# Pump-Storage Hydro Power Plants in the European Electricity Market

Presentation for CGNPC
at Andritz headquarter
Graz, 27th Oct. 2010

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Graz University of Technology

# Brief Introduction of the Institute

## General

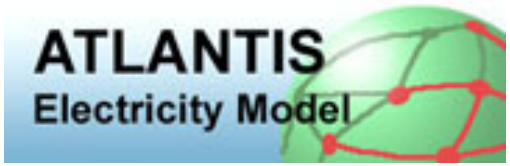
- Foundet 2000
- Interdisciplinary Approach

## Research

- ATLANTIS model of the european electricty system
- Energy Conception
- Public Interest
- Energy Psychology

## Teaching

- Electrical Engineering,
- Industrial Engineer




# The Team

| | |
|---|---|
| Udo Bachhiesl: | RES, regulation |
| Christoph Gutschi: | project management, thermal power, business models, |
| Christoph Huber: | grid and load flow, hydro power, algorithms |
| Alexander Jagl: | programming, database development |
| Gernot Nischler: | fuel prices, NTCs, phase shifting |
| Heinz Stigler: | project initiator, supervisor |
| Wilhelm Süßenbacher: | market development |

and many more

100 % self-financed by Graz University of Technology

# Content

# Content

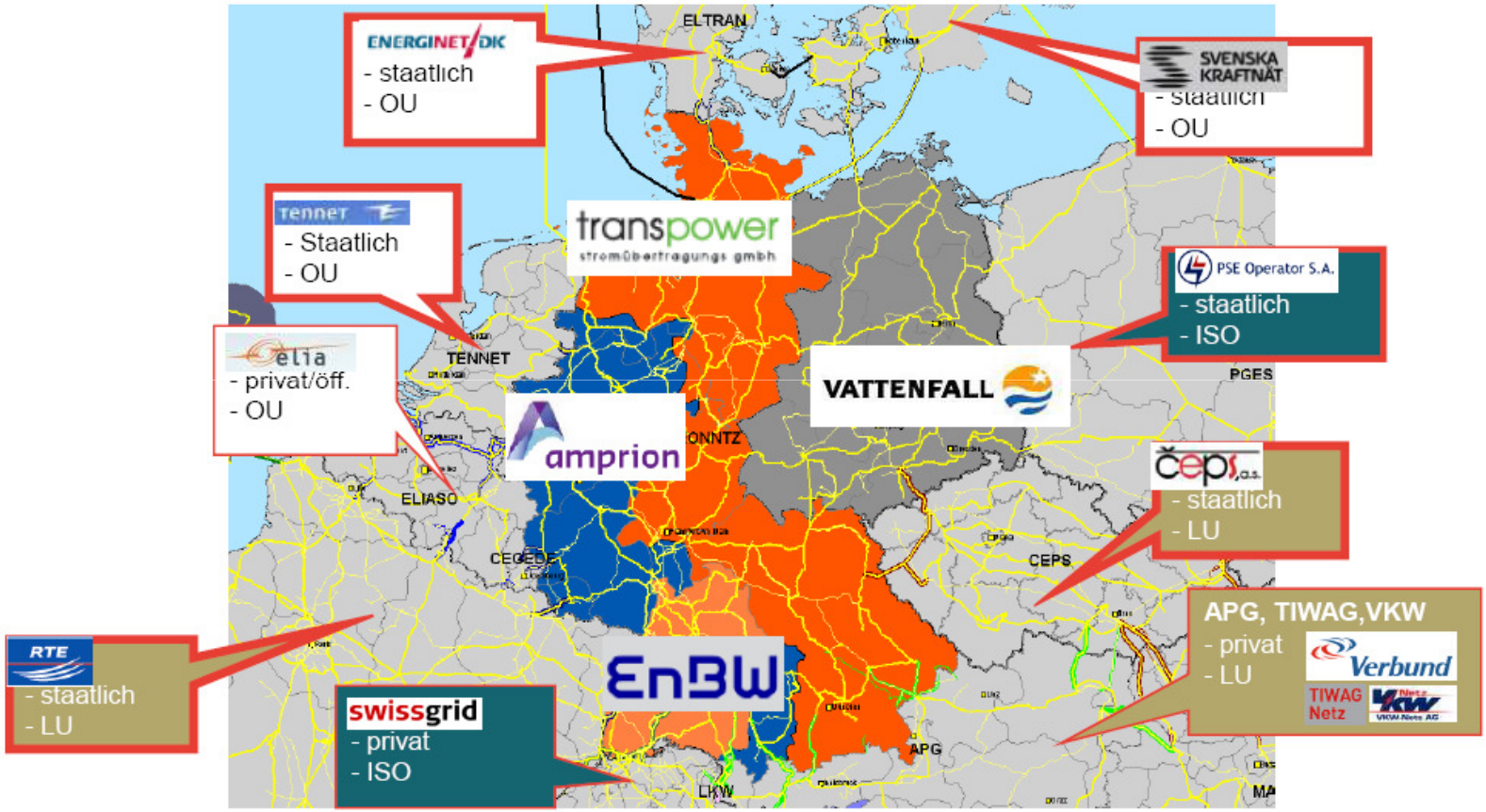
- Electricity Market in Europe
- Overview of pump storage power plants in Europe
- Key Properties of pump storage power plants
- Tasks of pump storage power plants in Europe
- Market participation of pump storage power plants
- Scenarios for the development of the electricity economy in continental Europe

# Overview of the European Electricity Market

# Market Liberalization in Europe

- 1996 First EU-Guideline to establish a common market for electricity
  - Stepwise market opening
  - Legal unbundling, Competition in Generation, Trade and Reselling
- 2003 Second EU-Guideline to accelerate the European market integration
  - Full liberalization June 2007
  - Establishment of national regulators
  - Transmission and distribution tariffs
- 2009 Third guideline for the European electricity market
  - Transmission system Unbundling
  - Promotion of regional cooperation
  - Indepedent Regulators

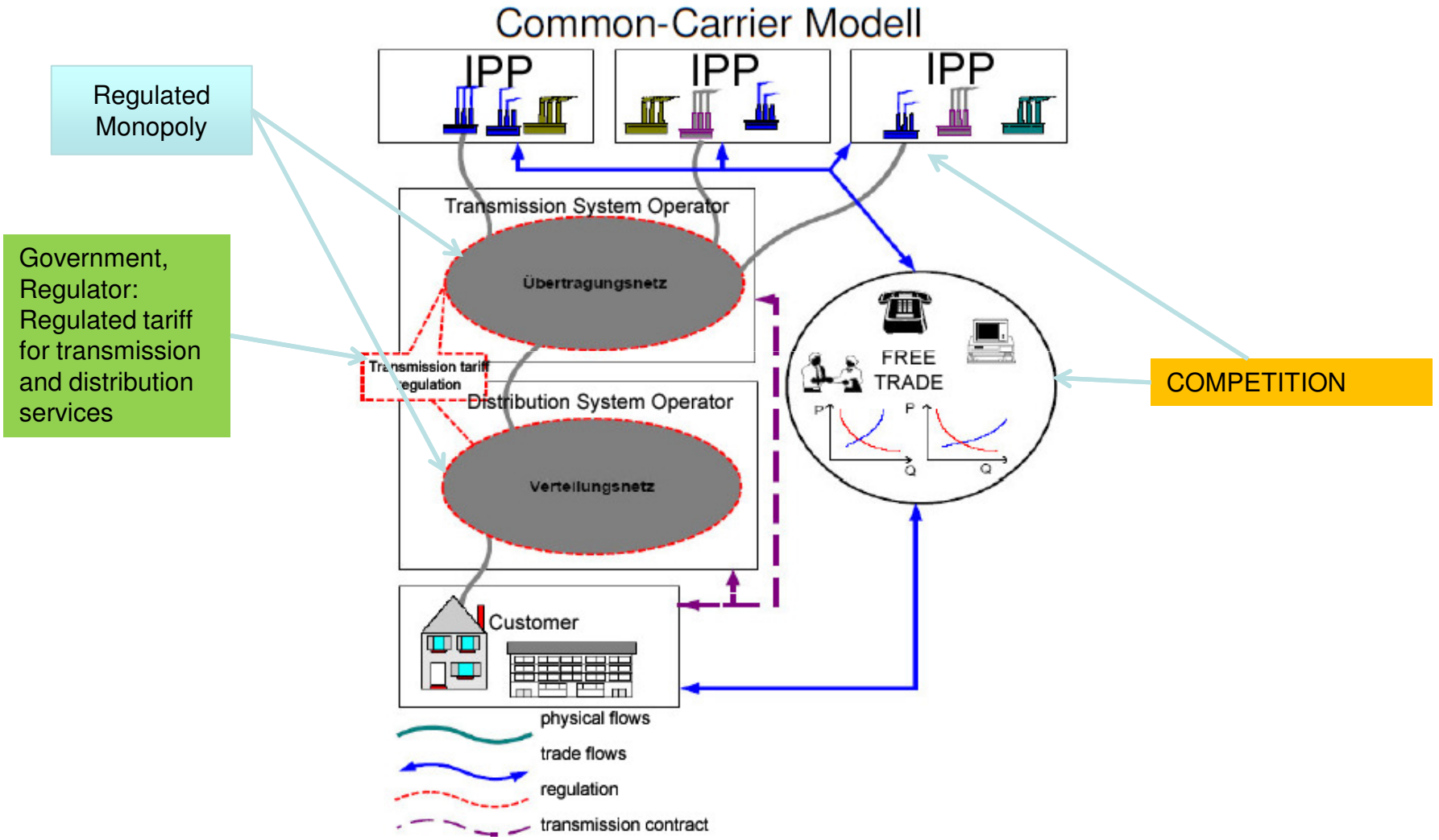
# Transmission Unbundling in Europe



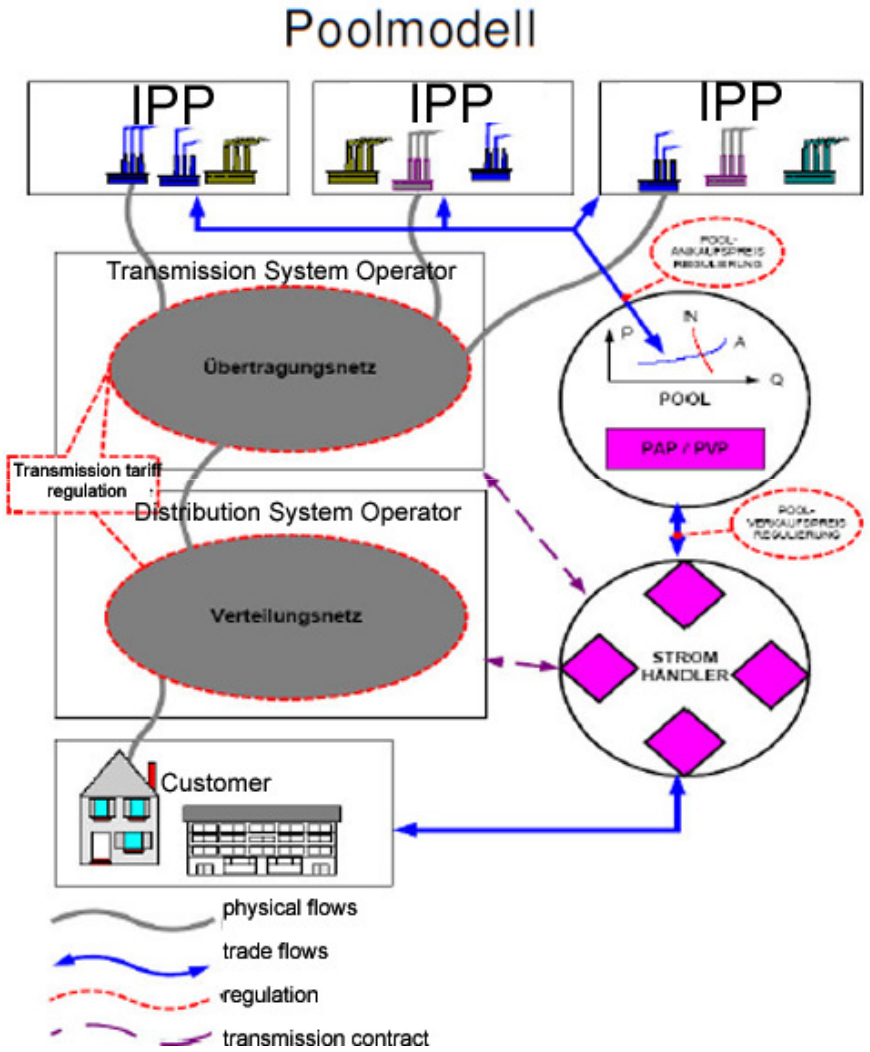

*LU: Legally Unbundled*
*OU: Ownership Unbundled*
*ISO: Independent System Operator*

International treffen wir auf sehr unterschiedliche Organsiations- und Eigentümermodelle

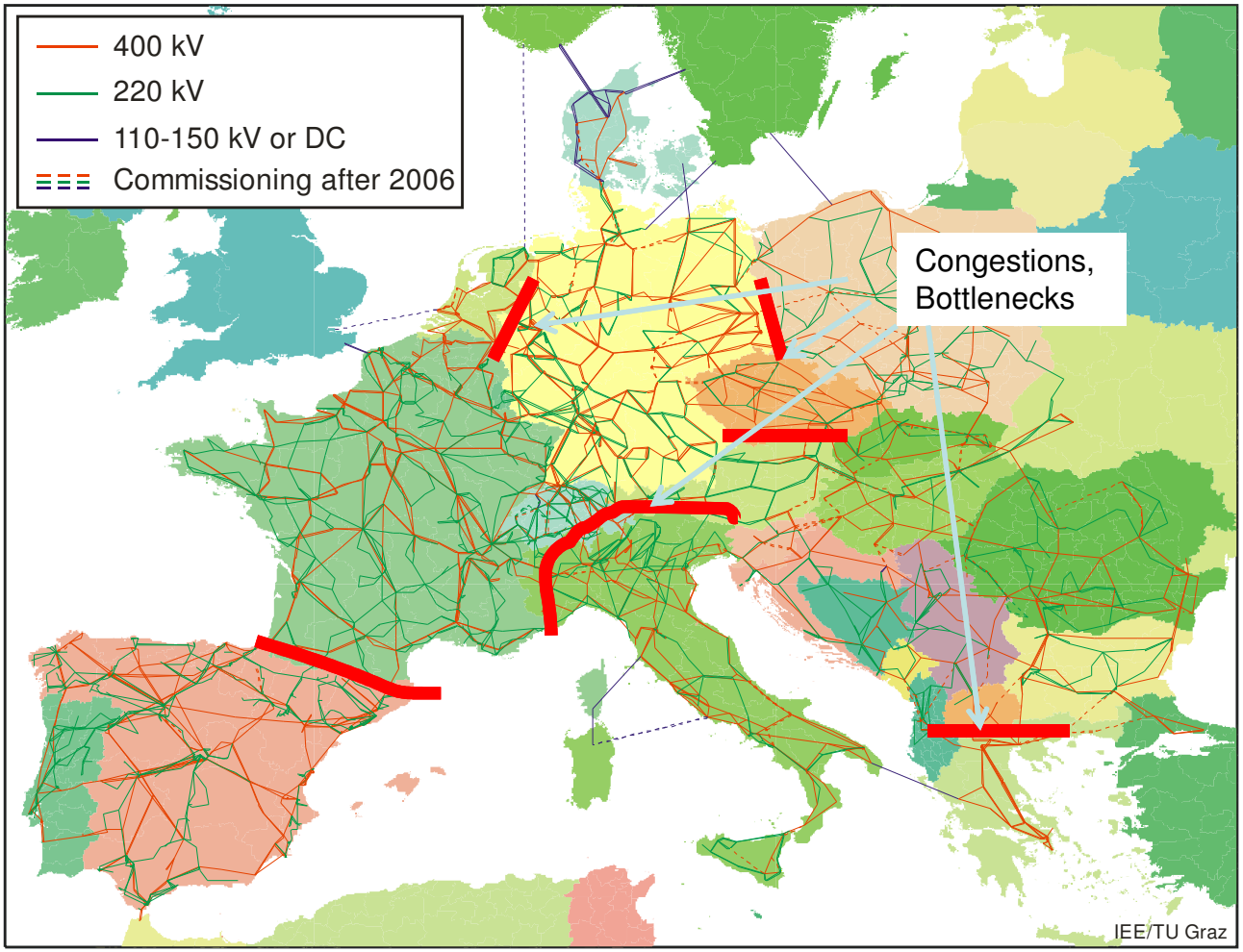
# Market Model (Standard in Europe)



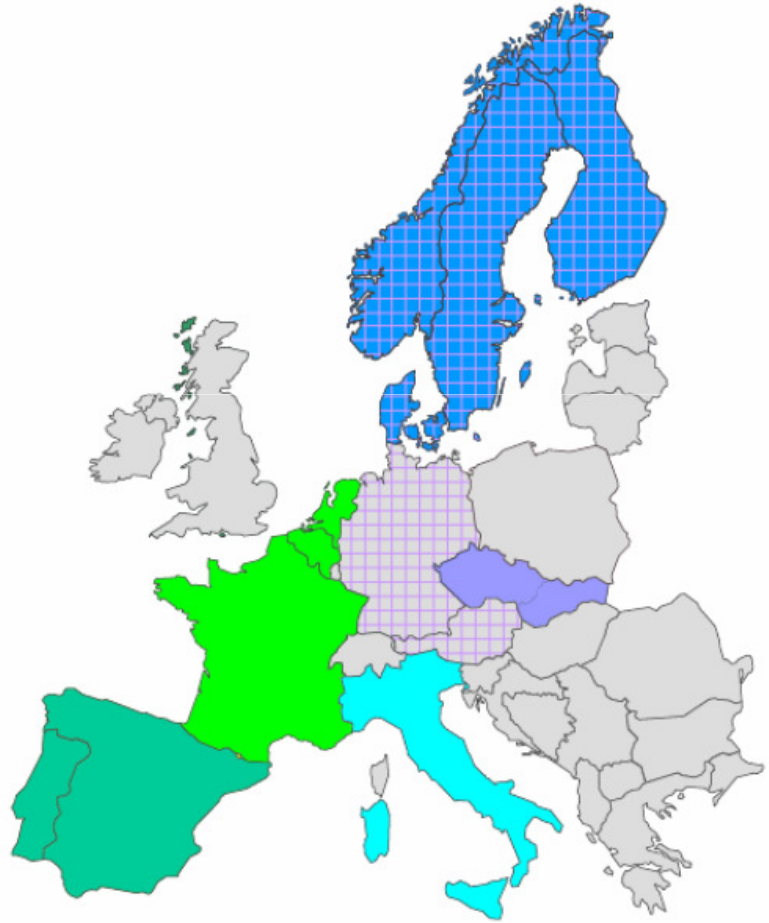
# Market Model



# Congestions in European Transmisison System



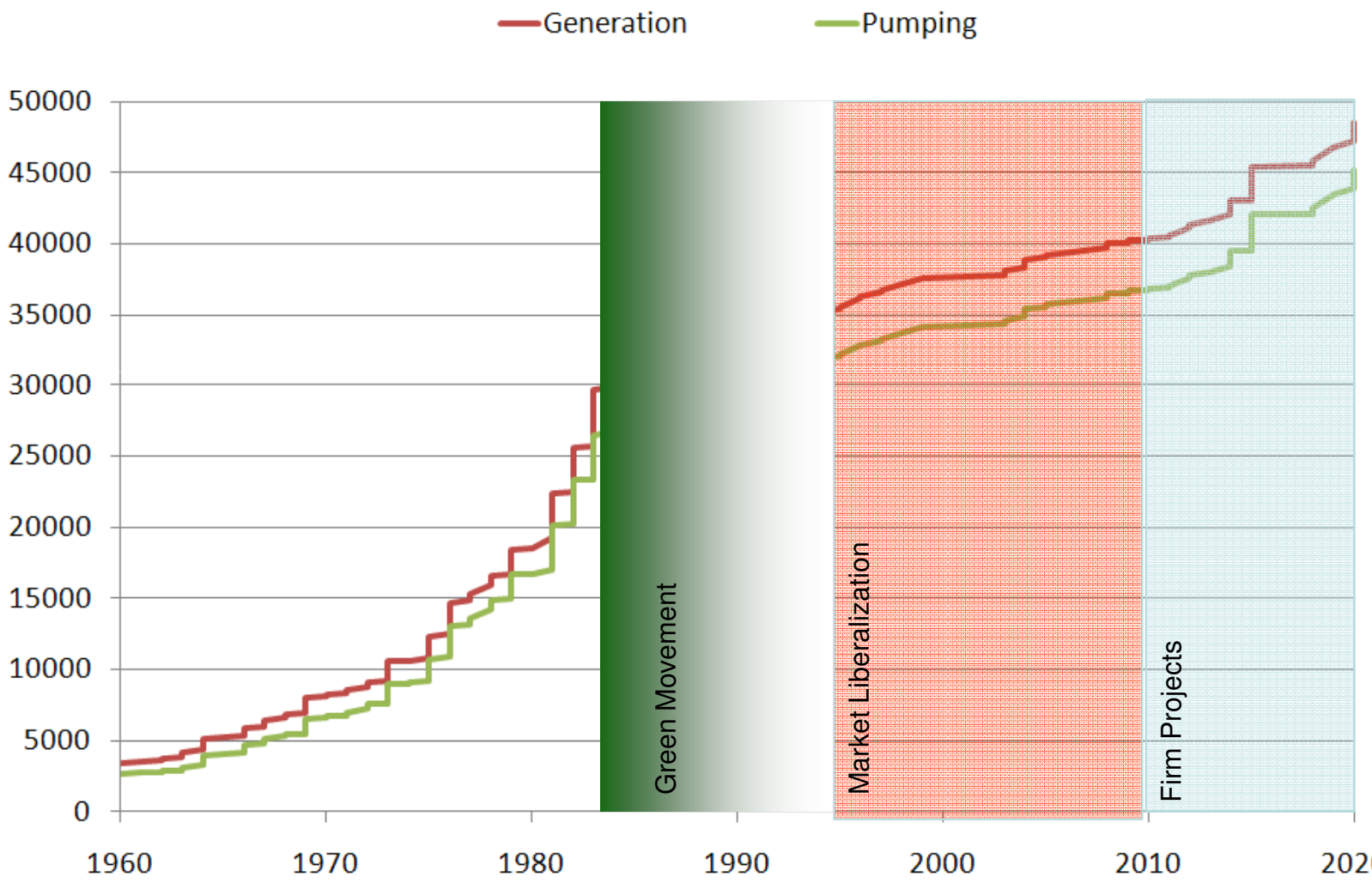
# regional markets with different market prices for electric energy through congestion



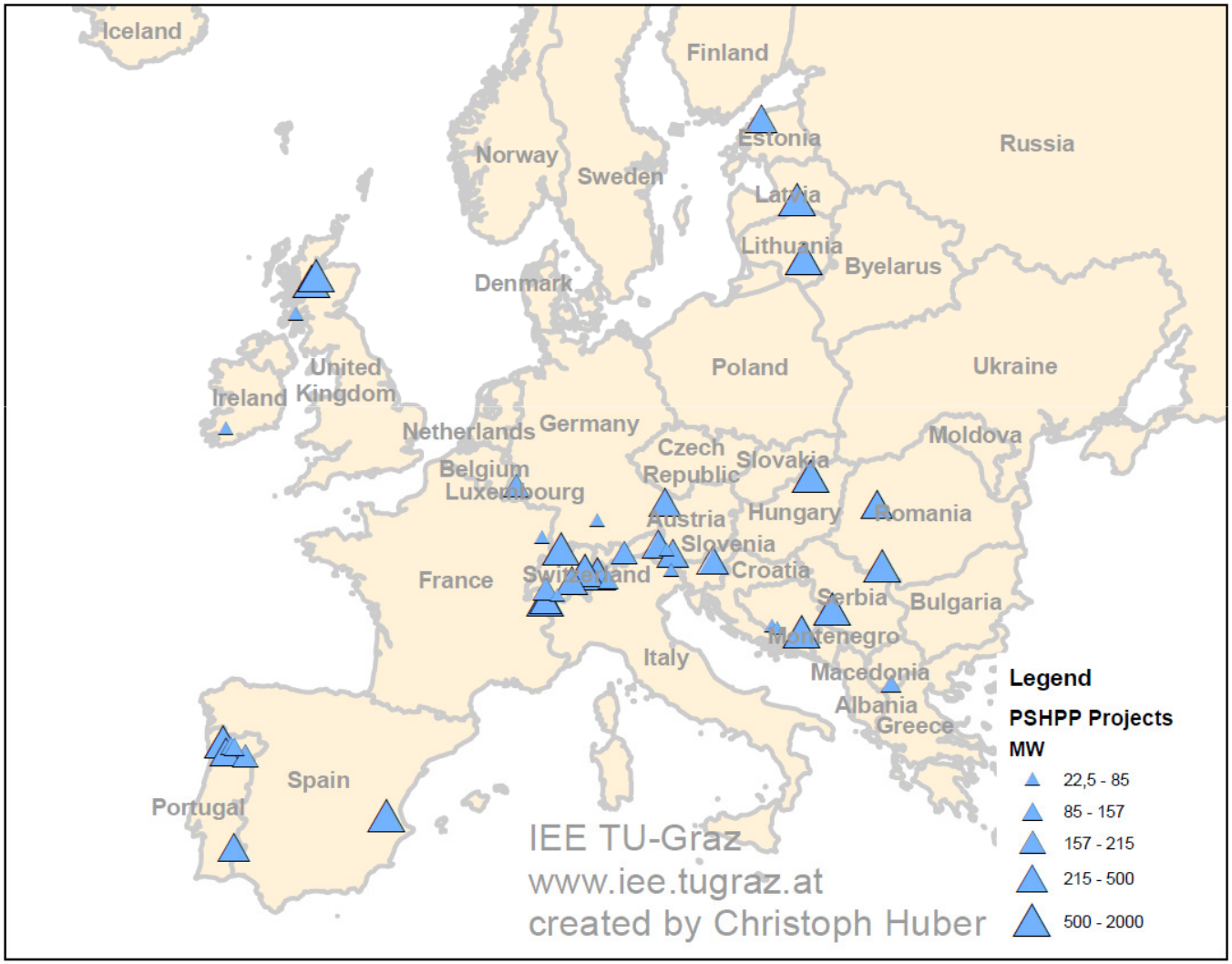
| | |
|---|---|
| Nordic | Market splitting |
| EMCC | Tight volume coupling |
| TLC | Price coupling |
| Mibel | Market splitting |
| Italy | Market splitting (internal boundaries) |
| Czech Rep - Slovakia | Market splitting |

# Overview of pump storage generation in Europe

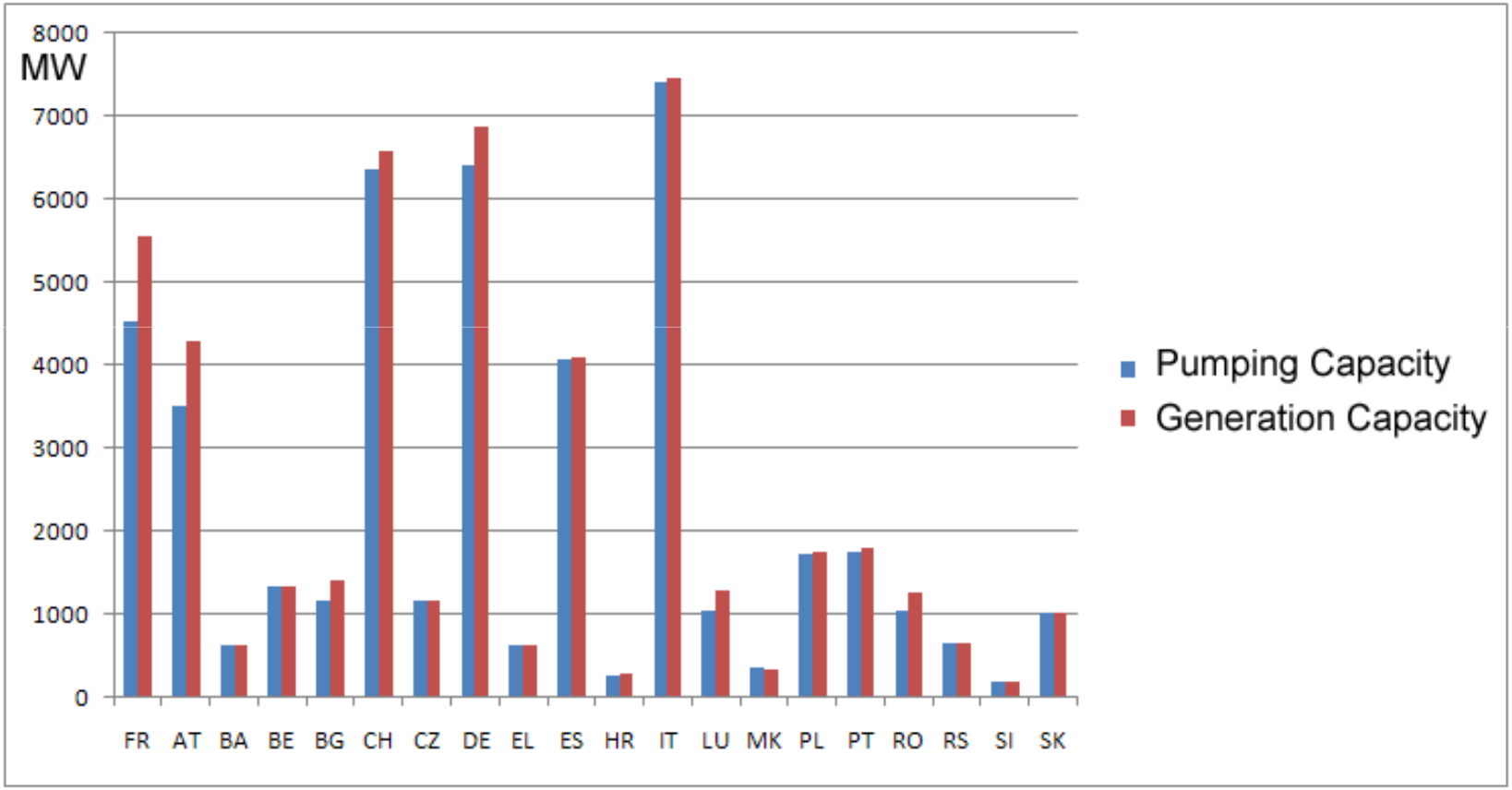
# Development of installed PSPP in Europe



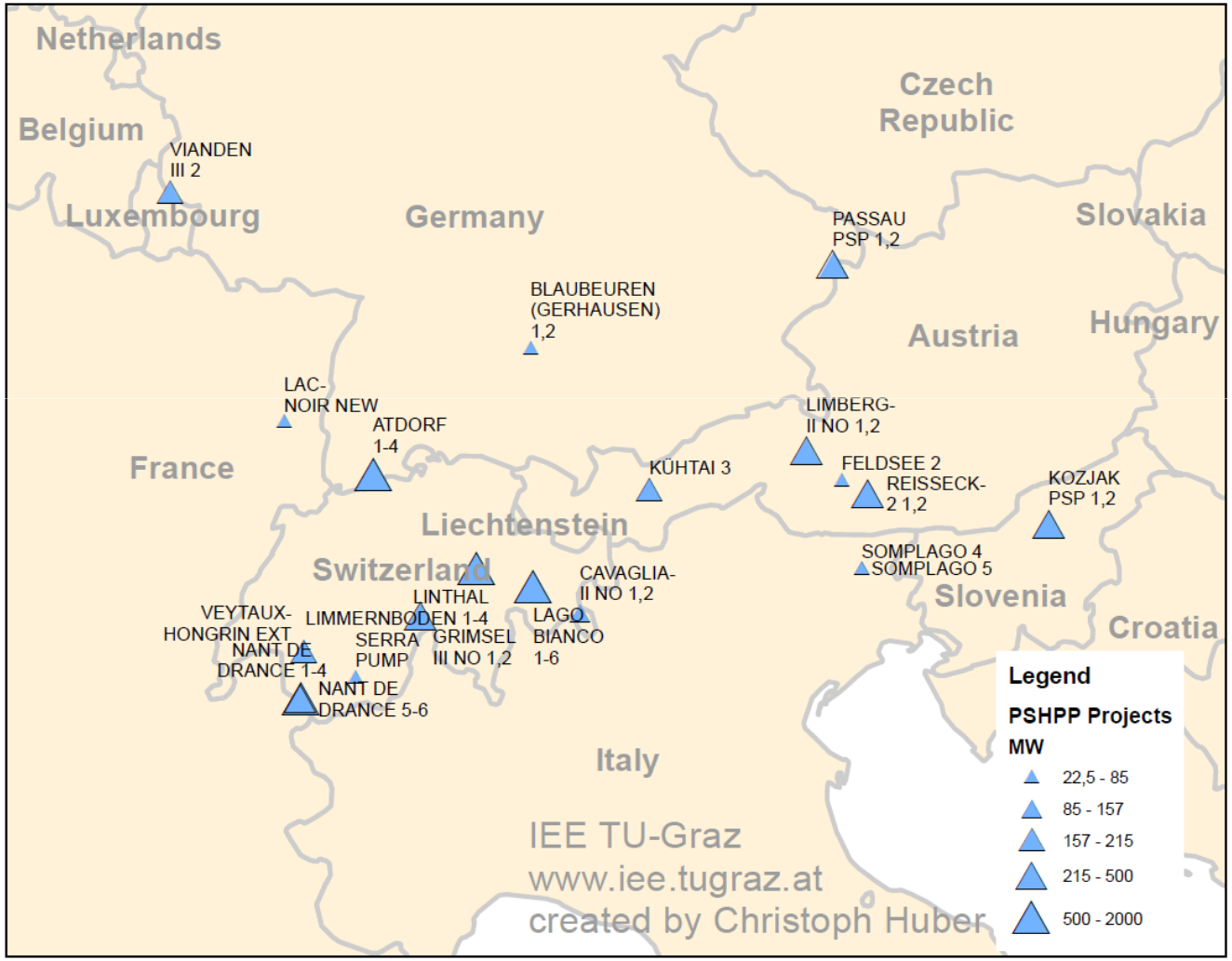
# Planned, projected and powerplants under construction in continental Europe



# Pump Storage Power Plants by Country

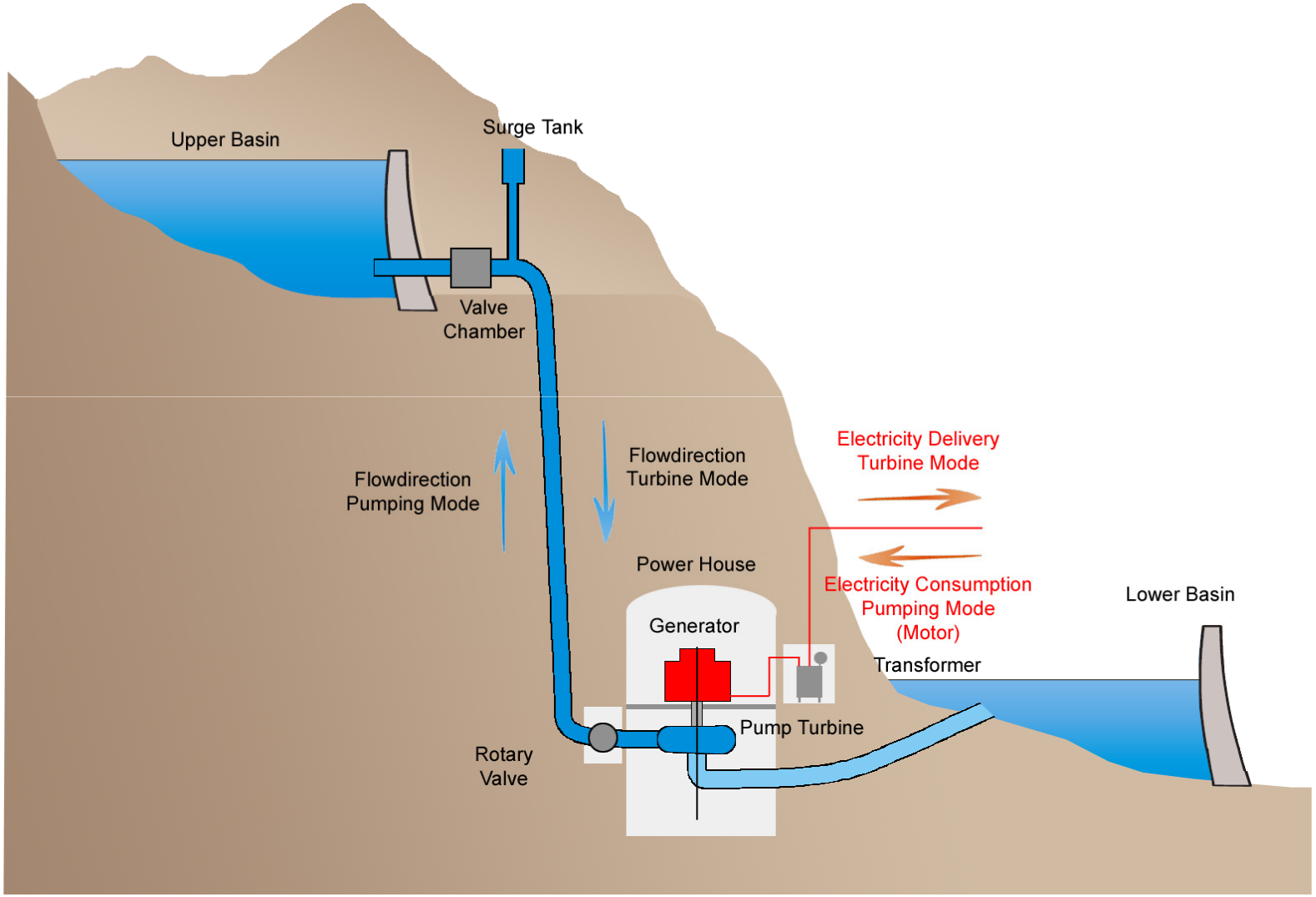


# Power plants und construction and planned PSPP

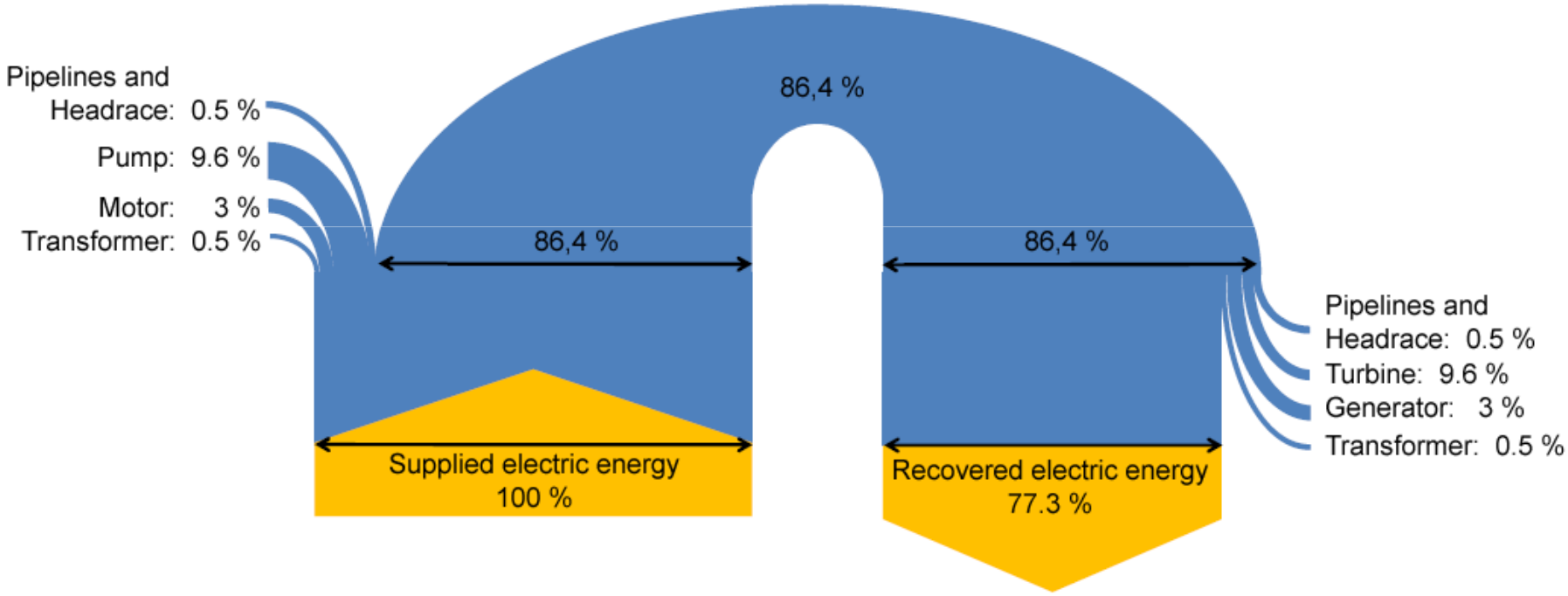


# Key Properties of Pump Storage Power Plants

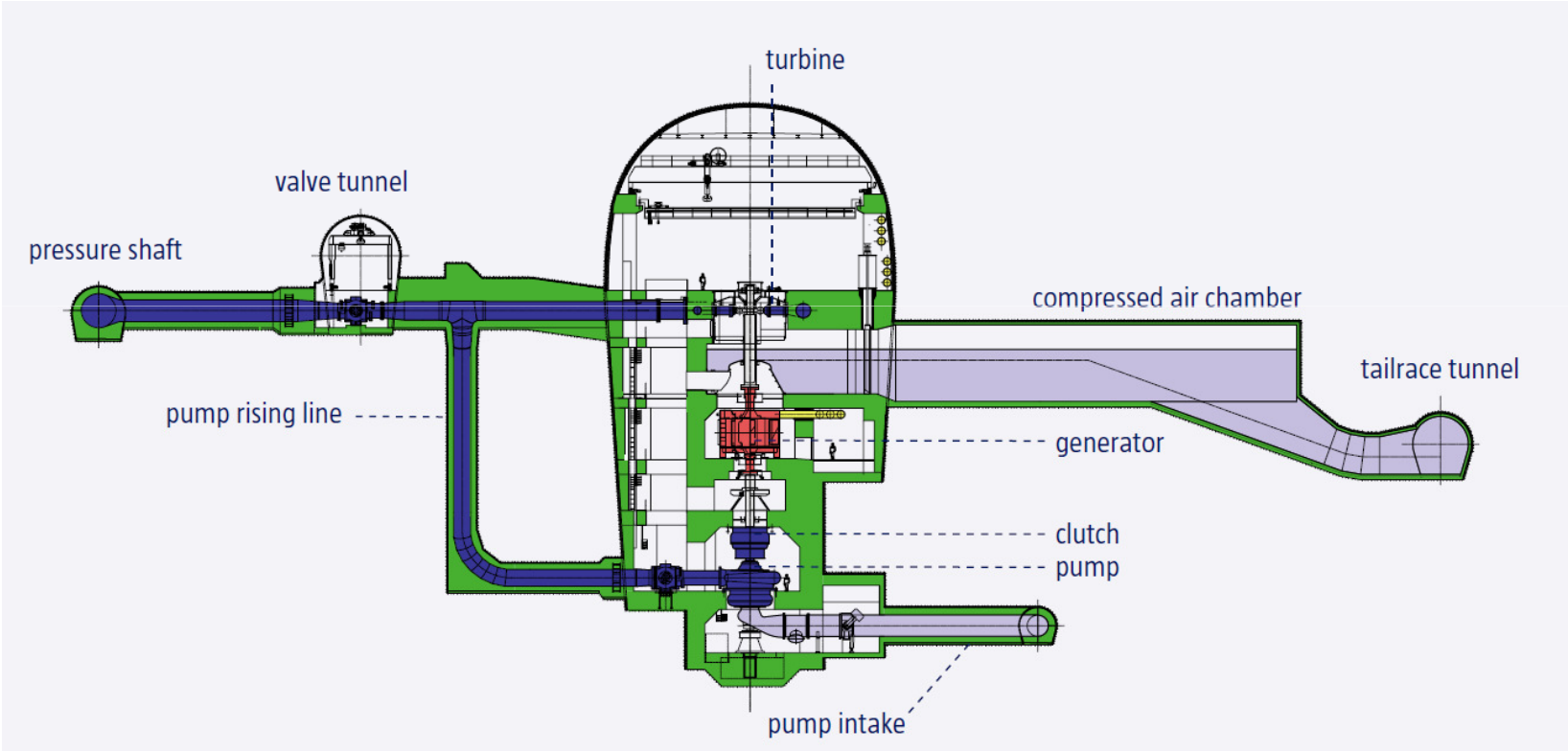
# Main operation modes of PSPP



# Energetic Efficiency of PSPP

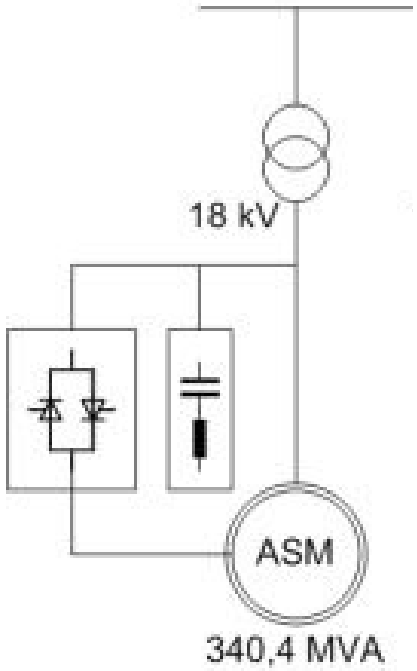


# Innovative PSPP System Conceptions (1)
# Ternary system with hydraulic short cuircuit

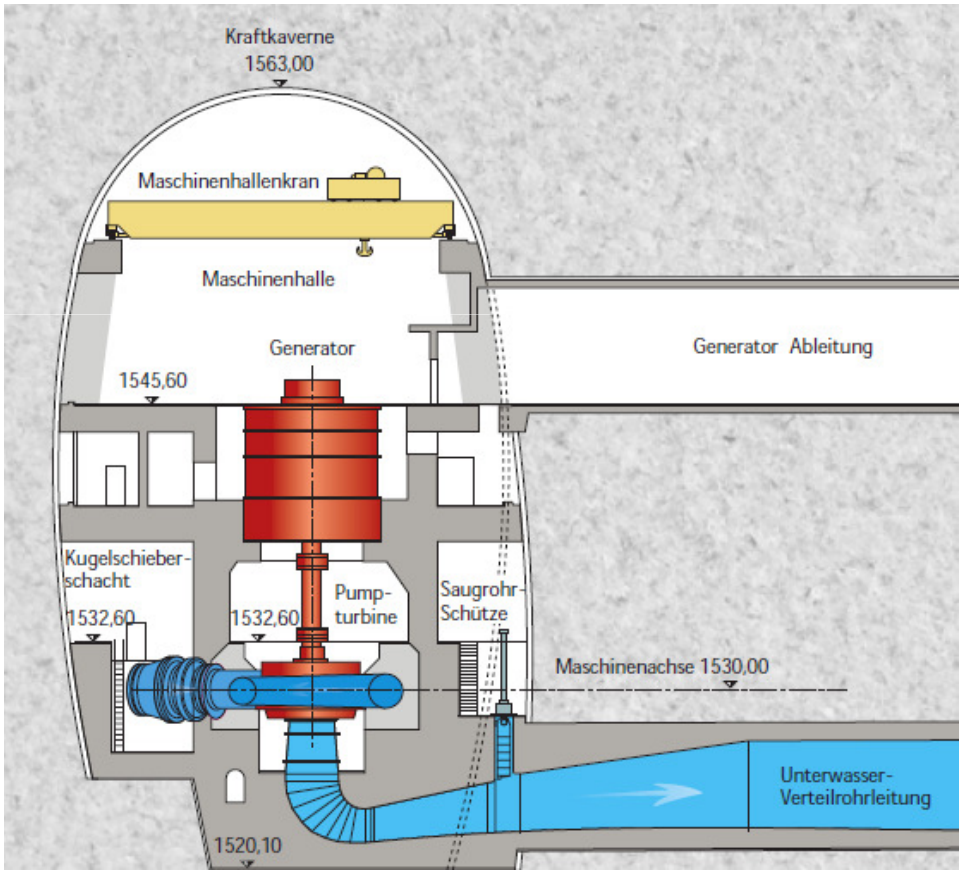



Source: Illwerke

# Innovative PSPP System Conceptions (2) Reversible Pumpturbine with converter fed Motor-Generator

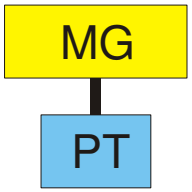



Source: VDE



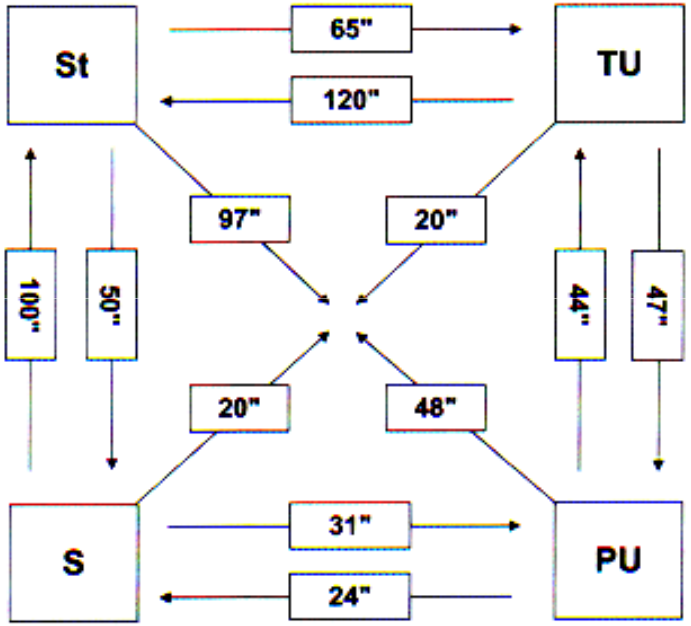

Source: Verbund

# Advantages of different Configurations

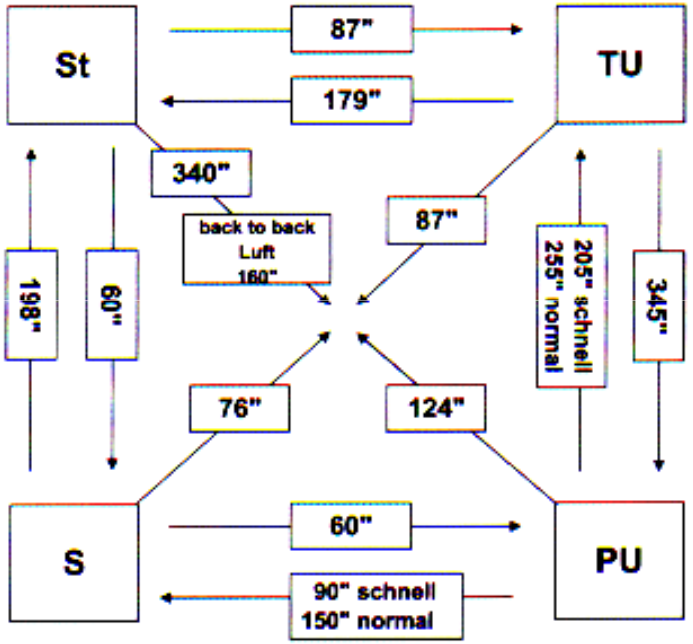
| Configuration |  |  |
|---|---|---|
| Investment costs | − | + |
| Space required | − | + |
| Efficiency | + | − |
| Installation depth | + | − |
| Transition time P➤T/T➤P | + | − |
| Hydraulic short circuit | + | − |
| Head | + | − |
| Operation costs | − | + |
| Technical risk | − | + |
| Maintainance | − | + |

# Typical Transition Times between operation modes in seconds

**Ternary Configuration**




**Reversible Pumpturbine**




**St…..IDLE**
**TU…TURBINE OPERATION**
**PU…PUMP OPERATION**
**S…...STANDBY**

Source:Heninger, Spitzer, E&I 2009

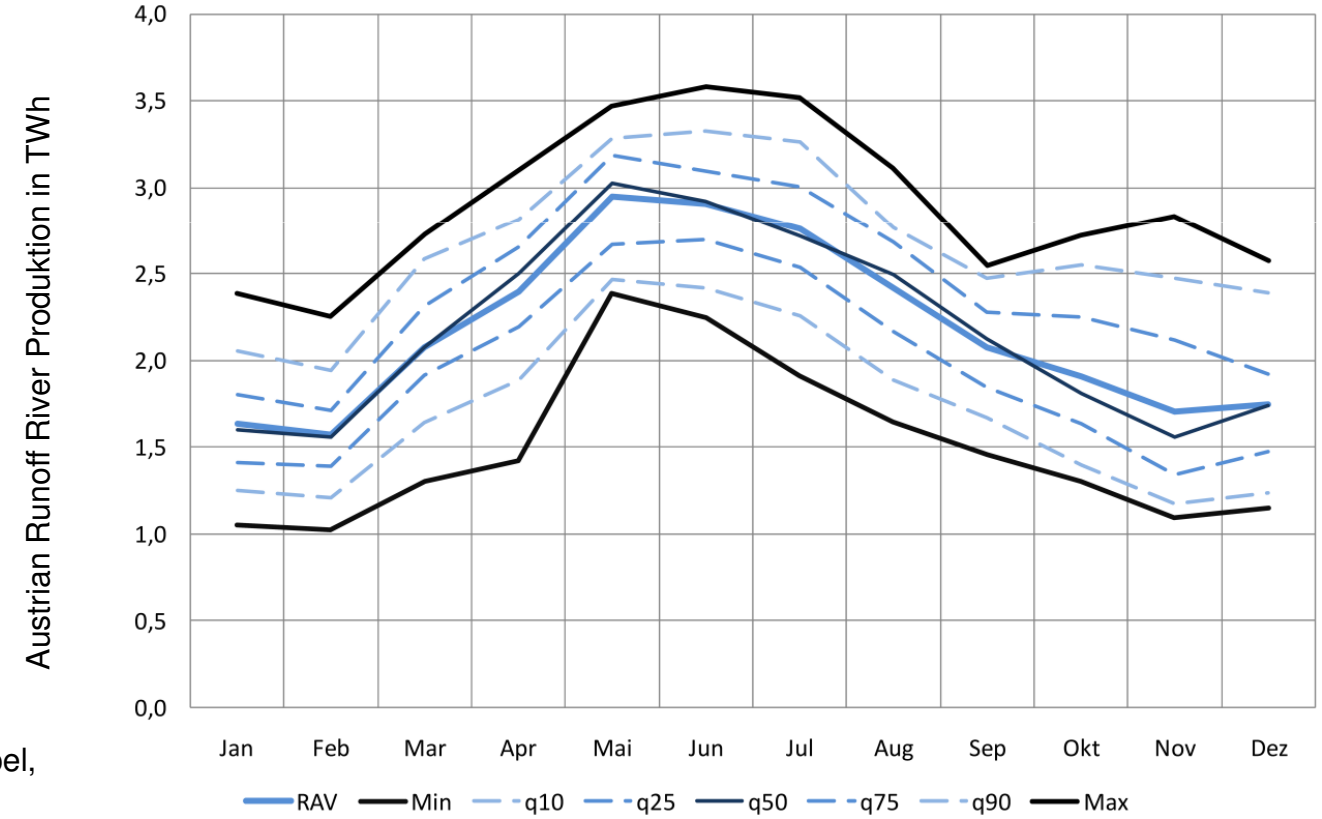
# Tasks of Pump Storage Powerplants in Europe

# Tasks fulfilled by pump storage power plants in Europe

- Generation shifting from summer to winter (eg. Switzerland)
- Annual Peak Load Coverage
- Storage of wind generation
- Providing ancillary services
  - “Black-Start” Capabilities
  - Very fast outage Reserve for large thermal or nuclear Units
  - Control Power (Frequency Control)

# Generation Shifting from Summer to Winter (1)

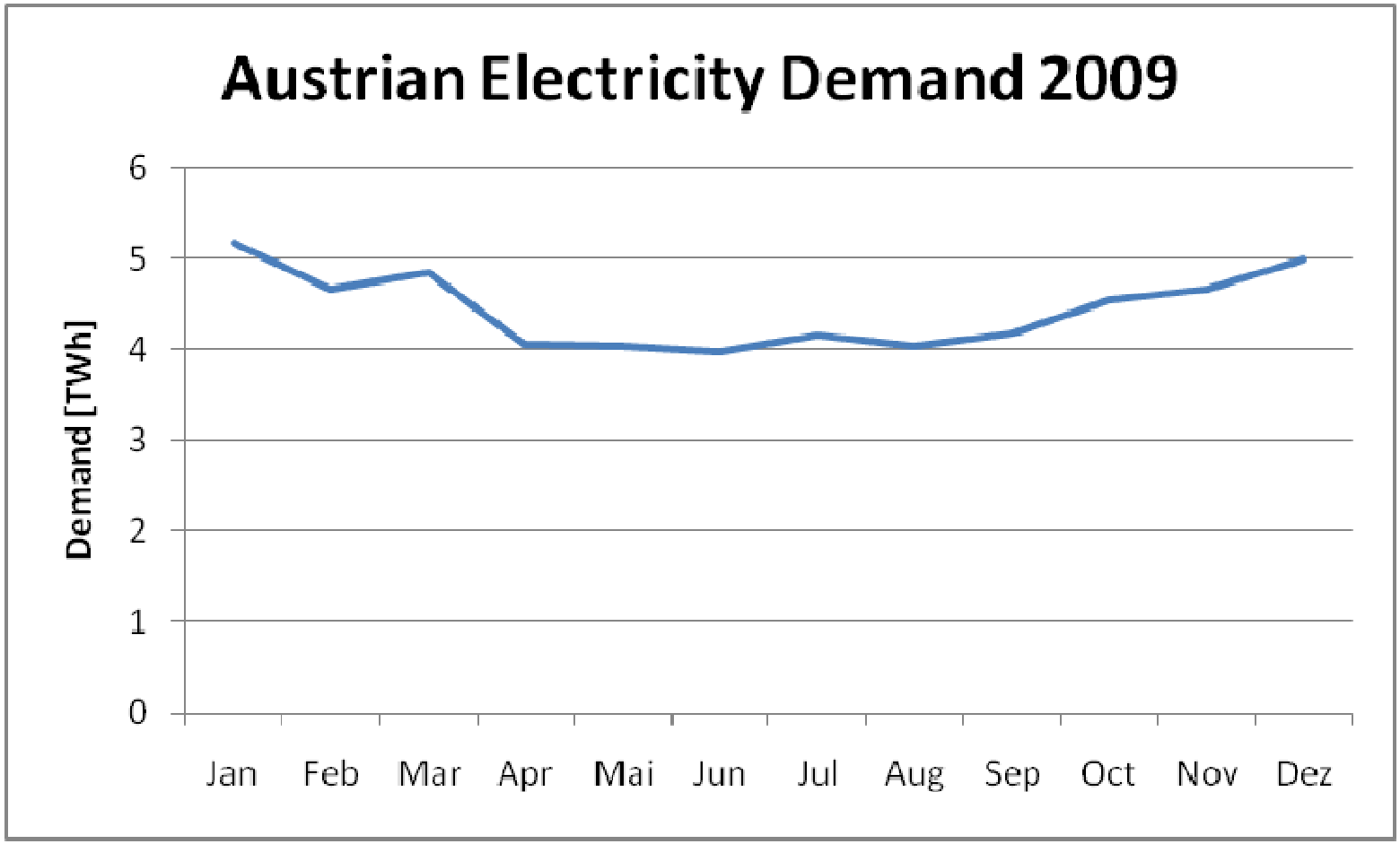
- In Countries with alpine regions the runoff in Rivers reaches its maximum in summer




Source: Schüppel, IEE-TUgraz

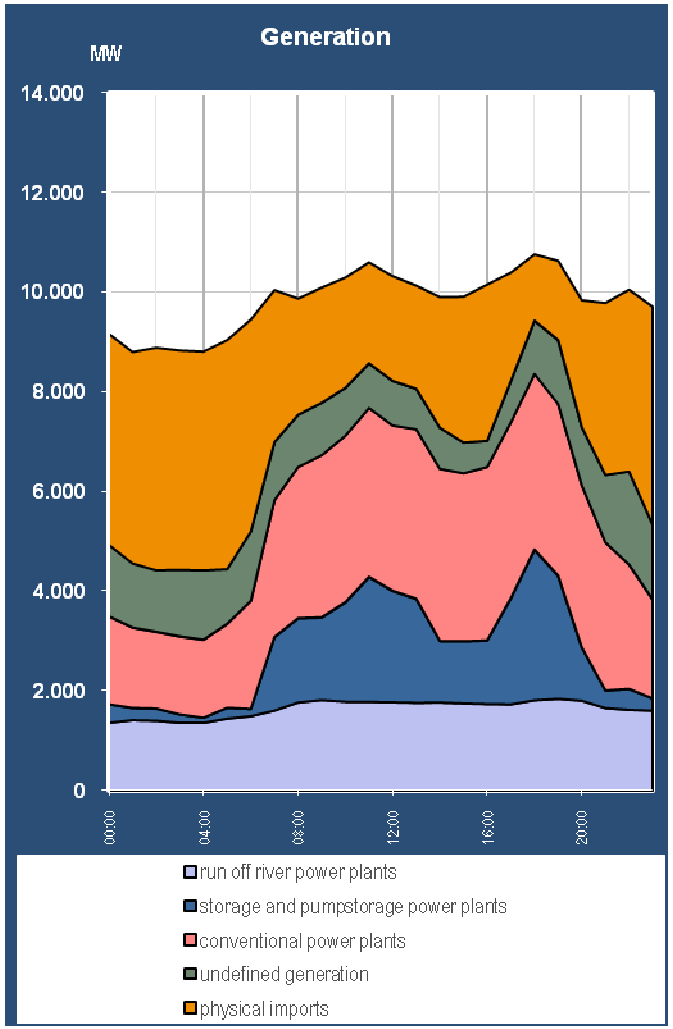
# Generation Shifting from Summer to Winter (1)

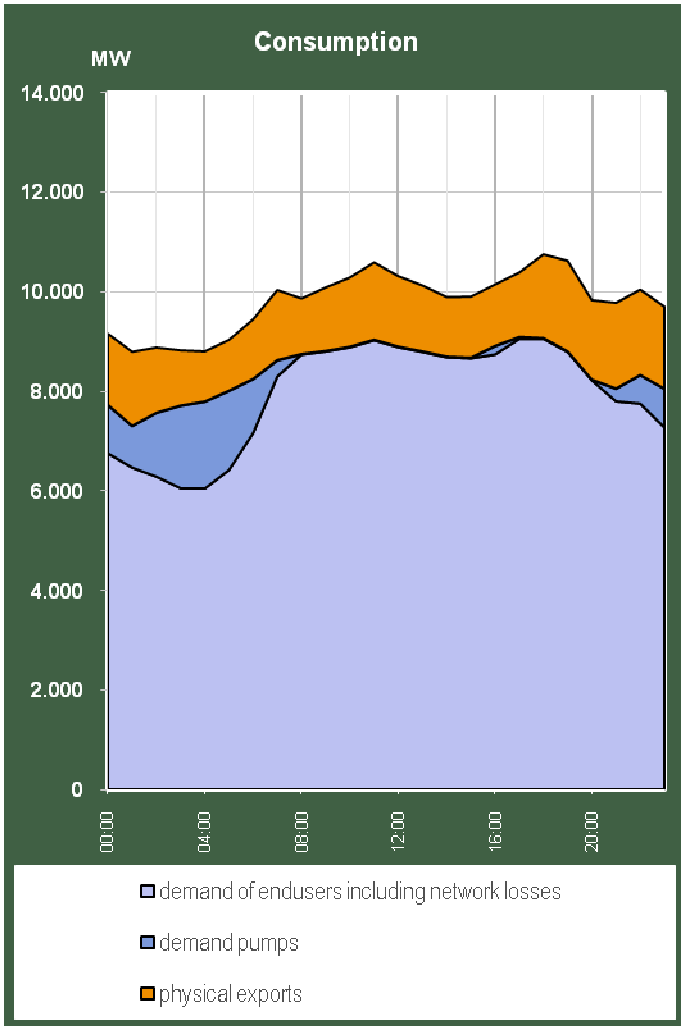
- The Maximum of demand is in Winter



# Providing contribution to peak load Coverage

Austria:
Wednesday 21st
January 2009



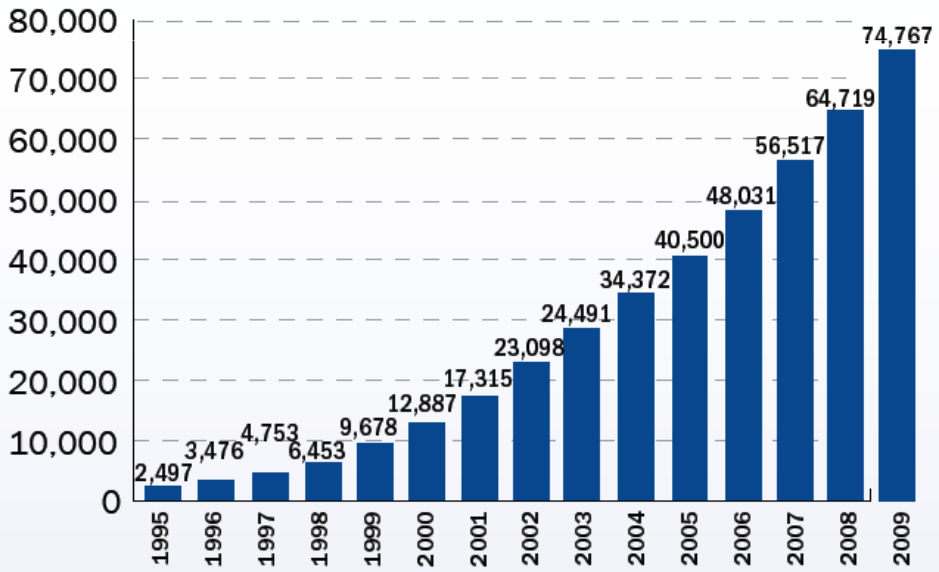




Source: e-control

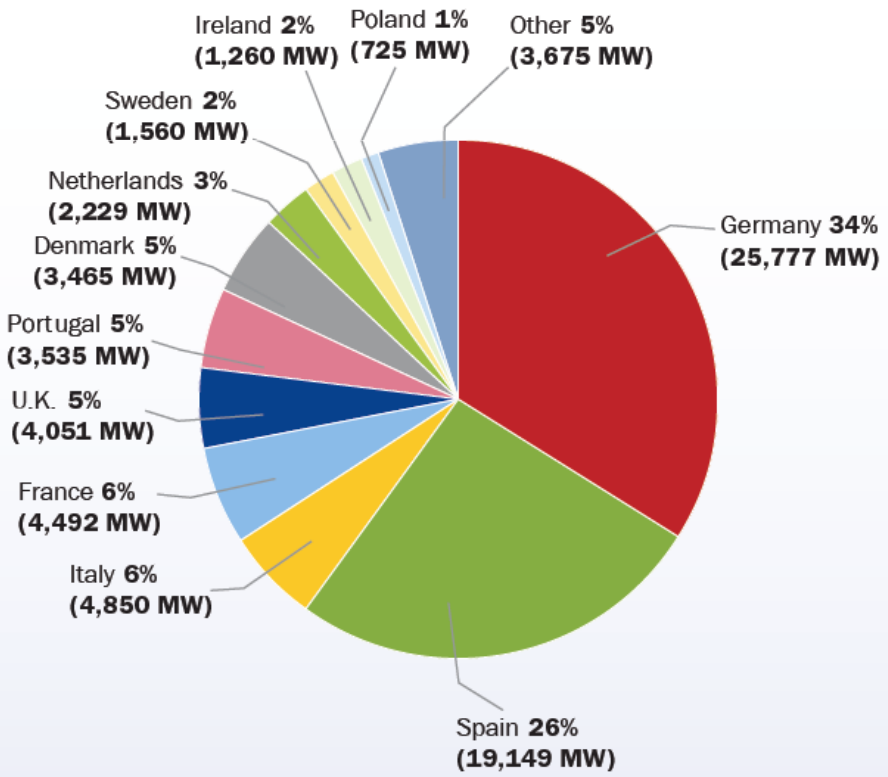
# Storage and Backup of Wind Power

## Wind Power is the main driver for new PSPP

CUMULATIVE WIND POWER INSTALLATIONS MW FIGURE 3.3

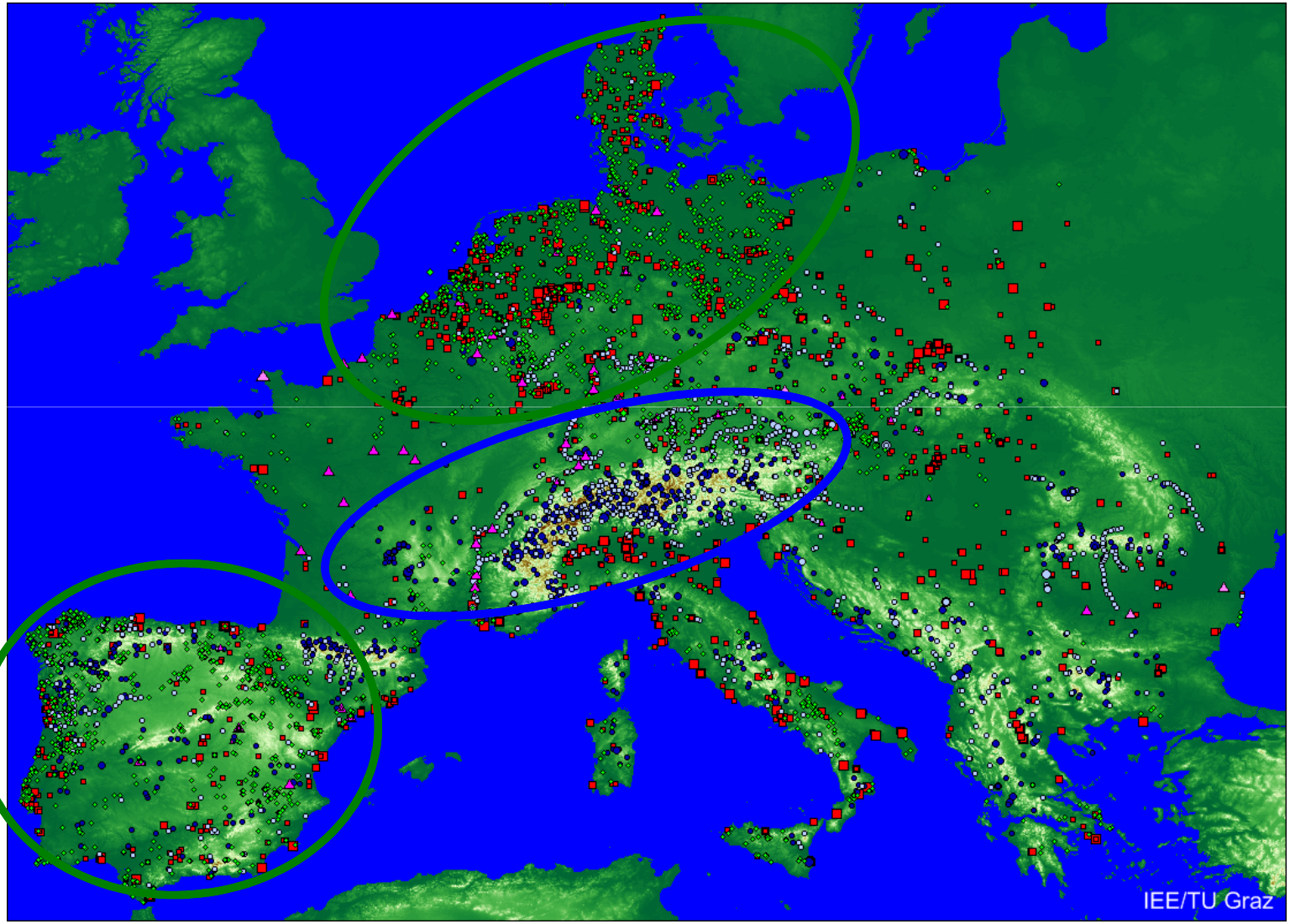



EU MEMBER STATE MARKET SHARES FOR TOTAL INSTALLED CAPACITY (2009). TOTAL 74,767 MW FIGURE 3.4

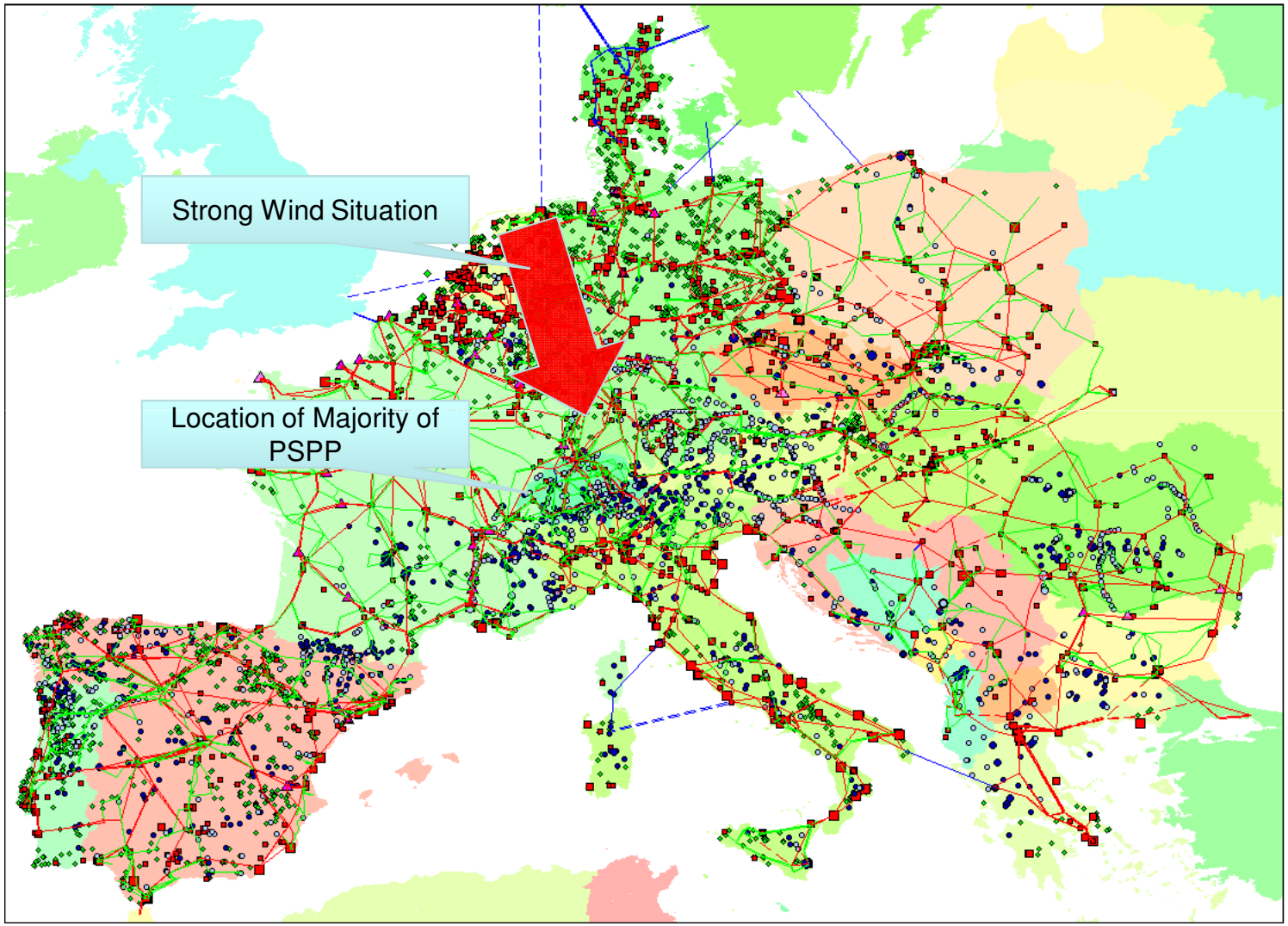



Source: EWEA

# Concentration of Wind Generation



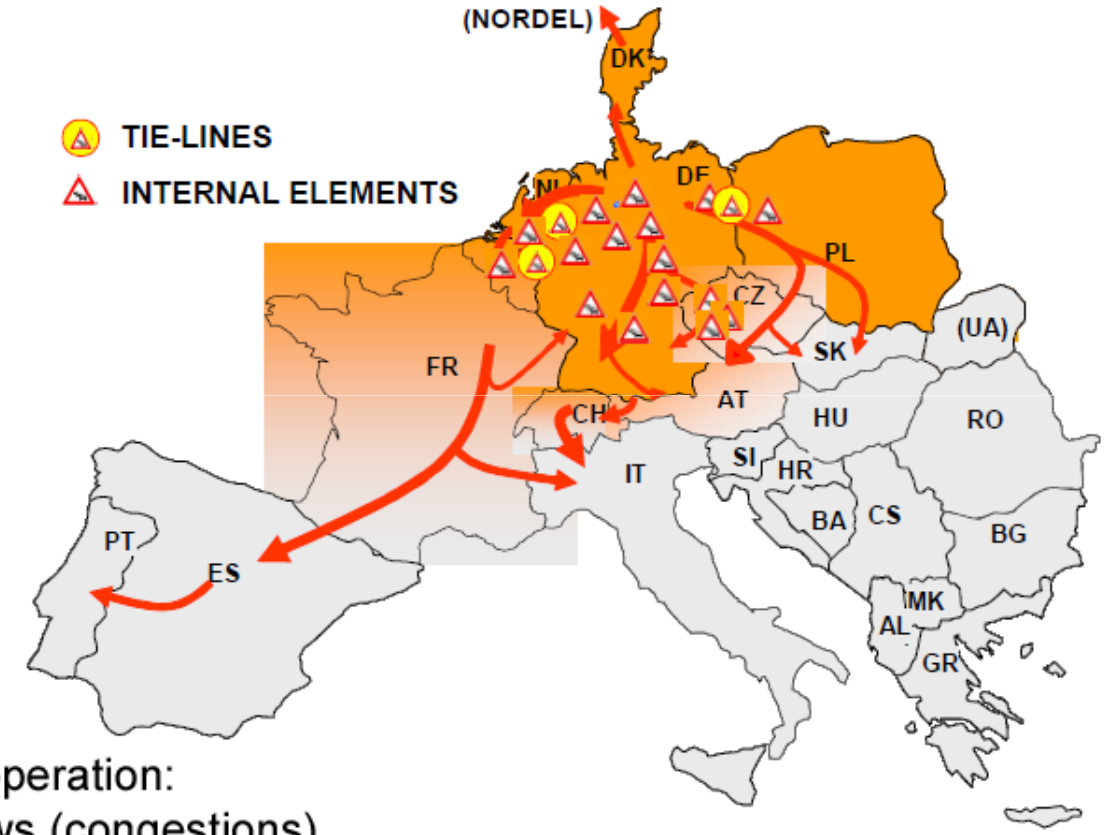
# Flows in the Transmission Grid



# Strong wind causes congestions

Congestions

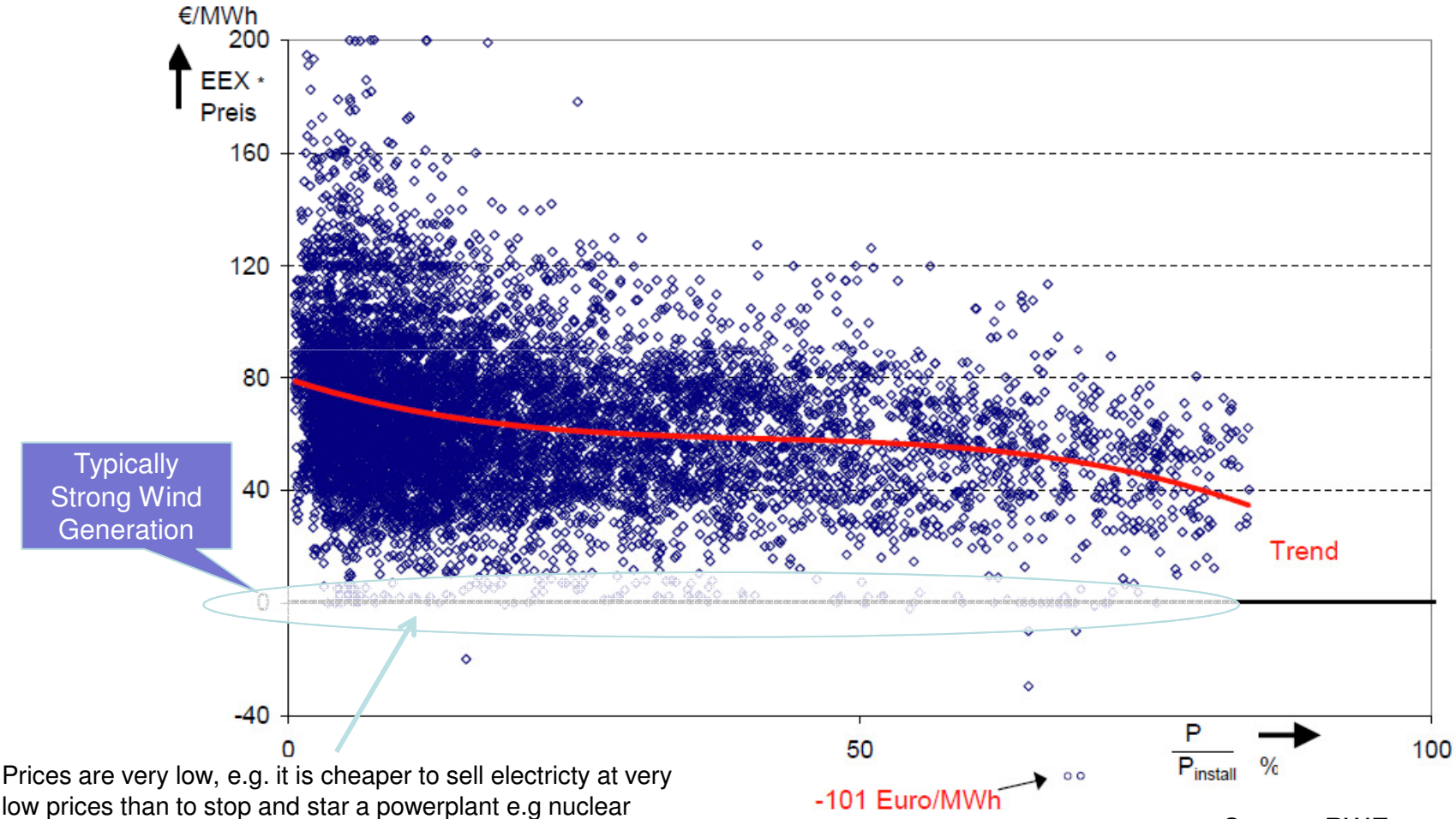
(UCTE Scenario Nord)




Main risks for system operation:
uncontrolled power flows (congestions)
missing ancilliary services

Source: EWIS, Vattenfall

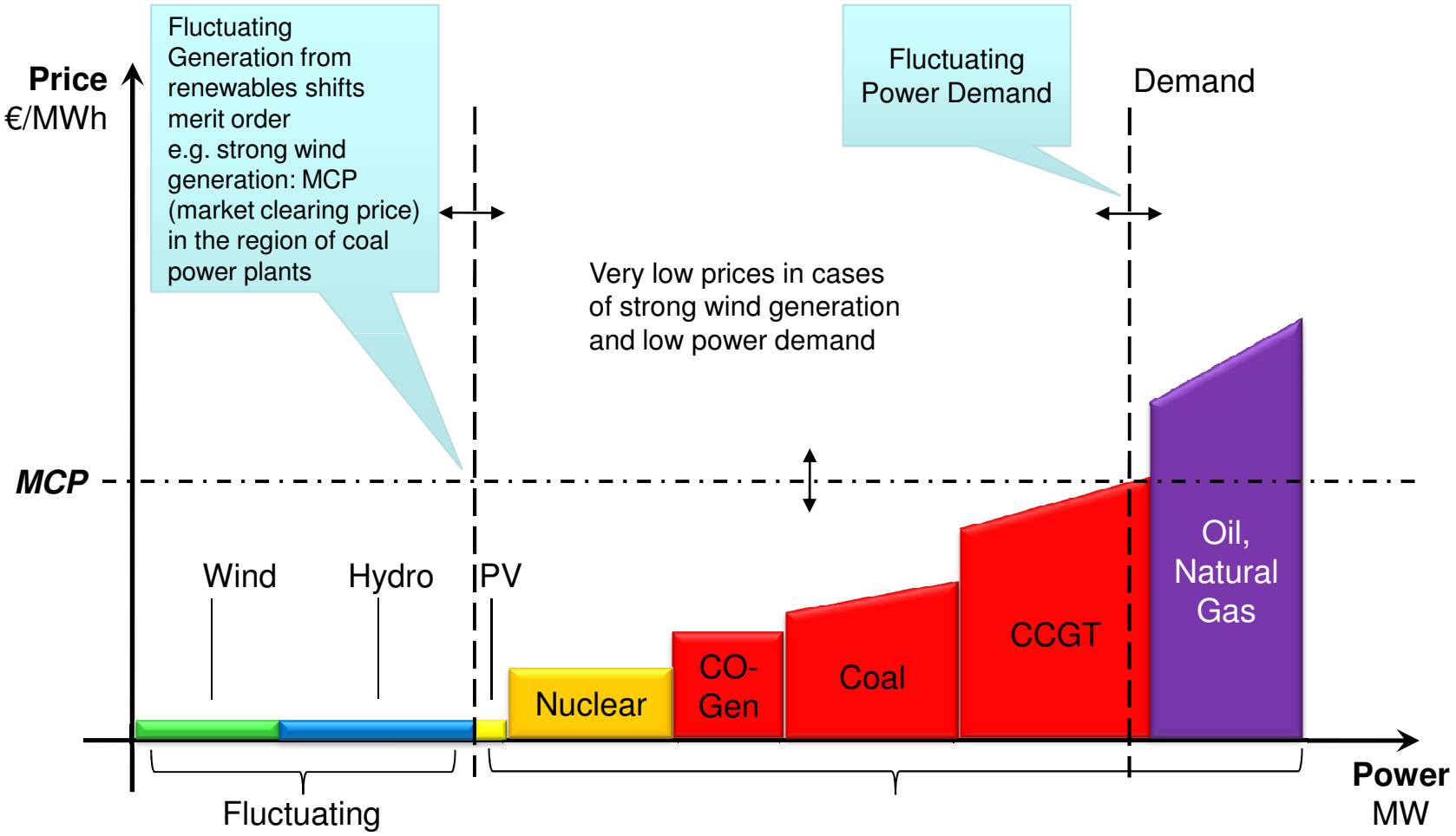
# Impact of Wind Generation on Power Prices




Prices are very low, e.g. it is cheaper to sell electricty at very low prices than to stop and star a powerplant e.g nuclear power plants

Source: RWE, Kleinkorte

# Impact of Wind Generation on Power Prices

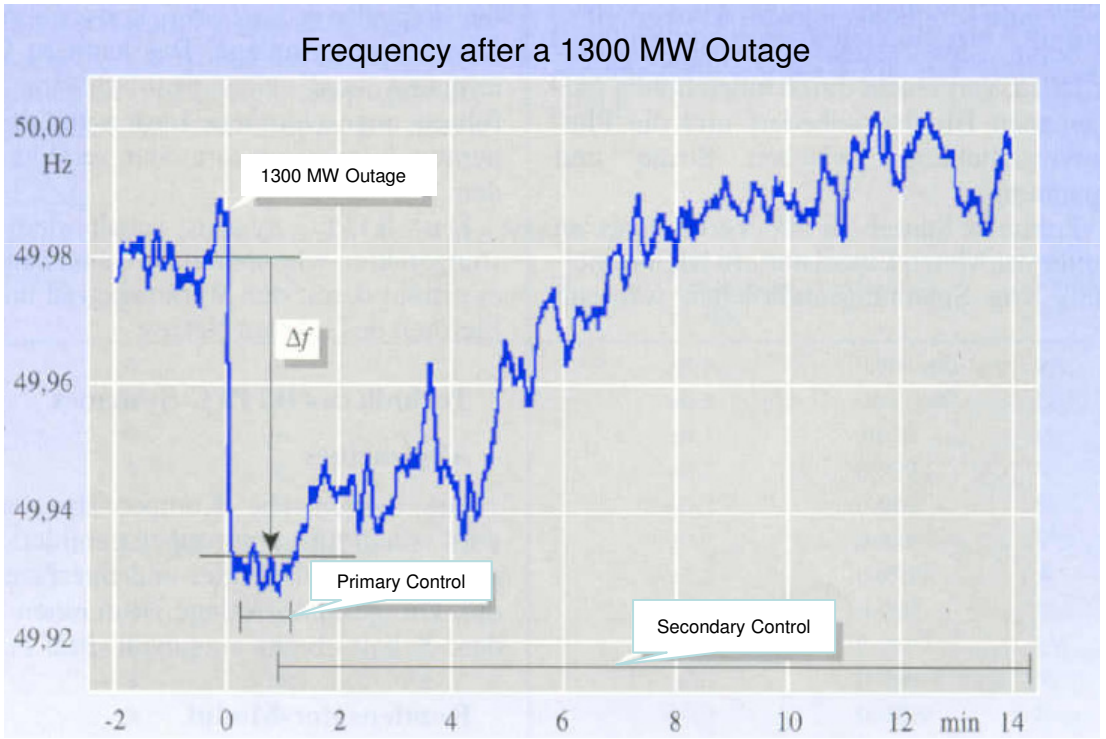


# Impacts of high wind generation

- Strong Wind leads to low energy prices at power exchanges
- Pump Storage Powerplants profit from low power prices -> Pumping
- Wind located in north of Germany and near the Atlantic, and North Sea
- Majority of PSPP is located in the alps
- Geographic Locations leads to high Power Flows in the transmission grid -> Bottleneck
- Wind generation shows steep gradients in power variations -> **back up needed**

# PSPP providing Control Power

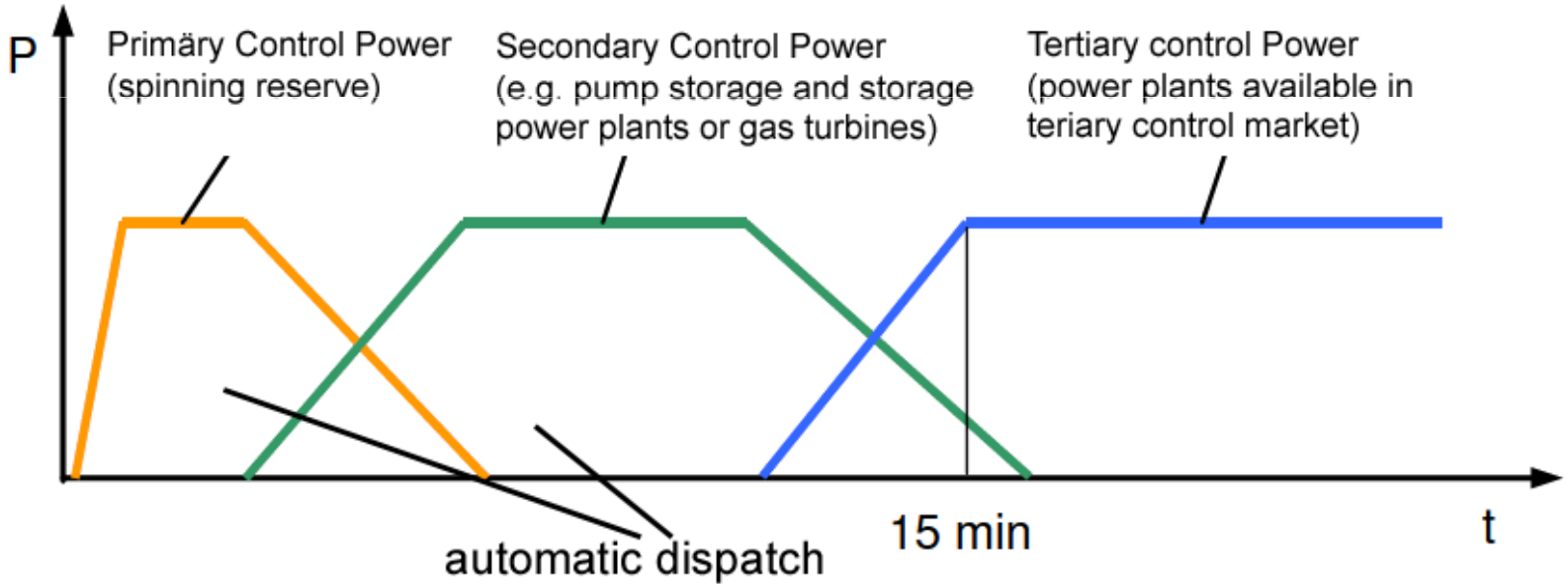
- Pump storage power plants show best properties to supply control power



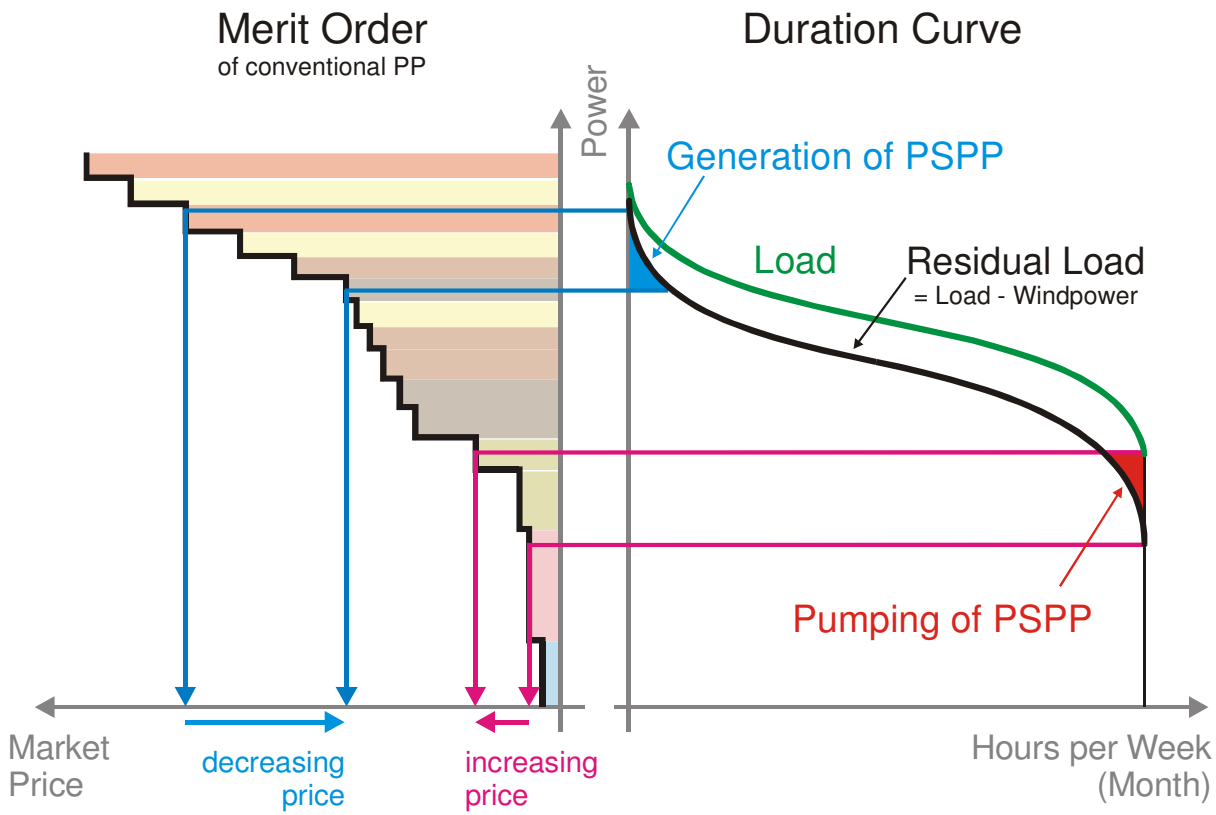

Source: Weber et al, EW JG 96, Issue 4

# PSPP providing Control Power

- Pump storage power plants show best properties to supply control power



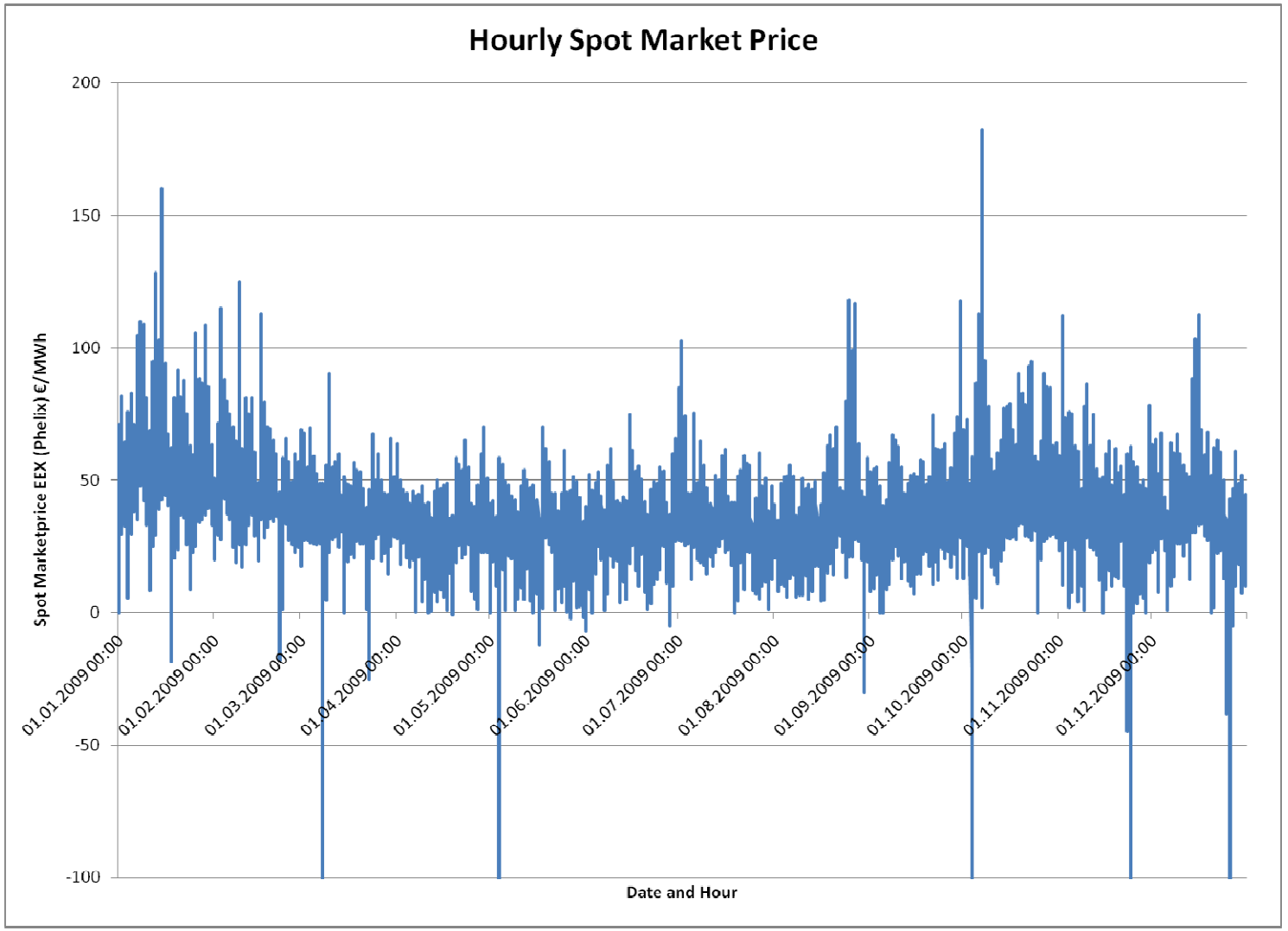
# Market participation of pump storage power plants


Merit Order
of conventional PP
Duration Curve
Power
Generation of PSPP
Load
Residual Load
= Load - Windpower
Pumping of PSPP
Market
Price
decreasing
price
increasing
price
Hours per Week
(Month)

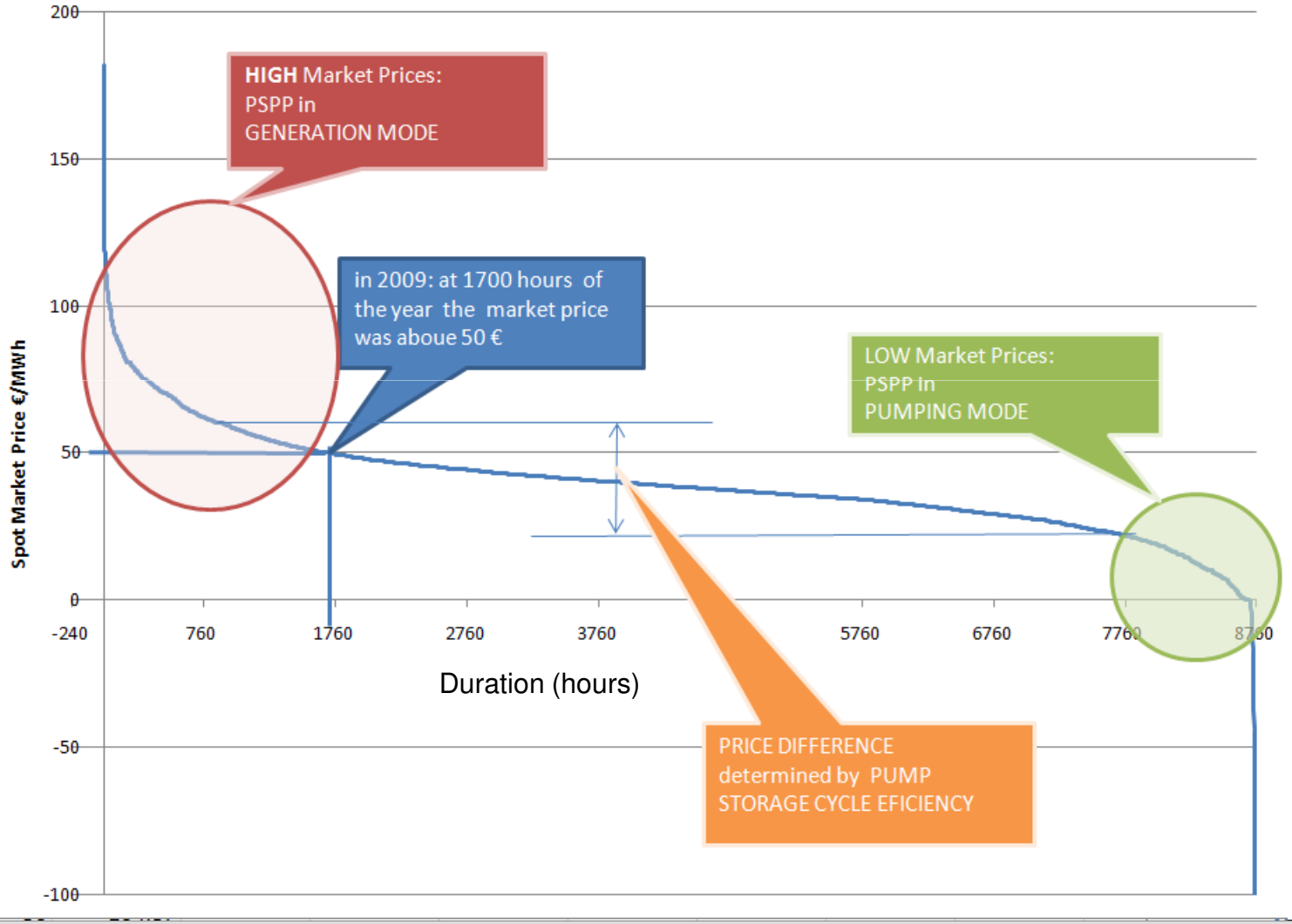
# Market segments

- Energy markets
  - Earnings from price differences
- Control power markets
  - Primary Control Power Market (not in Europe)
  - Secondary Control Power Market
  - Tertiary Control Energy Market
- Other Ancilliary services markets
  - Black Start Capabilities
  - Congestion Managment Markets
  - Reactiv Power Markets

# Market Participation on Energy (Spot) Market

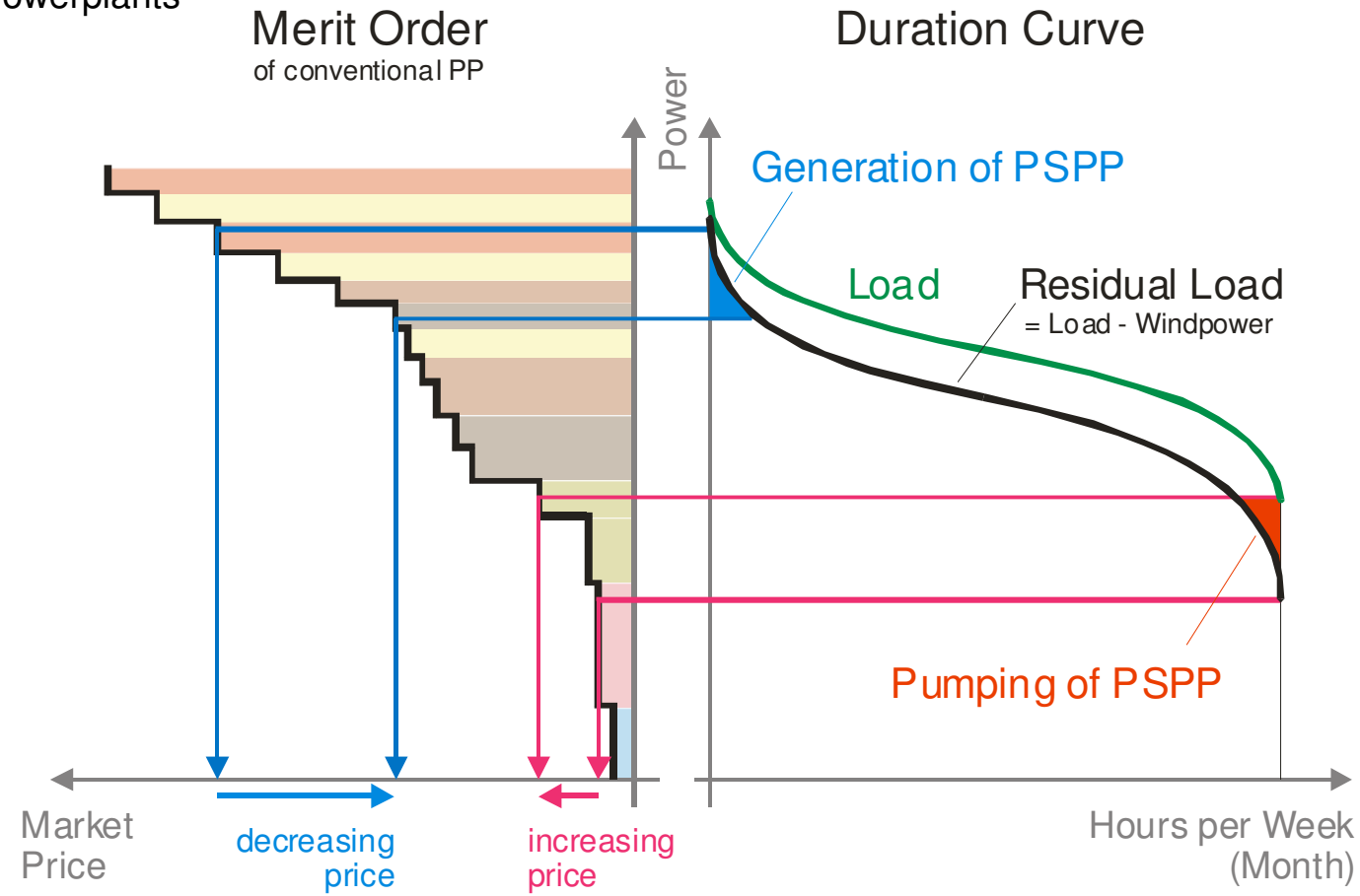


# Market Price Duration Curve (hourly Prices sorted descending)

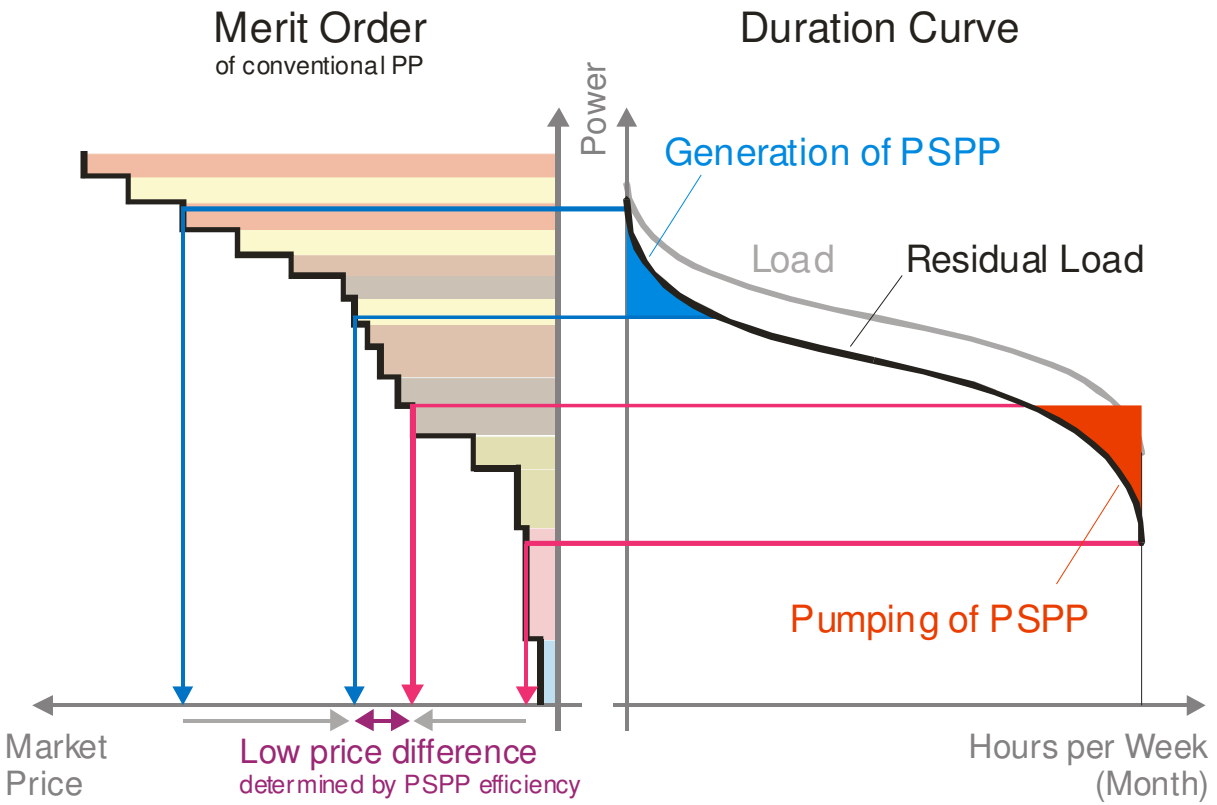


# Market Influence due PSPP operation

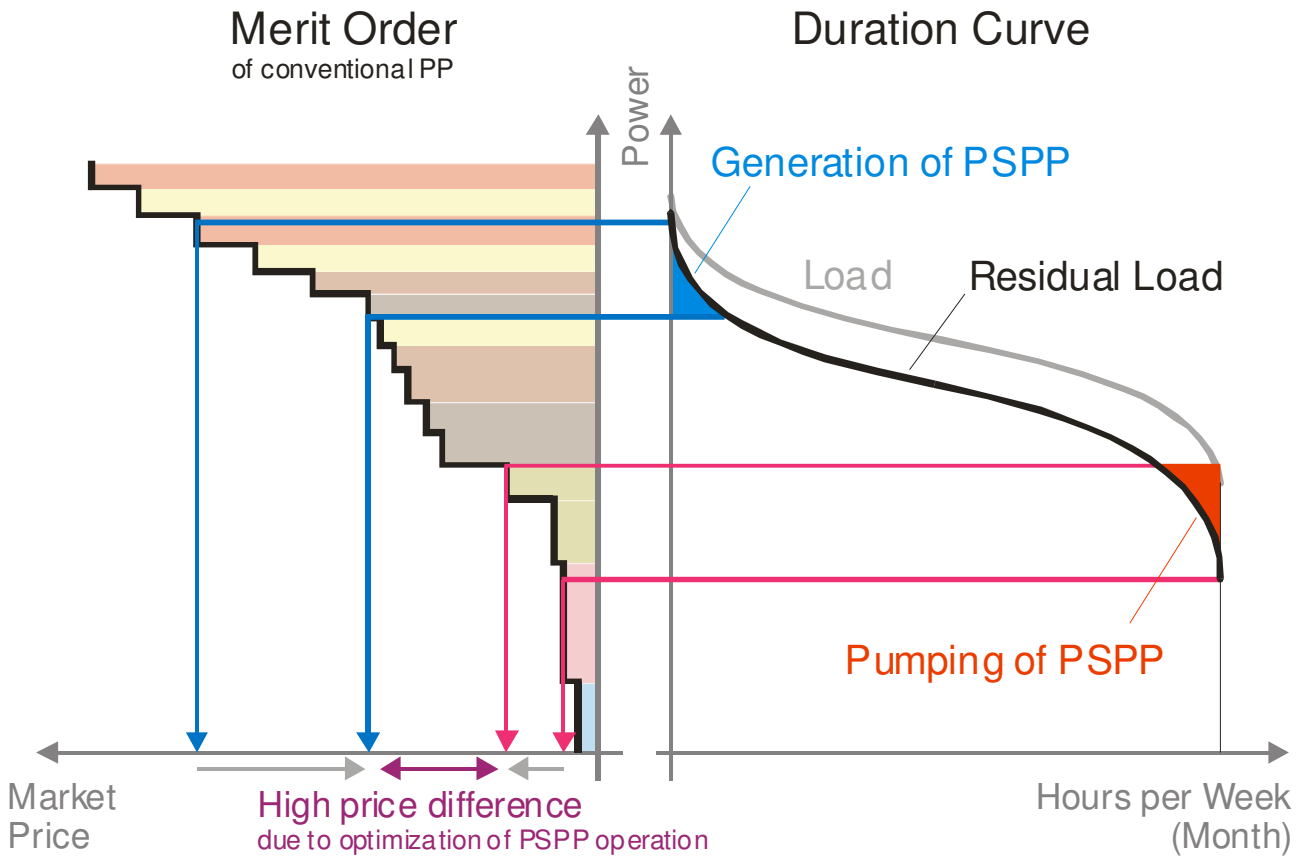
Operation of PSPP influences Market Prices because PSPP is additional and cheaper generation than the replaced conventional Plants
Operation of Pumps raises market Prices because of additional Demand which has to be covered by additional Powerplants



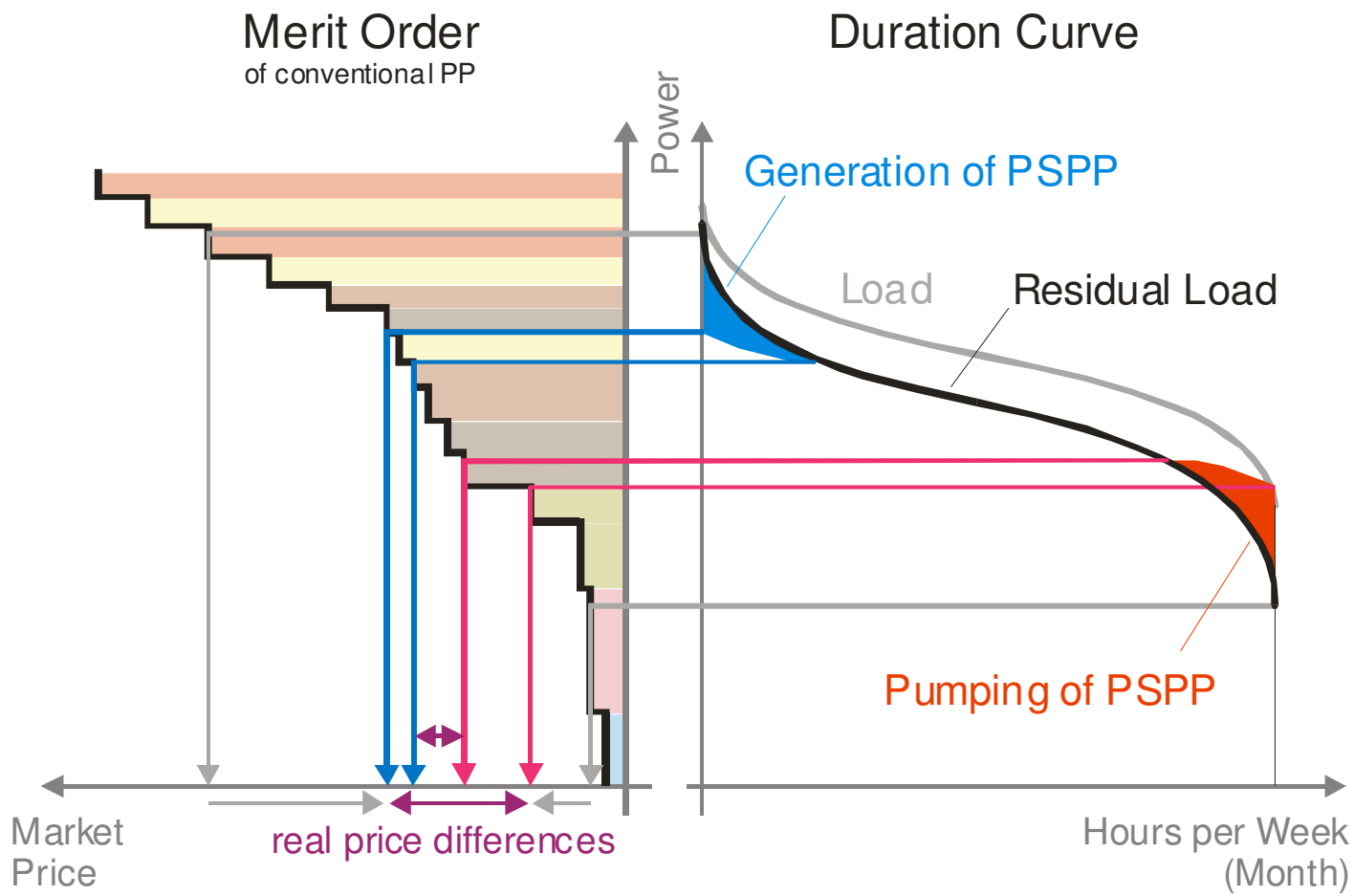
Influence of PSPP Generation to market prices under the unit comittment with respect to minimize overall variable generation costs:
Optimum for market operator (regulator, consumers)
= minimum (variable) costs of conventional generation (over the whole period)
**in some cases: Profit for PSPP operator = 0 !!!**



Influence of PSPP Generation on market prices under the regime of profit maximisation of Individual PSPP Generators:
Profit optimized operation of PSPP
**Profit for PSPP operator = Max!**
Profit = peak price * generated energy – offpeak price * pumped energy = max!
Withdraw of generation capacity to influence prices is possible.



Operation under real conditions
(Influences of hydrology, system stability, markets, technical limits, …)
=> range of price differences between peak and off-peak periods



# Example for Secondary Control Power Market Conception in Germany (1)

Transmission System Operator
requires **580 MW** Secondary Control Reserve

In germany secondary Control market is organized as “pay as bid” market.
Primary and secondary Control Power is asked since 2007 at monthly time intervalls

Example with 4 Powerplants:

| | Bid | Price / month | Accepted bids | costs/revenue per month |
|---|---|---|---|---|
| Power Plant A | 180 MW | 10 €/kW | 180 MW | 1.800.000 € |
| Power Plant B | 100 MW | 12 €/kW | 100 MW | 1.200.000 € |
| Power Plant C | 200 MW | 18 €/kW | 200 MW | 3.600.000 € |
| Power Plant D | 300 MW | 20 €/kW | 100 MW | 2.000.000 € |
| | | | Sum: 580 MW | 8.600.000 € |

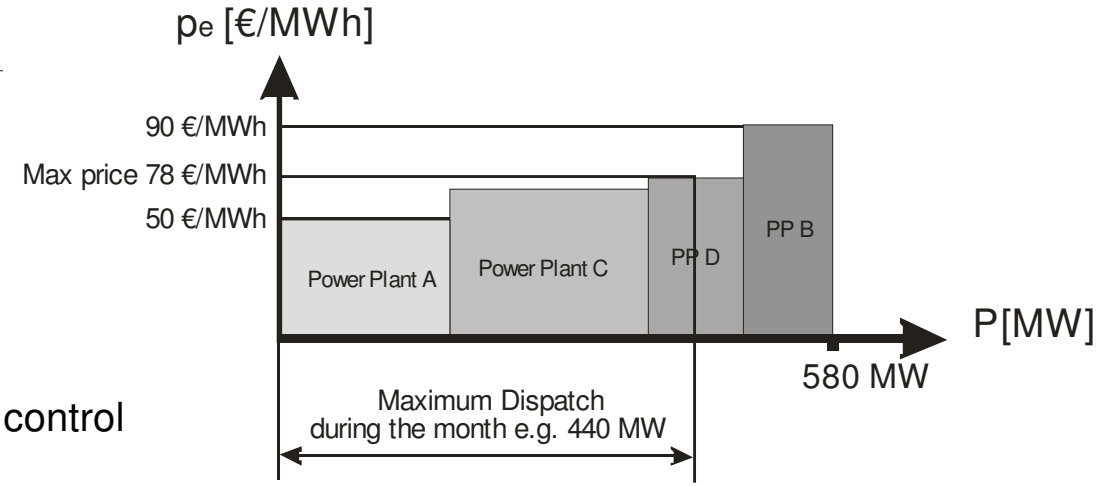
The bids are arranged by ascending price, in the example the most expensive bid is accepted partly.

# Example for Secondary Control Power Market Conception in Germany (2)

Each bid in the secondary control power market has two components:
The price for control power in €/kW and the price for energy delivered in €/MWh when secondary control power is needed.

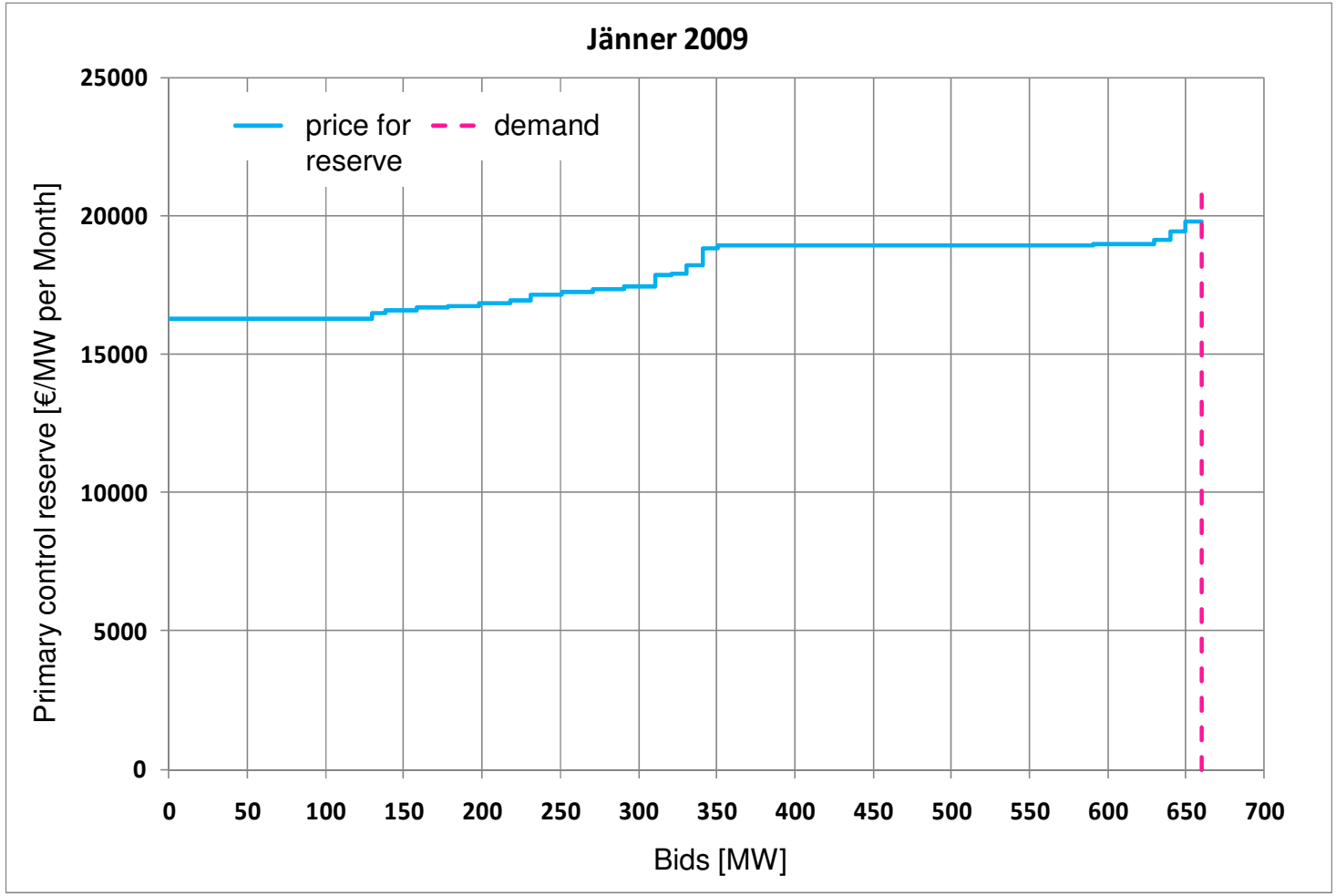
In addition to the provided control power price the power plants get an energy price payed for delivered energy in cases of needed secondary control power.

| | Price / month |
|---|---|
| Power Plant A | 50 €/MWh |
| Power Plant C | 65 €/MWh |
| Power Plant D | 78 €/MWh |
| Power Plant B | 90 €/MWh |



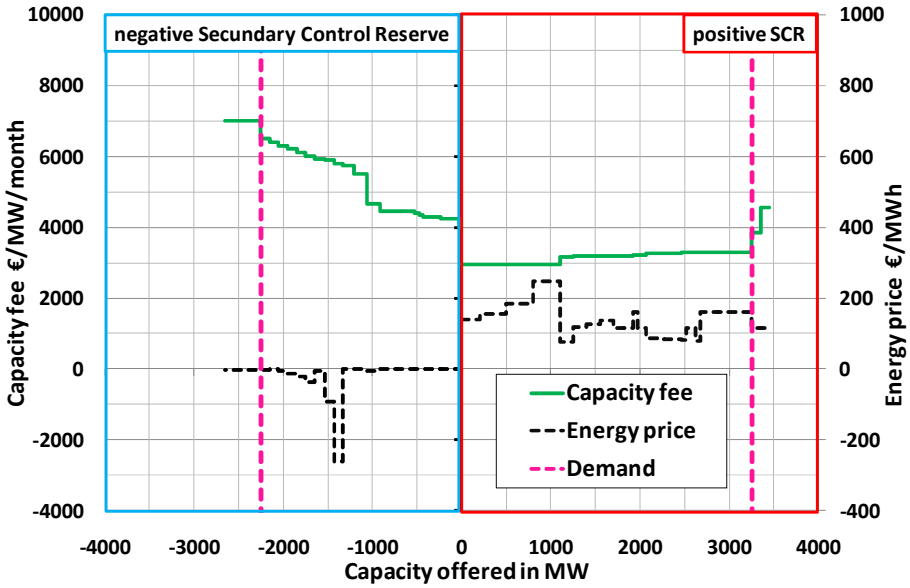

The clearing of dispatched secondary control reserve follows the “pay as bid” rule.
So the maximum price for delivered control power (energy) is determined by the maximum control power dispatch.

# Results Primary Control Power Market Germany January 2009

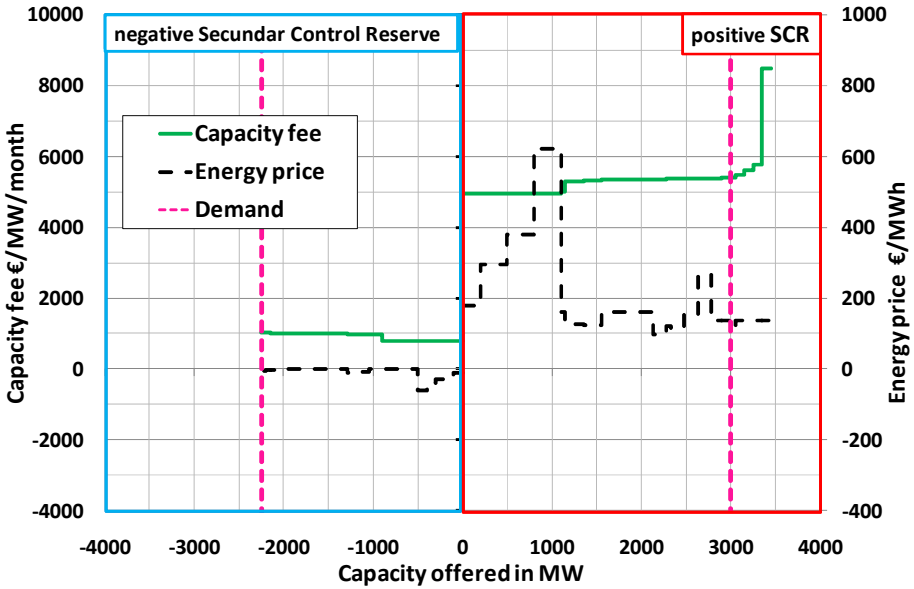


# Results Secondary Control Power Market Germany

**Merit Order: January 2009_Off Peak (20:00-08:00)**




**Merit Order: January 2009_Peak (08:00-20:00)**



# Vielen Dank für Ihre Aufmerksamkeit!