››› How project design can help to integrate vRE into power systems

Taking advantage of first experiences

Conference on integrating variable Renewable Energy into power grids
Copenhagen, October 21, 2014

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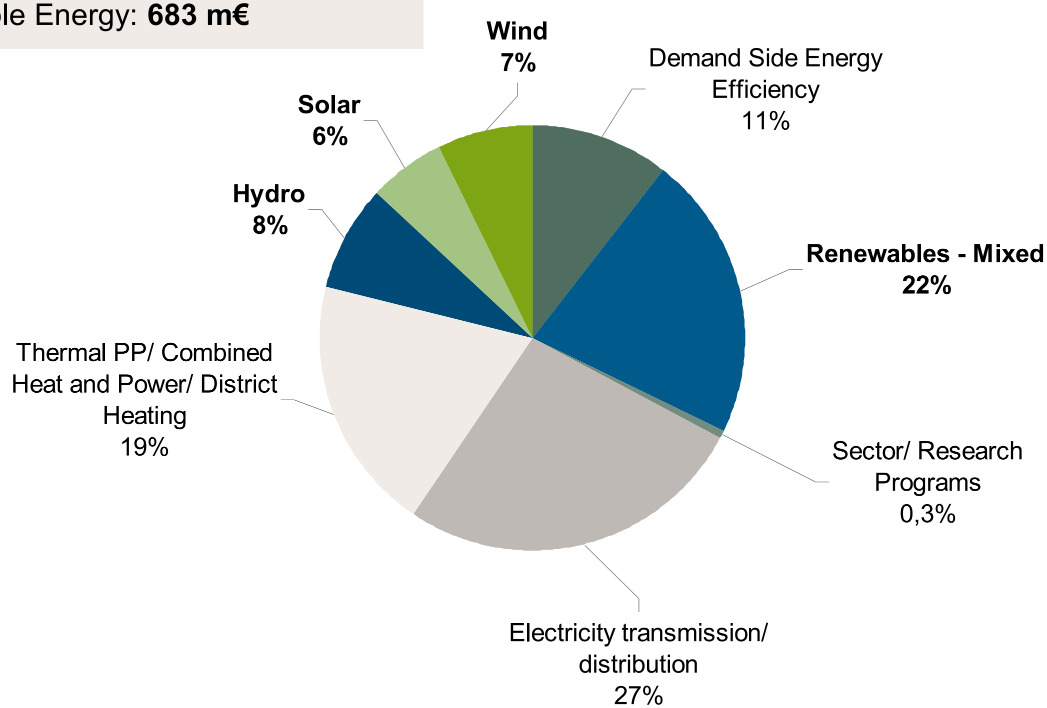
Bank aus Verantwortung

KfW Development Bank and Renewable Energy
Around 70 offices worldwide

- We are the world's largest financier of renewable energies in developing countries

Energy Sector Commitments 2013

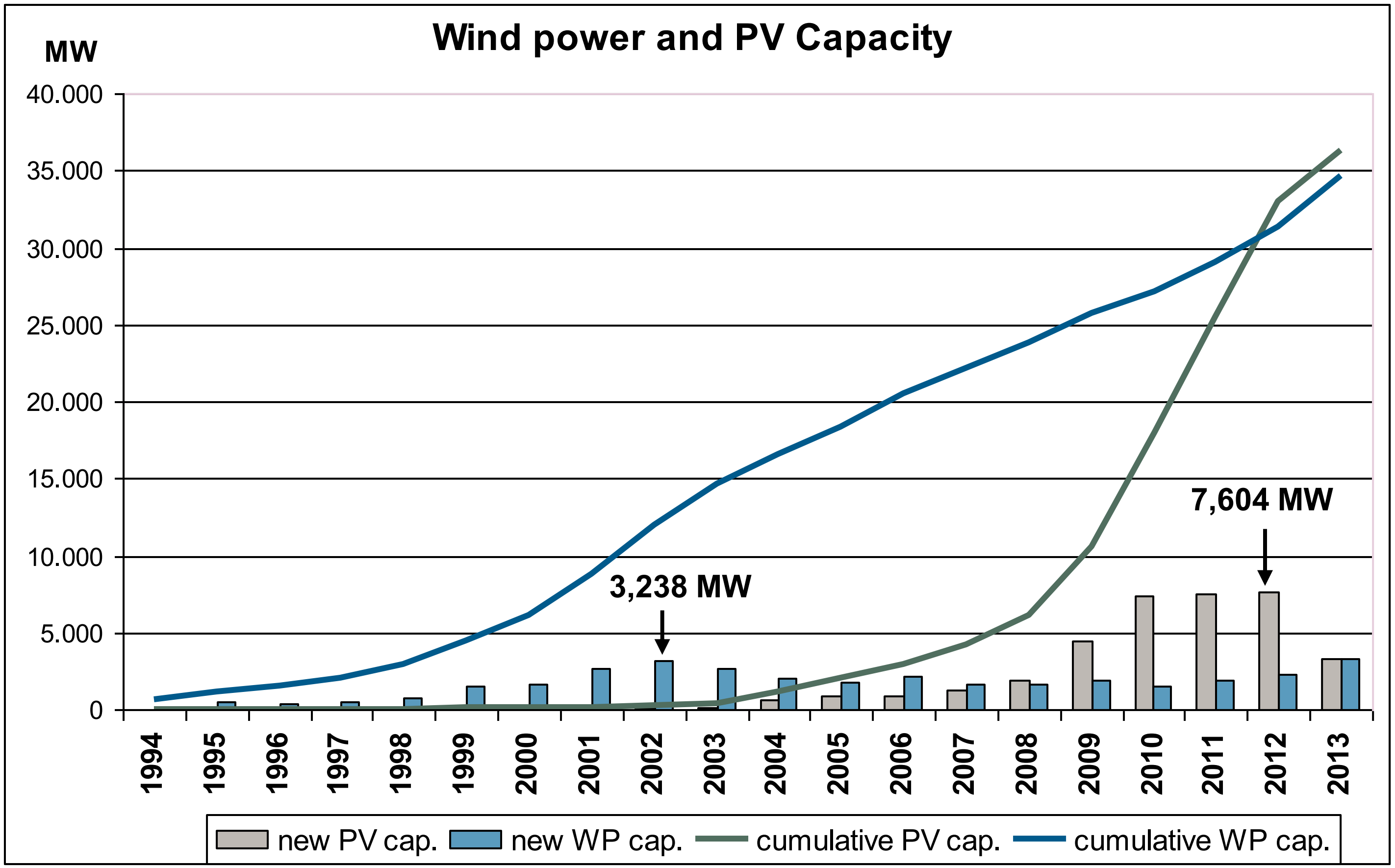
Total Energy Commitments (2013): **1,586 m€**
thereof Renewable Energy: **683 m€**



- Goal: Increase German ODA for RE and EE to at least 3.6 bn € annually until 2030

››› Experiences from the German power market
High shares of vRE in power generation

› In 2013 some 25% of power consumption provided by RE, 9% from wind power, 5% from PV



Annual peak load: 81.8 GW

PV: 36 GW

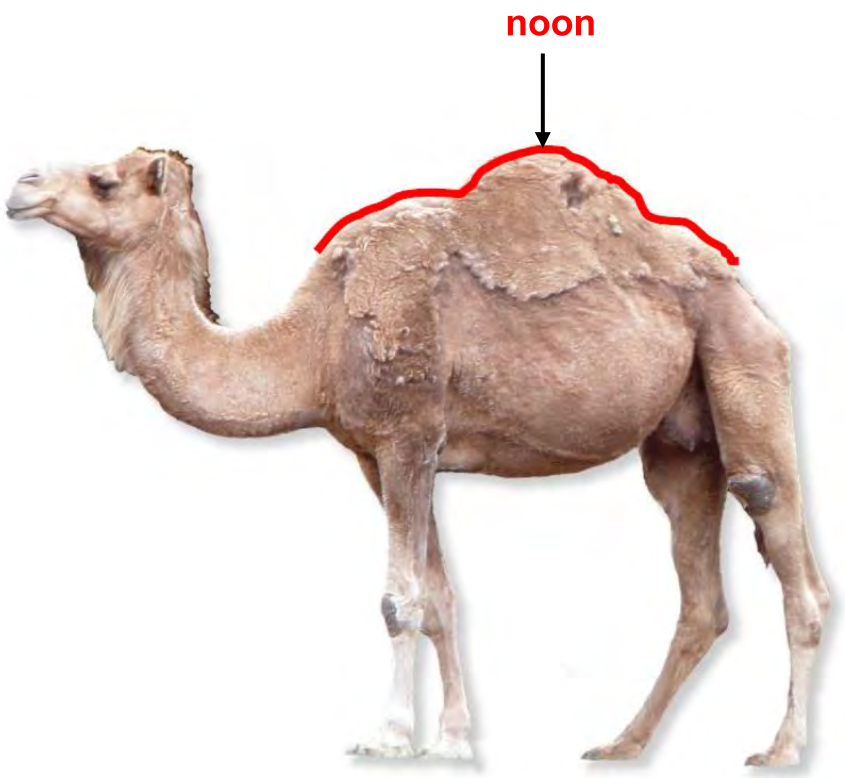
WP: 35 GW

Sources: BMWi; BDEW

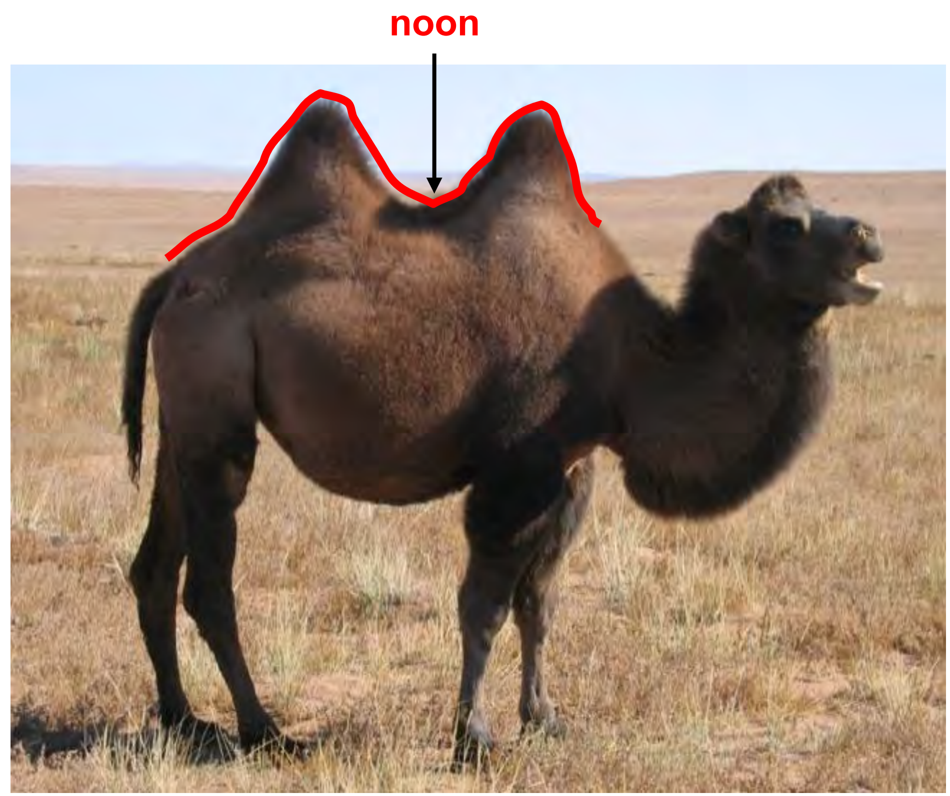
Experiences from the German power market

High shares of vRE in power generation - Consequences

- Decreasing value of power during traditional peak hours and negative power prices
- Need for grid extension and technological enhancements of RE plants



Yesterday: Dromedary-like price curve



Today: Camel-like price curve

Different time frames of variations

Technical challenges and mitigation strategies

- **Short run variations and technical challenges**
  - Variations caused e.g. by flurries
  - Technical challenges: missing inertia caused by increasing share of inverter based feed-in (PV and wind power), displacing rotating masses
    - Harmonic waves
    - Reactive power
    - Short circuit power
  - Technical solutions to be applied at the RE power plant itself and to be taken into account in project design ➔ experience of wind power in Egypt
- **Medium to long run variations and potential mitigation measures**
  - Geographic diversity ➔ experience of Albania
  - Technological diversity ➔ experience of Morocco
  - Storage ➔ experience of CSP with thermal storage
  - DSM and backup of flexible generation capacity

››› Addressing short run variations and technical challenges

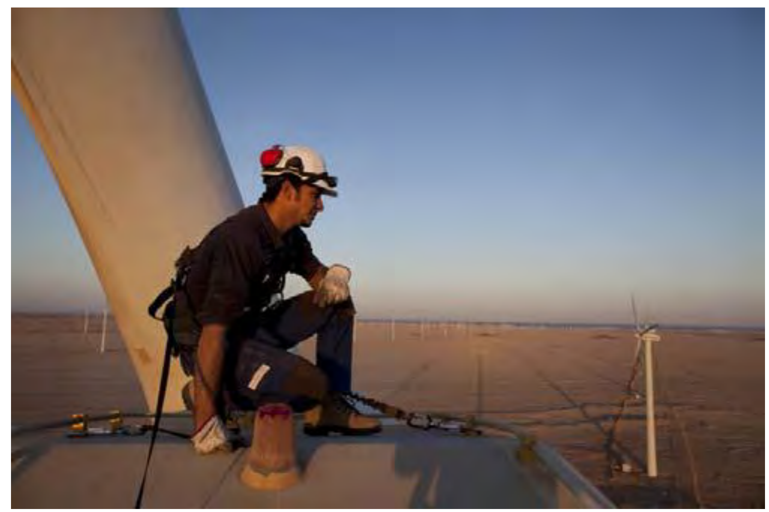
The experience of wind power in Egypt - Gabal el-Zayt

- **Context**
  - Enormous wind power potential ➔ 20% to be generated from wind and solar power by 2020
  - Displacement of rotating mass by inverter based feed-in could cause instability in a Transmission System, which is deficient anyway
- **Approach**
  - 200 MW wind farm at the gulf of el-Zayt + preparatory studies for another 200 MW
  - Starting point: **power network analysis**

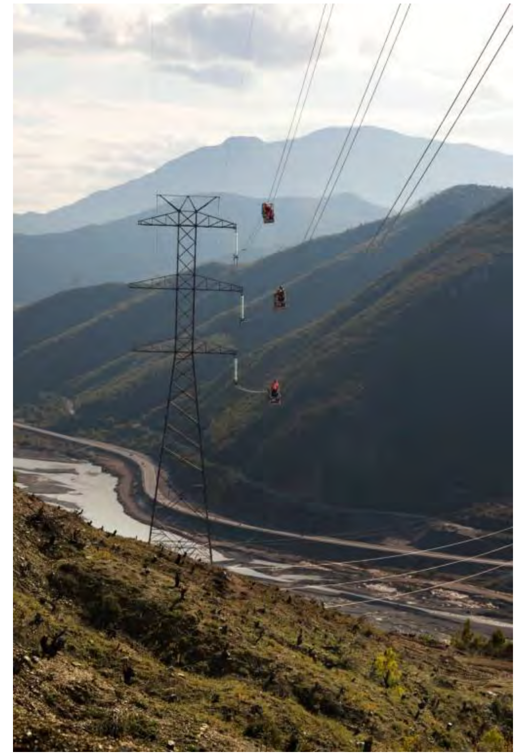
    ➔ **Enhancement of grid code**
    (Threshold values for harmonics)

    ➔ **Requirements in the tender documents**
    (Technical norms for power inverters)
- **Future Approach**
  - Requirements for short circuit power
  - Ex post network analysis

    ➔ Readjustments of power inverters



››› Geographic diversity
The experience of Albania



- **Context**
  - Albania is heavily dependent on hydro power (90% capacity)
  - Supply shortages during dry periods - seasonal and yearly variations
- **Approach**
  - Construction of two 400 kV transmission lines
    - Albania - Montenegro (60% hydro): commissioning May 2011
      - 155 km TL + extensions of substations
      - 44 m€ development loan to Albania
    - Albania - Kosovo (Tirana - Prishtina): procurement completed
      - 240 km TL, 600 MW + extensions of substations
      - 42 m€ development loan to Albania + 33.5 m€ dev. loan to Kosovo
- **Impact**: Important contribution to the extension of the SEE power network and connection of Albania with the ENTSO-E network

››› Technological diversity

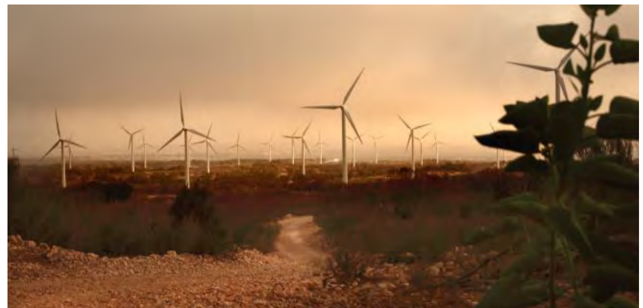
The experience of Morocco: wind, solar and hydro power

- **Context**
  - High solar radiation and abundant wind power potential
  - Target of the GoM to increase the RE share of installed capacity to 42% in 2020

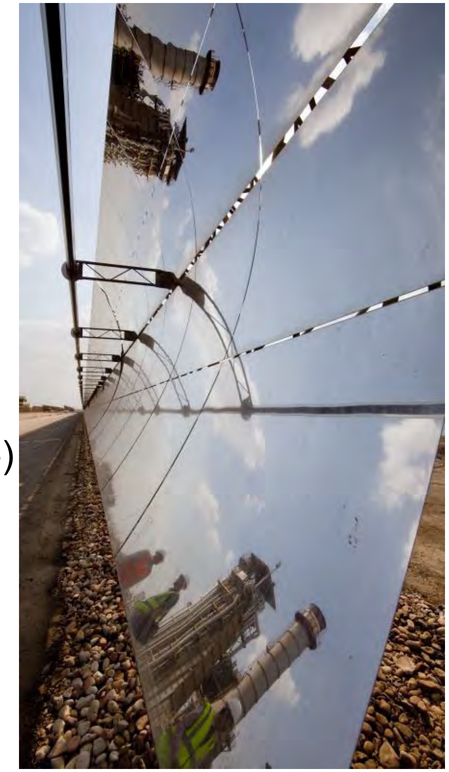
2,000 MW Wind power	2,000 MW Solar power (CSP + PV)	2,000 MW Hydro power	Grid extension to integr. vRE

- **Approach**
  - KfW contributes to the achievement of all these sub-goals

- **Impact**
  - Complementary technology mix to balance different variations
  - Avoidance of fossil fuel imports



››› Storage I - thermal storage
The experience of Ouarzazate CSP in Morocco (1/2)



- **Context:** Evening peak
- **Approach**
  - Largest solar power complex of the world, comprising
    3 CSP and 1 PV plant, target capacity (2017): some 560 MW
  - **Molten salt storage**
    - Noor I: 160 MW Parab. Trough; 3 h storage cap. (comm.: Oct 2015)
    - Noor II: 200 MW Parab. Trough; about 5 h storage capacity
    - Noor III: 150 MW Solar Tower; about 5 h storage capacity
  - KfW financing 769 m€ (total cost: 2.3 bn€)
- **Impact**
  - **Solar power generation even during night hours!**
  - „Adding thermal storage to a CSP facility was found to be an effective measure to mitigate the decline in the value of CSP with increasing penetrations“ (Berkeley Lab „mitigation report“)
  - LCOE of **CSP can compete** in some countries with alternative dispatachable power plants!

Storage I - thermal storage
The experience of Ouarzazate CSP in Morocco (2/2)

- **Cost estimations**
  - Generation costs for CSP with molten salt storage storage
    - Parabolic trough: some 13 €ct / kWh
    - Solar tower: some 13.5 €ct / kWh (forecast)
  - Storage costs (non-CSP) - depending on technology and site: 5 - 9 €ct / kWh

- **Features of Andasol-1 Storage**
  - Tank volume 2 x 14,000 m³
  - Salt inventory 28,000 t
  - Δ T = 386° C - 292° C = 94 K
  - Storage capacity 1,000 MWh = 7.5 h
  - Estimated investment cost 30 - 50 € / kWh

›› Storage II - Pumped-Storage HPP

The example of Vrilo PS-HPP in Bosnia-Herzegovina

- **Context**
  - High share of hydro power in BH: 50% of installed capacity
  - High wind power potential
  - Several hydro and wind power engagements of KfW in BH
- **Approach**
  - 66 MW PS-HPP at the river Suica,
    providing 106 peak + 84 GWh run-of-river generation p.a.
  - Height diff. upper to lower basin 155 m, 4.5 km distance
  - 100 m€ loan agreement signed mid-2014 (total cost: 110 m€)
- **Impact**
  - Grid stabilization (frequency and voltage regulation)
  - Enabling the exploitation of the high wind power potential by providing reliable large-scale and long-run energy storage

Thank you for your attention

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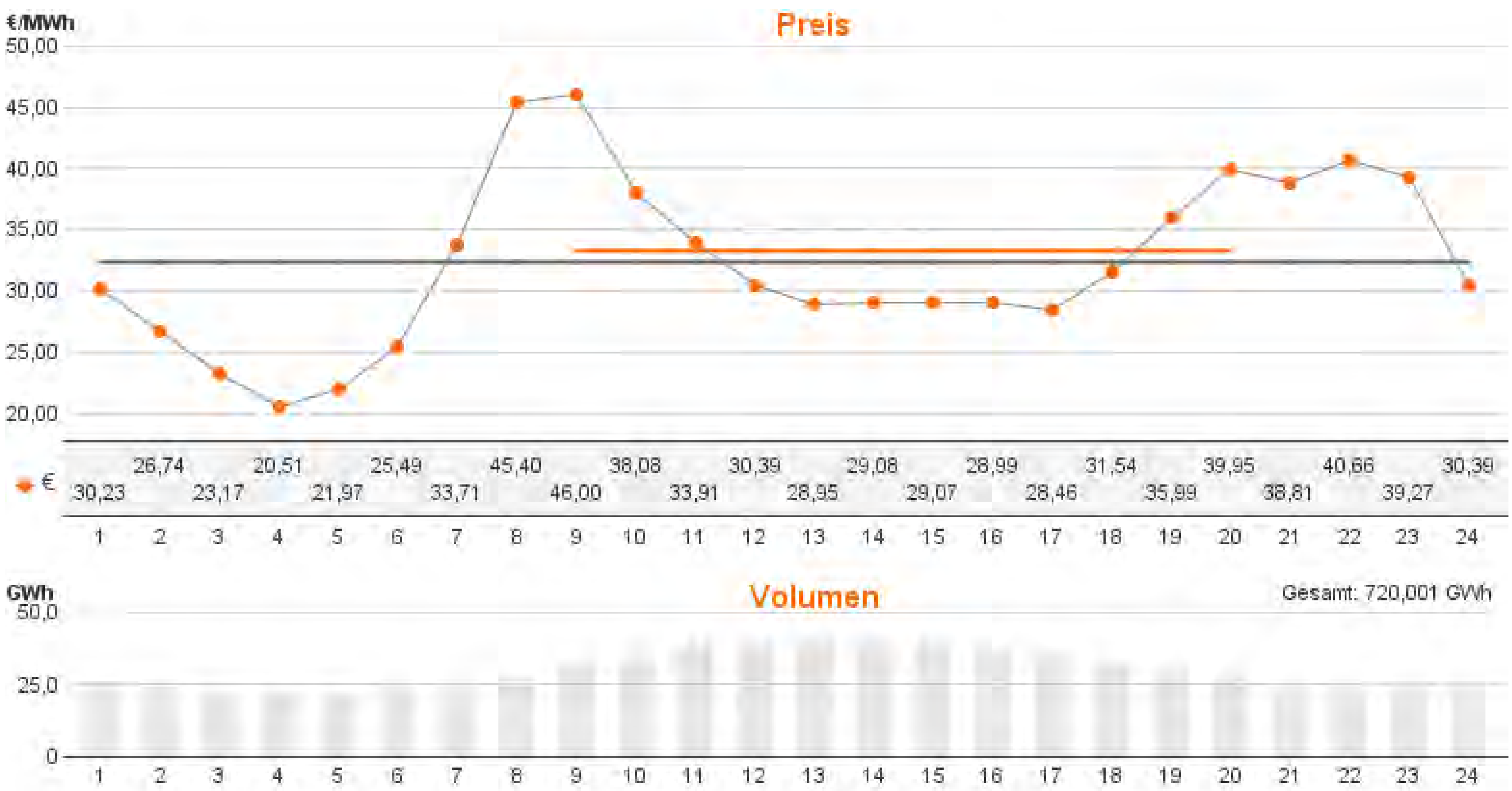
BACK-UP

››› BACK-UP: Experiences from the German power market

Camel-like spot market results

› Price Chart EPEX Day-ahead: Trading Date: May 13, 2014; Delivery: May 14, 2014 (Wednesday)

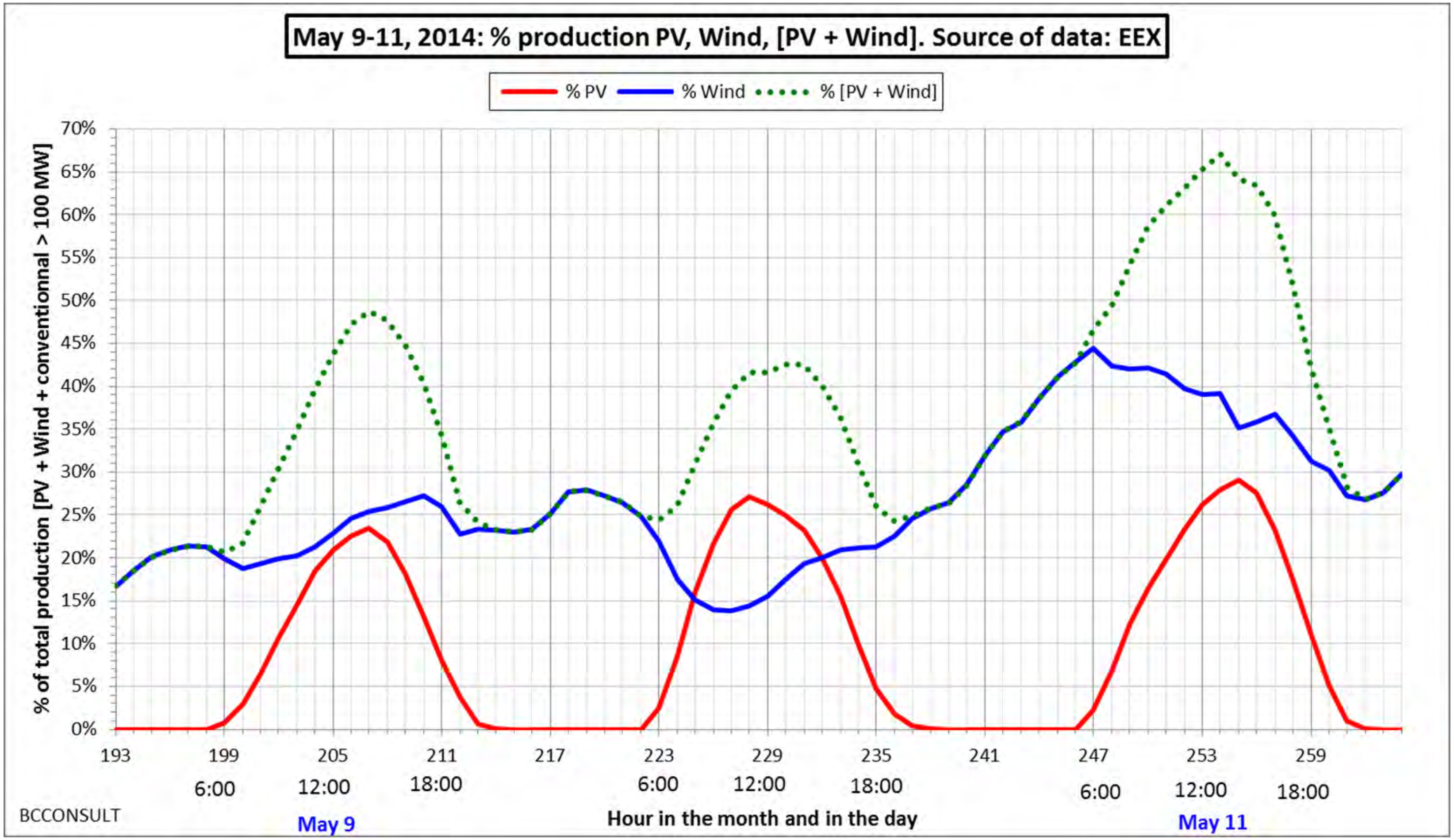


Source: EPEX

››› BACK-UP: Experiences from the German power market

Spot market: merit order effect with high share of RE

› Wind + PV at noon on May 11, 2014: up to 67% of production…

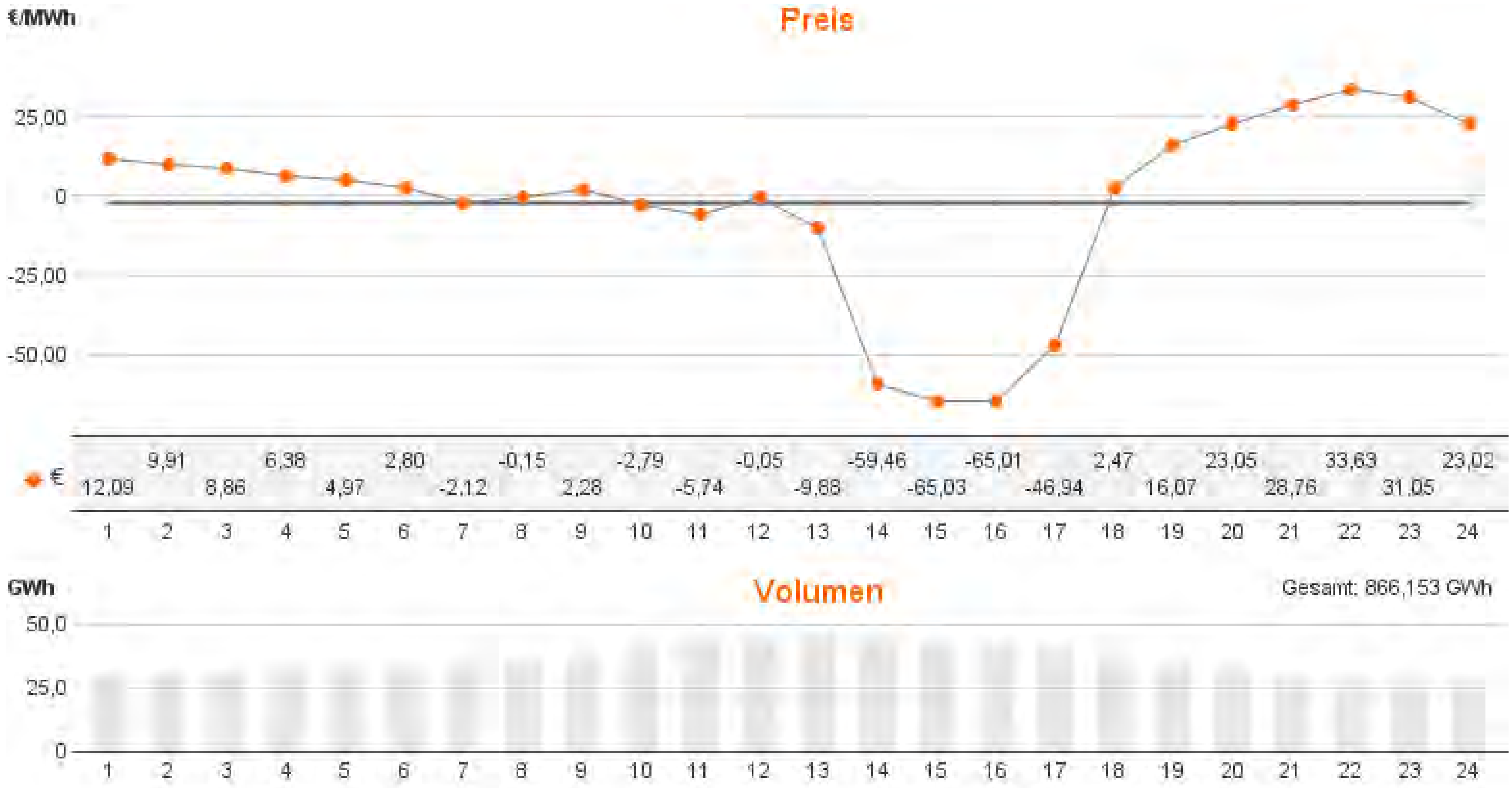


Source: BCCONSULT

››› BACK-UP: Experiences from the German power market

Spot market: merit order effect with high share of RE

› … causing negative power prices on May 11, 2014



Source: EPEX

››› BACK-UP: Storage I - thermal storage

The experience of Ouarzazate CSP in Morocco

Solar Complex Ouarzazate: 4 plants, 3 technologies, 560 MW
→ the largest solar complex world wide

Next complexes of the Moroccan Solar Plan

„Noor I"
- 160 MW Parabolic Trough Plant with 3 hours storage capacity
- CAPEX: 633 m EUR
- KfW financing: 115 m EUR
- Start of construction June 2013
- Estimated commissioning October 2015

„Noor II"
- 200 MW Parabolic Trough Plant
- About 5 hours of storage capacity
- CAPEX ca. 1 bn EUR
- KfW: 330m EUR

„Noor III"
- 150 MW Solar Tower
- About 5 hours of storage capacity
- CAPEX ca. 0.7 bn EUR
- KfW: 324m EUR

„Midelt"
- Ca. 500 MW
- technologies to be decided

„Tata"
- Ca. 500 MW
- technologies to be decided

››› BACK-UP: Storage I - thermal storage

The experience of Ouarzazate CSP in Morocco

Demand is not only increasing, it is also fluctuating

- Demand is almost doubled in 2024; tripled in 2030!
- Differences between summer and winter (summer consumption tends to be higher)
- Evening-peak prevailing, noon-peak will develop strongly