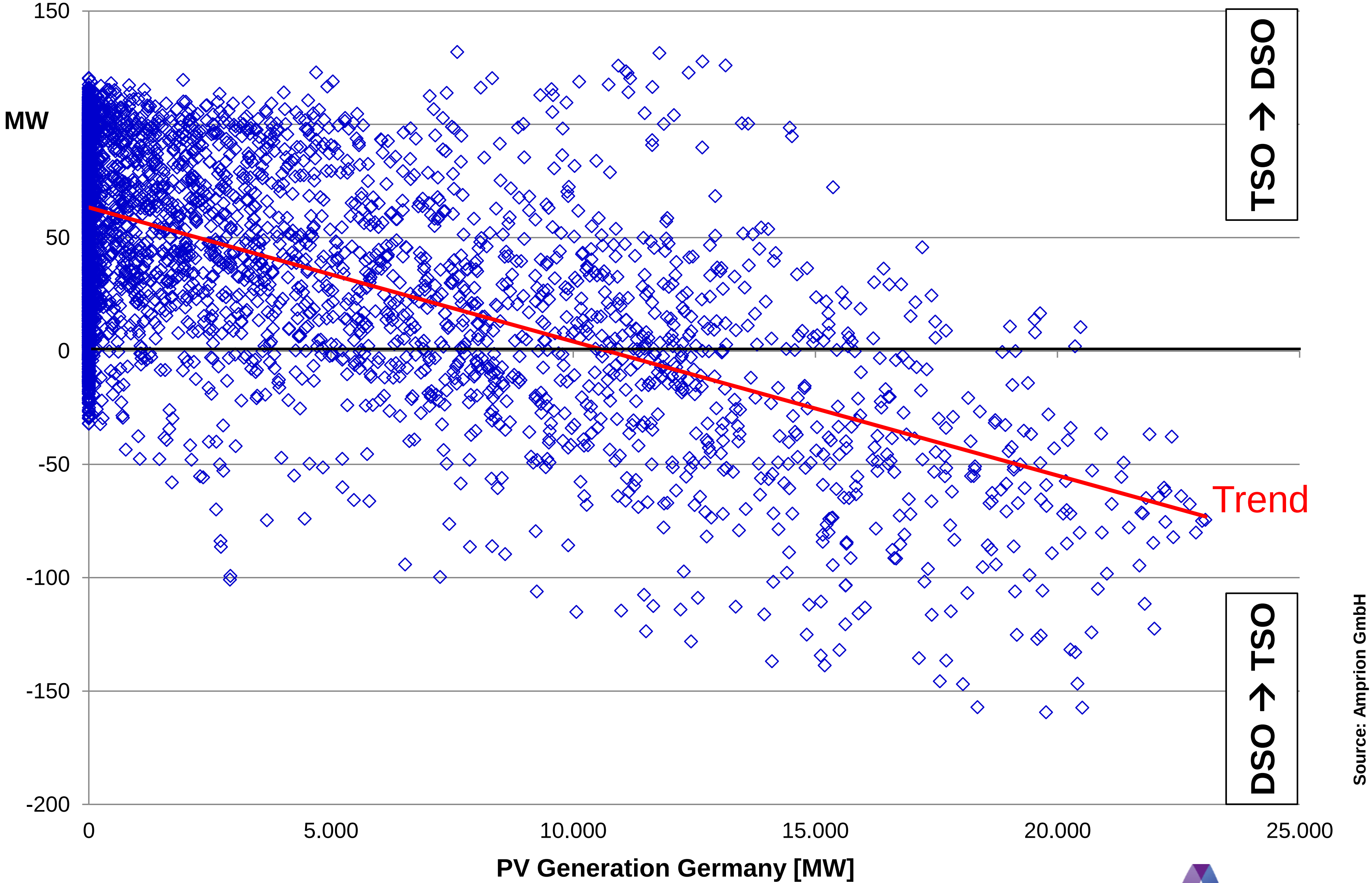
Influence of Dispersed Generation on the TSO
(Low infeed in **PV**)



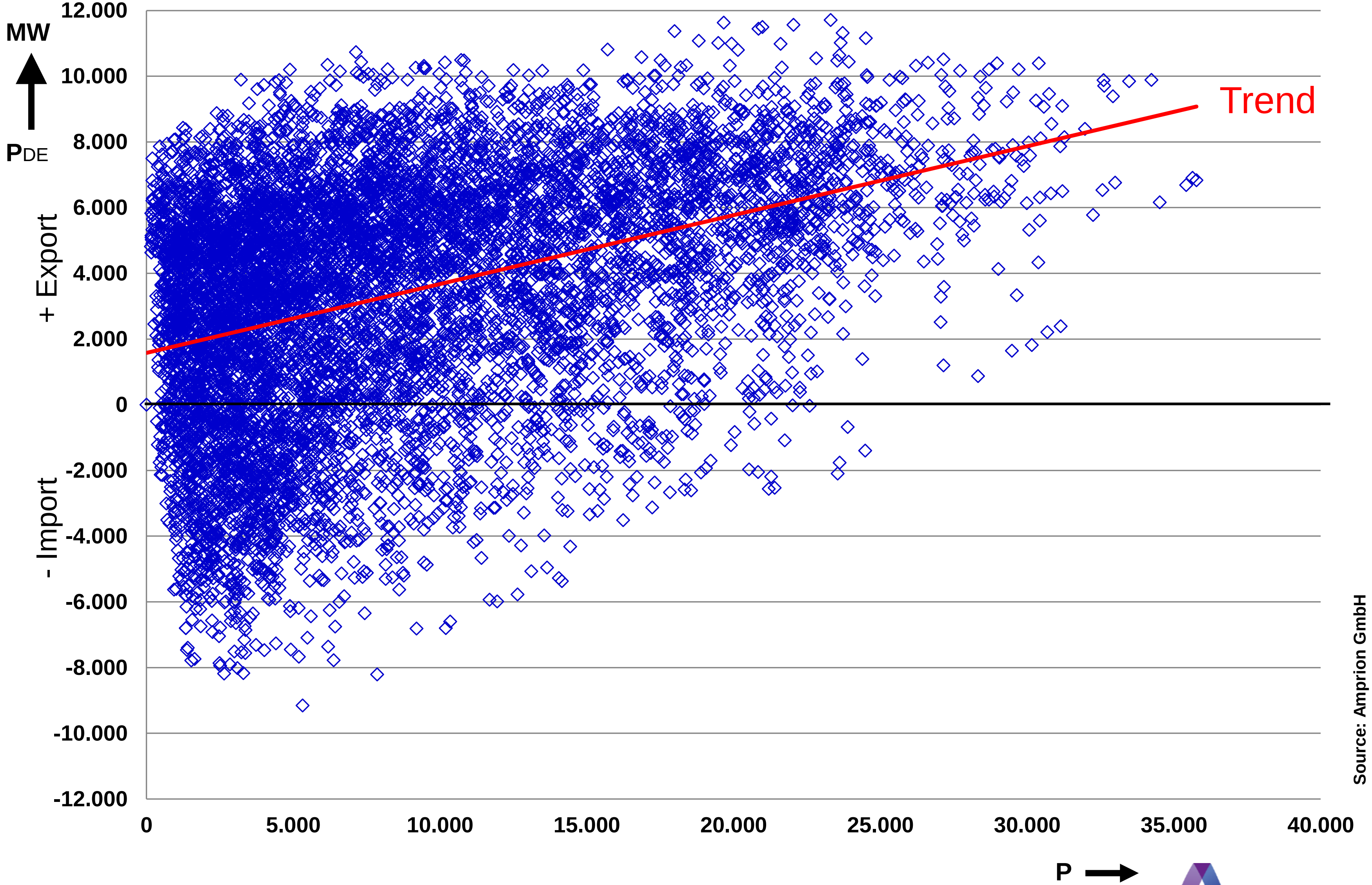
Influence of Dispersed Generation on the TSO
(High infeed in **PV**)



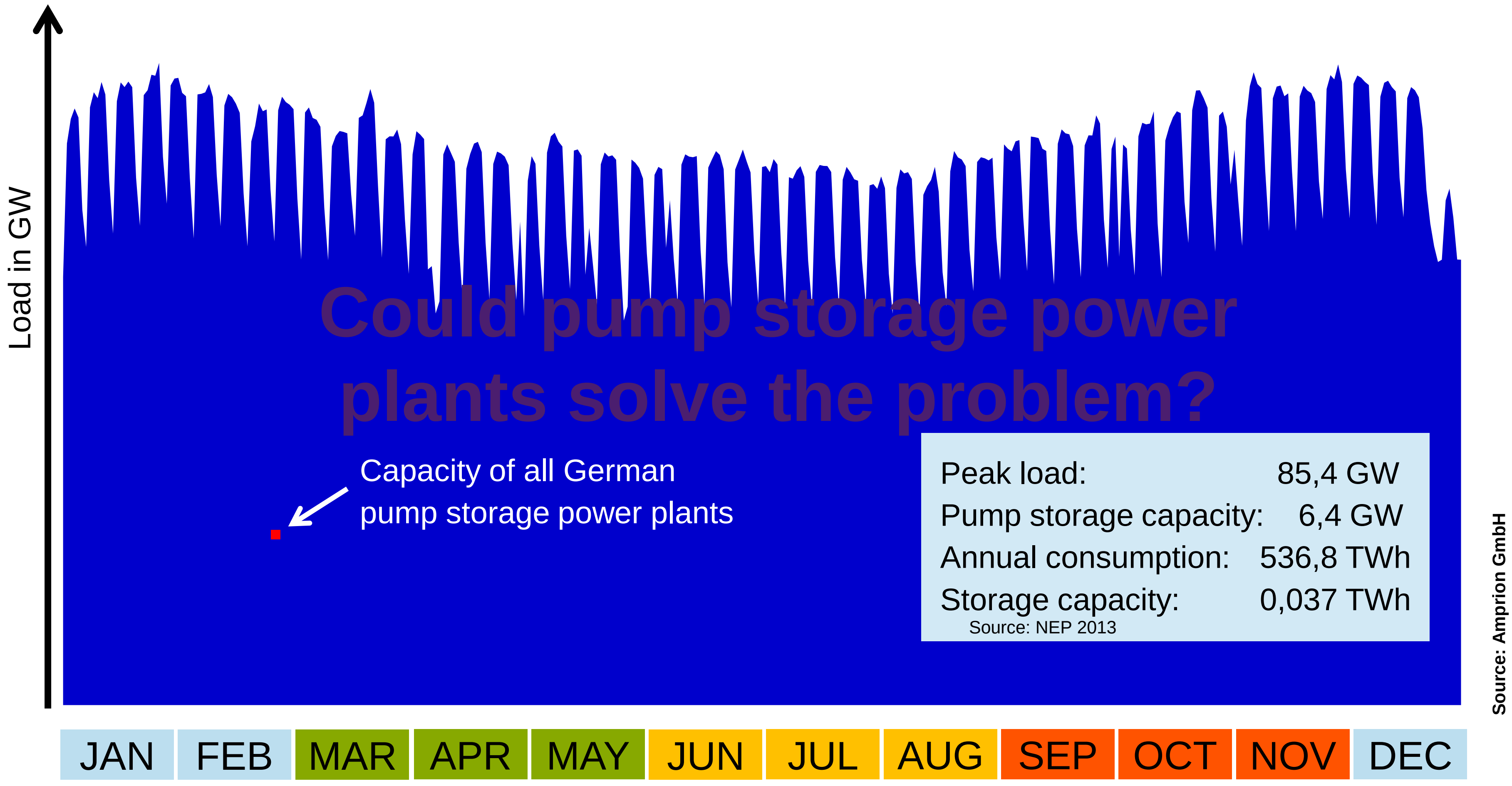
PV-Generation ↔ Reverse Flow on Transformer 400/110 KV (measurement values Amprion)



Correlation Wind+PV Energy Production ↔ Control Program DE (h-values 2013)



Peak Load vs. Capacity of all German pump storage power plants



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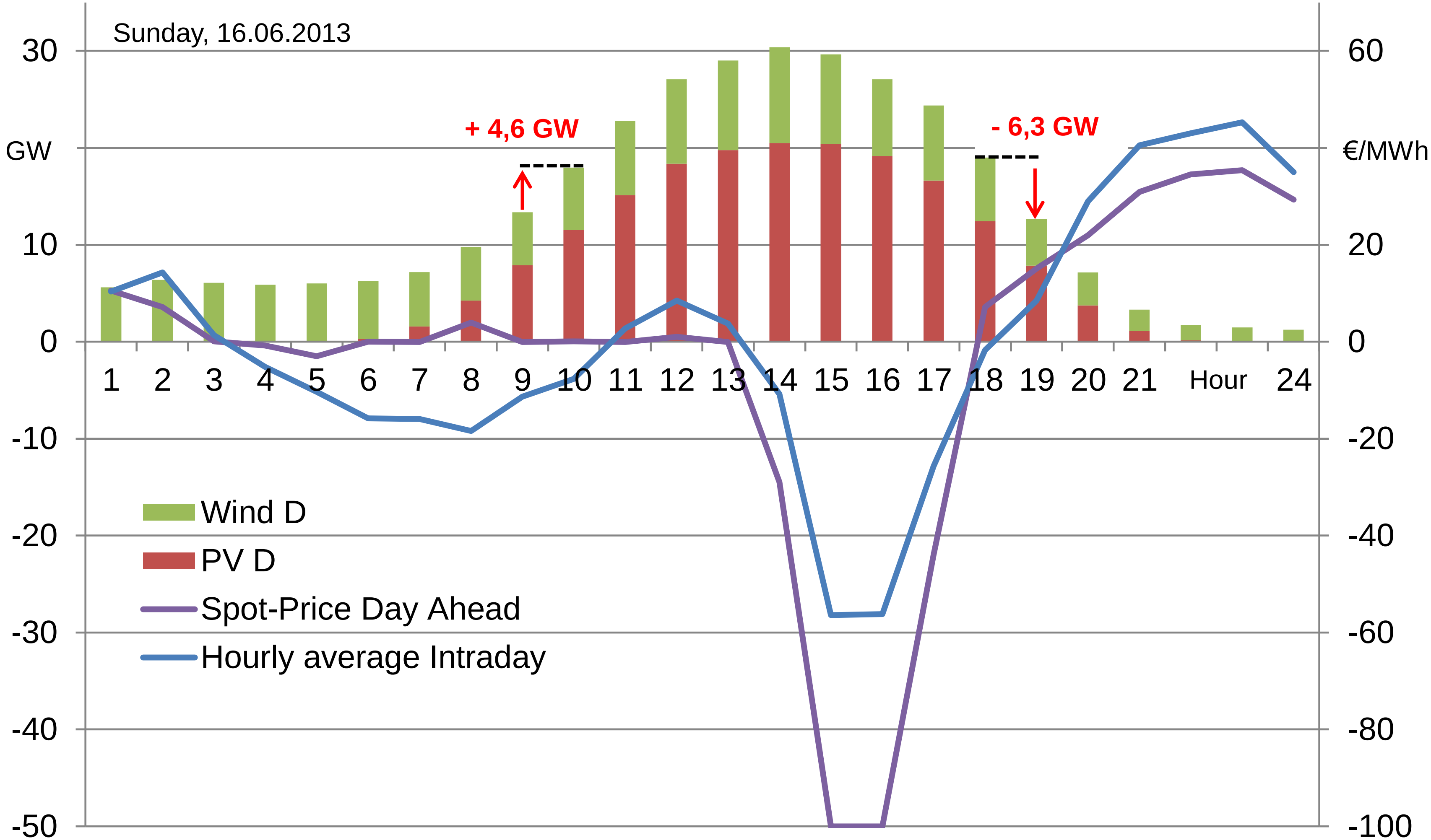
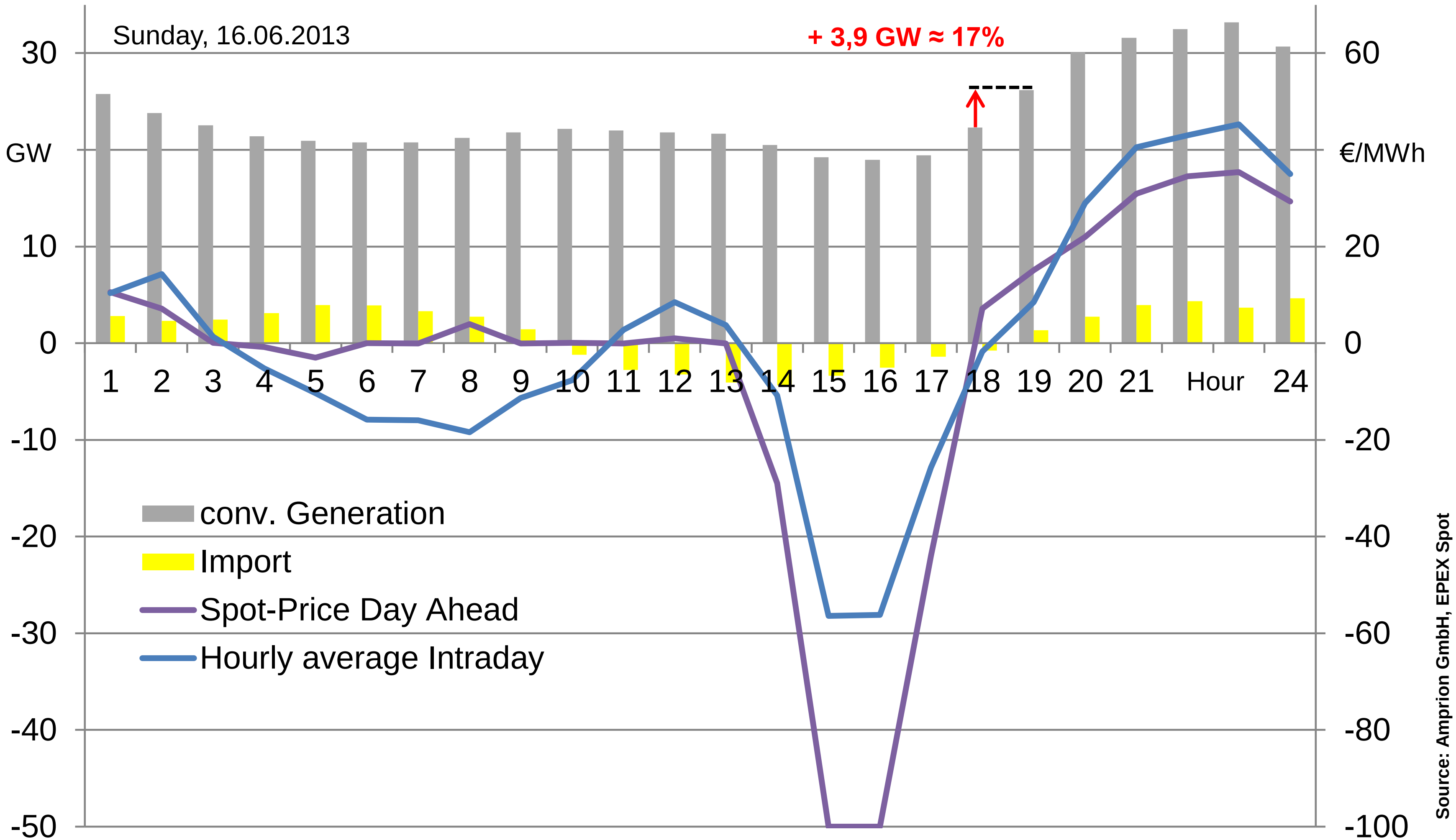
RES-Infeed and impacts on thermal generation (1/2)

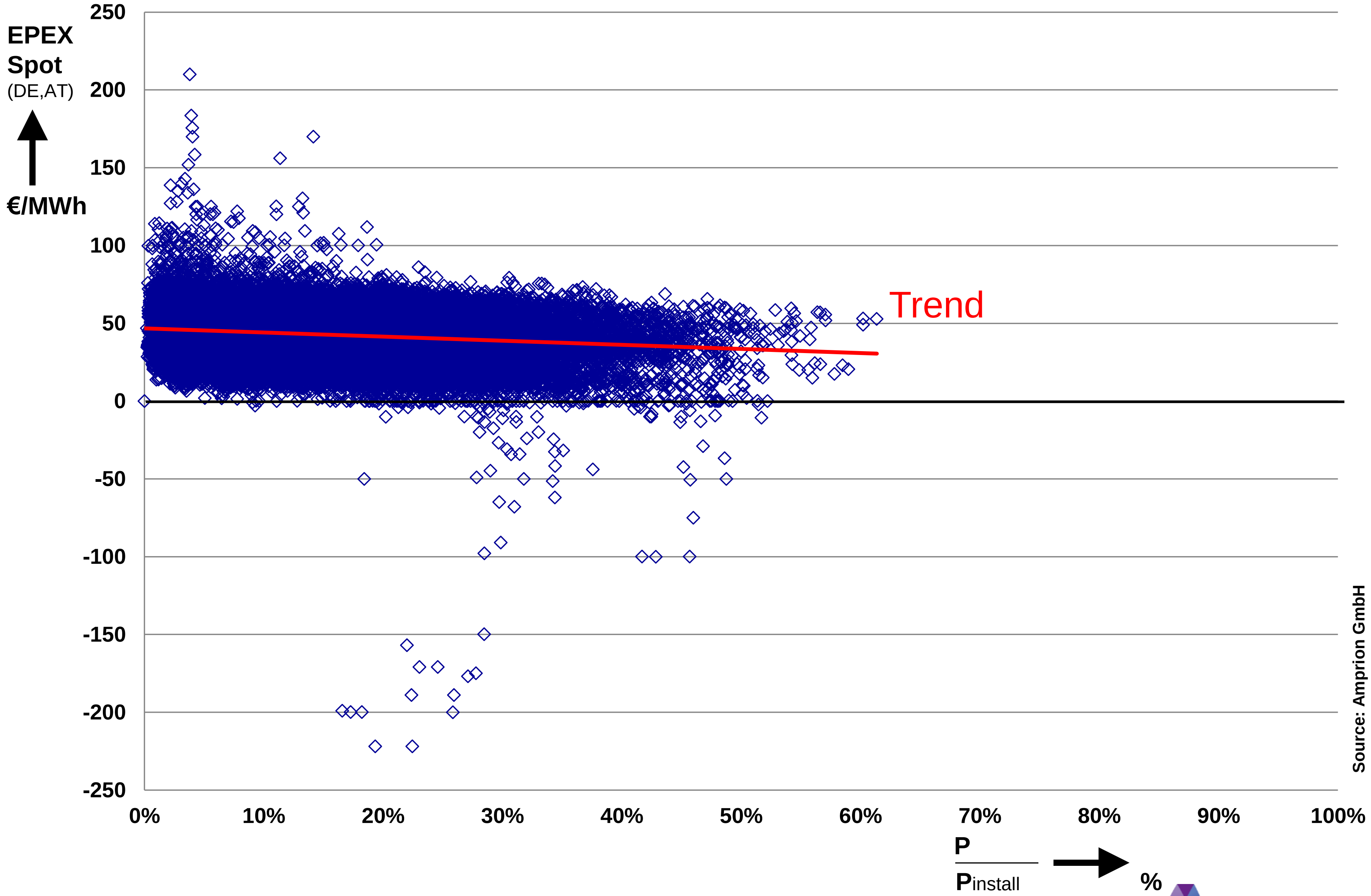


Source: Amprion GmbH, EPEX Spot

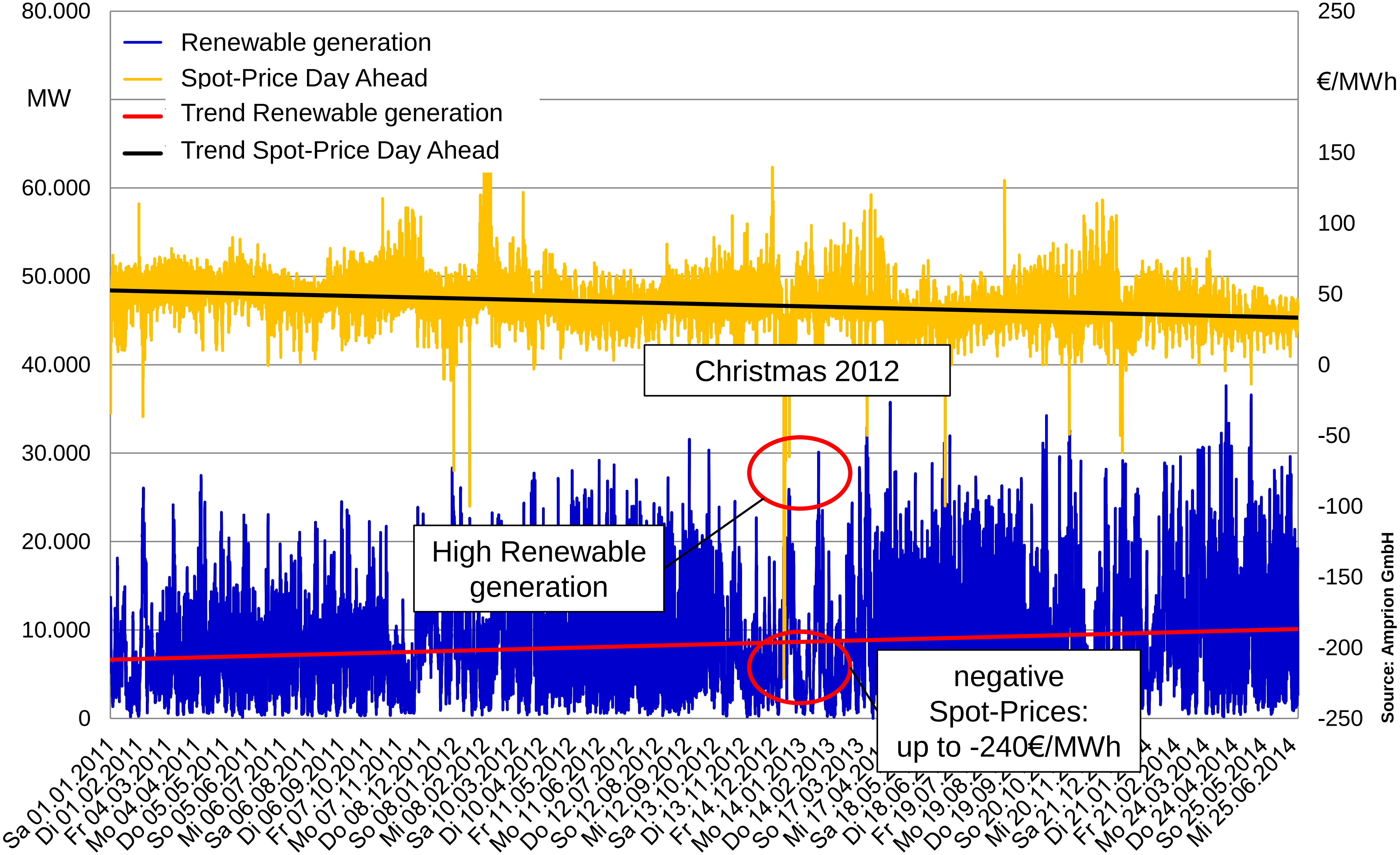
RES-Infeed and impacts on thermal generation (2/2)



Correlation Wind+PV Energy Production ↔ Day-ahead PX
h-values since 2011



Spot-Price Day Ahead vs. RES Generation since 2011



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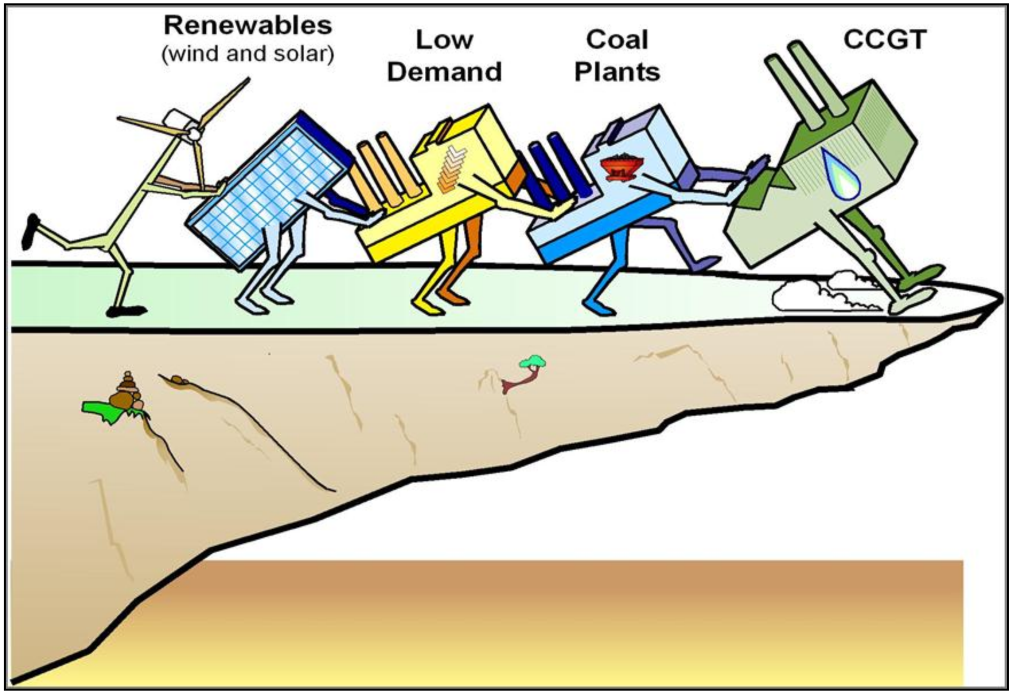
RES push conventional power plants out of the market



The shutdown of thermal generation capacity in the grid endanger system stability!

- Increasing share of renewables (Germany: approx. 37 GW PV and 35 GW Wind installed)
- conventional power plants become unviable because of low prices
- Steadily decreasing time of operation of conventional power plants
- just minor peak loads, thereby exposure of the profitability of energy storage

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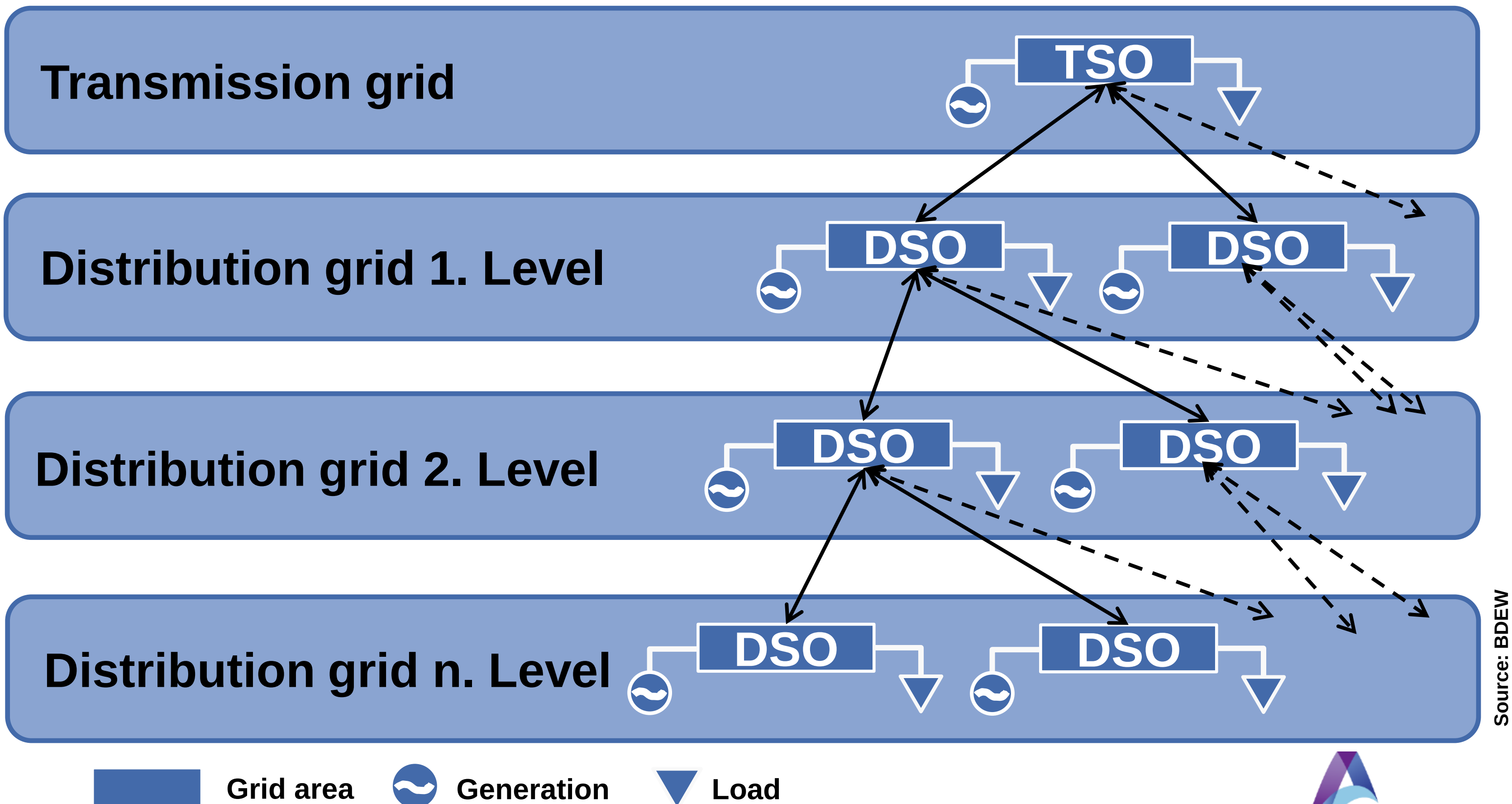
Cooperation of TSO and DSO:
Cascade in Generation Dispatching of Renewables

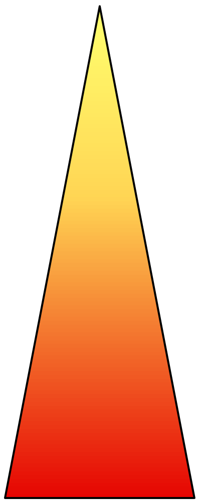
In case of (n-1)- security violations in the EHV-grid due to high dispersed generation TSO and DSO collaborate to lower the infeed of renewable generation in DSOs grid. TSO initiates and DSOs operate these measures according following cascade:



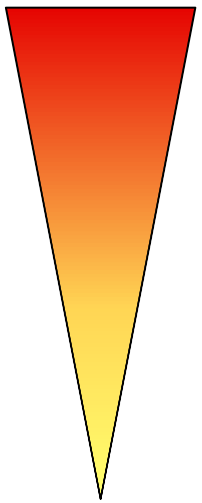
Challenges for DSOs

Operator		Grid level of Energy system		
TSO		Extra-high Voltage	220 / 380 kV	GL* 1
DSO		High Voltage	110 kV	GL 2
	Regional Distributors	Medium Voltage	20 kV	GL 3
				GL 4
		Low Voltage	400V (230 V)	GL 5
				GL n

Number of generation units



Level of automation

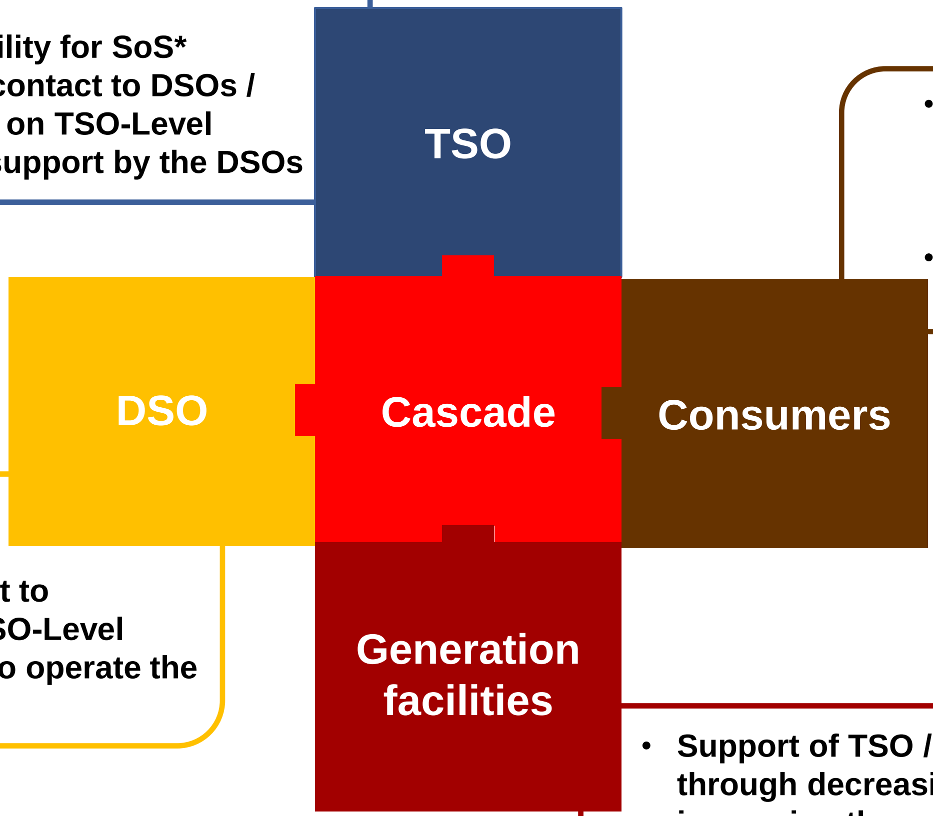


- Prevent incorrect voltage augmentation caused by decentralized generation
- Coordination of a large amount of small generation utilities without an adequate communication network
- Handling reversed load flows

*GL: Grid Level

Responsibilities within the cascade

- TSO monitoring the overall system
- Responsibility for SoS*
- Operative contact to DSOs / generators on TSO-Level
- Requests support by the DSOs



- Support of industrial customers to SoS through decreasing / increasing load
- End user can be disconnected

- Monitoring own system
- Operative contact to generators on DSO-Level
- Support of TSO to operate the cascade

- Support of TSO / DSO to SoS through decreasing / increasing the power of generation units

*SoS = Security of Supply

Agenda

- Germany’s Energiewende - Framework
- Transmission System Operation
- Major Challenge: Transition of the Electricity System due RES
- Impacts of RES on Conventional Generation and the Market
- Cooperation of TSO and DSO: Cascade in Generation Dispatching
- Outlook and Conclusion

What is now the influence of

wind and pv generation

and

power trading

on the grid ?

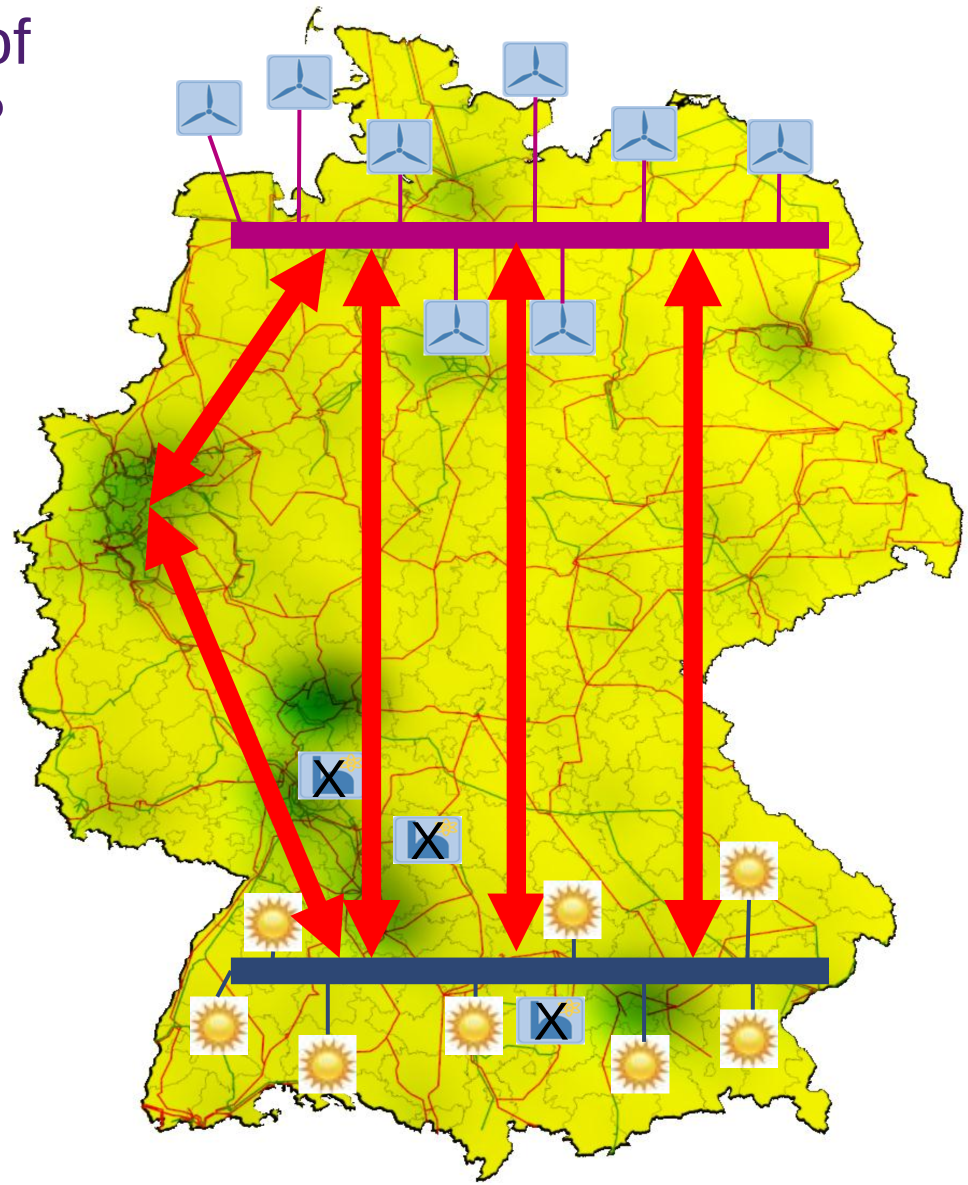
↓

Huge Load Flows

amprion

What are the key elements of the German grid expansion?

- Connection of wind farms in the north to a powerful, regional east-west-grid
  → wind-busbar
- Integration of solar energy in the south by the use of regional grid reinforcement
  → solar-busbar
- Connection of the buspars via HVDC-lines
- Depending on the existing situation north-, central- or south Germany can be supplied with power from renewable energy sources



Source: Amprion

German Grid Development Plan (NEP)

Optimizing of the existing corridors:

- AC- expansion: 2.800 km
- AC- reinforcement and additional lines: 1.300 km
- DC- lines: 300 km

about 20 Billion € invest one time

0 km

GW

0 km

Investments: approx. 20 billion €

Conclusion

The current Challenges for <u>Transmission System Operators</u> are:

- Stimulation of the European Electricity Market Integration
- Integration of Renewable Energy Sources (Wind and Solar Power)
- Changes in Generation Patterns (Shutdown of Nuclear PPs and Conventional PPs)
- Congestion Management and Management of Critical Grid Situations

The current and future Challenges for <u>Thermal Power Plants</u> are:

- Permanently decreasing load utilization due to high priority infeed of RES
- Flexibility needs and growing load gradients
- Reliable and flexible thermal generation capacity is essential for security of supply and stability of the transmission grid

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The „Energiewende“ consists of many components – To achieve this goal all parties need to work together

Thank you for your attention.