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50Hertz Transmission

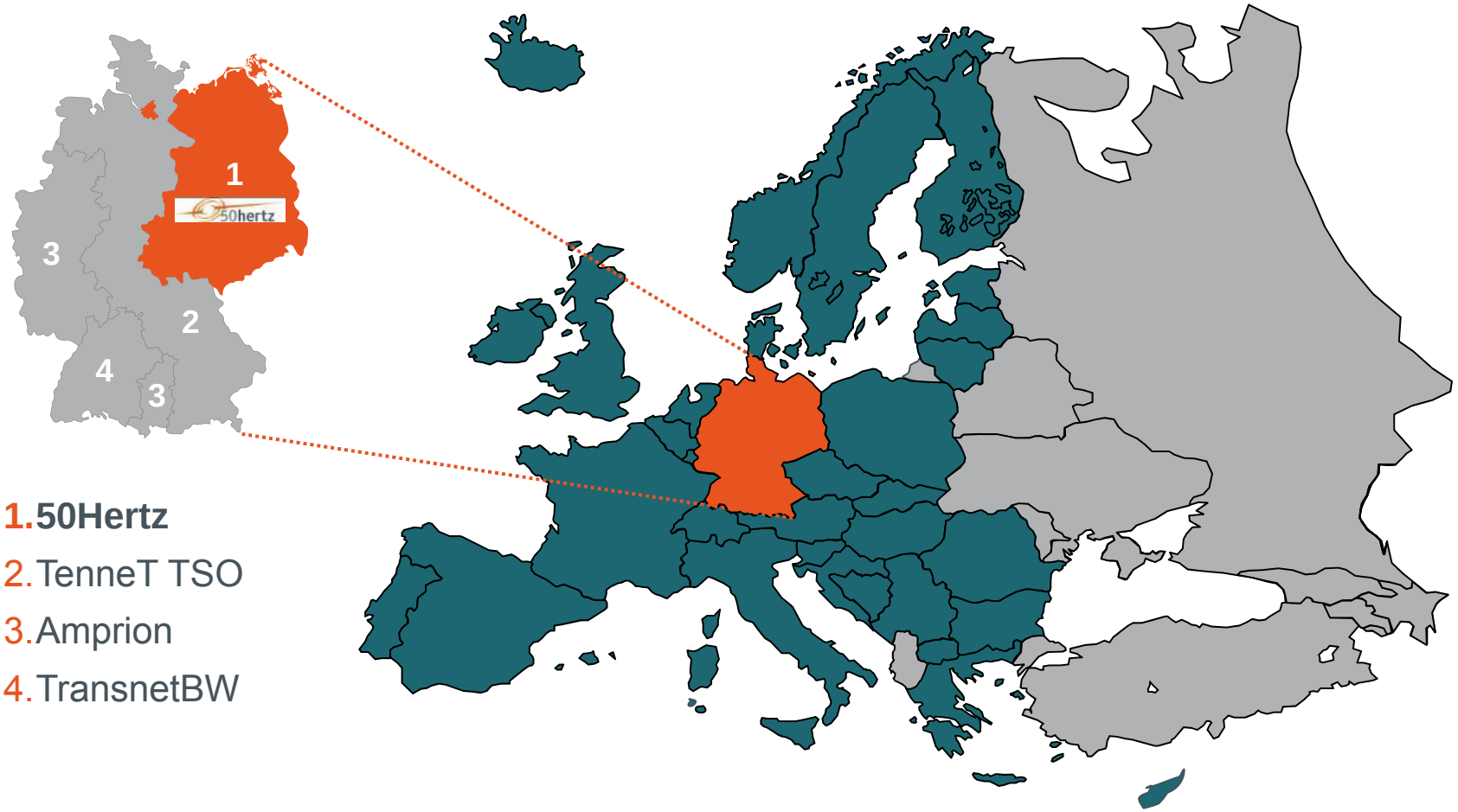
Present and future challenges of RES integration

BETD – 18 March 2006

Marco Nix, Board Member/CFO

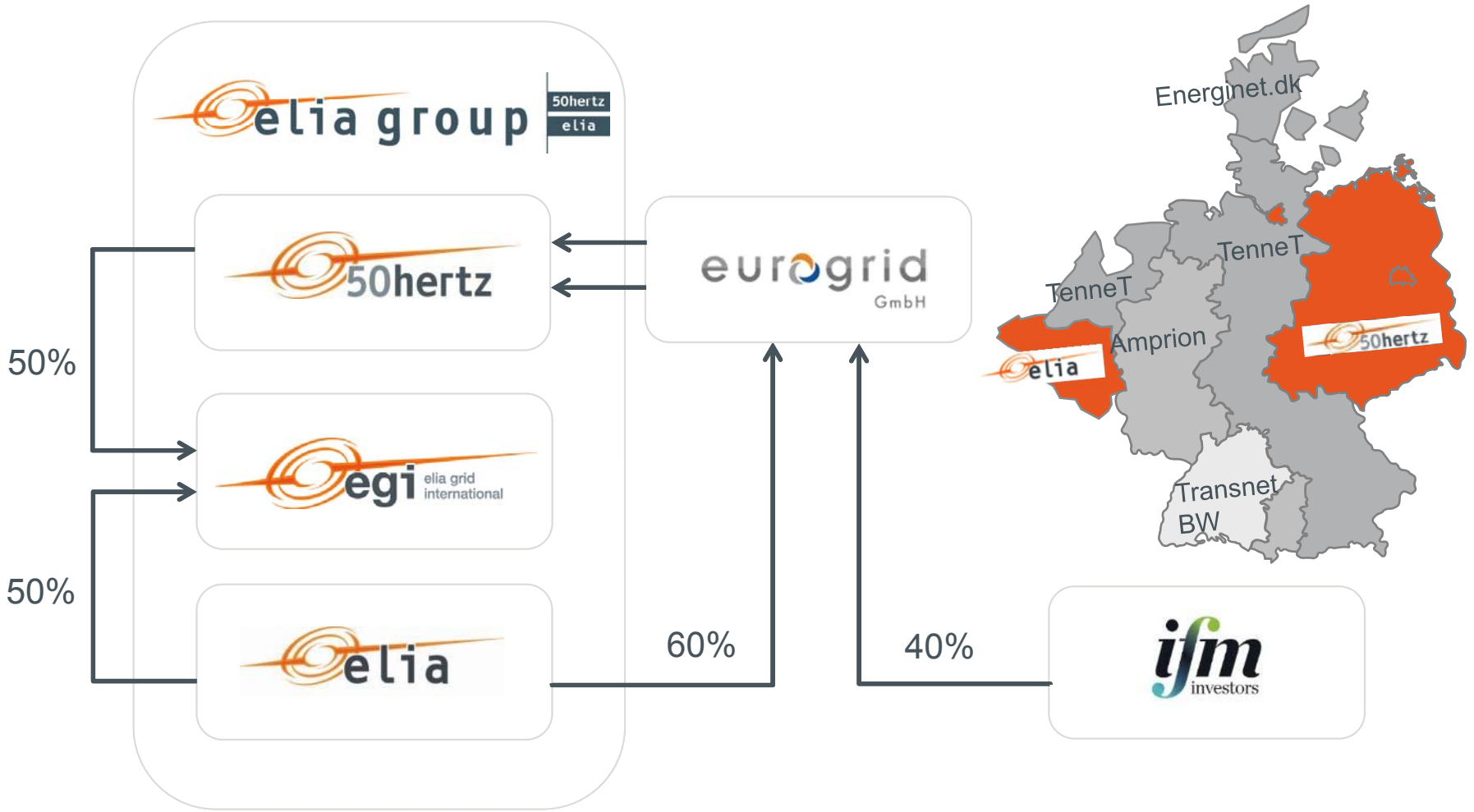
Gunter Scheibner, Head of System Operations

50Hertz as a part of the European Electricity System

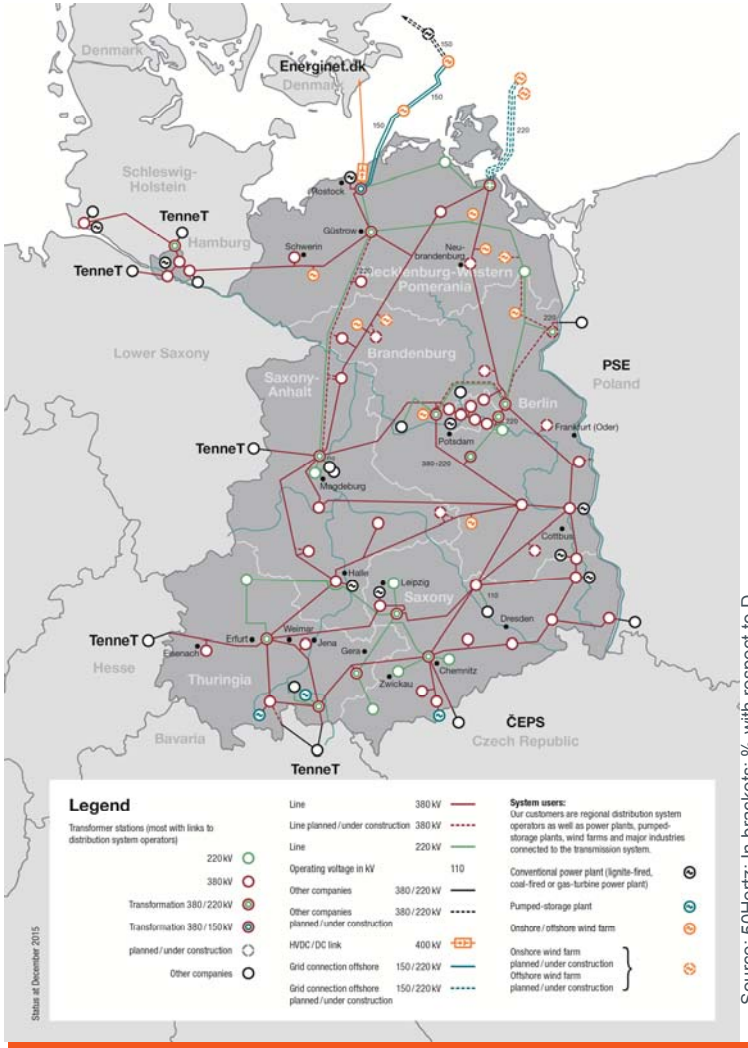


1. **50Hertz**
2. TenneT TSO
3. Amprion
4. TransnetBW

50Hertz as part of an international group



The Transmission System Operator 50Hertz



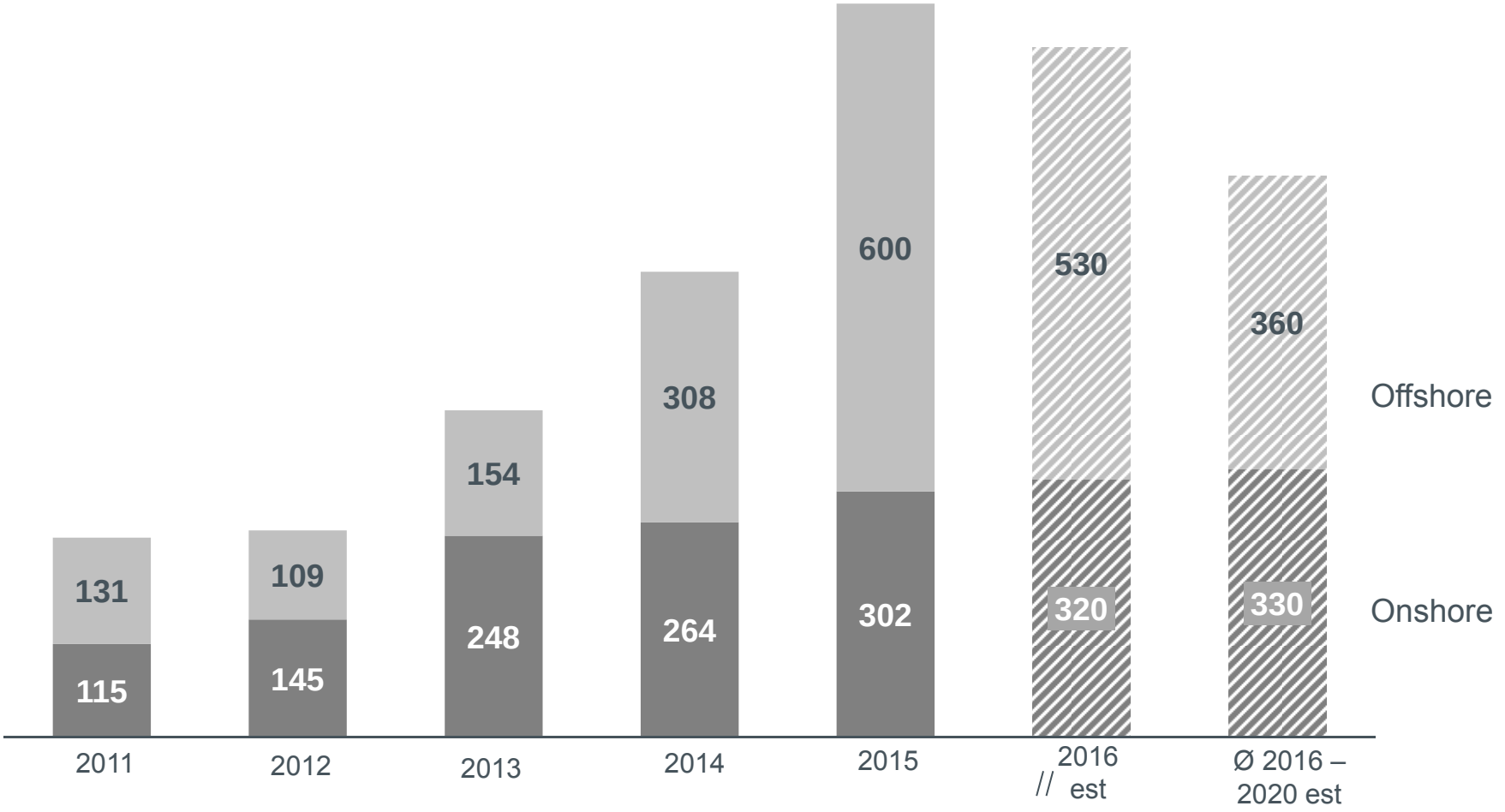
Source: 50Hertz; In brackets: % with respect to D

	2015	2010
Area	109,589 km² (~31%)	109,589 km² (~31%)
Total length of lines	10,150 km (~30%)	9,800 km (~30%)
Maximum load	Approx. 16 GW (~20%)	Approx. 17 GW (~20%)
Energy consumption (based on electricity supplied to end-consumers in acc. with the EEG)	Approx. 96 TWh (~20%)	Approx. 98 TWh (~20%)
Installed capacity: - of which RES - of which Wind	50,528 MW (~27%) 26,975 MW (~30%) 14,637 MW (~39%)	38,354 MW (~35%) 15,491 MW (~30%) 11,318 MW (~40%)
Workforce	955	650
Turnover - Grid	9.8 bn € 1.4 bn €	5.6 bn € 0.6 bn €

As at 31/12/2015; Provisional data; approved figures will be available in August 2016 Source: 50Hertz

50Hertz ensures the electricity supply to about 18 million people in Germany

Development of 50Hertz investment volumes



50Hertz investment volumes grow due to massive need of grid expansion in Germany

Transmission grids are the backbone of the energy supply in Germany and in Europe

 Owner of the transmission grid	In charge of operation, maintenance and the development of **extra-high-voltage lines** and **power junctions** (substations) as well as for the connection of **large-scale generators** and **consumers** (including offshore)
 System operator	Responsible for **system stability** of the transmission system around the clock: frequency control and voltage regulation, congestion management.
 Market developer	Catalyst for the **development of the energy market**, especially in Northern and Central-Eastern Europe.
 "Trustee" for managing EEG* cash flows	Responsible for managing cash flows **resulting from the Renewable Energy Law (EEG)**.

Source: 50Hertz * German Renewable Energy Law

RES Development Germany and 50Hertz grid area

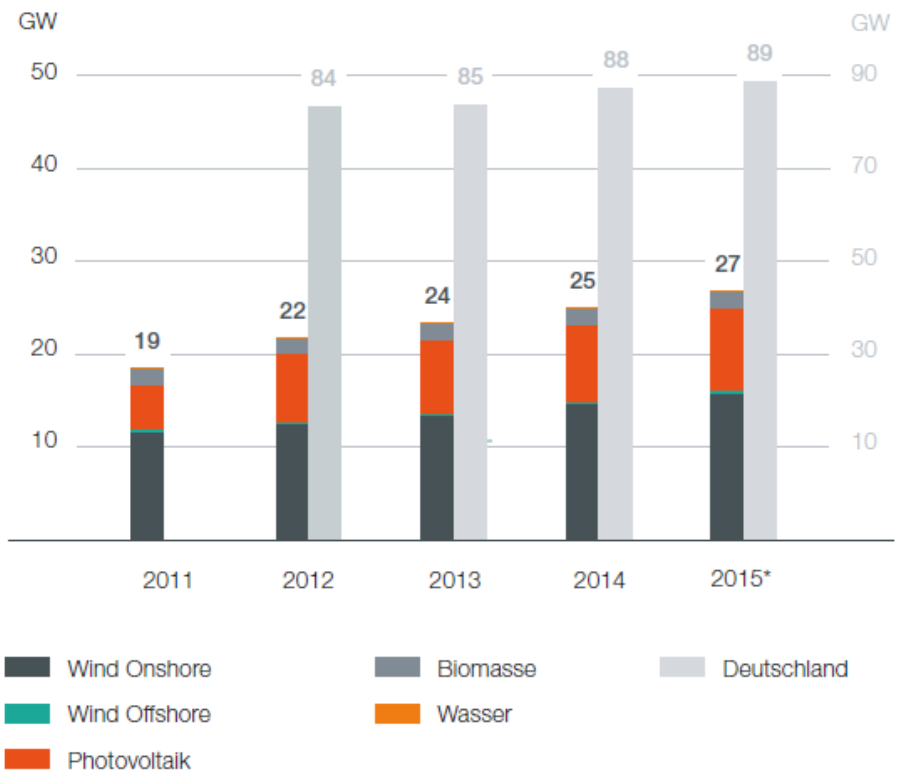


Abbildung ohne Geothermie und Deponie-, Klär- und Grubengas
* vorläufige Werte, testierte Werte für 2015 liegen zum August 2016 vor
Quelle Deutschlandwerte: Kraftwerksliste der Bundesnetzagentur, Stand Oktober 2015

Development of RES capacities Germany and 50Hertz grid area

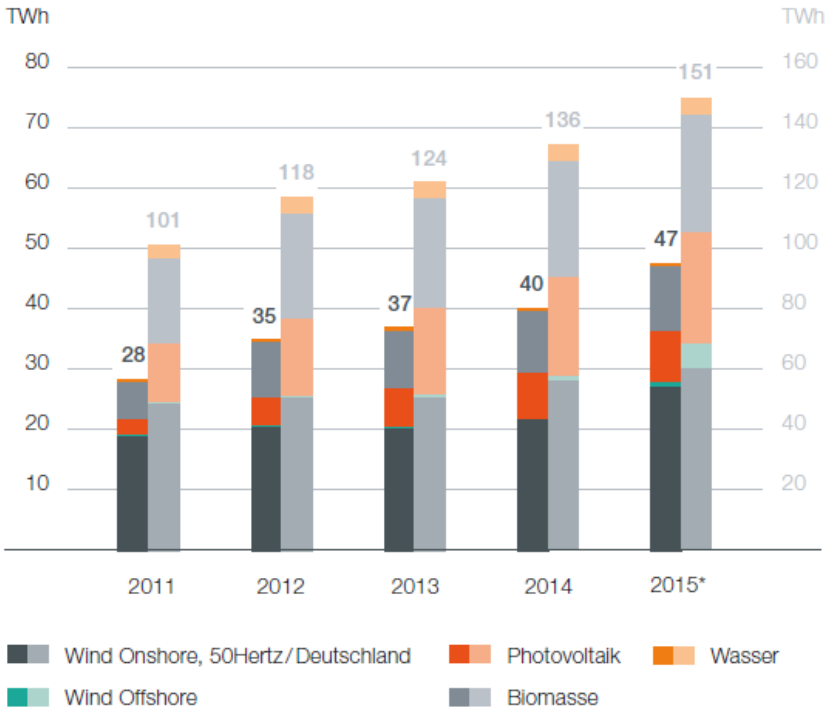
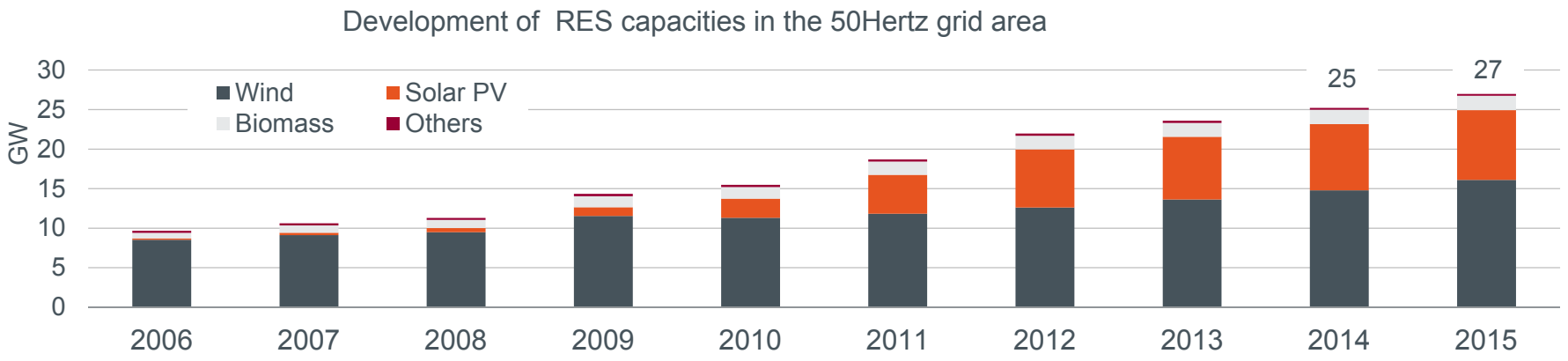
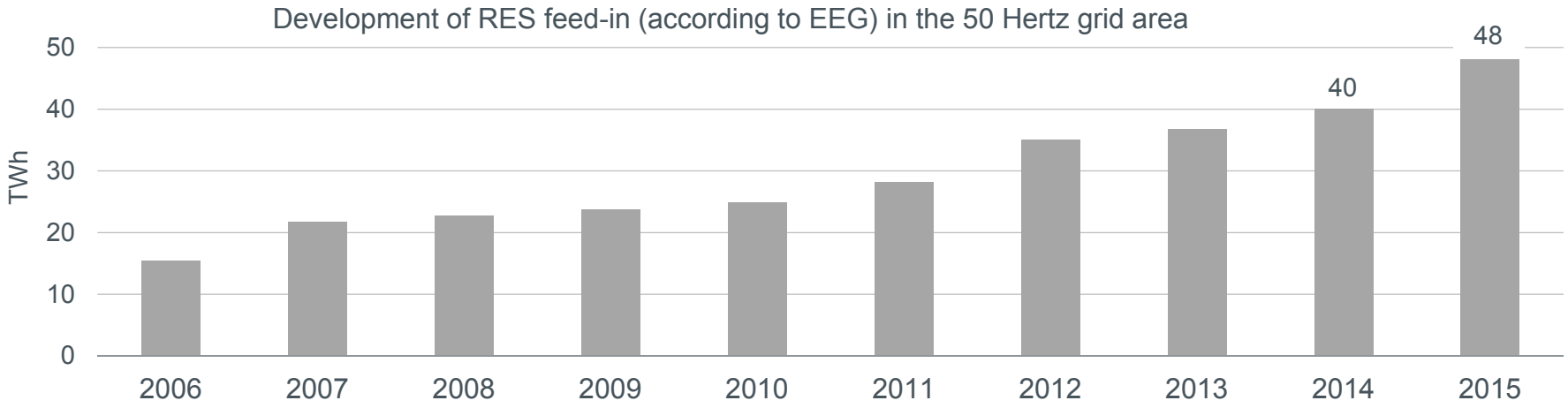


Abbildung ohne Geothermie und Deponie-, Klär- und Grubengas
ab 2012 inklusive Direktvermarktung
* vorläufige Werte, testierte Werte für 2015 liegen zum August 2016 vor
Deutschlandwerte werden mittels einer helleren Farbigkeit dargestellt.
Quelle Deutschlandwerte: netztransparenz.de, Zahlen für 2015 eigene Berechnung

Development of RES feed-in Germany and 50Hertz grid area

RES plants in the 50Hertz grid area





RES capacities are steadily growing in the 50Hertz grid area. RES feed-in amounted up to approx. 49% (knapp 48 TWh) of overall electricity consumption in 2015.

The German Energy Transition

What are the core elements of German „Energiewende“?

Policy-driven structural changes in the German energy system:

Phase out of nuclear energy production by 2022

Dynamic RES development (EEG 2.0)
Targets: 40-45% by 2025, 80% by 2050

Greenhouse gas reduction: Future of coal generation in question
Target: 40% CO_2 reduction by 2020, 80-95% by 2050

Energy efficiency: 50% increase of electricity efficiency by 2050

Grid extension to transport RES energy to the big industrial centres in Southern Germany

Core elements for a successful energy transition

Grid extension

- RES growth requires quicker grid extension
- Need to speed up approval processes
- Use of technology innovations is key

Acceptance

- No acceptance without security of supply
- Need to contain costs
- Information, dialogue and participation of the community is key

Transparency

- Open communication on grid projects
- Data transparency, e.g. 50Hertz load flow data
- “WindNODE”, an IT-based project to connect players

Digitalization

- No “Energiewende” without digitalization
- Need to cross-link system operations and market
- Visibility and controllability of multiple decentralized plants is key

Fair Cost Sharing

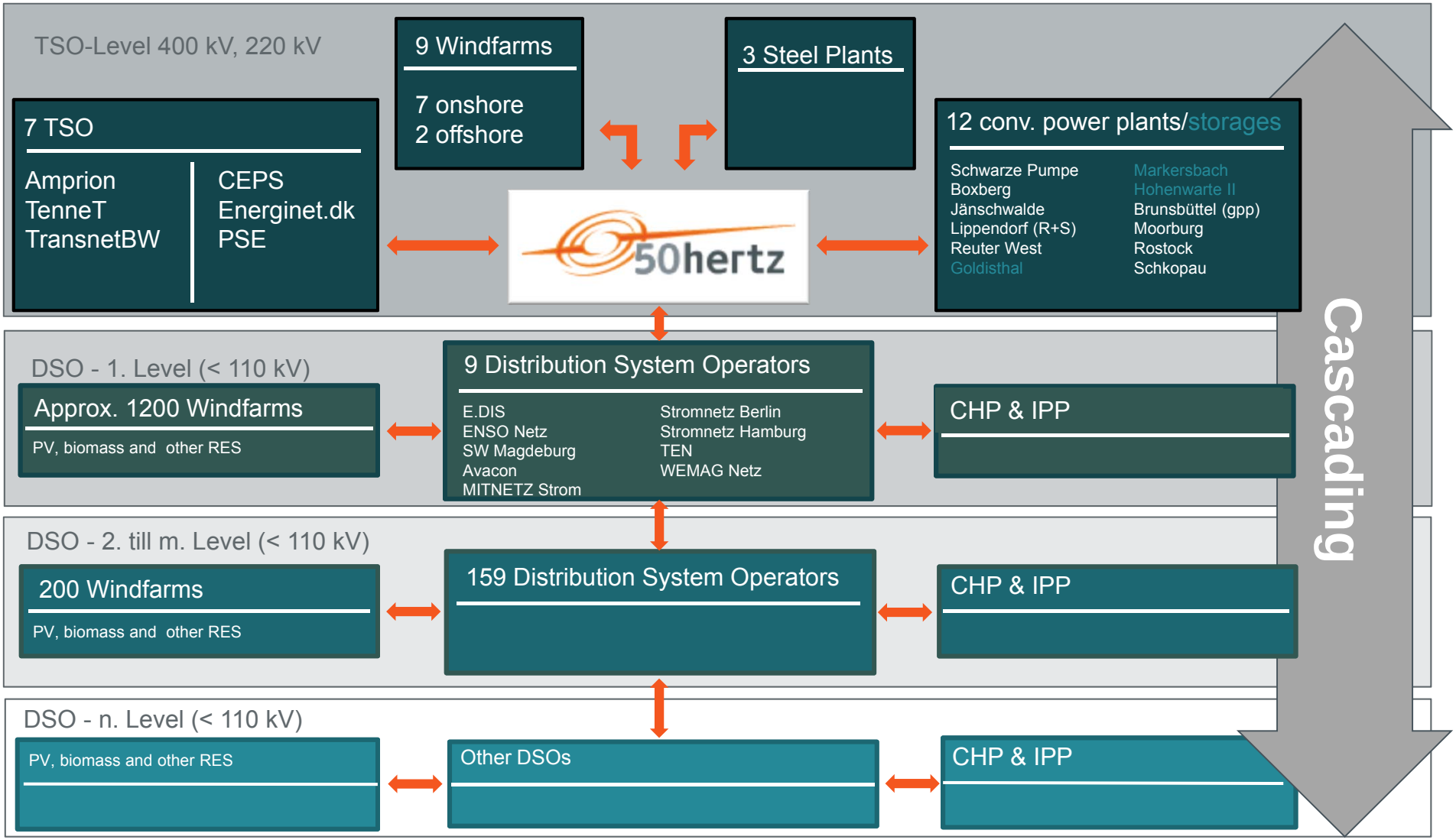
- Need to distribute costs of “Energiewende” equally
- Regional and social balance must be observed
- Fair distribution of grid fees over regions

Framework

- High investment volume requires a stable regulatory and political framework
- Economic efficiency is crucial

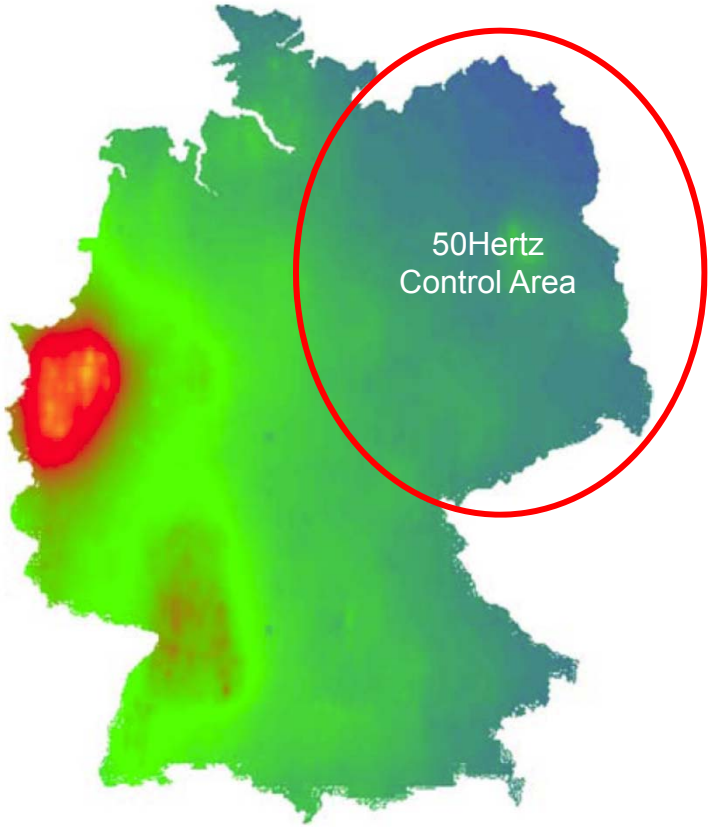
System operations – RES Integration is the essential challenge

The power system in the 50Hertz grid area



As at 12/2013

Load dispatching
in Germany



© Notwendigkeit und Ausgestaltung geeigneter Anreize für eine verbrauchsnahe und bedarfsgerechte Errichtung neuer Kraftwerke, Ein Gutachten für das BMWi, Frontier Economics and CONSENTEC, November 2008

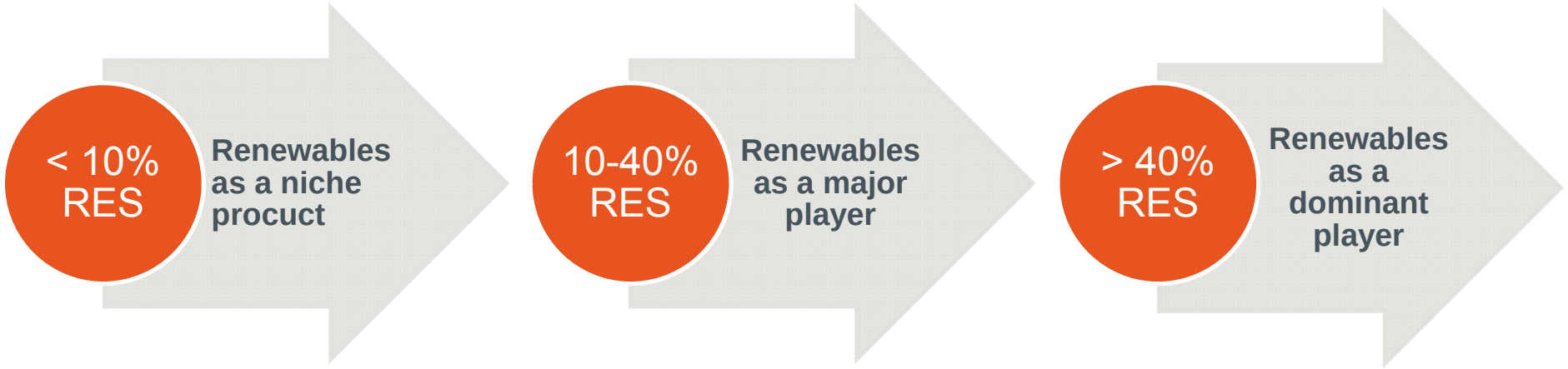
Energy consumption

approx. 96 TWh in the 50Hertz grid area*

Share of total power consumption in Germany: 20 %*

* Situation in late 2015

Rising share of RES challenges the electricity system

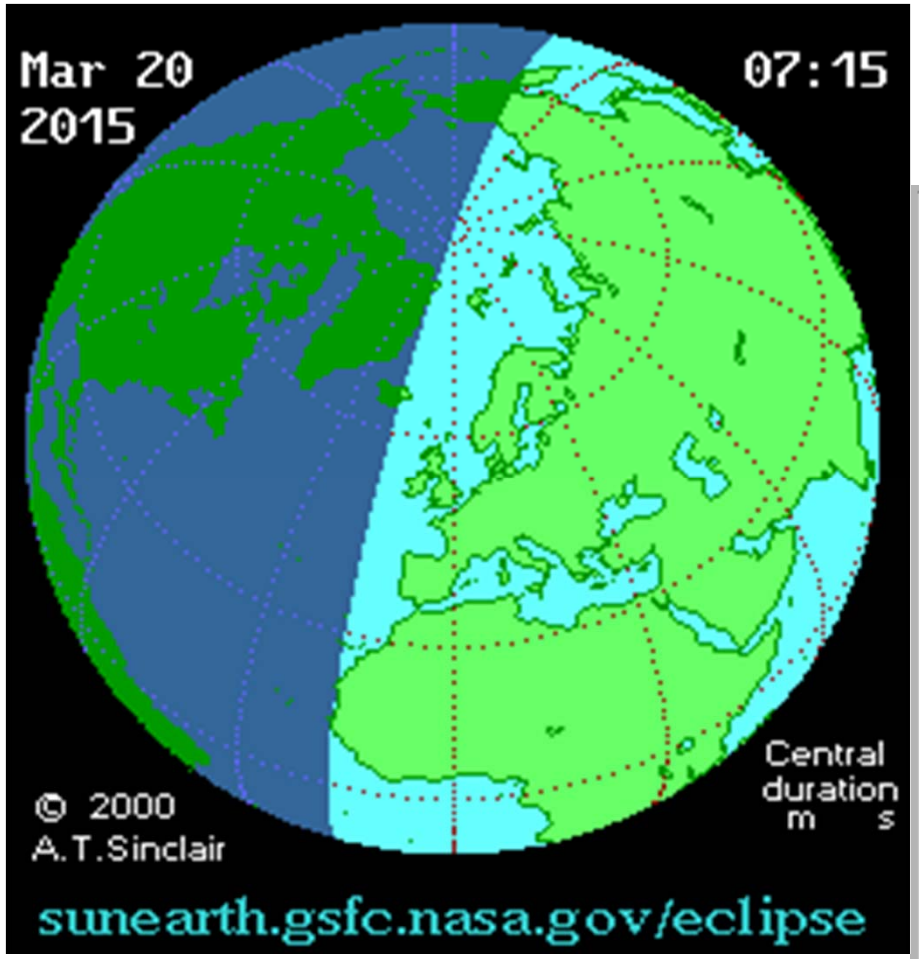


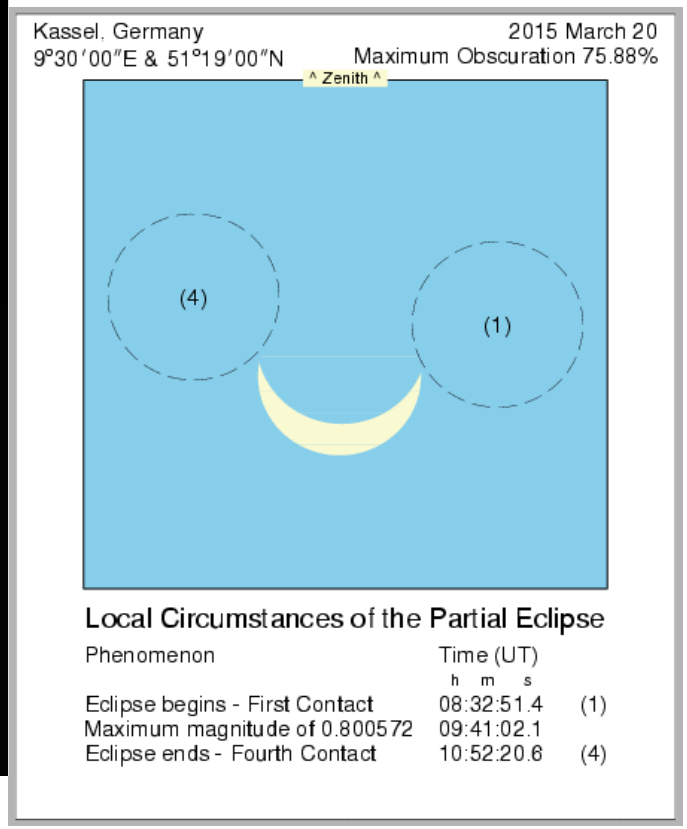
RES have evolved from a niche product to a dominant energy source in the 50Hertz grid area. The electricity system has to be adapted accordingly.

System operations – Challenges from PV

Operational challenges from PV

Solar eclipse 2015 March 20



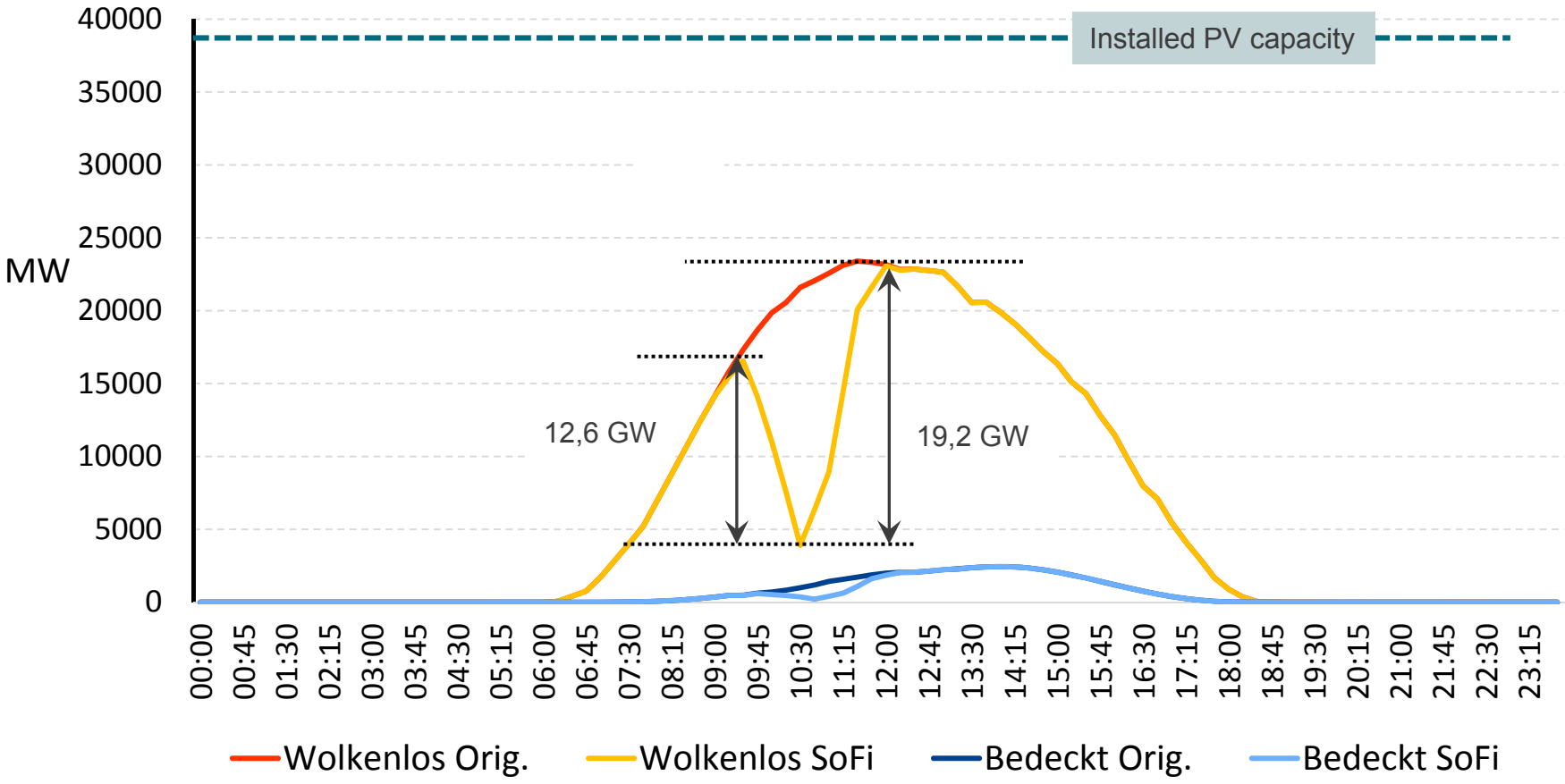


Installed capacity in Europe:
91.000 MW PV – there of in Germany 40.000 MW

Operational challenges from PV

Solar eclipse 20 March 2015

Simulated PV feed-in

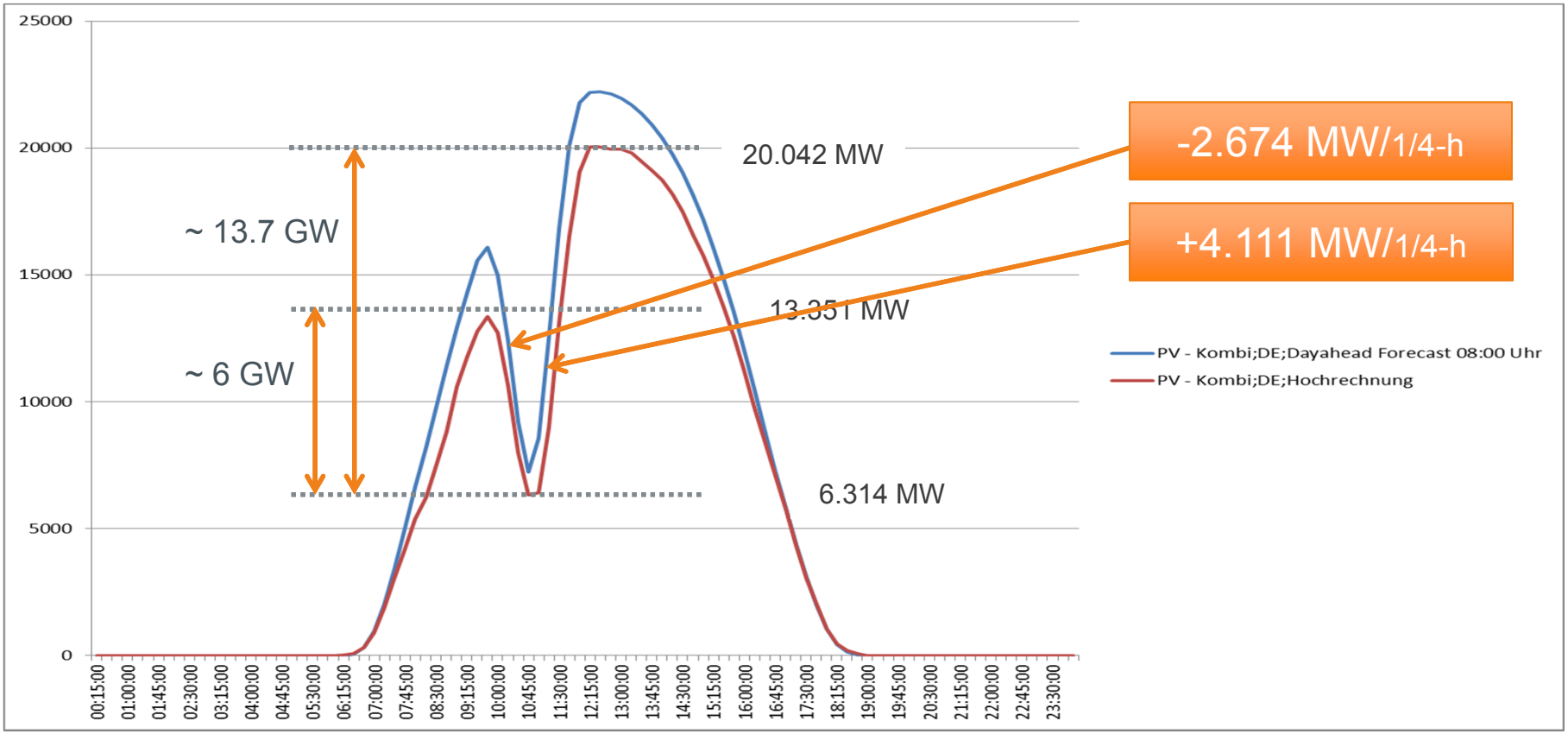


German TSOs count on working market mechanisms for basic balancing

Operational challenges from PV

Solar eclipse 2015 March 20

PV-forecast - Live extrapolation Germany

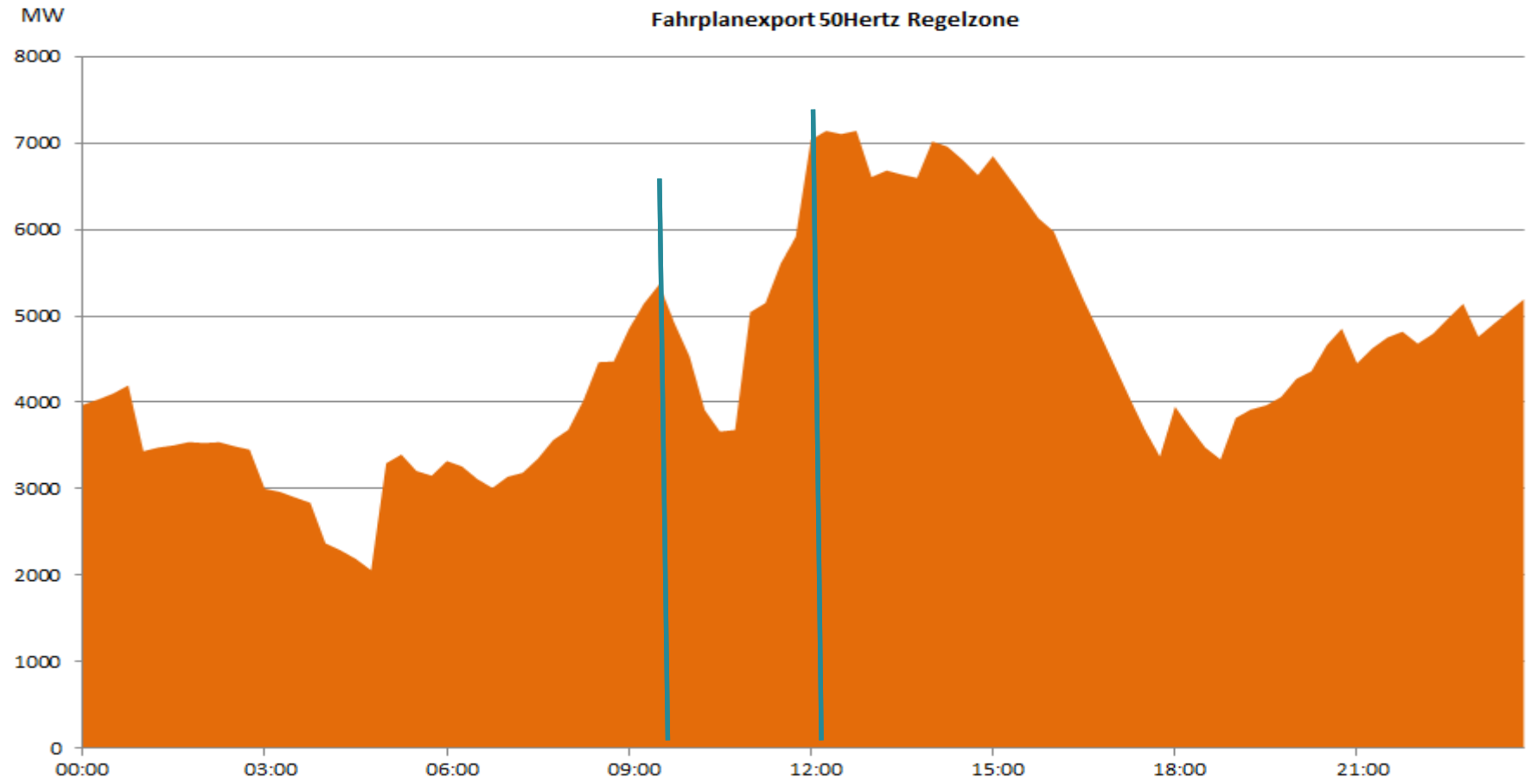


German TSOs can count on market mechanism for basic balancing

Operational challenges from PV

Solar eclipse 2015 March 20

Intraday (8:00 am) Export schedules 50Hertz control area

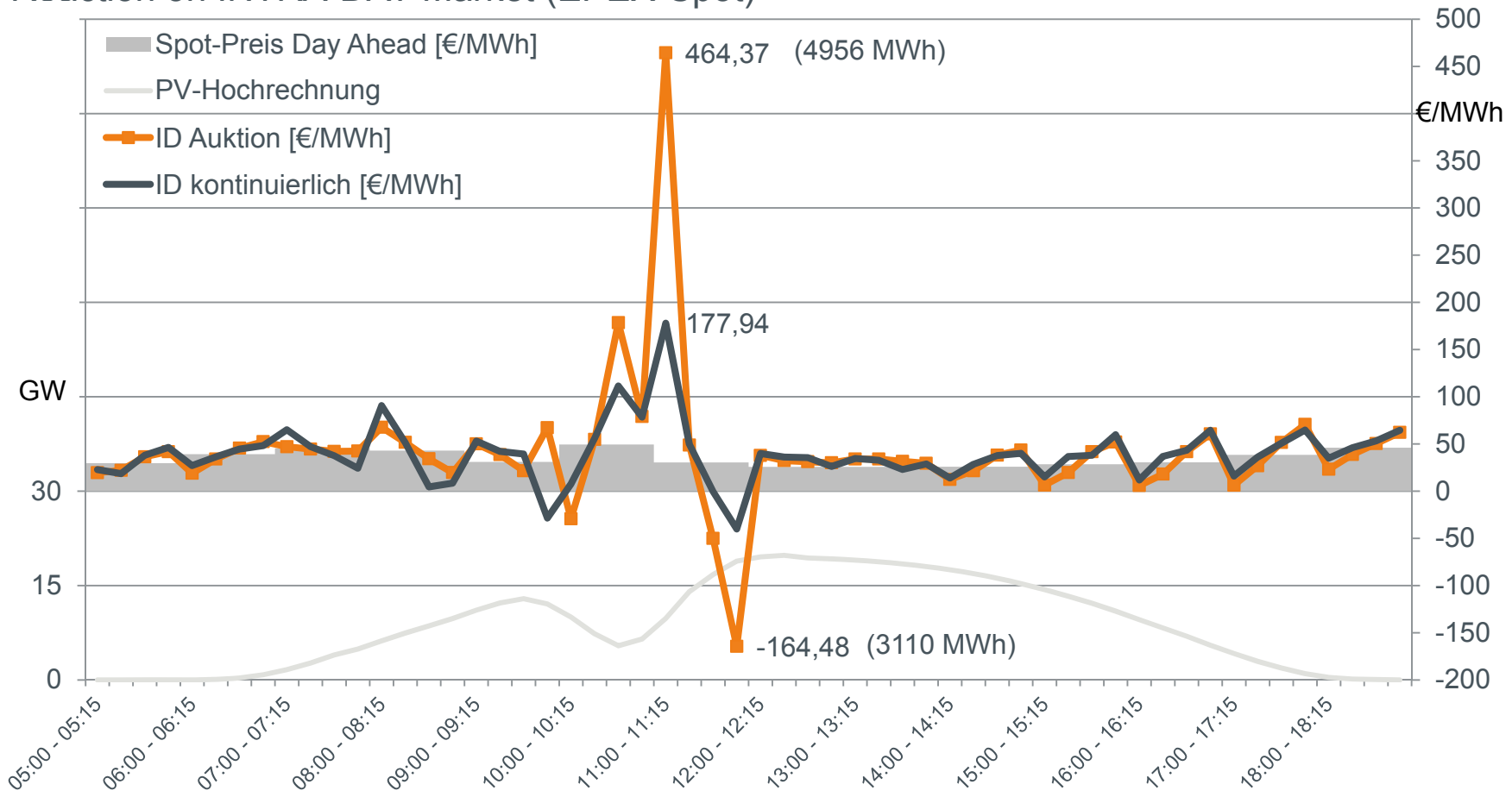


Market participants followed the Solar Eclips

Operational challenges from PV

Solar eclipse 2015 March 20

Reaction on INTRA-DAY Market (EPEX-Spot)

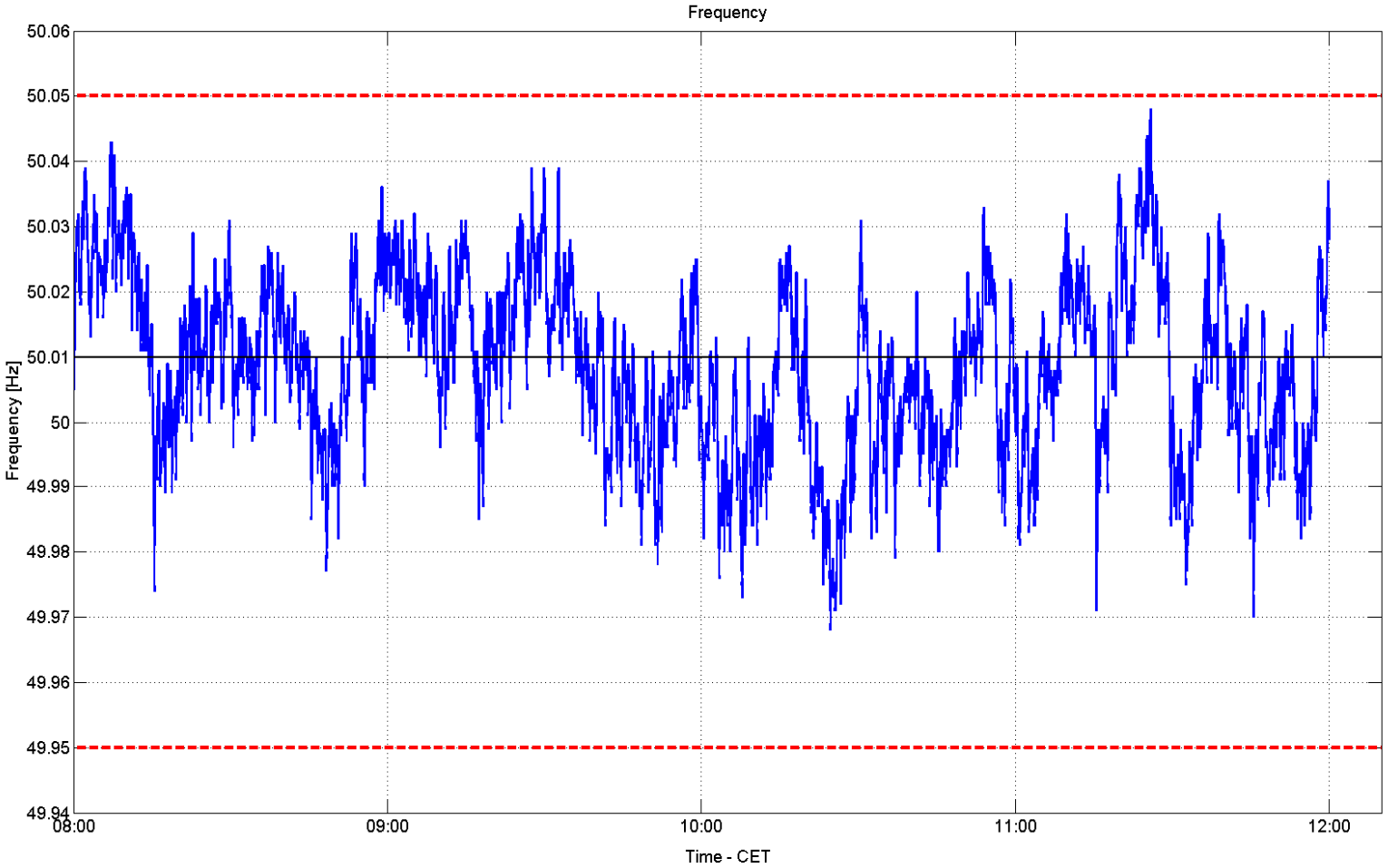


The market products that were developed and introduced over the last years worked properly

Operational challenges from PV

Solar eclipse 20 March 2015

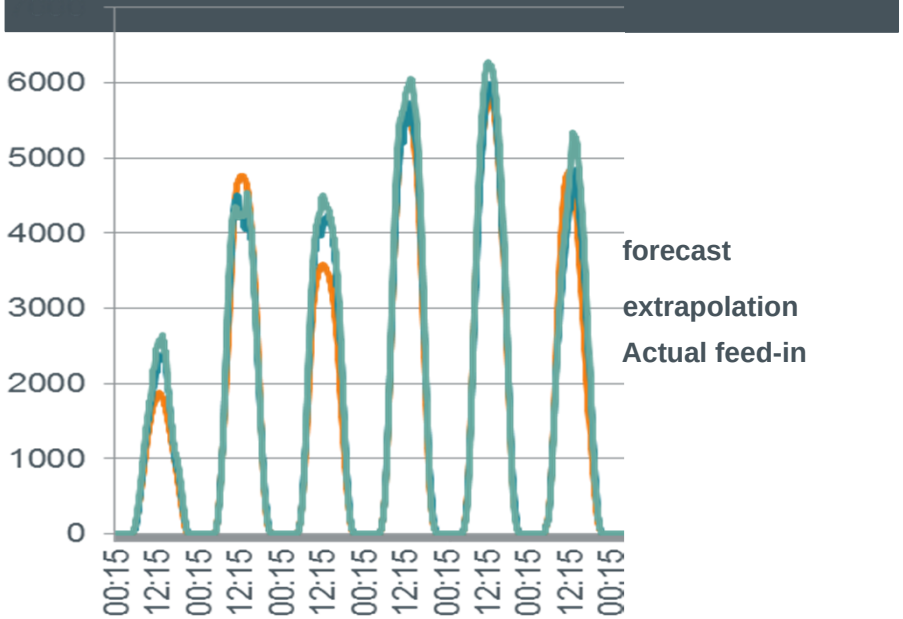
Frequency curve between 08:00am and 12:00 CET



Volatile RES feed-in – Solar PV

PV feed-in data 50Hertz area 2015	
Max. feed-in	5,995 MW
Min. feed-in	0 MW
Strongest feed-in increase within a ¼ hour slot	1,061 MW
Strongest feed-in drop within a ¼ hour slot	-709 MW
Strongest feed-in difference (min.-max.) in one calendar day	5,995 MW

PV-feed-in (01/06/2015 – 07/06/2015)

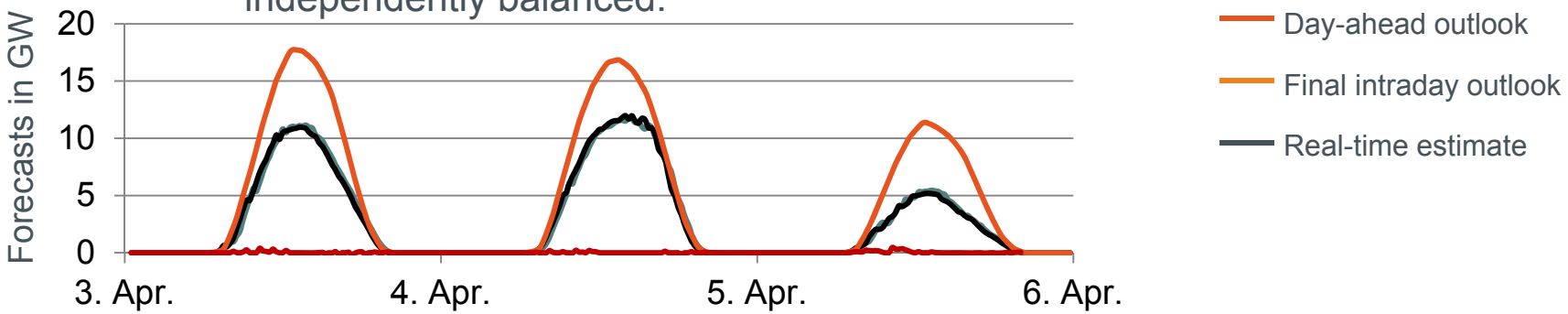


Exact forecasts and an extremely flexible and quickly reacting control system are essential to compensate fluctuations.

Operational challenge due to forecast inaccuracy

PV forecasts for Germany, April 2013

- Dramatic forecast errors of up to 8800 MW in the day-ahead forecast
- Intraday forecasts clearly better in comparison, closer match with actual feed-in
- Control and reserve power exhausted in Germany and German grid no longer independently balanced.

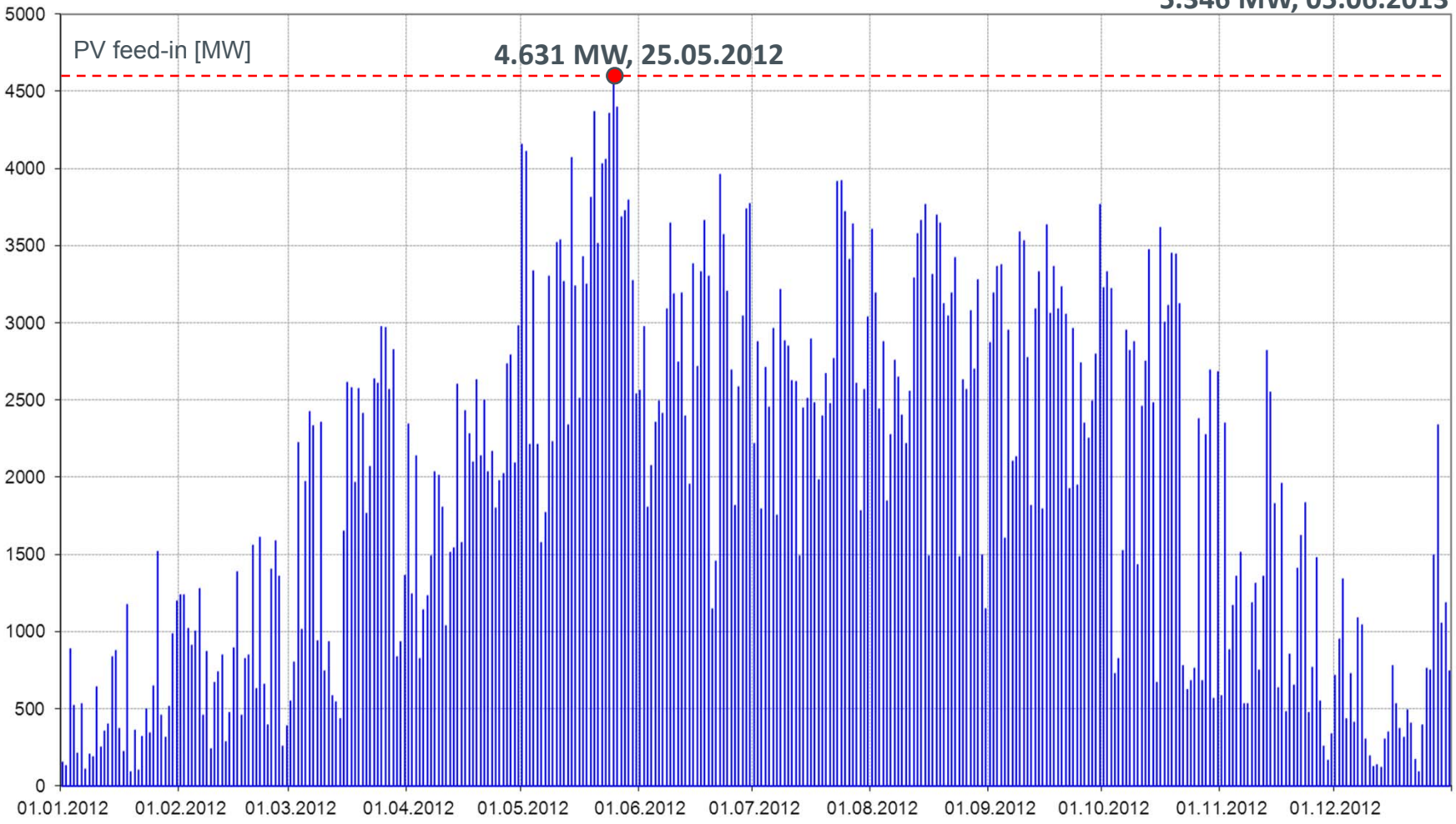


Incorrect PV forecasts can endanger system security!

Operational challenge PV

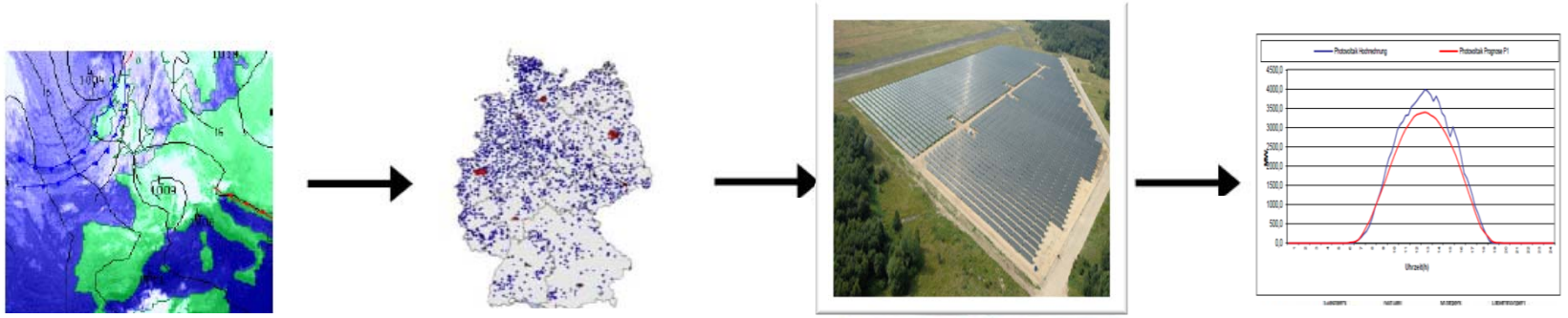
PV feed-in curve

5.995 MW, 05.06.2015
5.540 MW, 20.03.2014
5.346 MW, 05.06.2013



Operational challenges from PV

Day Ahead Forecast PV/ Intraday update



- **External input of meta-forecast:**
  - Solar power forecast 5 suppliers (EnergyMeteoSystems, Meteocontrol, Enercast, EnergyWeather, Meteologica) (in operation)
  - Areas: Germany, 50Hertz, DSO regions
  - Horizon day-ahead <= 96 hours; horizon short term <= 8 hours
  - 3 daily updates; ¼ hour short-term updates
- **Combined Forecast with weighted experience by 50Hertz**
  - Linear combination of commercially available forecasts

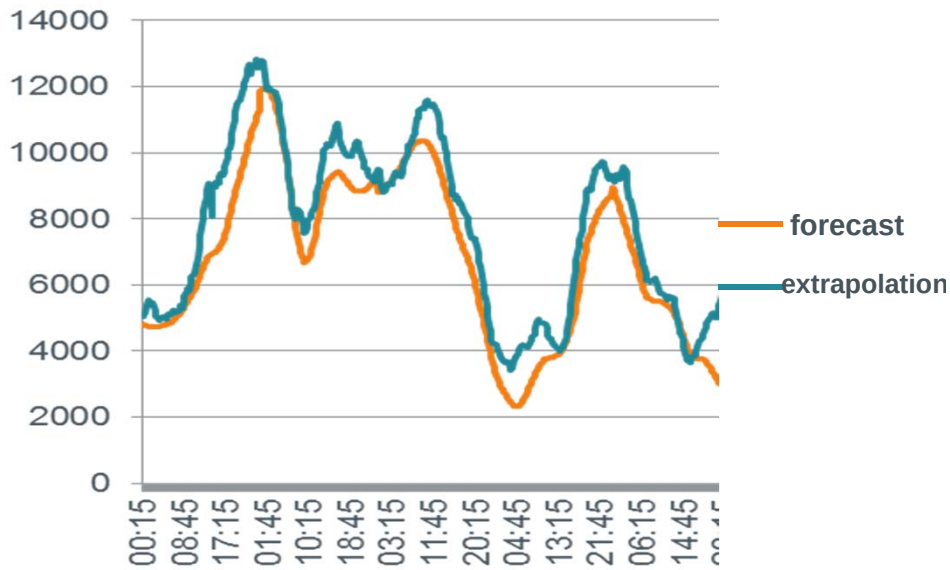
Accuracy of D-1 solar forecast has reached 5-7 % Root Mean Square Error (RMSE), excluding night hours

System operations – Challenges deriving from WIND

Volatile RES feed-in – Wind Energy

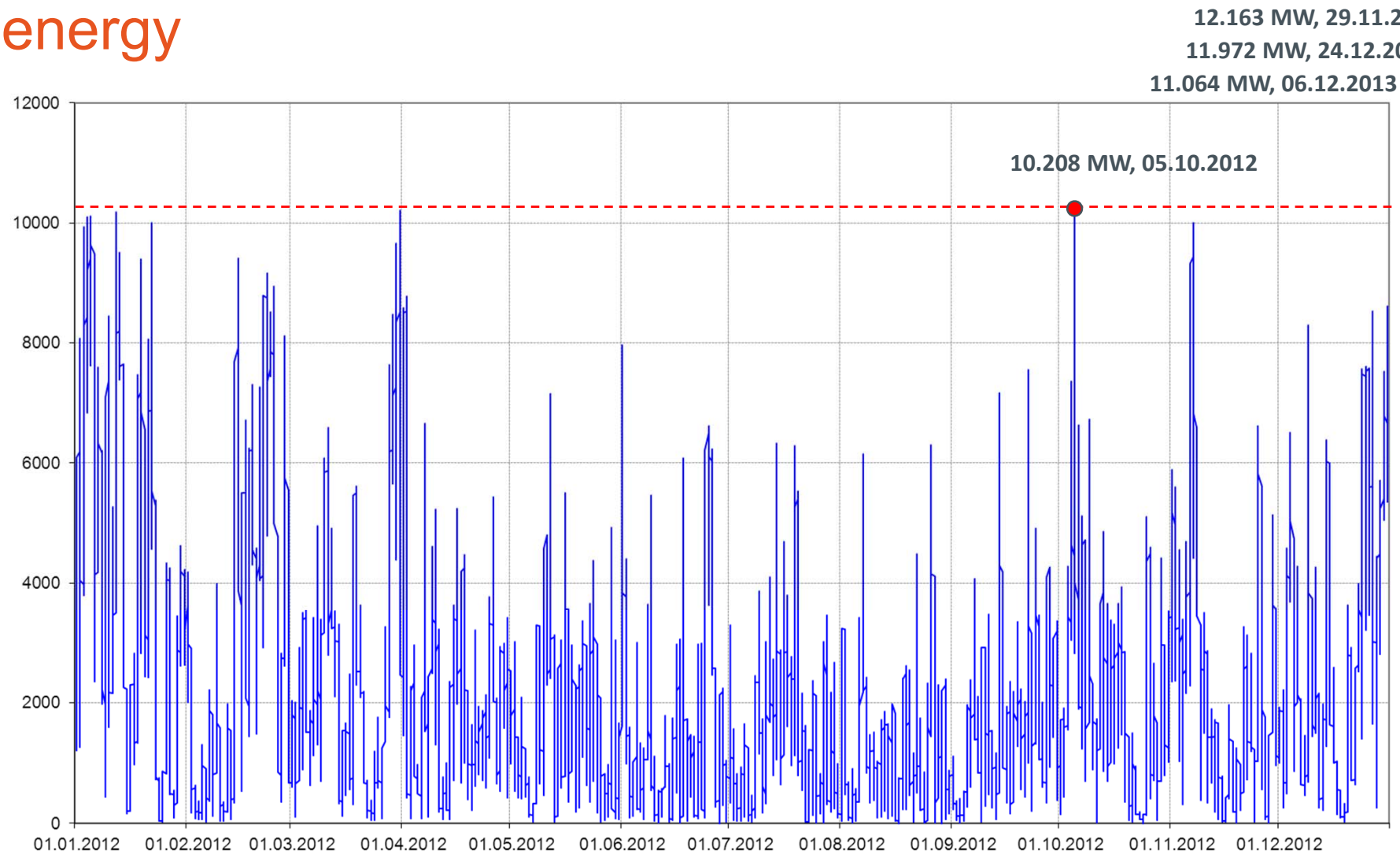
Wind feed-in data 50Hertz area 2015	
Max. feed-in	12,832 MW
Min. feed-in	9 MW
Strongest feed-in increase within a ¼ hour slot	1,192 MW
Strongest feed-in drop within a¼ hour slot	- 1,395 MW
Strongest feed-in difference (min.-max.) in one calendar day	10,277 MW

Wind Energy Feed-in (21/12/2015 – 27/12/2015)



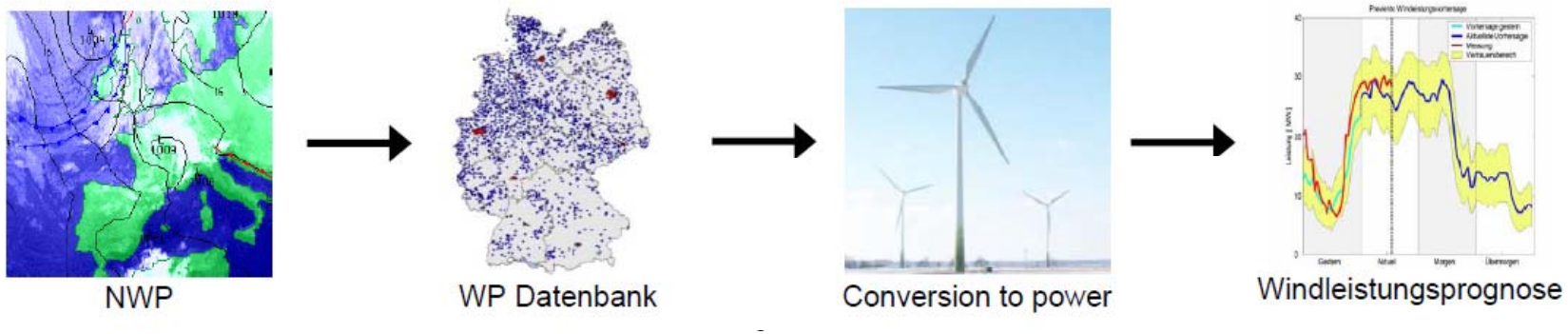
Exact forecasts and an extremely flexible and quickly reacting control system are essential to compensate fluctuations.

Fluctuating feed-in of renewable energies – Wind energy



Operational challenges from Wind

Day Ahead Forecast Wind/ Intraday up-date



- **External input of meta-forecast:**
  - Wind power forecast 6 suppliers (EnergyMeteoSystems, IWES, EuroWind, MeteoGroup, WEPROG, Meteologica, Weatherhouse) (in operation)
  - Areas: Germany, 50Hertz, DSO-regions
  - Horizon day-ahead <= 96 hours; horizon short term <= 8 hours
  - 3 daily updates; ¼ hour short term updates
- **Combined Forecast with weighted experience by 50Hertz**
  - Linear combination of commercially available forecasts

Accuracy of D-1 wind forecast has reached 2-4 % Root Mean Square Error (RMSE)

System security relevant incidents

Hurricane on 2015/07/07

380-kV Overhead line Lauchstädt-Klostermansfeld-Wolmirstedt

Disturbance 380 kV Overhead line Lauchstädt- Klostermansfeld-Wolmirstedt

Where: Regional center West;
switch off 380 kV overhead line
Lau-Wol 535 and Lau-Klm 538
through storm pylons break down

When: **07.07.2015 19:52 h**

What: 14 damaged pylons and
3 partly damaged pylons
Pylon 46 until 62

other connected damages
- 1x DB rail way
- 2x local street
- 1x regional street
- 8 country lanes

Documentation of the damages

Over head line 535/538 was switched on 21.November 2015 based on provisional towers.

System security relevant incidents

Hurricane on 2015/08/13

380-kV Overhead line Pulgar-Vieselbach

Disturbance 380 kV Overhead line Pulgar-Vieselbach

Where: Regional center south west;
switch off 380 kV overhead line Pul-Vib 589/590
through storm pylons break down

When: **13.08.2015; 17:36 h**

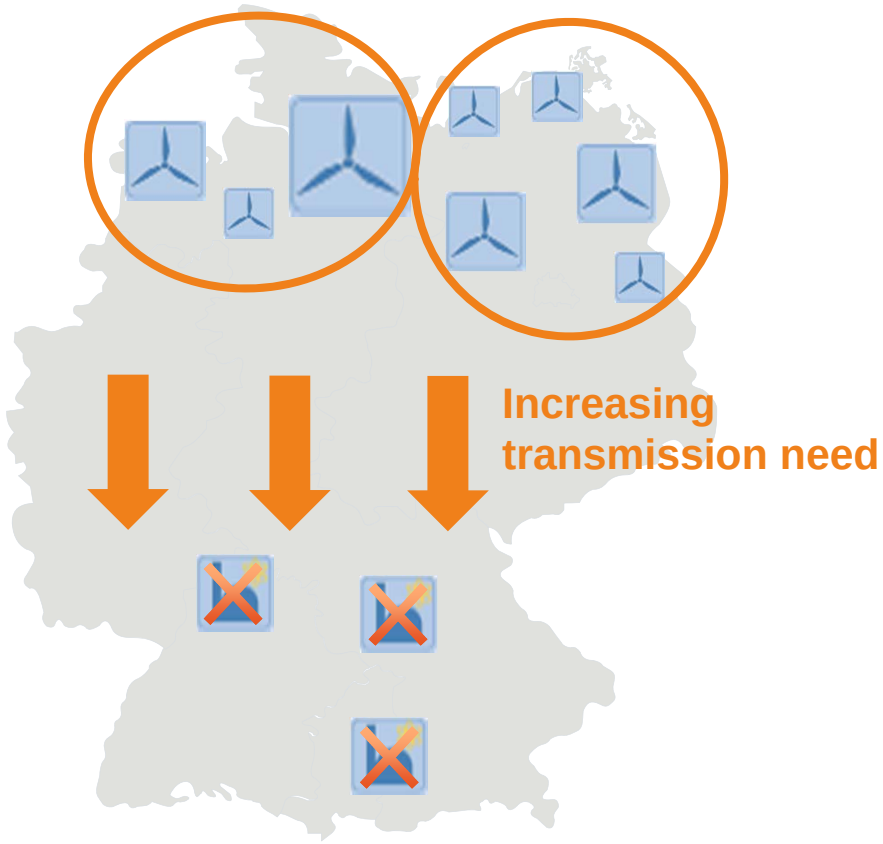
What: 5 damaged pylons and
2 partly damaged pylons
pylons 123 – 129

Documentation

Overhead line 589/590 was re-commissioned on 16th Dec. 2015 based on new towers.

Congestion Management

RES growth requires an adaptation of the transmission grid infrastructure



Overload of he existing transmission grid between North and South Germany

-> High redispatch costs

Further aggravation of the problem:

- Wind power generation increases in the North.
- Due to the nuclear phase-out, output in the South will drop by about 8 GW.

Grid adaptation is key to successfully implement the energy transition

Grid load in the 50Hertz area

Asynchronous line load > 5h/a

2009

Load ≤ 50%

50% < Load < 70%

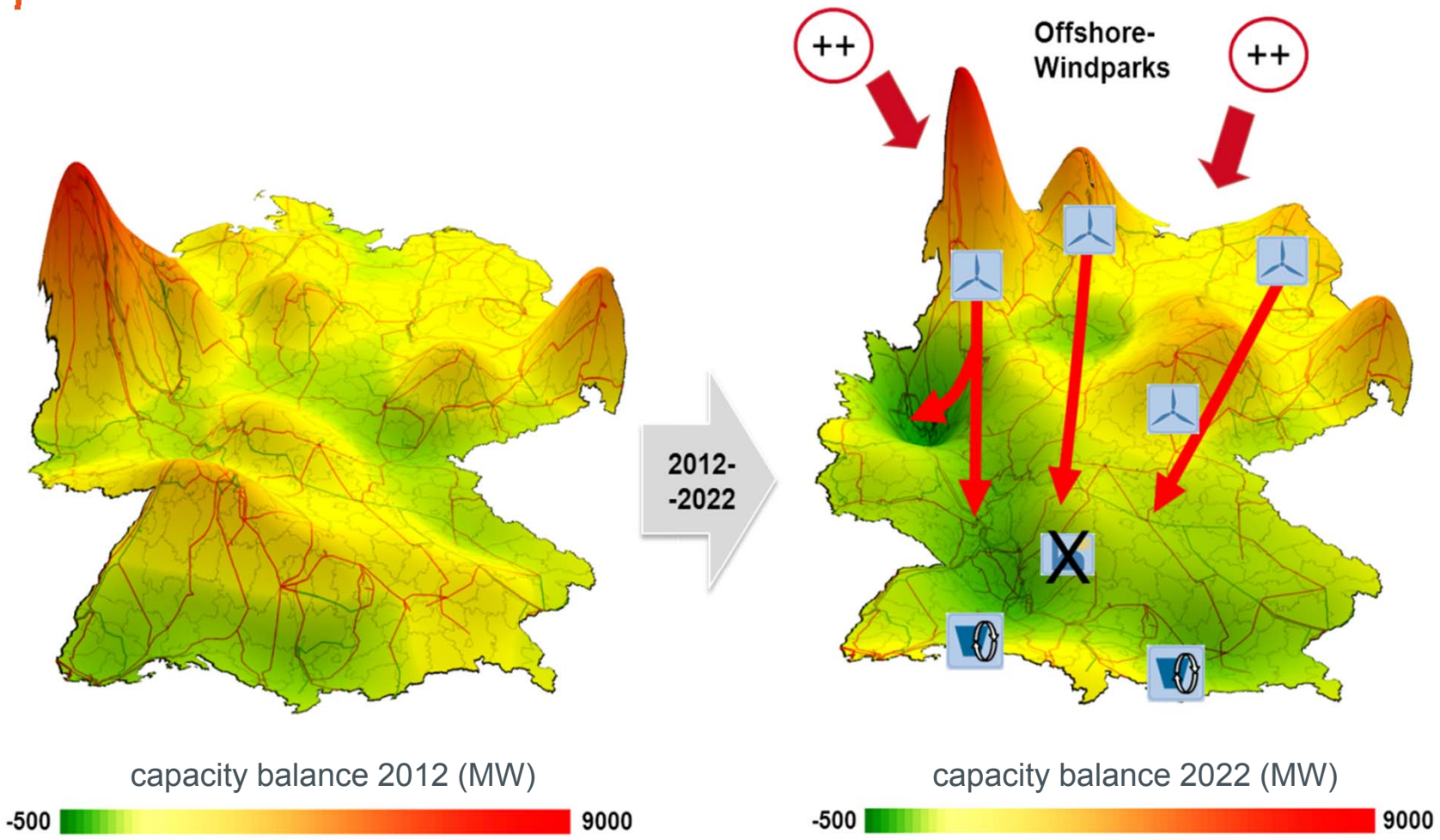
Load ≥ 70%

No Values

2015

Grid load increases dramatically due to the changing generation infrastructure

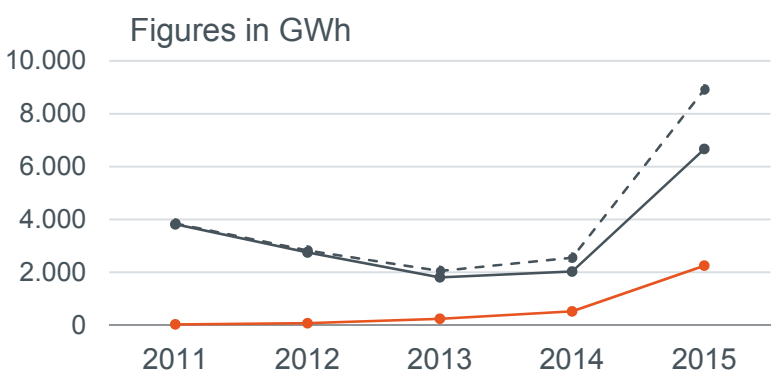
Increasing distance between consumption and production

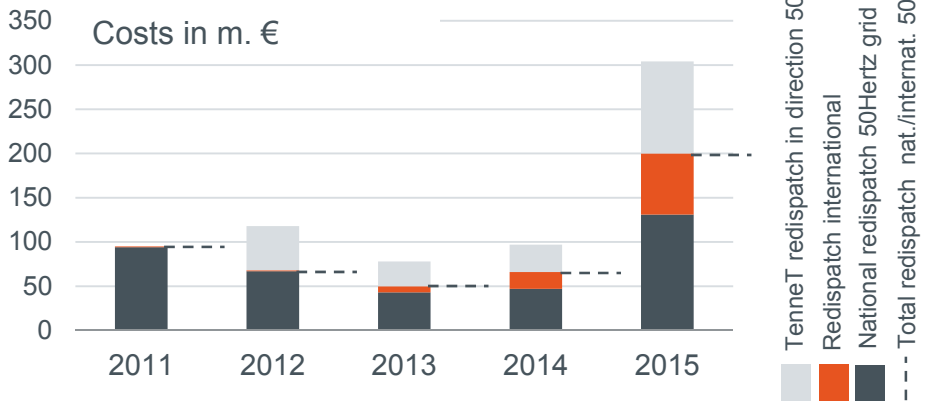


Source: GDP 2012, German TSO 31.01.2012

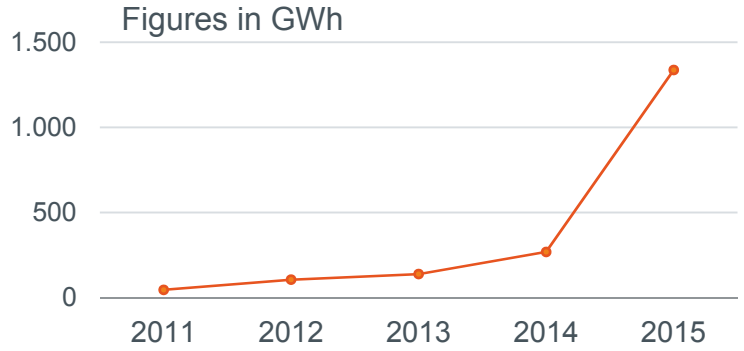
Missing grid capacities lead to overload of lines and a negative redispatch record in 2015

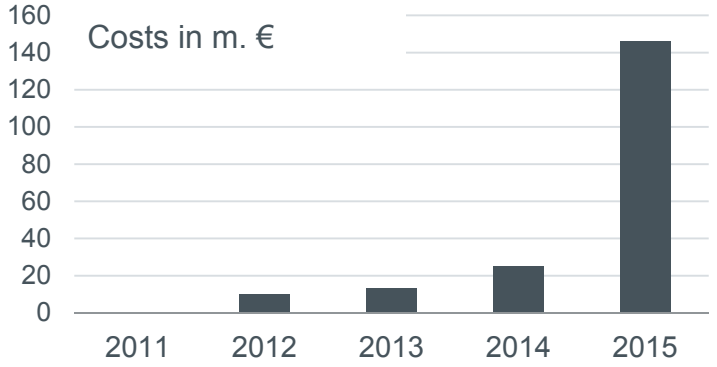
Electricity volumes and costs for redispatch





Electricity amounts and costs to curb wind feed-in



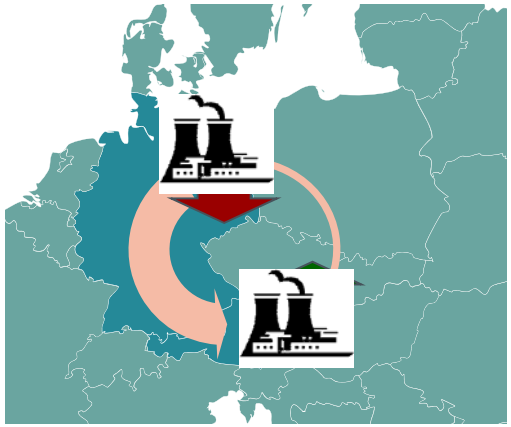


*Situation on 2015/12/31; Approved values will be available in June 2016
Source 50Hertz

The only solution to reduce the enormous redispatch costs to prevent grid congestion is the expansion of the transmission grid.

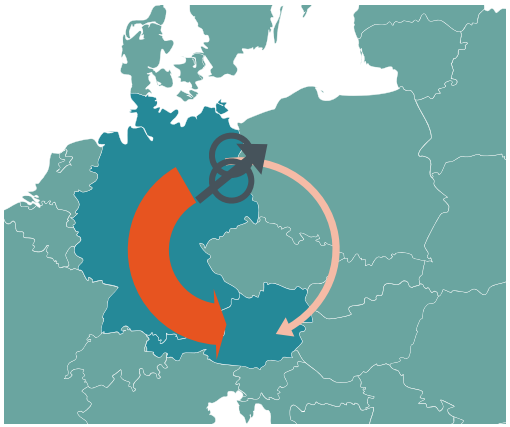
Congestion of European neighbouring grids due to unplanned load flows – 50Hertz-measures

Redispatch („virtual PST“)



- reduces system-security-relevant flows
- ensuring efficiency and cost effectiveness = challenge

Phase shifters (physical PST)



- reduces system-security-relevant flows
- investment required

Grid expansion

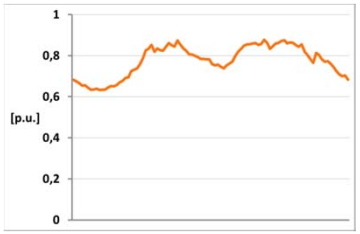
- ensures system-security in entire system
- enables integrated European market

short-term middle-term long-term

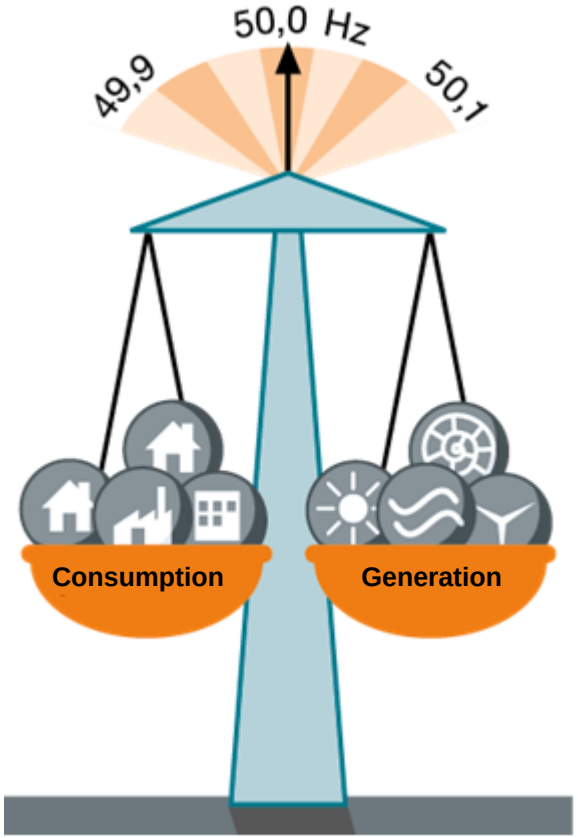
Control power – maintaining balance between load and generation

Balance between Generation and Consumption

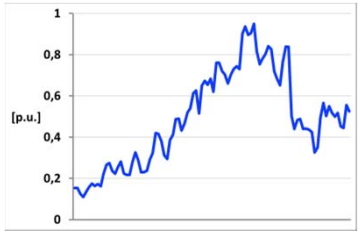
Slowly changing consumption



Daily load profile of the 50Hertz control area



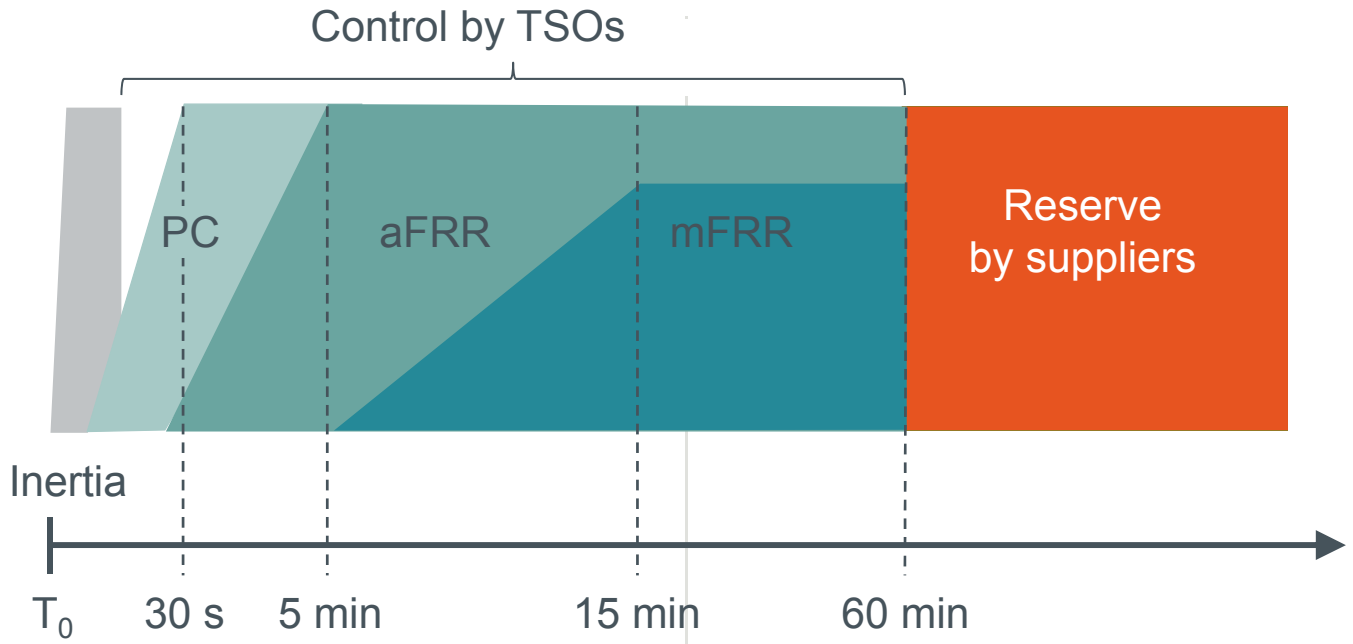
Generation with high share of volatile RES



Wind farm feed-in

Challenge for system operation: control the balance between consumption and generation to ensure a frequency of 50 Hz!

Three control power types exist to keep frequency at 50 Hz



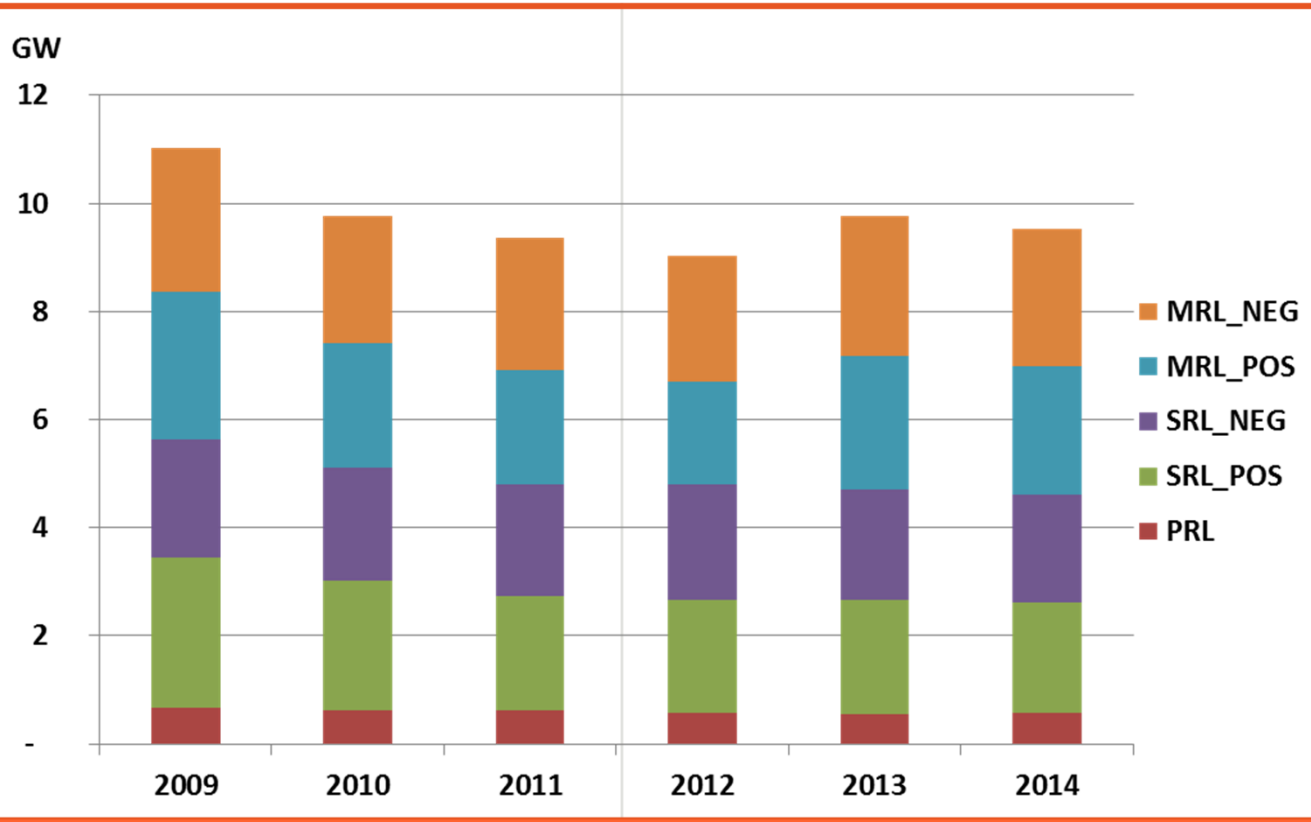
PC: Primary control
aFRR : Automatic Frequency Restoration Reserve = secondary control
mFRR: Manual Frequency Restoration Reserve = tertiary control (minute reserve)

Source: 50Hertz

So far there has been no need for significant changes in control power products, as control power prices have been steadily decreasing in recent years. This might change as the “Energiewende” is gaining pace.

Despite a slight downward trend in the recent years, control power volumes are expected to increase in the future

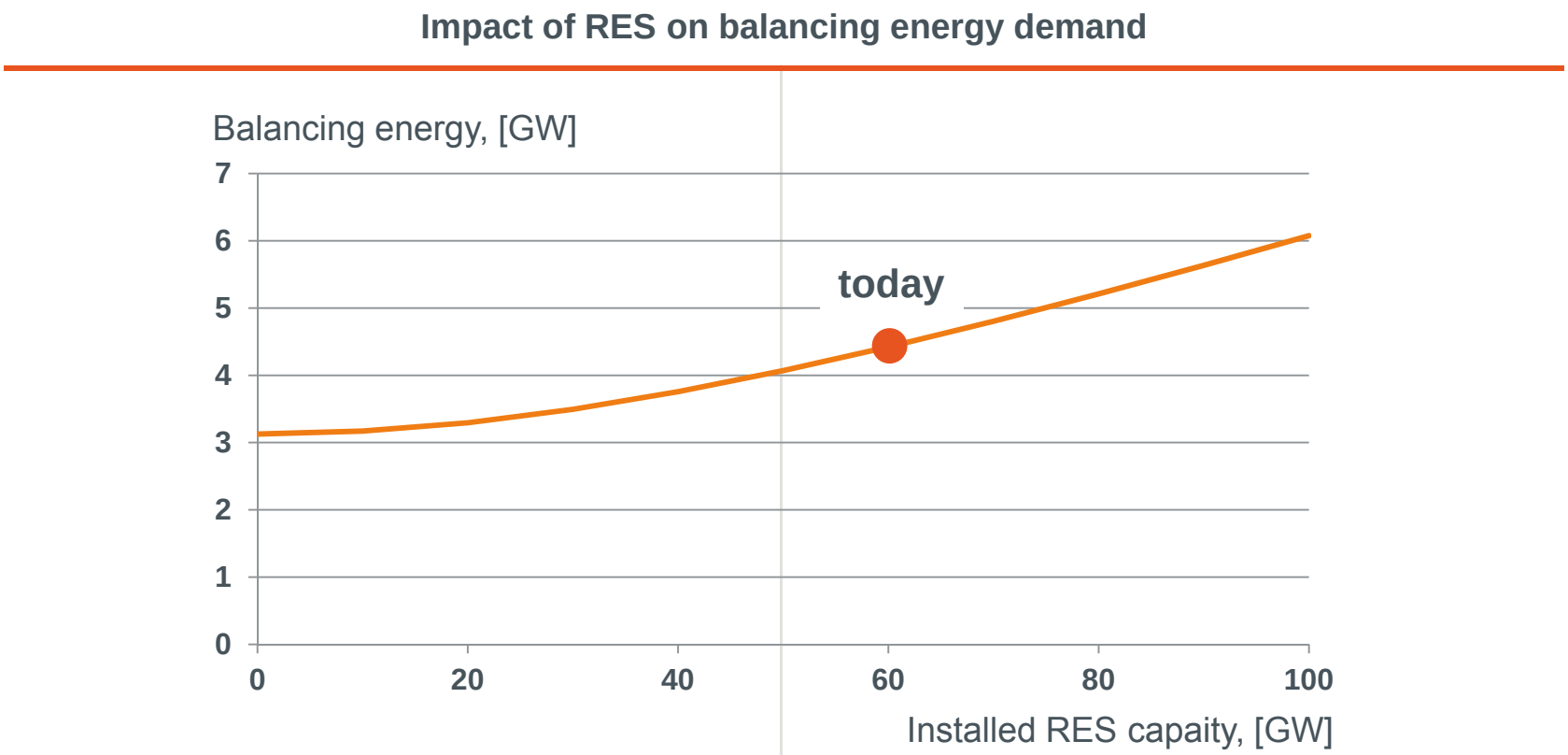
Development of control power volumes



Source: 50Hertz

Grid Control Cooperation (GCC) made it possible to reduce control power volumes in the recent years. Despite GCC we expect an increase of control power in the future as RES share will continue to rise.

Increase of RES share has a strong impact on balancing energy demand



Model: Normally distributed load forecast mistakes, normally distributed RES forecast mistakes

Source: 50Hertz

Increase of installed RES capacity by 1 GW leads to increase of balancing energy demand by 50-60 MW

New providers of control power are very welcome: Electric boilers and a steel mill prequalified in the 50Hertz control area

Electric boilers Stadtwerke Schwerin

- Three electric boilers prequalified for **secondary control** (aFRR) provision
- Up to **10 MW** aFRR
- Start of aFRR marketing in December **2013**

Steel mill Hamburg

- Electric furnace 3 of ArcelorMittal Hamburg GmbH prequalified for **tertiary control** provision (mFRR)
- Up to **70 MW** mFRR
- Start of mFRR marketing in **2010**

Sources: Stadtwerke Schwerin, ArcelorMittal Hamburg GmbH

New providers of control power are very welcome: Batteries prequalified in the 50Hertz control area

Source: YOUNICOS

Battery Berlin-Adlershof

- **Power:** 1 MW
- **Capacity:** 6.2 MWh
- **Technology:** Lithium-Ion Sodium-Sulphur
- **Commissioning:** 01/2012
- **Usage:** primary control

Battery Schwerin

- **Power:** 5 MW
- **Capacity:** 5 MWh
- **Technology:** Lithium-Ion
- **Commissioning:** 09/2014
- **Usage:** primary control

New providers of control power are very welcome: Aluminium electrolysis and small end-consumer plants in 50Hertz area

Lichtblick pilot (small end-consumer plants)

- Joint project of LichtBlick Energie und Innovation GmbH and German TSOs
- Start in 2014 with **5 MW secondary control** (aFRR)
- **Potential** of **up to 100 MW** control power
- Utilisation of storage potentials of the so-called **Zuhausekraftwerke** (Home power plants)

Trimet project (aluminium electrolysis)

- Provision of **30 MW primary control** by TRIMET Aluminium AG via aluminium electrolysis
- Start of primary control marketing in **2011**
- Thanks to technology applied best control quality in the 50Hertz control area

Sources: LichtBlick Energie und Innovation GmbH, TRIMET Aluminium AG

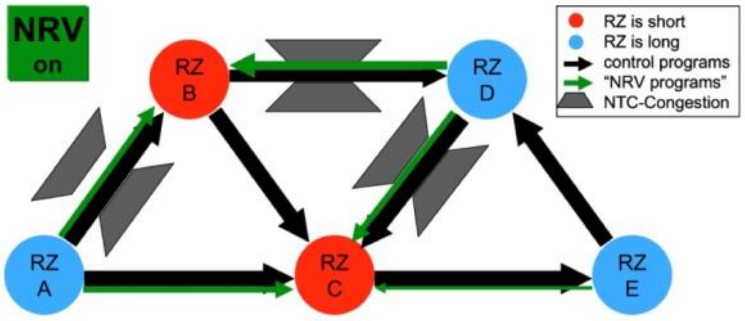
Integration of balancing markets to foster competition and promote exchange of balancing services

entsoe
Reliable Sustainable Connected

network codes.eu

Network code on Electricity Balancing

- Integration, coordination and **harmonisation of** electricity balancing **rules**
- **Harmonisation of products**
- Move from balancing on a national level to **larger markets** allowing effective resources usage
- Code **submitted** to ACER **in December 2013**



Projects with 50Hertz participation

- **International Grid Control Cooperation** (IGCC) for imbalance netting in DE, BE, AT, DK, NL, SH, CZ
- **Joint procurement of primary control** with Switzerland (25 MW) and Netherlands (35 MW)

Source: ENTSO-E; network codes.eu, Wikipedia

IGCC Introduction

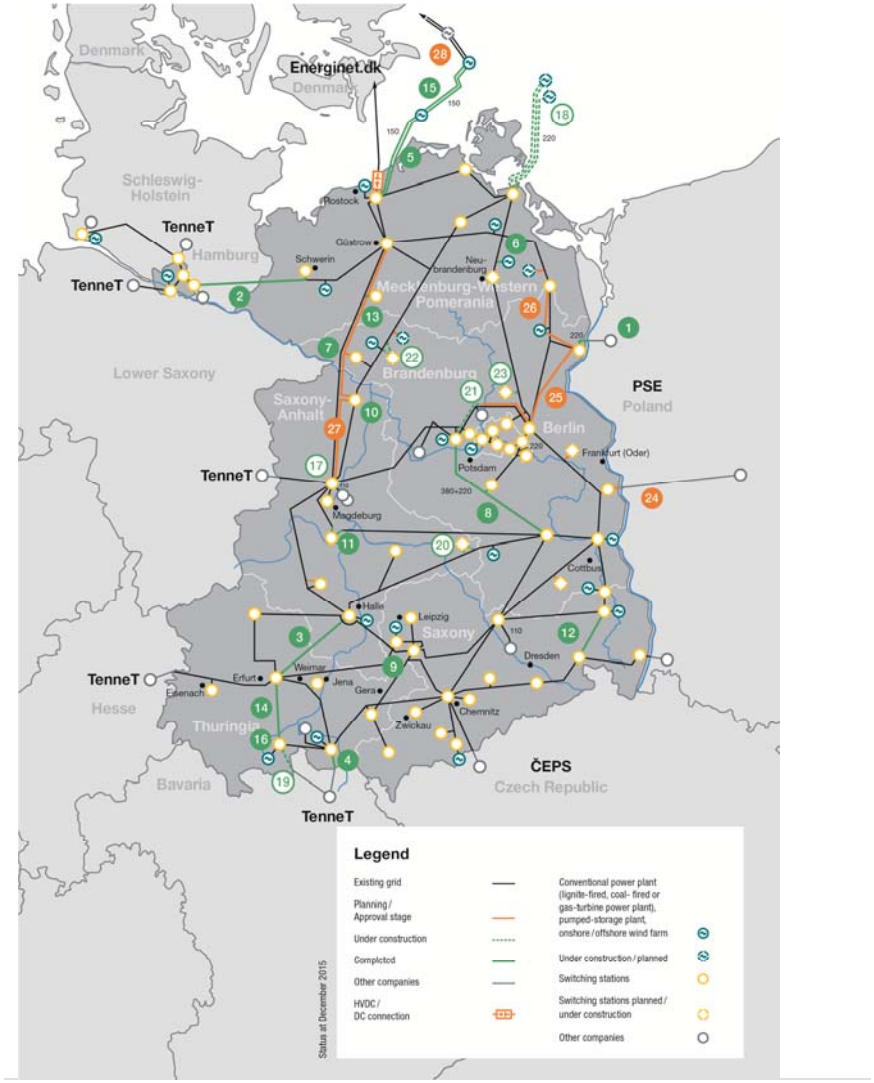
Since May 2010, all four German TSOs have launched the so called **Grid Control Cooperation (GCC)** to optimize secondary control procurement and activation

Many aspects of the GCC system are open for a contribution of TSO's from neighboring countries, so called **International Grid Control Cooperation (IGCC)**

Grid extension

Grid extension projects 50Hertz area since 2009

(as of 2015/12/31)



Grid expansion

Grid expansion projects since 2009

	Project (selection)	Project status	Line length
1	Vierraden – Krajnik (section)	Operational	3 km
2	Northern line Hamburg – Schwerin	Operational	65 km
3	South-west coupling line 1, Lauchstädt – Vieselbach	Operational	76 km
4	Remptendorf – Redwitz high-temperature cable (Thuringia / Bavaria border)	Operational	18 km
5	Baltic 1 offshore wind farm grid connection	Operational	75 km
6	Altentreptow North substation grid connection	Operational	1 km
7	Perleberg substation capacity expansion	Operational	2 km
8	Migration from 220 kV to 380 kV, Ragow – Thyrow and Ragow – Wustermark	Operational	3 km
9	Reconstruction of Eula – Großdalzig for Schlehnhain surface mine	Operational	6 km
10	Stendal / West substation grid connection	Operational	1 km
11	Förderstedt substation 380 kV grid connection	Operational	12 km
12	Bärwalde – Schmölln 380 kV overhead line (reinforcement)	Operational	46 km
13	Parchim South substation grid connection	Operational	1 km
14	South-west coupling line 2, Vieselbach – Altenfeld	Operational	57 km
15	Baltic 2 offshore wind farm grid connection	Operational	~58 km [b]
16	Capacitor bank Altenfeld	Operational	-
17	Wolmirstedt 380 kV upgrade	Under construction	6 km
18	Offshore wind farms Wikinger and Arkona-Becken Southeast grid connection	Under construction	~96 km [a]
	First circuit switched on on 17 December 2015		
20	Jessen North substation grid connection	Under construction / planning approval proceedings not started yet	~1 / ~2 km
21	380 kV Berlin Northern Ring western / eastern part	Under construction / In planning-approval process	~30 / ~50 km
22	Putlitz South substation grid connection	Under construction	~5 km
23	Gransee substation grid connection	Under construction	~1 km
24	3rd interconnector to Poland (to Germany / Poland border)	pending [d]	~10 km
25	Uckermark line Neuenhagen – Vierraden – Bertikow	Planning approval decision	~120 km
26	Bertikow – Pasewalk	In Prior to federal planning stage	~30 km
27	Wolmirstedt – Perleberg – Güstrow	In planning-approval process	~210 km
28	Kriegers Flak Combined Grid Solution	In the approval process	~27 km [b]

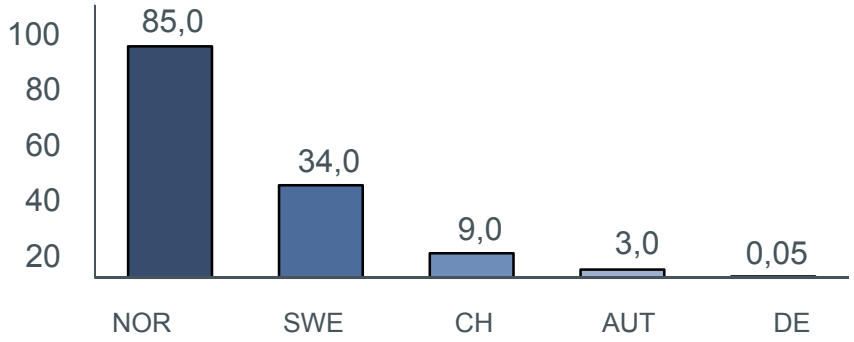
Operational:	**~424 km**
Under construction:	**~165 km**
In the approval process:	**~449 km**

[b] The length indicates the distance of the route between Baltic 1 and 2, new cable lengths cover ~ 190 km in total.
[a] The length indicates the distance of the route between Lubmin and the OWF, the cable lengths cover ~ 290 km in total.
[a] One electrical circuit has been operational for testing purposes since 17/12/2015.
[d] Corridor for the 2nd connection line Eisenhüttenstadt determined in the regional planning procedure.
[b] Connections Baltic 2 (50Hertz) - Kriegers Flak (Energinet.dk), cable lengths ~ 55 km in total.

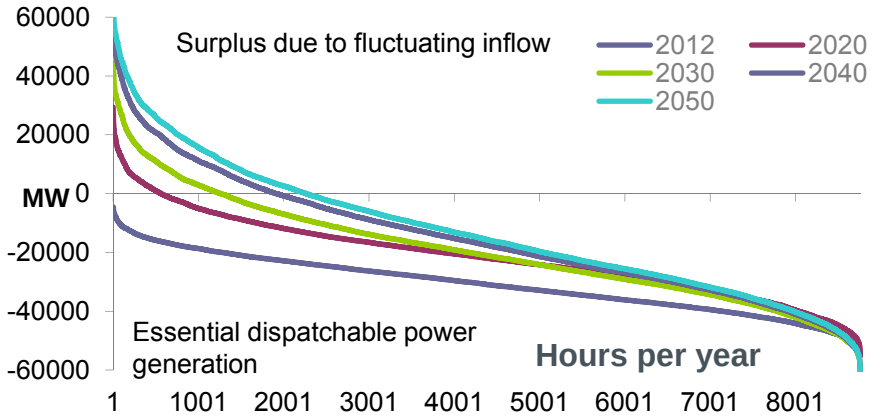
Grid development and storage

* Maximum available storage capacity of water reservoirs in 2011

Maximum available storage capacity of water storage in 2011 (in TWh)



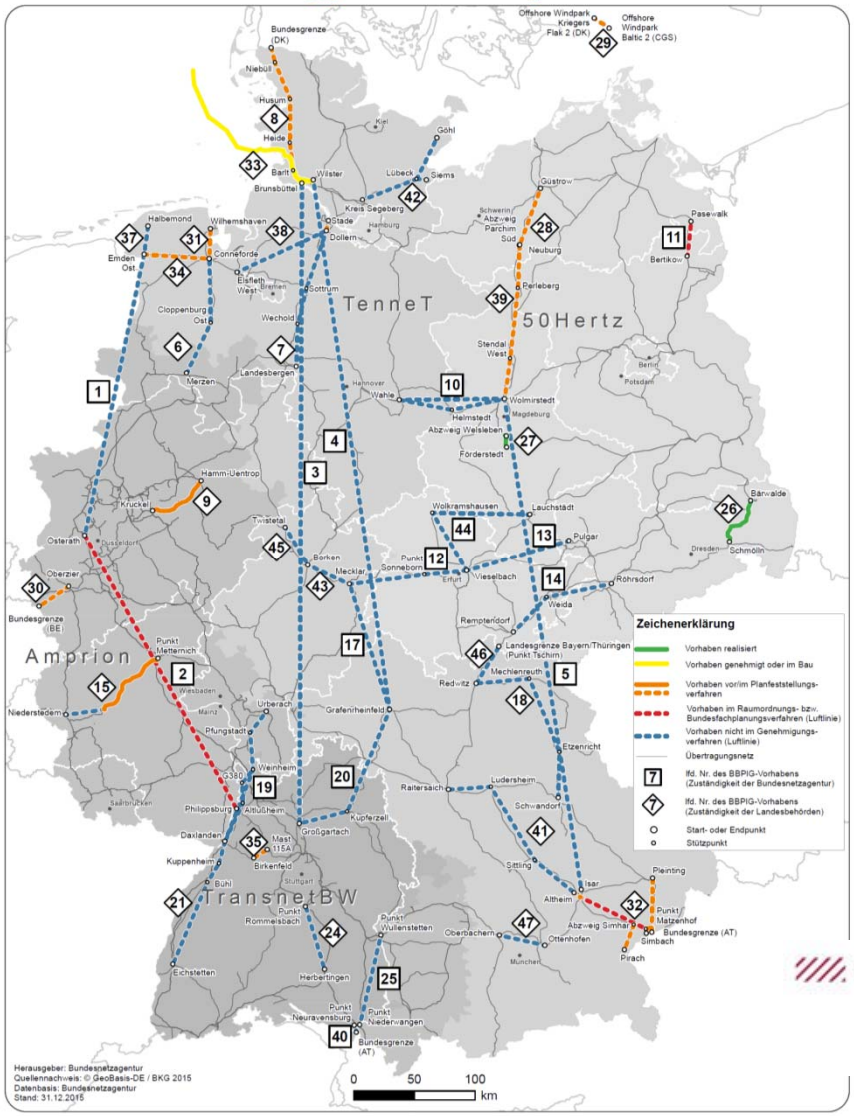
Yearly surpluses in Germany



Source: World Energy Council, 2012

Study of World Energy Council proves high economic value between GER and Nordic countries (between 7 and 12 GW!)

Federal Requirement Plan 2012 as legal basis for grid expansion need

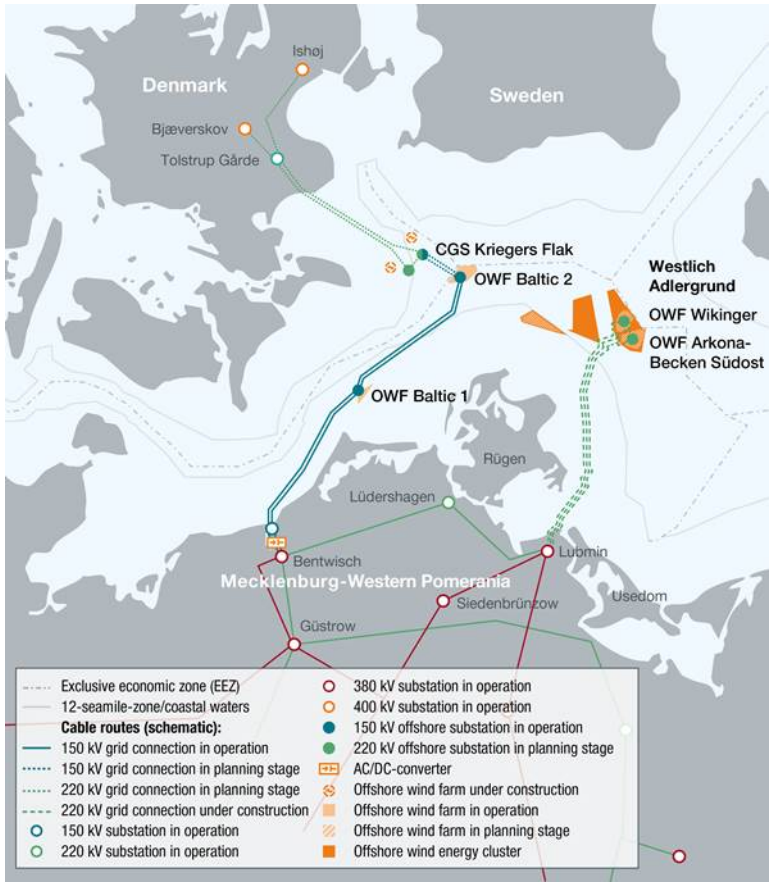


Federal Requirement Plan passed by German Parliament in June 2013 - Adjustments in Dec. 2015

- Basis: 2012 Grid Development Plan of the TSOs
- 43 projects confirmed
- 3 HVDC corridors
- Pilot project for respectively 5 direct-current and alternating current cable lines
- Current Grid Development Plan confirms Federal Requirement Plan

Vorhaben BBPlG | Vorhaben BBPlG vor/im Planfeststellungsverfahren | Vorhaben BBPlG genehmigt oder im Bau
Übertragungsnetz | lfd. Nr. des Vorhabens (Zuständigkeit der Bundesnetzagentur) | lfd. Nr. des Vorhabens (Zuständigkeit der Landesbehörden) | Start- oder Endpunkt | Stützpunkt

Progress of offshore projects in the Baltic Sea



2011: Commissioning of Baltic 1
2012: Start of construction Baltic 2
2014: Connection granted to windfarm operators in the "Westlich Adlergrund" region; first cables ordered
2015:

- Allocation of grid connection capacity to the OWF Wikinger (350 MW) and Arkona-Becken Südost (385 MW)
- Grid connection of Baltic 2
- Grid Connection „Westlich Adlergrund": Receipt of all necessary approvals for the construction of the cable connection; start of preliminary works for the sea- and landline cable laying

Steady development of wind offshore projects in the Baltic Sea – Grid connections for existing projects according to plan

Thank you for your attention!

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