Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Das elektrische Energieversorgungssystem der Zukunft
Herausforderungen und Möglichkeiten

Göran Andersson
Power System Lab
ETH Zürich

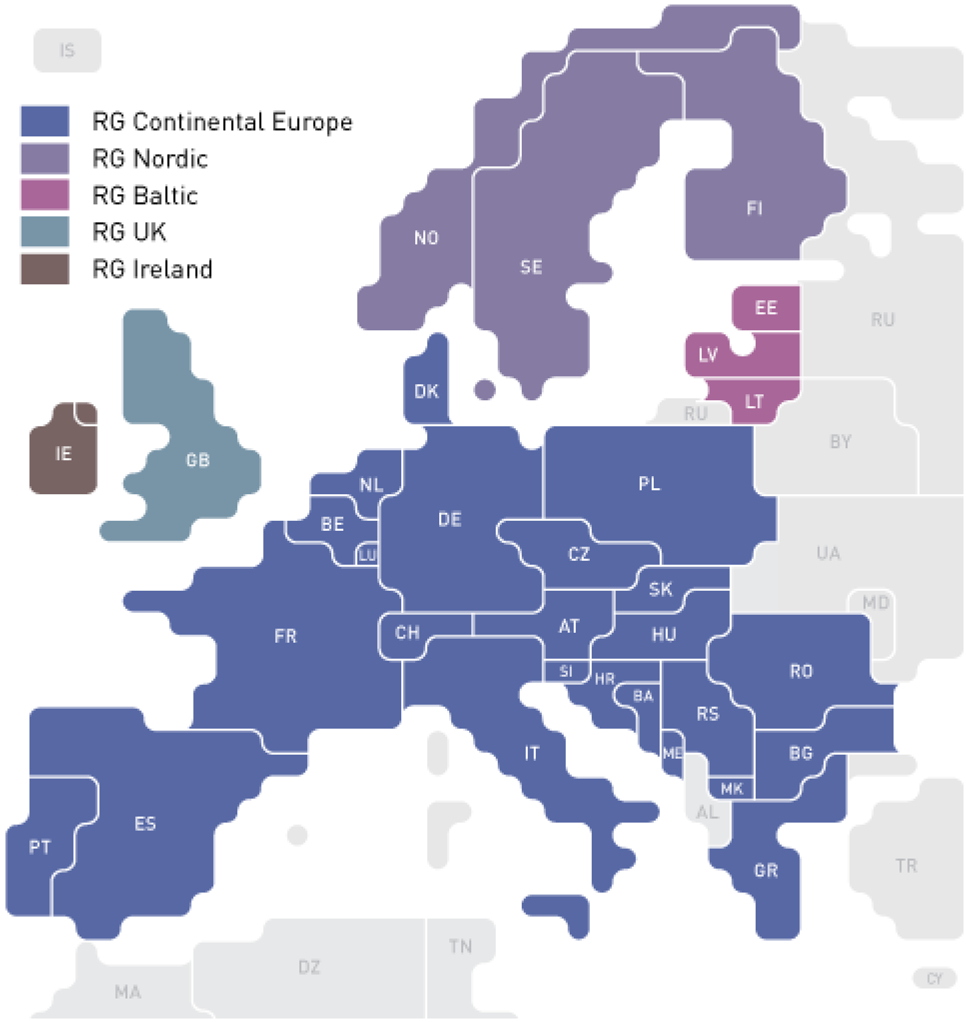
AGENDA

- Das Europäische Stromnetz
- Technische Herausforderungen
- Technische Lösungen (Forschung an der ETH Z)
- Schlussfolgerungen

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

eeh power systems laboratory

European Network of Transmission System Operators for Electricity ENTSO-E

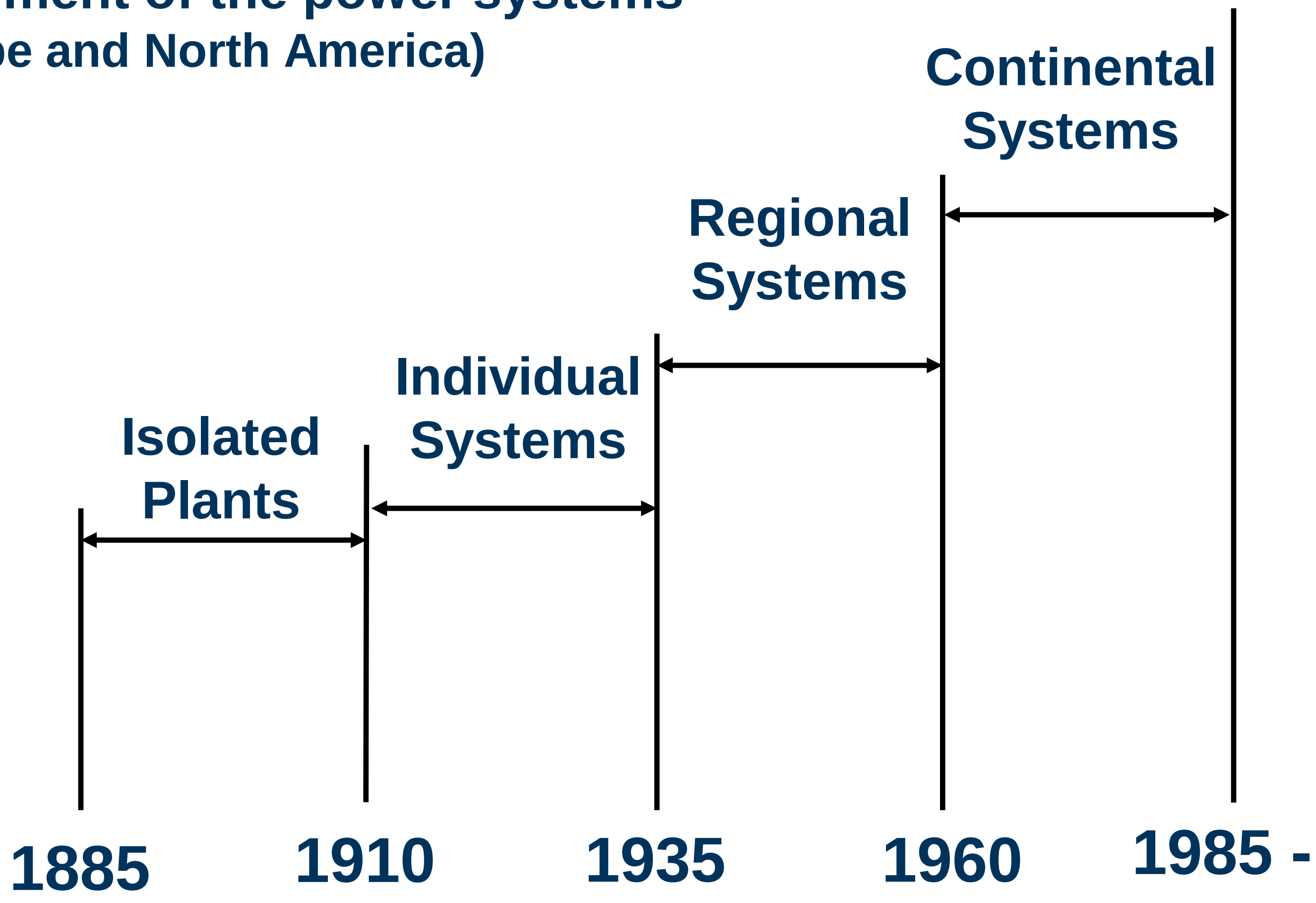


RG Continental Europe

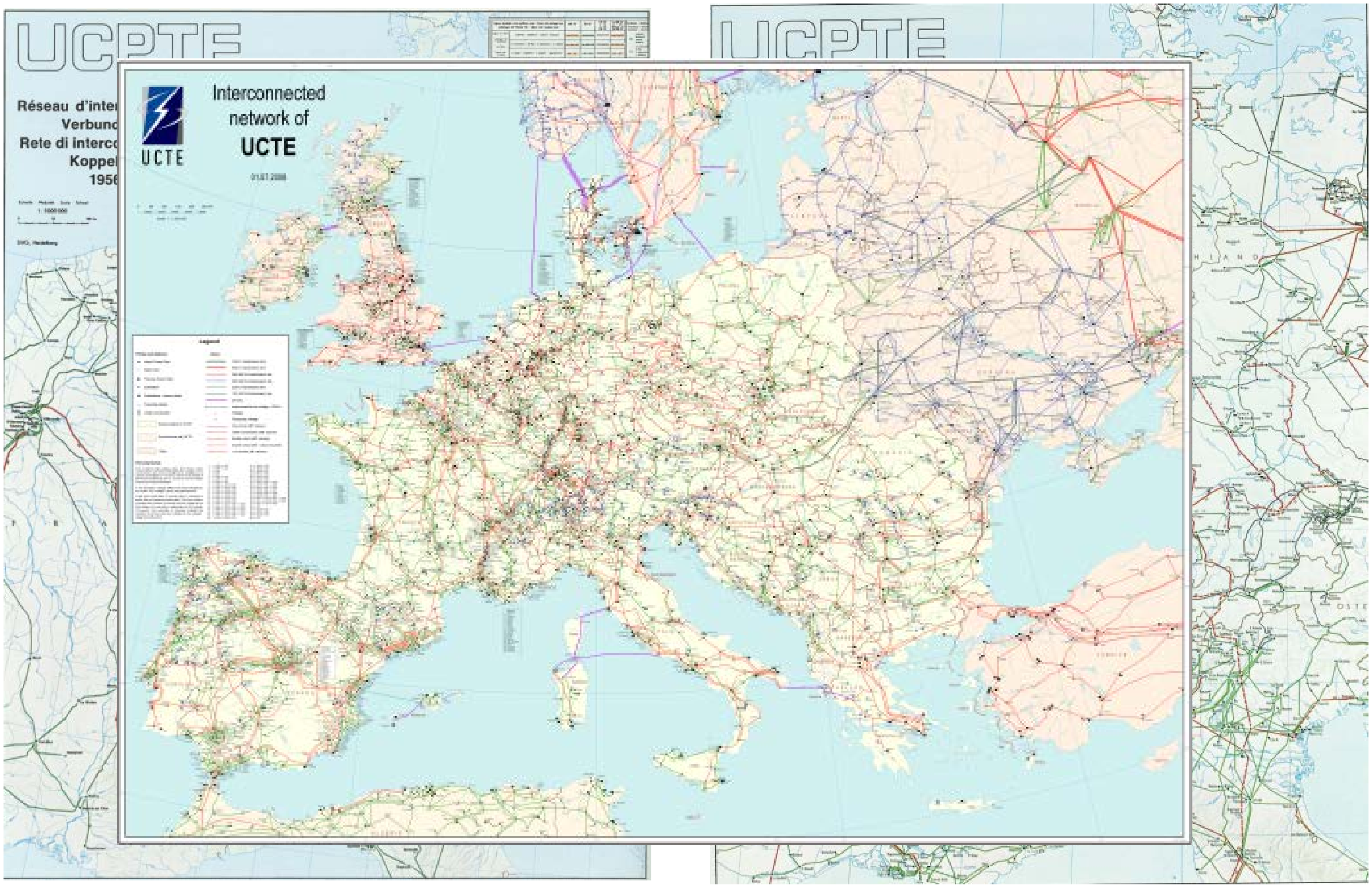
=

ex UCTE

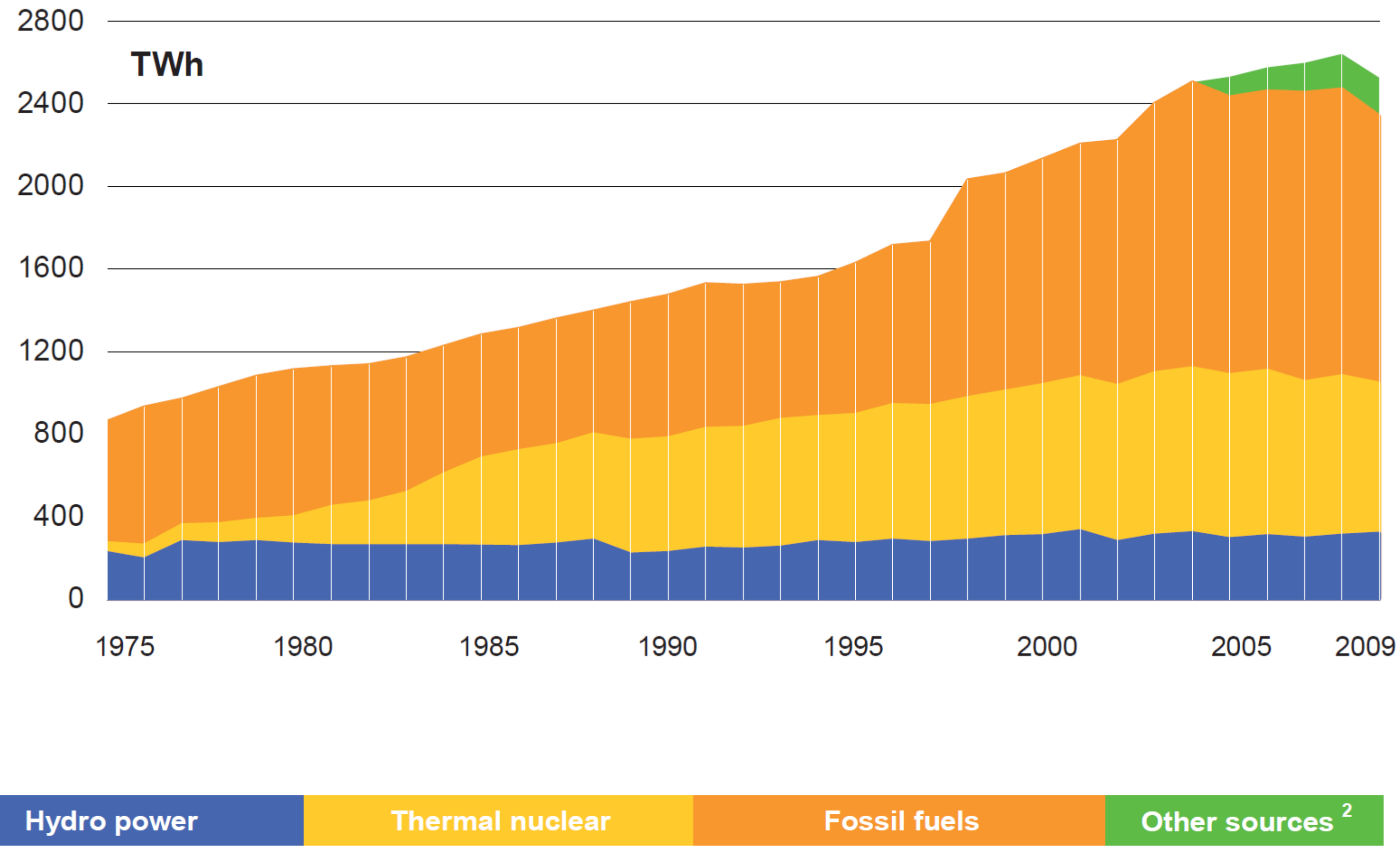
Development of the power systems
(In Europe and North America)



Development of the European Electricity System: from UCTPE to ENTSOE-E

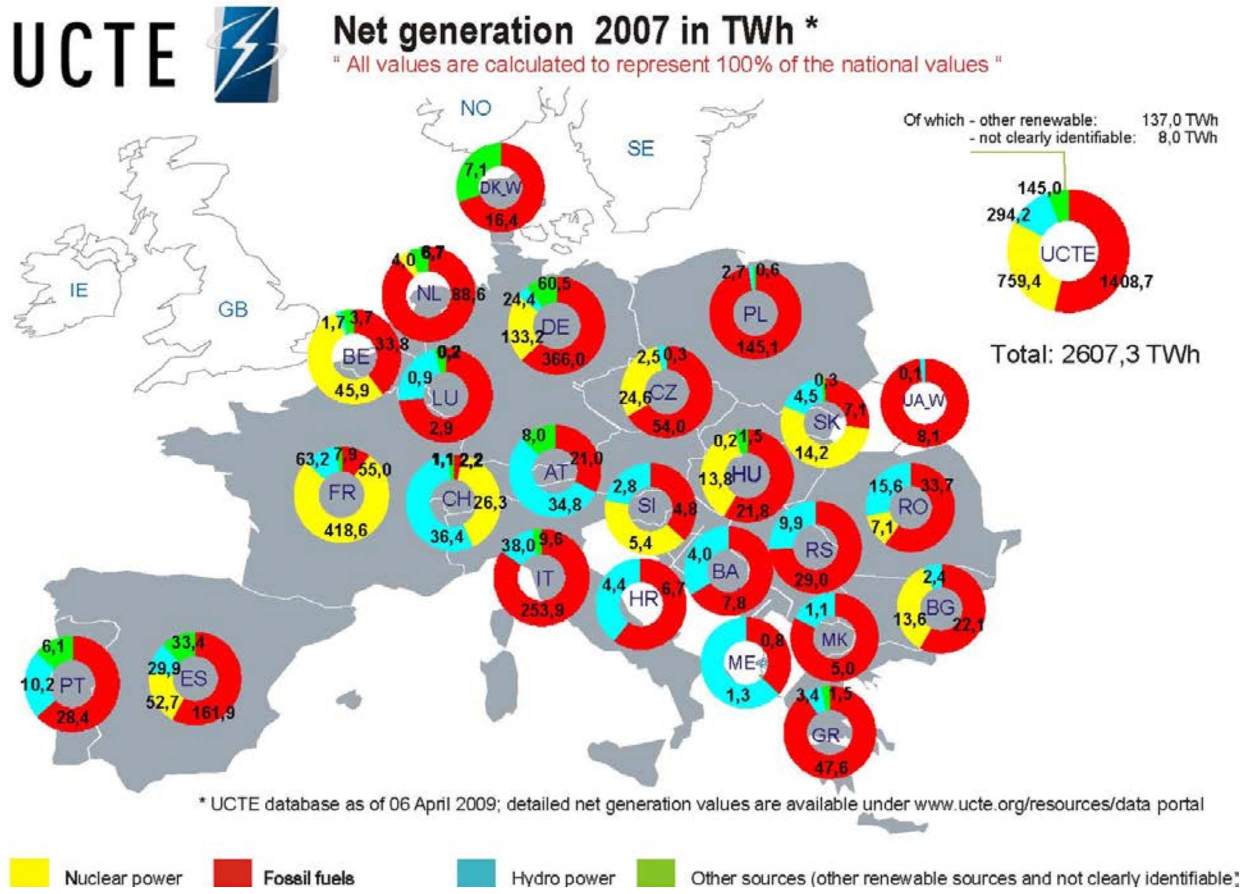


Development of net electricity generation [1]

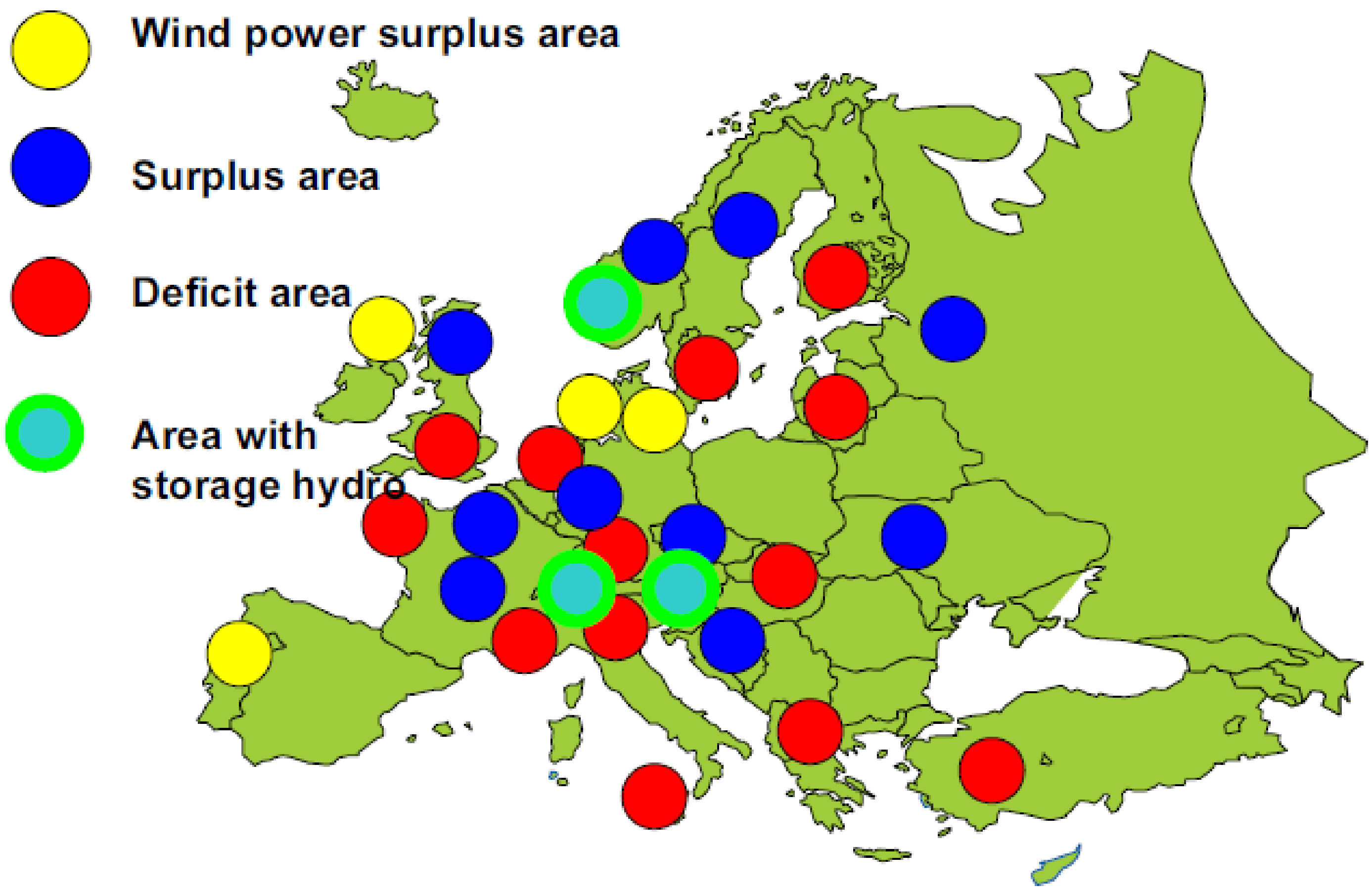


Source: ENTSO-E

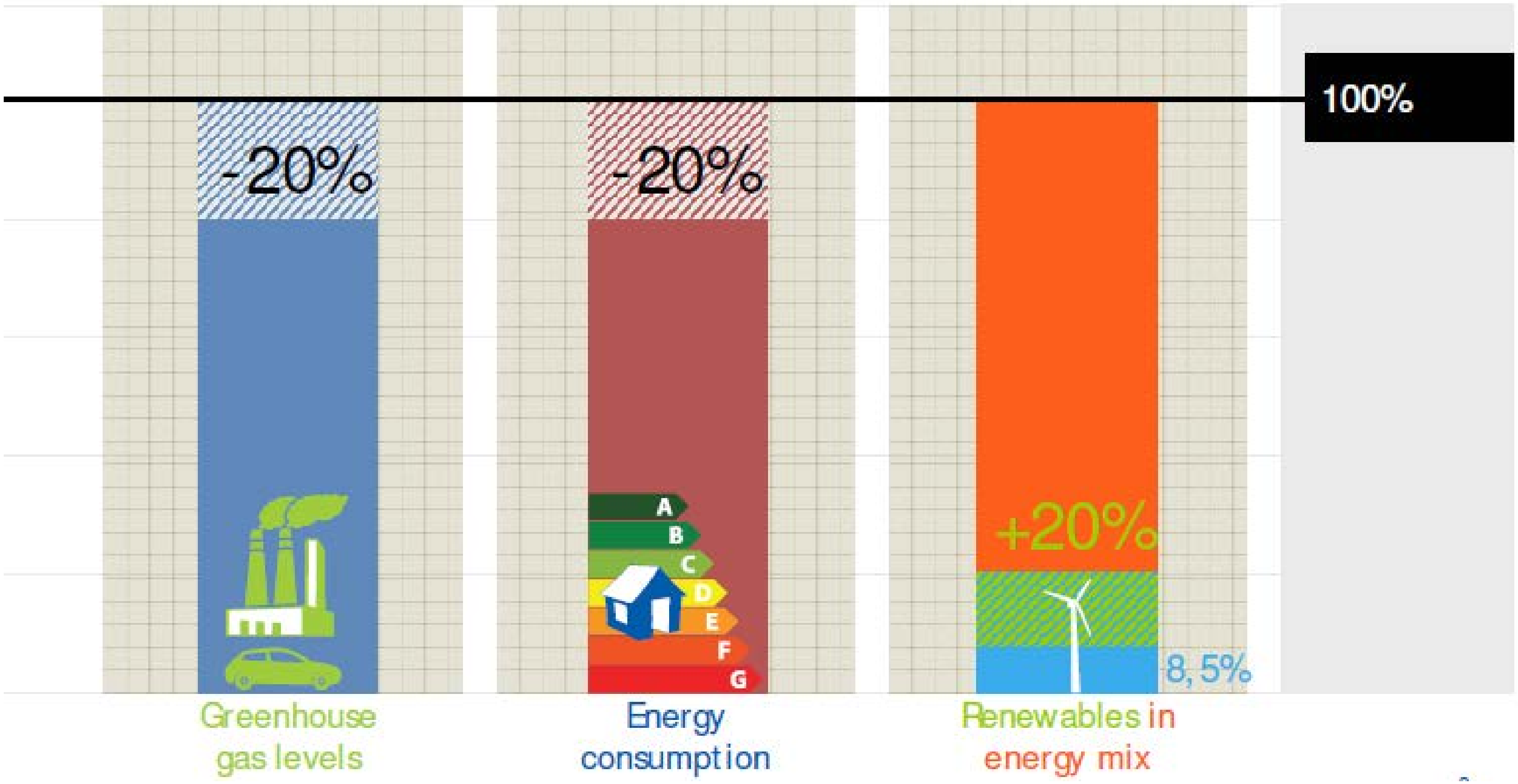
- **Dominating**
  - Coal
  - Nuclear
- **Additional**
  - Hydro
- **Increasing**
  - Wind
  - Gas
  - Biomass
  - Photovoltaic



Surplus and deficit areas



The 20-20-20 EU policy by 2020



- Value of wholesale electricity market in Europe is over 150 G€, approx. 12% is cross border trade

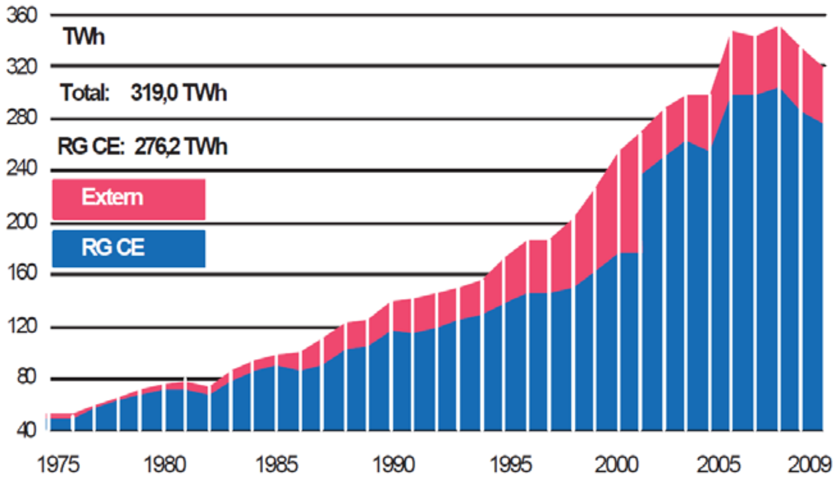
- Annual cost of operating the transmission network is 10 – 11 G€

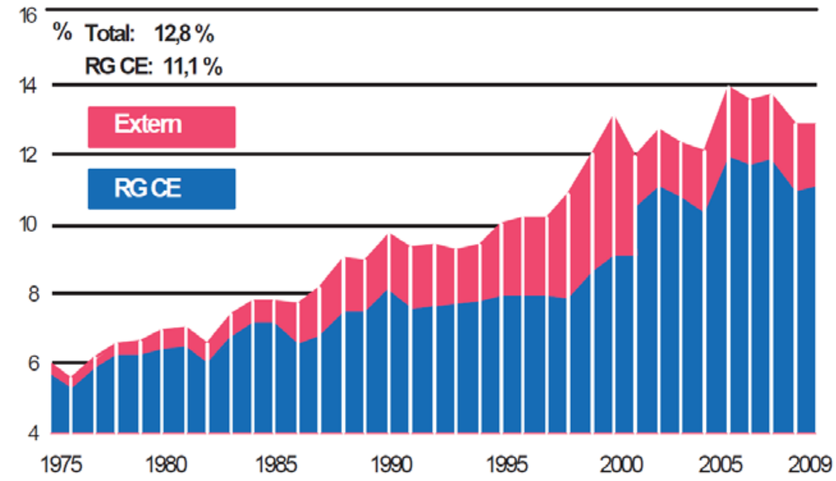
- Ageing networks
  - Missing E-W and N-S links
  - Poorly adapted to renewable and distributed generation

- New institutional architecture with Third Package
  - ENTSO – E
  - Agency

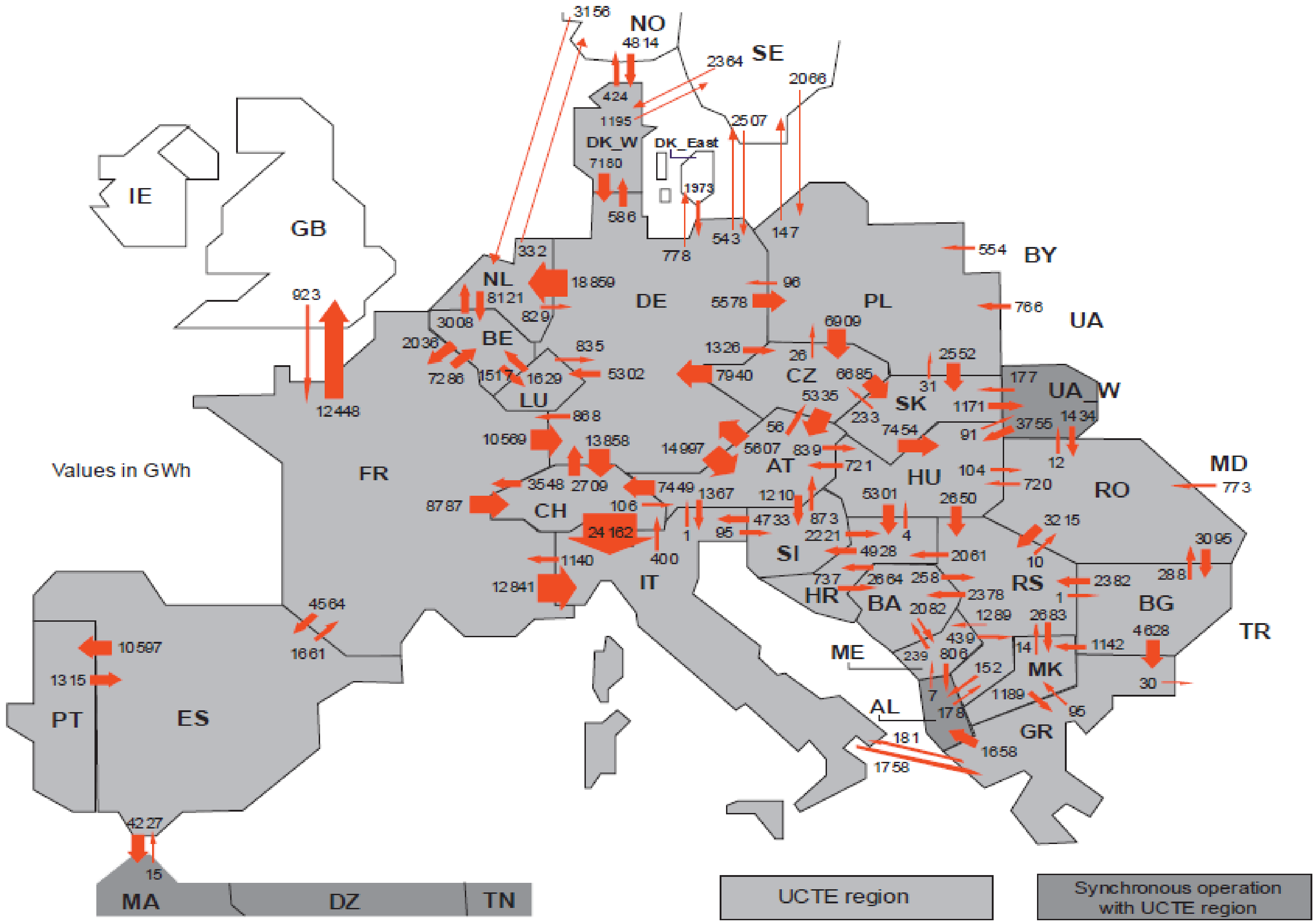
Cross border transfer of power in Europe

Development of physical exchanges on tie lines





Source: ENTSO-E



Source: ENTSO-E

AGENDA

- Das Europäische Stromnetz
- Technische Herausforderungen
- Technische Lösungen
- Schlussfolgerungen

The traditional tasks of the ENTSO-E system

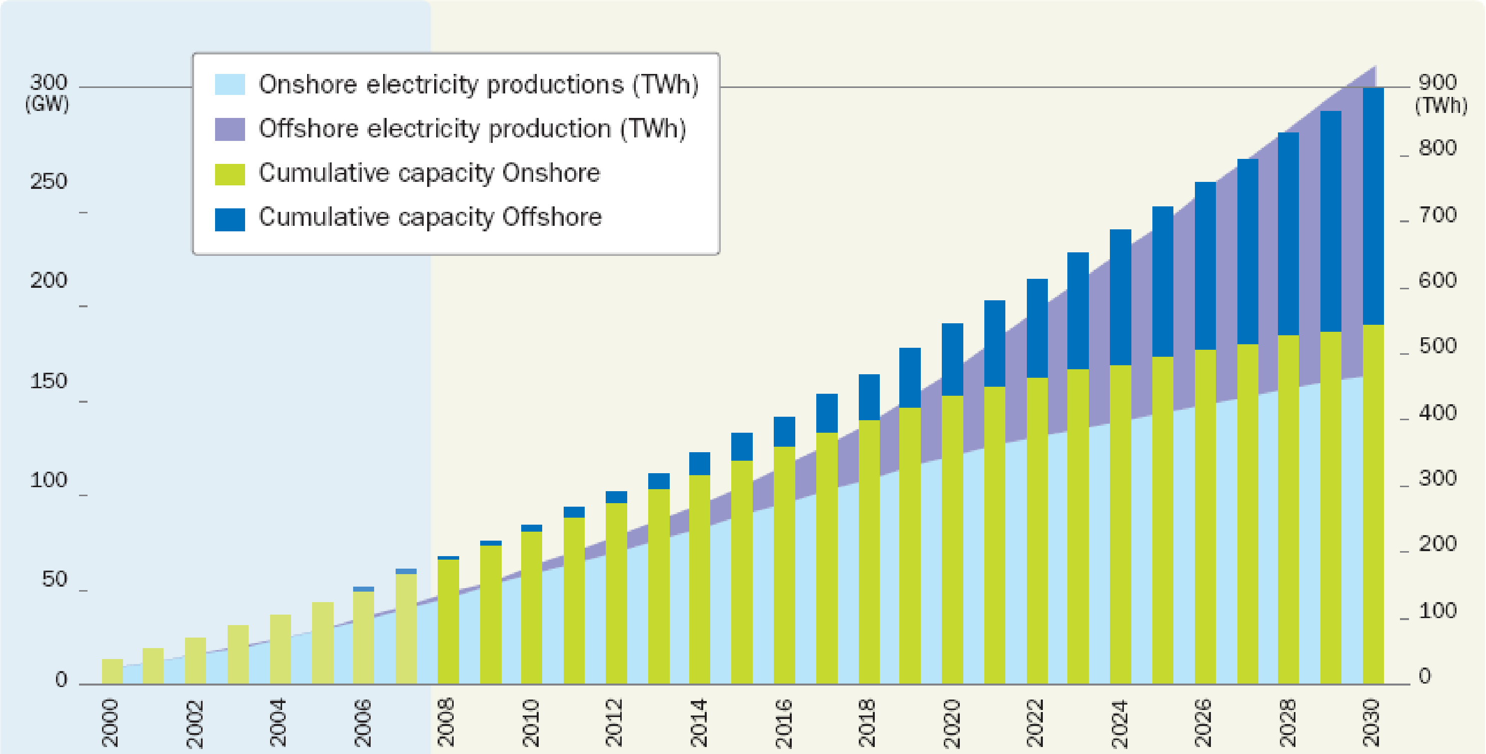
- Increase reliability and security by providing redundancy (*meshed networks*)
- Improving efficiency by joint frequency control and shared power reserves (*tie lines, power pooling, …*)

The new tasks of the ENTSO-E system

- Transmit power from remote power sources to load centers (wind power …)
- Constitute a power market for different actors

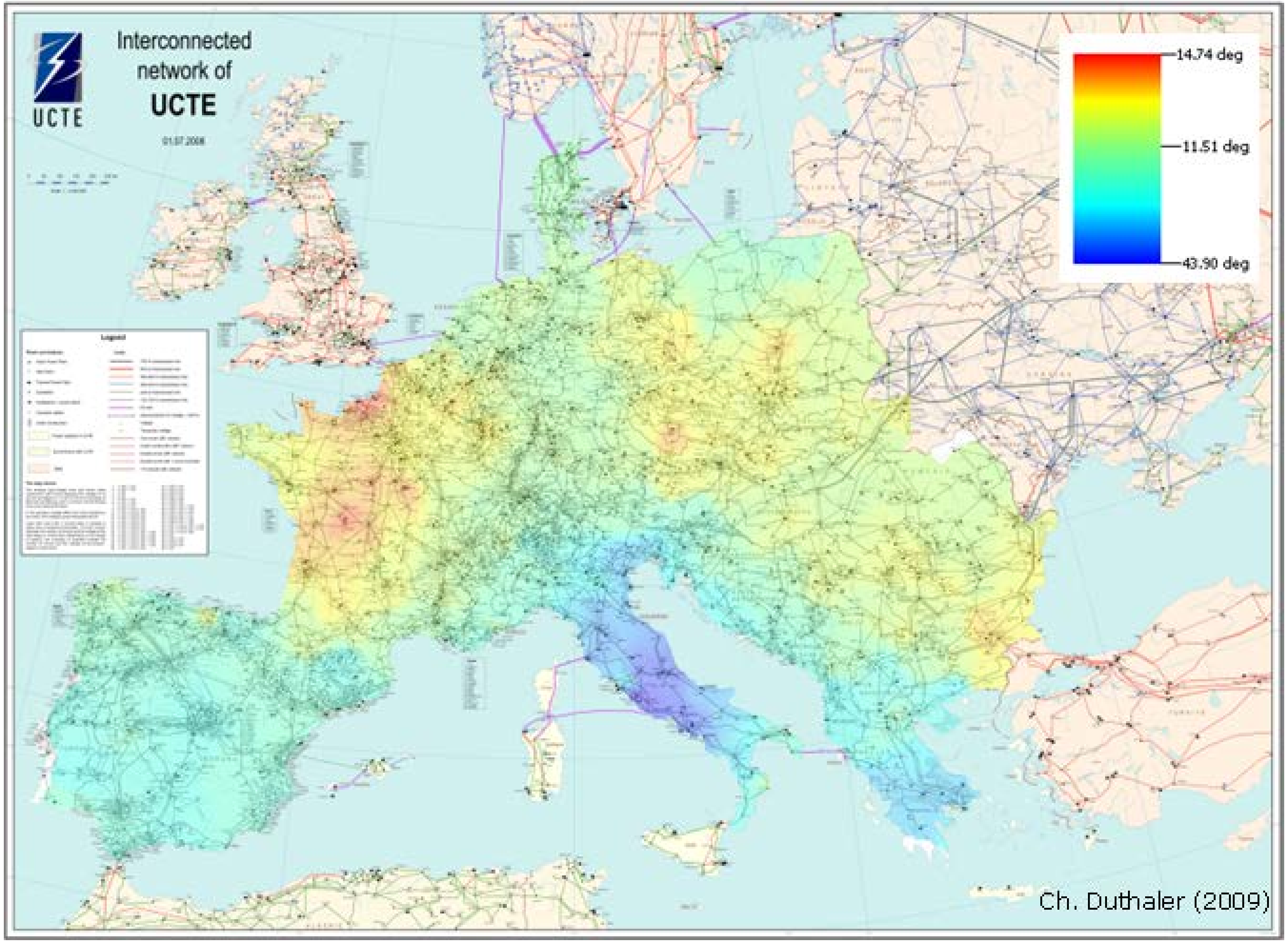
Integration of Wind Power

Electricity from wind up to 2030



EWEA (2008)

The Dynamics of Wind Power

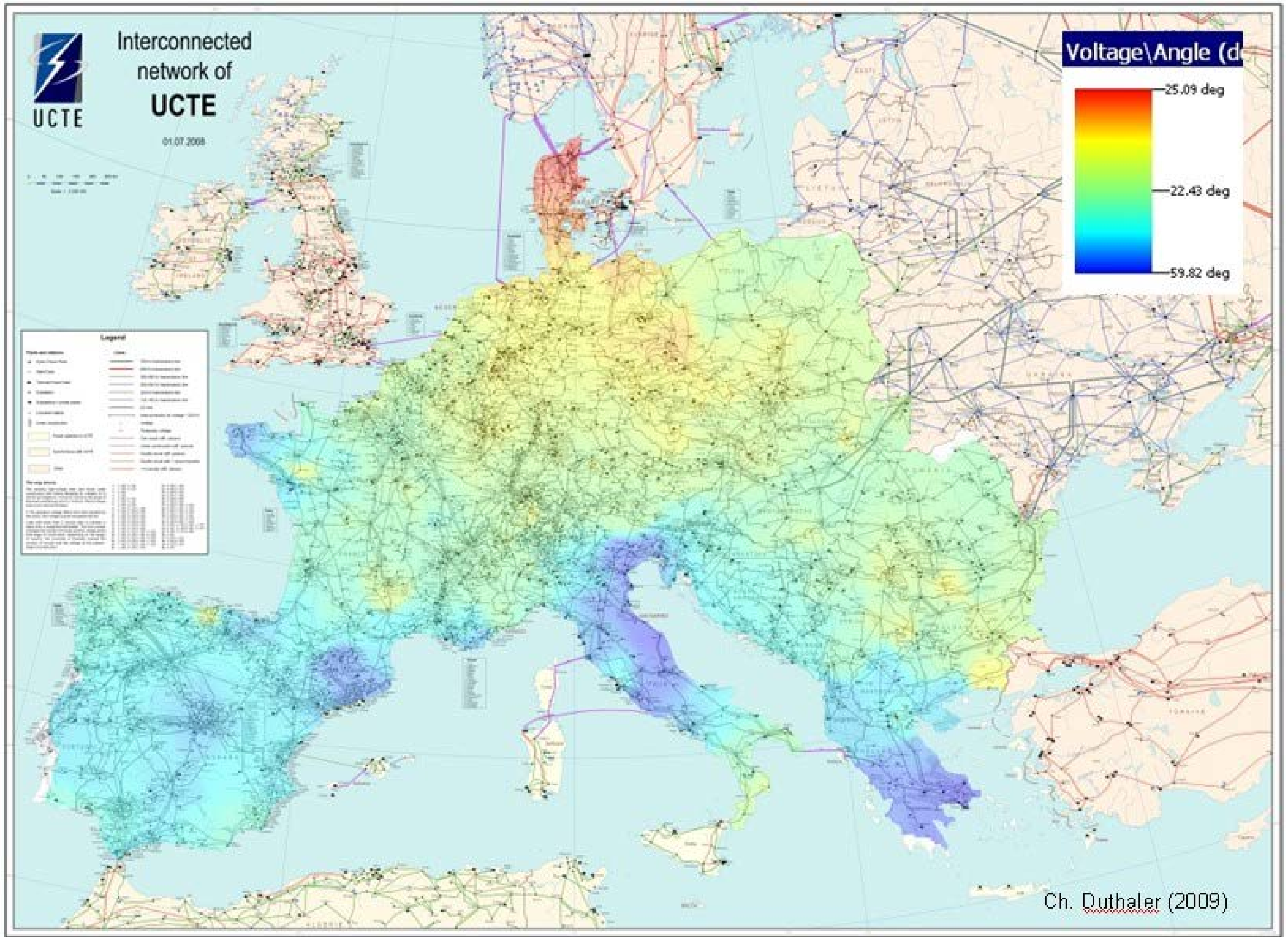


July 16, 2008

03.30 am

swissgrid

The Dynamics of Wind Power



July 16, 2008

10.30 am

swissgrid

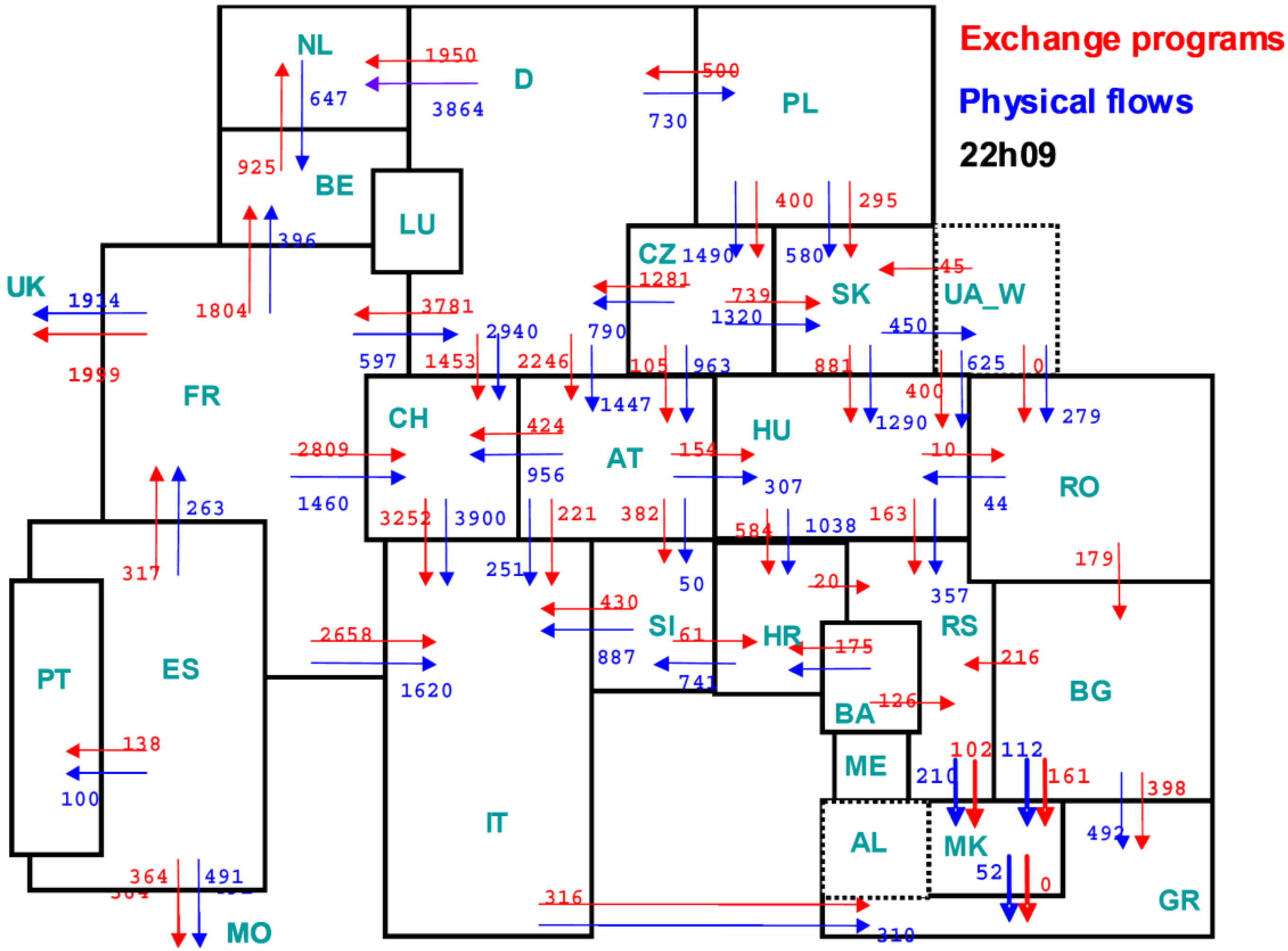
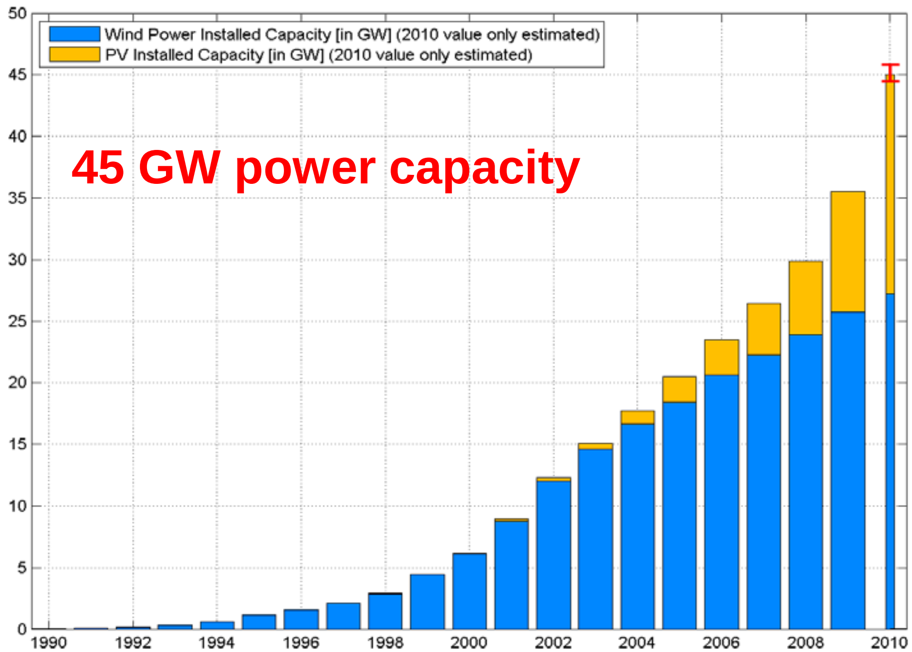
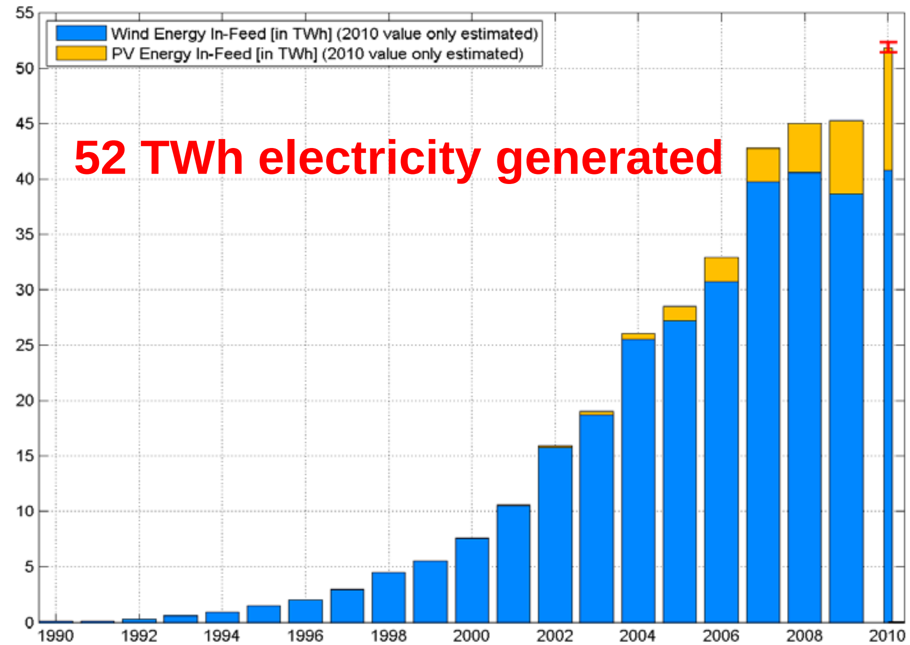


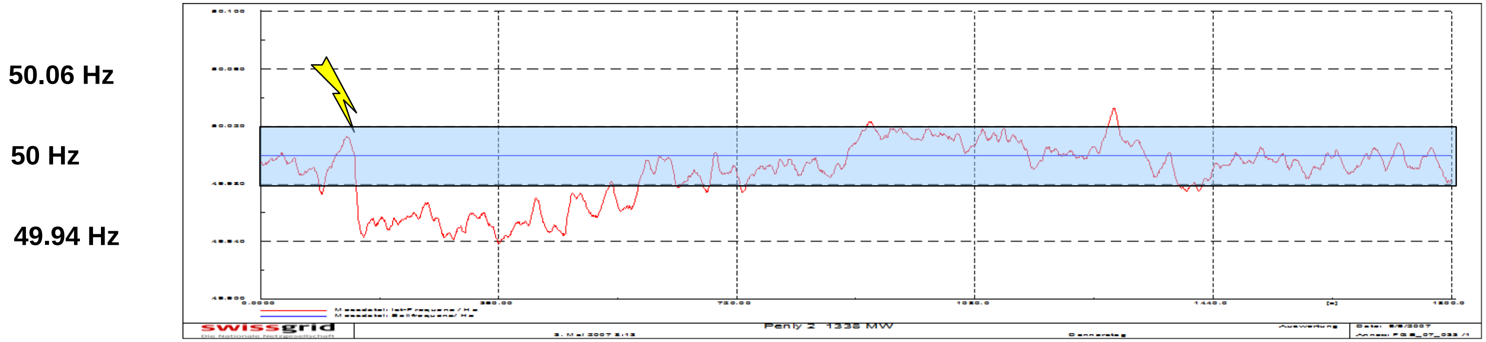
Figure 2: Exchange programs (red) and physical flows (blue) on 4 November at 22:09

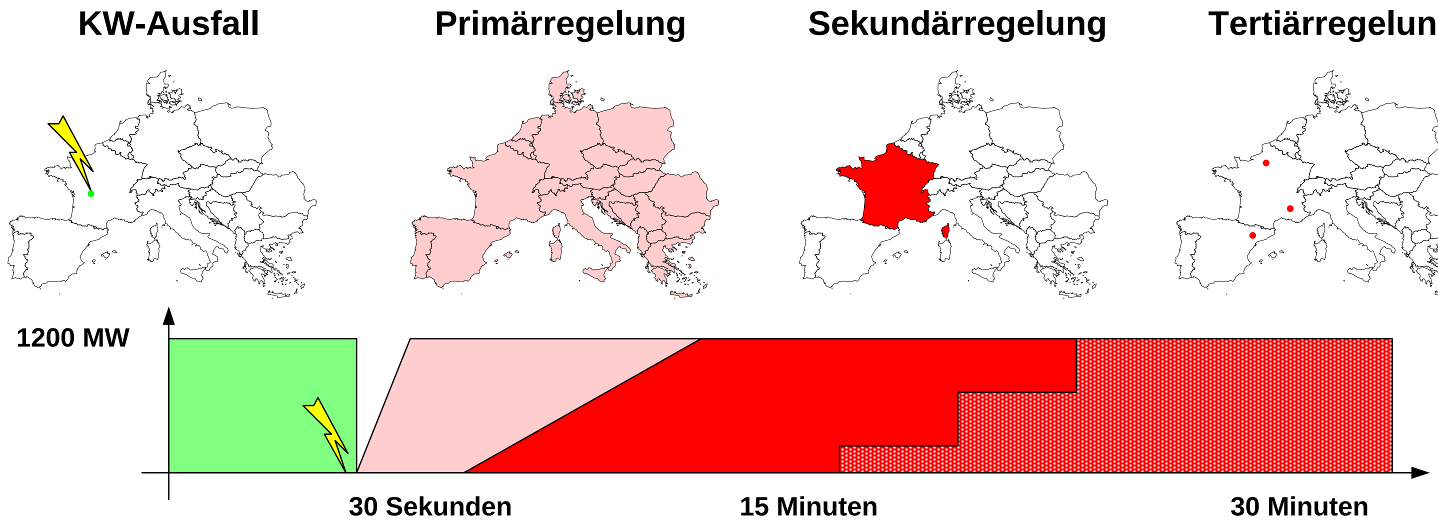
Current Trends in Power Systems

- **Increasing RES deployment (= fluctuating power in-feed)**
  - **Germany 2010: 45 GW power capacity, 52 TWh ≈ 10% of total generation**
  - ***Still* mostly uncontrolled power in-feed**
  - **Curtailment of wind power in-feed for contingencies implemented in some countries (= partial controllability)**
  - **Measurement and prediction of PV and Wind in-feed (state estimation)**





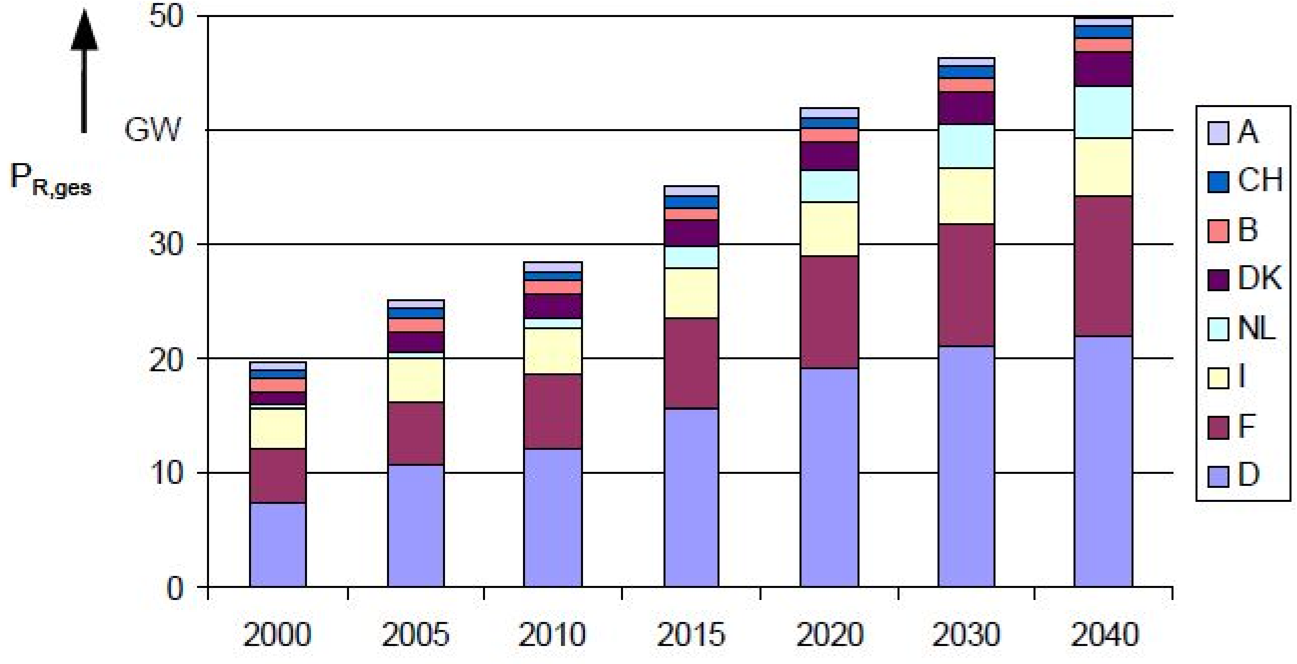




The grid is acting like a huge storage!

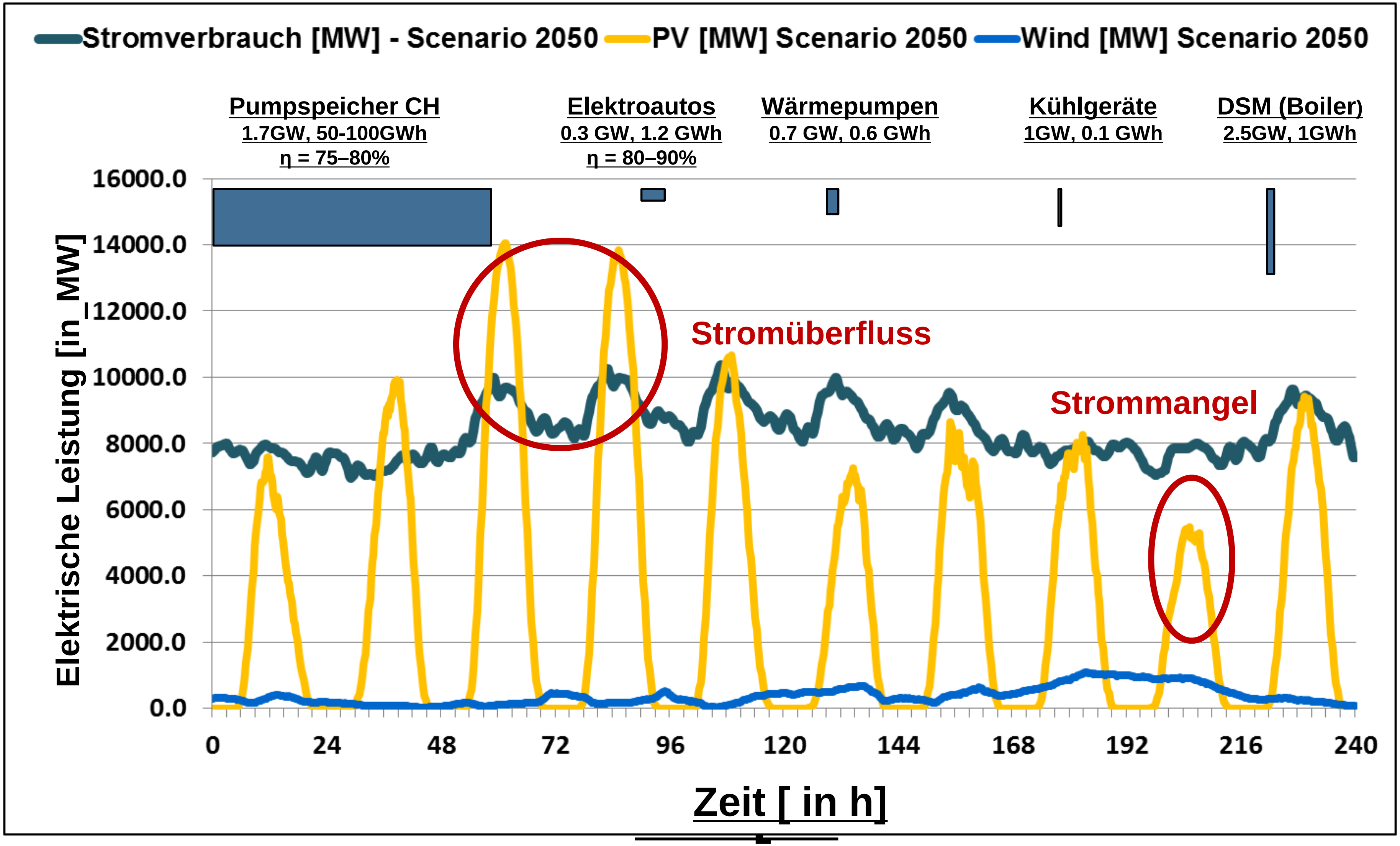
Source: W. Sattinger, swissgrid

Europe will need more Balancing Power

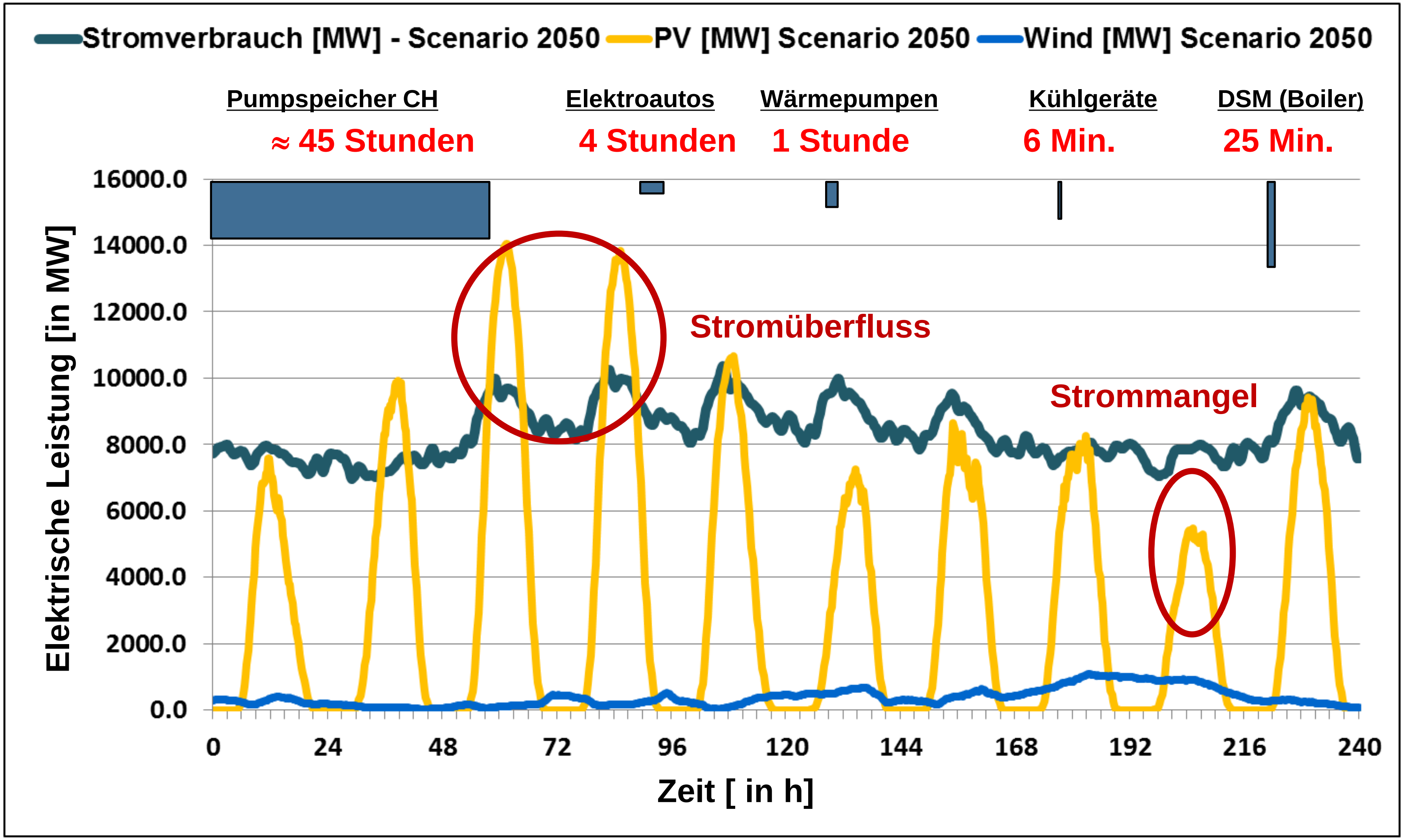


Figur 28: *Aufteilung des Bedarfs $P_{R,ges}$ an Sekundär- plus Tertiärregelreserve auf die verschiedenen Staaten (Maximaler WEA-Zubau, σ_{err} = 12 %)*

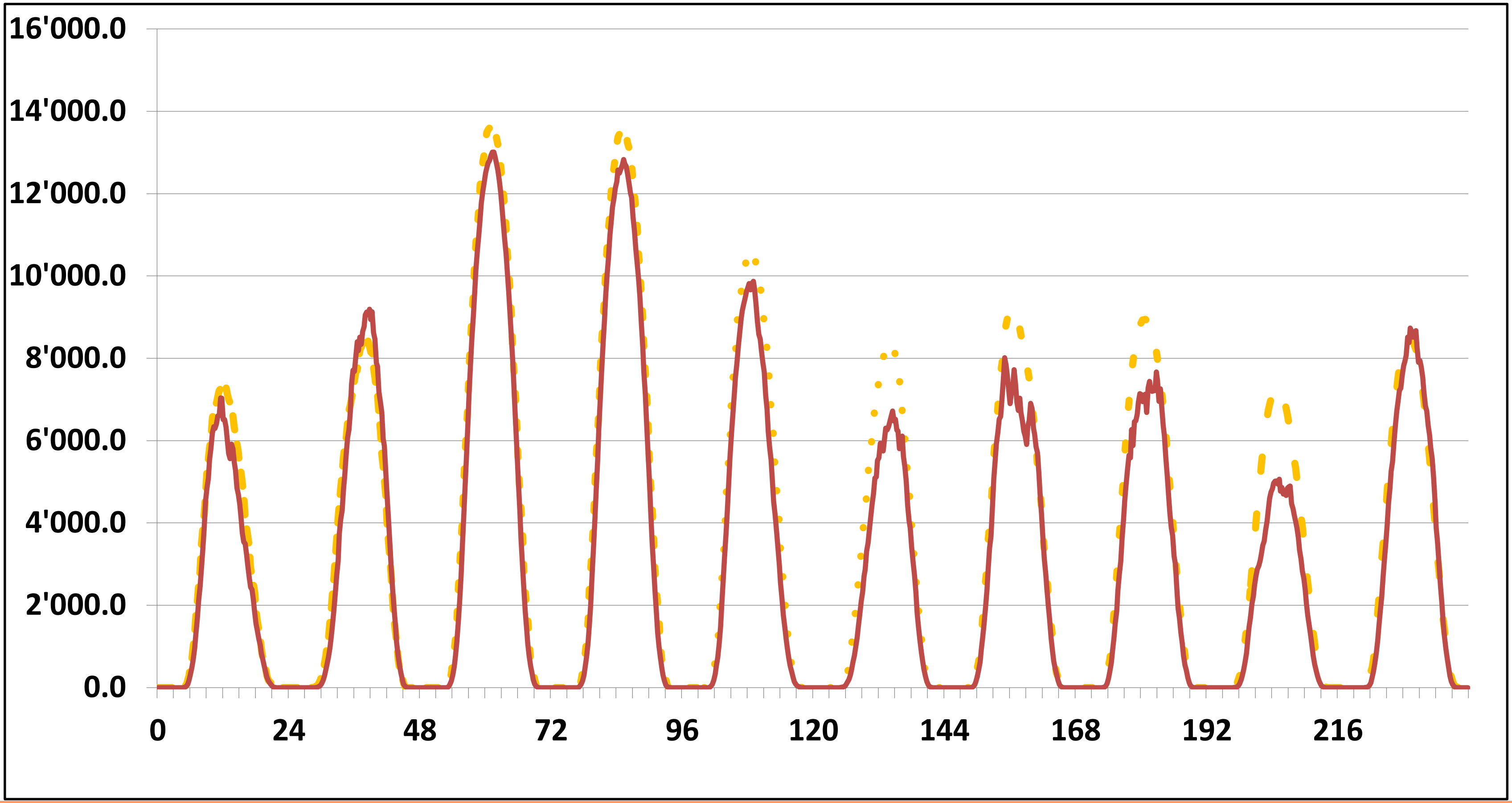
Ein mögliches Scenario für die Schweiz 2050



Ein mögliches Scenario für die Schweiz 2050



Prognosen sind bereits gut (Beispiel PV-Erzeugung)

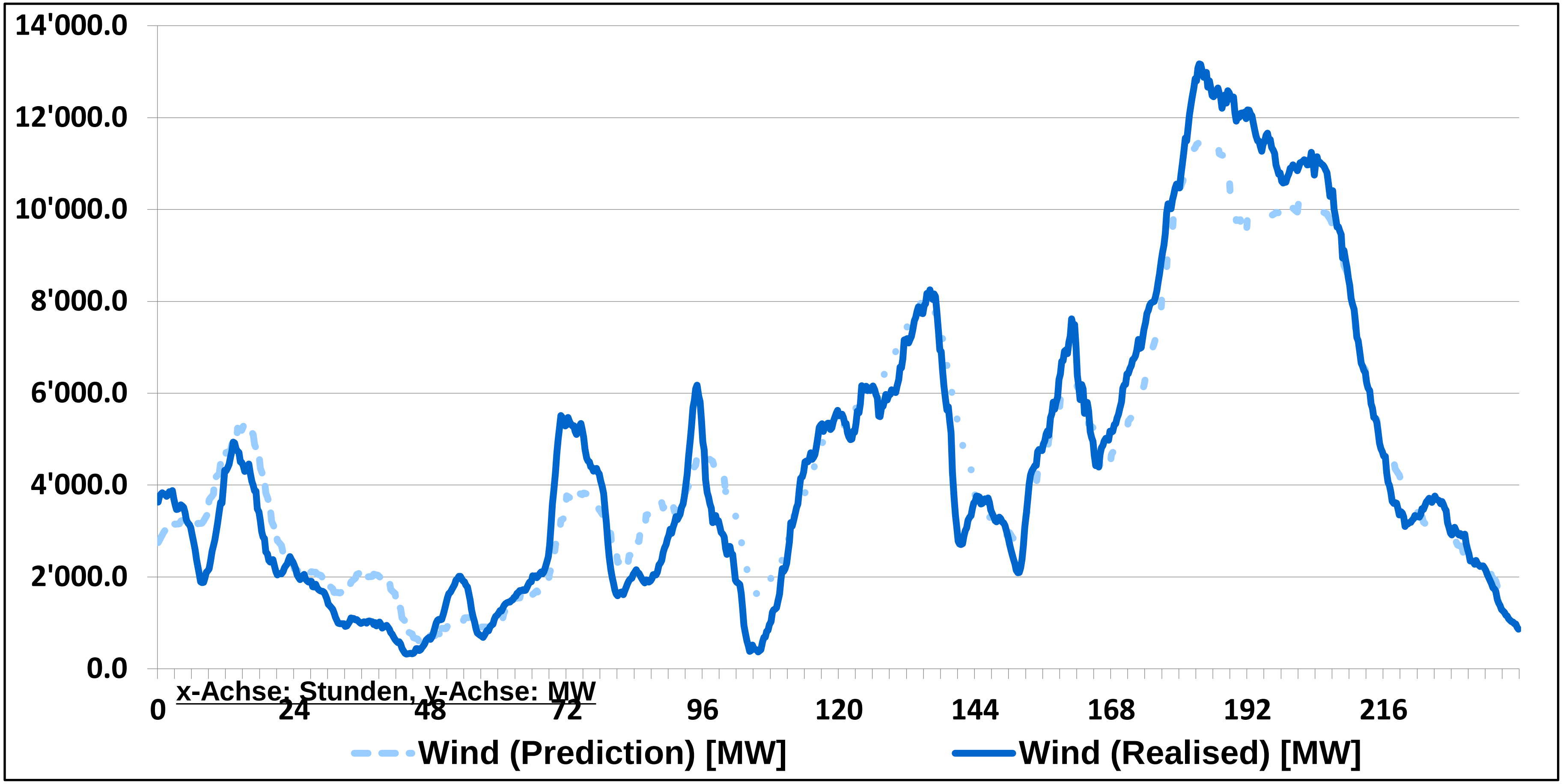


PV-Erzeugung in DE: 10 Tage vom 25.06.2011 - 03.07.2011

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

eeh power systems laboratory

Prognosen sind bereits gut (Beispiel Wind-Erzeugung)



Wind-Erzeugung in DE: 10 Tage vom 25.06.2011 - 03.07.2011

Installation von Windkraft und PV

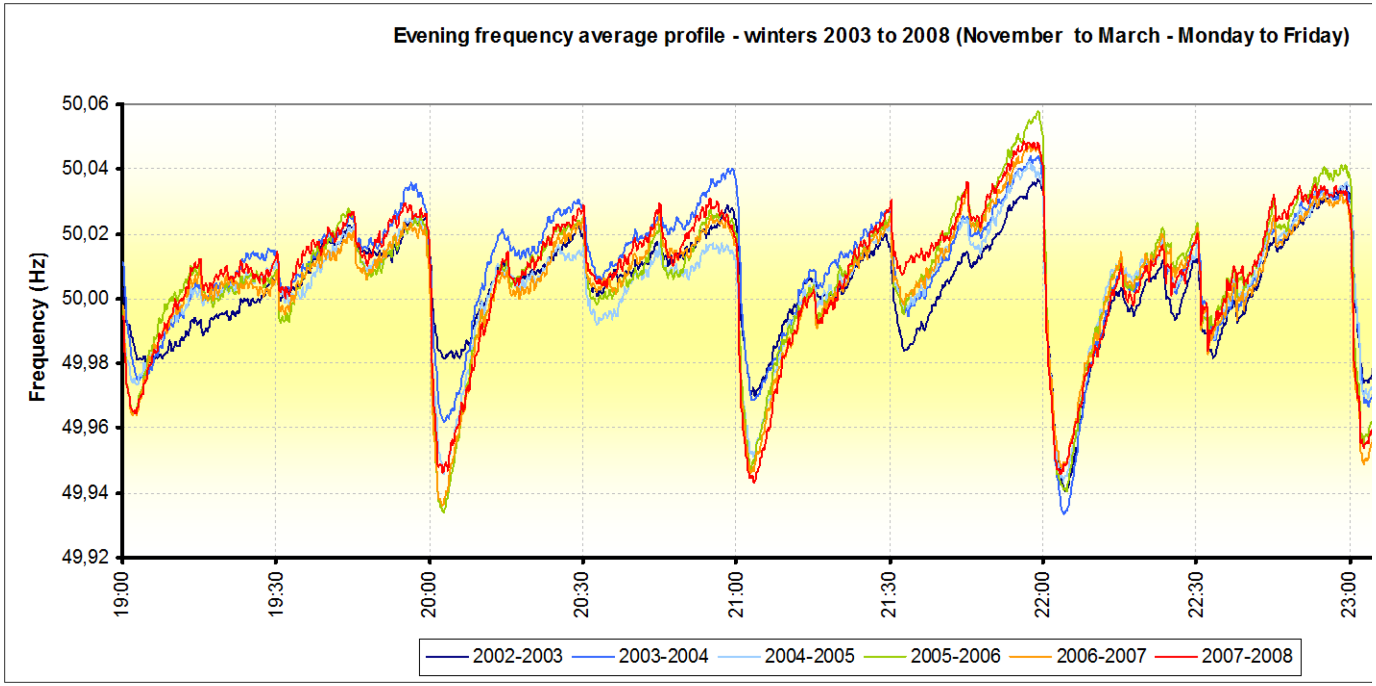
⇩

Reduktion der Schwungmasse des Systems

⇩

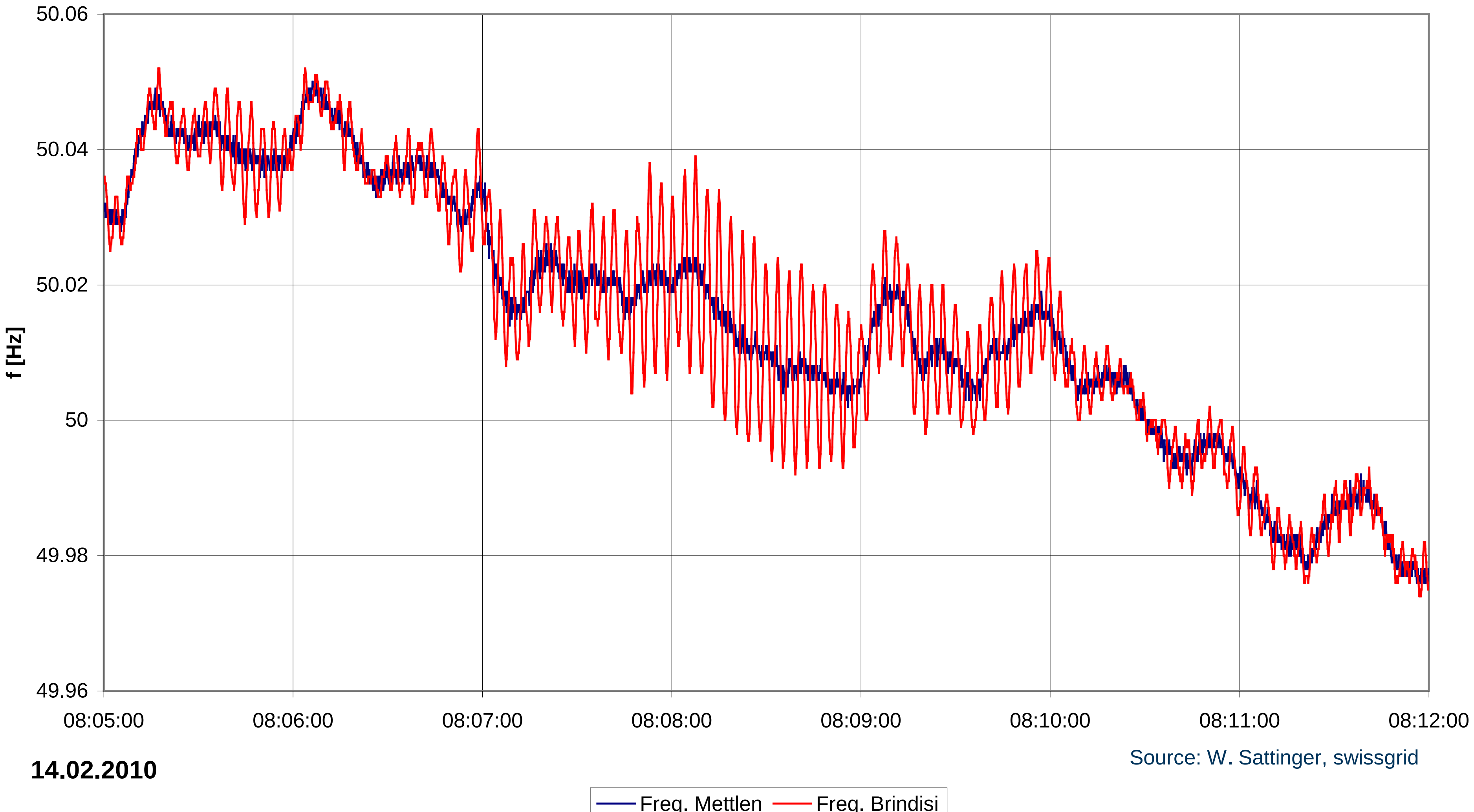
Die Frequenzstabilität wird gefährdet

Frequency Variations, 1



Source: W. Sattinger, swissgrid

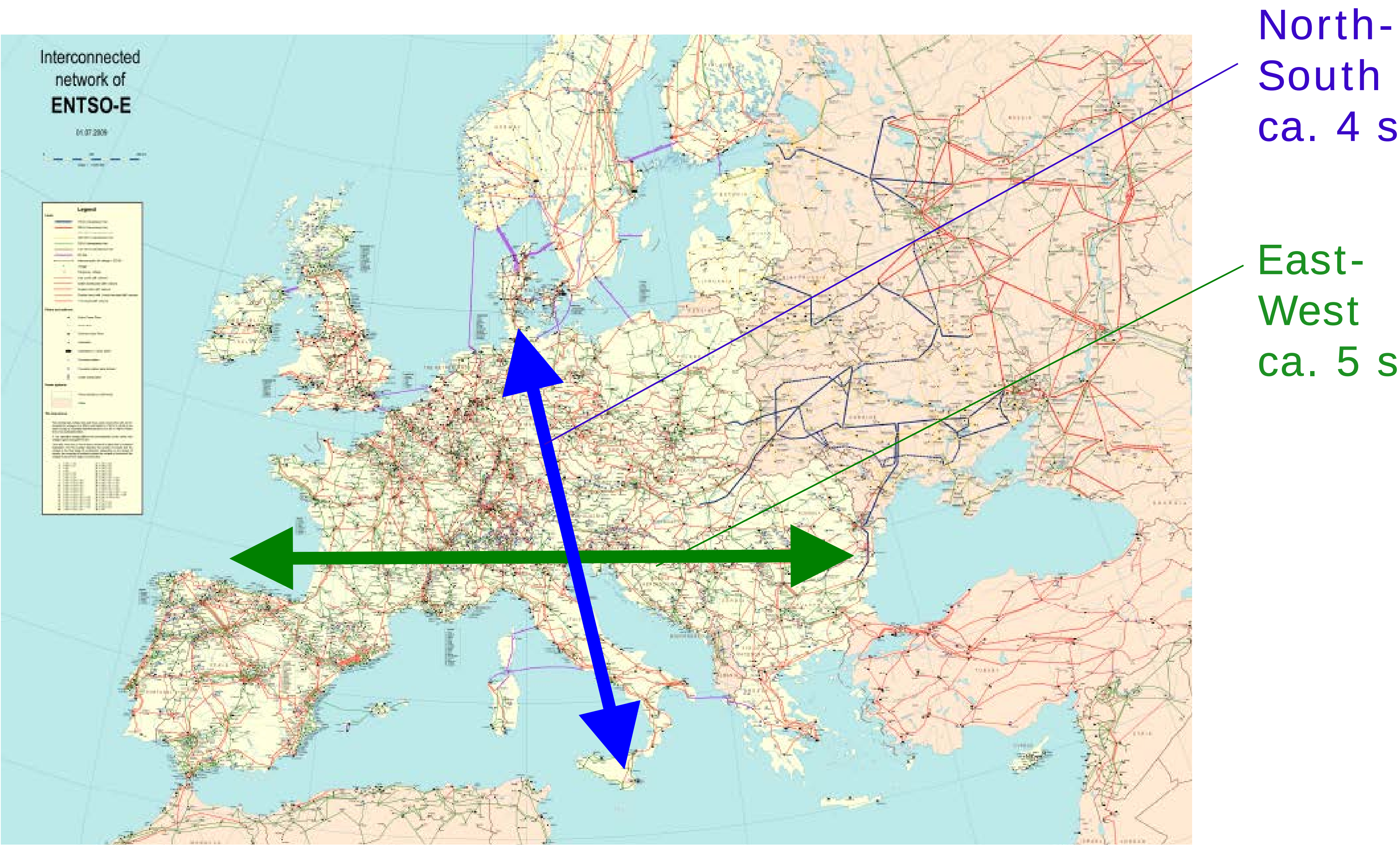
Oscillations in Multi-Machine Systems, 1



14.02.2010

Source: W. Sattinger, swissgrid

Oscillations in Multi-Machine Systems, 2



Source: W. Sattinger, swissgrid

AGENDA

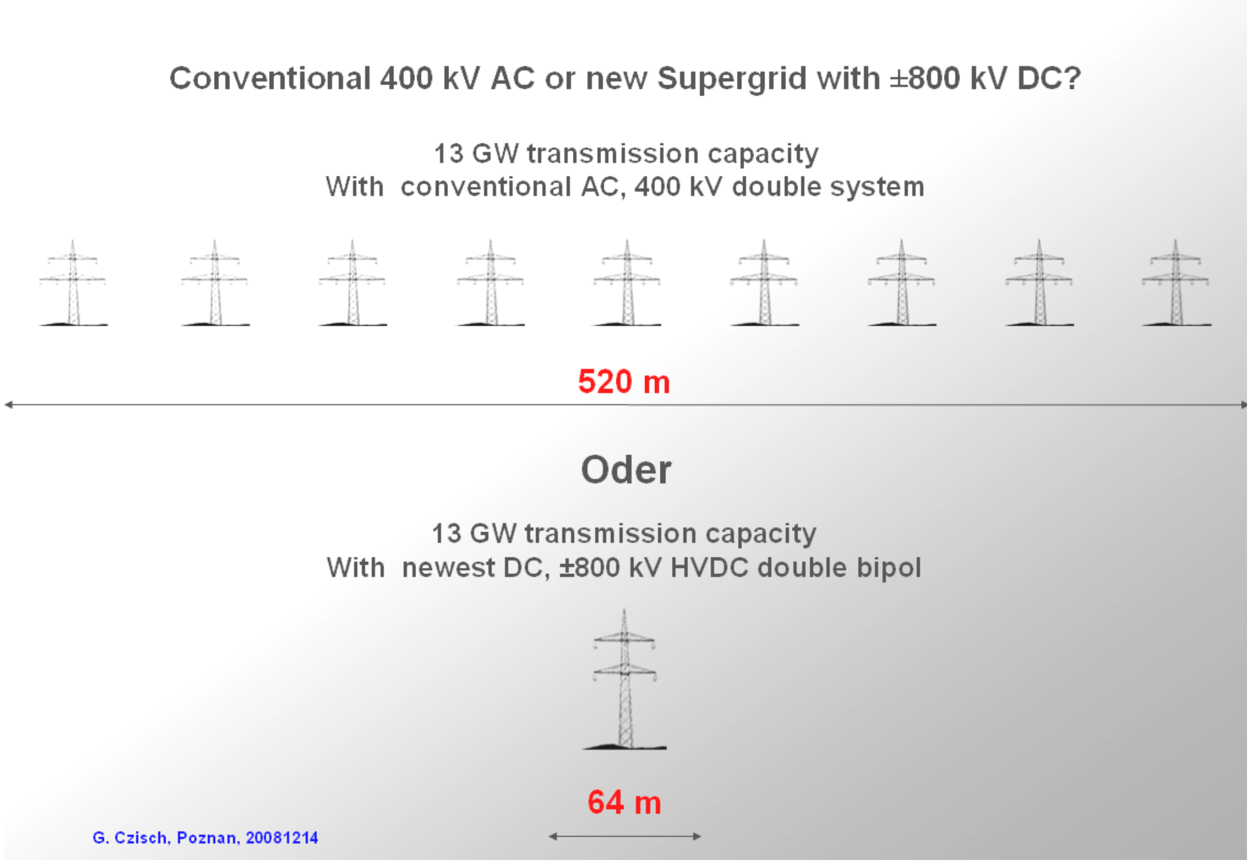
- Das Europäische Stromnetz
- Technische Herausforderungen
- Technische Lösungen
- Schlussfolgerungen

“General” Opinion:

High Voltage DC will be a important system component in
the future European Power Grid

Power flows can be controlled

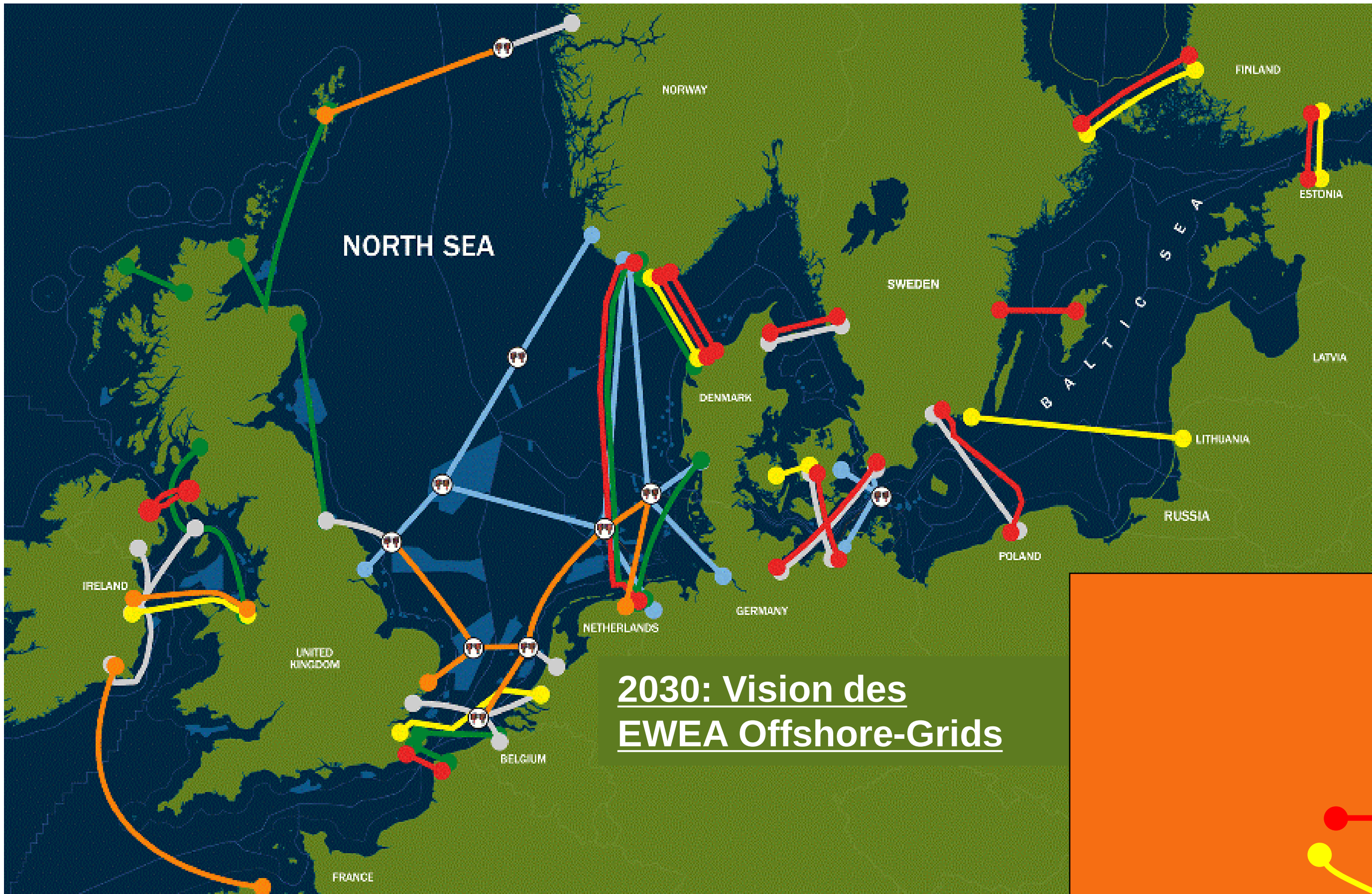
Upgrading the existing Grid – Sufficient to transport future Volumes?



A new transmission layer is essential to master the European energy challenges of the 21st century.

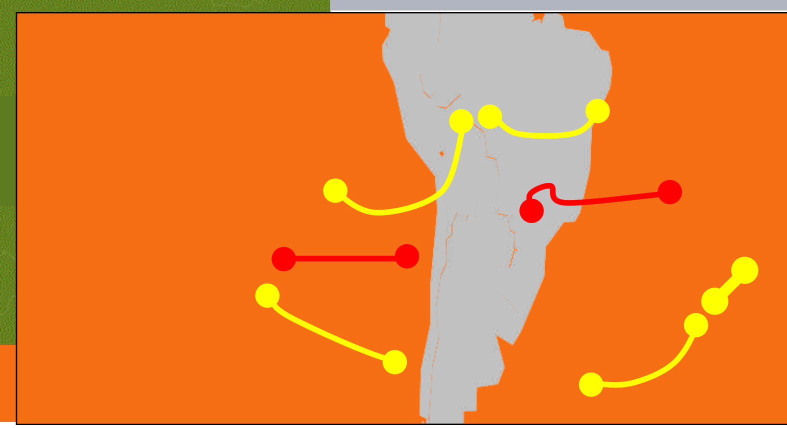
Source: T. Tillwicks, swissgrid

Plans and Visions, 1



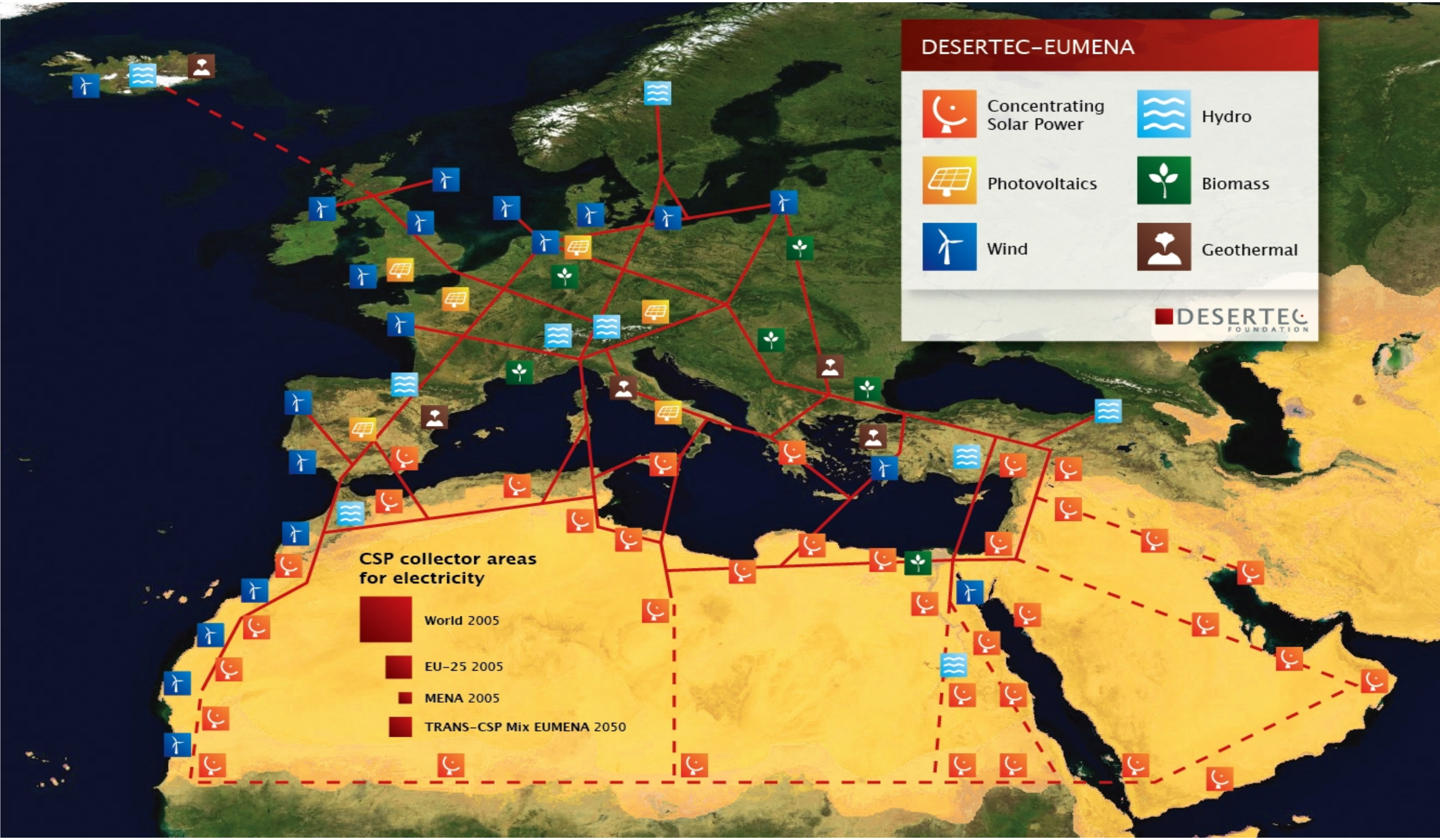
- In Betrieb 7.350 MW
- In Planung 4.950 MW
- Vorstudien 10.400 MW
- Vorstudien (mit EWEA-Empfehlung) 9.600 MW
- EWEA-Empfehlung 7.100 MW (2020)– 11.100 MW (2030)

2030: Vision des EWEA Offshore-Grids

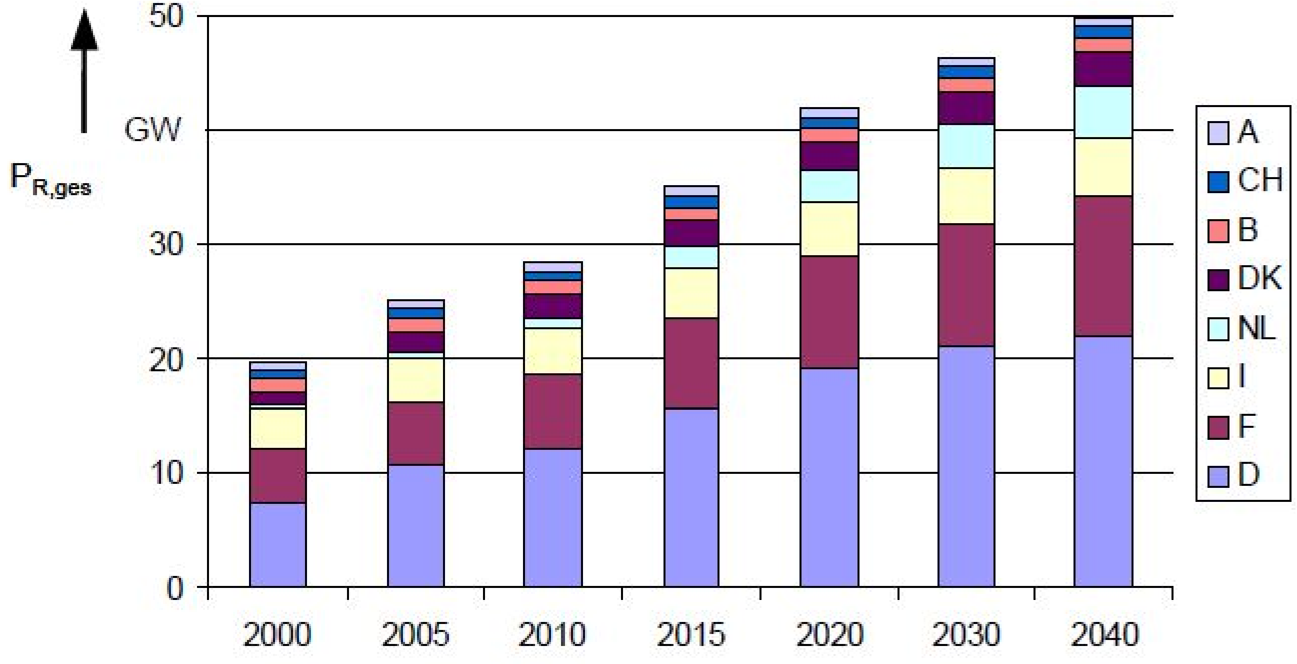


Investitionsvolumen über 13 Mrd. €

Plans and Visions, 2



Europe will need more Balancing Power



Figur 28: Aufteilung des Bedarfs $P_{R,ges}$ an Sekundär- plus Tertiärregelreserve auf die verschiedenen Staaten (Maximaler WEA-Zubau, σ_{err} = 12 %)

How provide it in a renewable

& cost-efficient way?

Not only new hardware is needed!

"Old structure"

Energy Flow

Generation → Transmission → Distribution → Consumer

Information Flow

Generation ← Consumer

"Future structure"

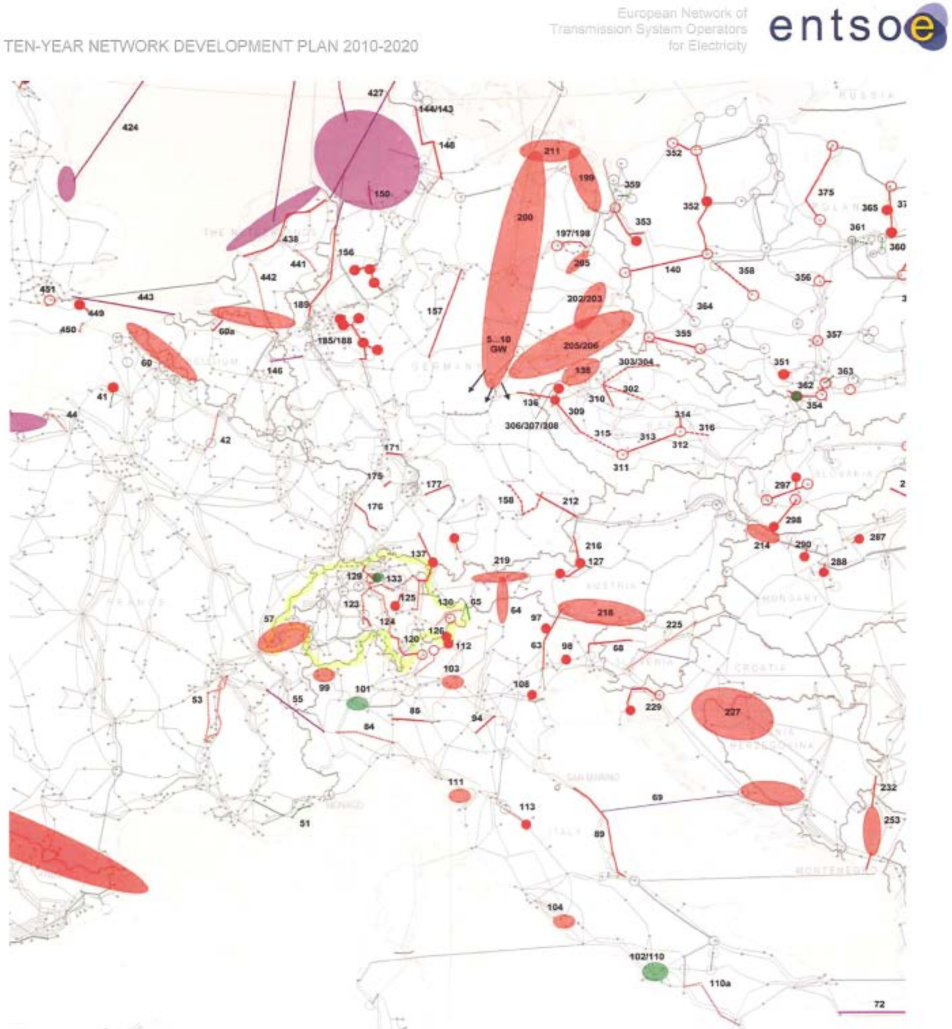
Energy Flow

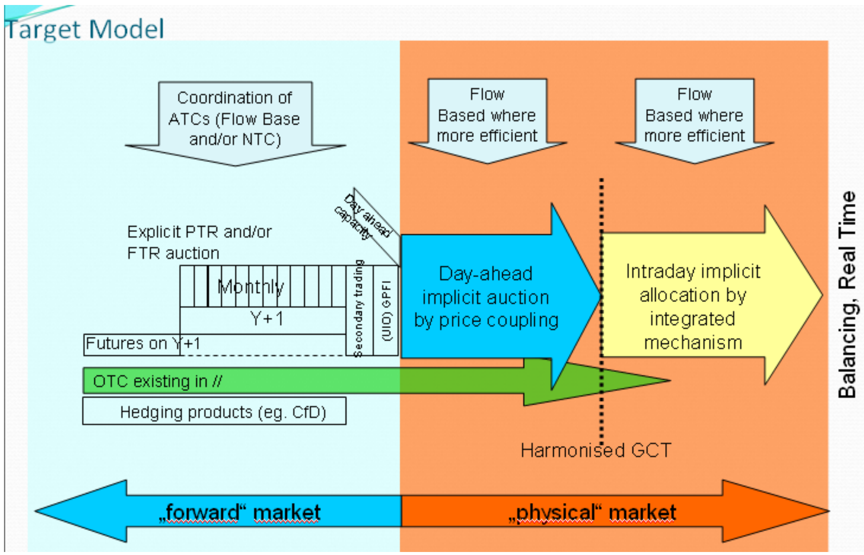
Generation ↔ Transmission ↔ Distribution ↔ "Prosumer"

Information Flow

Generation ↔ "Prosumer"

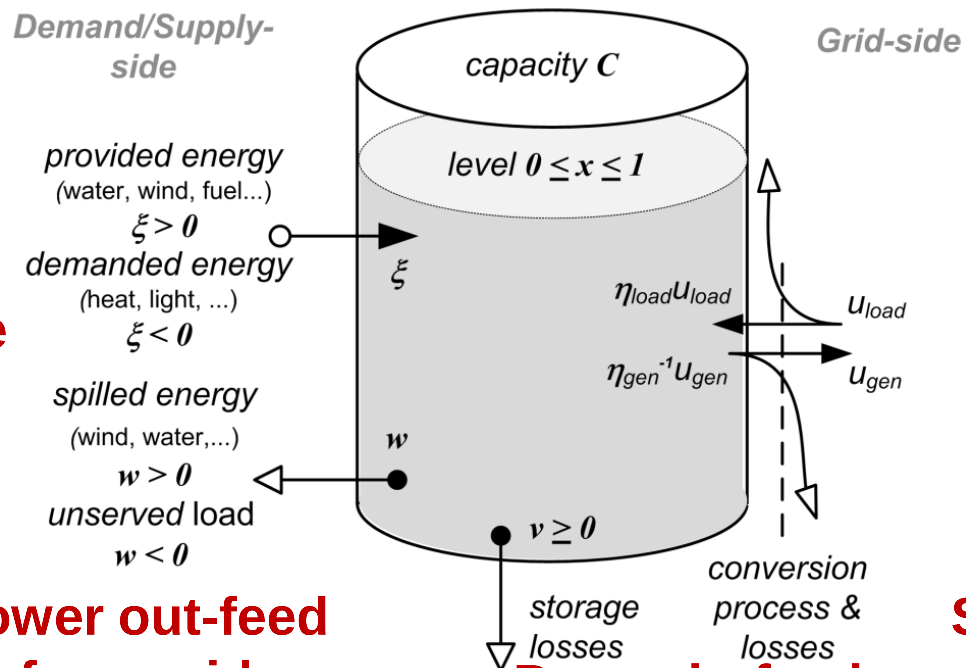
Connecting Generation with Demand & Storage – Extending the Grid & Integrating Markets





Forschung an der ETH Zürich

One Power Node



Storage capacity × state-of-charge

Power out-feed from grid

Power in-feed to grid

Internal losses

Shedding term

$$C_i \dot{x}_i = \eta_{load_i} u_{load_i} - \eta^{-1}_{gen_i} u_{gen_i} + \xi_i - w_i - v_i$$

Efficiency factors

Provided / demanded power

Examples of Power Node Definitions

General formulation: $C_i \dot{x}_i = \eta_{load_i} u_{load_i} - \eta_{gen_i}^{-1} u_{gen_i} + \xi_i - w_i - v_i$

Combined Heat/ Power Plant(CHP), Berlin-Mitte

- **Fully dispatchable generation**
- **no load, no storage (C)**
- **Fuel: natural gas ($\xi>0$)**

$$\eta_{gen_i}^{-1} u_{gen_i} = \xi_i$$

Offshore Wind Farm, Denmark

- **dispatchable generation, if wind blows (ξ) and energy waste term (w) non-zero**
- **no load, no storage (C)**
- **Fuel: wind power ($\xi>0$)**

$$\eta_{gen_i}^{-1} u_{gen_i} = \xi_i - w_i$$

Examples of Power Node Definitions

General formulation: $C_i \dot{x}_i = \eta_{load_i} u_{load_i} - \eta^{-1}_{gen_i} u_{gen_i} + \xi_i - w_i - v_i$

Hydro Pumped Storage, Germany

- Fully dispatchable generation (turbine) and load (pump)
- Constrained storage ($C \approx 8\ GWh$)
- Fuel: almost no water influx ($\xi \approx 0$)

$$C_i \dot{x}_i = \eta_{load_i} u_{load_i} - \eta^{-1}_{gen_i} u_{gen_i}$$

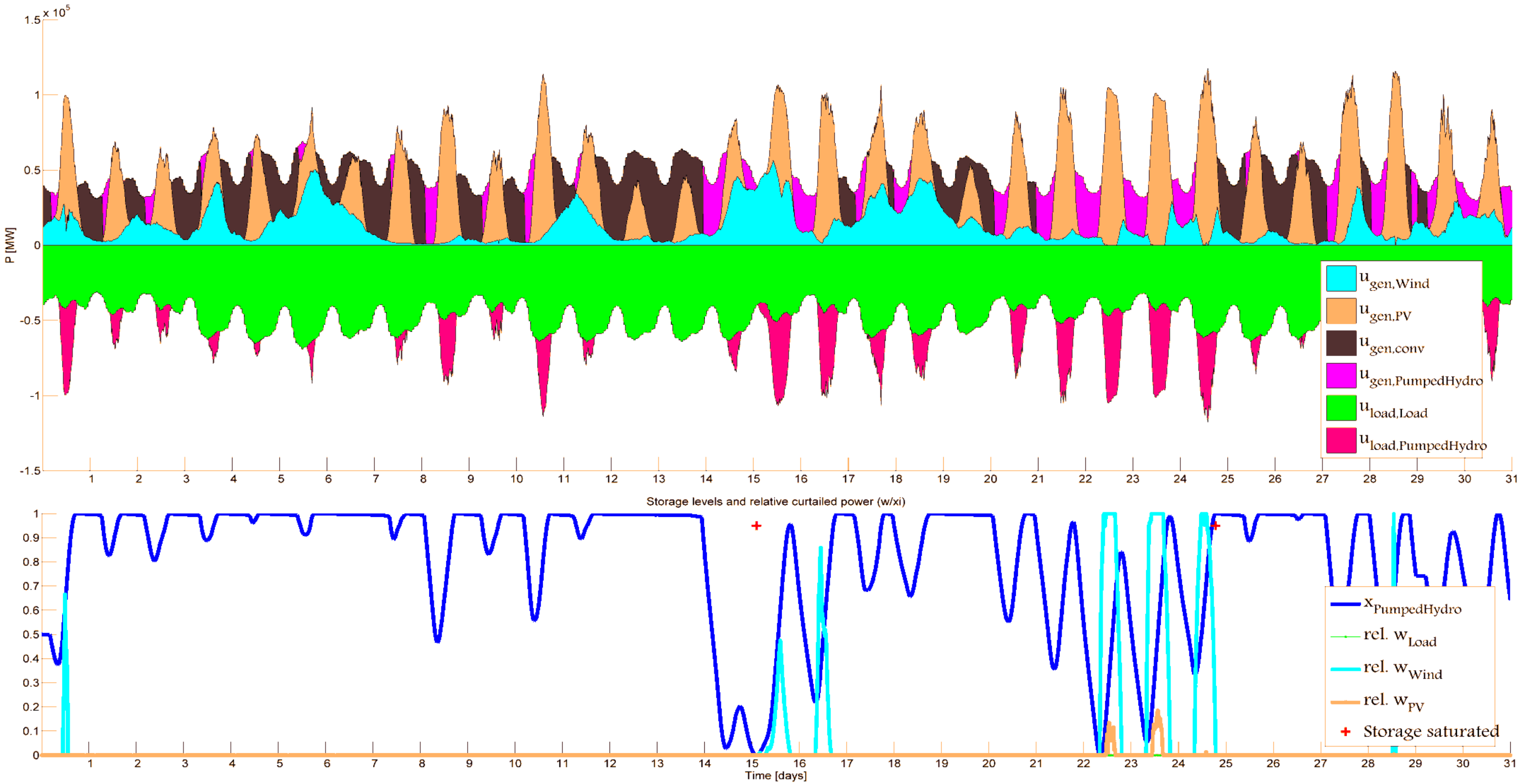
Emosson (Nant de Drance), Switzerland

- Fully dispatchable generation, but no load (pump)
- large storage ($C \approx 1000\ GWh$)
- Fuel supply: rain and snow melting ($\xi >> 0$)

$$C_i \dot{x}_i = -\eta^{-1}_{gen_i} u_{gen_i} + \xi_i$$

Variants: modelling of hydro cascades (time-delay of water flow between stages).

- **Optimal predictive power dispatch (Germany, high PV)**
- **$T_{pred.}$ = 72h, $T_{upd.}$ = 4h, T_{sample}=15min.**
- **Simulation Period: May 2010 (30% Wind, 50% PV, no DSM)**



- **Evaluation of balance terms (May 2010)**
- **Case: 30%Wind, 50% PV, no DSM**

Balance Term	Value [GWh]
Electricity consumed by loads	36450.0
Electricity produced by conv. generator	9482.4 (≈48%)
Wind generation – fed into grid	10062.8
Wind generation – curtailed	**872.6**
PV generation – fed into grid	18111.9 (≈248%)
PV generation – curtailed	**113.1**
Warm-water heater – Load	not available
Pumped hydro storage – Generation	4810.1 (≈424%)
Pumped hydro storage – Load	6017.2 (≈496%)

AGENDA

- Das Europäische Stromnetz
- Technische Herausforderungen
- Technische Lösungen
- Schlussfolgerungen

Challenges ahead

- Technical challenge = TSOs and ENTSO-E
- Economic challenge = Market players
- Regulatory challenge = NRAs and Agency
- Conceptual challenge = Technical + Economic + Regulatory challenges
- Political challenge = EU, Governments and Citizens

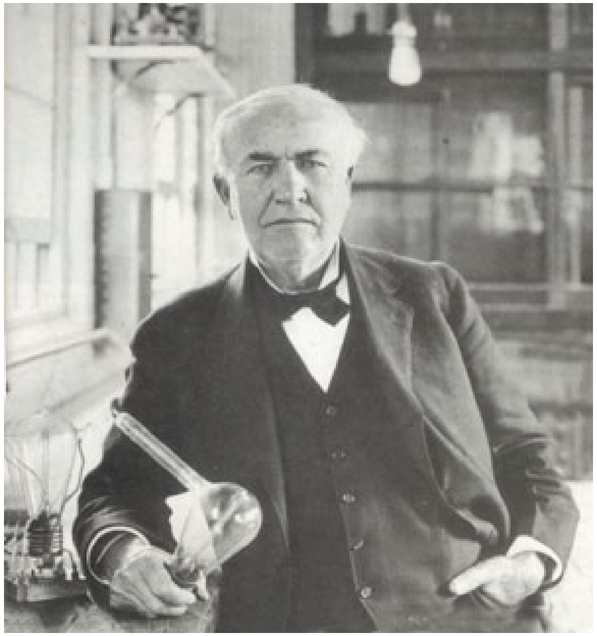
Ein sicheres elektrisches Energiesystem mit hohem Anteil neuer erneuerbarer Energiequellen ist ohne Komfortverlust möglich

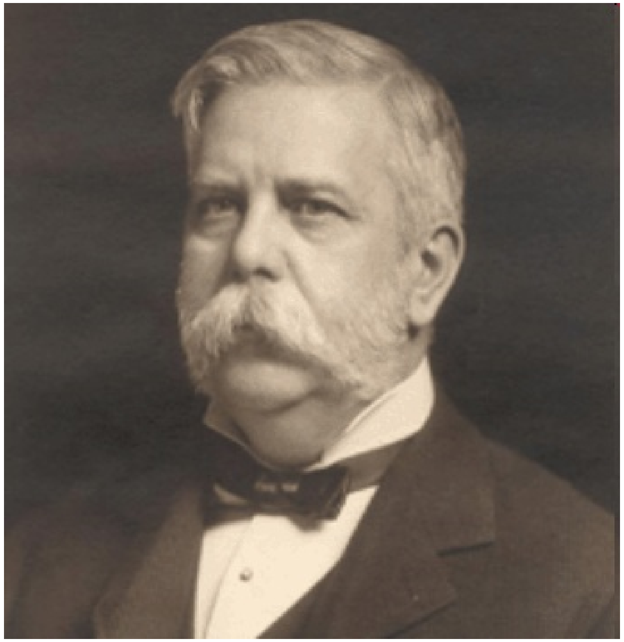
Aber wir brauchen:

- einen starken Ausbau von Kurz- und Langzeitspeicher
- ein flexibles Netz und intelligente Netzführung
- noch bessere Prognosemodelle (auf lokaler Ebene)

The history of the electric power system

In the beginning was Edison (DC)





Then Westinghouse (Tesla) took over (AC)

In the future electric power system they will / must co-exist

Fragen?