Impact of the spatial fluctuation of wind power on the stability of the UCTE network

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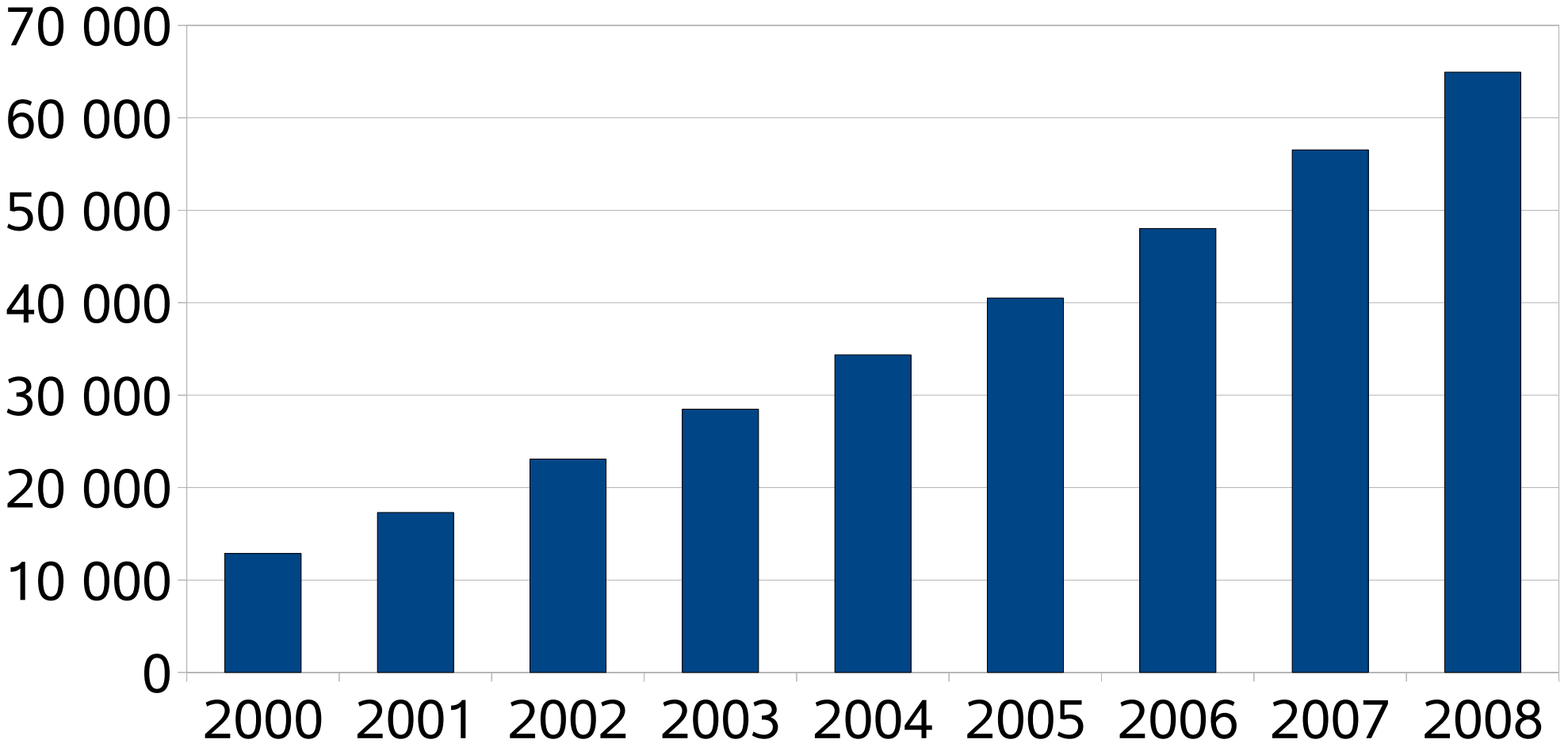
Outline

- Growth of wind power capacity
- UCTE: Continental Europe's synchronous power grid
- The story of the November 2006 UCTE blackout
- Power grid simulation: Linearised AC model
- Case study: German wind power vs. UCTE
- (Power grid simulation 2: Linear programming)

Growth of wind power

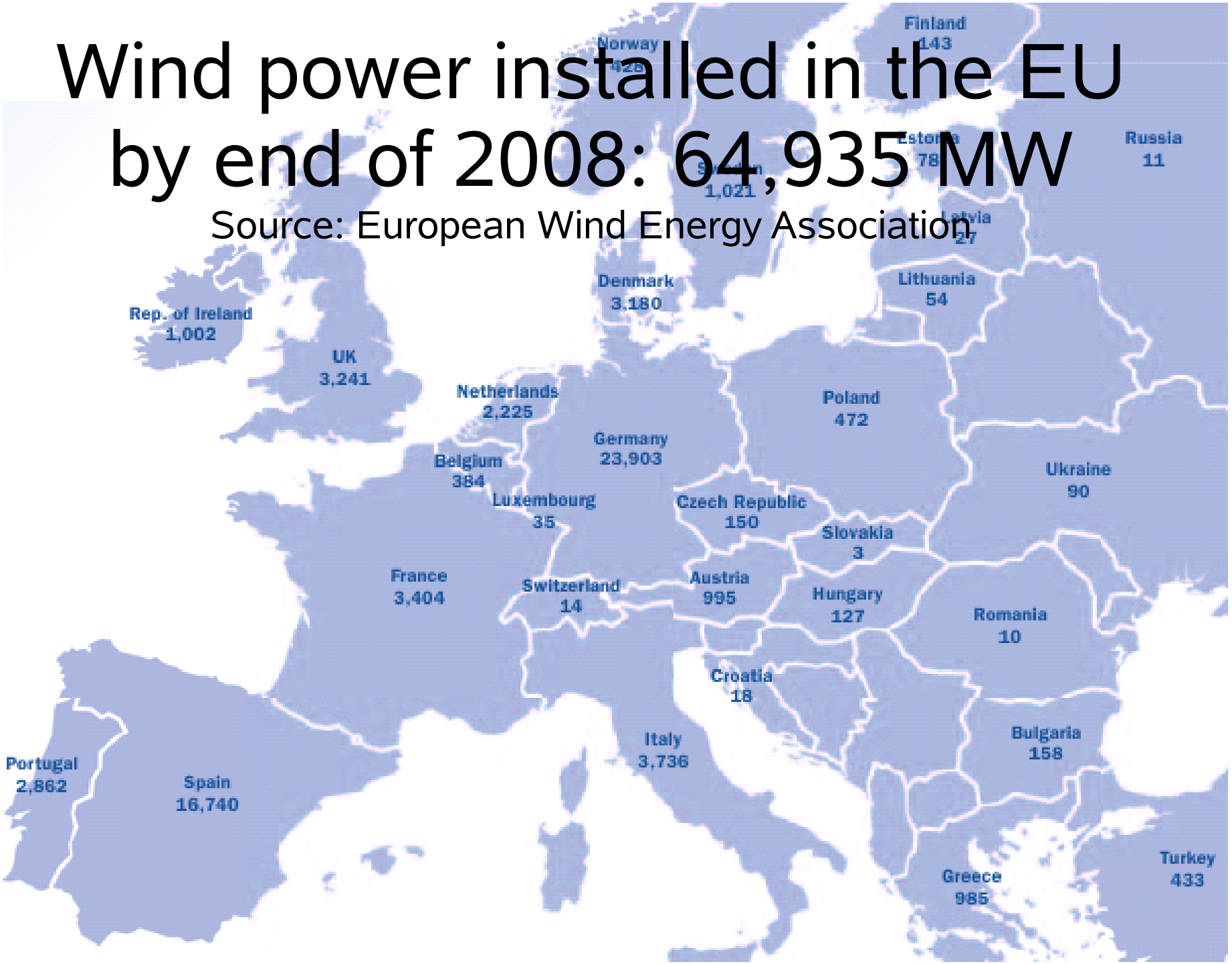
Cumalative wind power capacity in the EU [MW]

Source: European Wind Energy Association



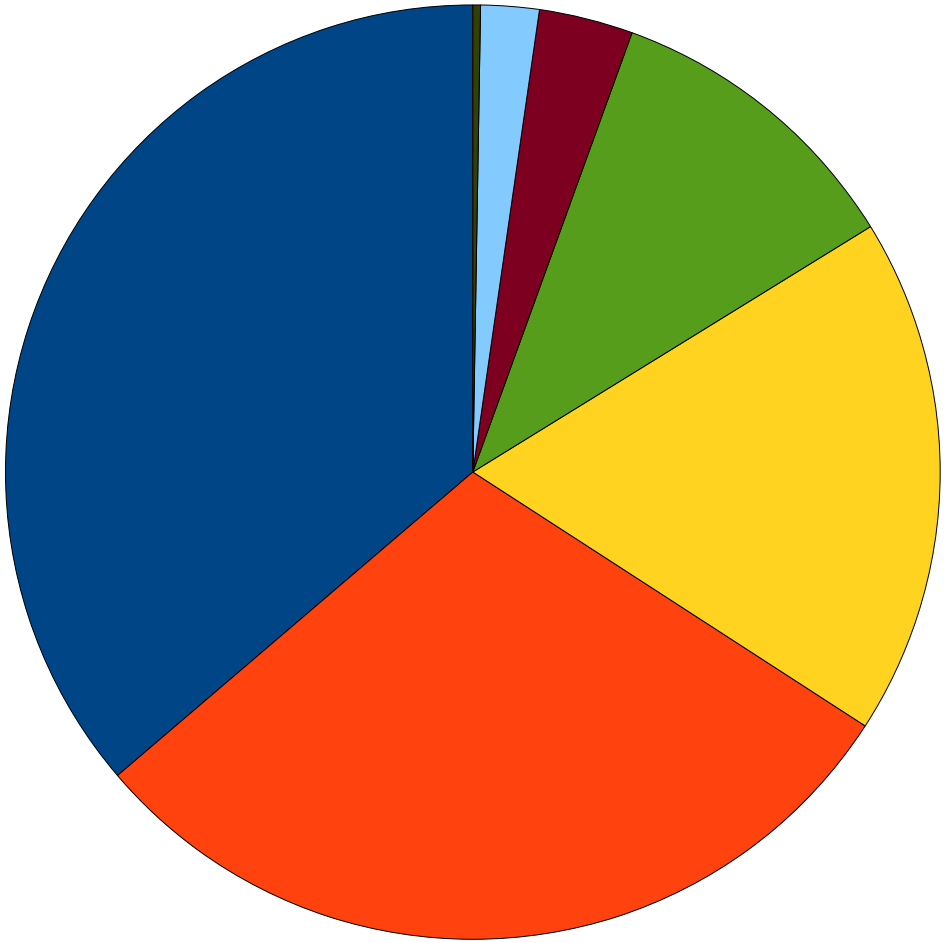
Wind power installed in the EU by end of 2008: 64,935 MW

Source: European Wind Energy Association



New installed power capacities in the EU in 2008

Source: European Wind Energy Association



- Wind: 8.484MW (35.6%)
- Natural gas: 6.932MW (29.1%)
- Solar (PV): 4.200MW (17.6%)
- Oil: 2.495MW (10.5%)
- Coal: 762MW (3.2%)
- Hydro: 473MW (2.0%)
- Nuclear: 60MW (0.3%)

How much wind power can Europe produce?

European Environmental Agency: “Europe's onshore and offshore wind energy potential” (technical report, June 2009). Its main conclusion is that considering

- technological development in turbine design,
- environmental constraints and
- economical competitiveness,

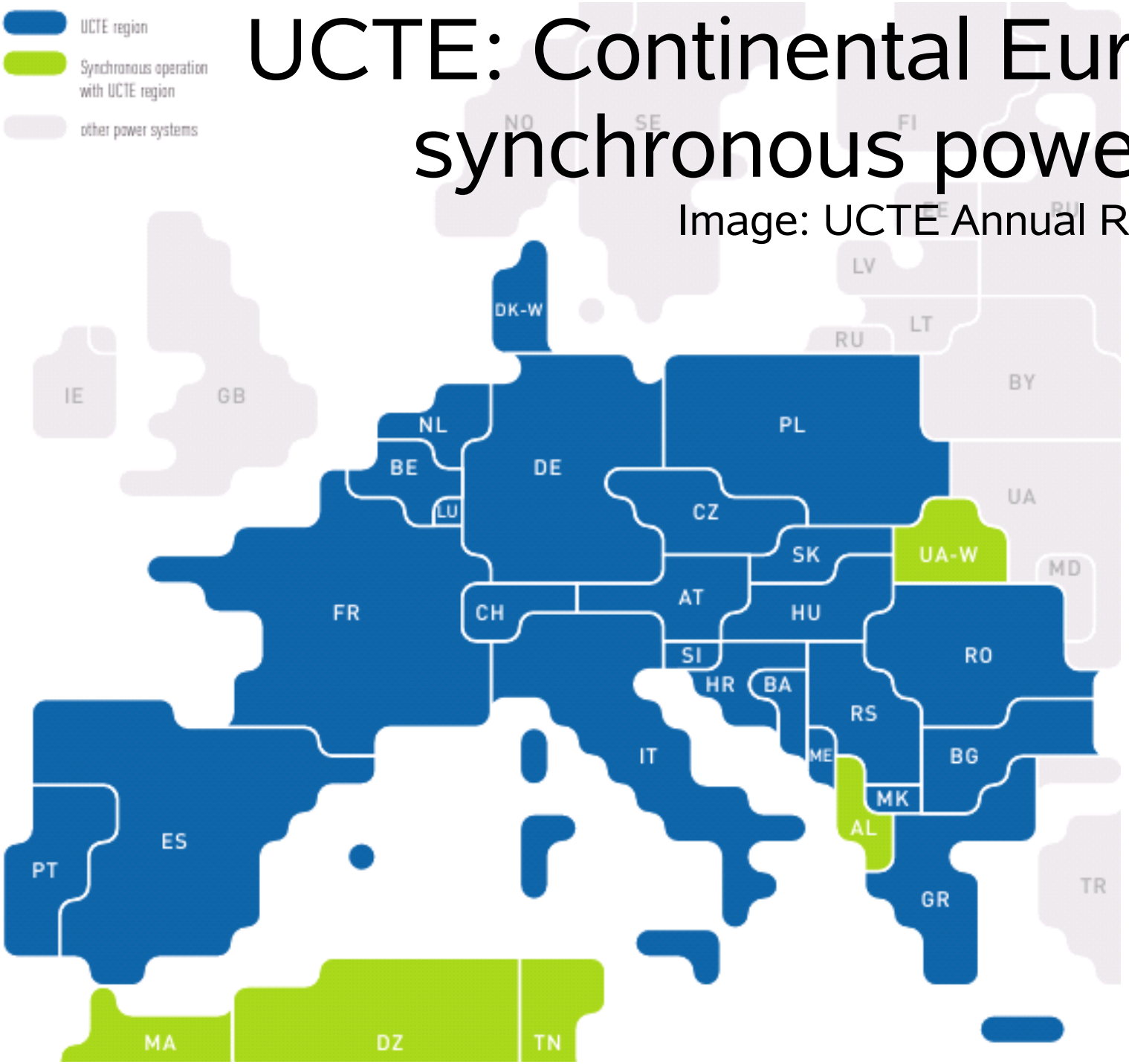
potentially approx. 12 200 TWh/year wind energy can be produced in 2020, which is 3 times larger than the EU's projected total energy demand.

Why does wind make transmission system operators unhappy?

- Power generation and consumption should be in balance in every moment, and the intermittent nature of wind makes planning difficult
- The spatial fluctuation (on the continental scale) of wind power generates macroscopic flows accross Europe
- Originally the power grid was not designed for such flow patterns, it is a new challenge

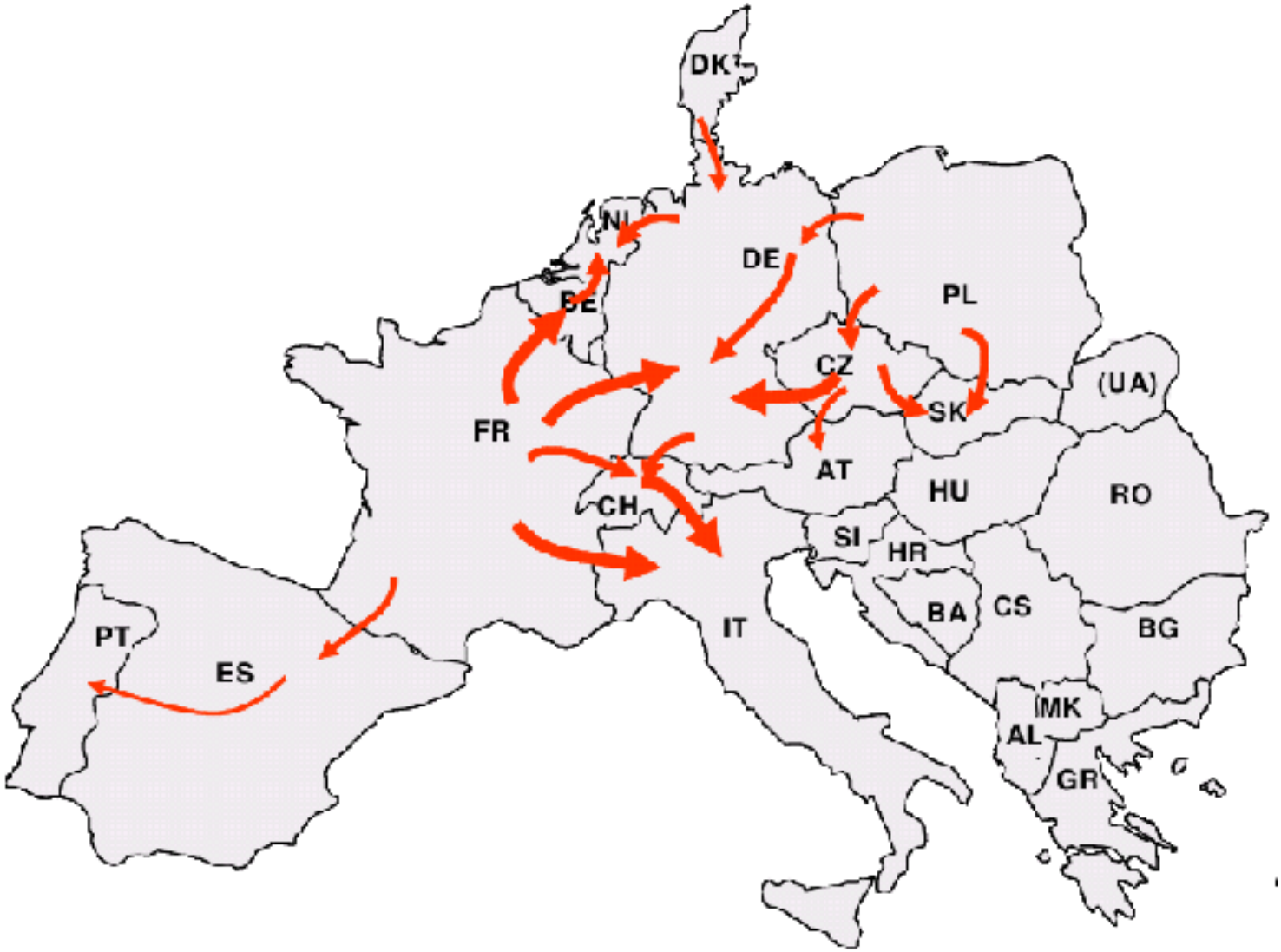
UCTE: Continental Europe's synchronous power grid

Image: UCTE Annual Report 2008



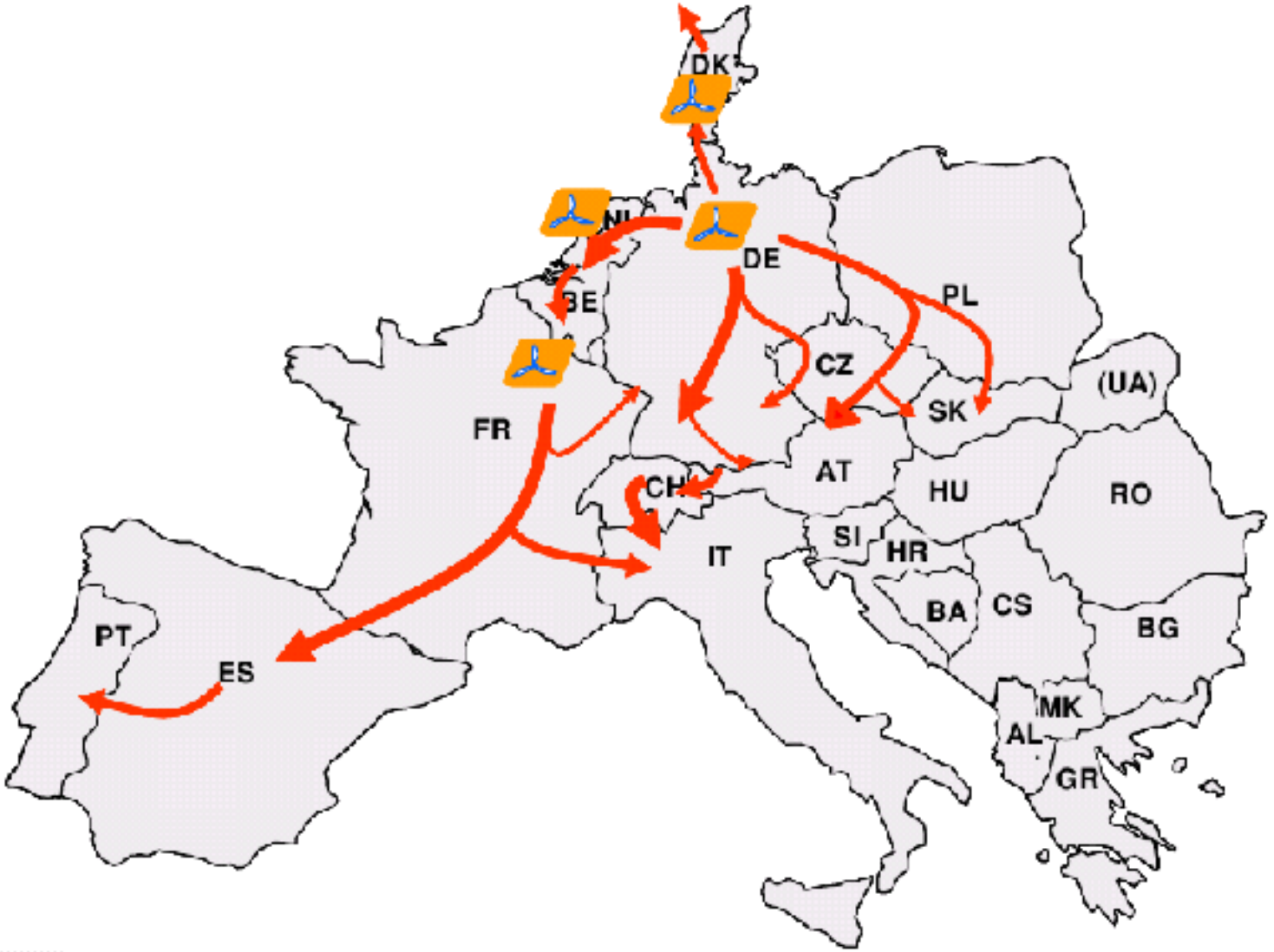
Power flow in the UCTE grid: Business as usual scenario

Image:European Wind Energy Integration Study Interim Report 2008



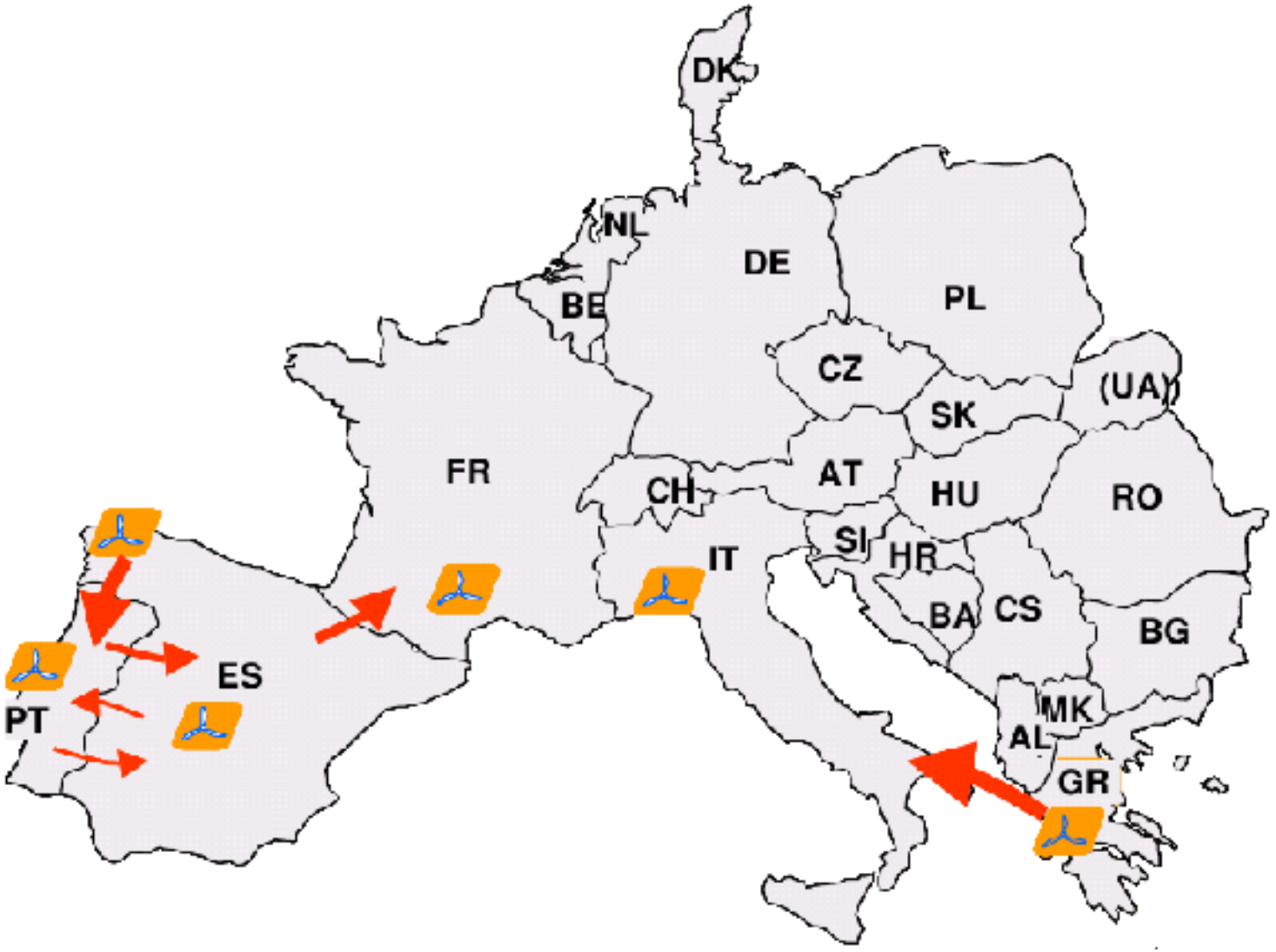
Power flow in the UCTE grid: Northern wind scenario

Image:European Wind Energy Integration Study Interim Report 2008



Power flow in the UCTE grid: Southern wind scenario

Image:European Wind Energy Integration Study Interim Report 2008



UCTE blackout on 4 November 2006

Source: UCTE Final Report, 2007

- A shipyard requested E.On to disconnect a double-circuit 380 kV power line going across the river Ems, to let through a ship
- Analysis showed no violation of the N-1 criterion
- The time of disconnection was advanced by 3 hours, E.On forgot to notify the other operators
- For E.On's bad luck, it was the “Northern wind scenario”...

Consequences of the blackout

- After disconnecting the double-circuit 380 kV power line, the remaining parallel lines could not carry the power flow coming from North-Germany
- The whole UCTE network rapidly split into three parts
- 15 million European households remained without power for hours, some of them for days

Power grid simulation: Linearised AC model

Assumptions:

- Connecting lines at a node have the same voltage (U) and phase (θ)
- Along a line, phase shift $\Delta\theta << 1$
- $x << r$ for the complex resistance $r+i*x$

Power flow: $P = U^2 \Delta\theta / x$

Constraints: sums of power flows at nodes are zero → set of sparse linear equations for the phases.

Case study: German wind power vs. UCTE

We have used the UCTE part of the power network database supplied by the MANMADE project. Assumptions:

1. In the same country, power plants' generation is proportional to their rated power
2. Consumption at a node is proportional to the number of 120 kV lines connecting to the node
3. System failure if power flow along a cross-border line exeeds its maximum capacity

Results

- According to the UCTE dataset, Germany has 7832 MW cross-border transport capacity
- We ran the linearised AC model on the network with real load data for each country (taken from UCTE publications), and found that with these rules some cross border maximum capacities are violated already without putting in extra wind power → the naive physical model is not enough
- We have implemented some system operator logic as a linear programming problem → cross border maximum capacities were no longer violated

Conclusions

- Physical power flow simulations must be completed with routing algorithms
- Limited cross border capacities are surely major bottleneck for large scale wind integration → massive grid upgrade is necessary for large scale wind energy utilisation in Europe