Wind Power Development in Europe – Experiences and Lessons Learned

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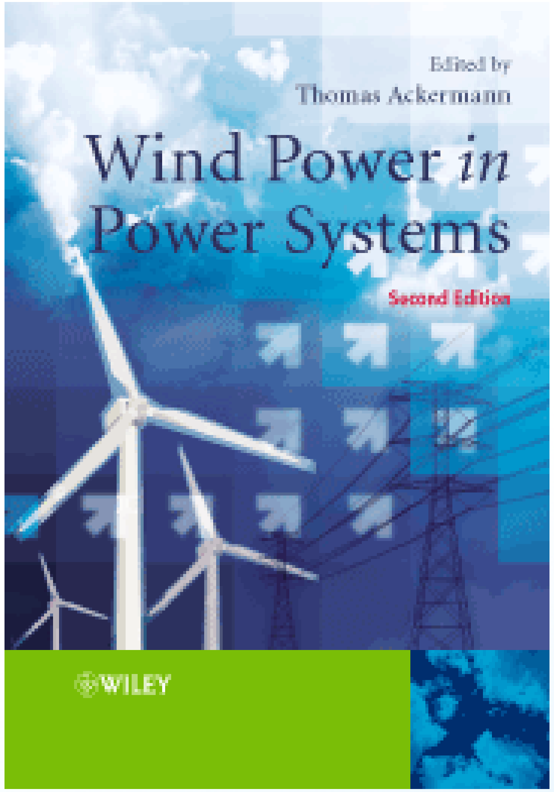
High Share of Renewables in Europe
… and the lights will stay on!

Edited by Thomas Ackermann



Picture © Felix Pharand-Deschenes.

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Introduction

The European Power System: Well integrated but still very different on the national level

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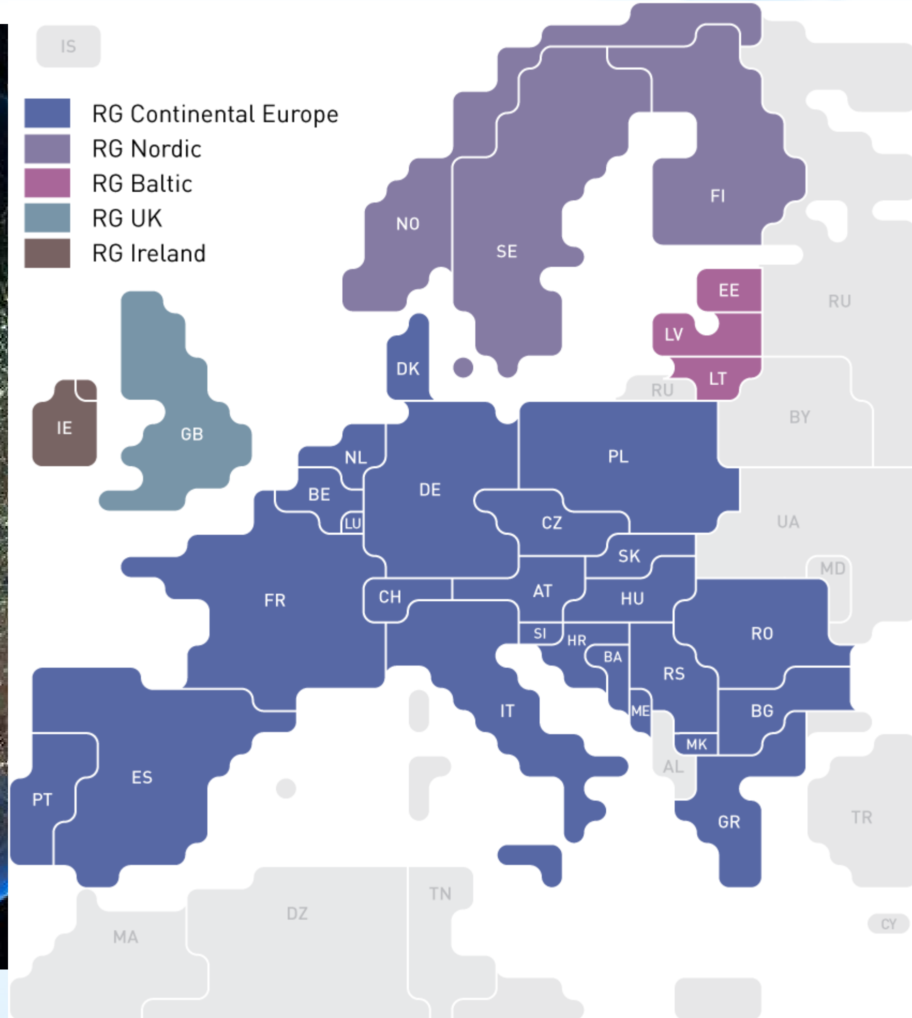
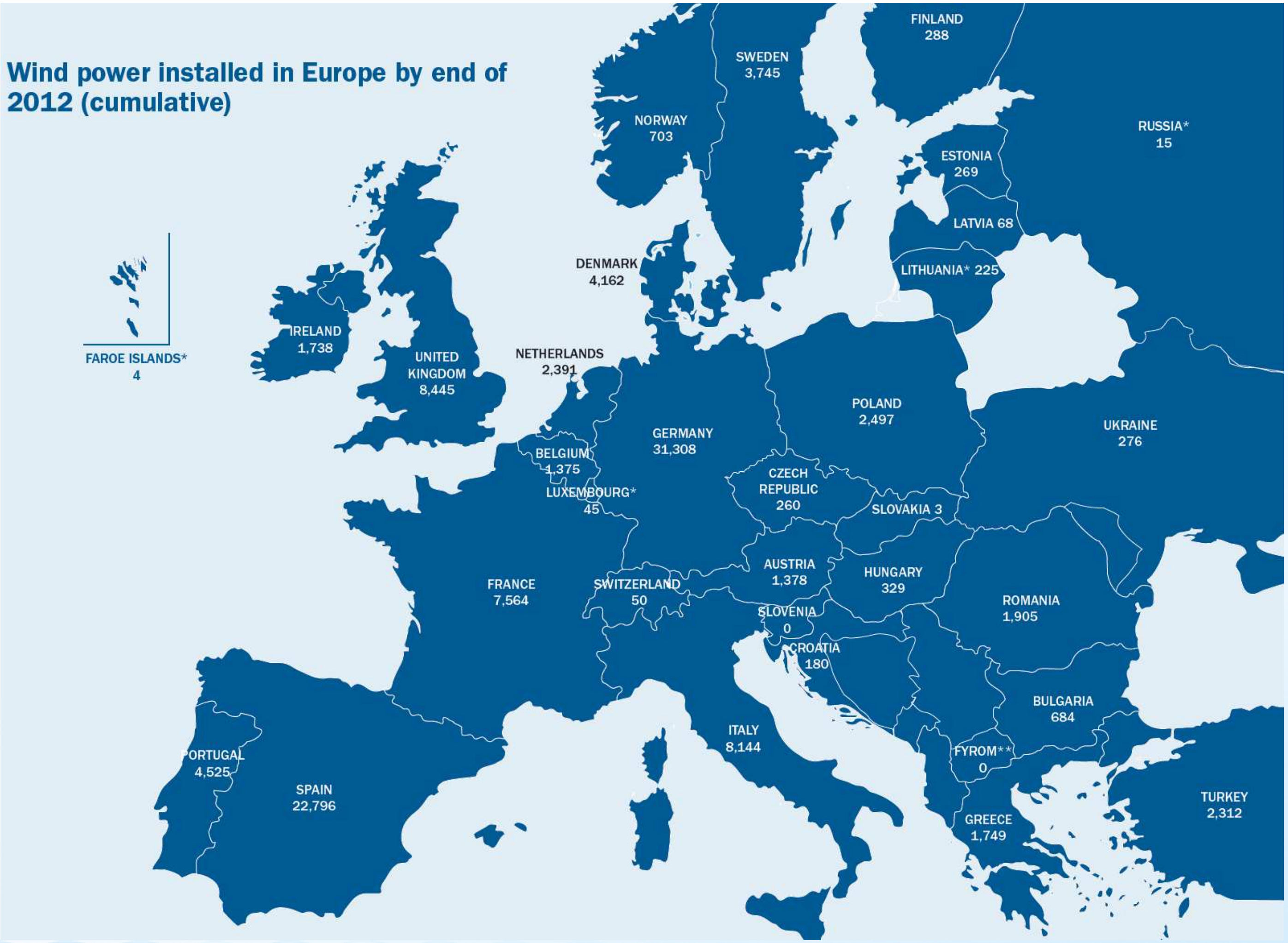


Wind Power Status in Europe (2012): 110GW



Record Year in Denmark 2013

	2013	2012
Wind power generation	11.1 billion kWh	10.3 billion kWh
Electricity consumption (including loss in the electricity grid)	33.5 billion kWh	34.1 billion kWh
Wind power share of electricity consumption the entire year	**33.2 %**	30.1 %
Wind power share of electricity consumption in December	**54.8 %**	33.5 %
Wind power capacity at the end of the year	4,792 MW	4,166 MW
Energy content of the wind	Approx. 93 % of a standard year	Approx. 102 % of a standard year

Record Year in Spain 2013:
Wind Power – the top generation technology

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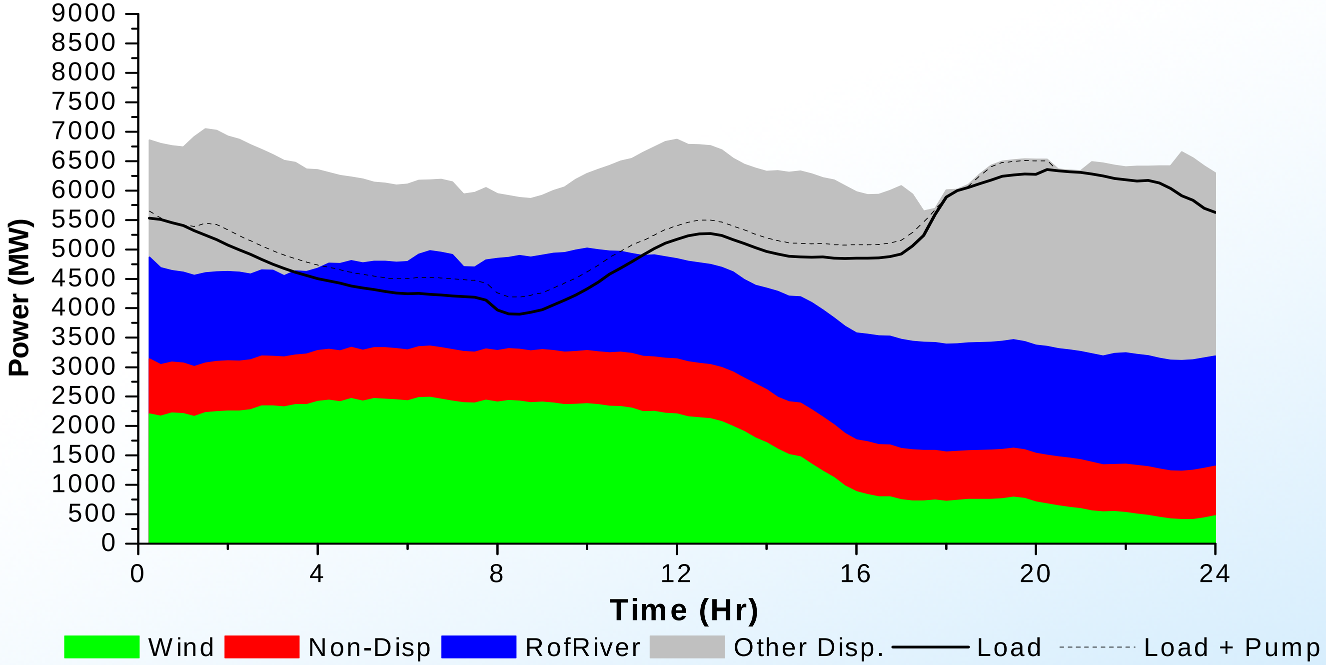
- **Spanish peninsula electricity demand coverage 2013 [1]**

- Combined cycle 9.6%
- Coal 14.6%
- Nuclear 21.0%
- Hydro[1] 14.4%
- Solar thermoelectric 1.8%
- Solar photovoltaic 3.1%
- Wind 21.1%
- Renewable thermal 2.0%
- Cogeneration and the rest of the technologies[2] 12.4%

(1) Pumped storage not included. **(2)** Includes non-renewable thermal and fuel / gas.

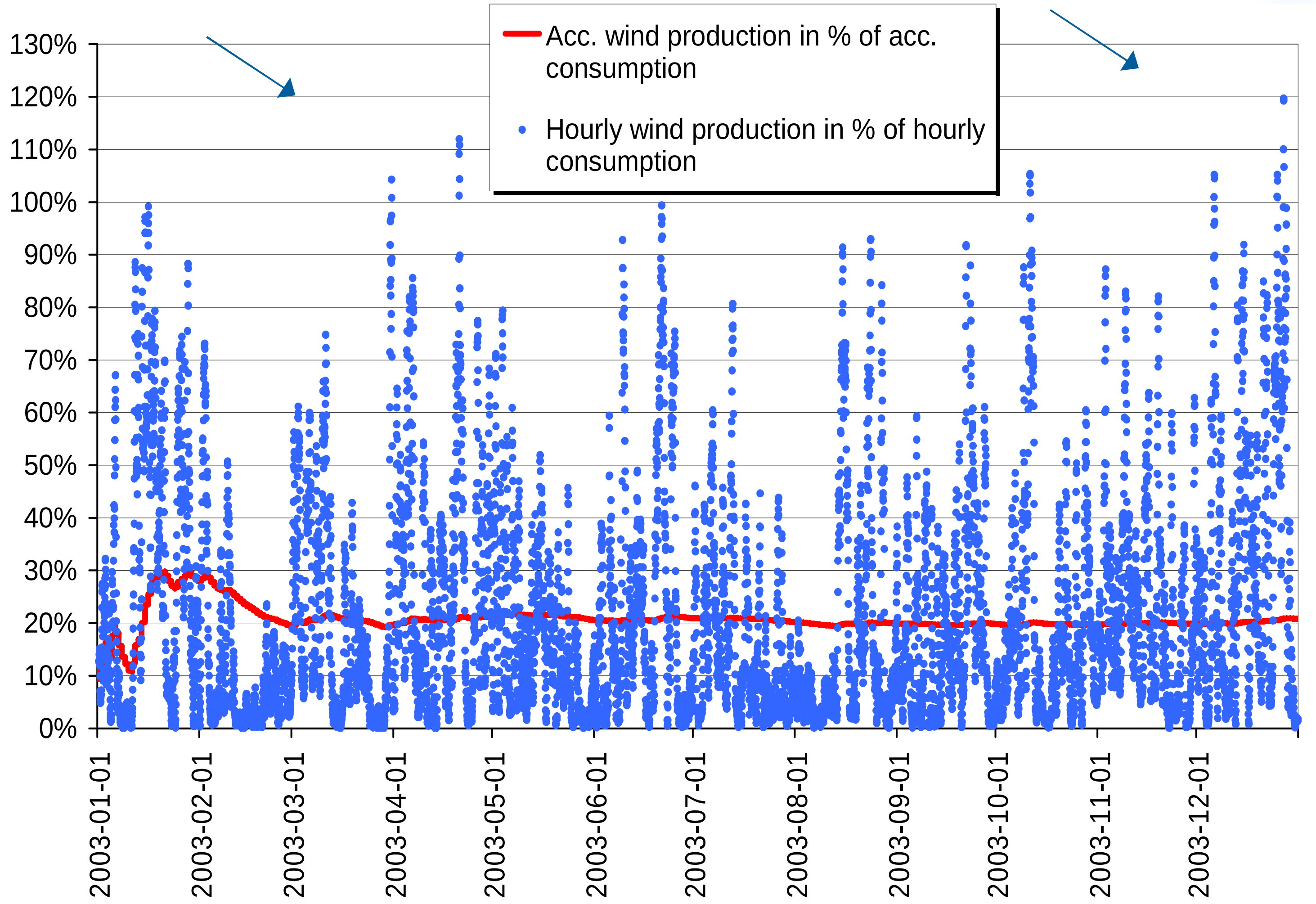
Portugal's Record on 1. January 2010

- **117 % peak penetration of non-regulated plants (8am, aprox.)**
- **The demand had a very low value while the wind and run of the river plants were both peaking… The system had the absolute maximum penetration of 117% of non-regulated power plants...**



Source: REN

Wind Power in Denmark already reached 100% in 2003 (2012 peak penetration level of around 230 %)



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Q 1:

Why has wind power developed differently in different countries?

10% higher wind speed means 30% more energy production, i.e. 30% higher income, but…

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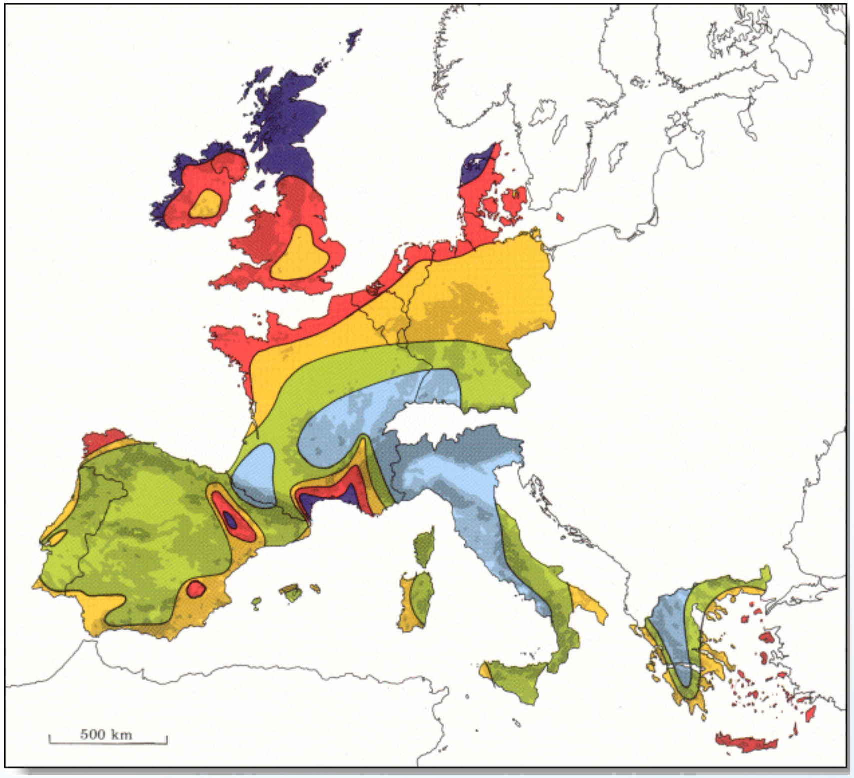
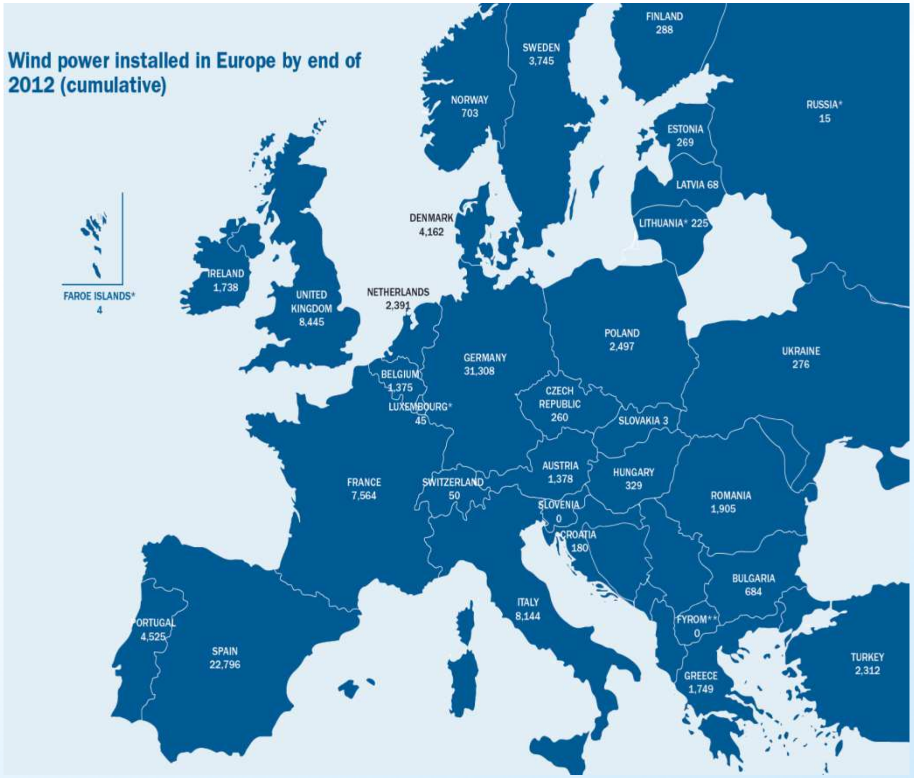
Wind Speed Distribution

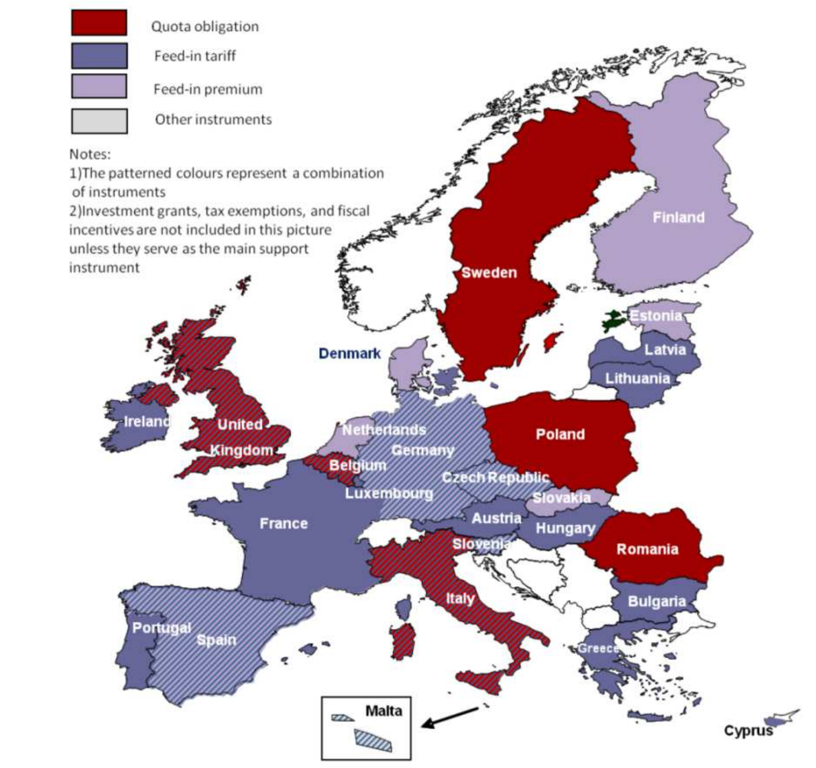


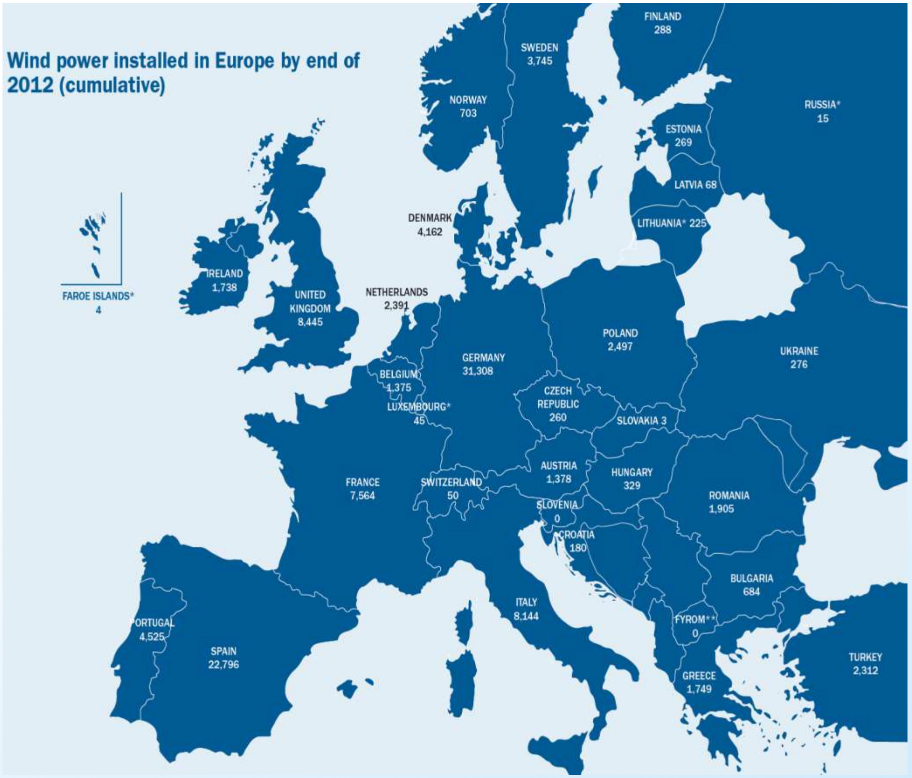
Wind Installation



Fixed Feed-in & Feed-in Premium Tariff

- **Fixed Feed-in tariff is the most successful support scheme**
- **Feed-in Premium includes a bonus if wind is sold on the Market**





Source: Recent developments of *feed*-in systems in the *EU*
Feed-in Cooperation, January 2012

Overview of Fixed Feed-in Tariffs incl. Premium

Country	Type	Since	Choice FIT/FIP	Total remuneration wind onshore 2012	Support duration (years)	Definition of support level	Technology specific	Relevant electricity price
CZ	Fixed	2006	Yearly	73 €/MWh + electricity price	20	Government	Yes	Actual
DK	Fixed	2009	No	36.6 €/MWh + electricity price; maximum for utility companies 57.4 €/MWh	10 - 20	Government, tender offshore	Yes	Actual
EE	Fixed	2010	No	53.7 €/MWh + electricity price		Government		Actual
FI	Sliding	2011	No	83.50 €/MWh			Yes	Three month average
DE	Sliding	2012	Monthly	101.3 €/MWh (in the first 5 - 20 years, depending on yield; after that 48.7 base tariff; available bonus: 4.8 - 9.8)	20	Government	Yes	Monthly average
IT	Fixed	2007	No	n/a	20	Government	Yes	Actual
NL	Sliding	2009	No	90 - 96 €/MWh	12 - 15	Tender	Partially	Annual average
SK	Fixed	2009	No	80.91 €/MWh (2011)	15	Government	Yes	?
SL	Fixed	2009		41.05 – 52.88 €/MWh + electricity price	15	Government	Yes	?

Comparison: Average Power Price
EEX 2012: **42.6 €/MWh**

„Feed-in Tariff“ for Nuclear in the UK for the proposed Hinkley Point C plant in Somerset

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Strike price agreed for new **nuclear power** in the UK: **92.50 Pounds/MWh**. The price will be fixed for 35 year, but will be inflation adjusted, hence the price can increase to £121 per MWh by 2023

Strike price for **onshore wind** in 2017 was proposed by the UK government **90.00 Pounds/MWh**, fixed for 20 years.

Current Market price in the UK: 55.05 Pounds/MWh

Question & Answer

Q 1: Why has wind power developed differently in different countries?

Support schemes are different in different countries, which results in very different deployment of wind power /renewable generation.

Q 2:

What is the status of the German “Energiewende”?

German Energy Policy Targets

	2020	2030	2040	2050
GHG (wrt 1990)	-40%	-55%	-70%	-80-95%
RE share (electricity)	35%	50%	65%	80%
RE share (end-use energy)	18%	30%	45%	60%
Primary energy (wrt 2008)	-20%			-50%
El. consumption (wrt 2008)	-10%			-25%
Energy requirements in buildings (wrt 2008)	-20% (heat)			-80 % (primary energy)
Energy end-use productivity	2.1% annually			

Table 1: German climate change and energy policy targets. Source: BMU, BMWi (2011); wrt = with respect to.

Current status Renewables Germany:
Share Renewables of total Production: 19%

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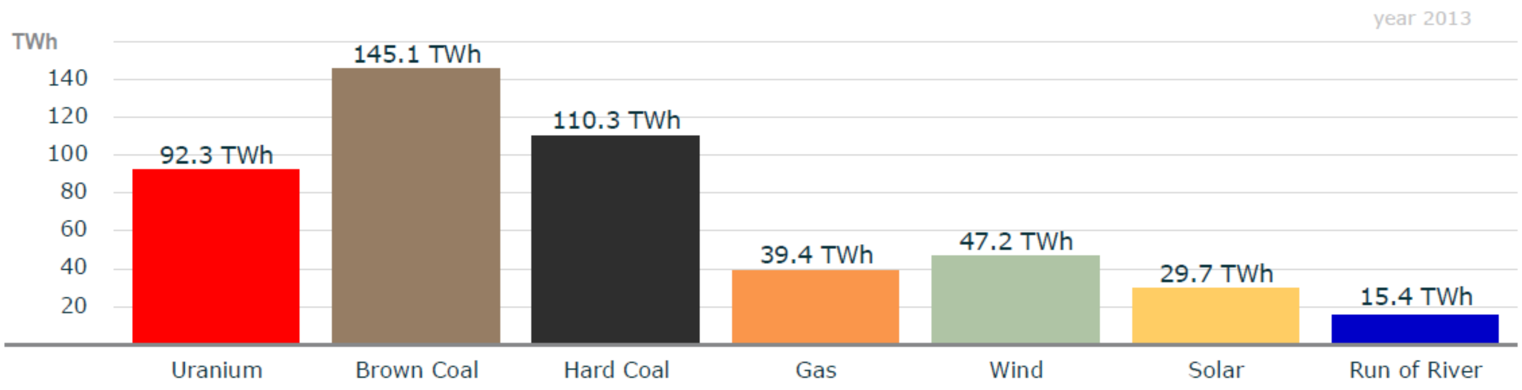
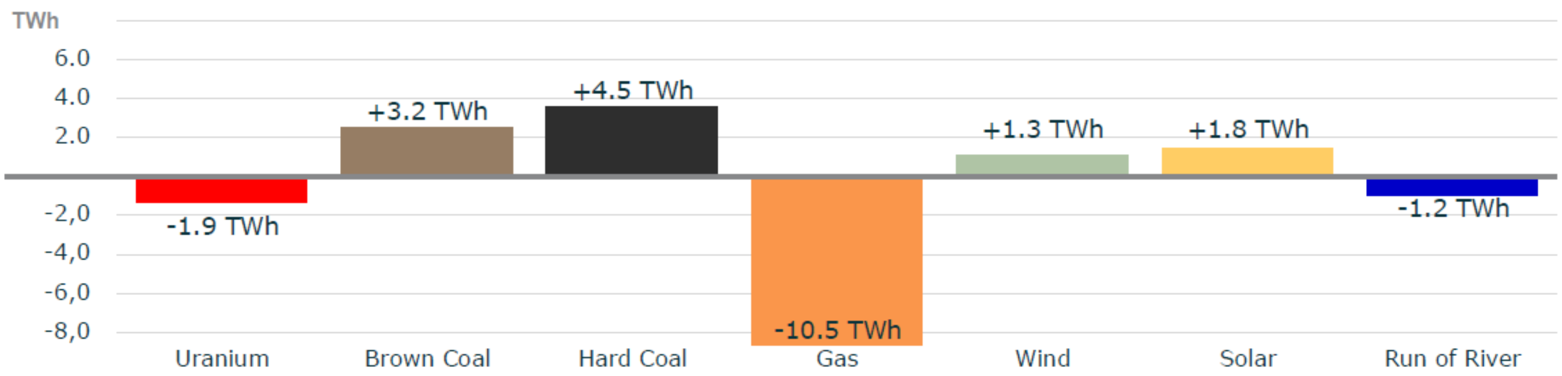
Electricity production in 2013

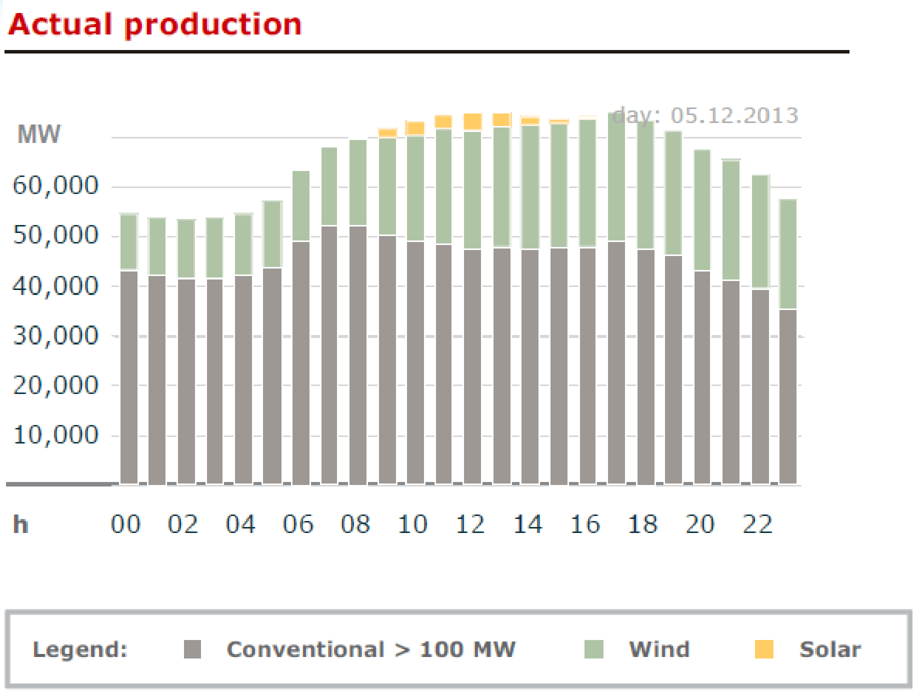


Change in electricity production: 2013 versus 2012



Source: Electricity production from solar and wind in Germany in 2013, Burger, Fraunhofer, ISE.

Peak Wind Capacity: 5th December 2013

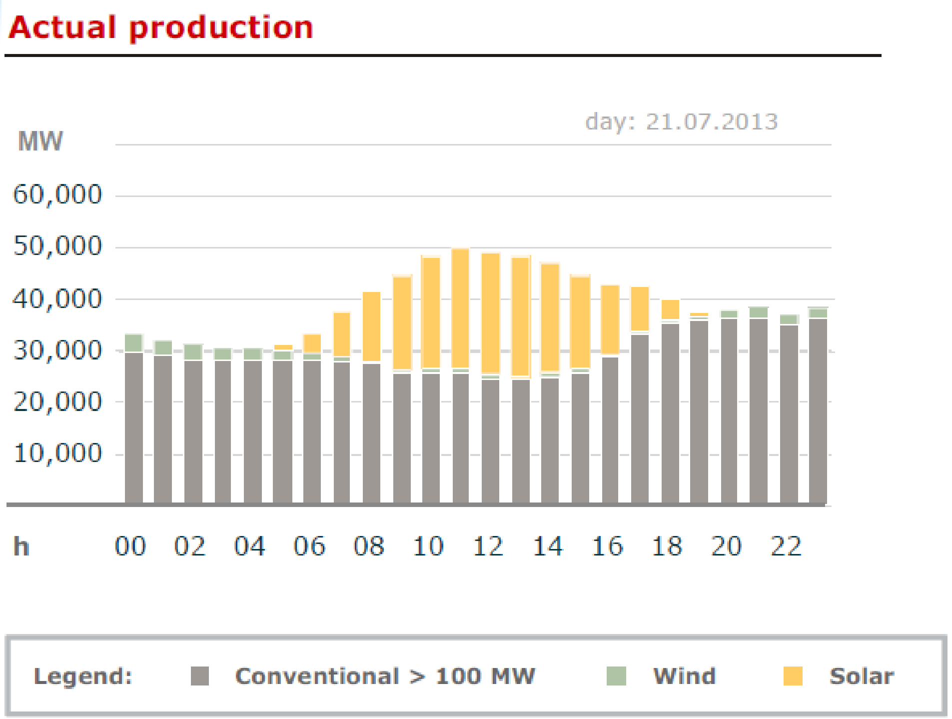


- Solar: max. 3.6 GW; 16 GWh
- Wind: max. 26.3 GW at 18:15 (+1:00); 485 GWh
- Conventional: max. 52.0 GW; 1130 GWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform

Source: Electricity production from solar and wind in Germany in 2013, Burger, Fraunhofer, ISE.

Maximum Solar Capacity: 21 July 2013



- Solar: max. 24.0 GW at 13:30 (+2:00); 204 GWh
- Wind: max. 3,7 GW; 34 GWh
- Conventional: max. 36,3 GW; 710 GWh

Graph: Bruno Burger, Fraunhofer ISE; Data: EEX Transparency Platform

Source: Electricity production from solar and wind in Germany in 2013, Burger, Fraunhofer, ISE.

Maximum Wind/Solar production: 36 GW

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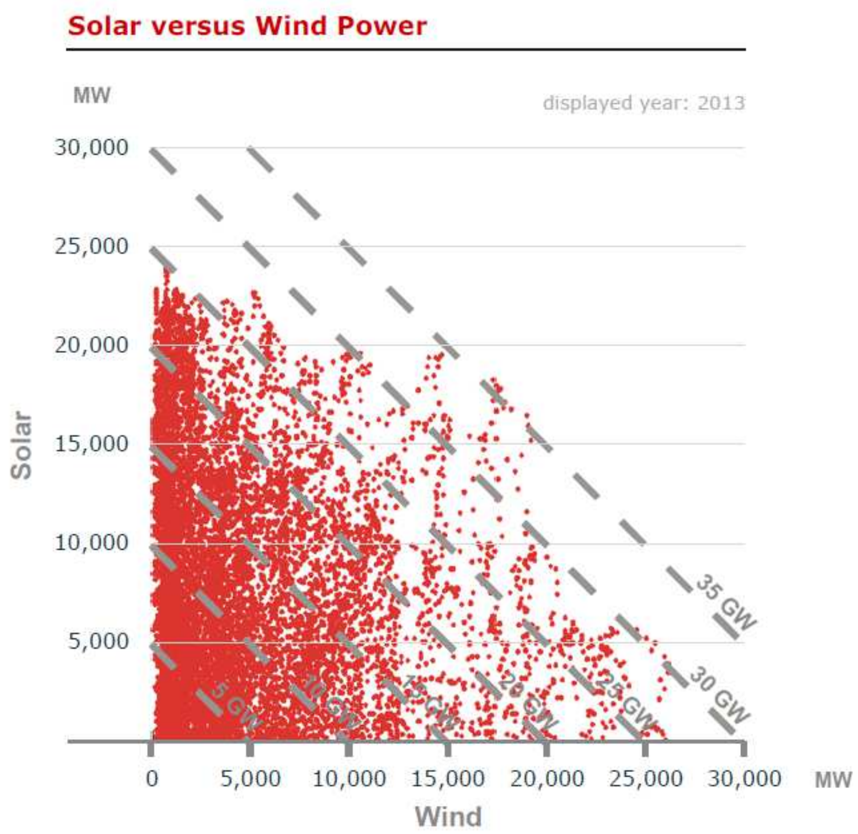
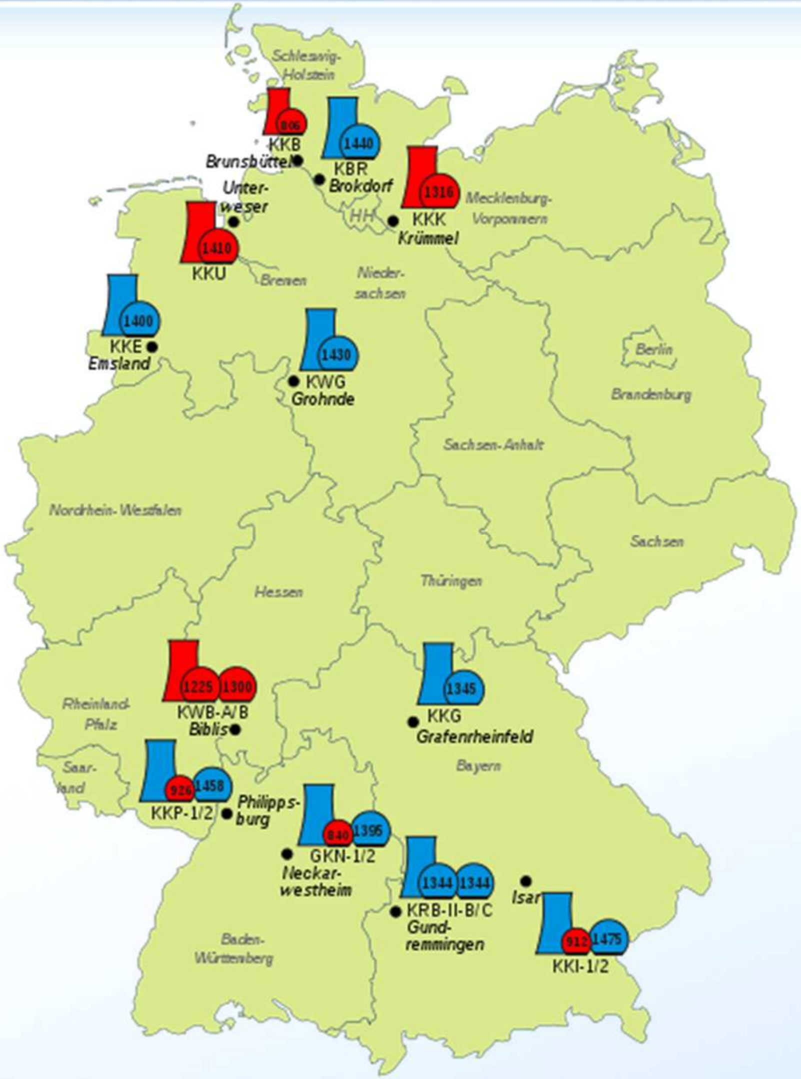
Power Solar versus Wind



- The maximal sum of Solar and Wind power was up to now approx. 36 GW

Source: Electricity production from solar and wind in Germany in 2013, Burger, Fraunhofer, ISE.

Status Nuclear Power in Germany



6 August 2011**, six units shut down:** Biblis A and B, Brunsbuettel, Isar 1, Kruemmel, Neckarwestheim 1, Philippsburg 1 and Unterweser.

Remaining units shut down until 2022

Electricity Market Germany 2013

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- The average Day-Ahead base price was 37.85 €/MWh, the peak price 42.45 €/MWh (in prices of 2013).
- Day-Ahead prices in 2013 were the lowest since 2004 and almost half the prices of the record year 2008 (inflation adjusted in prices of 2010).
- The spread in Day-Ahead prices between peak and baseload hours reached an all time low of 4.36 €/MWh in 2013, the maximum spread was 2006 with 13.85 €/MWh (inflation adjusted in prices of 2010).
- Day-Ahead prices were negative in 48 hours, zero in 23 hours and below 10 €/MWh in 326 hours.
- Intraday prices were negative in 79 hours, zero in 2 hours and below 10 €/MWh in 355 hours.

Source: Electricity prices and production data in 2013, Burger, Fraunhofer, ISE.

Case Study of an event with negative prices (I)

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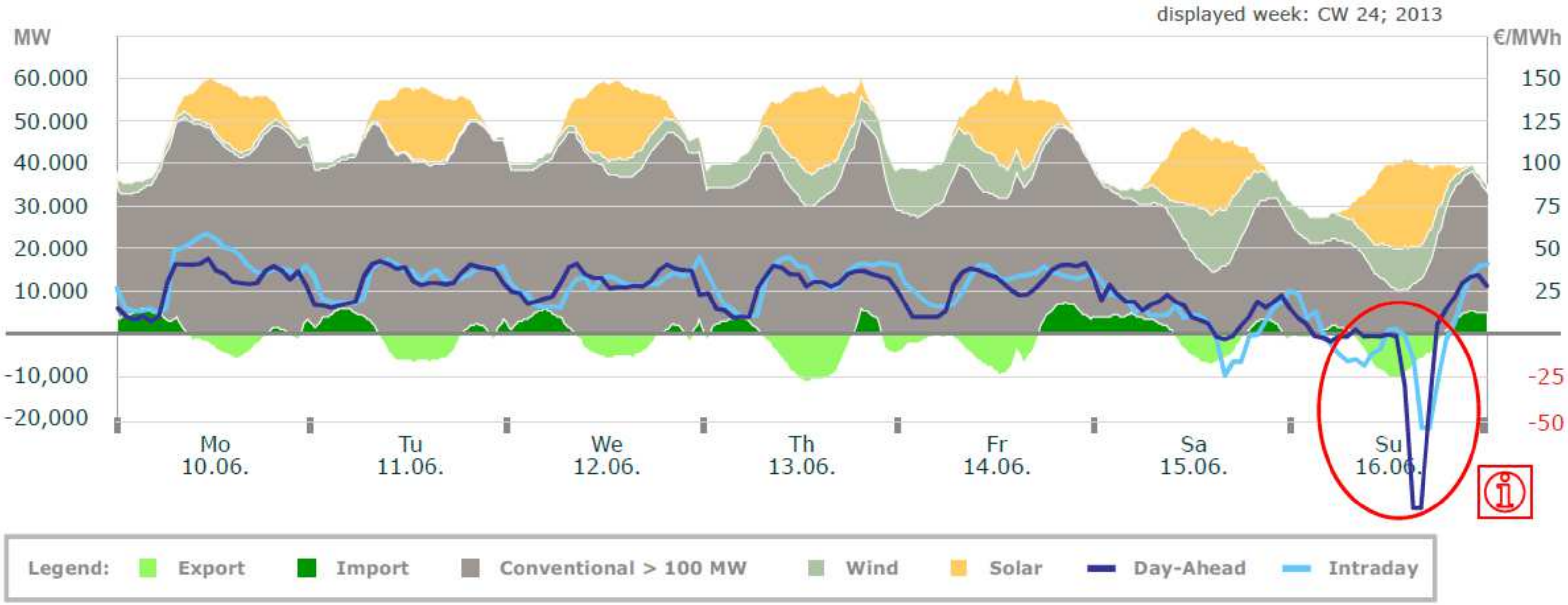
Electricity Production and Spot-Prices: CW 24 2013



€ / MWh	Period Mean	Period Min	Period Max	Trading / GWh
Day-Ahead	**23.28**	**- 100.00**	**45.00**	**4 783**
Intraday	**26.95**	**- 53.50**	**59.50**	**288**

Source: Electricity prices and production data in 2013, Burger, Fraunhofer, ISE.

Case Study of an event with negative prices (II)

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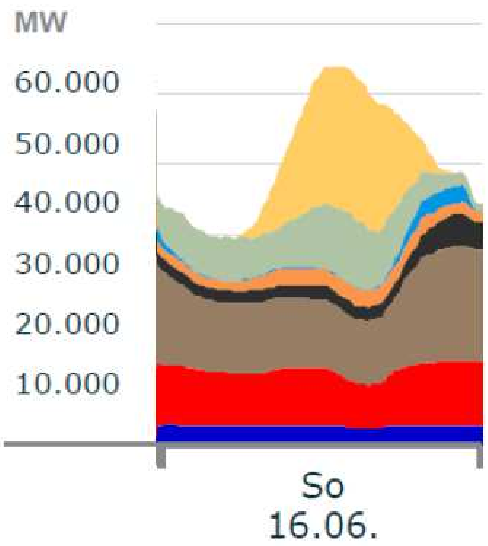
- Solar and wind produced app **29 GW** of power between **2** and **3** pm during this **Sunday**.
- The total grid load was about **45 GW** at this time.
- Conventional baseload power plants (Uranium, Brown Coal) were not able to reduce their production below 53% of the installed capacity.



- Utilization ratio of power plants (14:00 – 15:00):

16.06. | 14:00-15:00	RoR	Uran	BC	HC	Gas	PSt	Wind	Solar
Production	2,0 GW	6,3 GW	9,1 GW	2,2 GW	2,6 GW	0,1 GW	8,8 GW	20,1 GW
Plant Utilization*	53,8 %	67,1 %	53,9 %	10,8 %	12,2 %	1,0 %	29,1 %	60,2 %

*compared to available capacity

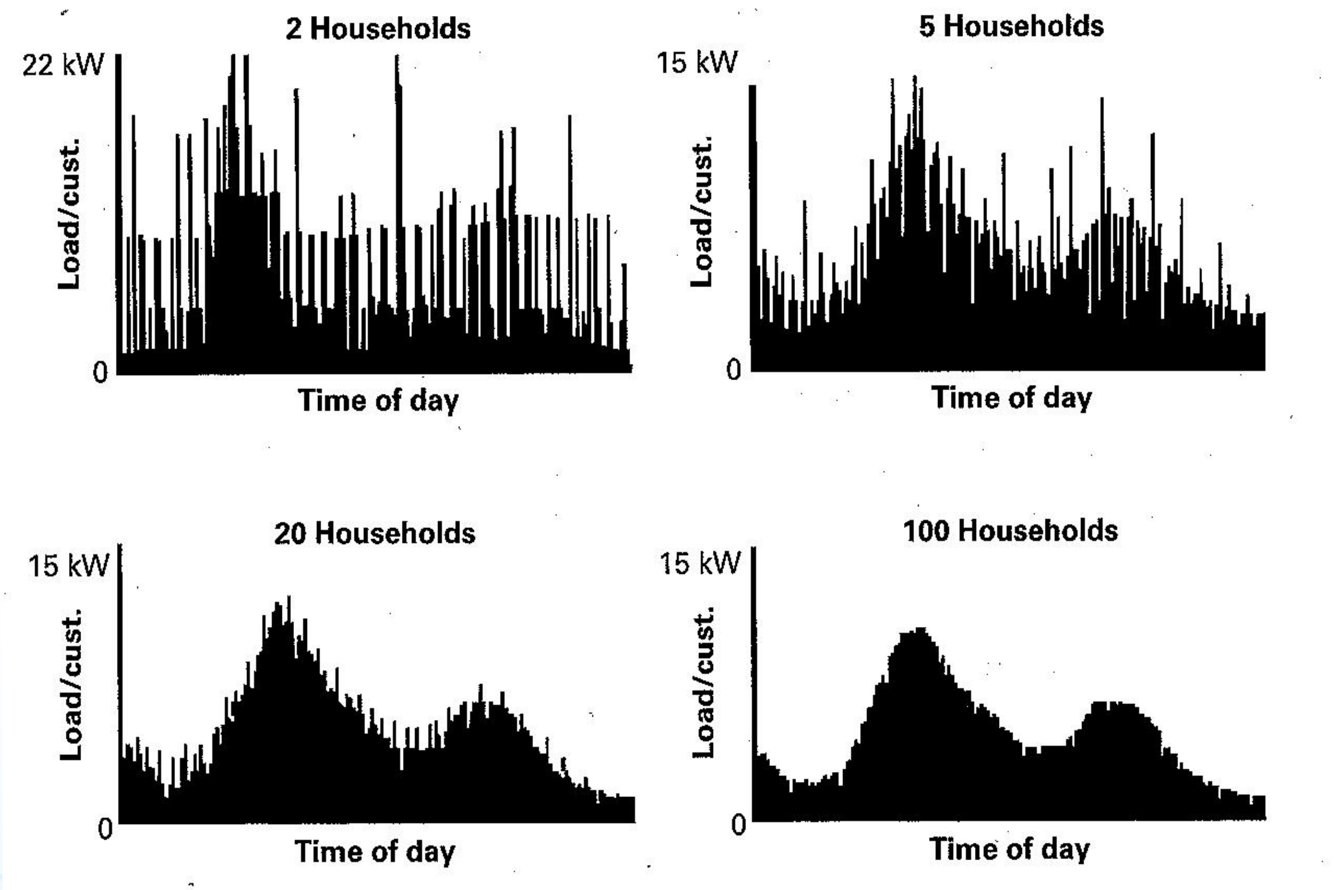
Source: Electricity prices and production data in 2013, Burger, Fraunhofer, ISE.

Q 3:

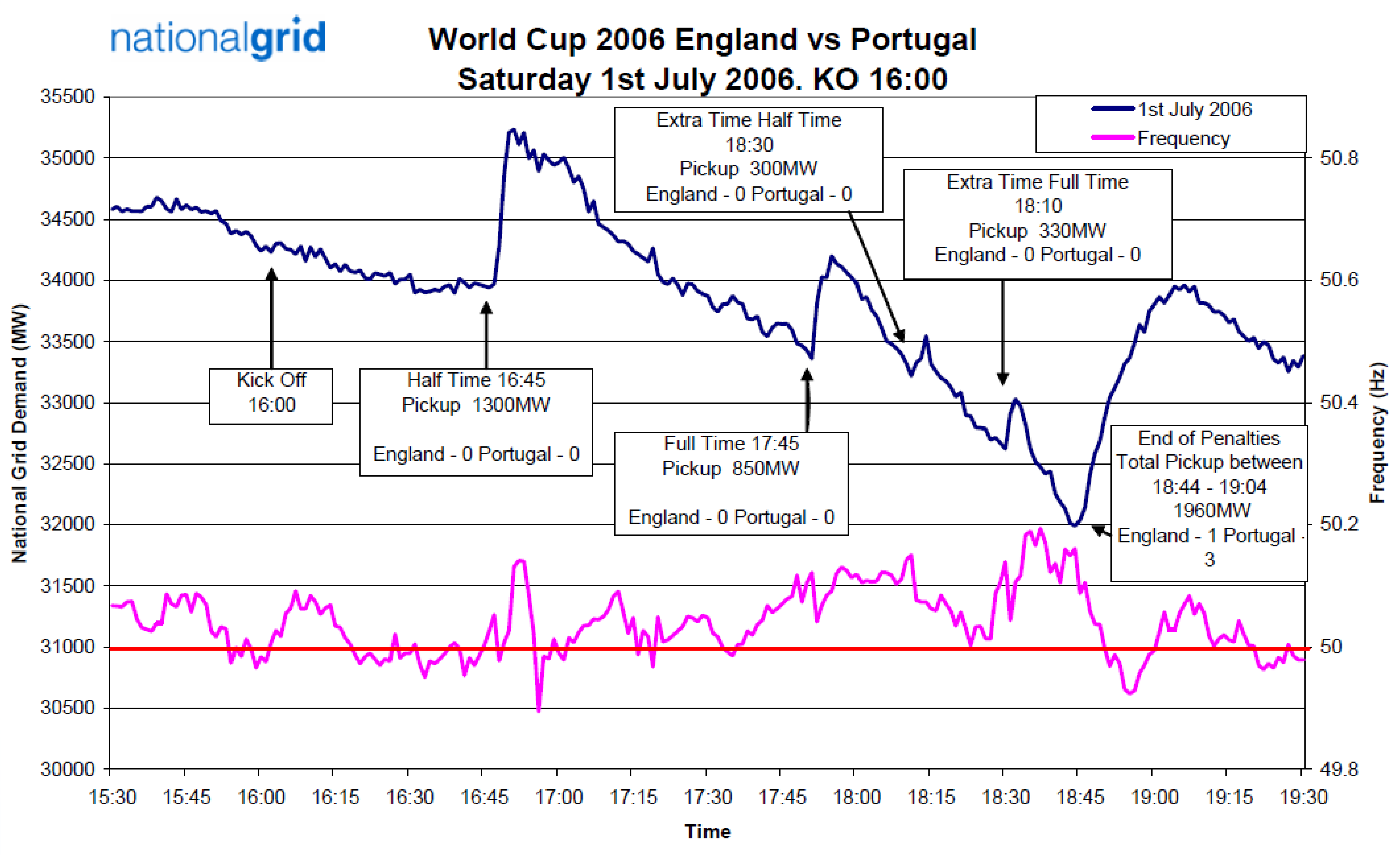
How are grid operators in Europe deal with the variability of renewable generation?

Aggregation of Customers

- Stochastic load events are aggregated

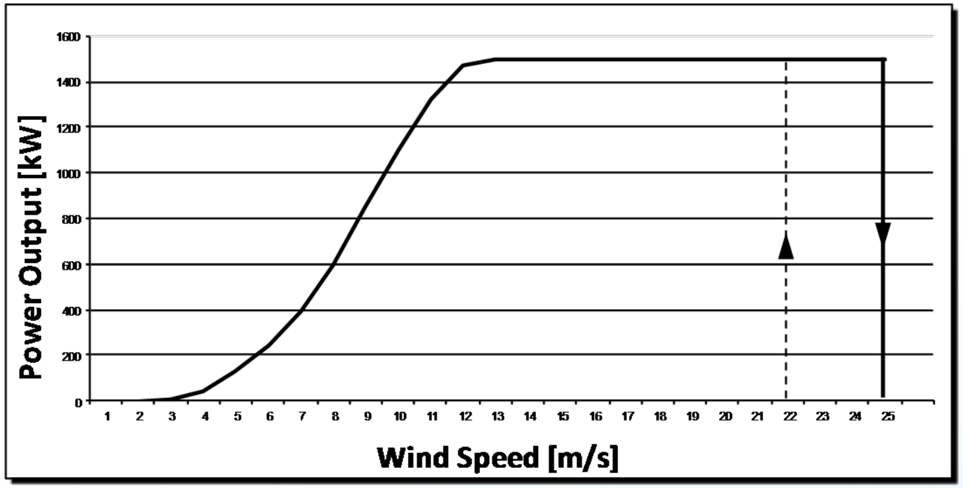


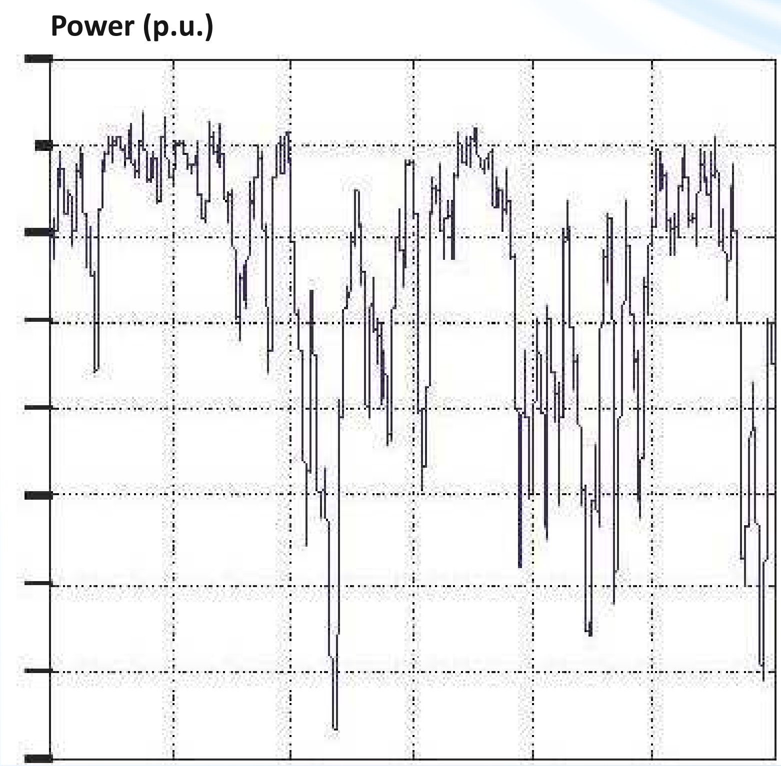
Soccer World Cup 2006 Quarter Final



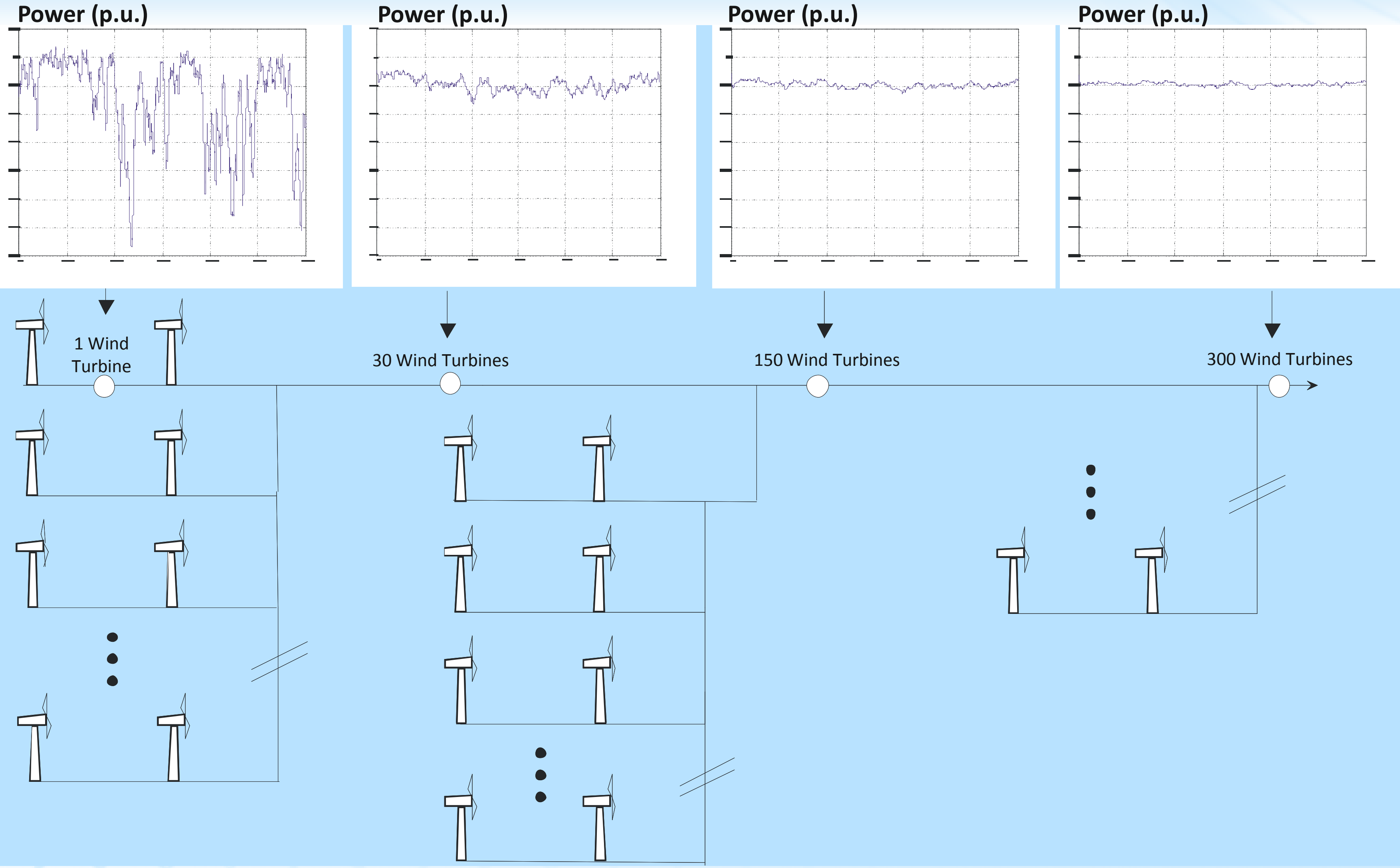
Source: nationalgrid

Short-term (Seconds) Power Output Variations from a Single Turbine





Aggregation of Wind Power (Seconds)



Distributed Renewable Generation in Germany and Denmark

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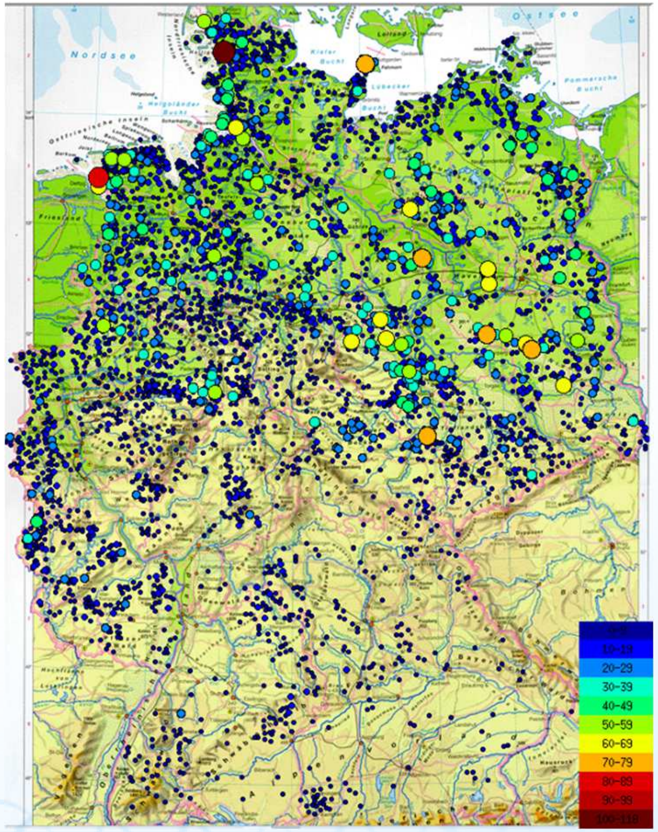
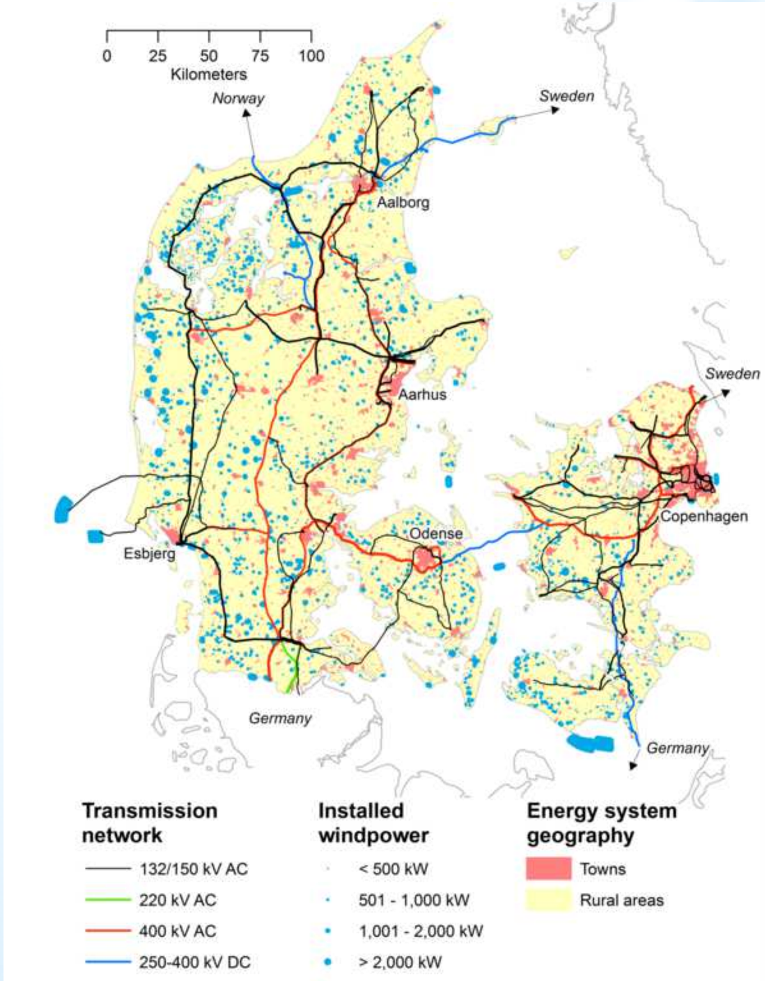
- **The German „Wind Power Plant“**
- **End of 2013 (est): 34.000 MW (Wind)**
- **35,000 MW (PV)**





Real Time Status

- **Denmark:**
  http://energinet.dk/Flash/Forside/UK/index.html
- **Continental Europe System Frequency:**
  http://www.swissgrid.ch/swissgrid/en/home/reliability/frequency.html
- **Ireland and the UK:**
  http://ercrt.ucd.ie/
- **UK:**
  http://www.gridwatch.templar.co.uk/
- **Germany (PV Generation):**
  http://www.sma.de/unternehmen/pv-leistung-in-deutschland.html

Question & Answer

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Q 3: How are grid operators in Europe deal with the variability of renewable generation?

So far the available flexibility in the system is sufficent in Europe, but the required flexibility depends on the renewable penetration level, the size of the balancing area, interconnection as well as the geographical concentration of renewables

Q 4:

Does renewable generation need back-up generation or storage?

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All power generation need back-up, but a system wide approach is typically applied!!!

Extreme Summer Event

No problem, as there is enough PV within the energymix – further grid upgrade not necessary.

figure 36a: **power production (in MW) from different sources and overall demand in europe during extreme august event.**

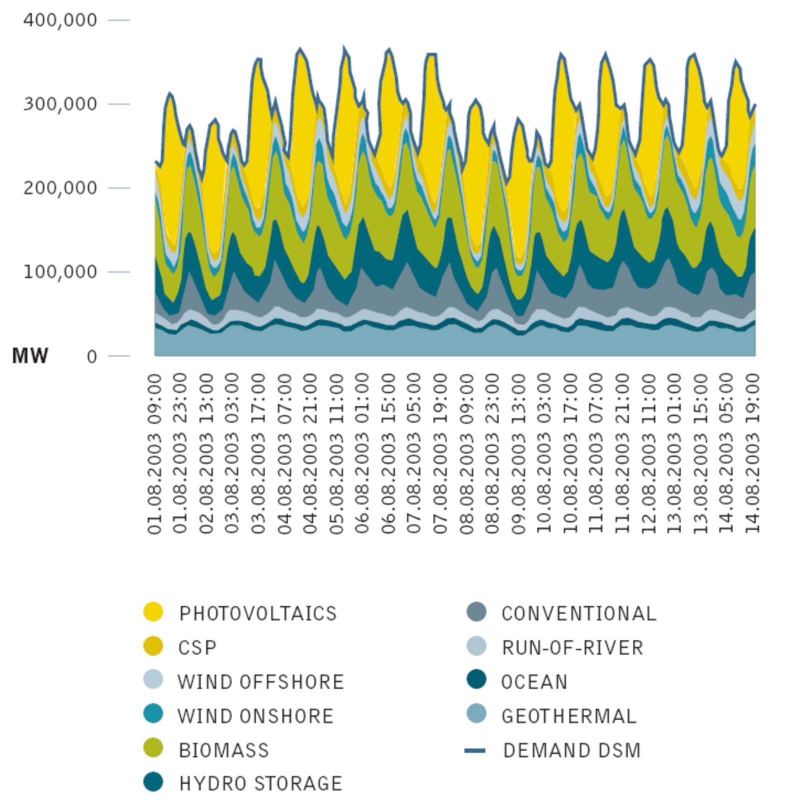
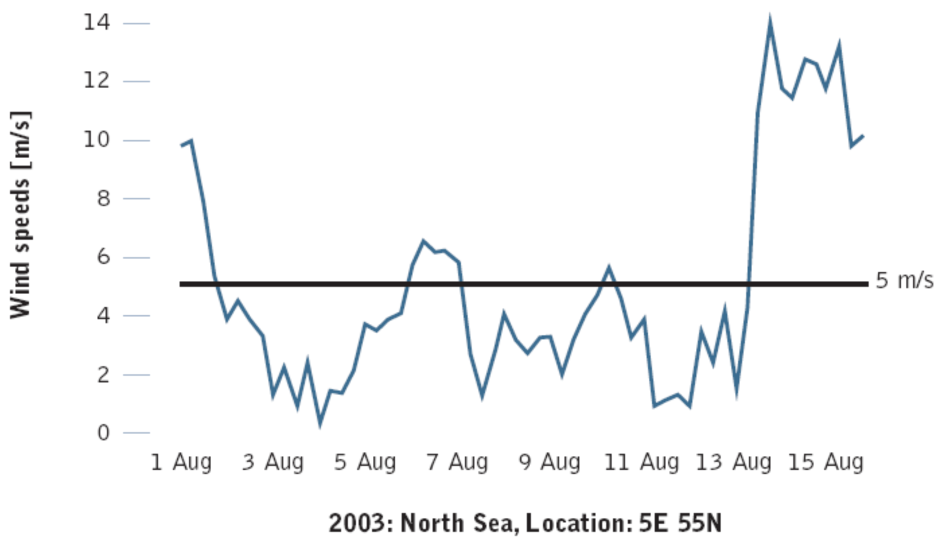
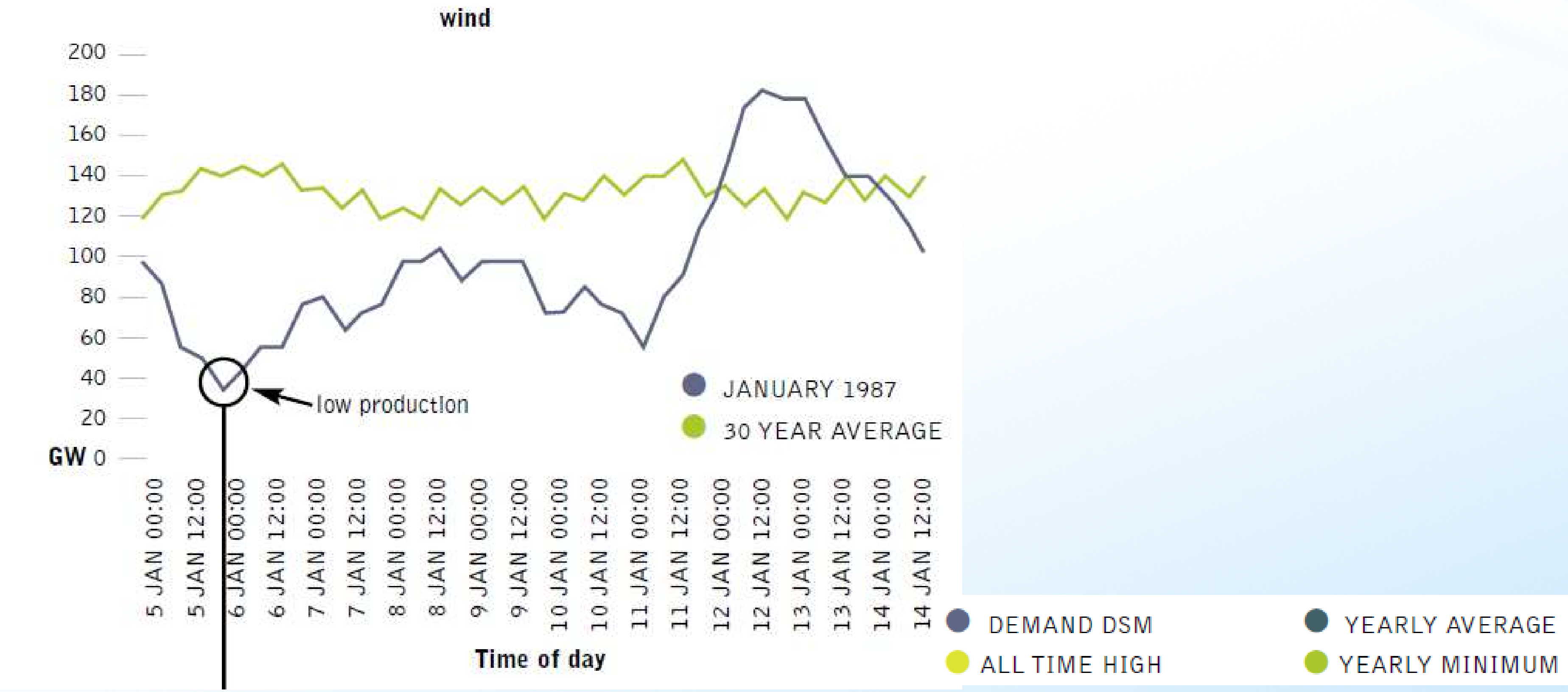


figure 33: **wind speed in the north sea during august 2003 (extreme summer event).**



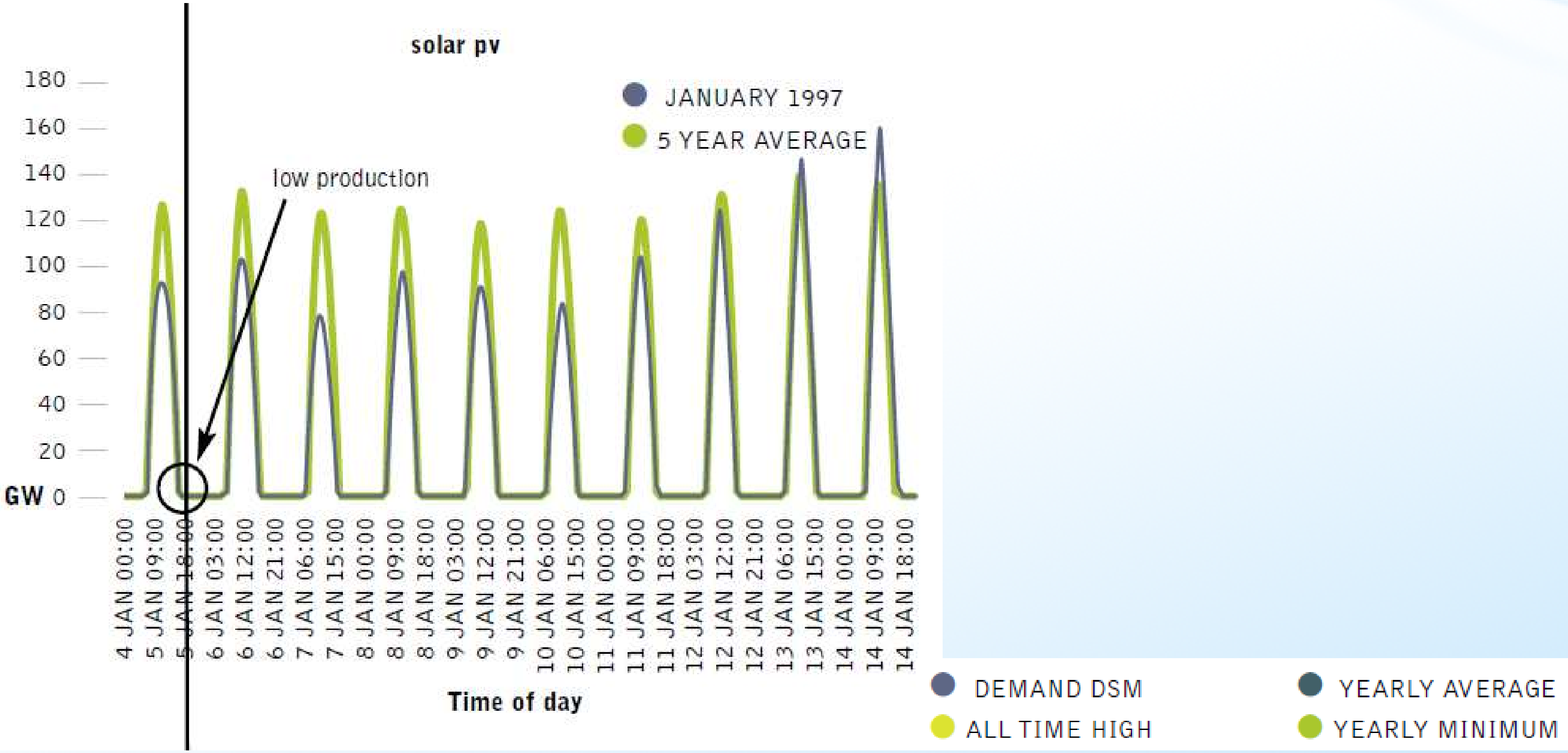
Extreme Winter Event

Low wind production!



Extreme Weather Events

Low solar production!



Extreme Weather Events

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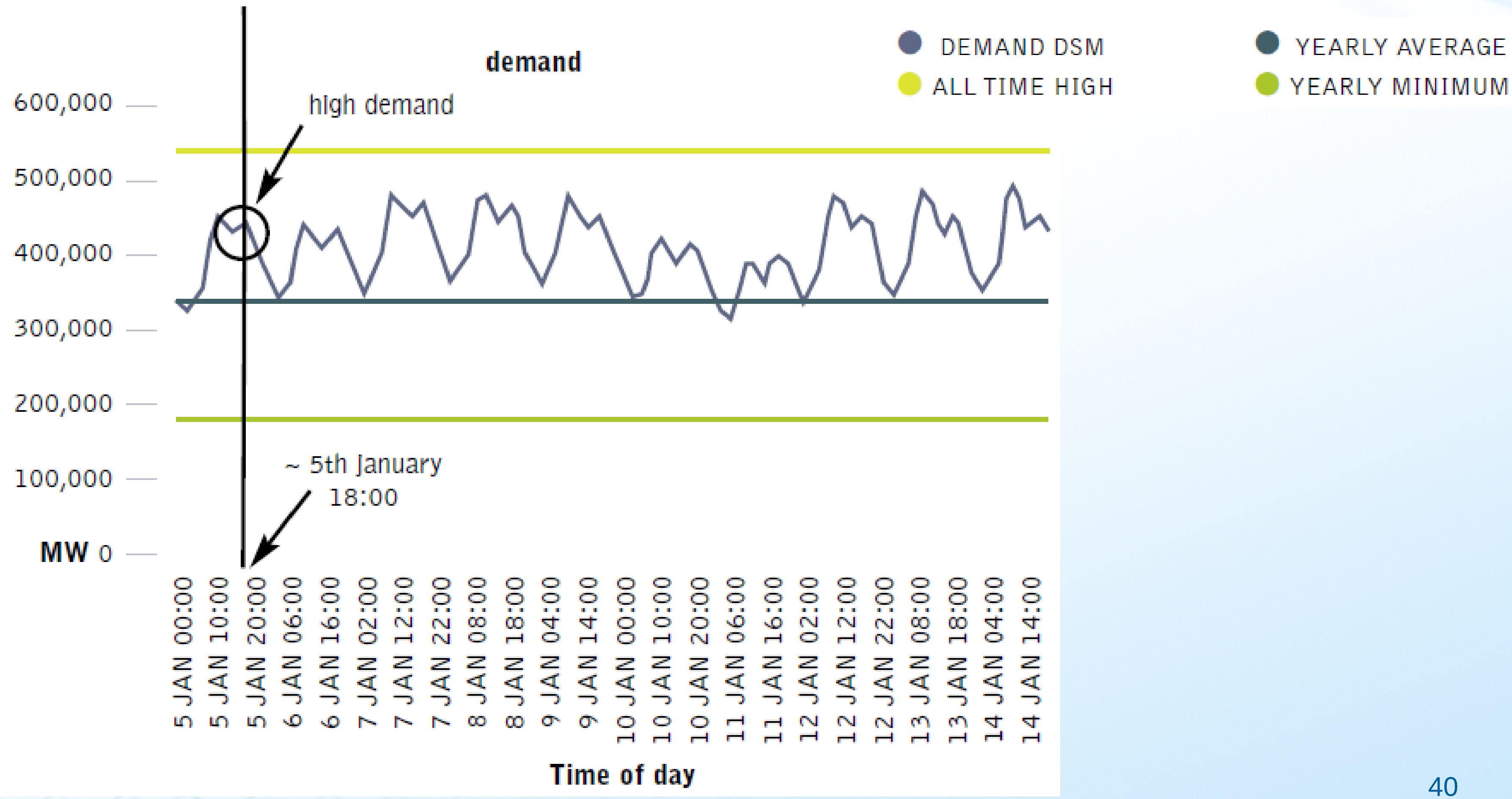
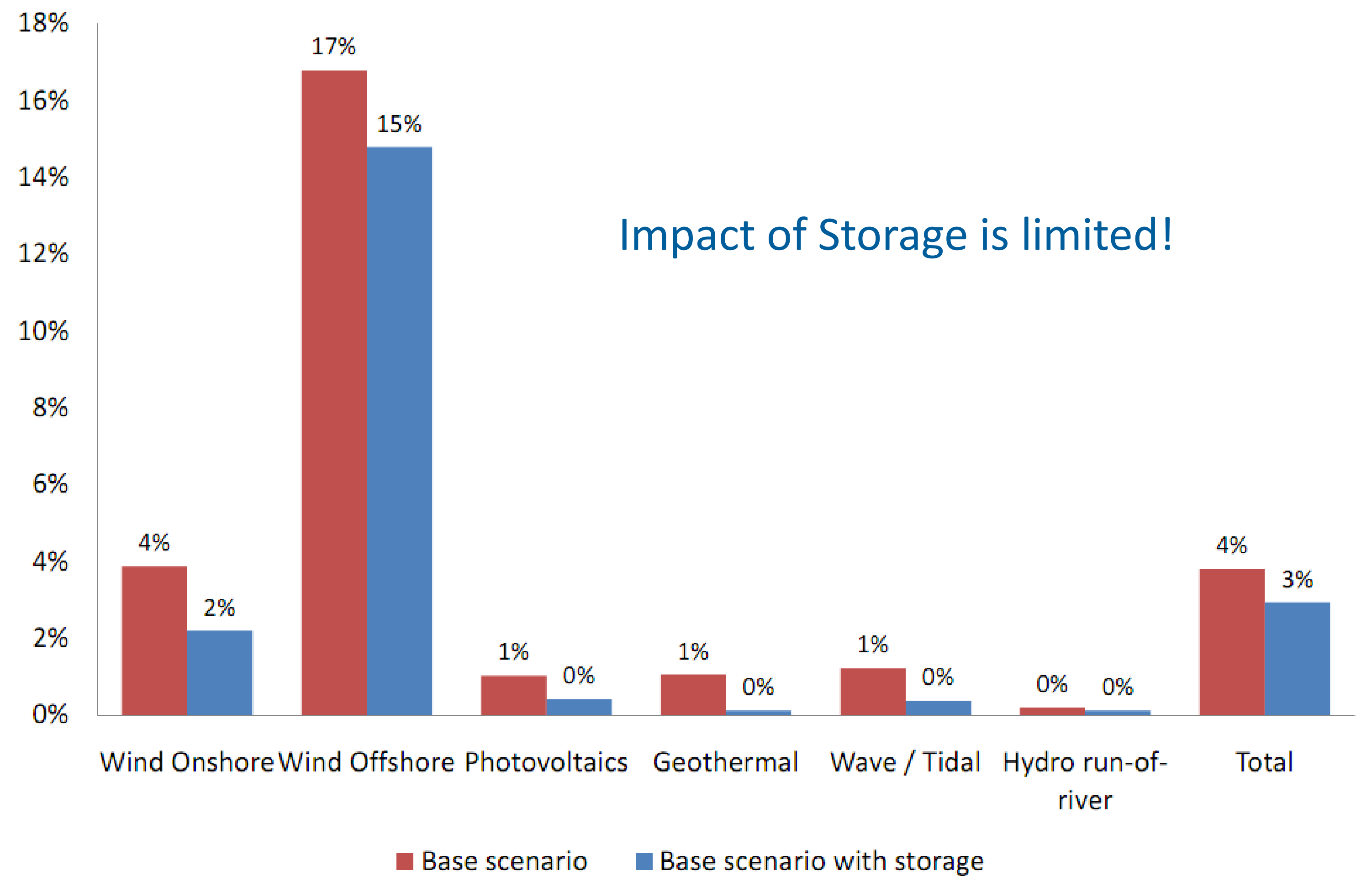
High demand!



Curtailed energy for Base Scenario 2030 with storage (batteries, comp. air, excl. hydro)



Question & Answer

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- **Q 4: Does renewable generation need back-up generation or storage?**

So far, European system operators don‘t use storage (besides some hydro) and sufficient generation capacity is available, upgrading interconnection is a cheaper option to share generation capacity from different countries.

Studies indicate that storage will be economically viable as an additional flexibility starting at a wind penetration level of 40%.

But storage will be no economic option for balancing low wind for long term situations (weeks), hence controllable generation such as biomass, hydro or conventional generation must be available for those situations.

Main discussion topic in Europe at the moment: Are market incentives enough to secure sufficient generation capacity or are capacity markets required

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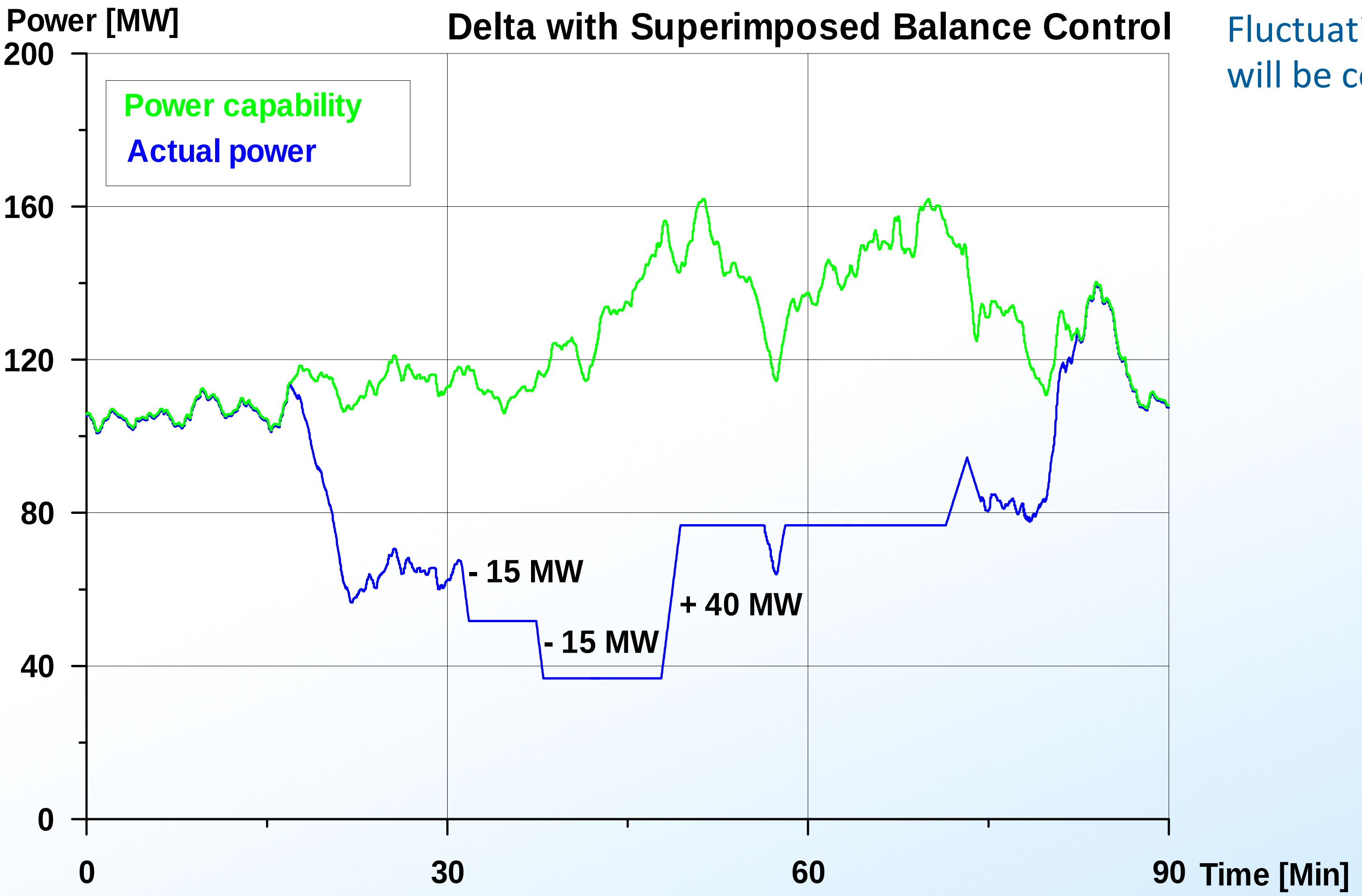
Q 5:

How can wind power help to balance the power system?

Wind Power Plants Supply Primary and Secondary Control (Horns Rev)



Fluctuating renewables will be controllable!!!

Question & Answer

- **Q 5: How can wind power help to balance the power system?**

Wind power can be used as a very fast flexibility resource, as long as wind is available.

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Q 6:

Will renewable power production need new transmission?

All Power Generation Need

Transmission Lines!!!

Grid Upgrades planed in Germany

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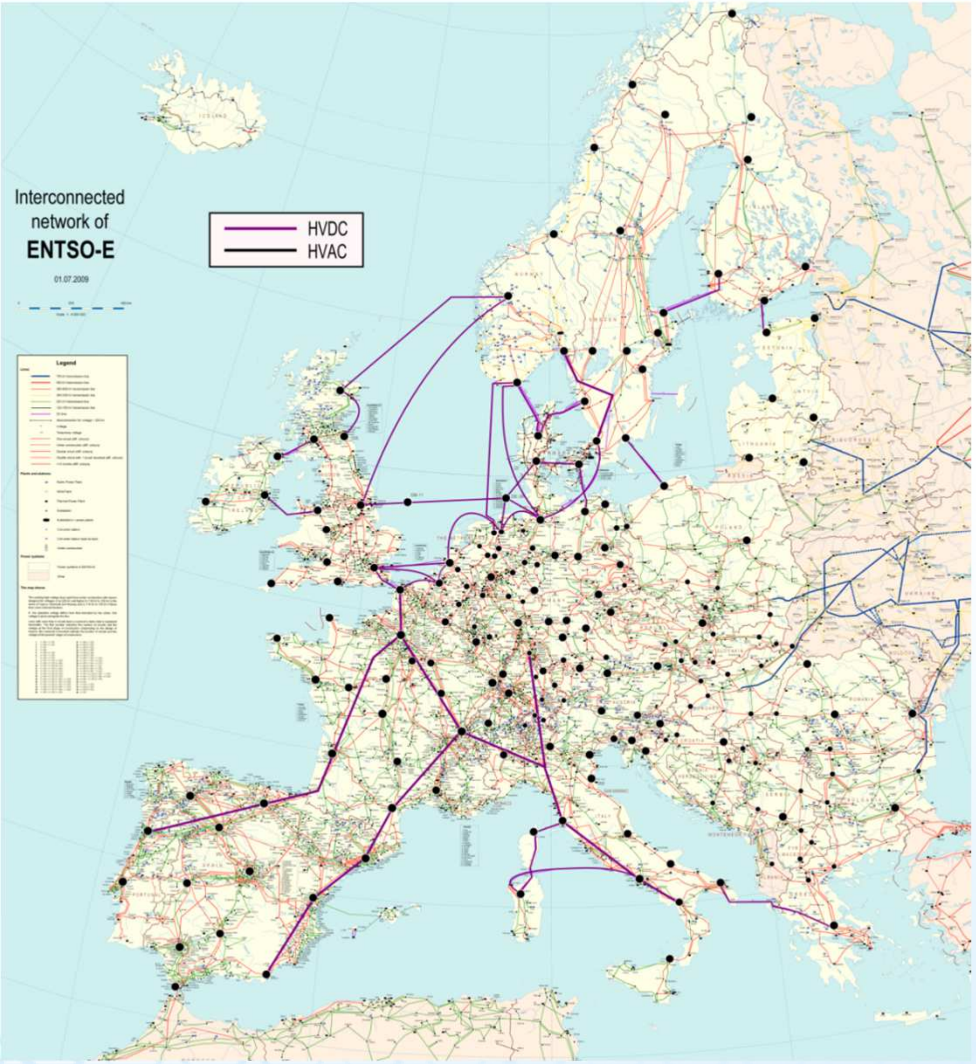
High-voltage network of Europe with the proposed HVDC Supergrid in 2030 (65 % renewables based Scenario)



The Supergrid starts to develop:

It connects South and Central Europe!

Source: Reproduced with permission of ENTSO-E by energy**nautics**.

High-voltage network of Europe with the proposed HVDC Supergrid in 2050

The Supergrid is formed:

It connects North Africa with the Centre of Europe!

Source: Reproduced with permission of ENTSO-E by energy**nautics**.

Summary of Grid Upgrades for different Scenarios

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		Optimised Scenario 2030	Import Scenario 2050	Regional Scenario 2050
Capacity (GW)	HVAC	879	1.311	995
	HVDC Onshore	71	1.221	266
	HVDC Offshore	97	419	161
	Total	1.046	2.951	1.421
Distance (thousand km)	HVAC	170	242	190
	HVDC Onshore	19	125	26
	HVDC Offshore	43	135	62
	Total	233	501	278
Cost of upgrades vs 2010 grid (billion euro)	HVAC	20	59	31
	HVDC Onshore	21 -49	300 – 452	65 – 89
	HVDC Offshore	29	168	53
	Total	70 - 98	528 - 679	149 – 173
Cost of upgrades vs 2030 grid (billion euro)	HVAC	-	39	10
	HVDC Onshore	-	279 - 403	40 – 44
	HVDC Offshore	-	139	24
	Total	-	458 - 581	74 - 79

Q 6: Will renewable power production need new transmission?

Transmission lines will help to make the balancing task much easier and they are typically the cheapest solution. Options like dynamic line rating or high temperature conductor will help to reduce the construction of new transmission lines. The key problem is that the public acceptance for new transmission lines is low in Europe!

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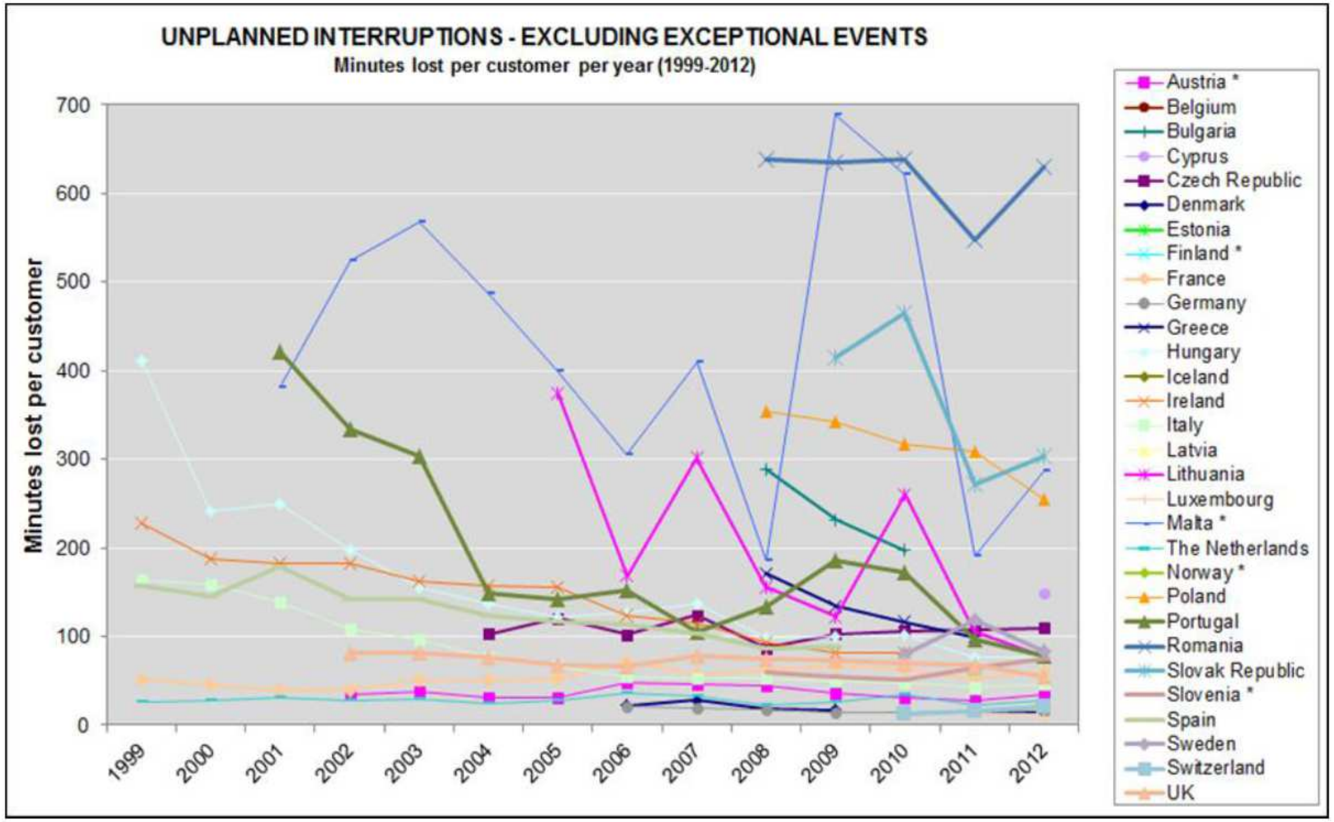
Q 7:

Will we see black-outs caused by renewables?

Overview of Unplanned Interruptions in Europe



Germany (2011):

15 minutes

France:

62 minutes

U.S.:

240 minutes

Source: CEER Benchmarking Report 5.1 on the Continuity of Electricity Supply, Data Update, European Energy Regulators, 19 December 2013; Highest renewable Share in Europe: Germany, Denmark, Spain, Ireland, and Portugal

The countries with the highest share of distributed generation have the lowest interruption times

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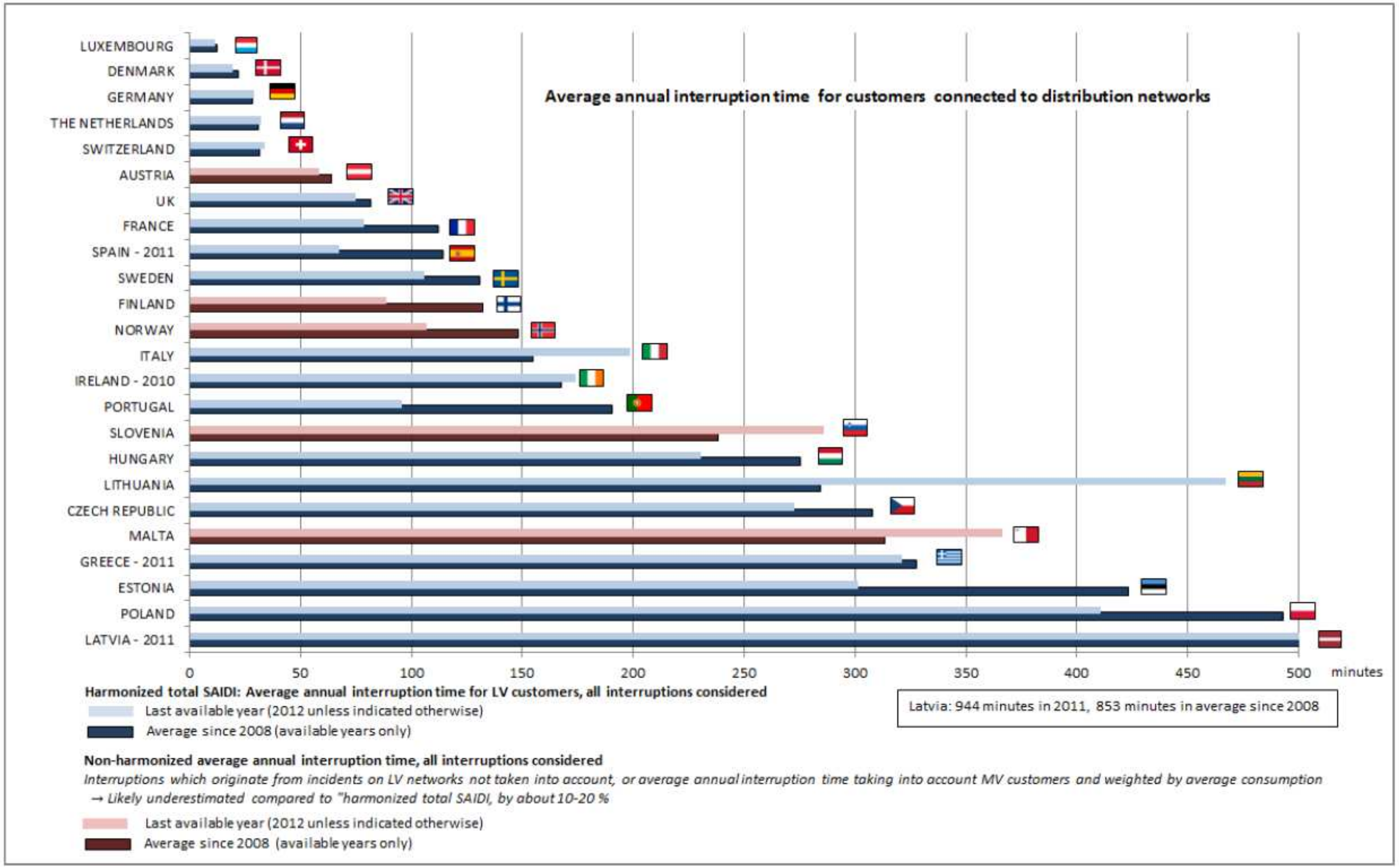

Source: CEER Benchmarking Report 5.1 on the Continuity of Electricity Supply, Data Update, European Energy Regulators, 19 December 2013; Highest renewable Share in Europe: Germany, Denmark, Spain, Ireland, and Portugal

*“I am not aware of any black-out ever caused by renewables.
But by trees, salt, birds, big nuclear and fossil power stations.*

One day, however, renewables will be to blame… “

Question & Answer

- **Q 7: Will we see black-outs caused by renewables?**

Black-outs are not depening on the generation technology, and they play an important role in learing the limits of the system. Grid codes considering the new role and technical capability of renewables will play a very important role for a future secure power system operation.

Conclusions

- The type of support system is key to the speed of wind/renewable energy development;
- The power system is a system designed by engineers, they can also redesign the system to accommodate very high shares of renewables, but a redesign is required – the integration of the first 10-20 % of renewables was easy to integrate, the next 80 % will be more challenging;
- With high wind/renewable penetration, may be incentives are needed to secure sufficient generation capacity.
- Ancillary service contribution of wind/PV (e.g. Delta control) must be utilized and integrated (very economic solution)
- The design of grid codes is key for a long-term secure power system operation, but the grid code designers must be also have a high renewable penetration system in mind !


Thank you very much for your attention !