Modellierung zukünftiger auf Erneuerbaren Energien basierender Stromversorgungssysteme

Stefan Weitemeyer, David Kleinhans, Thomas Vogt, Carsten Agert

Herbstsitzung des AK Energie der DPG, Bad Honnef

15. November 2013

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

NEXT ENERGY: Energy Research for the Future

NEXT | ENERGY

EWE-Forschungszentrum für Energietechnologie e.V.

- Founded in 2007 as an **independent Research Institute** at the University of Oldenburg (D)
- About **100 employees** in R&D and admin.
- Research in the fields of **Fuel Cells, Energy Storage, Thin-film PV** and **Energy Systems**

www.next-energy.de

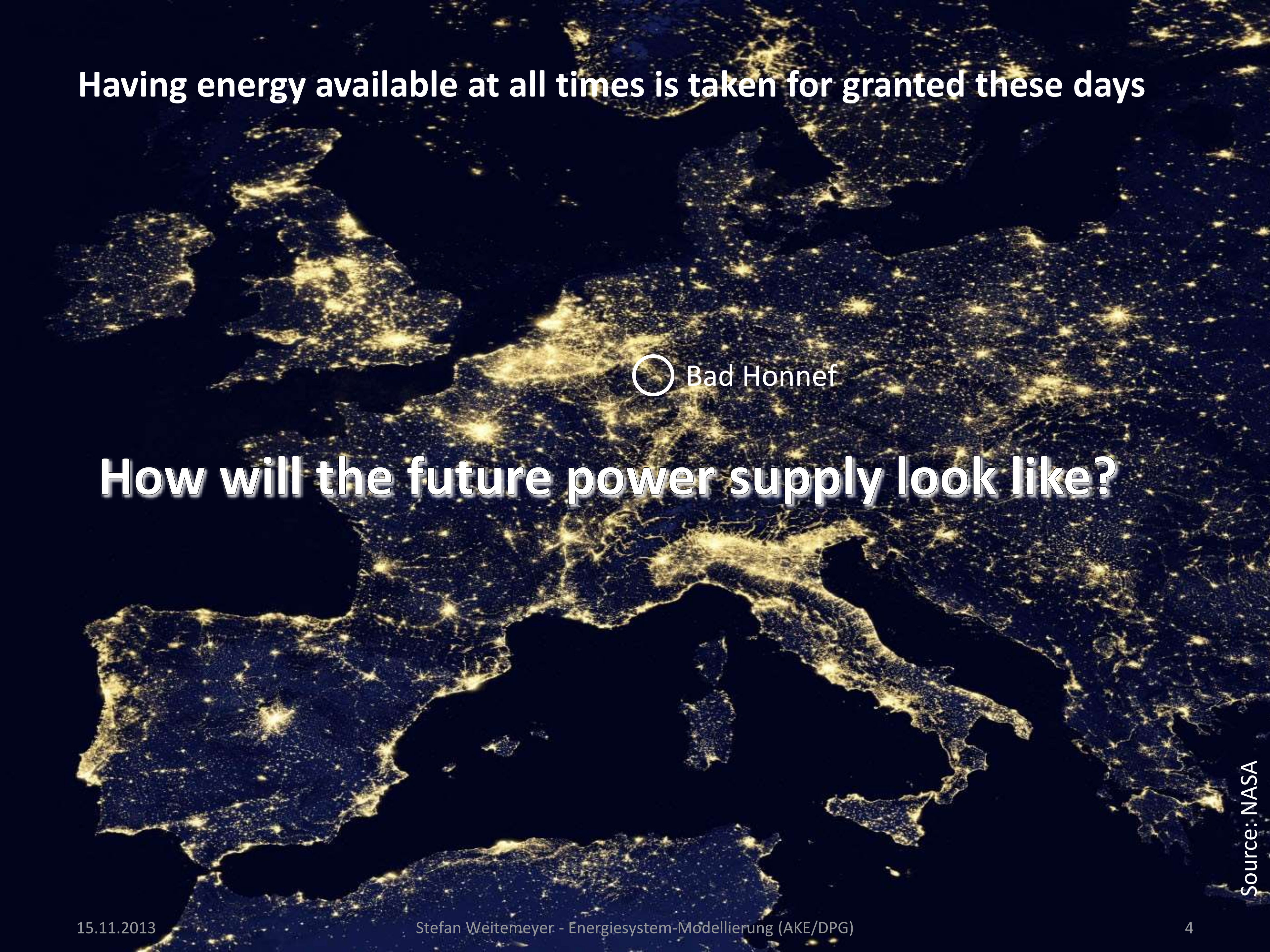
Modellierung zukünftiger auf Erneuerbaren Energien basierender Stromversorgungssysteme

Stefan Weitemeyer, David Kleinhans, Thomas Vogt, Carsten Agert

Herbstsitzung des AK Energie der DPG, Bad Honnef
15. November 2013

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Having energy available at all times is taken for granted these days

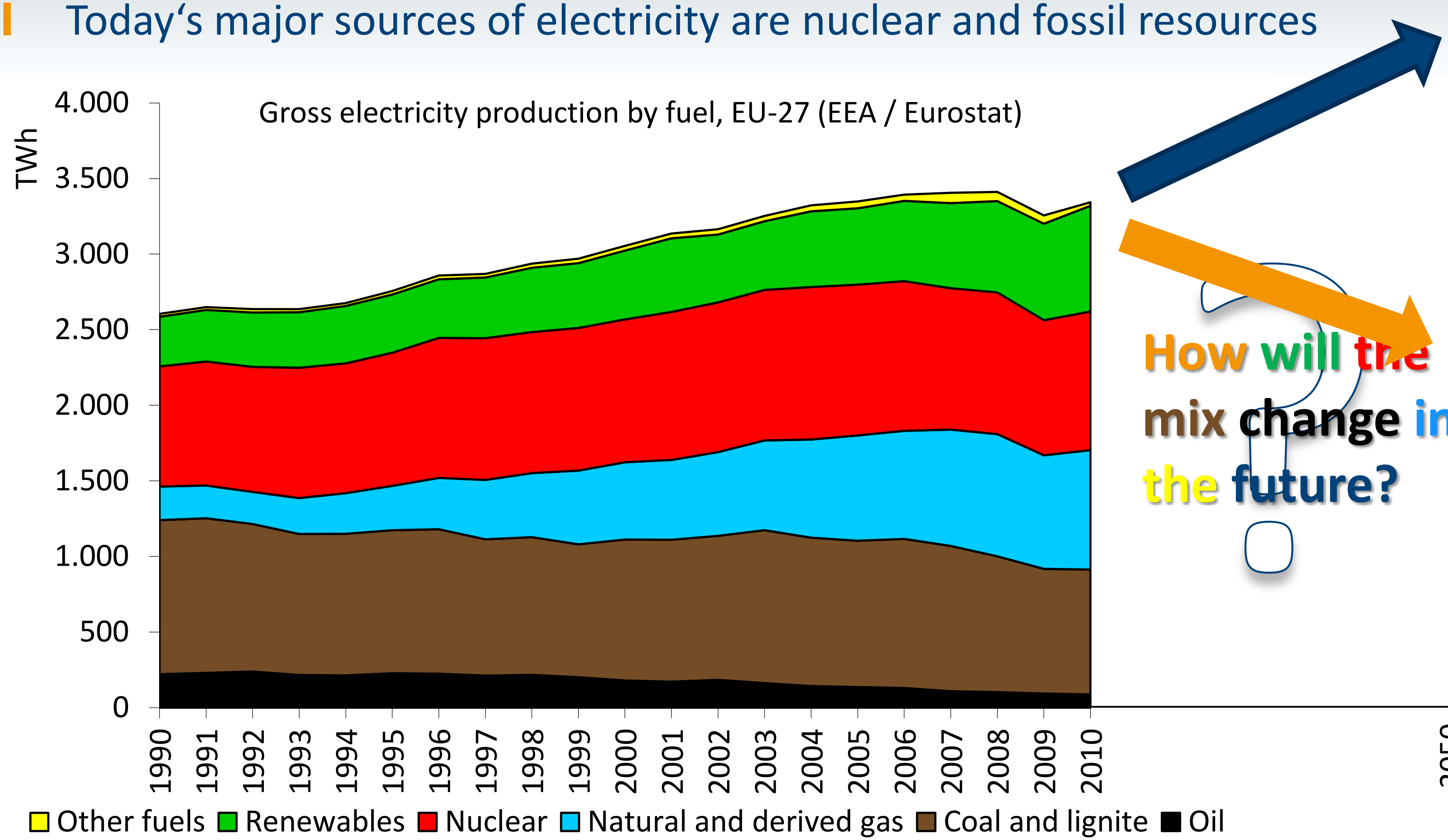


How will the future power supply look like?

Today's Power Supply System

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Today's major sources of electricity are nuclear and fossil resources



The Future is …

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Coal is cheap & sufficiently available

But: CO_2 emitting

Source: Stern/DPA

NEXT ENERGY

EWE-Forschungszentrum für Energietechnologie e.V.

The Future is …

Nuclear power is cheap and CO_2-free

But: increasing safety requirements & waste-problem unsolved

Source: Cryptome

The Future is …

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

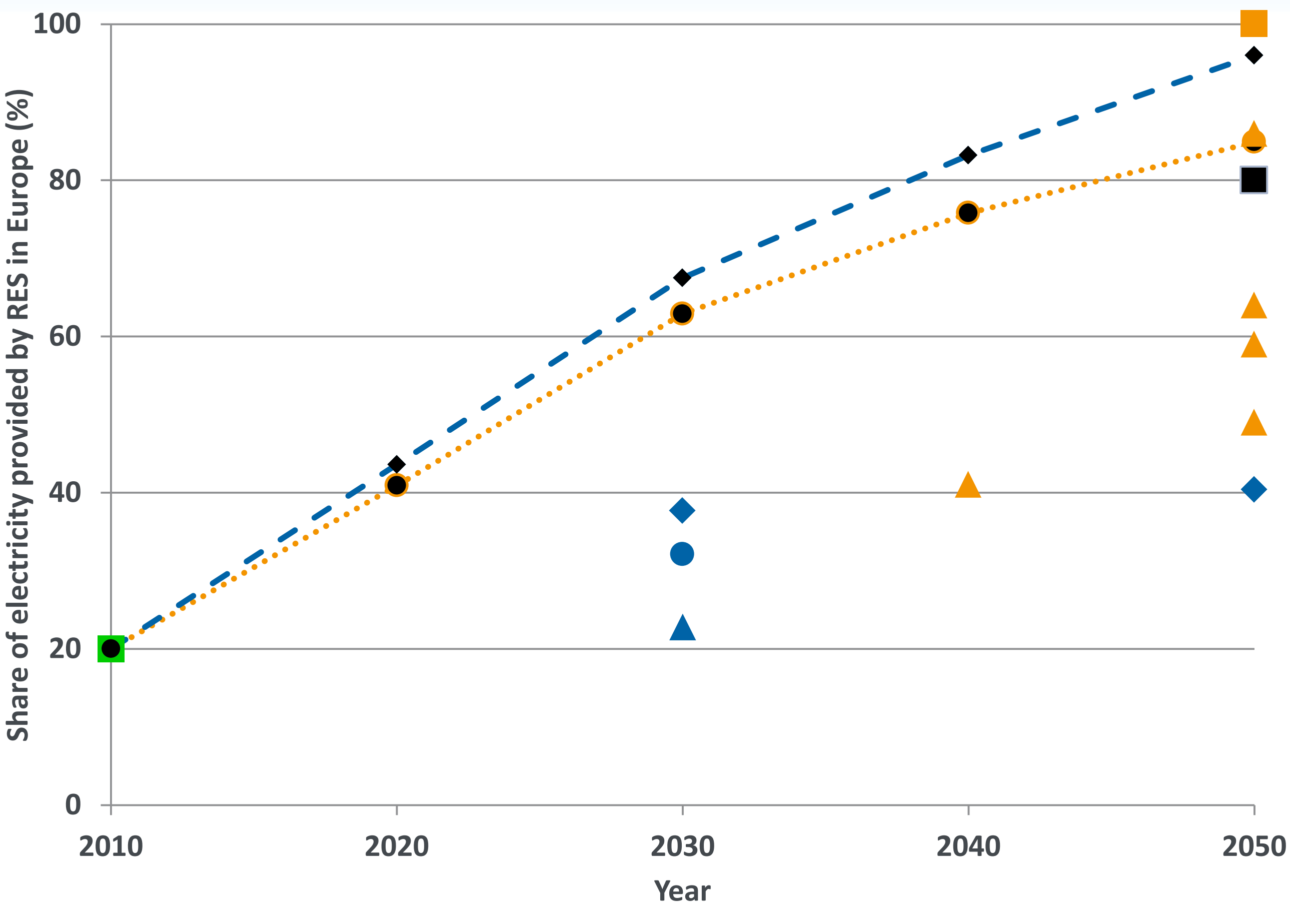
Renewable Energy is CO_2-free and might be even cheaper

But: depends on weather

Source: Renewable Energy Installer / iStock

Renewable Energy Sources

What is the potential for integration of Renewable Energy Sources?



100% by 2050: ■
- RE-thinking (EREC)
- 100% renewable electricity (PWC)
- Pathways towards a 100 % renewable electricity system (SRU)

41% by 2040: ▲
- The Outlook for Energy - A View to 2040 (ExxonMobil)

85% by 2050: ●
- Long-term scenarios and strategies … (DLR/IWES)

23% by 2030: ▲
- EU energy trends (EC, 07)

32% by 2030: ●
- EU energy trends (EC, 09)

Renewable Energy Sources

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- High share of RES: Power production depends on weather

- Upcoming issues with large-scale integration of RES
  - Technological issues, e.g.
    - Voltage stability, balancing power
    - Reactive Power
    - Black-start capability
  - Economic issues, e.g.
    - Current increase in electricity prices
    - Large-scale investments in grids needed to connect RES

- Numerous tools available to study different aspects of RES integration
  - David Connolly et al, Applied Energy **87** (2010) 1059–1082

Renewable Energy Sources

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Transformation of the European Power System

- Significant changes in the way we produce and consume energy
- Production by RES is driven not any more by consumer but by the weather
- Many energy-producing consumers (*prosumers*)

Renewable Energy Sources

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Conceptual issues:

- How should our future power supply system look like to guarantee a stable, reliable and cheap supply of electricity for everyone?

- How can we study our prospective energy system?

Renewable Energy Sources

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

EU scenarios

RE portfolio

Electricity demand

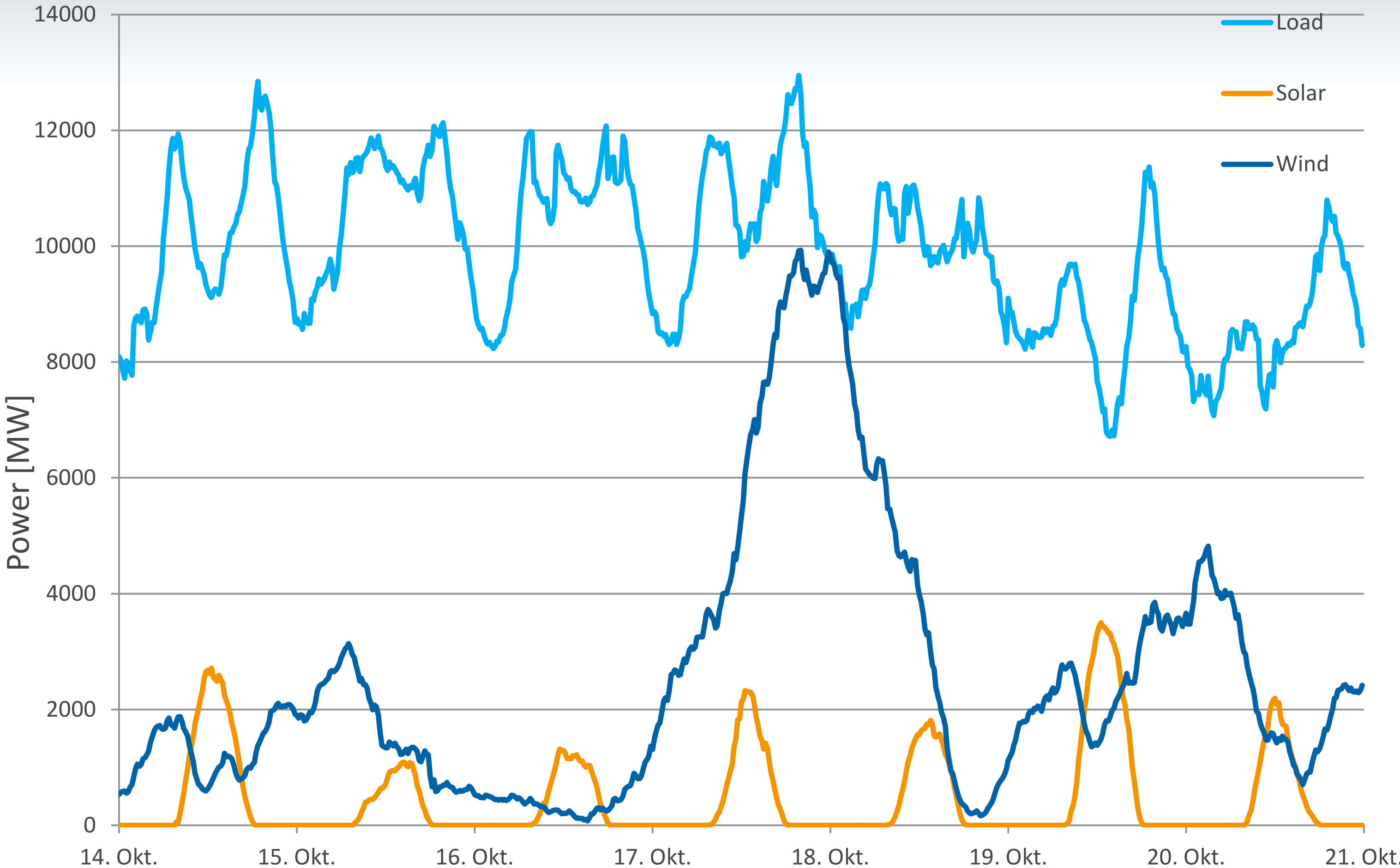
Energy balance

Long-term
meteorological data

Source T. Feck, Presentation in Bosch-Forschungs-Kolloquium, 17.03.11

Renewable Energy Sources

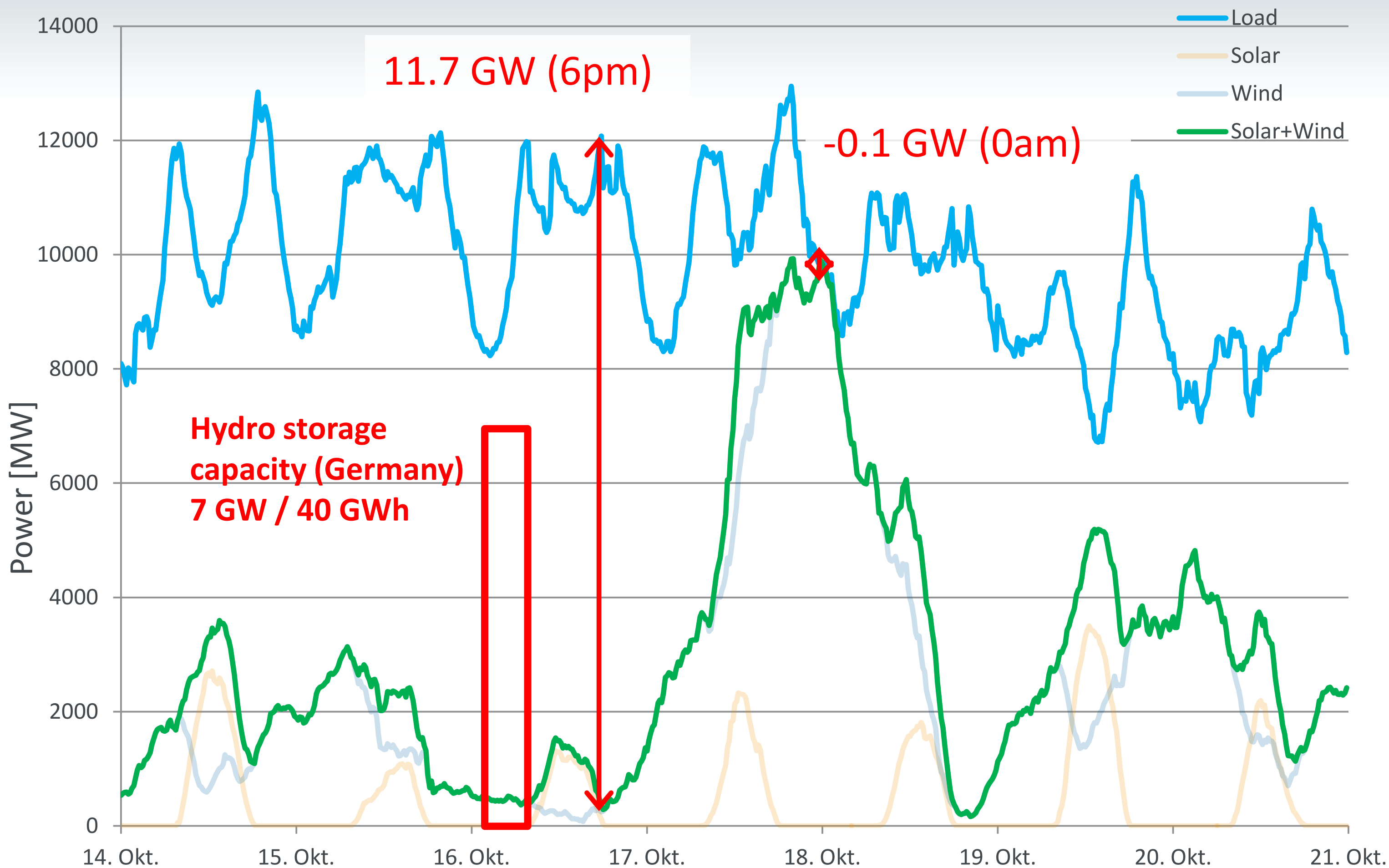
NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.



Data source: www.50Hertz.com, Kennzahlen, 21.10.2013; Image: Wikipedia, Regelzone

Renewable Energy Sources

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.



Data source: www.50Hertz.com, Kennzahlen, 21.10.2013; Image: Wikipedia, Regelzone

Storage

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Storage

Source: Vattenfall

Storage

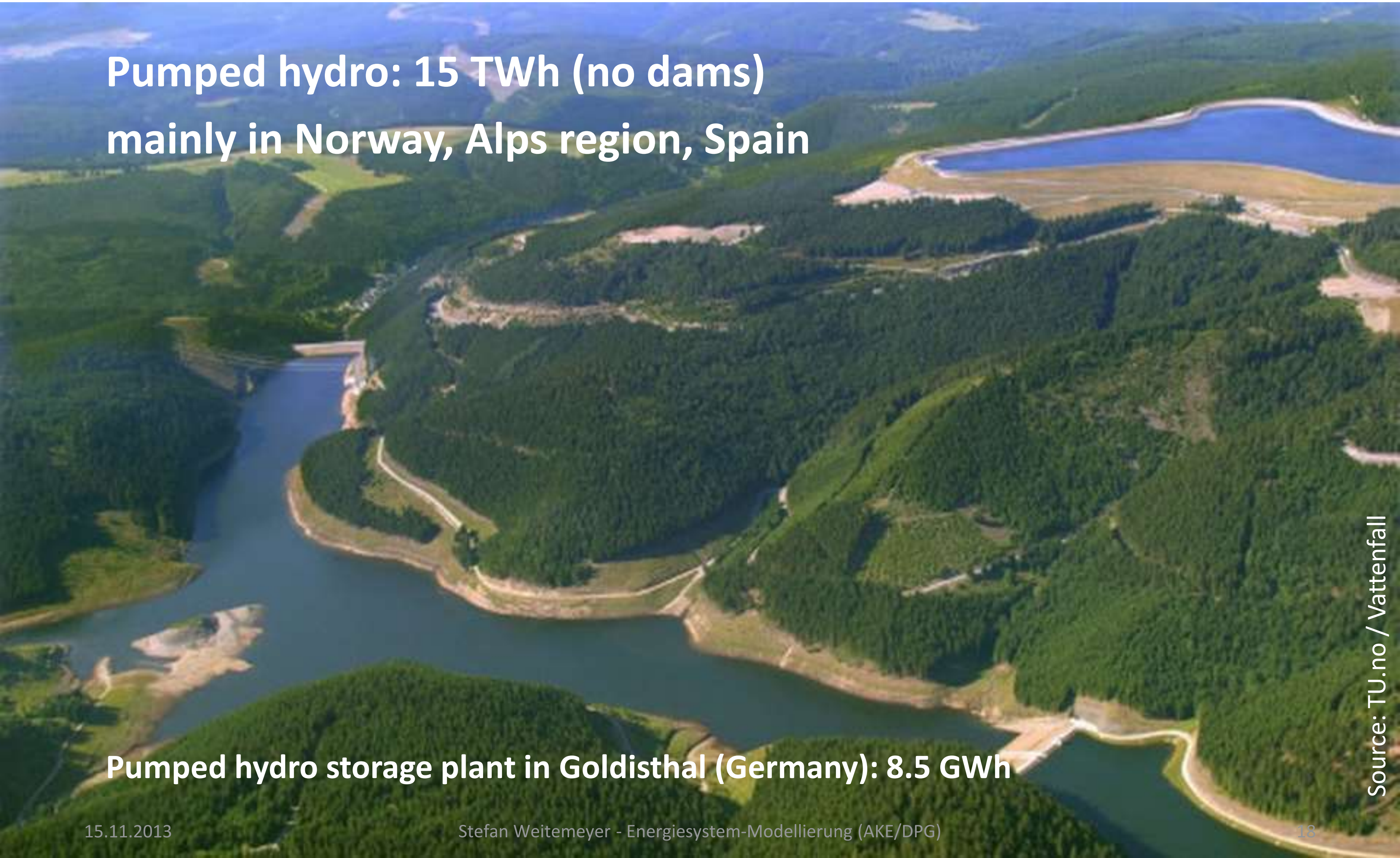
- Days of calm and “darkness” need to be bridged

- Europe
  - 500 million people
  - 215 million households
  - Power consumption: 3500 TWh per year today (+50%? in 2050)

Storage

Pumped hydro: 15 TWh (no dams)

mainly in Norway, Alps region, Spain



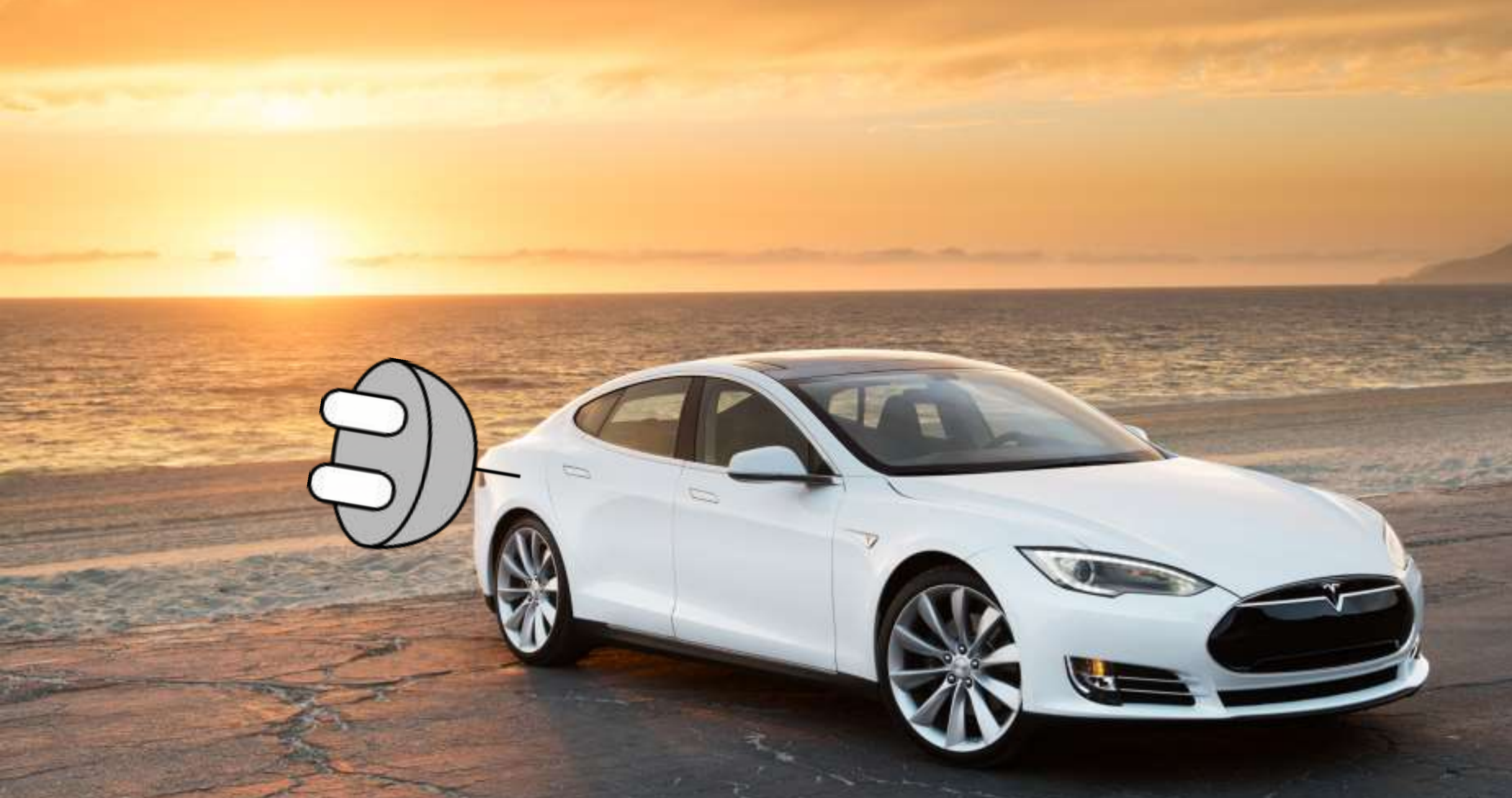
Pumped hydro storage plant in Goldisthal (Germany): 8.5 GWh

Source: TU.no / Vattenfall

Storage

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

One electric car (85kWh) per household: 19 TWh



Source: Tesla Motors

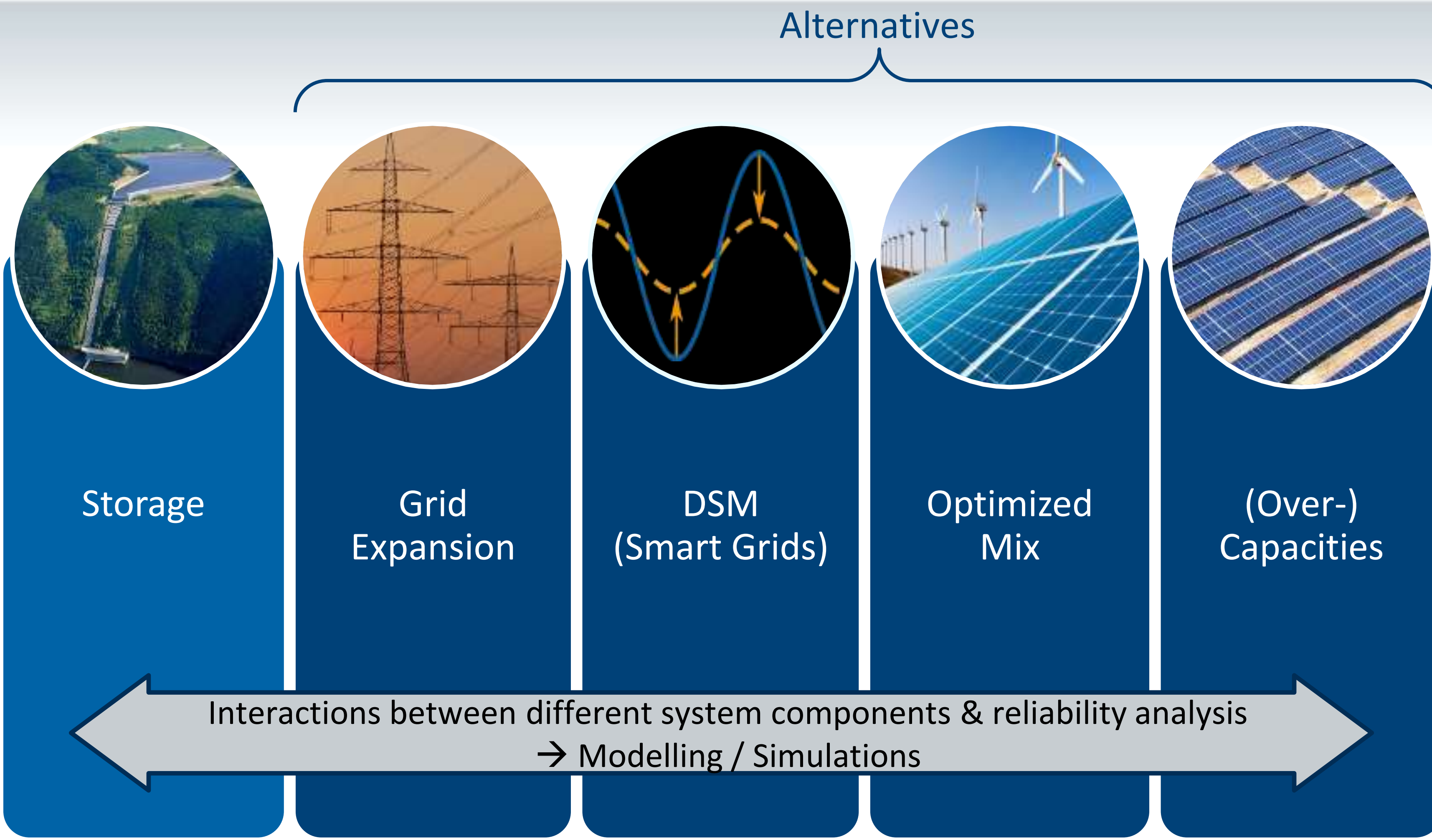
Storage – Chemical storage can provide seasonal storage

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Salt caverns in Europe: 32 TWh (hydrogen)

Source: KBB / Günter Radke

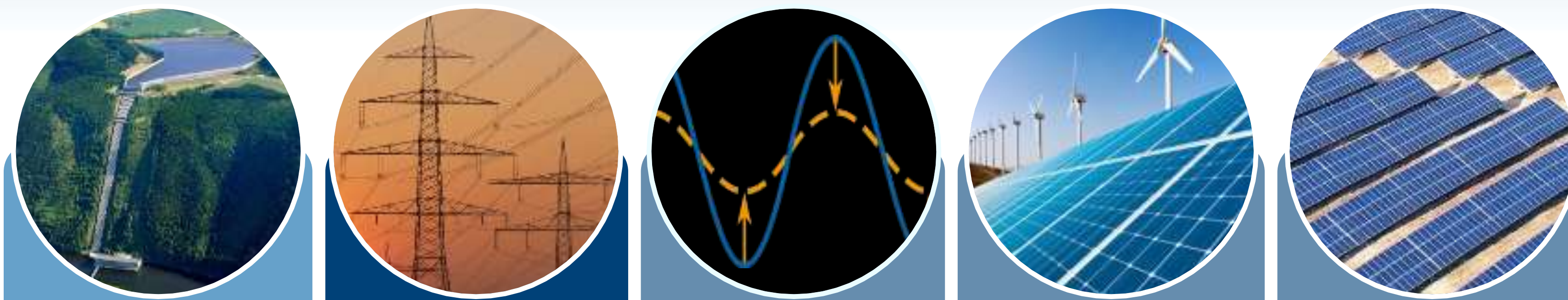
Storage – and Alternatives



Source: Vattenfall, Pitopia, Siemens

Grid Expansion

Alternatives



Storage	Grid Expansion	DSM (Smart Grids)	Optimized Mix	(Over-) Capacities

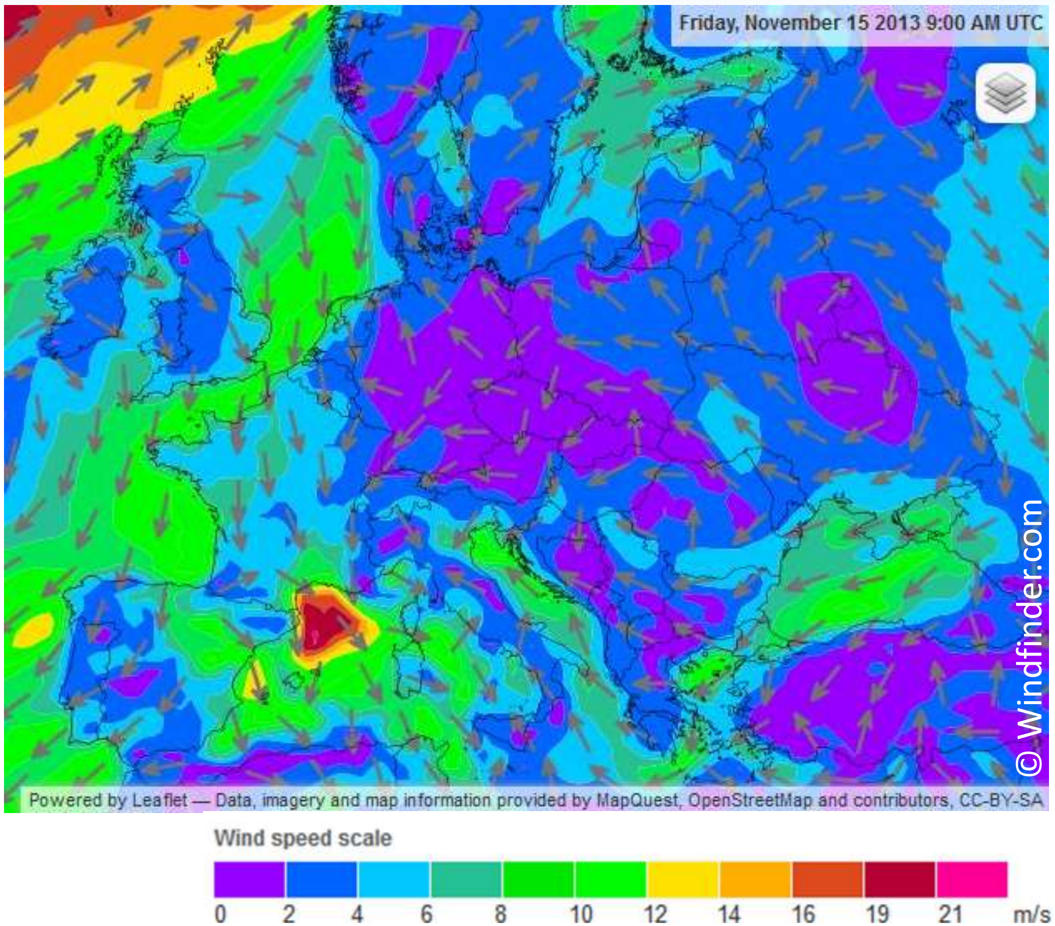
Source: Vattenfall, Pitopia, Siemens

Grid Expansion

NEXT ENERGY

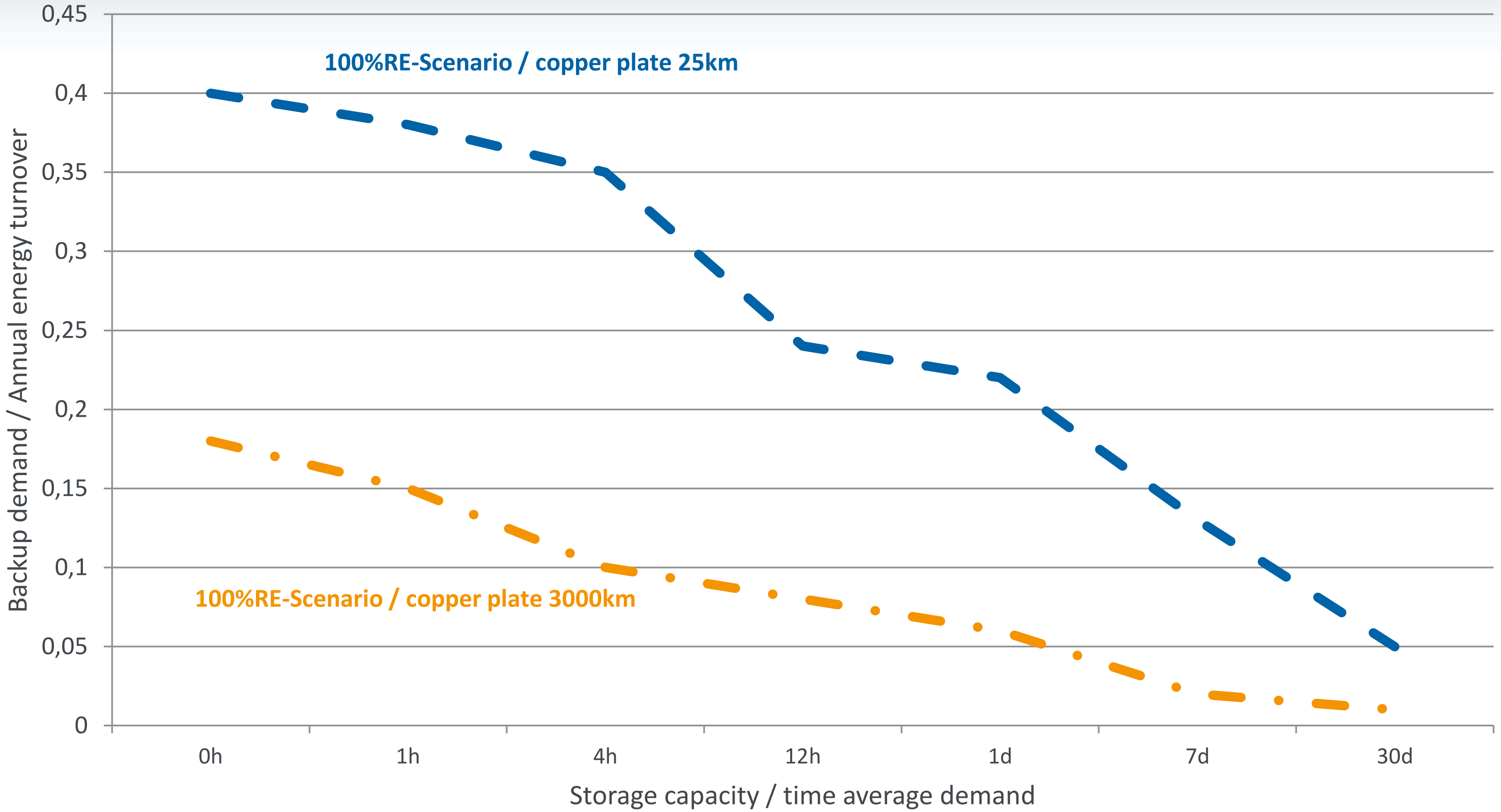
EWE-Forschungszentrum für Energietechnologie e.V.

Grid expansion allows for balancing production and load over larger distances



Grid Expansion: reduces need for storage / backup devices

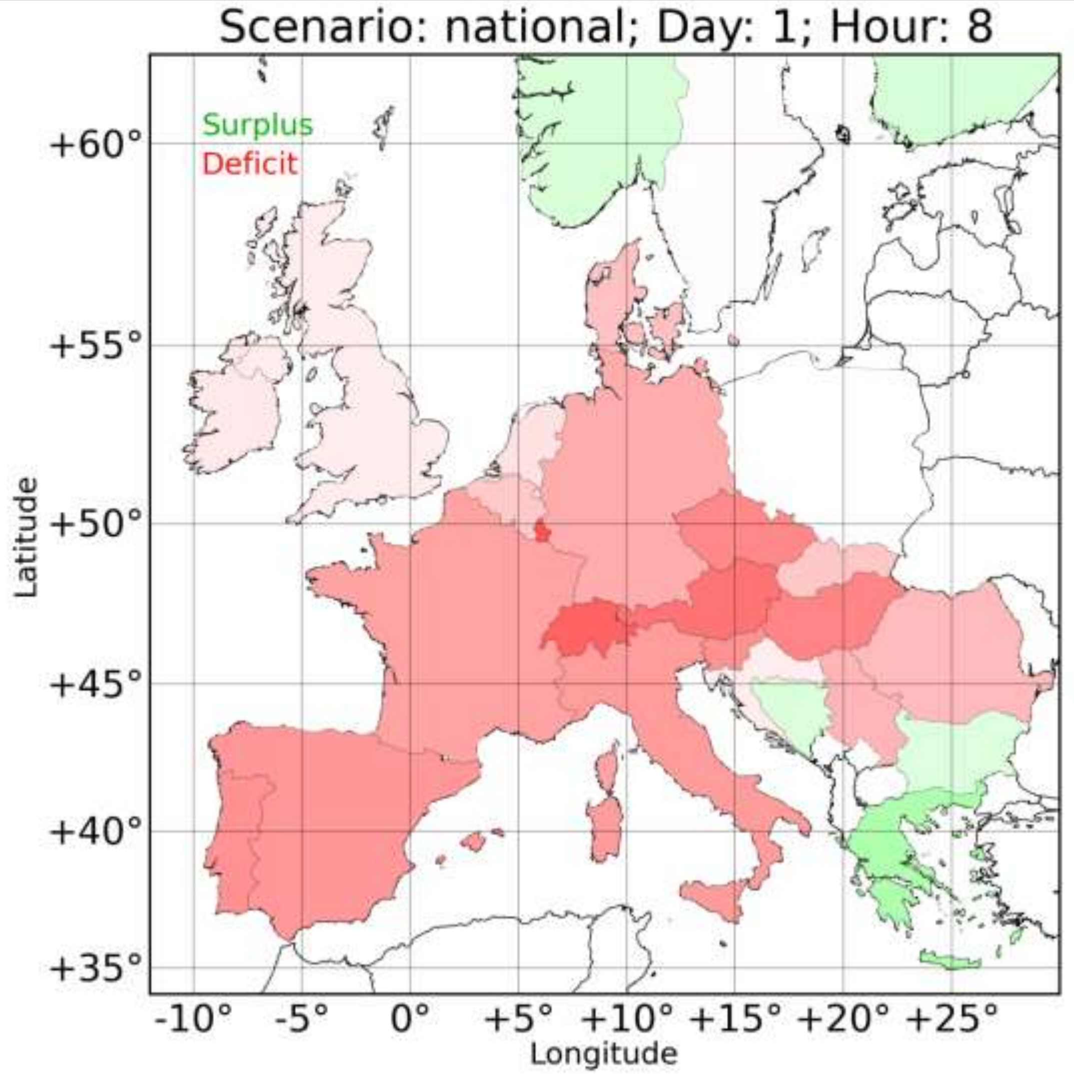
NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.



Data source: Steinke et al, Renewable Energy **50** (2013)

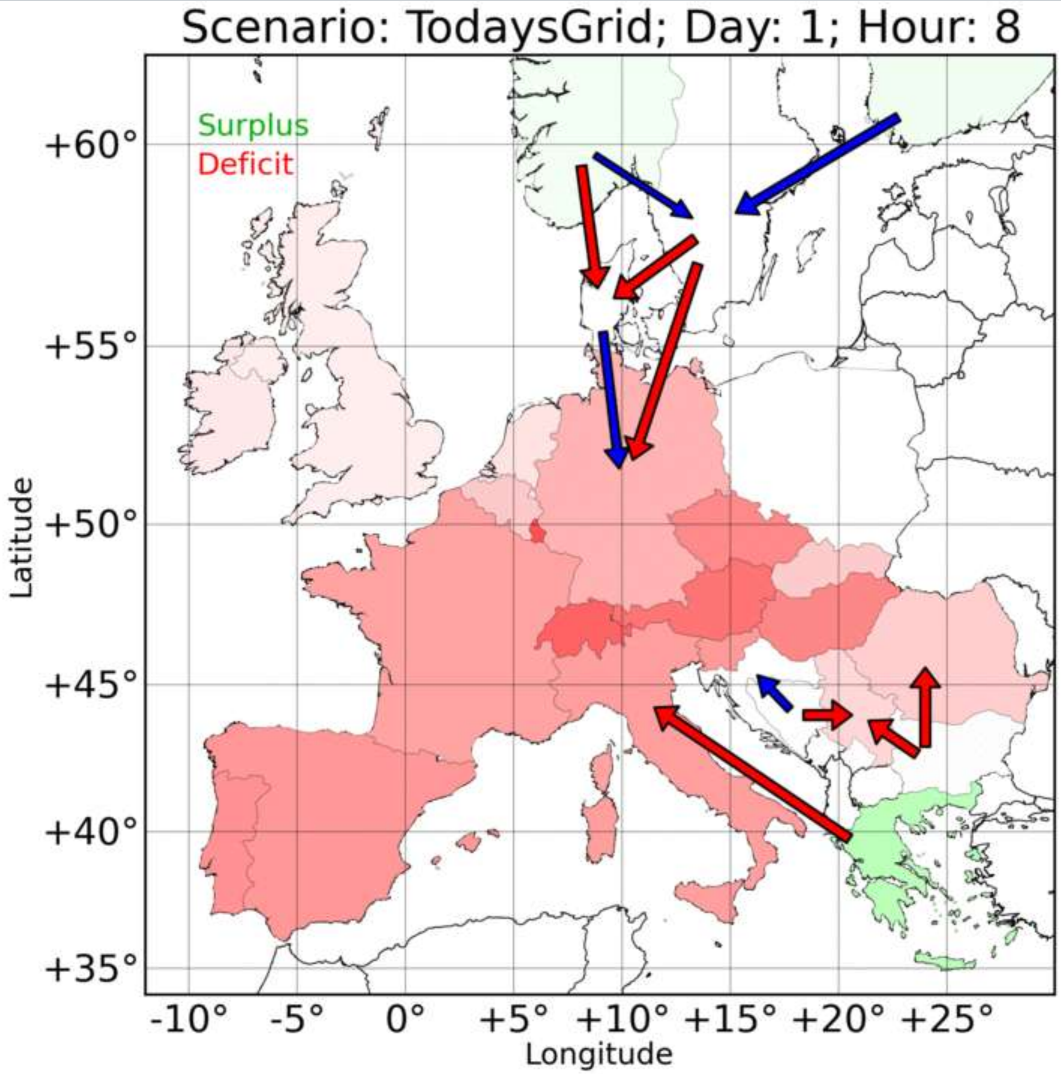
Grid Expansion: No interconnectors

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.



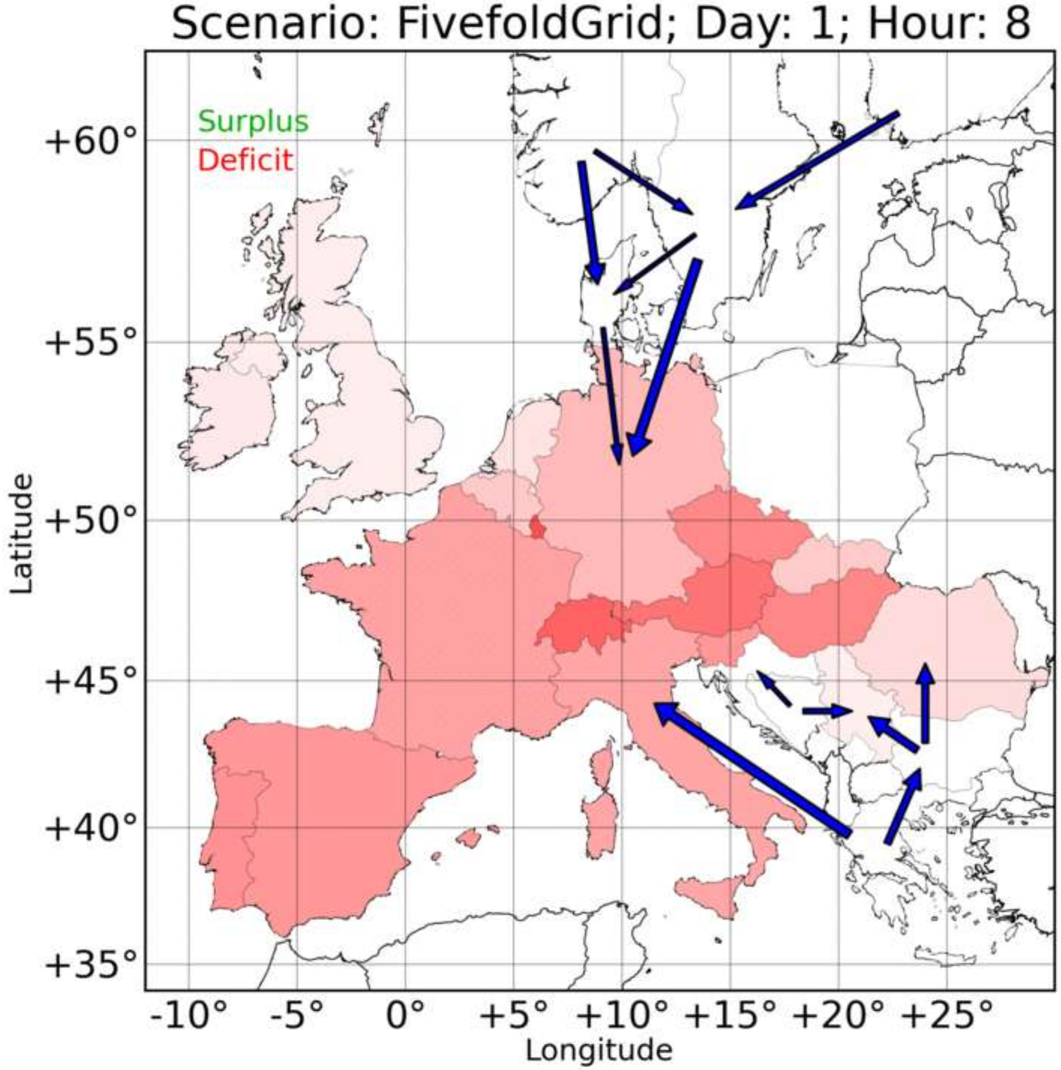
NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Grid Expansion: Today's interconnection capacities



Grid Expansion: Extended interconnection capacities

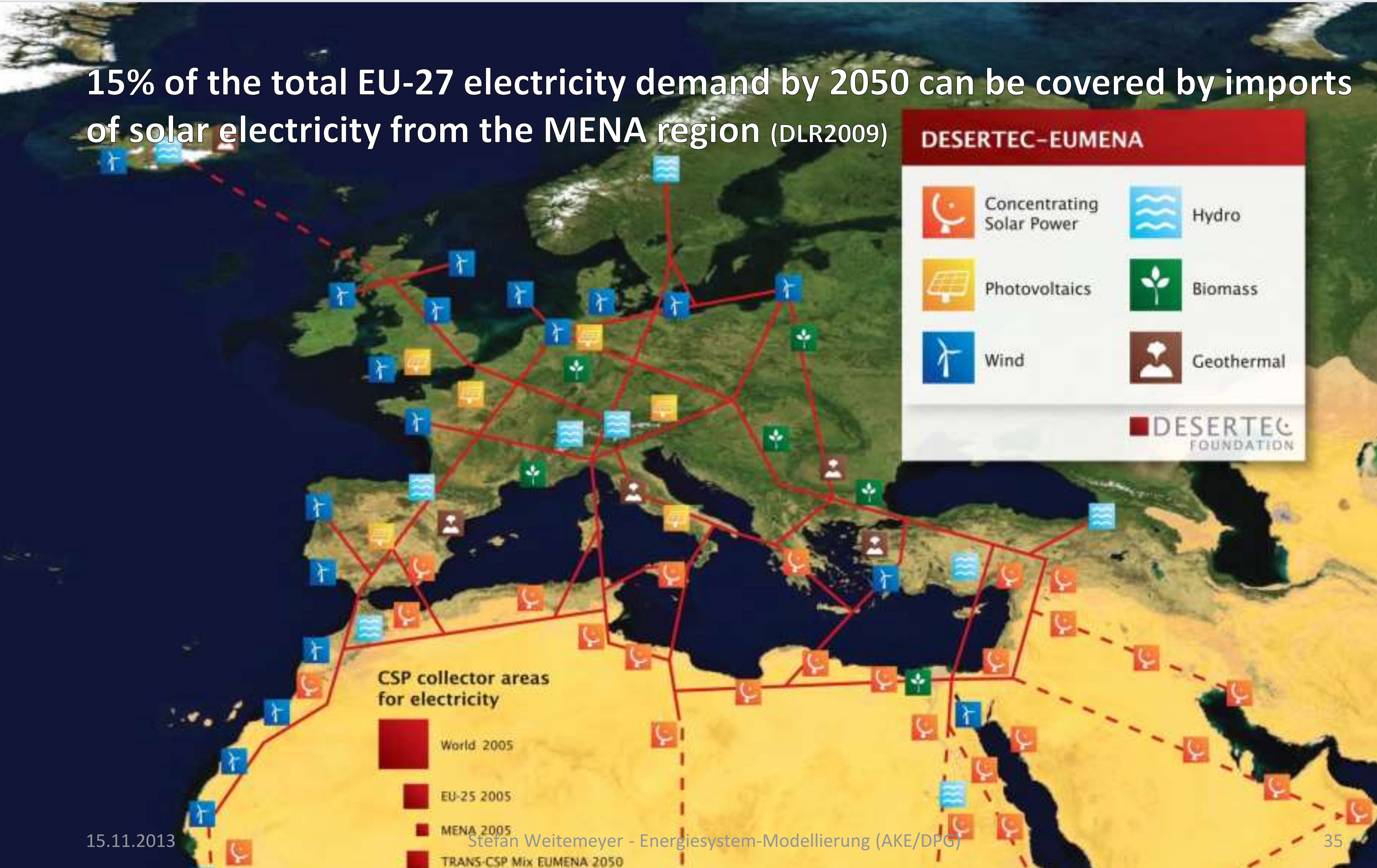
NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.



Grid Expansion

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

15% of the total EU-27 electricity demand by 2050 can be covered by imports of solar electricity from the MENA region (DLR2009)



Source: Desertec

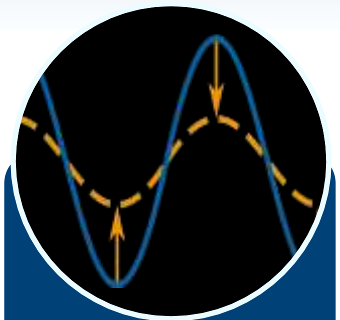
DSM (Smart Grids)

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Alternatives

Storage

Grid Expansion



DSM (Smart Grids)

Optimized Mix

(Over-) Capacities

Source: Vattenfall, Pitopia, Siemens

DSM (Smart Grids)

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Load management / Demand side management (DSM)
  - Actively manipulate demand (by the supplier)

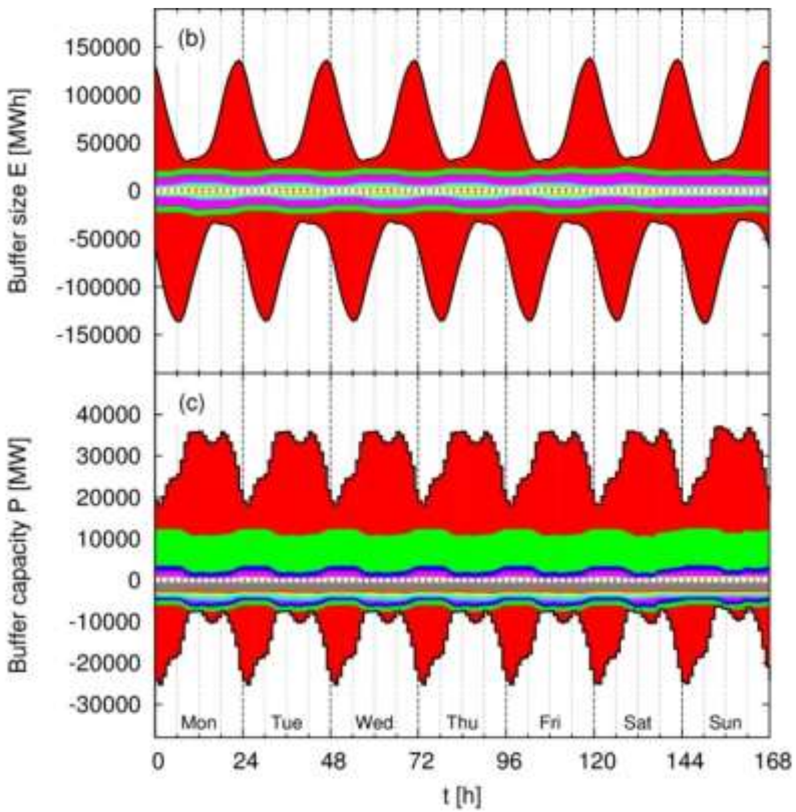
- Two classes:
  1. Curtailment (energy demand is decreased temporally)
     Generally high impact on consumers
  2. **Load shifting (energy demand is conserved)**
     Formal analogy to energy storage

- → Quantitative characterisation required!

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

DSM (Smart Grids) – used for short-term "storage"

- Estimate storage-equivalent potential from scheduled loads (no individual devices are considered)



- Storage-equivalent of heating devices is up to 100 GWh / 30 GW for Germany in winter
- Potential to replace short-time storage
- Usage on local level to overcome technical issues

Source: D. Kleinhans, Towards a systematic characterization of the potential of demand side management, 2013 (submitted)

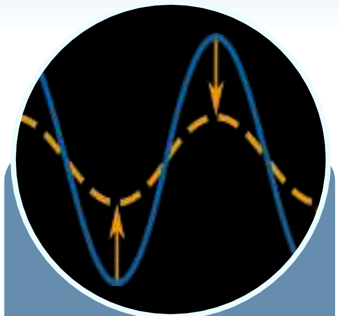
Optimized Mix

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Alternatives

Storage

Grid Expansion



DSM (Smart Grids)

Optimized Mix

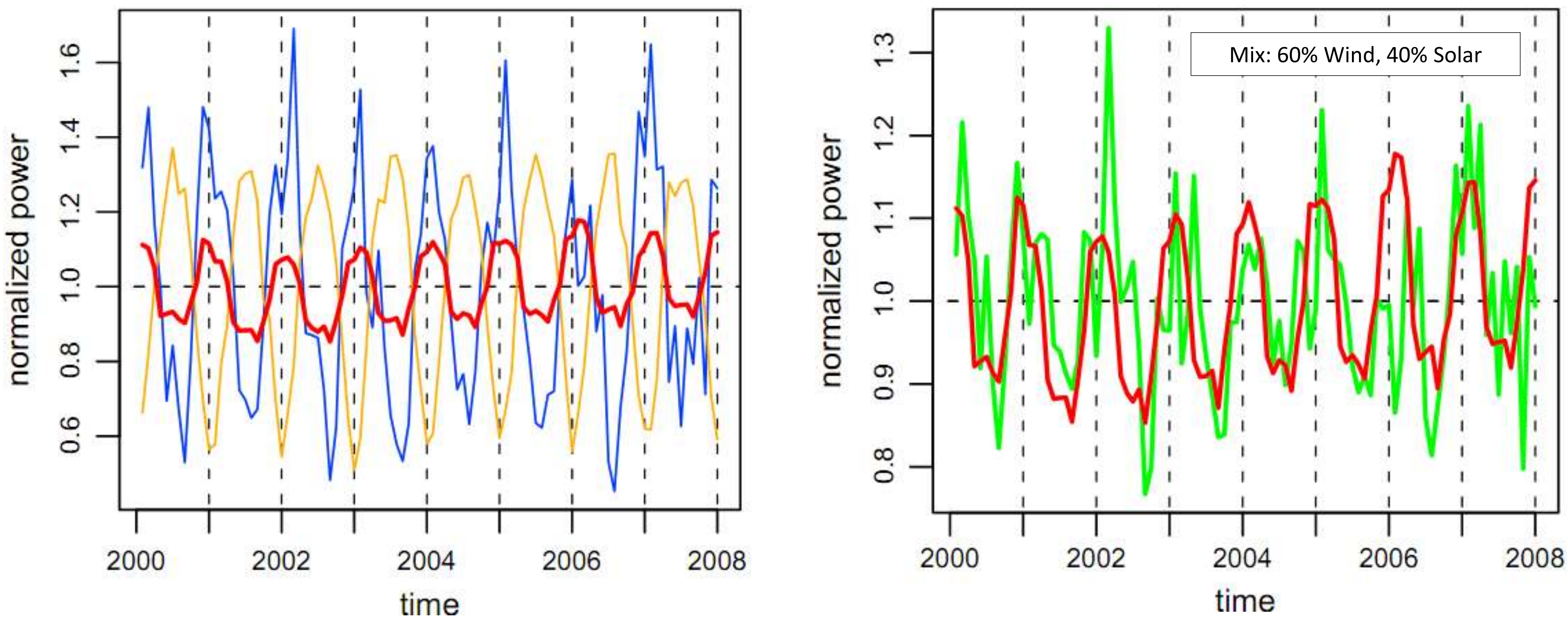
(Over-) Capacities

Source: Vattenfall, Pitopia, Siemens

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Optimized Mix to better match load curve

Combination of solar and wind resources to match demand



Left: Normalised power production from wind (blue), solar (orange) and demand (red) over a period of 8 years in Europe.
Right: Combination of power production from wind and solar with a ratio of 60%/40% (green).

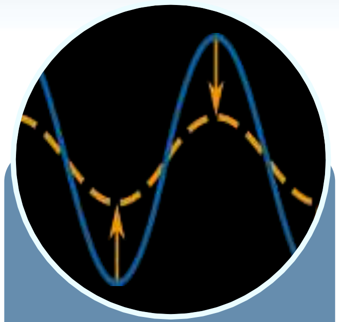
Source: Heide et al., Renewable Energy **35** (2010)

(Over-)Capacities

Alternatives

Storage

Grid Expansion



DSM (Smart Grids)

Optimized Mix

(Over-) Capacities

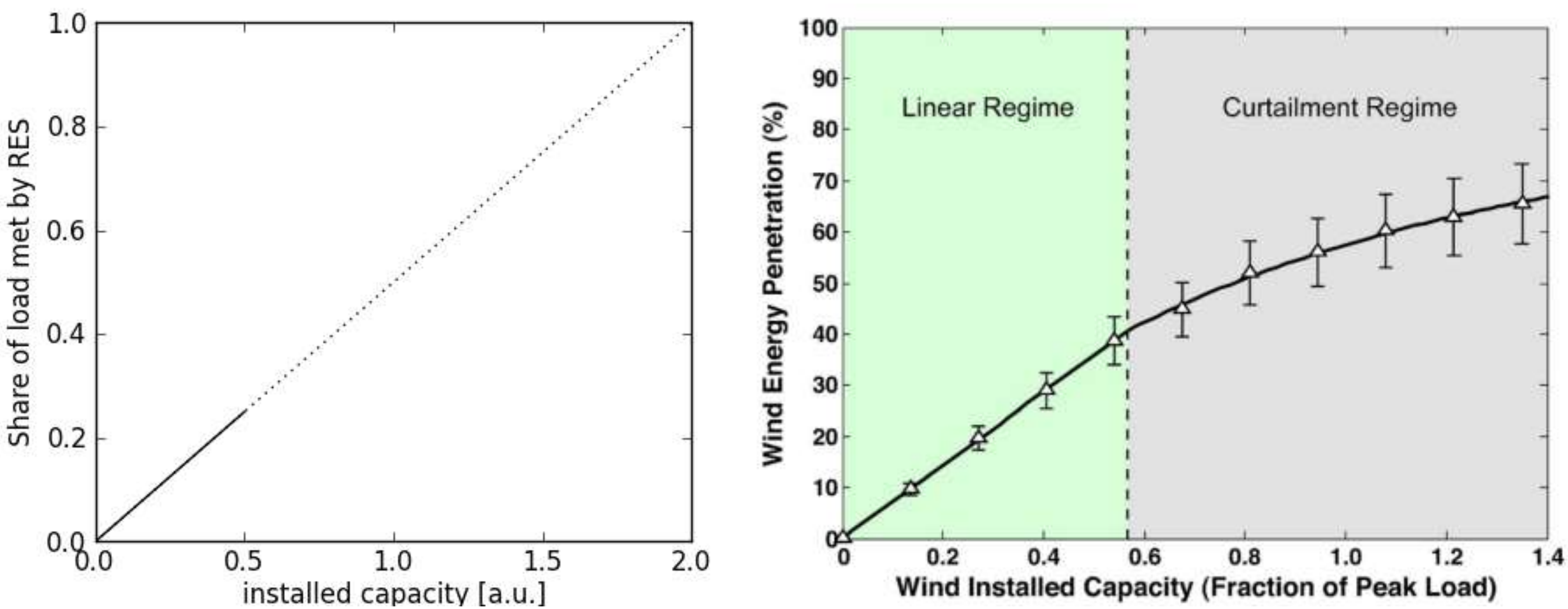
Source: Vattenfall, Pitopia, Siemens

(Over-)Capacities

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- How soon do we need more storage capacities?

- Integration of renewable energy sources into the system



Source: Hart et al. IEEE Proc. **100** 2, 2012

(Over-)Capacities

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Hourly power generation time series (8 years, Germany)
  - Wind *W(t)*
  - Solar *S(t)*
  - Load *L(t)*

  - γ: average renewable energy power generation factor ["installed capacity"]
  - α: share of wind power generation [(1-α) share of solar power generation]

- Mismatch (cf. Heide et al 2010):

$$\Delta(t) = \gamma\left(\alpha W(t) + (1-\alpha)S(t)\right) - L(t)$$ [fixed α and γ]

Source: Heide et al., Renewable Energy **35** (2010)

(Over-)Capacities

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Decreasing slope means curtailment (lower capacity factor)
- BUT: today already large "over-capacities"

- Power capacities in Europe: 920 GW (non-RES: 600 GW, hydro: 200 GW) peak demand: 520 GW

- Capacity factors for current power plants (2005):
  - Nuclear: 0.80
  - Thermal conventional: 0.49

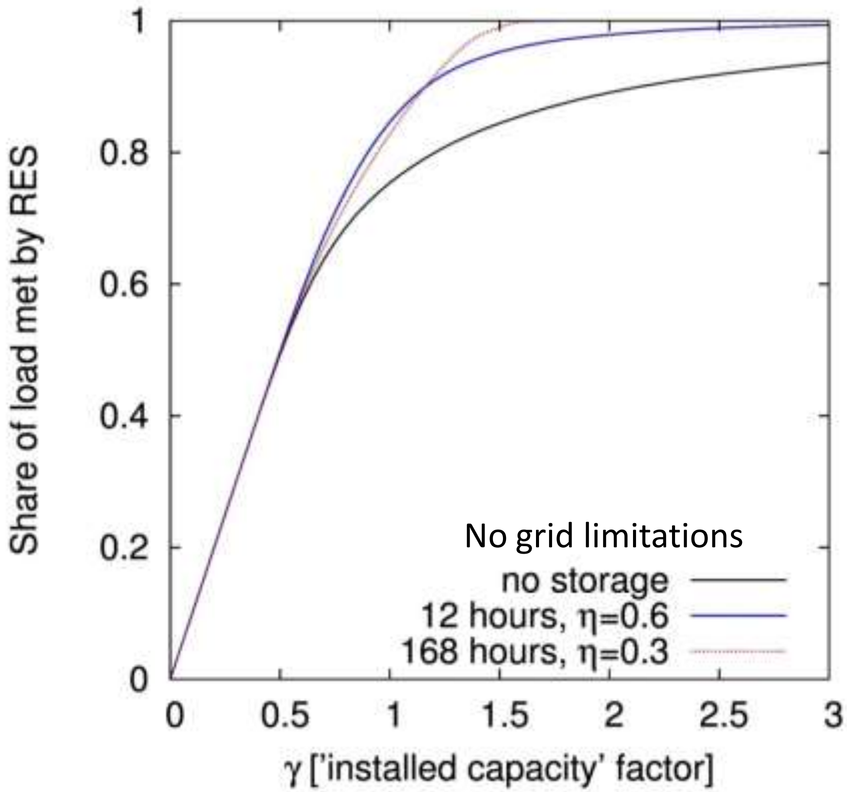
- Limited "over-capacities" needed for large-scale integration of RES

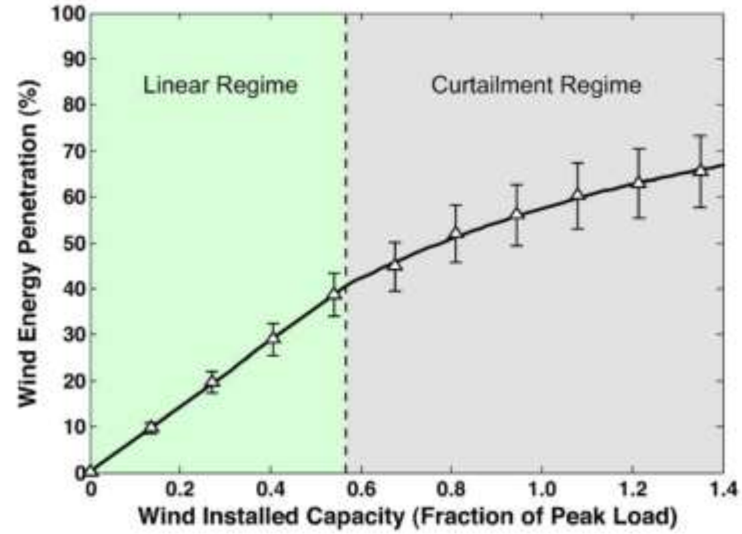
- Controllable RES (biomass, hydro) might fill the top percentages

(Over-)Capacities

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Limited, highly efficient storage capacities are good to start with





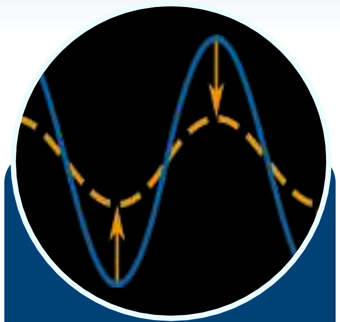
Source: Hart et al. IEEE Proc. **100** 2, 2012

- Results will soon be published – preprint available upon request

Energy System Modelling

EWE-Forschungszentrum für Energietechnologie e.V.

Alternatives



Storage	Grid Expansion	DSM (Smart Grids)	Optimized Mix	(Over-) Capacities

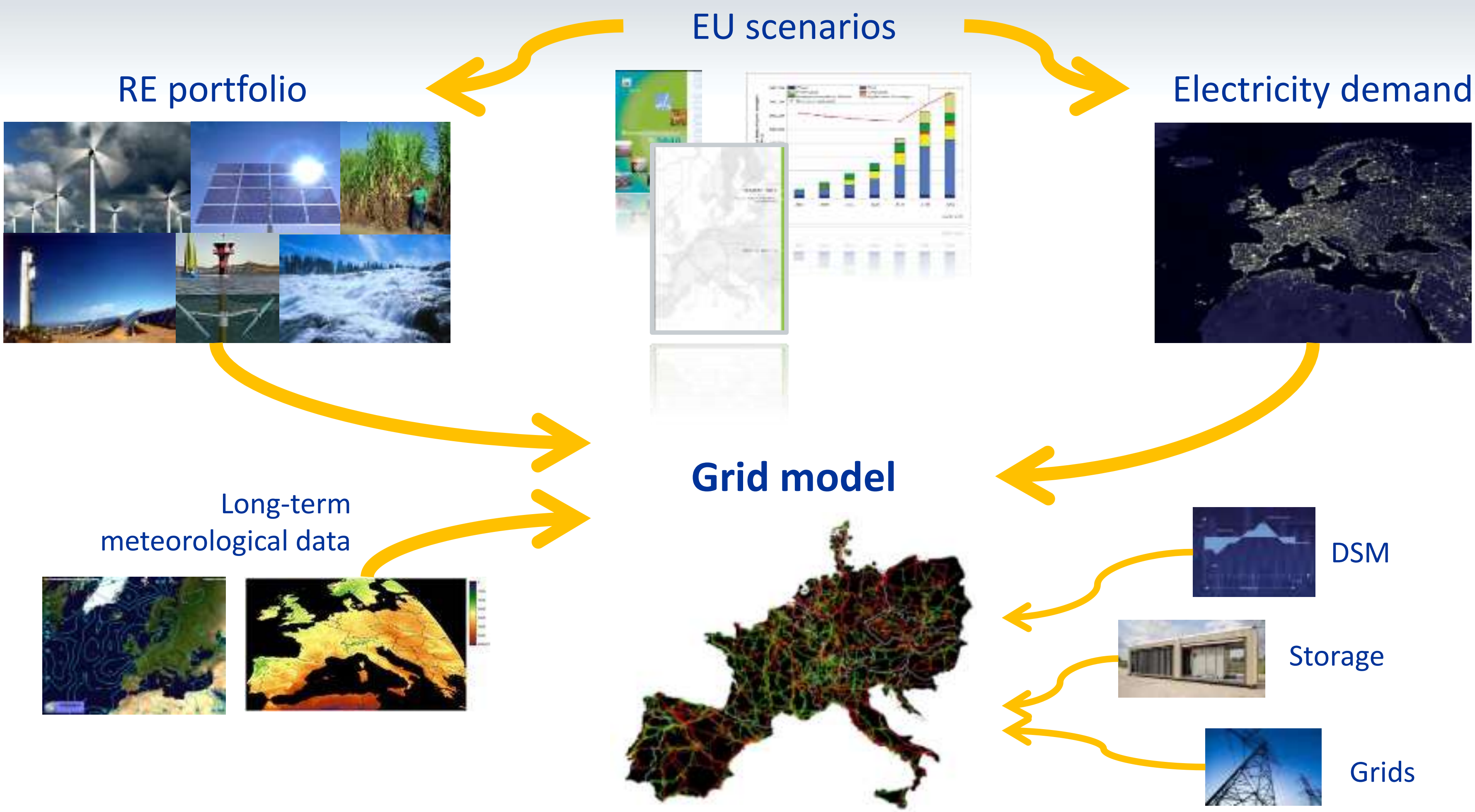
Interactions between different system components & reliability analysis
→ Modelling / Simulations

Source: Vattenfall, Pitopia, Siemens

Energy System Modelling

NEXT ENERGY

EWE-Forschungszentrum für Energietechnologie e.V.



Source T. Feck, Presentation in Bosch-Forschungs-Kolloquium, 17.03.11

Outlook & Discussion

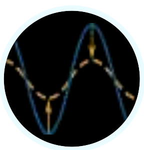
NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

- Open questions:


What is the optimum mix of RES to reduce backup capacities?


Can the expansion of the European transmission grid significantly reduce the demand for storage capacities?


Over-capacities vs backup capacities: where is the optimum?


To what extent can intelligent methods like demand-side management contribute to a reduction of storage capacities?


Which share of the energy could be imported from the MENA region?

RESTORE2050 : research project, coordinated by NEXT ENERGY

ENERGIESPEICHER Forschungsinitiative der Bundesregierung
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

Outlook & Discussion

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

What do we need? **DATA**

- Load data with higher temporal and spatial resolution
- Detailed, standardized grid model
- Reference data set
  - Physical data (e.g. radiation, wind speed)
  - Technological data (e.g. learning curves)
  - Economical data (e.g. costs for CO_2, prices)

NEXT ENERGY

EWE-Forschungszentrum für Energietechnologie e.V.

Summary

- A stable and reliable European Power System is possible with a system based mainly on Renewable Energy Sources
- Fluctuations of wind and solar power generation: Need for large storage capacities with high share of RES
- High cost and limited capacities of storage: Need to reduce storage or backup capacities by use of alternative options
- Small storage capacities lead to significant increase of share of RES
- Limited overcapacities needed for large-scale integration of RES

Acknowledgements

- Thanks to
  - » Energy Systems 2050 group
    - Thomas Vogt, David Kleinhans, Alaa Alhamwi
  - » Carsten Agert
  - » Martin Greiner and his group (Aarhus University)

  - » SEE scholarship for financial support

NEXT ENERGY EWE-Forschungszentrum für Energietechnologie e.V.

Carl von Ossietzky universität Oldenburg

ForWind Zentrum für Windenergieforschung

OFFIS

SE Systemintegration Erneuerbarer Energien

NEXT ENERGY
EWE-Forschungszentrum für Energietechnologie e.V.

Vielen Dank für Ihre Aufmerksamkeit !

Fragen? Anmerkungen?

stefan.weitemeyer@next-energy.de

Appendix