Market Triggered Step Response of Electric Power Systems

„Wind Eclipse“

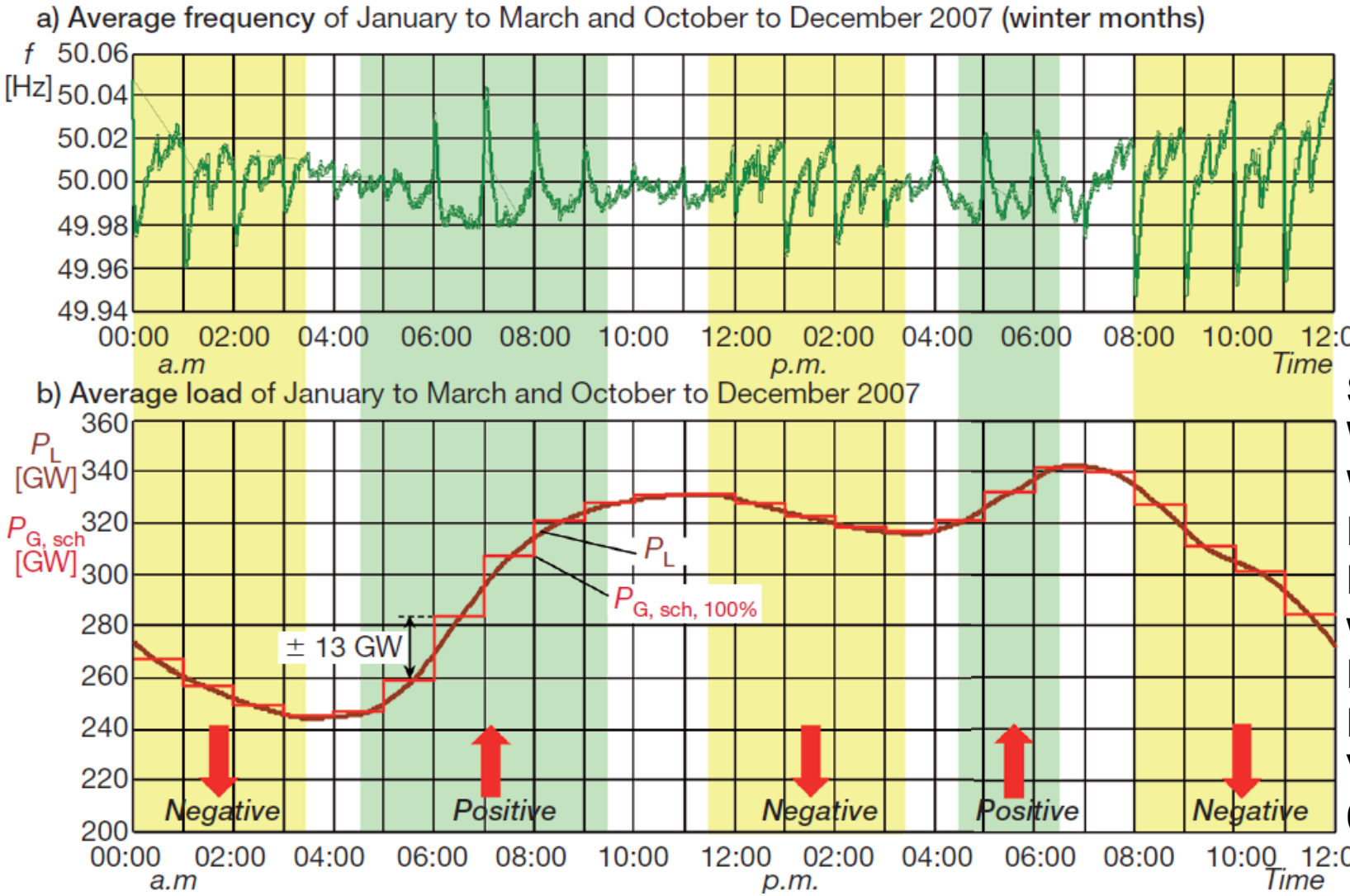
Gunnar Kaestle

European Stakeholder Committee on System Operation
Wednesday, 2020-12-09, Webmeeting

Agenda

- Known Deterministic Frequency Deviations
- Visible Phenomena
- Negative Prices as Trigger Event

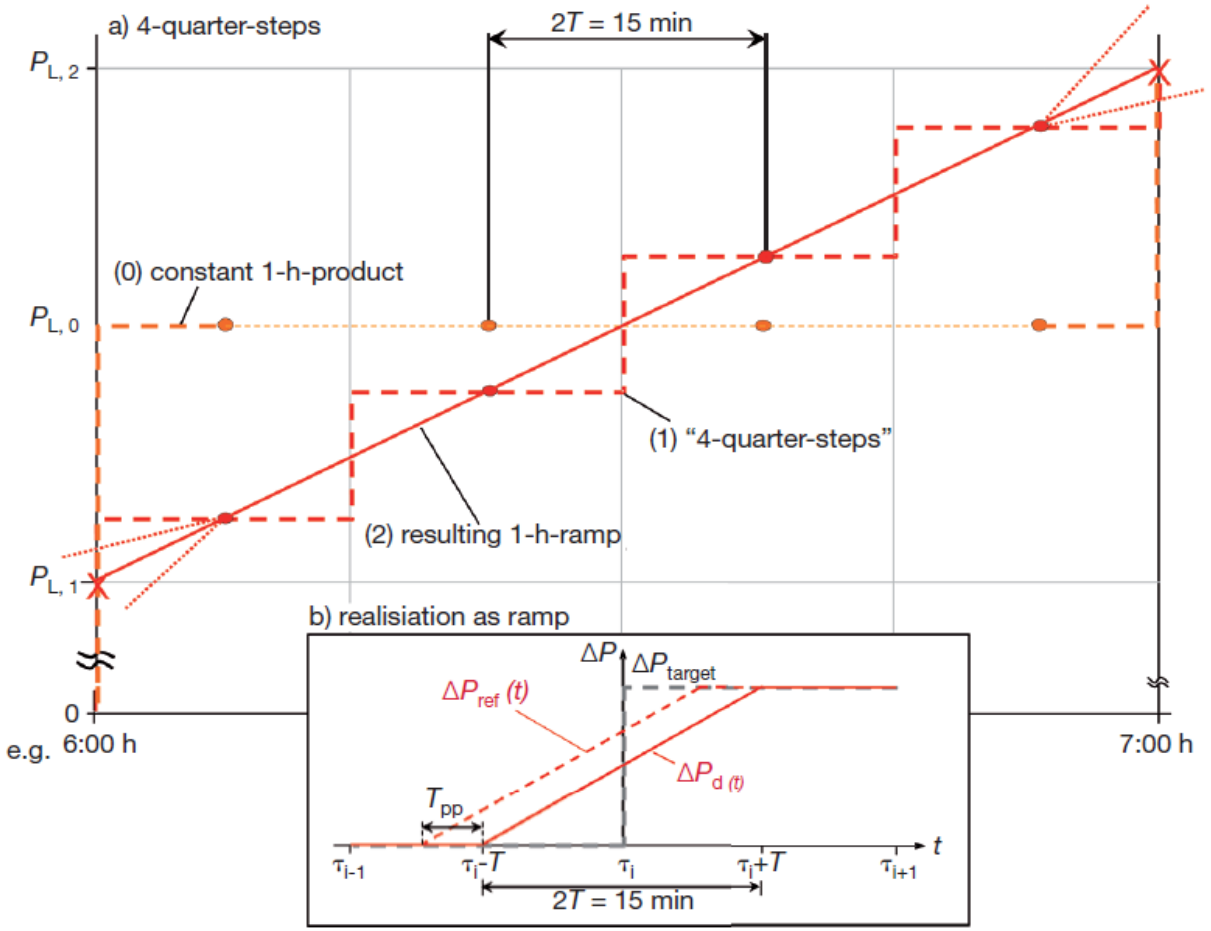
1-h-Block Trading as Reason for Frequency Deviations



Source: Weißbach & Welfonder: High Frequency Deviations within the European Power System, VGB PowerTech 06-2009, S. 27

Countermeasures

- 1-h-block trading -> ¼ h blocks (DE: 2011-12)
- Define ramps for transition between blocks



Source: Weißbach, Welfonder: High Frequency Deviations within the European Power System, VGB PowerTech 06-2009, S. 31

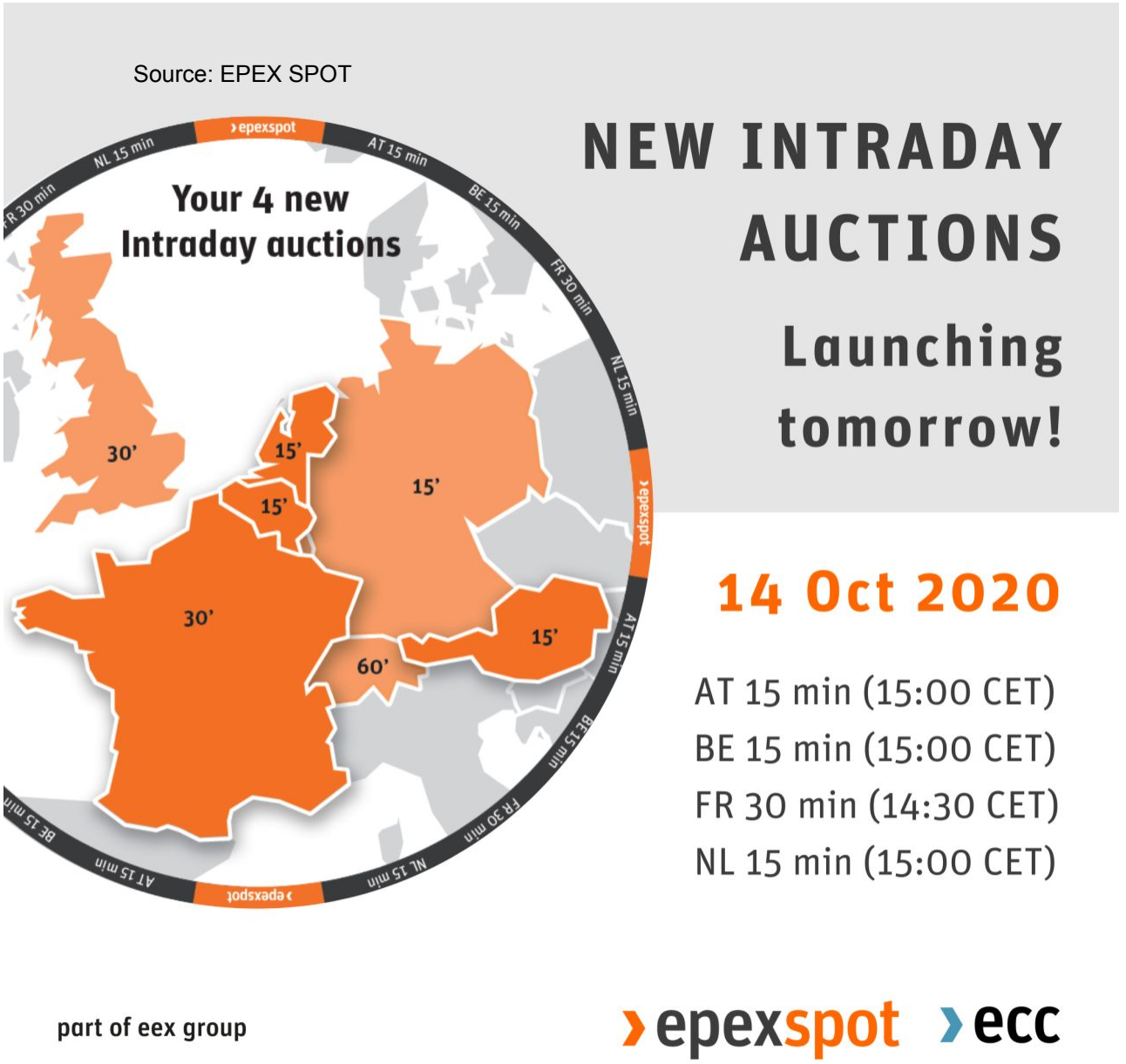
Problem Solved?

- Smaller time steps
- make deterministic frequency deviations smaller,
- but they occur more often.

However,

the market begins to trigger even bigger steps.

Source: EPEX SPOT

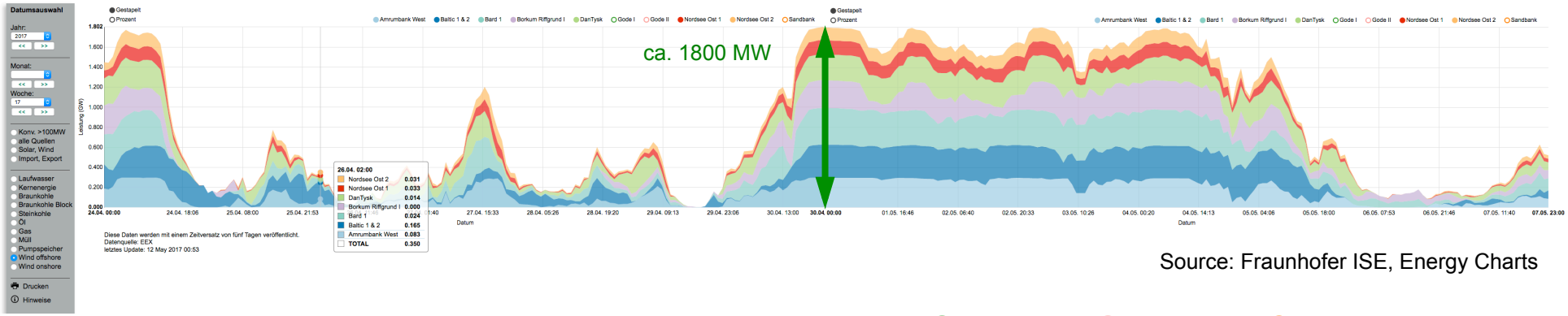


Agenda

- Known Deterministic Frequency Deviations
- Visible Phenomena in DE
- Negative Prices as Trigger Event

Wind Eclipse on 30th April and 1st May 2017

Offshore Windfarms commissioned until December 2015:

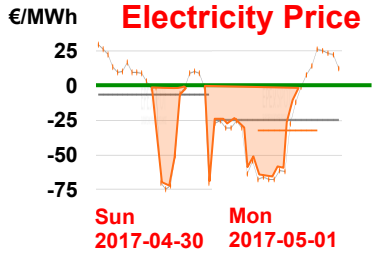


Source: Fraunhofer ISE, Energy Charts

Offshore Windfarms commissioned since January 2016:

Wind Eclipse: Gode Wind I, Gode Wind II, Sandbank

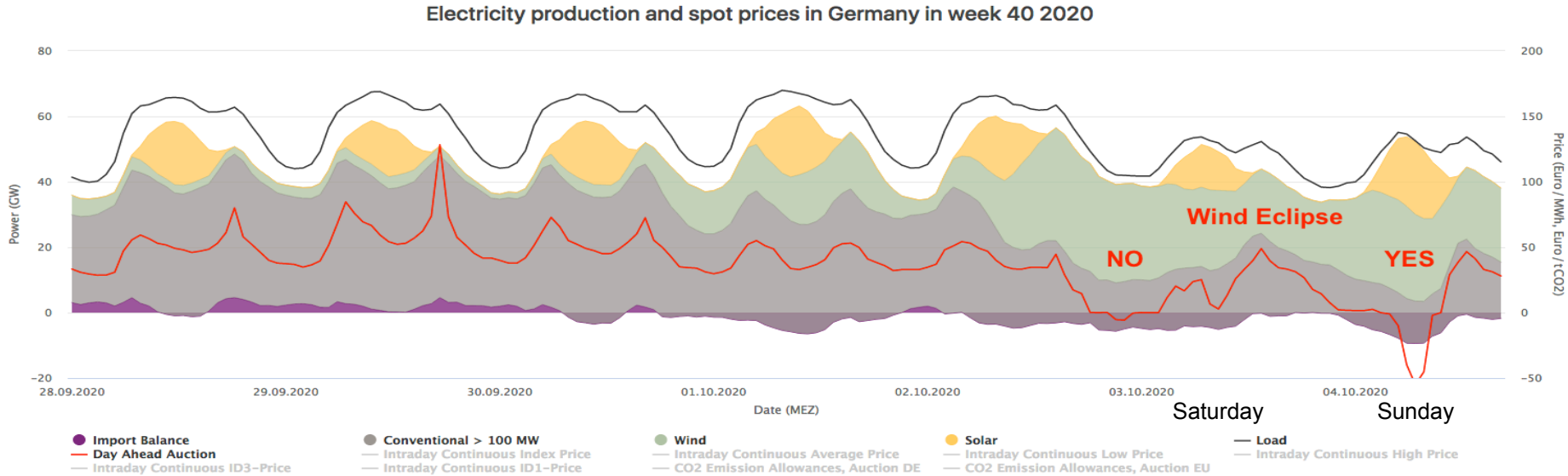
Source: EPEX Spot,
Day-Ahead-Auction



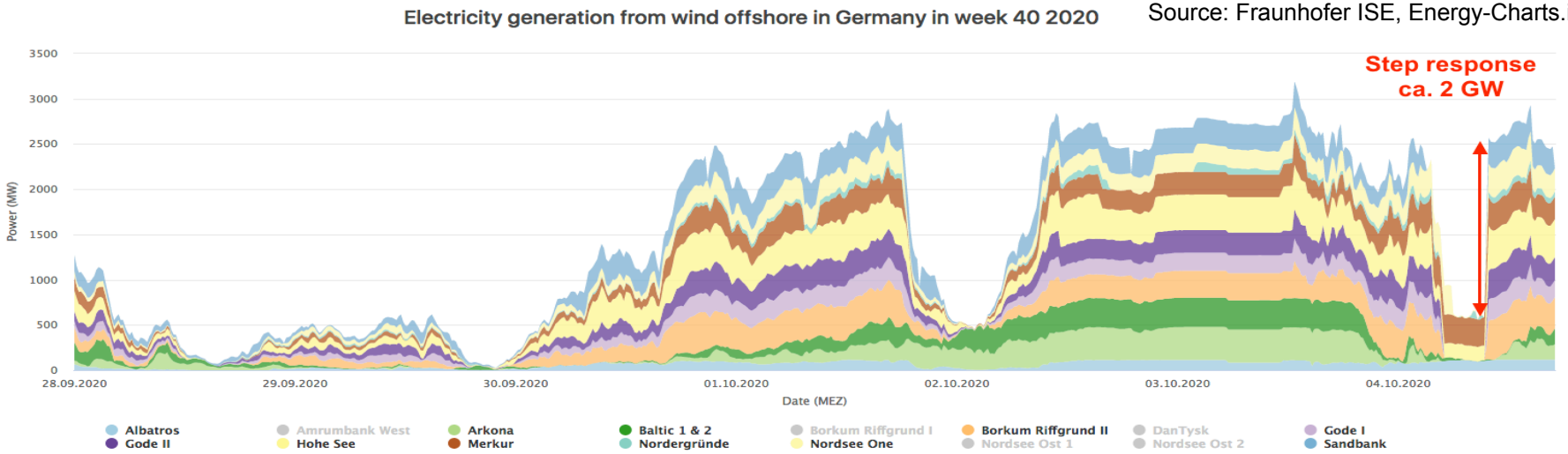
Affected electricity producers in Germany:
0,8 GW Offshore wind
4,6 GW Onshore wind in 2016
4,6 GW Onshore wind in 2017 (estimated)
1,1 GW Large PV (≥ 500 kW per plant)

≥ 10 GW Sum of installed RES-E capacity

Most Recent Event on Sun, 2020-10-04 from 9:00-16:00

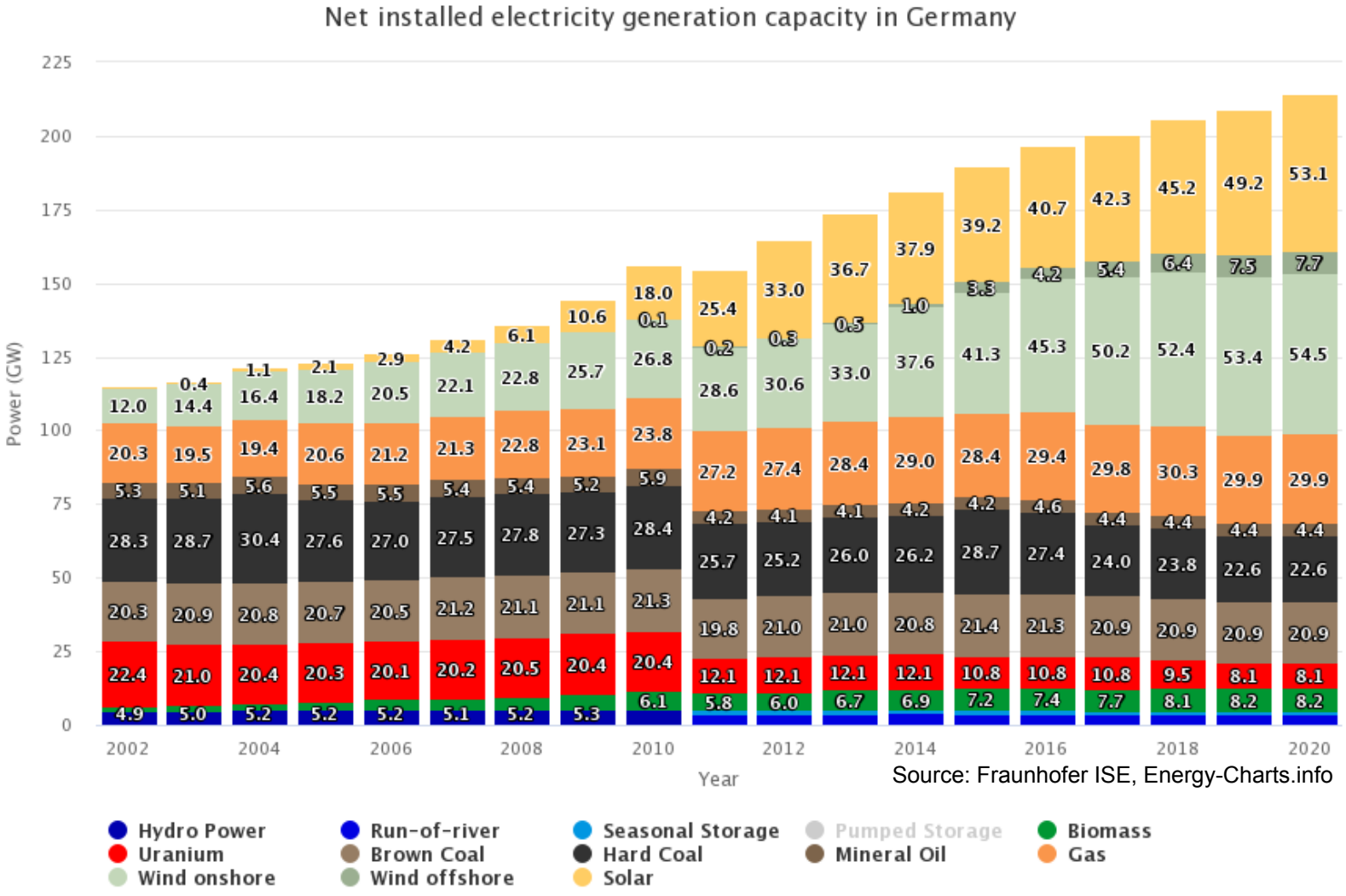


Source: Fraunhofer ISE, Energy-Charts.info



Offshore Windparks commissioned since 2016-01-01

New Installations of RES-E Generators



Source: Fraunhofer ISE, Energy-Charts.info

Since 2016-01-01

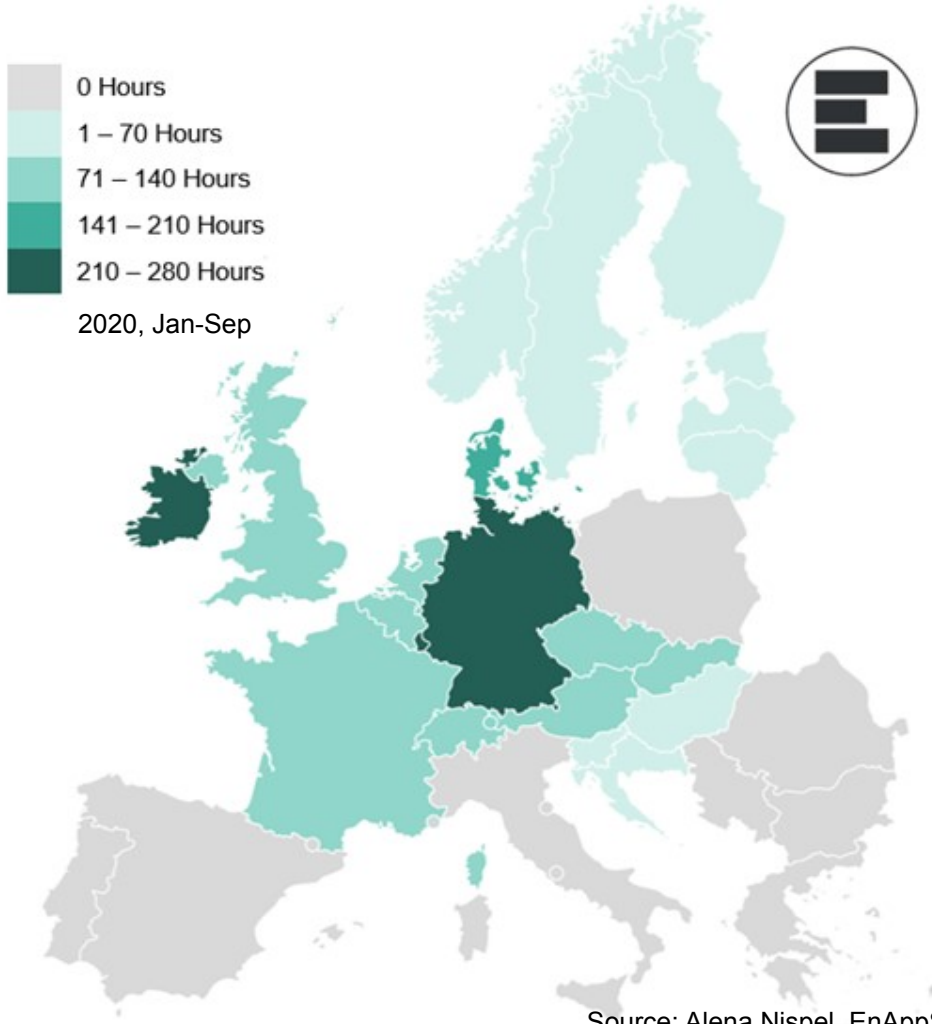
Solar
13.9 GW
Offshore
4.4 GW
Onshore
13.2 GW

However,
with PV only plants ≥ 500 kW are infected.

DE as the Canary in the Coal Mine?

- No, IE as well.
- Ireland is an island and has it‘s own synchronous zone.
- Negative prices as trigger event are wide spread.
- Market coupling leads to synchronised prices.

- Don‘t panic with negative prices!



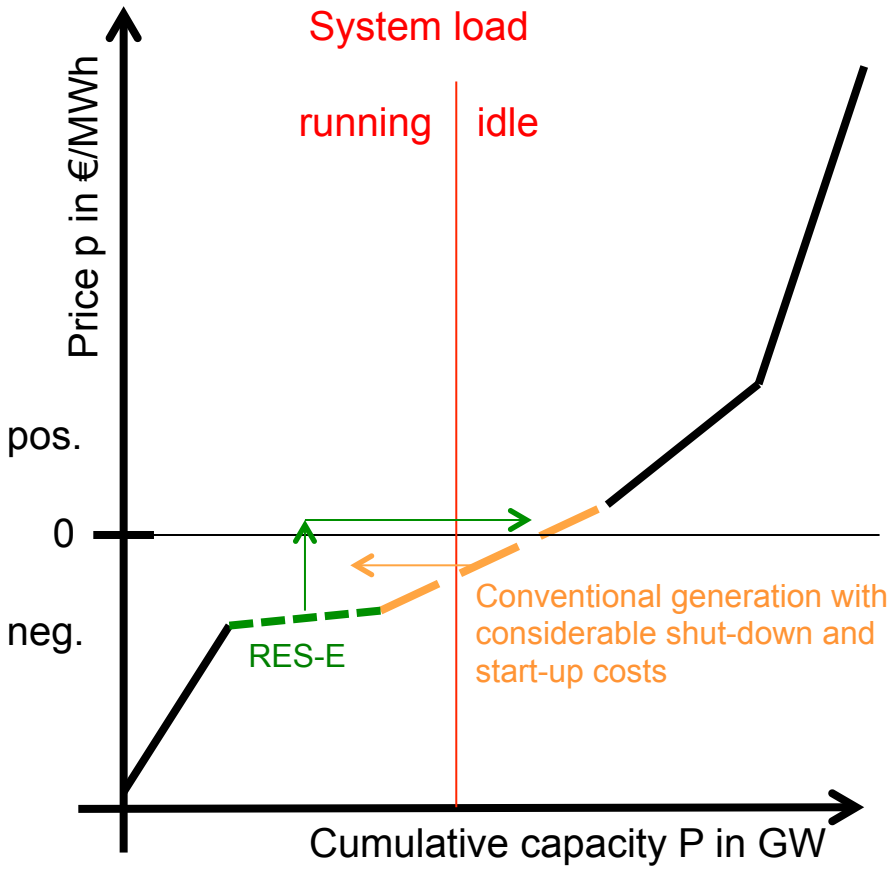
Source: Alena Nispel, EnAppSys

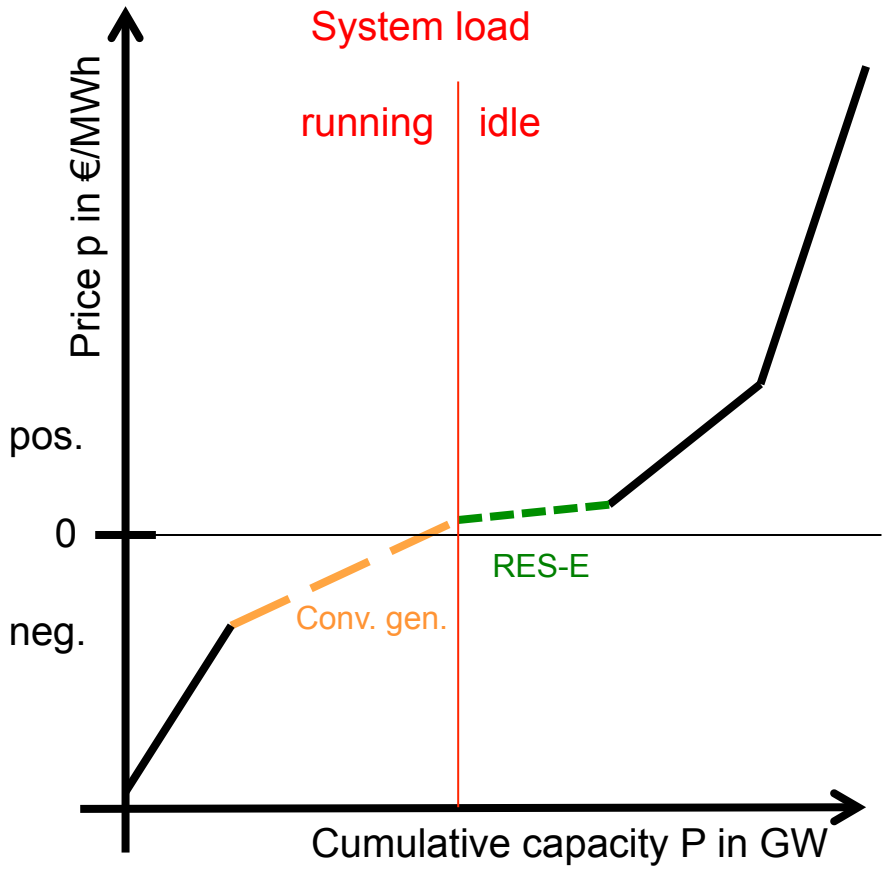
The total number of hours of negative day ahead prices in the markets in 2020.

Agenda

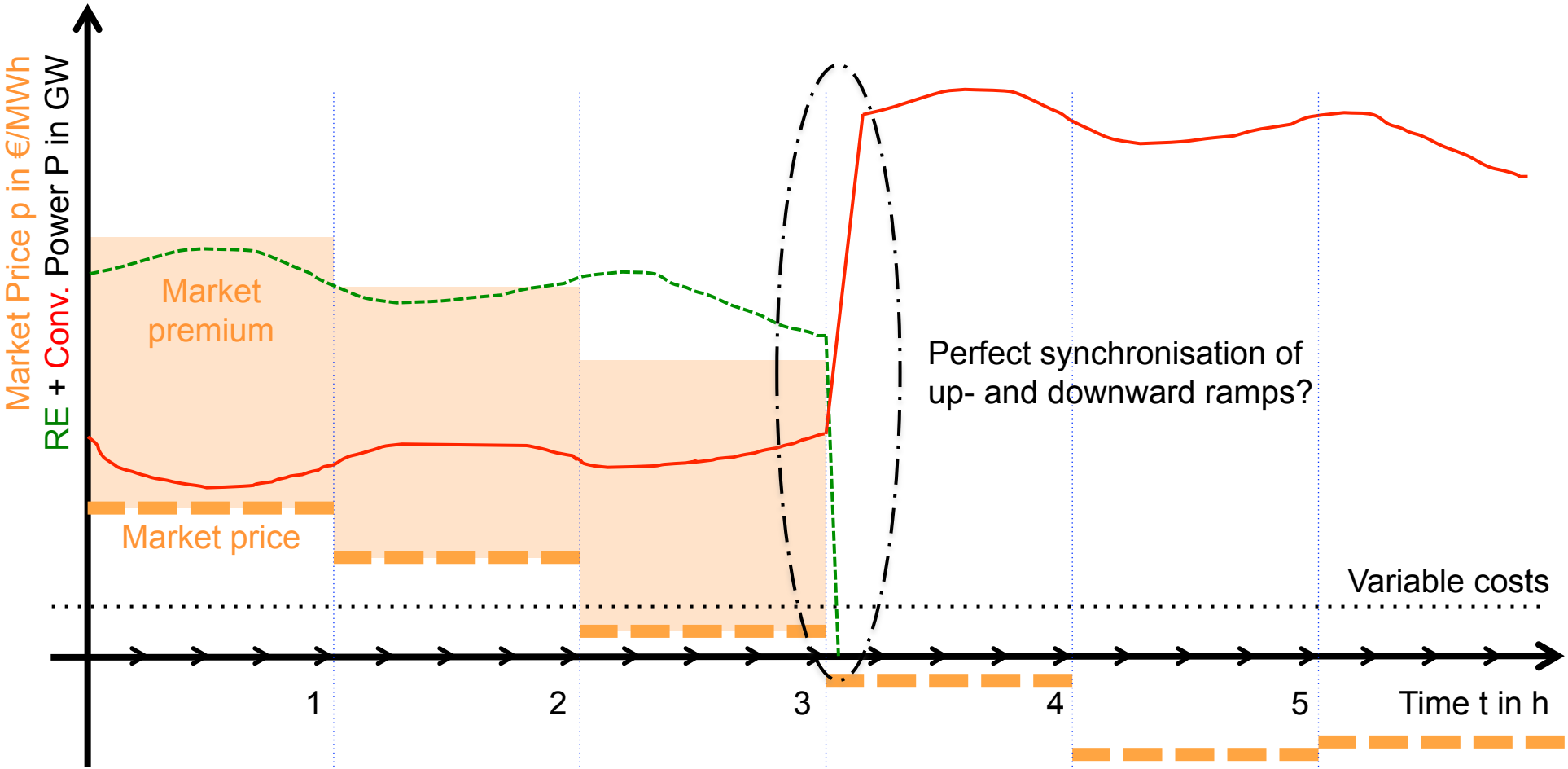
- Known Deterministic Frequency Deviations
- Visible Phenomena
- Negative Prices as Trigger Event

Merit Order Resorted after Loss of Financial Support for RES-E



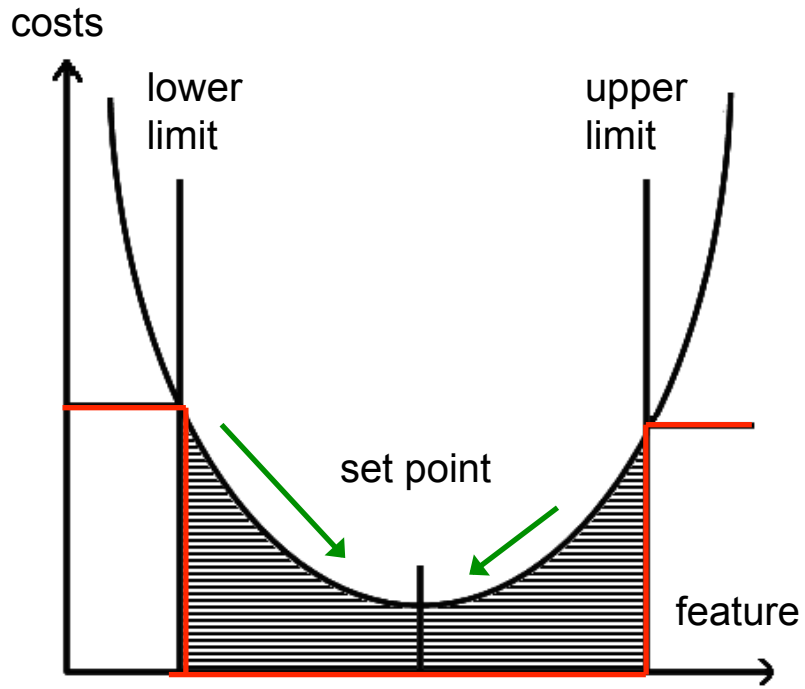


Changes within Energy-Trading Blocks



Any questions?
Ask now or later:

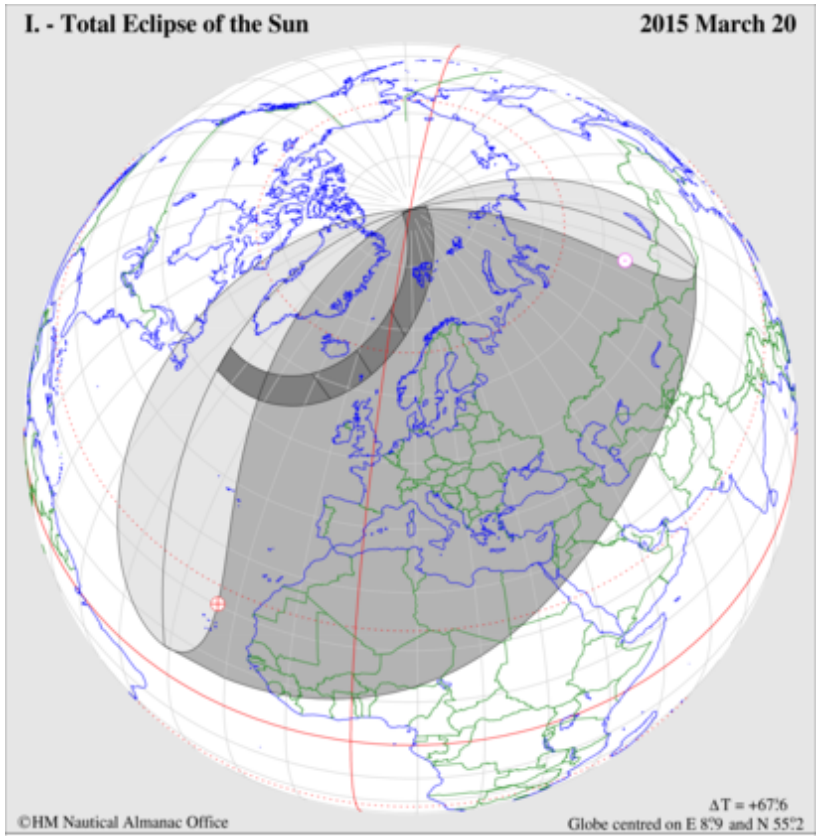
gunnar.kaestle@tu-clausthal.de
Tel. +49 5323 997724



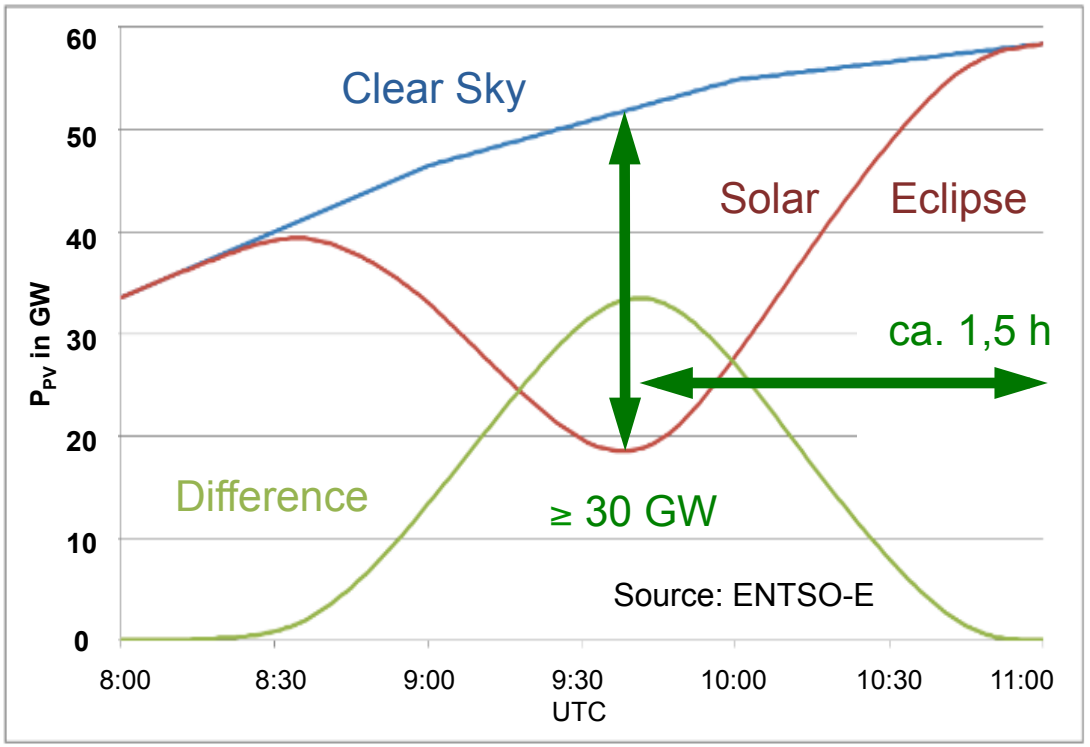
quality function according to Genichi Taguchi

Back-up Slides

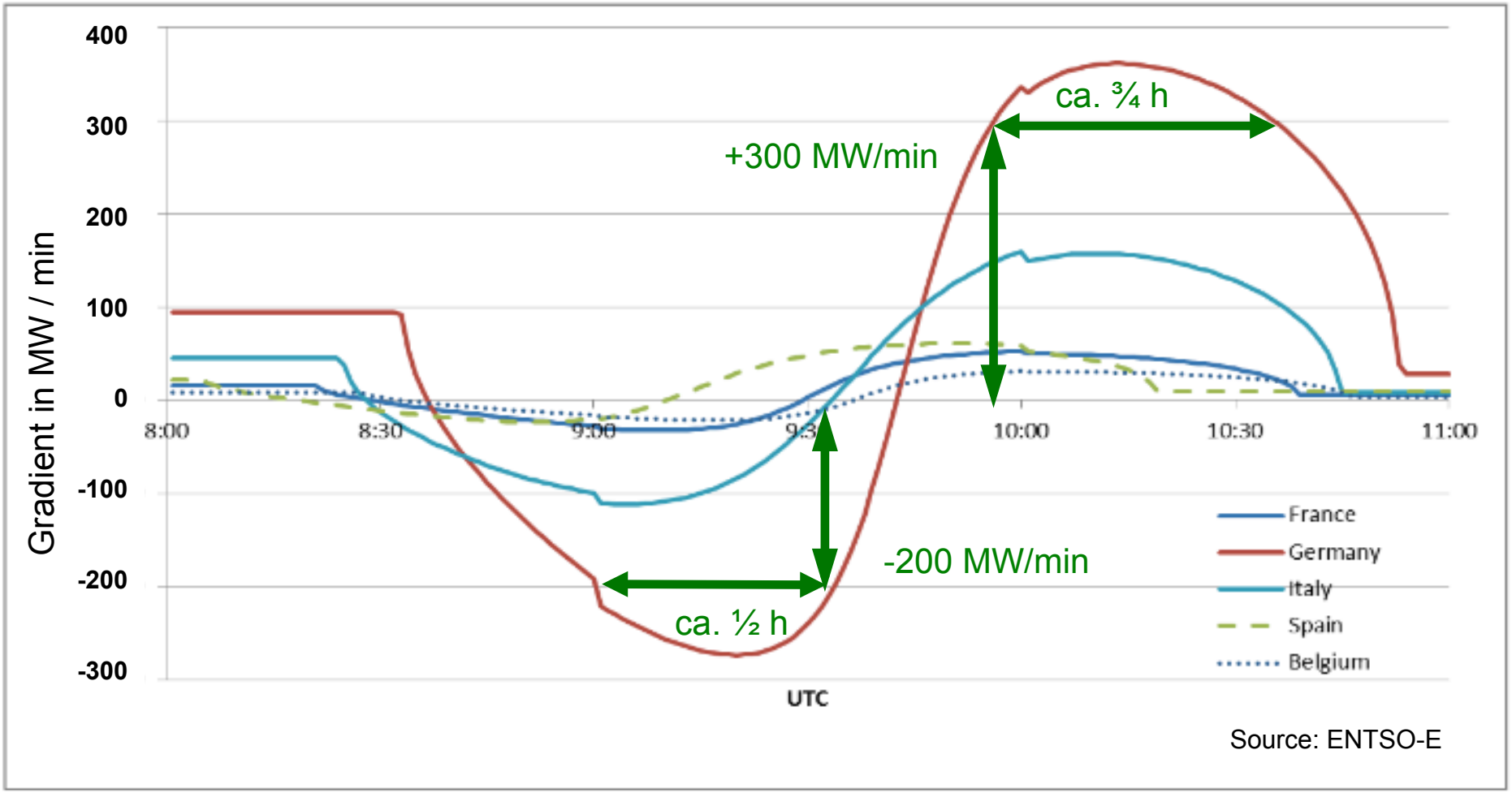
Solar Eclipse on 20th March 2015



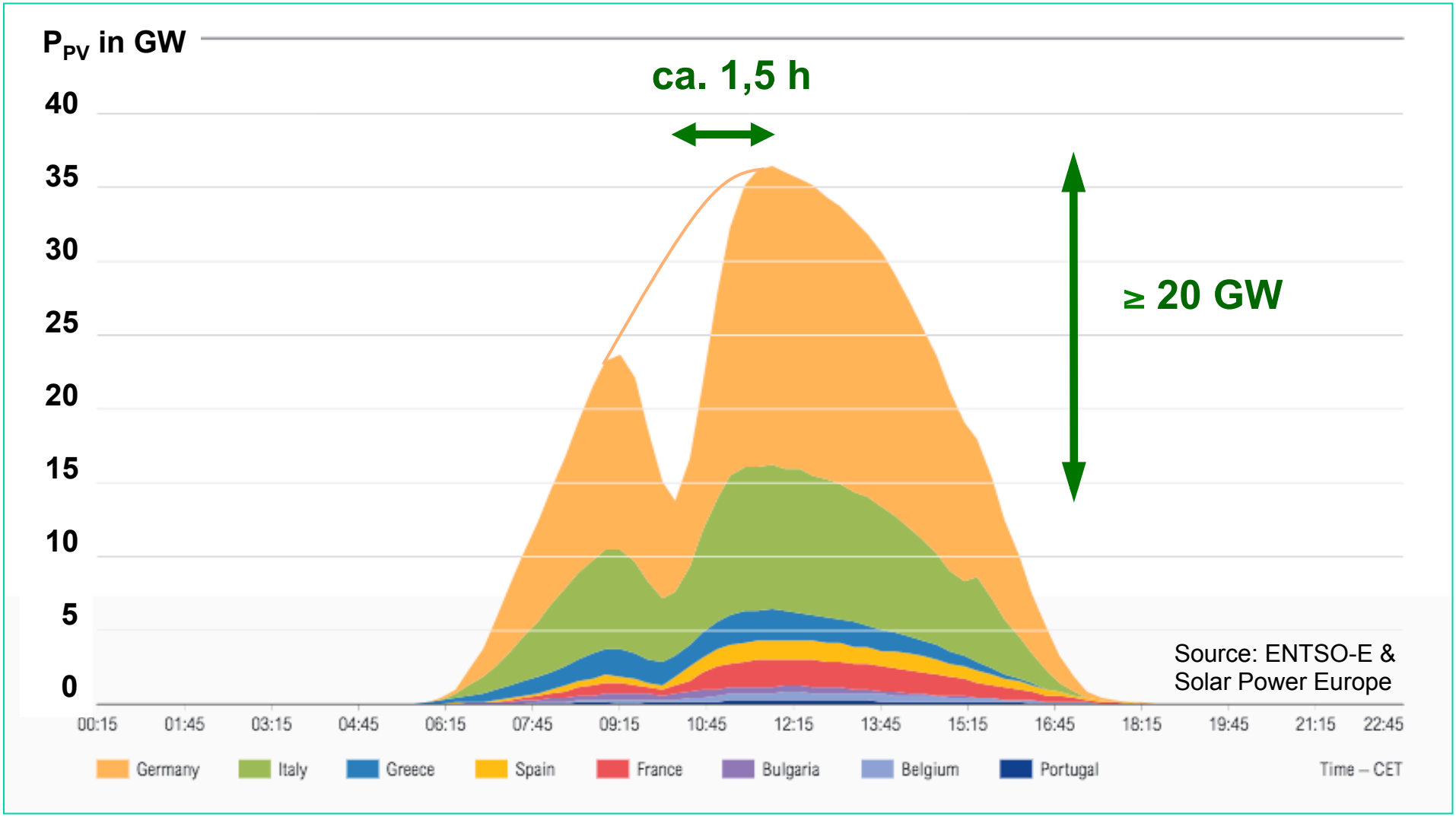
Maximum PV-Power Dip with Clear Sky Conditions



High Ramp Rates are Critical



Measured Feed-in on 20th March 2015



Different Stability Aspects

- A simplified view on stability of interconnected system demands:
  - sufficient voltage stability margins,
  - sufficient rotor angle stability margins,
  - sufficient frequency stability margins,
  - sufficient transmission capacity margins,
  - sufficient economical margins.

- Working Theses:
  - Frequency stability is questioned by eclipses in the form of deterministic frequency deviations.
  - Transmission capacity allocation & redispatching is getting more complicated.

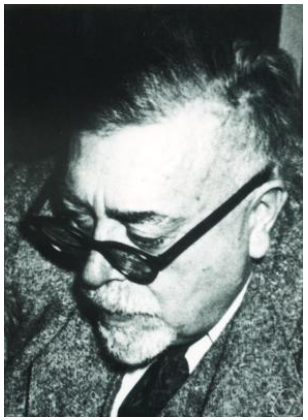
Take Care of Basic Principles!

- Stable behaviour from the viewpoint of control theory not only of technical but also economical systems
- LTI systems (linear time-invariant) are easy to analyse and should be an objective of system design

- Avoid dead time
- Avoid dead band
- Avoid hysteresis
- Avoid hard switching threshold **(step)**
  - Step in renumeration of ca. 50 €/MWh
  - High coincidence synchronised by energy markets

Two Control Theory's Fathers

- Norbert Wiener: Cybernetics
- Kybernètès (gr.) = helmsman
- Science of Control Loops & Controlled Systems
- Cybernetics or Control and Communication in the Animal and the Machine, 1948



Source: Wikimedia

- Jay Forrester: System Dynamics
- Simulation & Analysis of Complex Systems
- Including socio-economic models
- World3 – Meadows et al: Limits of Growth, 1972

Source: Wikimedia

European Commission, DG Competition: Implementing a Step

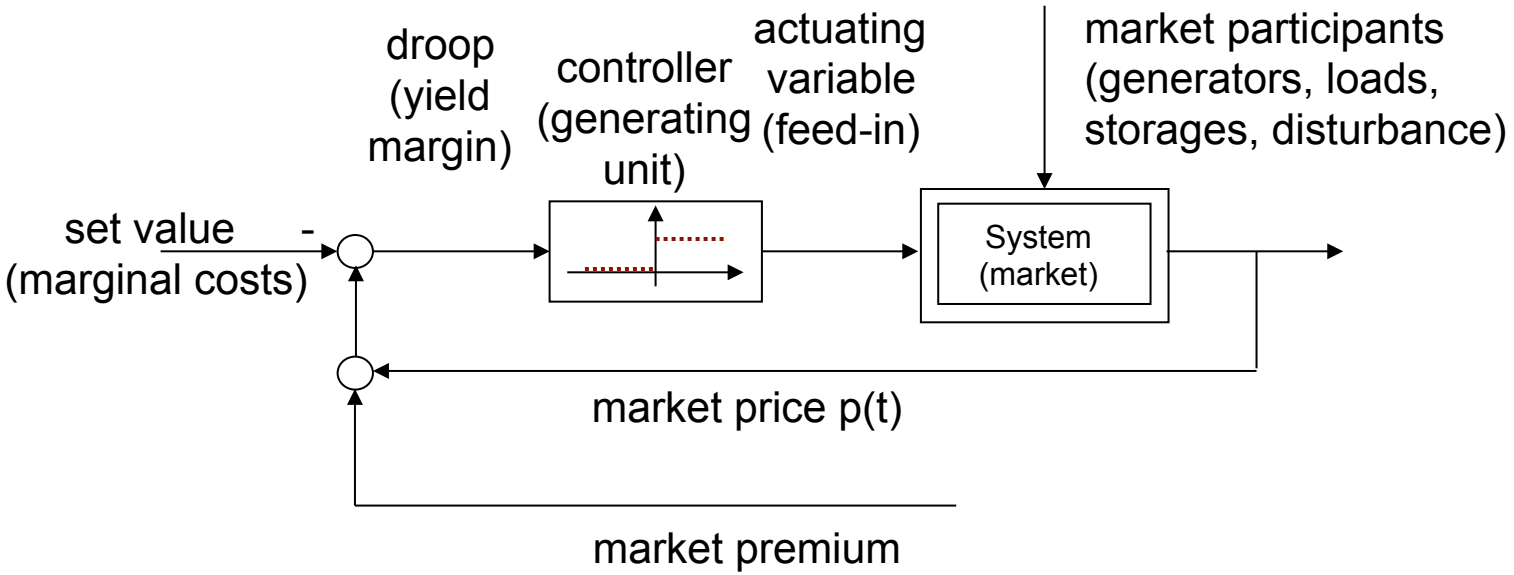
- Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01)

  3.3.2.1. Aid for electricity from renewable energy sources
- "measures are put in place to ensure that generators have no incentive to generate electricity under negative prices“

- Example: Implementation in Germany (EEG)
  - Renewable Energy Sources Act 2014, §24(1)
  - Renewable Energy Sources Act 2017, §51(1)
- “If the value of the hourly contracts on the day-ahead auction for the German price zone at the spot market of the electricity exchange is negative for at least six consecutive hours, the value [of RES-E support] to be applied shall be reduced to zero for the entire period in which the hourly contracts are negative without interruption.”

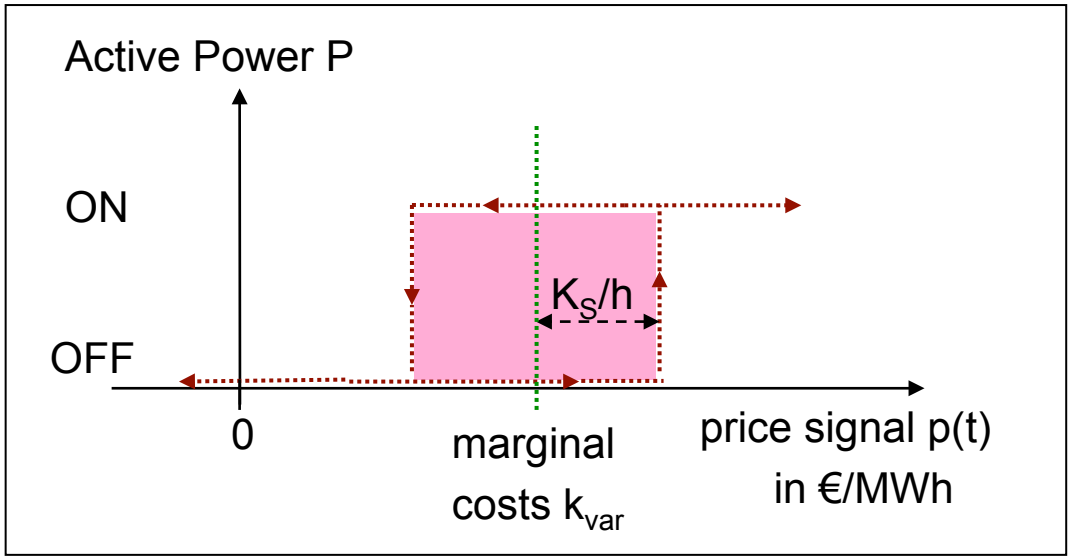
Price Signals in Closed Control Loops

- Generating unit (controller) reacts on price signal
- Market (plant/system) reacts on generation
- Closed loop structure, but only useful for price-elastic units

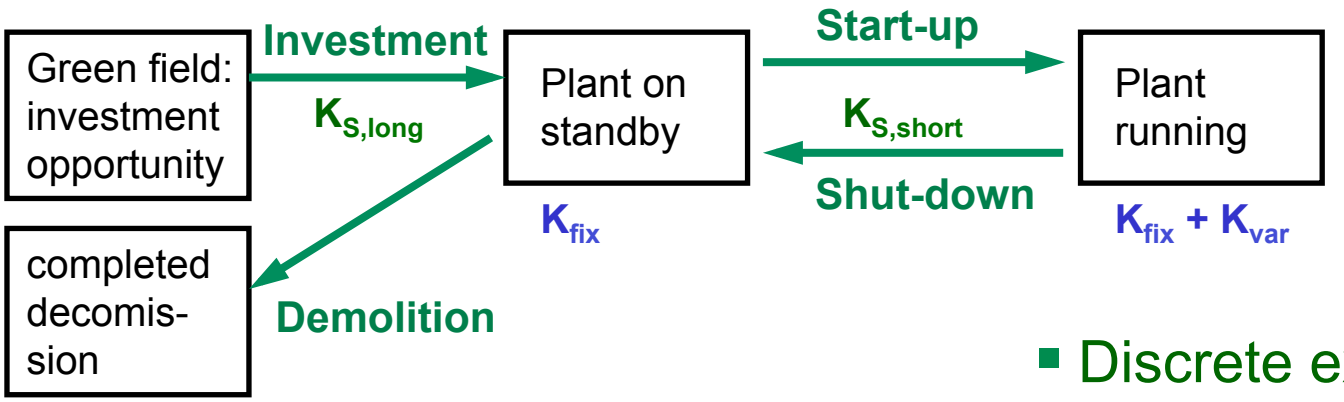


Market Distortion by Hysteresis

- Discrete switching costs K_S for on/off cycles cause
  - delayed start-up (higher market price)
  - delayed shut-down (negative profit margin)
- Width of hysteresis K_S/h is determined by the expected length h of the following On or Off cycle



Hysteresis in Different Time Domains



Short term hysteresis between

Start-up: Marginal costs + switching costs are covered

Shut-down: Marginal costs – switching costs are not covered

Long term hysteresis between

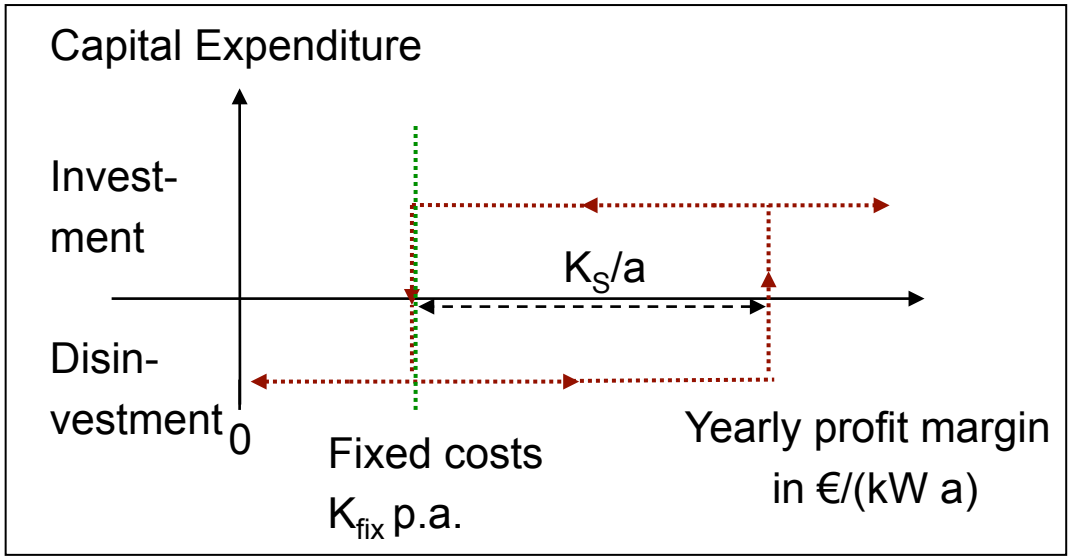
Investment: full costs are covered by market price

Decomission: variable and fixed costs (influenceable, w/o capital costs) are not covered by market price

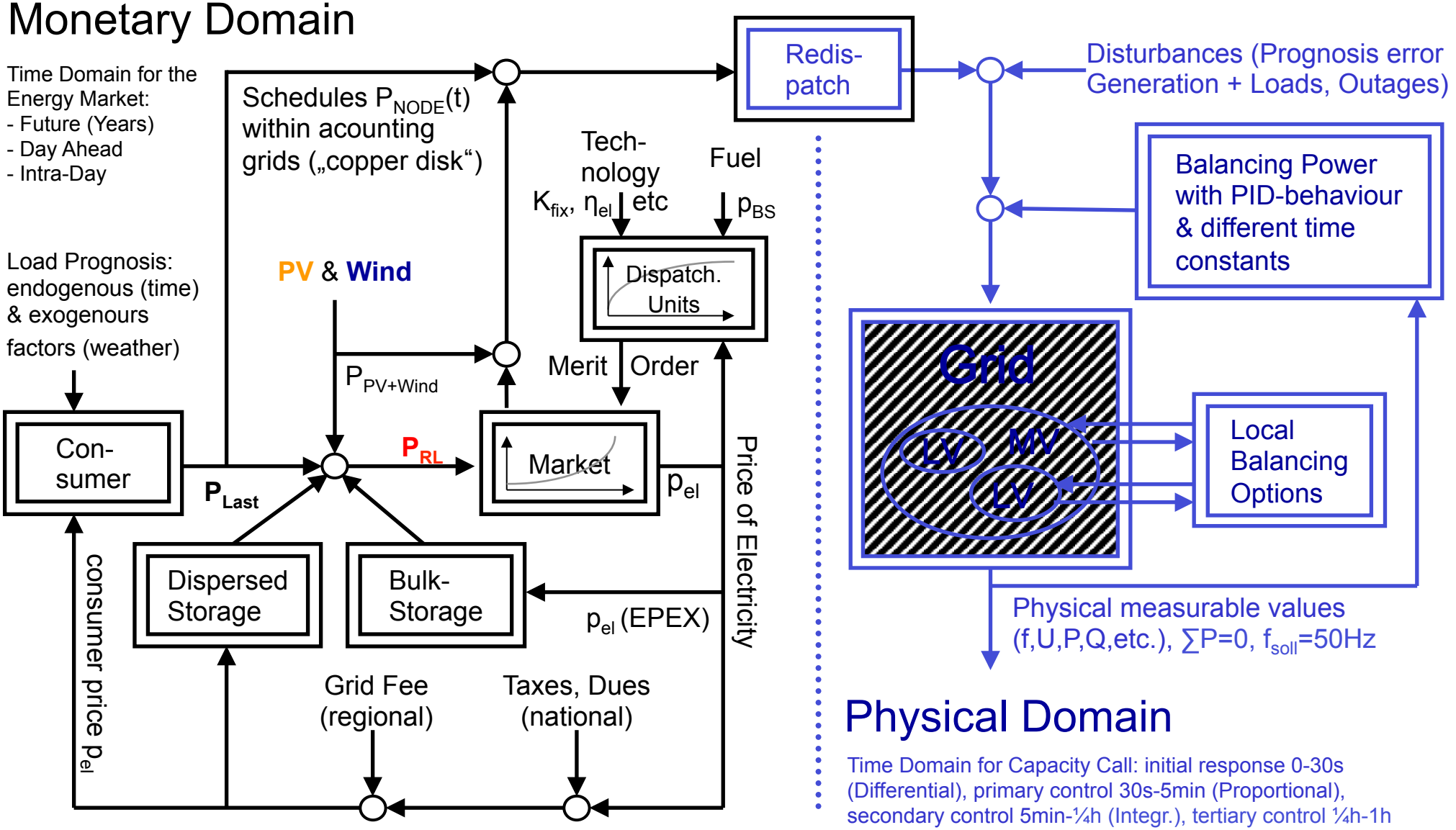
- Discrete expenses caused by changes of system state („switching costs“)
- Sunk costs are not relevant for decisions, only cost influencible in the future
- Continuous expenses in a certain system state (K_{fix}/a; K_{var}/h)

Deficiency to Adjust in the Long Term

- Discrete switching costs K_S for investment expenses
- Width of hysteresis K_S/a is determined by depreciation strategy and return on capital employed
- Wide range insensitive to market price changes
- Distinctive non-linear behaviour



Coupling of Technical and Economical Control Loops



Refinancing Mechanisms / Feed-in Remuneration at Cost

- Type **Energy Harvester**
  - uses non-storable primary energy
  - non-dispatchable & price-inelastic
  - wind, solar, run-of-river, etc.
  - **fixed feed-in tariff / sliding market premium with neg. feedback**

- Type **Load Following Unit**
  - uses storable primary energy
  - dispatchable & price-elastic
  - hydro (reservoir), biomass, CHP, energy storage etc.
  - **flexible market premium with positive feedback**

Smart Bidding: Short Term Option

- EEG 2017 makes clear:
  - Reference price is provided by day-ahead-auction
  - No change in the general scheme from EEG 2014 to EEG 2017, e.g. ID opening auction or ID_3-price from continuous trading as trigger signal
- If the day-ahead price stays positive, the EEG remuneration is kept even if the intraday price falls below zero.
- Proposal for bidding strategy:
  - Submit to DA-auction only selling orders with positve limit (e.g. marginal costs without the EEG market premium)
  - If DA market price is negative (RES energy partially not sold) the residual volume can be sold on ID market at negative price without loosing EEG payment

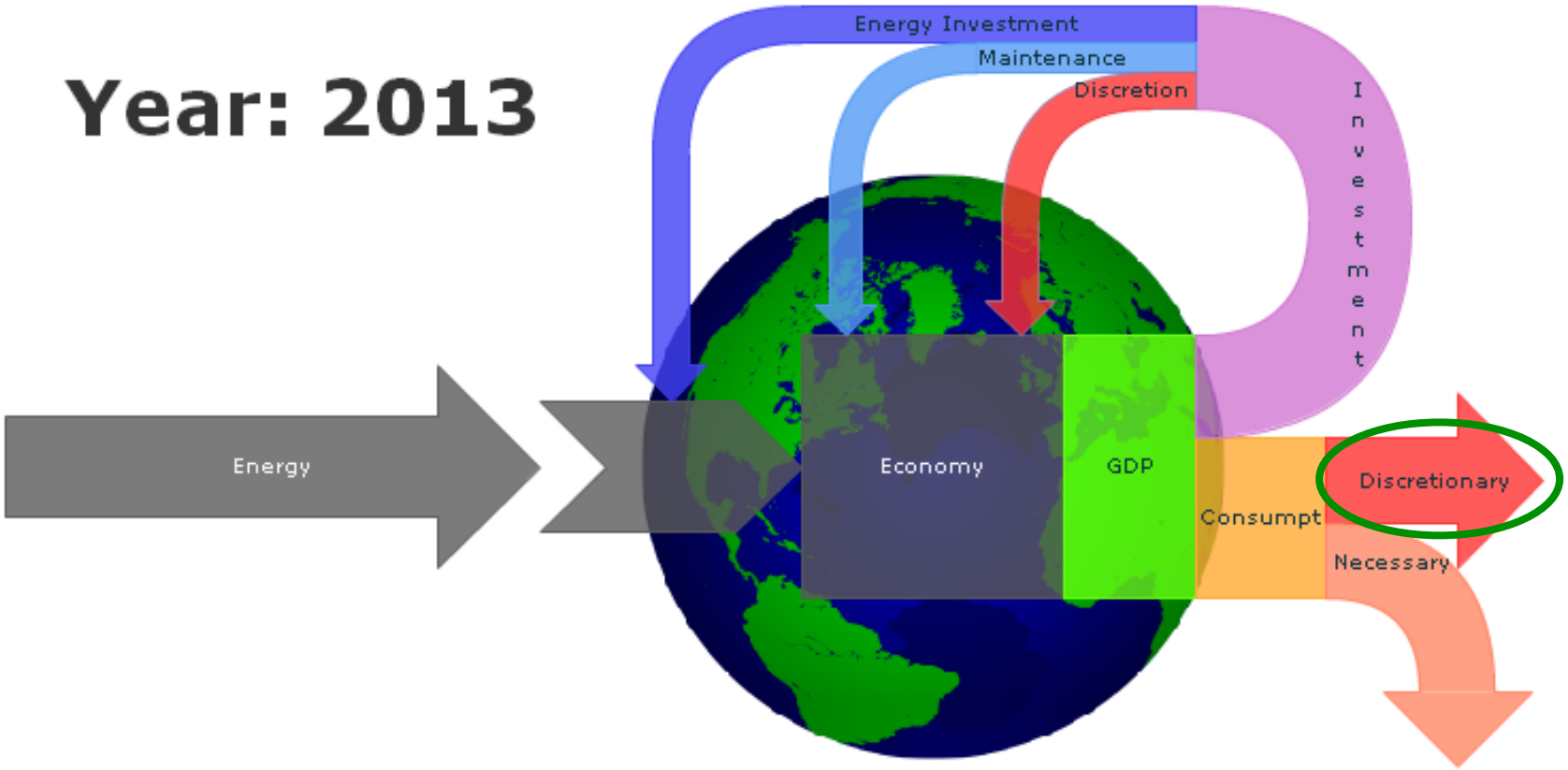
Teleological Interpretation: Long Term Option

- Guidelines on State aid for environmental protection and energy 2014-2020 (2014/C 200/01)

  3.3.2.1. Aid for electricity from renewable energy sources
- "measures are put in place to ensure that generators have no incentive to generate electricity under [considerable] negative prices“

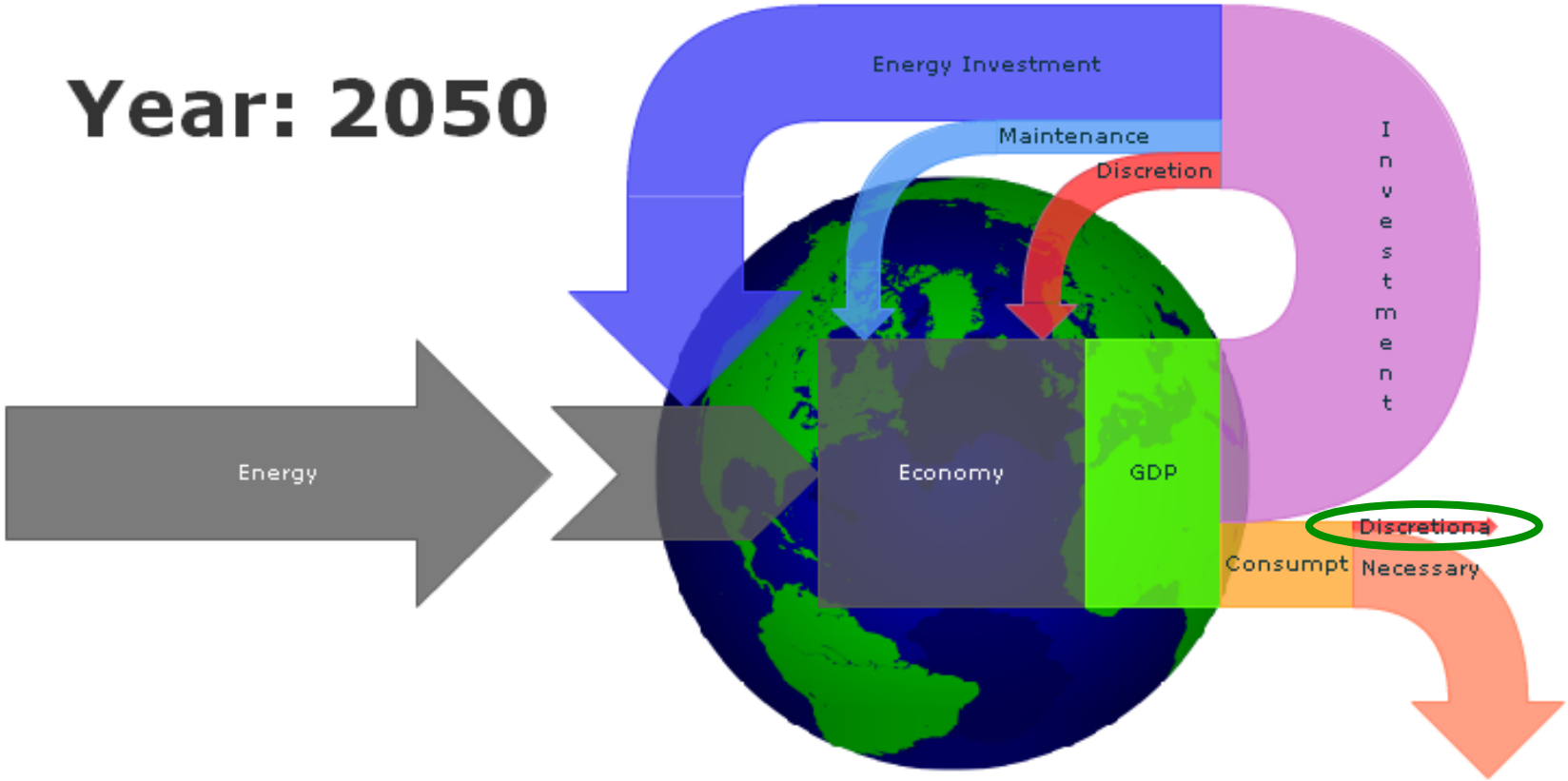
- Negative prices are valuable signals that address inflexible assets in dispatchable power plant parks and should not be be diluted.
- Market premium model already leads to a curtailment of RES-E at considerable negative prices.
- Solar and wind power are not price elastic, i.e. at higher prices the RES-E production tends to be less than at lower prices.

Reinvestments in Energy Infrastructure I



Source: Charlie Hall

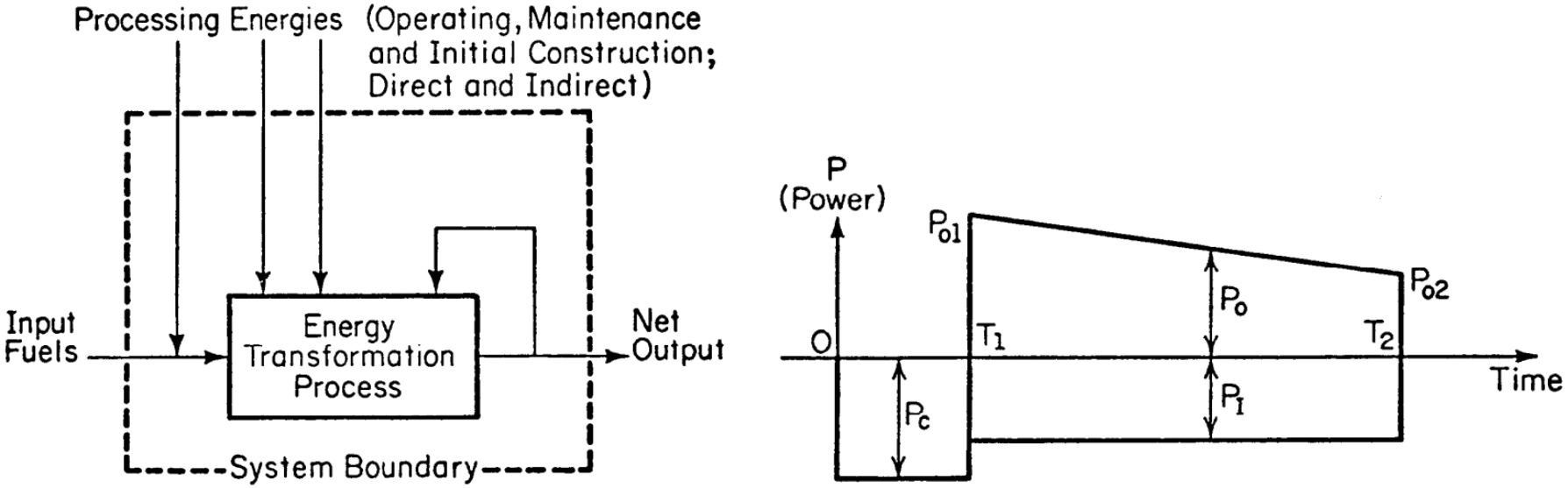
Reinvestments in Energy Infrastructure II



Source: Charlie Hall

Energy & Exergy Discounting

- Discounted integral of en-/exergy flow P(t) as physical yardstick
- Exergy investment (cumulated exergy used for construction)
- Useful end exergy pays back invested exergy
- Exergetic NPV with internal interest rate = „natural“ energetic yield



Source: Bruce Hannon, 1982

Perspective Outlook for a EU 100%-RES-E-Szenario

- 1000 GW wind turbines – ca. 2000 TWh
- 1000 GW photovoltaics – ca. 1000 TWh

- short term storage: 3000 GW
  - seconds to hours; 10 kW × 300 Mio electric vehicles
- medium term storage: 500 GW
  - hours to weeks; use of (renewable) fuels during dark calms
- seasonal storage avoided by 1:1 ratio of wind & solar

- Development of electricity prices at negative residual load?
- Dual use of short term storage, but who invests in medium/long term storage?

Load Duration Curve for 100%-RES-E-Scenario (Example)