GEOELEC training course Strasburg

Session VII: Plant operation, energy supply and grid integration

Geothermal power in the reality of the electricity market

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Strasburg, 8th November 2012

Supported by INTELLIGENT ENERGY EUROPE

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8. November 2012

Topic of the presentation: energy supply, electricity grid & plant operation
department: Research & Innovation
author: Sören Reith
version: 121107

EnBW

Energie
braucht Impulse

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   a. Demand for geothermal power
   b. Lessons learned

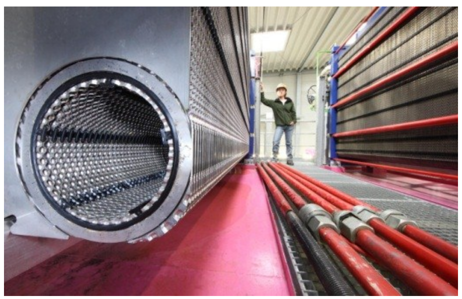
Brief portrait
EnBW Energie Baden-Württemberg AG

EnBW

- One of the largest energy companies in Germany and Europe
- Business segments:
  electricity generation and trading, electricity grid and sales,
  gas, energy and environmental services
- Annual revenue 2011: in excess of € 18 billion
- Customers: some 5,5 million
- employees: some 20,000

Business segments - electricity

Electricity generation and trading



13, 402 MW
Generation capacity thereof
2538 MW from renewable energies

59,500 GWh
own generation

2
geothermal power plants:
Bruchsal (hydrothermal)
Soultz-sous-Forêts (EGS)

Electricity grid

153,166 km
Electricity grid

34,600 km²/18,892 km²
Transportation network/Distribution network

2.95 Million
House connections

Sales

65.5 GWh
Electricity sold

4
Brands: EnBW; yellow; watt; Naturstrom

~ 5.5 million
Customers in Germany

Geothermal power plant – Soultz-sous-Forêts

French-German consortium (federal agencies, research agencies; industry)

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Thermal capacity

25-35 l/s
Flow rate

175 °C
Flow temperature

70 °C
Return flow temperature

~ 14 MW
Thermal capacity

Power plant

ORC power plant

~ 19 bar
Pressure

Isobutan
Working fluid

Air cooling tower

~ 2,1 MW
Gross electrical output

boreholes

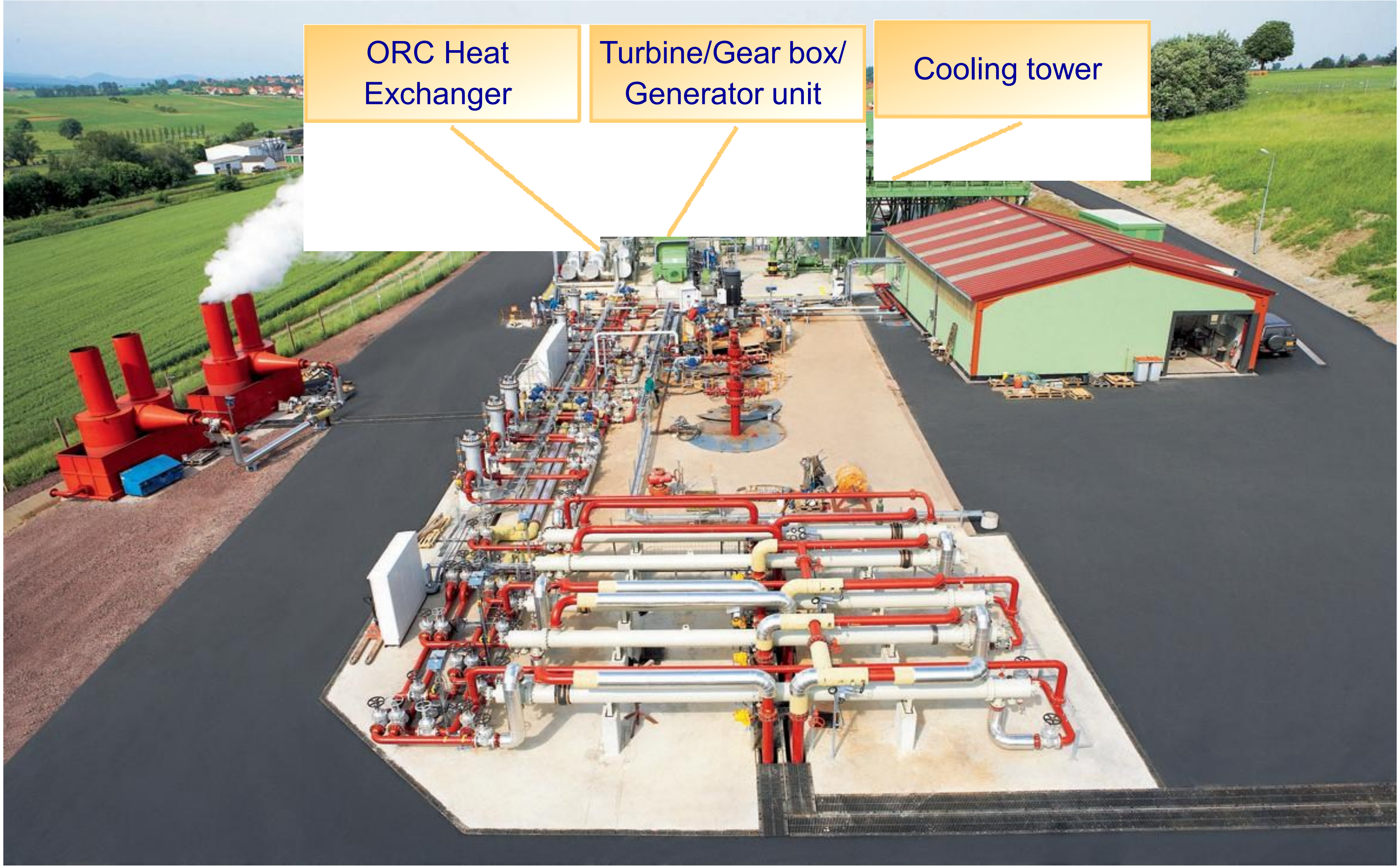
EGS-power plant

4
Number of boreholes

3600 m / 5100 m / 5100 m / 5260 m
Depth of GPK1/GPK2/GPK3/GPK4

Electric submersible pump/ lineshaft pump

Geothermal power plant in Soultz-sous-Forêts, France
Upper Rhine Valley



Source G.E.I.E, 2010

Geothermal power plant – Bruchsal
consortium between ewb & EnBW

EnBW

Thermal water

24 l/s
Flow rate

120 °C
Flow temperature

60 °C
Return flow temperature

~ 5.5 MW
Thermal capacity

Power plant

Kalina power plant

~ 22 bar
pressure

Water-ammonia
Working fluid

Wet cooling tower

~ 0.55 MW
Gross electrical output

boreholes

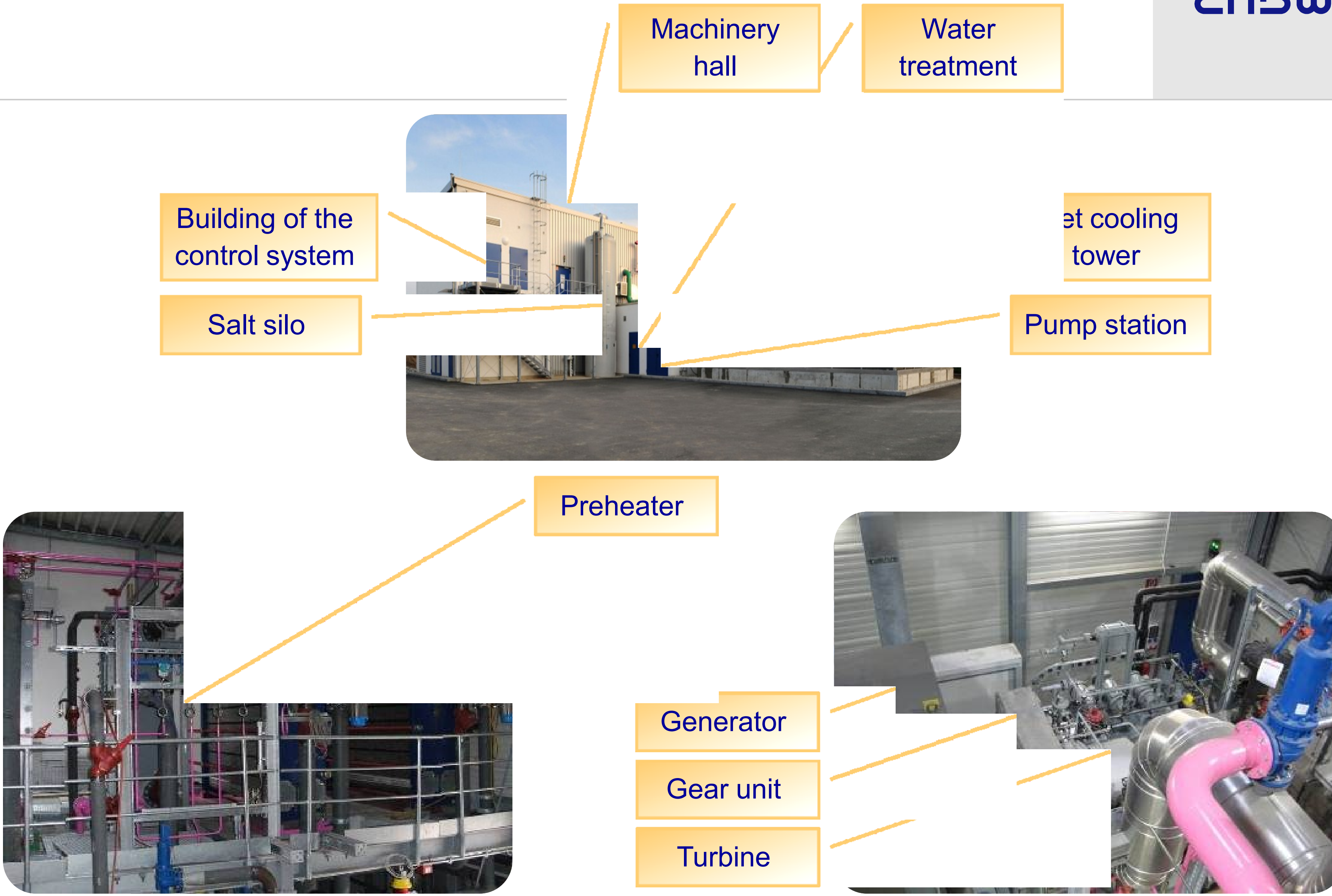
Hydrothermal

2
Number of boreholes

- 1874 m/ - 2542 m
Depth of GBI/GBII

Electric Submersible pump

Kalina pilot plant in Bruchsal



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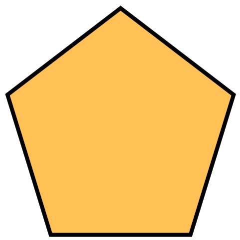
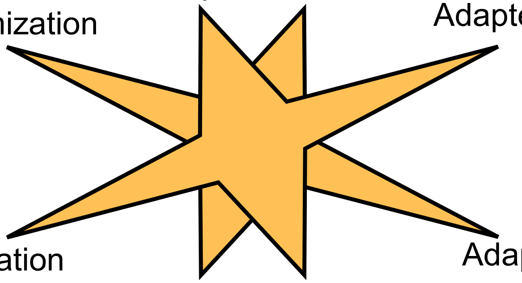
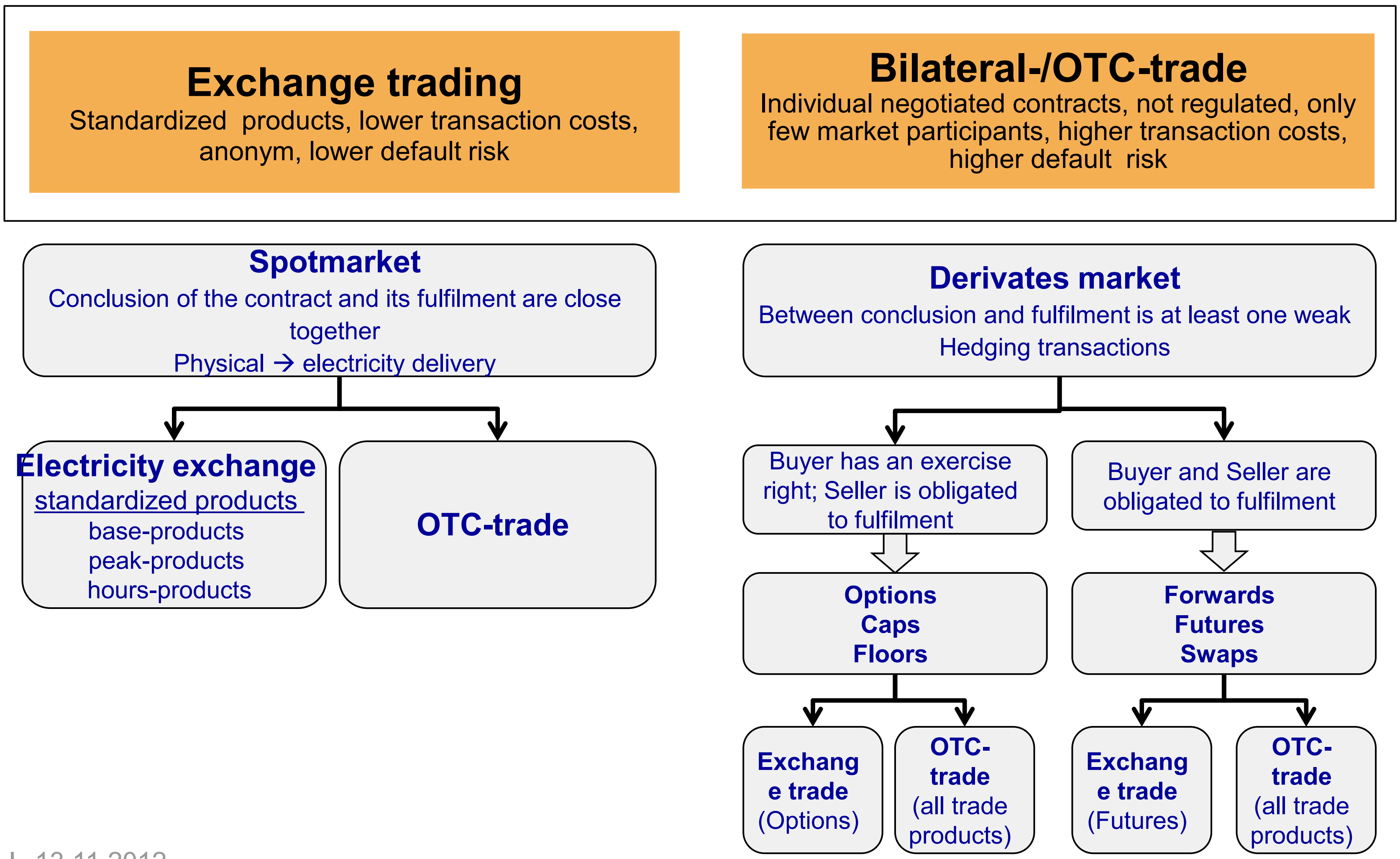
Regulation in the European electricity business





- 96/92/EC – Liberalization of electricity and gas markets
  - Free Choice of electricity supplier
  - Unbundling of production; transport; distribution; sales/trade
  - Discrimination free grid access
  - Network fees are regulated

Electricity trade in the liberalised market

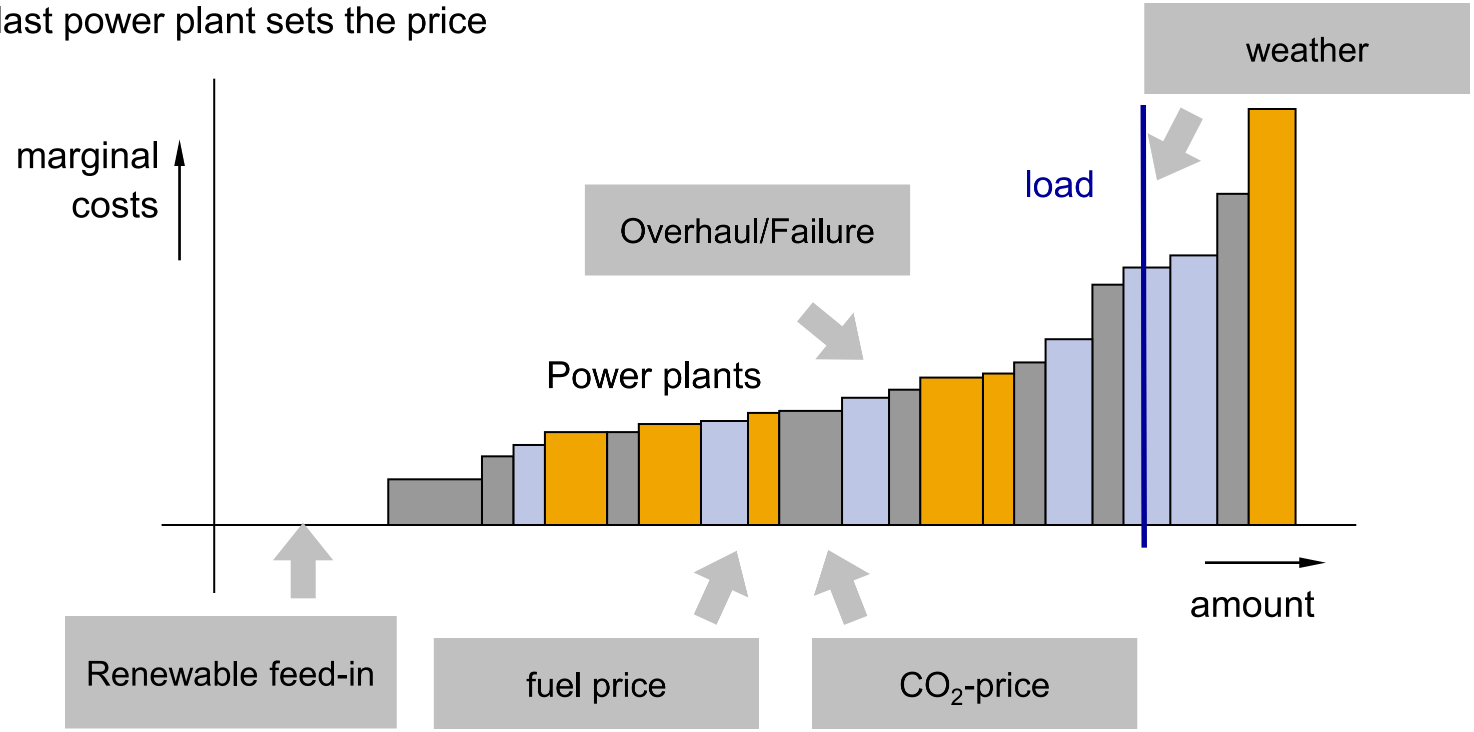


Source: Konstantin, 2007, S. 42

Electricity trade in the liberalised market

Development of the electricity price - theoretical

- Electricity prices develop through the equilibrium of
  - Offered power plant capacity (Merit-Order)
  - Load demand.
- Amount offered, price and demand are influenced by different circumstances.
- Typically there are hourly price equilibriums identified
  → This means 8760 different markets with different influencing factors
- The last power plant sets the price

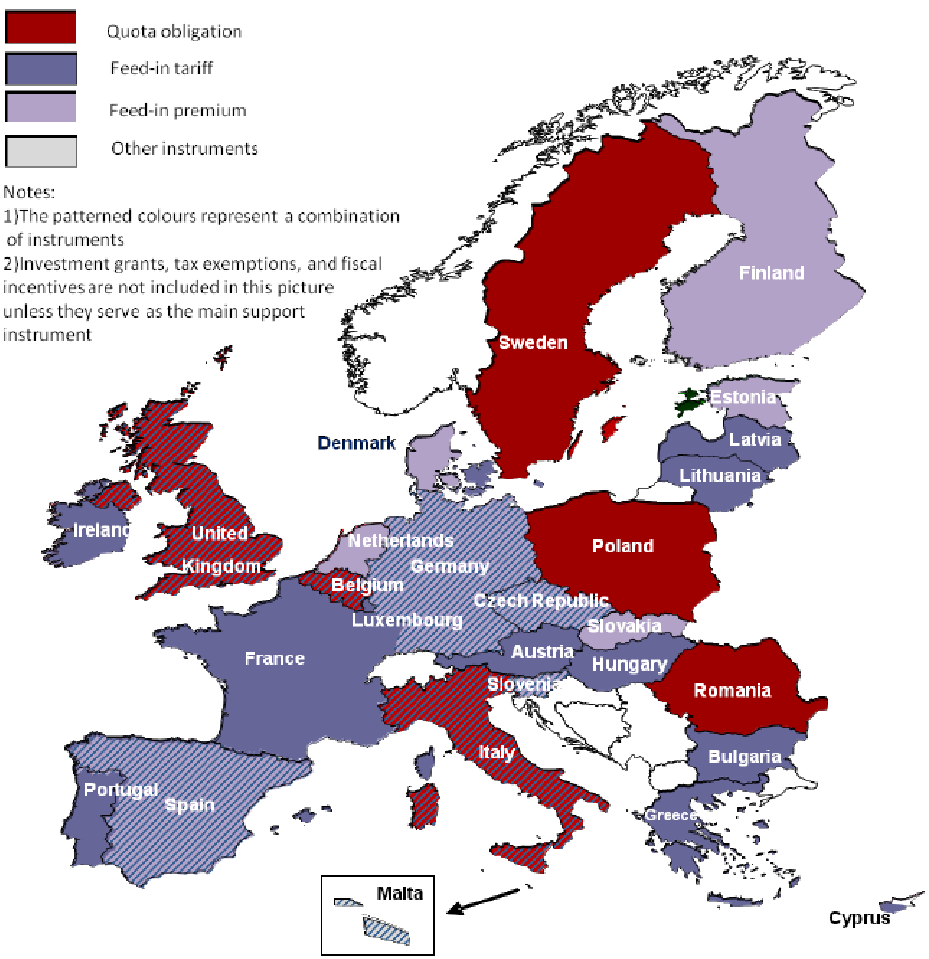


Support Systems for renewable energy in Europe Directive 2009/28/EC

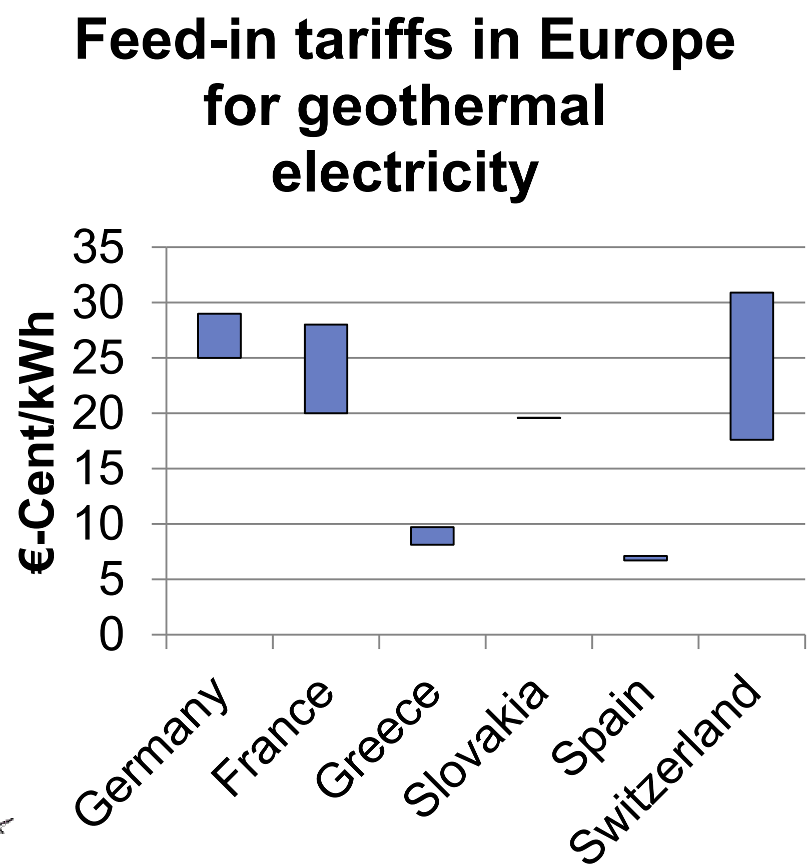
- Goals
  - Reduction of CO_2 – emissions
  - Reduction of the dependence on fossil energies
  - Fulfilment of the individual goals from directive 2009/28/EC
- Directive 2009/28/EC guaranties a priority feed-in for Renewables

Feed-in tariffs	• Legal determined feed-in tariff • Customers are charged for the extra costs
Quota systems	• Legally determined quota for RES in the elec. production • Projects are financed through energy price and certificate price
Tender models	• Tendering for a fixed amount for renewable capacity • Cheapest project is done
Tax reduction	• Tax reduction for renewable energy • Widely used

Support Systems for renewable energy in Europe



Source: Ragwitz et.a l.; 2012; Recent developments of feed-in systems in the EU



Source: Gipe; 2011; Geothermal Feed-in Tarifs Worldwide

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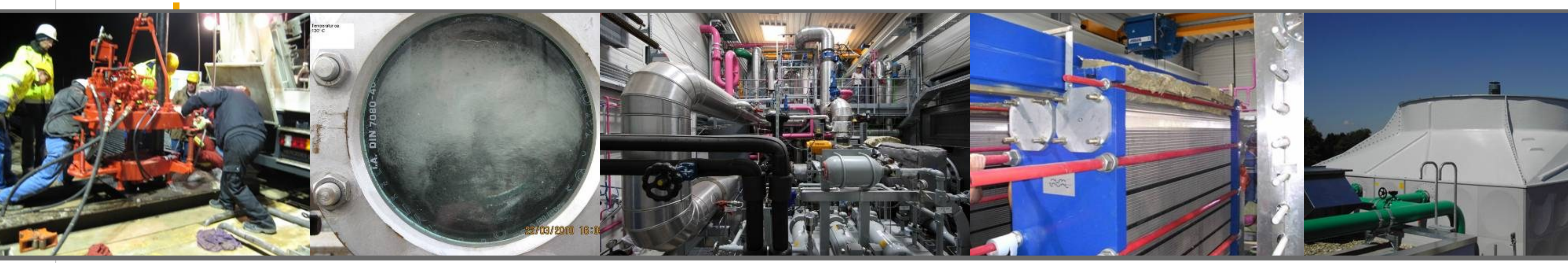
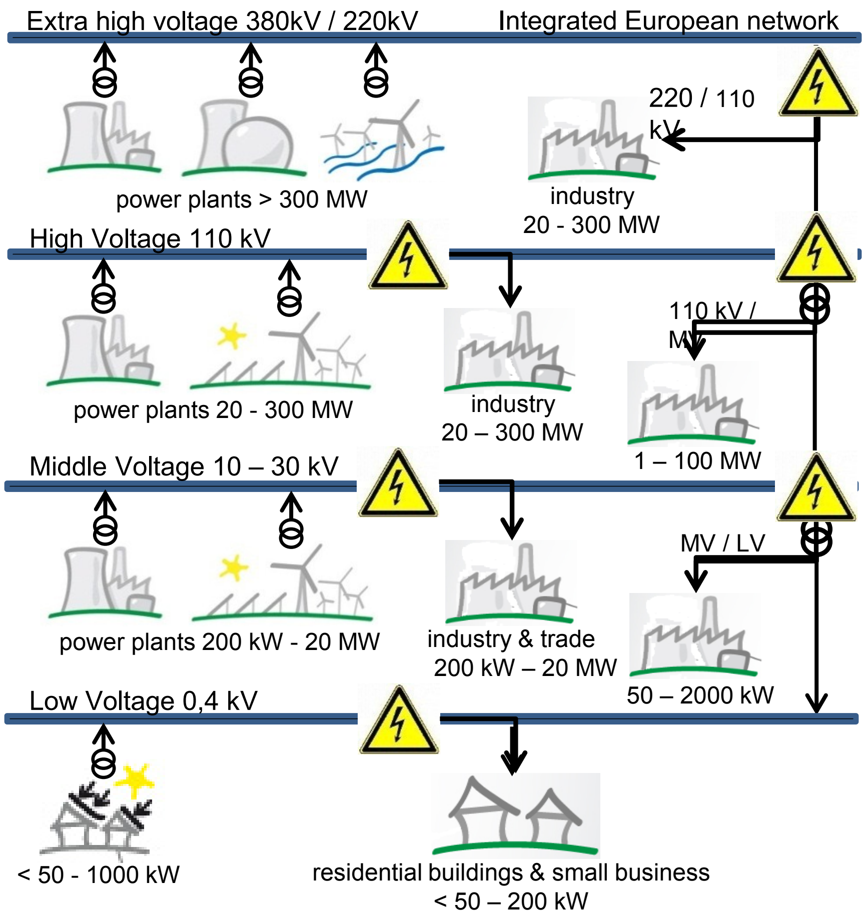


The electricity network



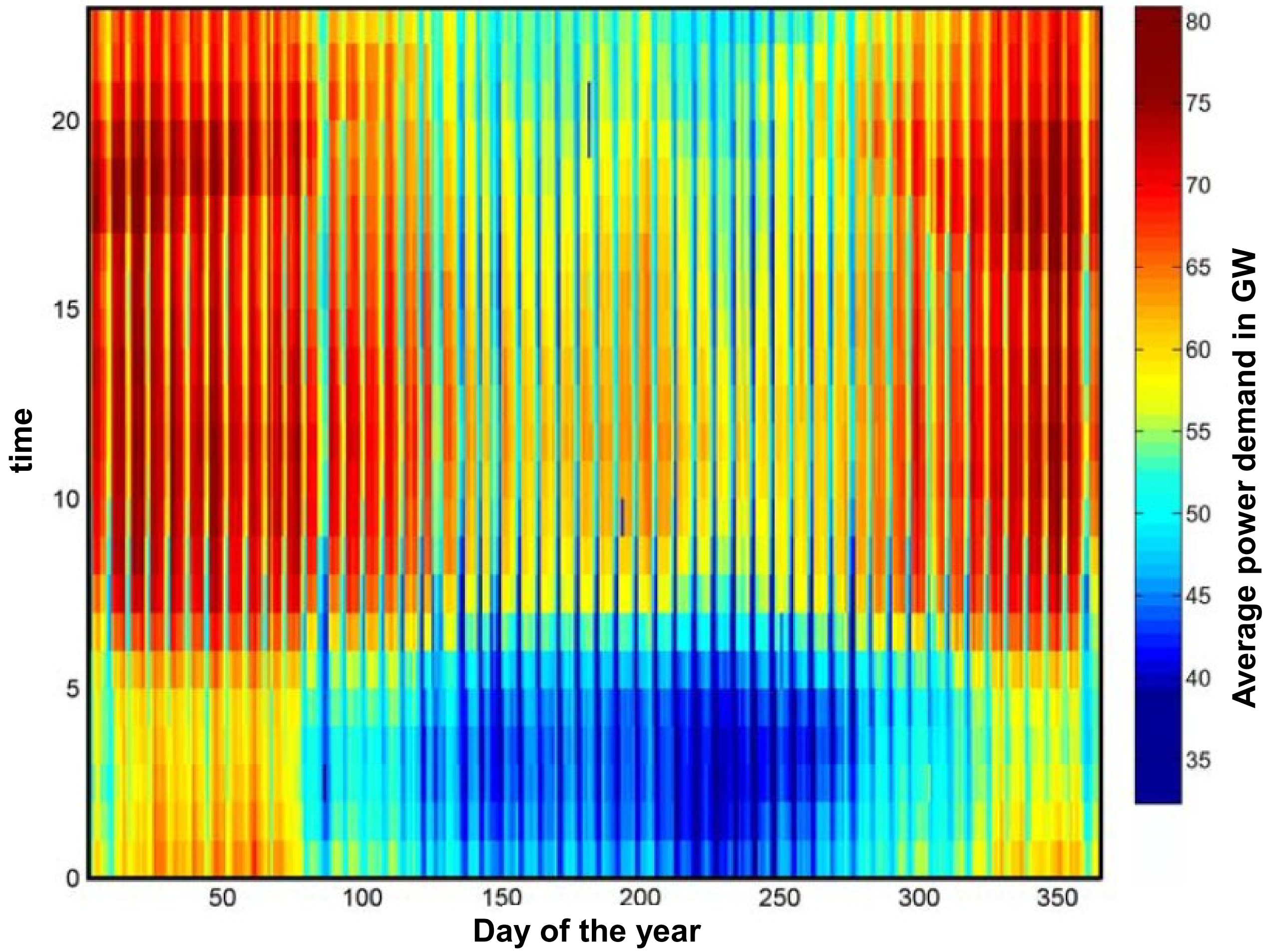
Fundamentals of electricity distribution:

$$P = U * I * \sqrt{3} * \cos\varphi$$
$$P_V = n * R' * d * I^2$$

- Different losses occur through electricity transport
  - Losses of the alternating current (AC)
  - Losses of the overhead lines
  - Losses of the wire
- Losses of the wire
  - Ohmic resistance
  - Limited heat resistance

Load distribution in the network

›Quelle: M.Beer, CO2-Vermeidung in DE, Teil II „Umwandlung & Ind., S.17, FfE München, 2009,



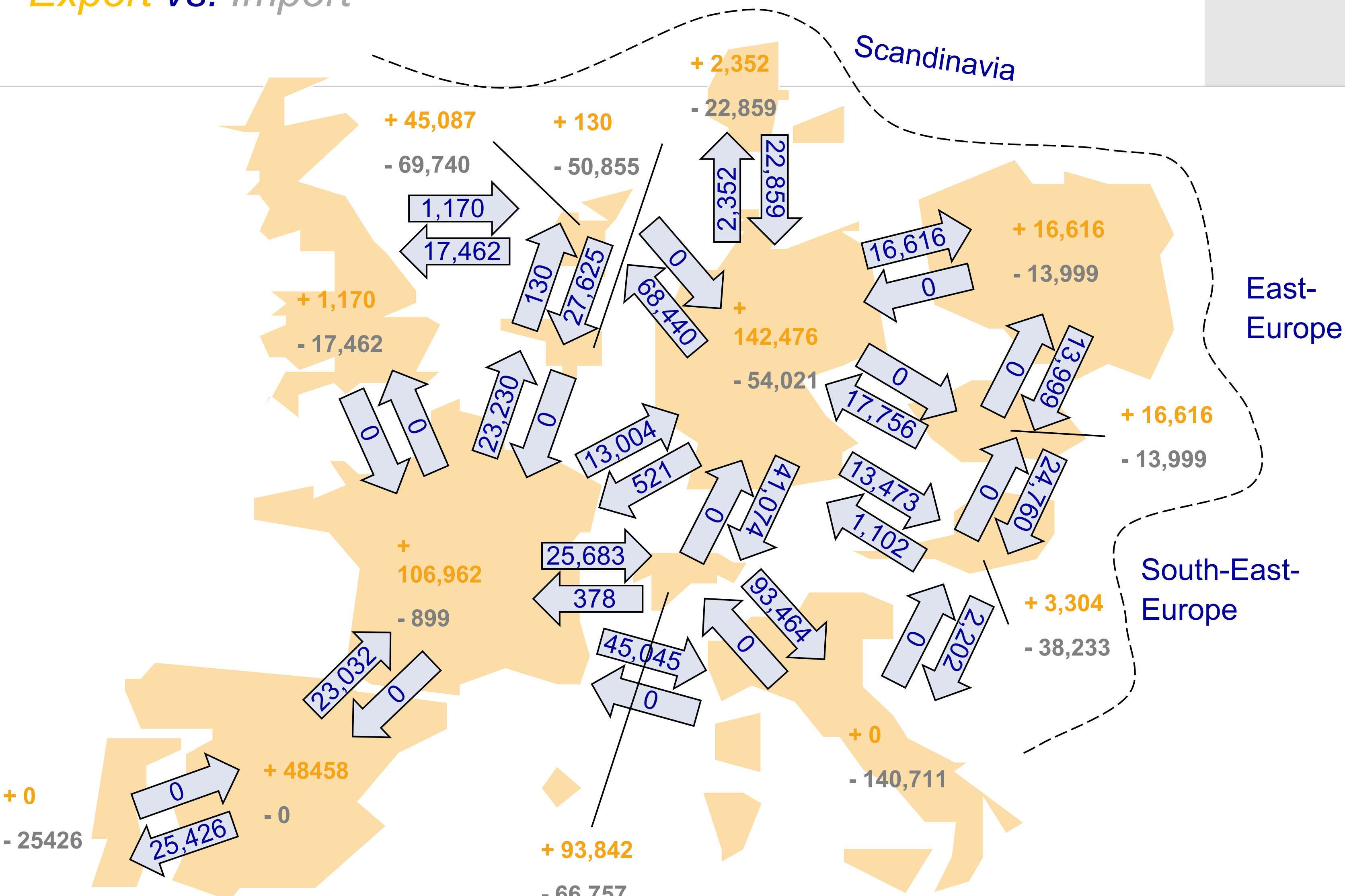
Load and demand in Europe

Country analyses under normal & severe conditions

ENTSO-E 2011

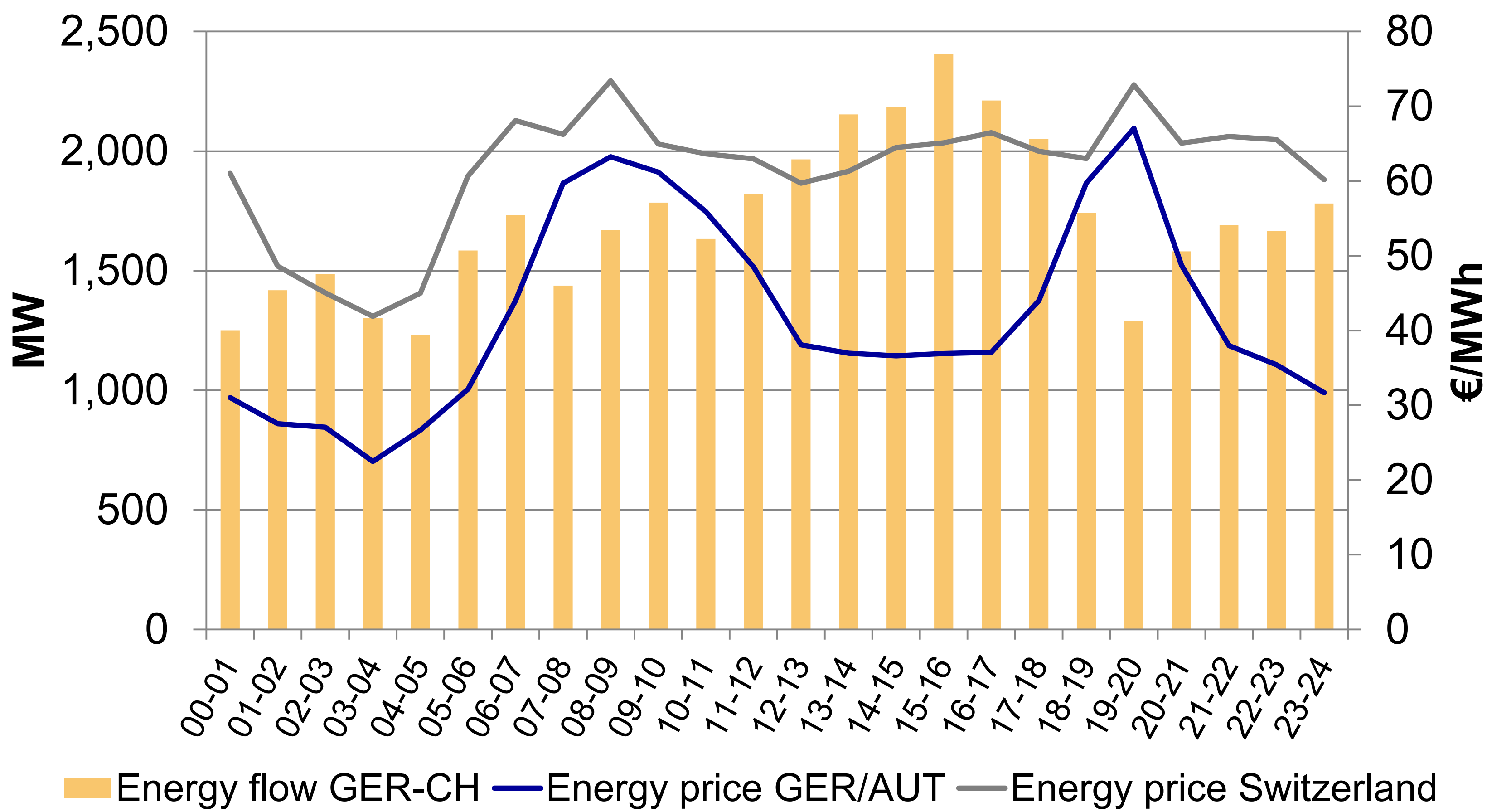
Physical power flows in Central - Europe 17.10.2012;

Export vs. *Import*



Source: entso-e

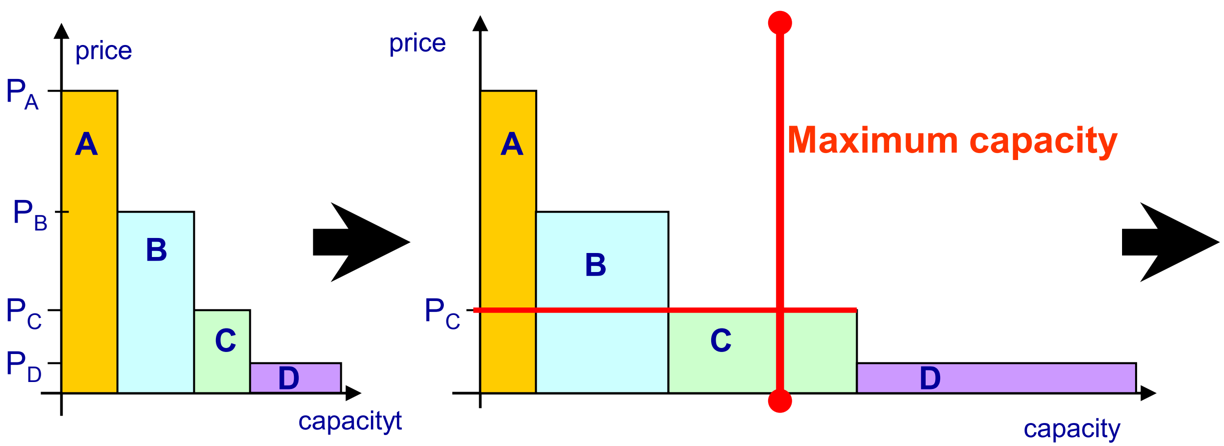
Physical power flows between Germany and Switzerland 17.10.2012



Source: entso-e; EEX

Possibilities for congestion management
Auction

- Most congestion in the European electricity network are managed through auctions
- Every market participant bids for the „right“ to transport electricity from his controlling zone to the other through the congestion between the control zones.
- Normally there are auctions for different time periods (year, month, day)
- Similar to the electricity trade at the spot market there is closed order book and a deadline for bids
- Bids are sorted according to the price descending
  - Price and amount of needed capacity
  - The highest price wins
  - The last achievable bid sets the price



- Tenderers A, B, C win the auction
- C can only use a part of its desired capacity
- D doesn‘t get any transport capacity
- The costs for the capacity of A, B, C are set by the price of C

Transport capacity – a more and more scare good
Challenges for the network operation in Europe

EnBW

Example: TenneT-control zone

- Currently there is a high burden through wind energy and trade flows from Scandinavia
- 6.200 MW transport capacity/ 3.500 MW min. demand

- Additional wind capacity
- Integration of new power plants
- Expansion of transport capacity with Scandinavia is demanded

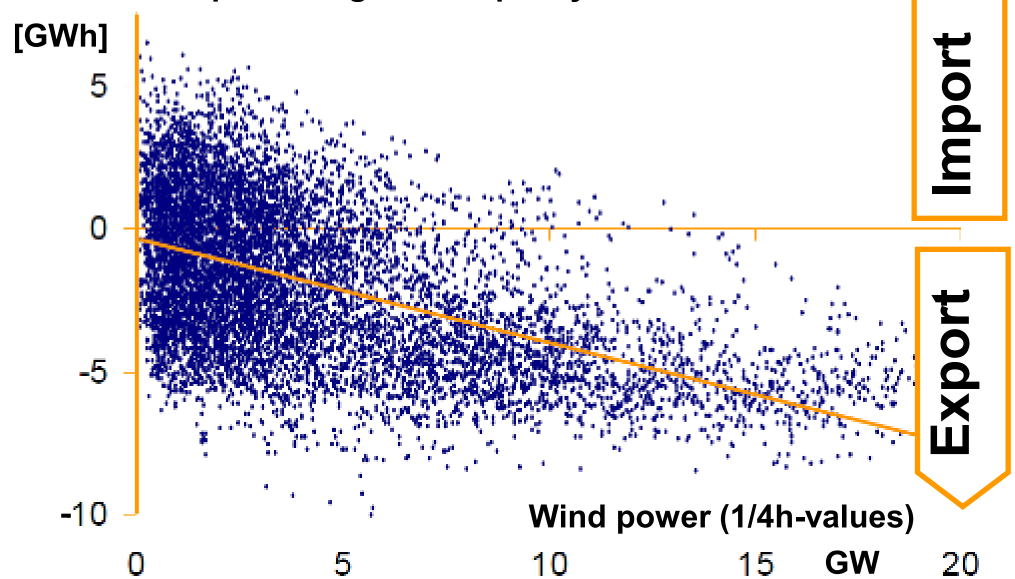
Example:

- Central Europe at the 22.12.04, 17:30 h, phys. Load flows
- Wind feed-in: 11,461 MW
- Export balance: ca. 6200 MW

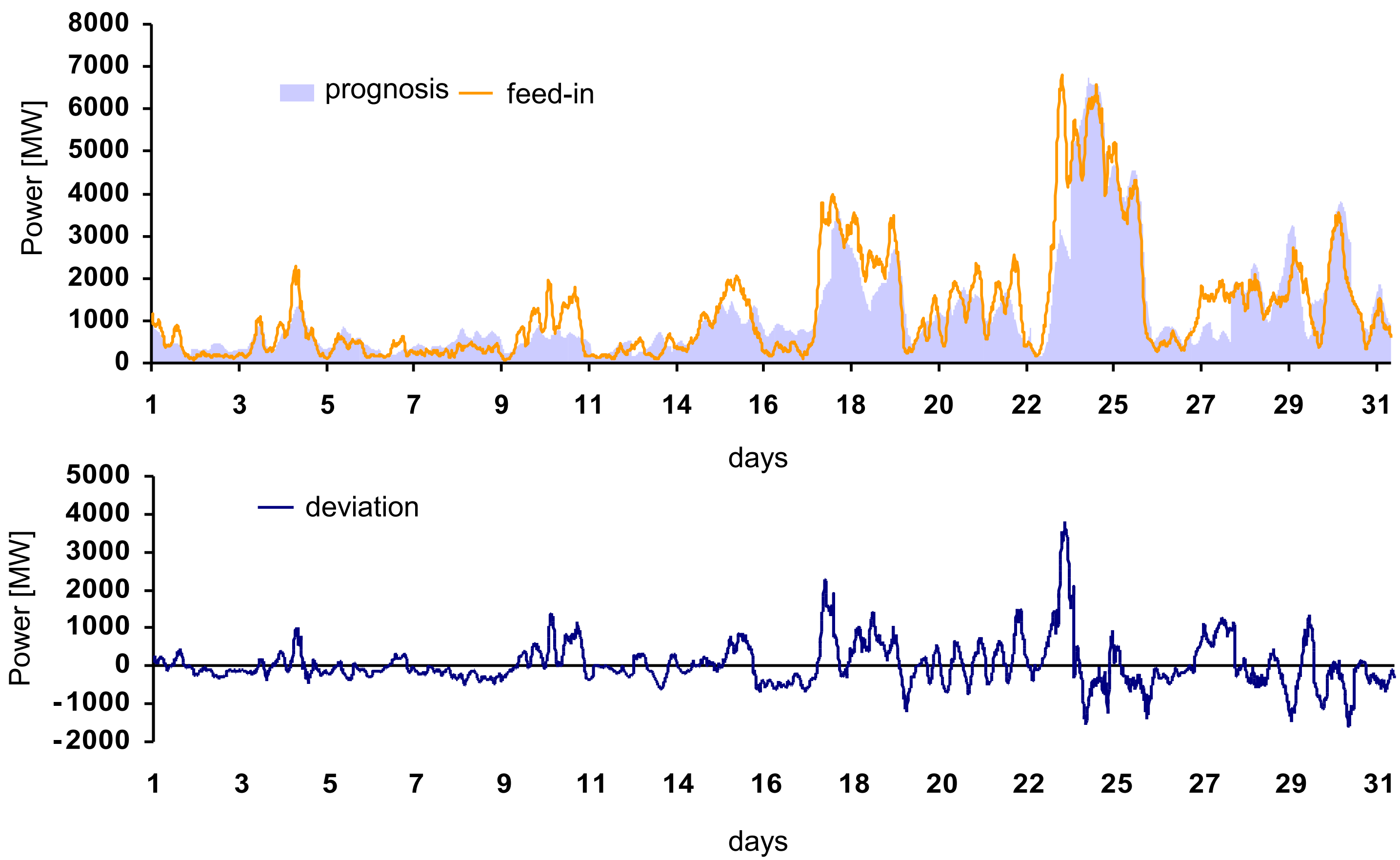
Result:

- With a growing wind feed-in the electricity is pushed in the neighbouring countries
- Growing stress on the cross-border transfer capacity
- Overloading of the neighbouring networks

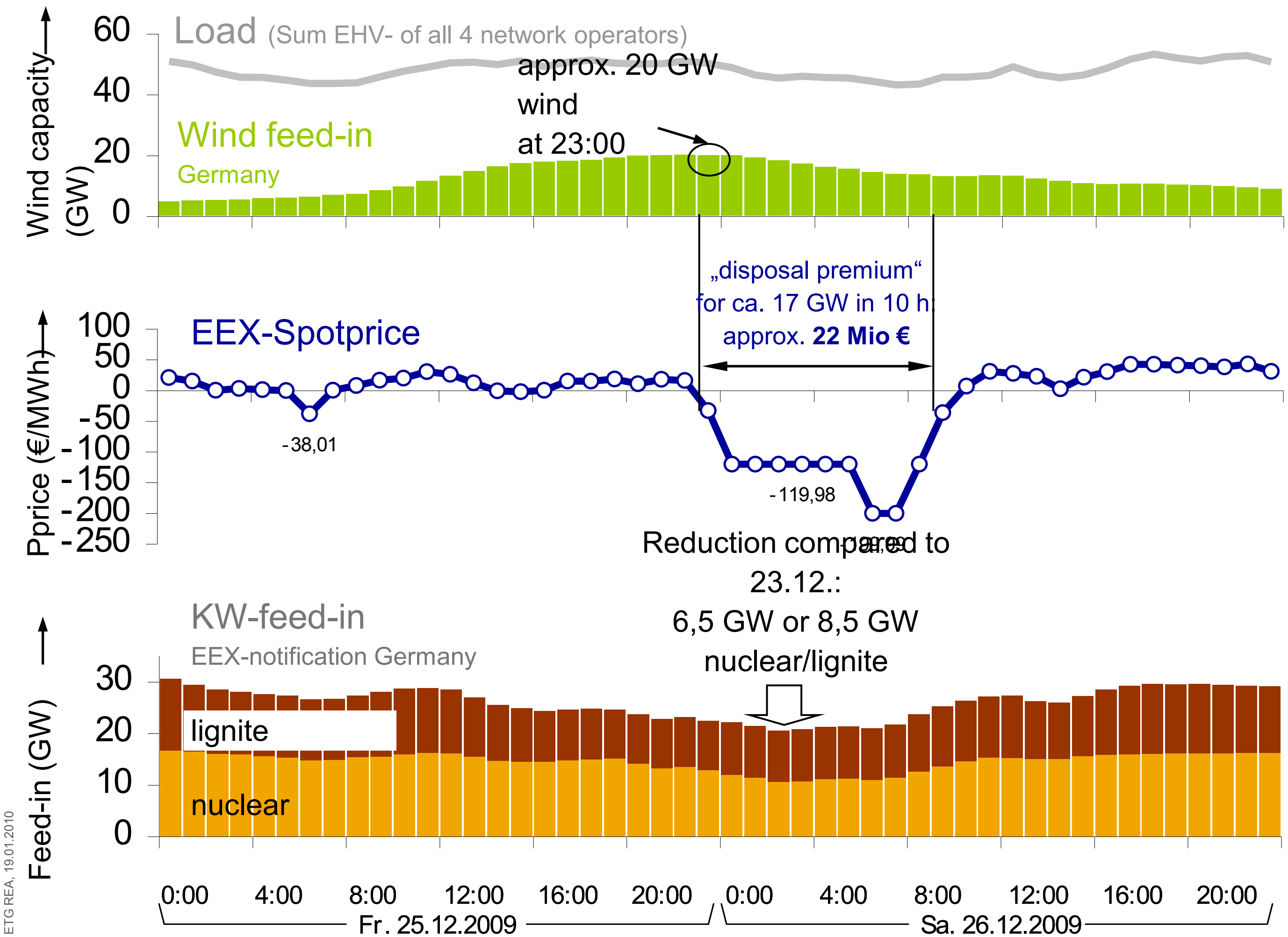
Import-/Export balance depending on the producing wind capacity 2008



Wind energy feed-in in the TenneT-network, Aug. 2010
prognosis and real feed-in



Market reaction strong wind situation 25./26.12.2009:

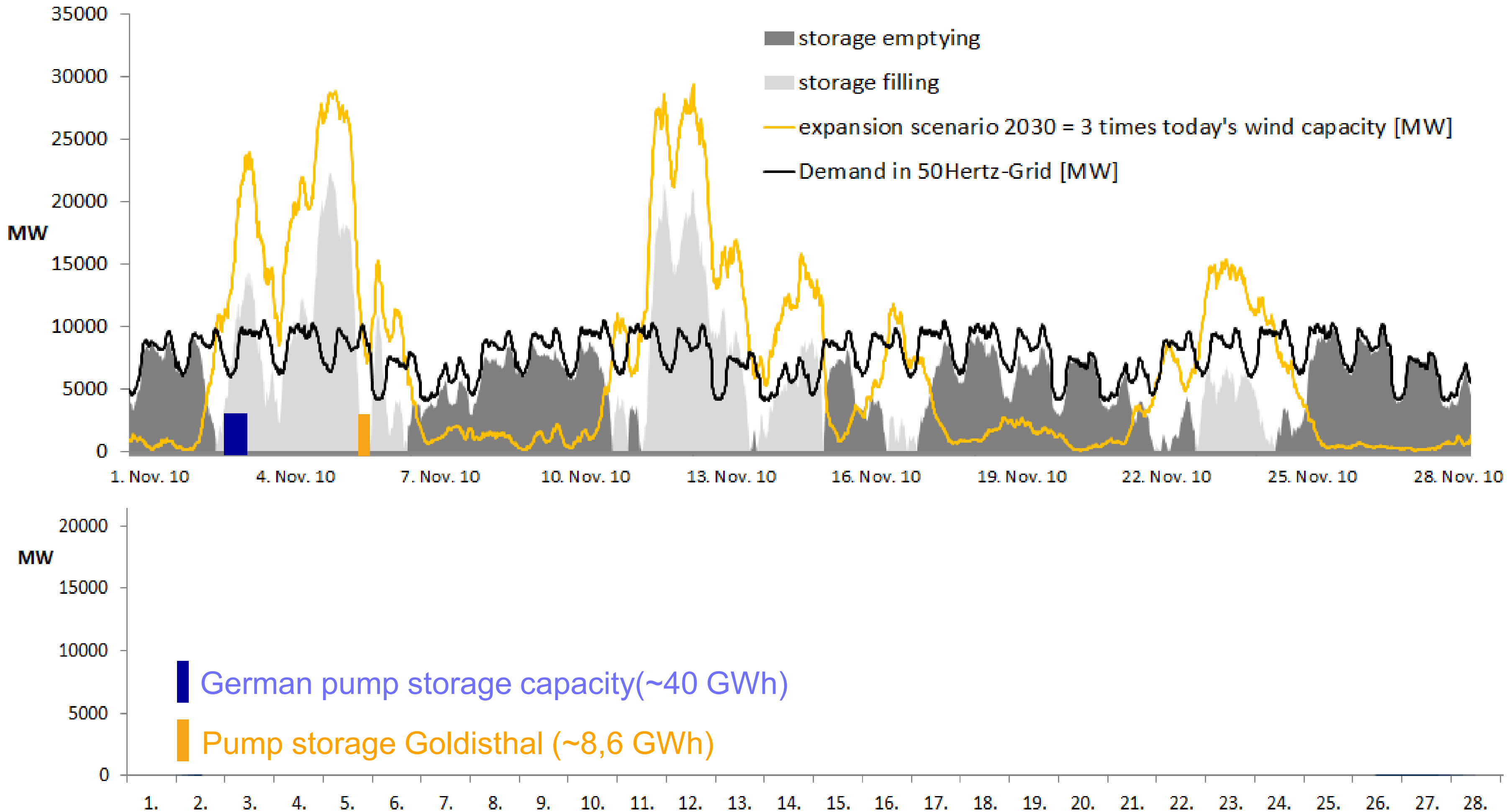


September 2012:

29.6 GW installed wind capacity in Germany

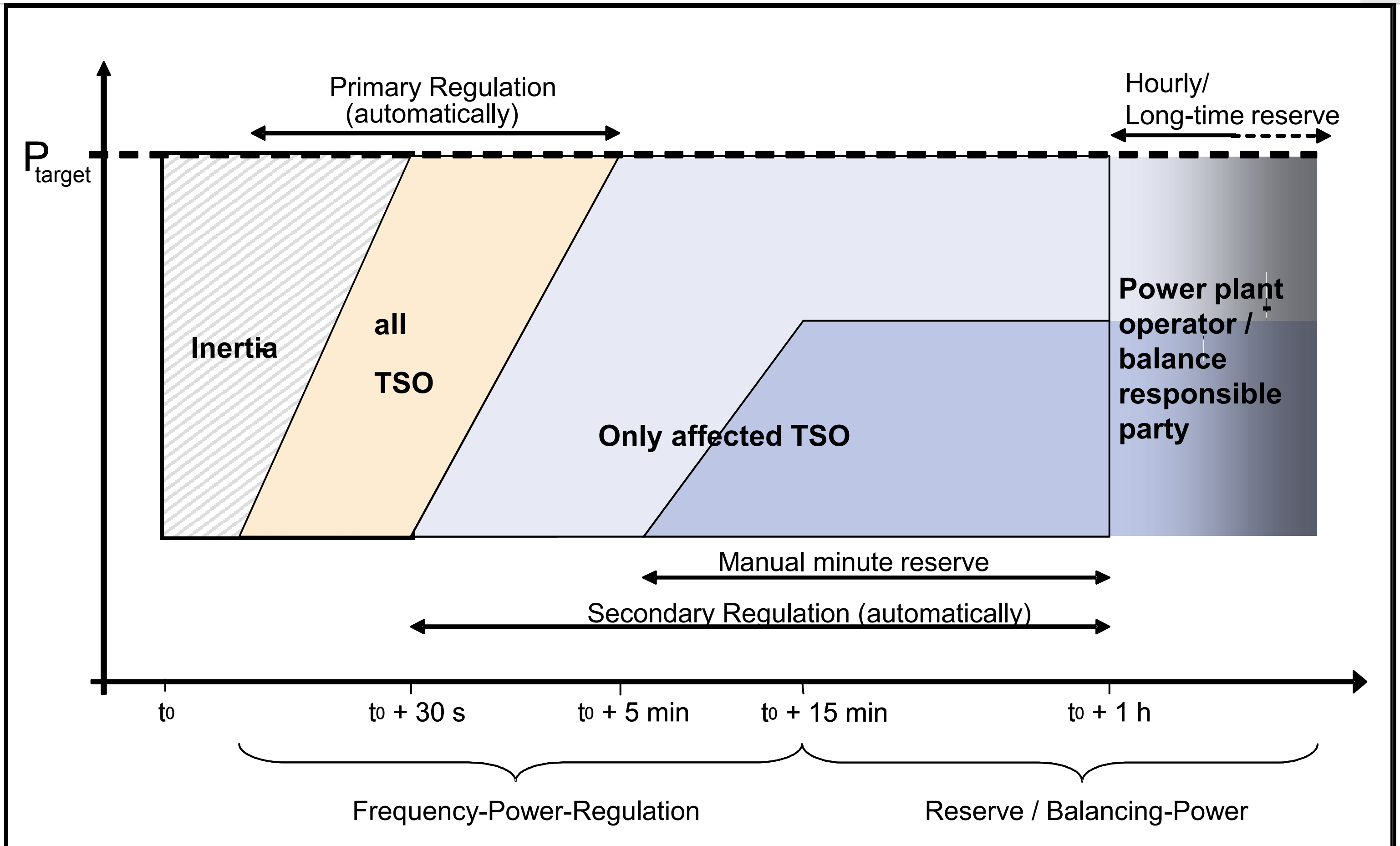
The Challenge

Difference between electricity demand and operating wind capacity



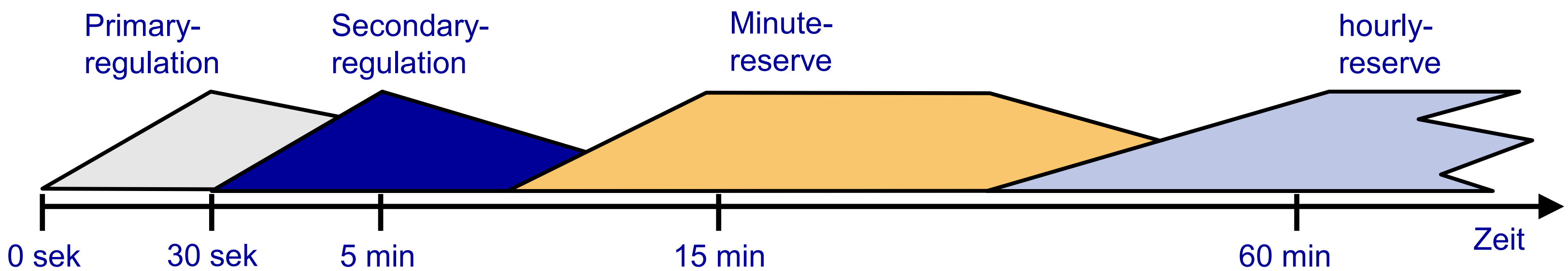
Balancing power

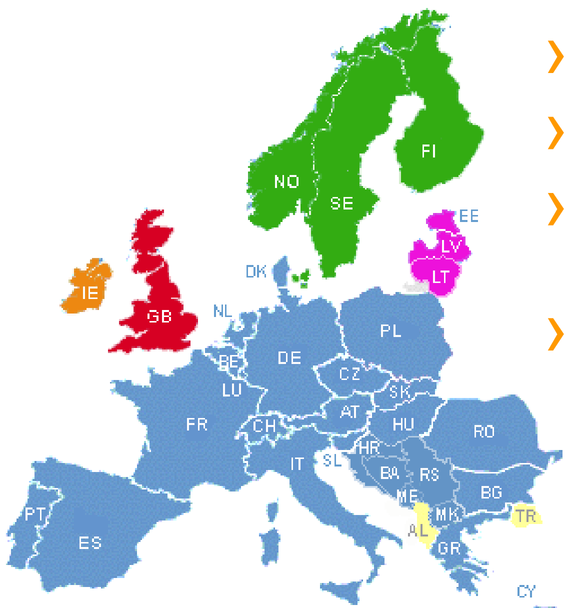
Theoretical process of frequency-power-regulation



Balancing power – security system of the electricity business

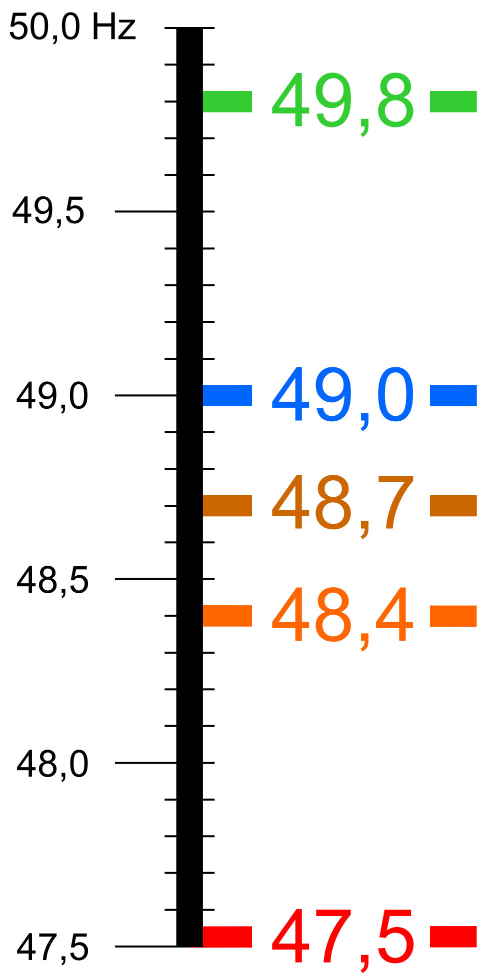
Demand for balancing energy in Germany 5200 MW thereof 2500 MW for minute reserve





- 5 different control zones in Europe
- Primary regulation works international
- Secondary regulation, minute reserve and hourly reserve national
- Coordinated and bilateral provision of balancing power in Europe
  - 3000 MW shared by the different countries
  - $P_x = 3000\ MW * ci = 3000\ MW * \frac{E_i}{E_U}$

VDN-5-steps plan to limit disorders in the electricity grid



Step 1:
Alerting the control centres;
Use of the not mobilised power plant capacity

Step 2:
Immediate disconnection of 10 – 15% network load

Step 3:
Immediate disconnection of additional 10 – 15 % network load

Step 4:
Immediate disconnection of additional 10 – 15 % network load

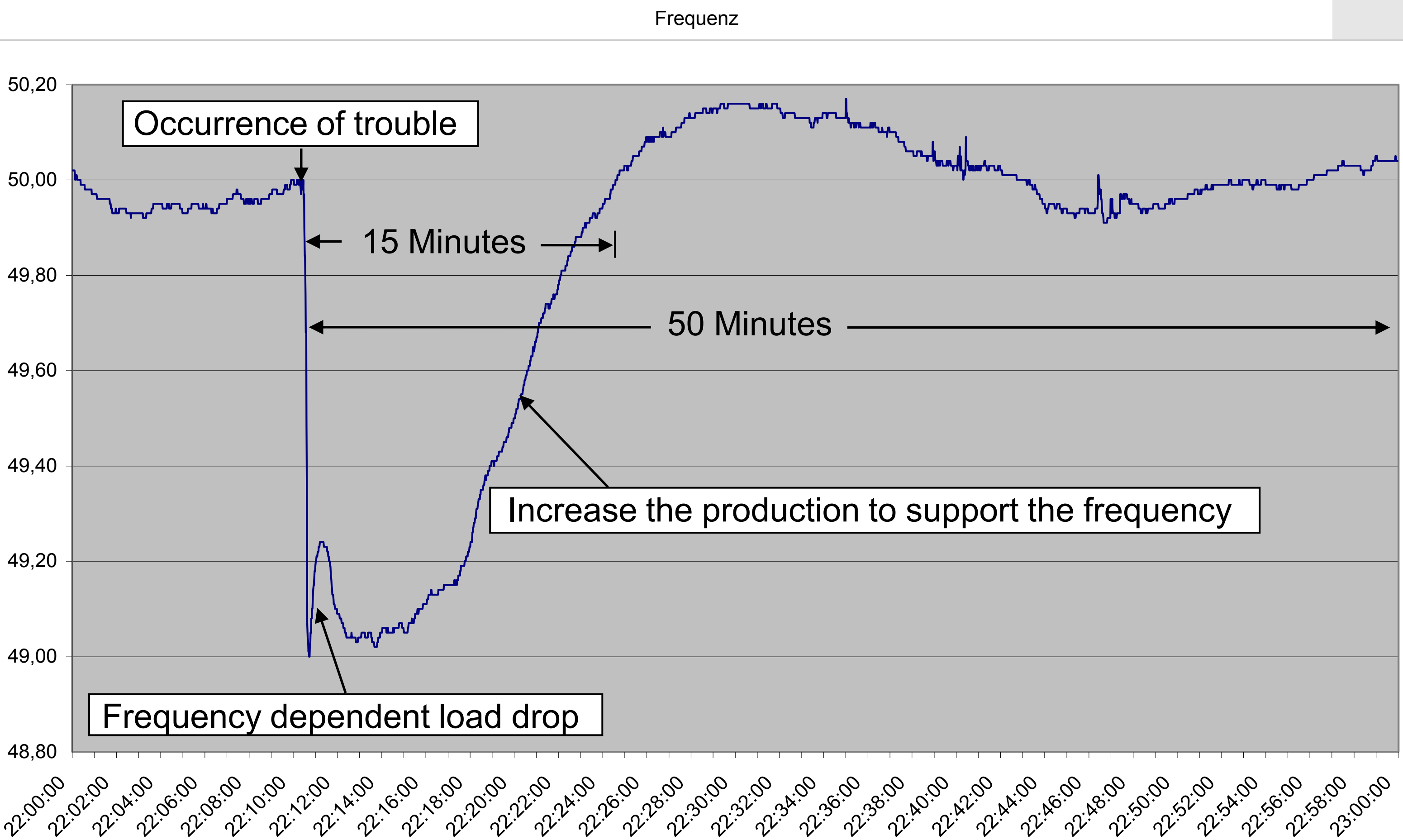
Step 5:
disconnection of power plants from the network

Disruption of the integrated network 04.11.2006:
load drop at 49,0 Hz

- in France approx.. 5.000 MW
- at Amprion approx.. 2.000 MW
- at TenneT ca. 400 MW
- at TransnetBW approx.. 158 MW (approx.. 2% of the current network load)
- Additional load drops in Belgium, Italy and Spain

Trouble history – 4th November 2006

Frequency curve in the south-west UCTE-network



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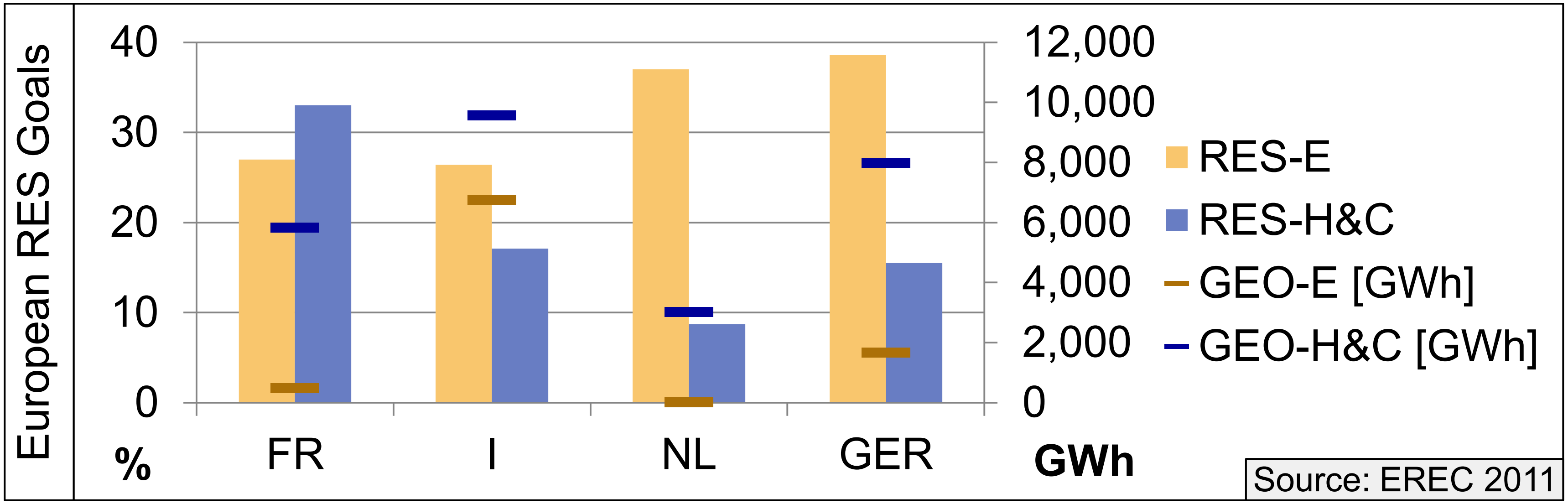
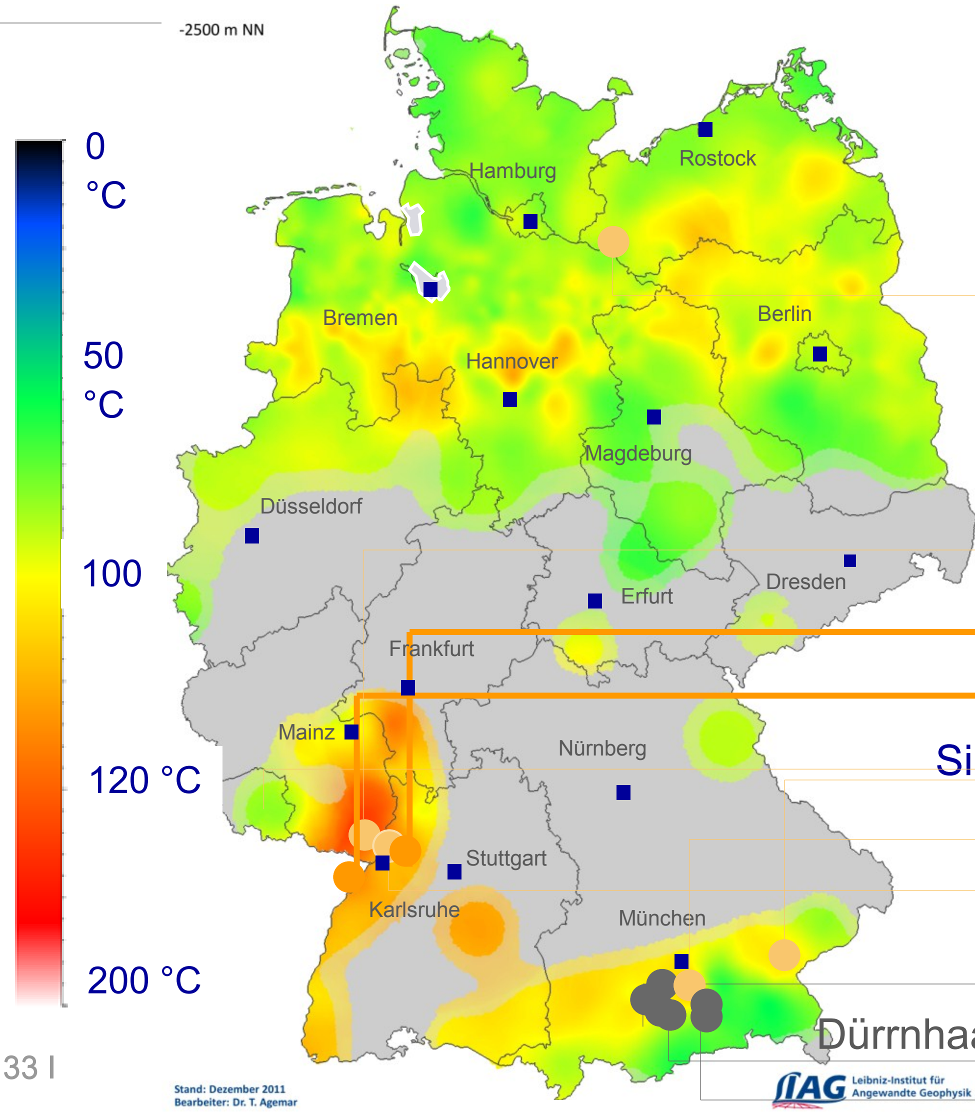
European directives and goals concerning renewable/geothermal energy sources

- European directive 2009/28/EC
  - Article 2a: “energy from renewable sources’ means energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, … “
  - Article 2c: “geothermal energy’ means energy stored in the form of heat beneath the surface of solid earth;”



Geothermal power plants in Germany



*existing *planned

Neustadt-Glewe

Landau

Bruchsal

Soultz-sous-Forêts

Simbach-Braunau

Unterhaching

Insheim

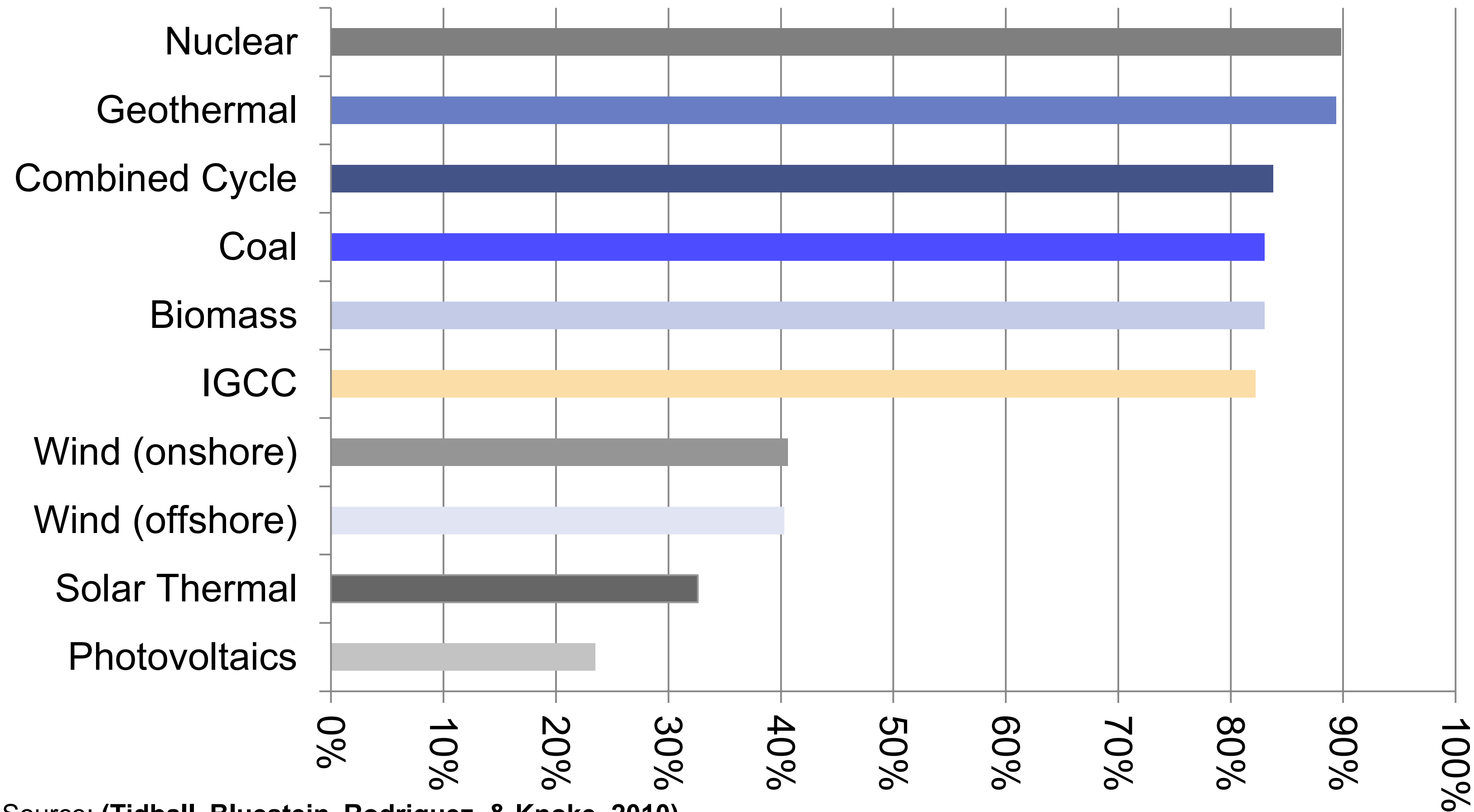
Sauerlach

Kirchstockach

Dürrnhaar, Taufkirchen

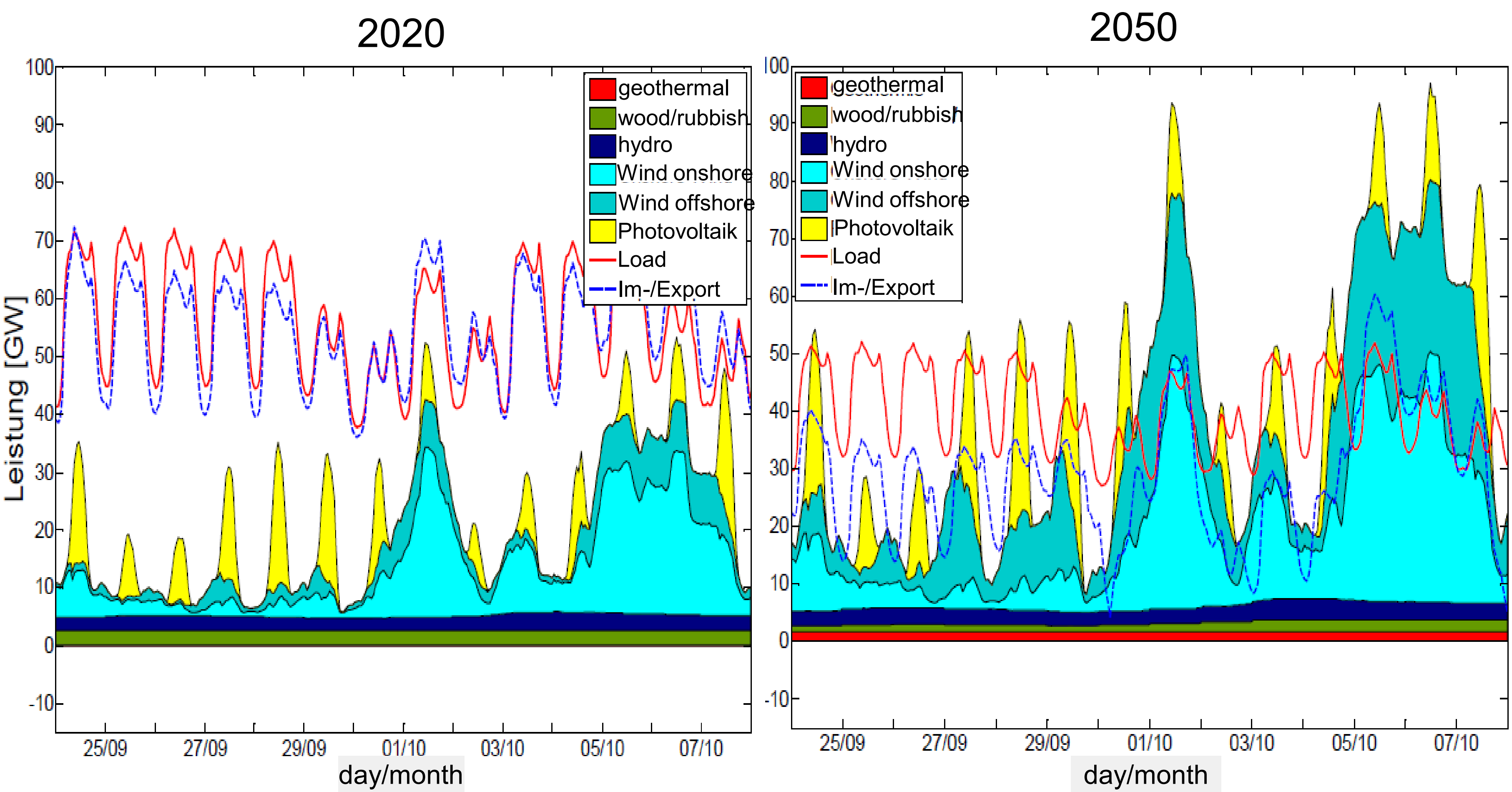
Kirchweidach, Traunreuth

Capacity factors for electricity production
Availability of power plants



Source: **(Tidball, Bluestein, Rodriguez, & Knoke, 2010)**

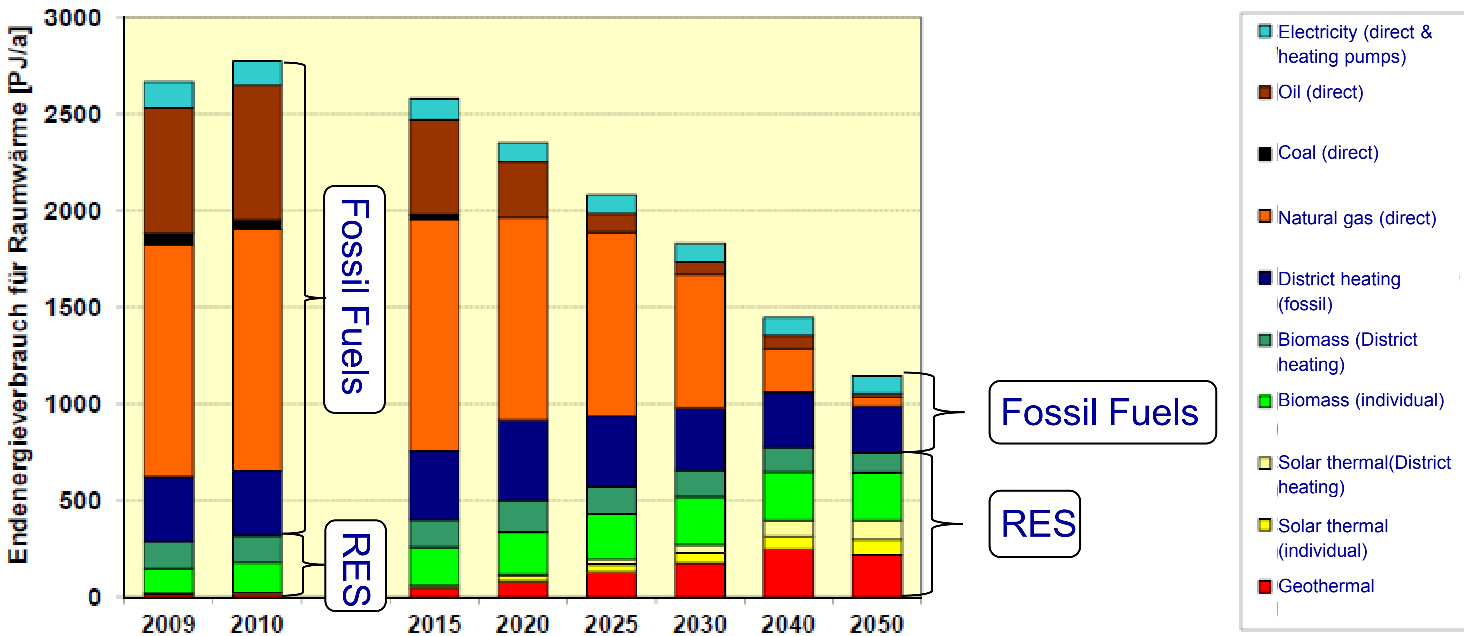
Future demand for base load power



Source: Nitsch et. al 2012

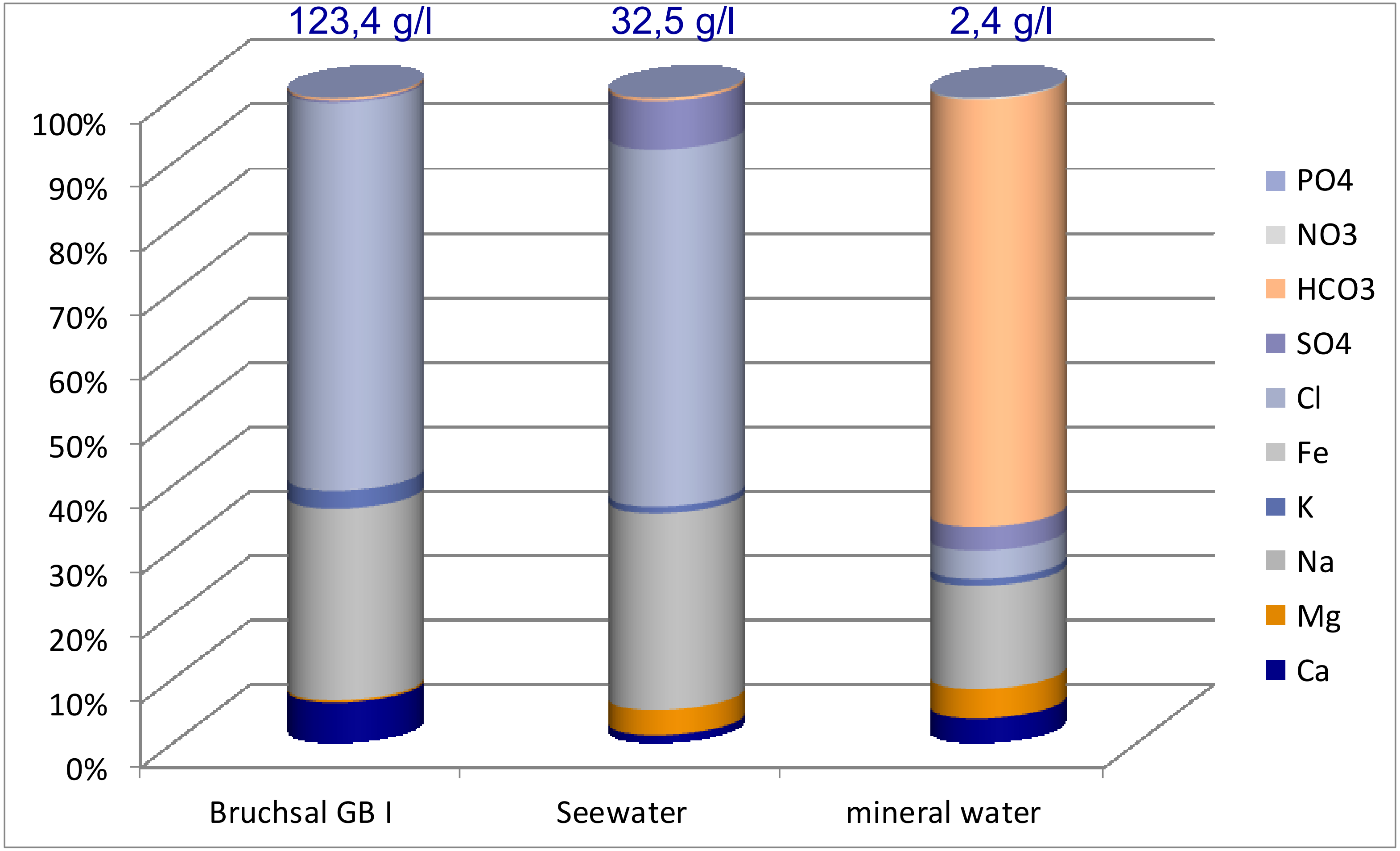
Renewable heat production – the sleeping giant of climate protection

- Ambitious goals for renewable heating in Europe
- 10.2 % of German heat demand (heating; warm water) comes From RES (2011)
- In Germany around 90 % of a households energy demand is used for heating
- Only 3 renewable Sources



Source: Nitsch et. al 2012

Mineralisation of the brine (Bruchsal)



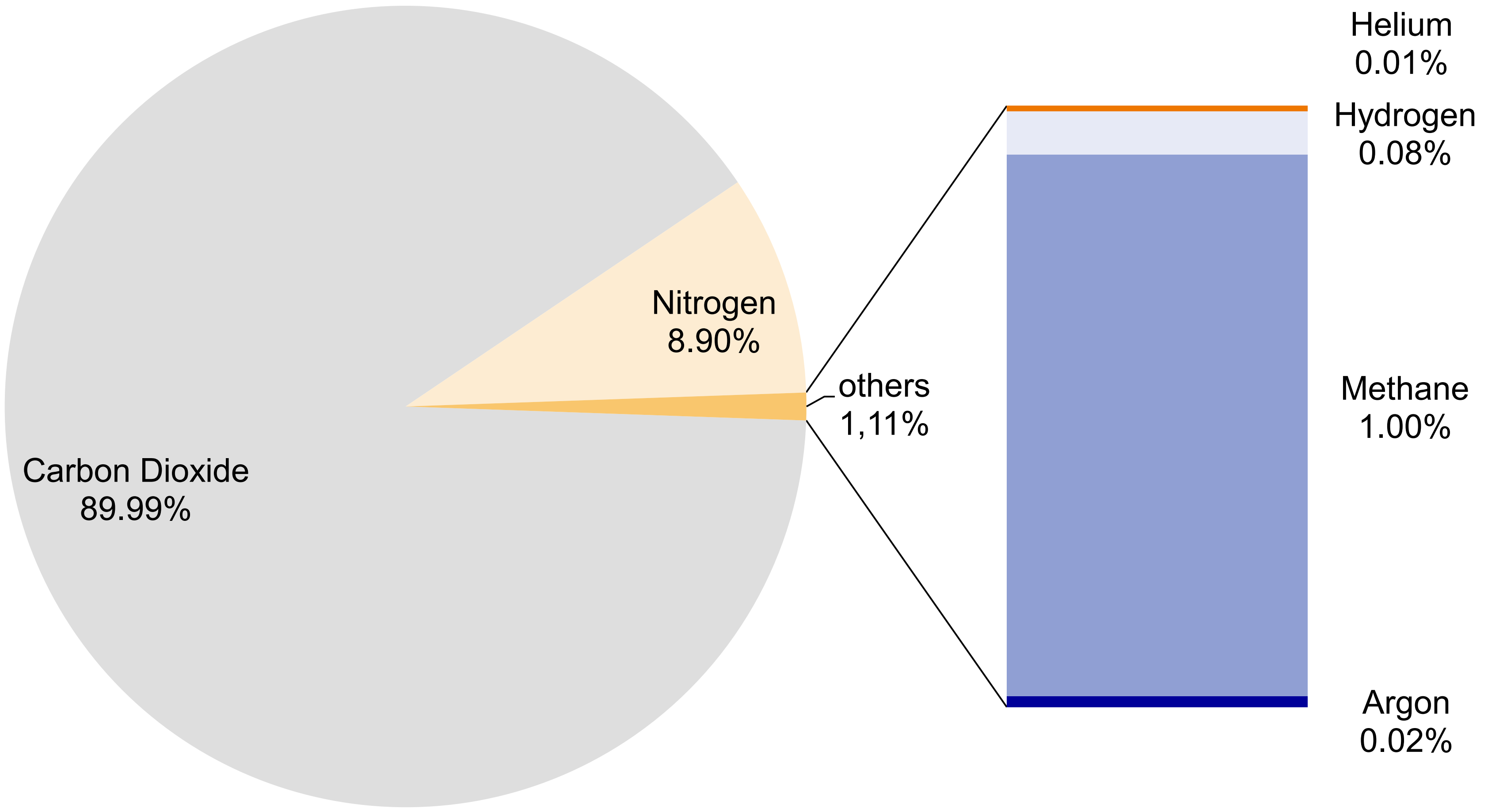
Scaling - Bruchsal

Source: ewb Bruchsal

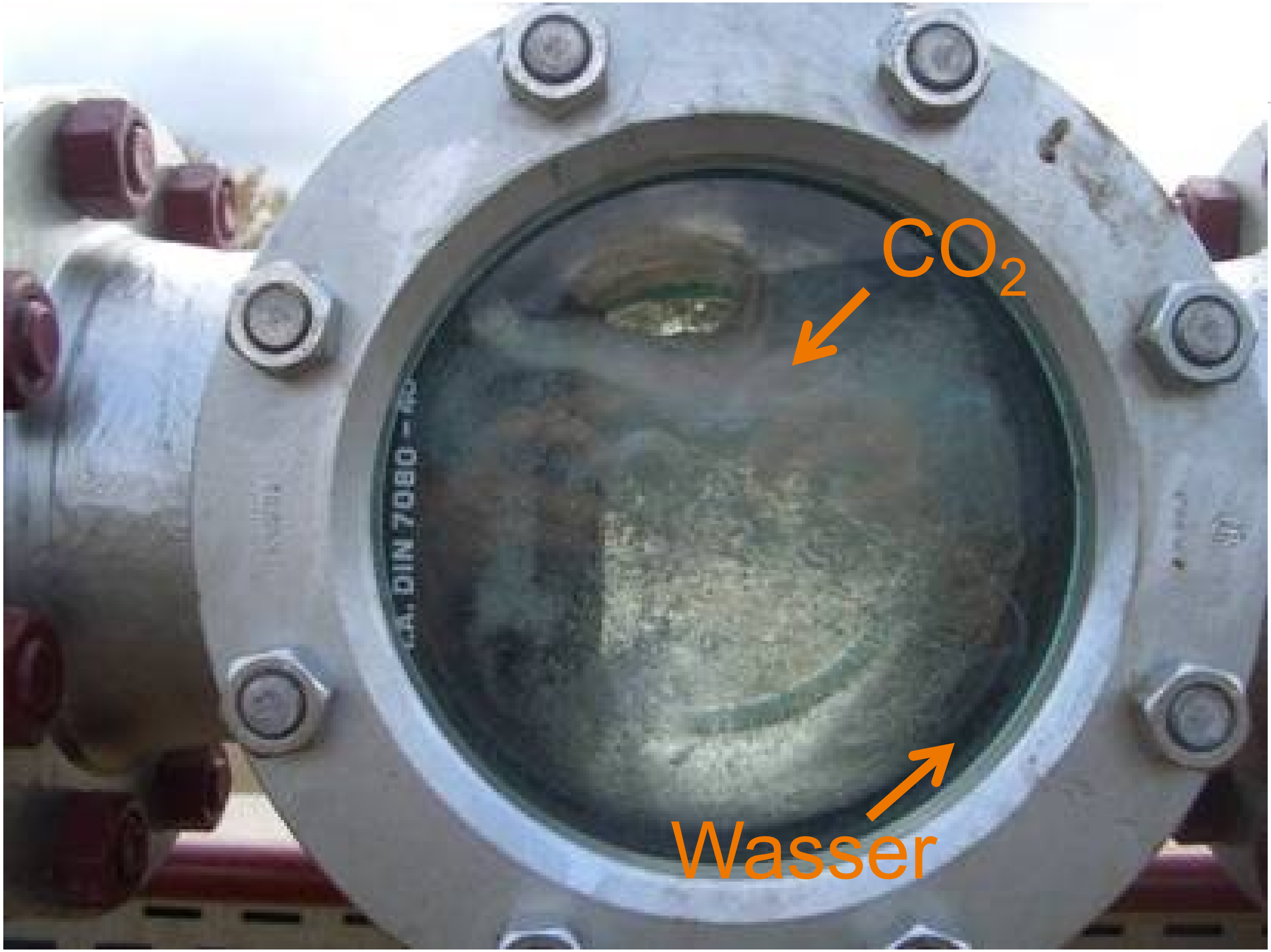
Measures to handle scaling and corrosion

- Thermodynamic equilibrium
  - Keep pressure and temperature constant
  - Less precipitation
- Inhibitors
  - Currently no convincing solution available
  - Practical test are necessary
- Carbon steel pipes with extra thick walls
  - Non corrosive steel is to expensive
  - Thicker walls allow a certain corrosion

Gas Composition - Bruchsal

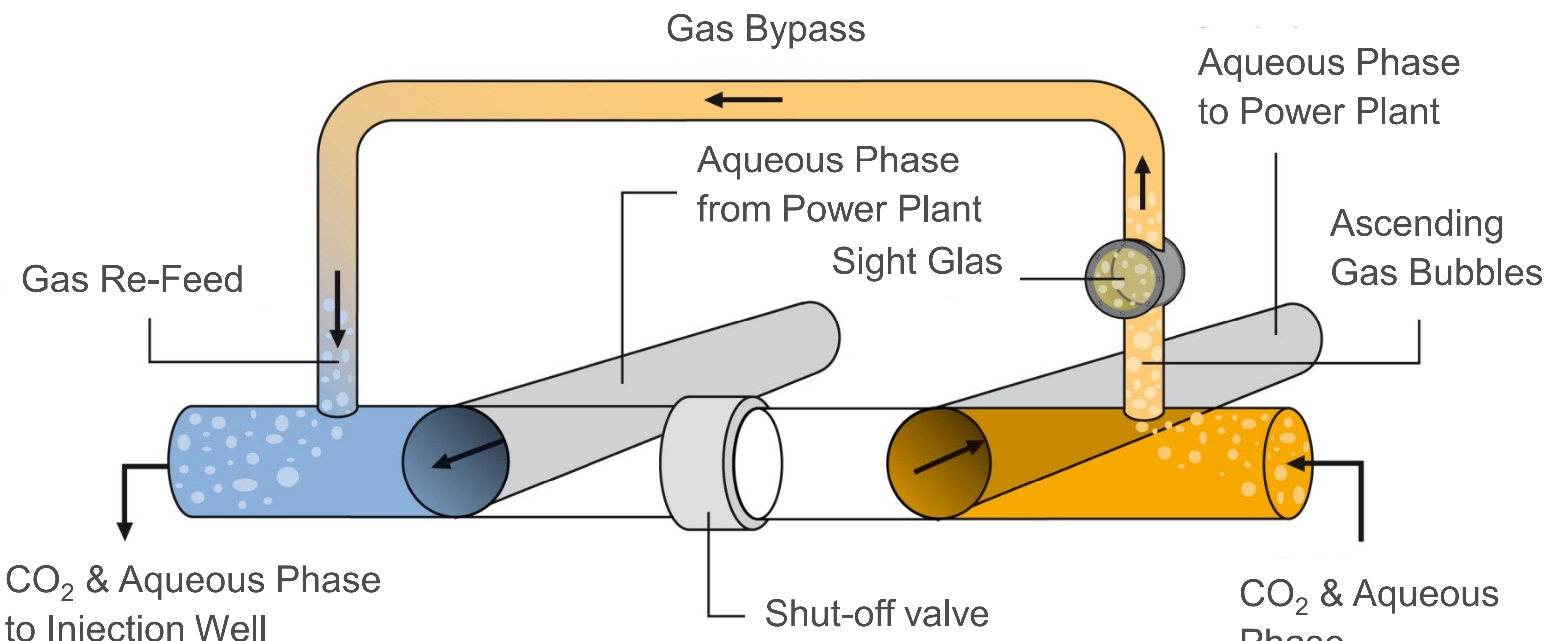


Two Phase Flow: CO_2 and Aqueous Phase



Two Phase Flow: CO_2 and Aqueous Phase

- Technical measures to prevent precipitations and low efficiency of heat exchange:
  - Pressure maintenance
  - Acidifying
  - Application of inhibitors



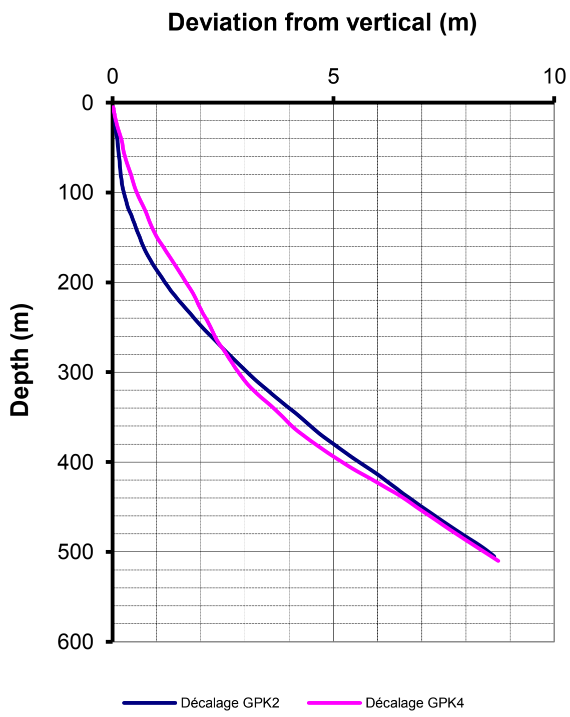
Pumping technologies applied and tested in Soultz

Three different kind of pumps are used in the geothermal loop

- Line Shaft Pump (LSP): the hydraulic pump is down-hole, the motor drive is at surface, connection being done through a line shaft
  - ⇨ mechanical risk
- Electric Submersible Pump (ESP): both electrical motor and pump are down-hole, the motor drive is fed by a MV cable
  - ⇨ electrical risk
- Injection pumps : horizontal, multistage high pressure pump (surface equipment)

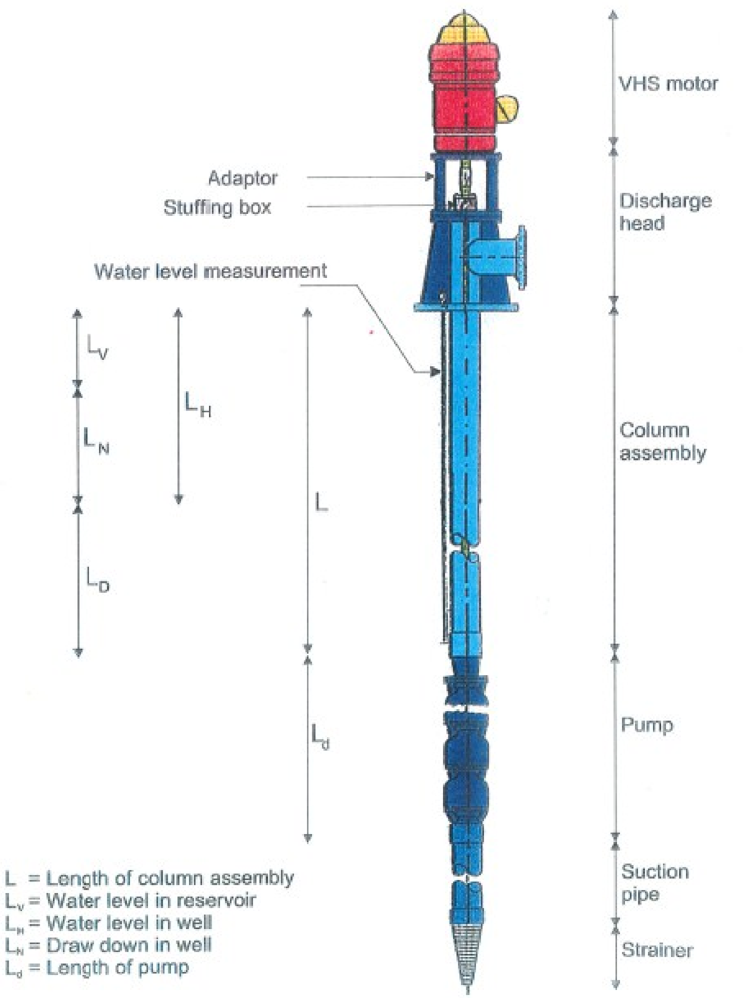
Key data LSP - located in well GPK2

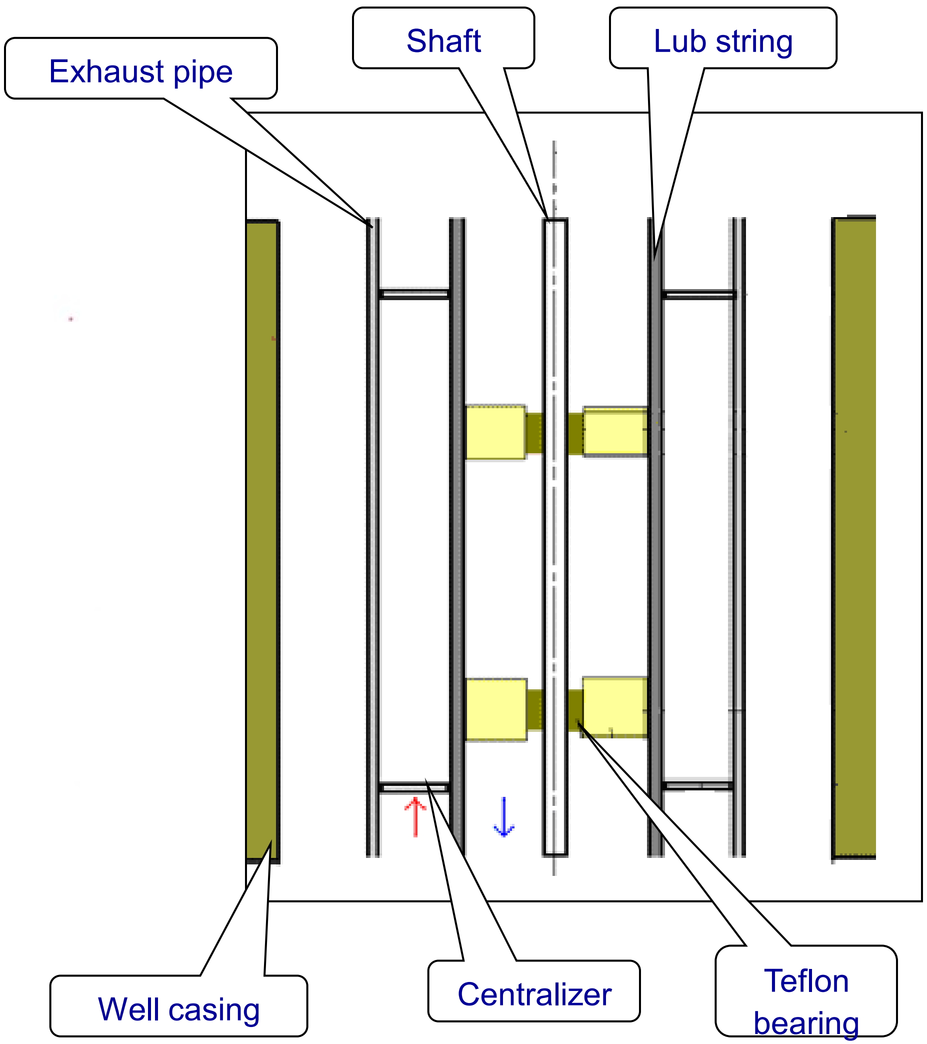
- Design data:
- Ordered in June 2006 (Manufacturer: IGE Ltd.)
- Initial shaft length of 350 m
- Max. volume flow 40 l/s
- Surface motor 350 HP, Variable Frequency Drive
- Lubrication by demineralized tap water



- operation conditions:
- Initial productivity of GPK2 was 1 l/s/bar
- Productivity improved during operation time
- The LSP is now installed at 270 m depth due to verticality issue
- ~ 25 l/s, ~170 °C and a TDH of 300 - 400 m

Working principle and general configuration of LSP





Ref: IGE Ldt.

Working principle and general configuration of LSP

riser, enclosing tube, shaft

Teflon bearings

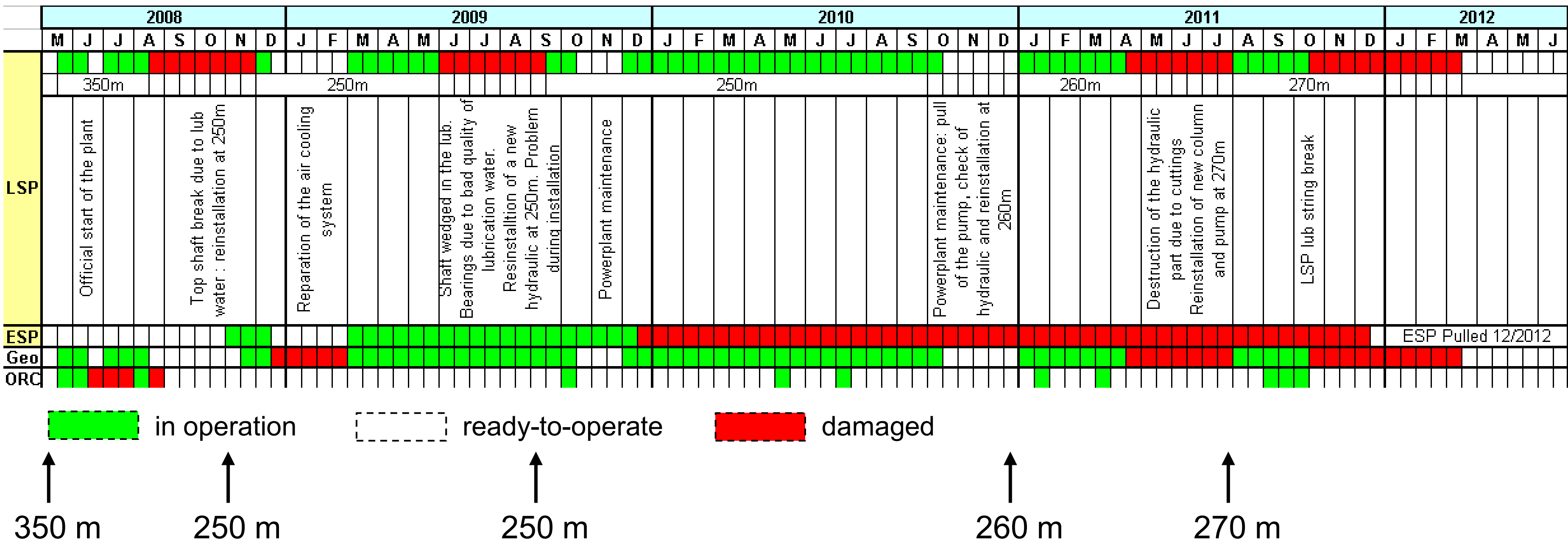
hydraulic part, 17 stages

installation

motor/shaft coupling

view at well head/motor

Operating time and maintenance of LSP



- The LSP pump has been installed/removed 5 times at different depth
- ~23 month of operation, ~15 to 20 start ups
- All installations have been carried out by the GEIE team.

Dismantling one and two due to lubrication problems

- Failure mode
- Shaft wedged in enclosing tube and broke
- Caused by bad quality of lubricant (demineralized tap water)

- Problem solving
- Re-engineer of water treatment plant

Dismantling due to hydraulic problems

- Failure mode
- Damage of impellers (all stages), bearings, centralizers and enclosing tube
- Caused by abrasion, corrosion, local cavitation?
- Problem solving
- Material selection, adapted operation conditions (to be proven!)



Design and operation improvements done for the restart in March 2012

- Test of new bearing material (lub string): Bronze
- Increase the number of stages in order to decrease the rotation speed of the pump ⇨ avoid vibration problems
- Replacement of damaged parts (hydraulic part, piping)
- Adjustment of shaft diameter ⇨ reduce sleeve diameter from 47,5 to 47mm
- Renew surface connection (shaft/motor coupling)

Lessons learned during LSP operation

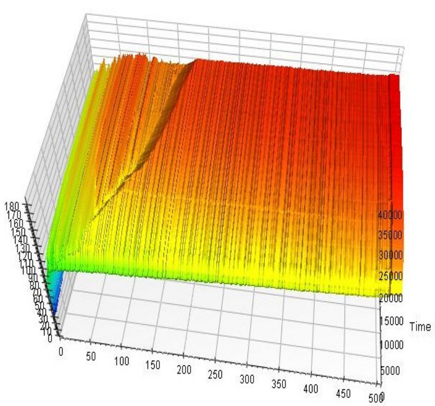
- Research and improvements done on LSP at Soultz
  - Test of new materials for hydraulic part (Bronze)
  - Test of metal hardening (Boronization)
  - Improvement of some pieces of the hydraulic part
  - Improvement of pump installation procedure, development of new tools
  - Test of new internal bearing design
  - Improvement of water level measurement device

Key data ESP - located in well GPK4

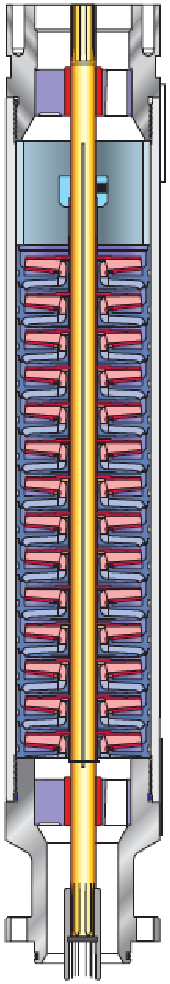
- Design data:
- ESP REDA Schlumberger ordered in June 2007
- 339 kW, max. 40 l/s, min. 20 l/s, total ESP length of 20 meters
- Specific high temperature design for brine temperatures of 185 °C; Motor is cooled by hot geothermal brine why oil temperature can reach up to 260 °C
- Noble materials due to specific working conditions
- Temperature monitoring along ESP

operation conditions:

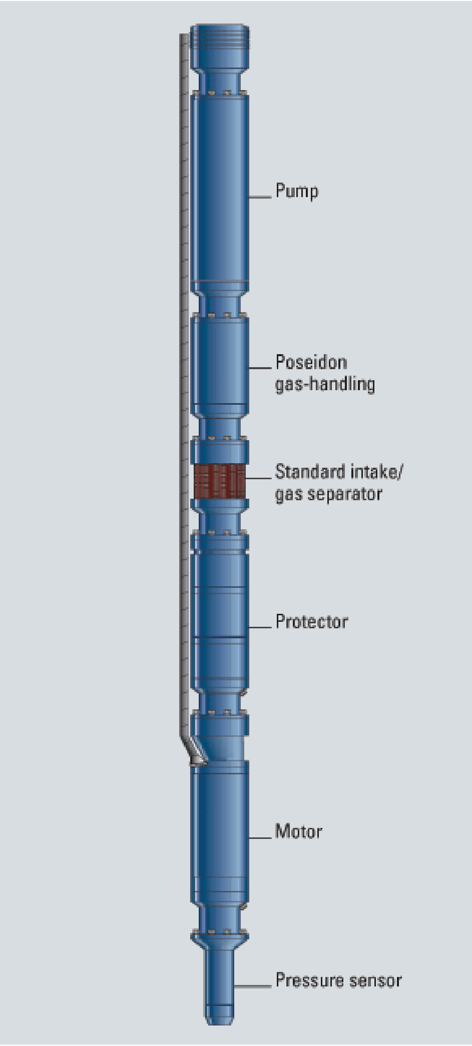
- Installed at 500 meter depth in GPK4
- ~ 25 l/s, ~170 °C and a TDH of 400 to 600 m

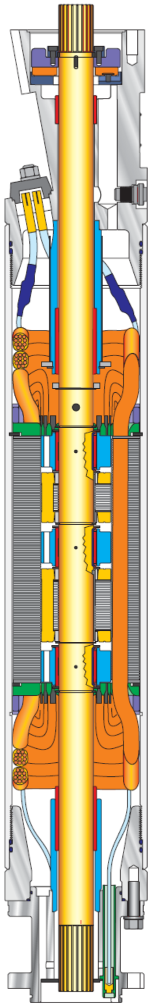


Working principle and general configuration of ESP



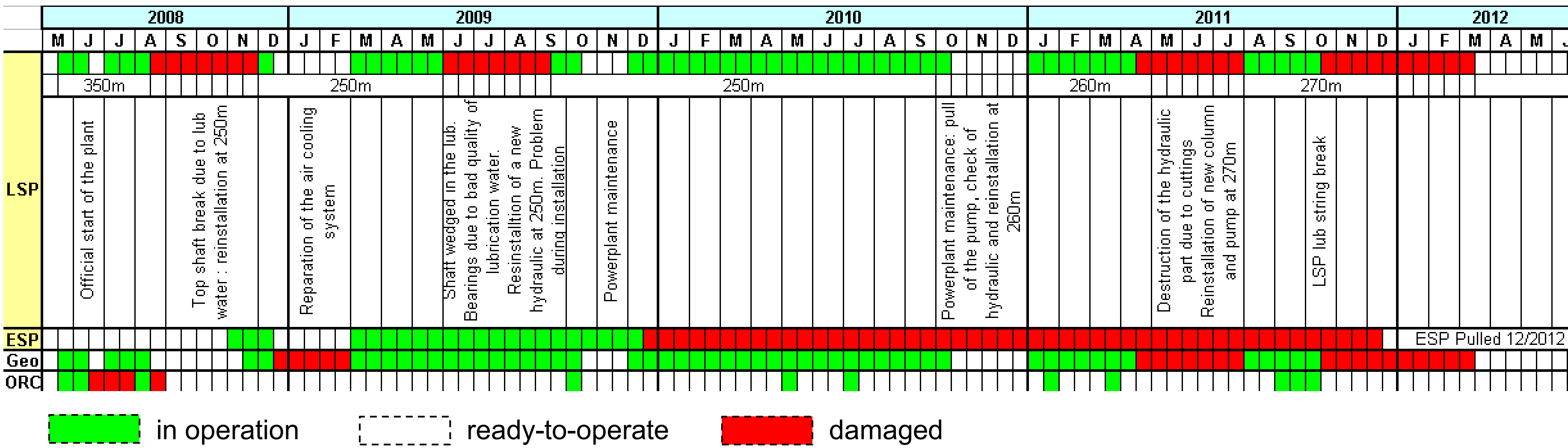
Radial-flow centrifugal pump





Ref: Reda/Schlumberger

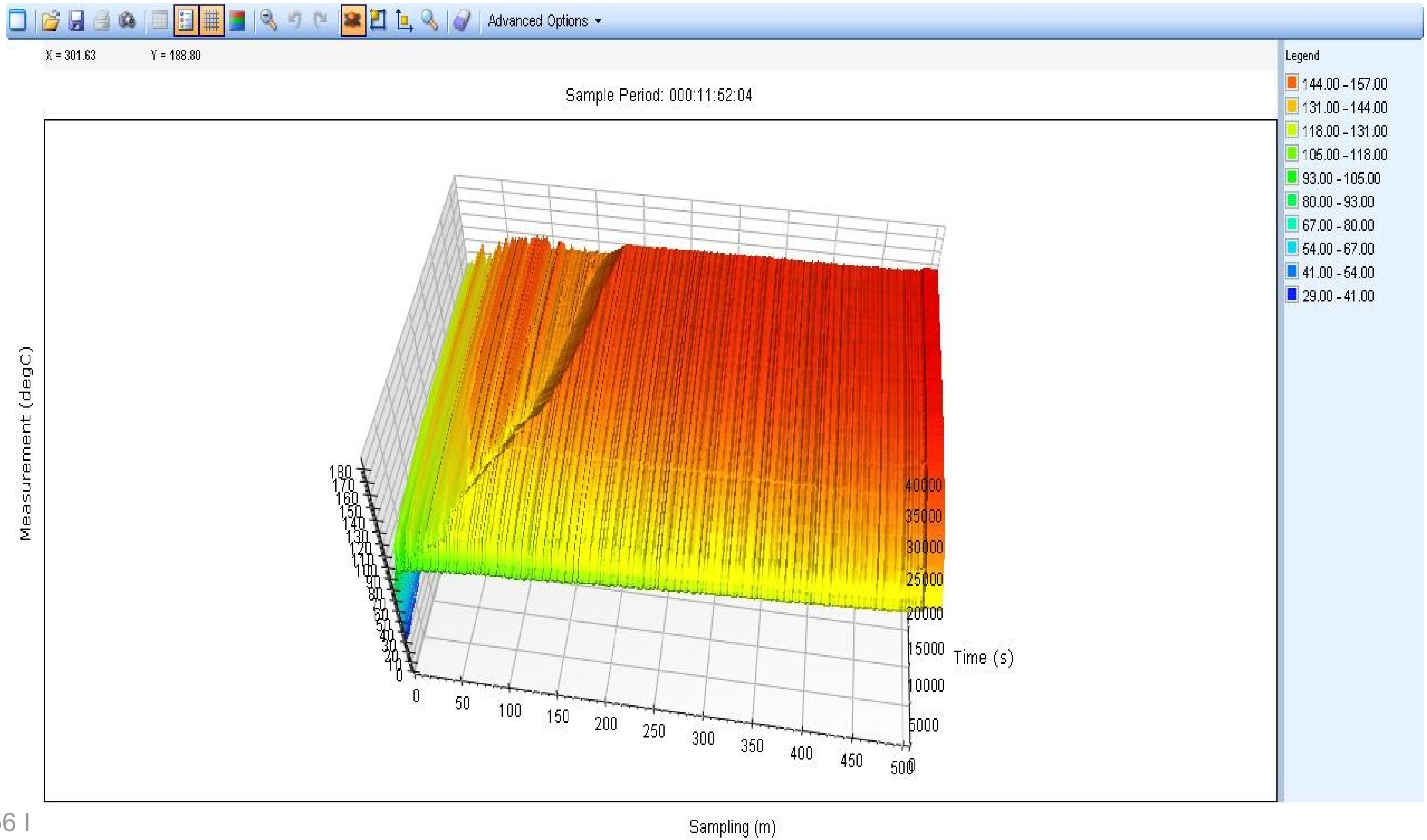
Operating time of ESP



- The ESP was installed from November 2008 to December 2011
- 10 month of operation, 12 start ups
- Operation outside operating range, as GPK4 is no good producer
- Tear down analysis is still in progress

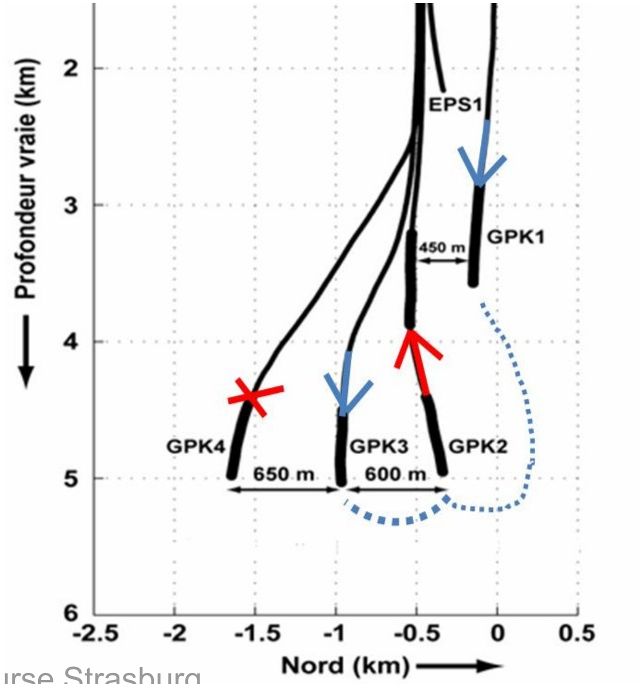
Installation of ESP in November 2008

Temperature monitoring of ESP by fiber optic cable
T = f (depth, time)



Injection pumps

- Injection pumps were used in 2008, 2009 and beginning of 2010 to re-inject the brine into GPK3
- Since 2010, trial of a new strategy without reinjection pump
- Today brine is re-injected in GPK3 (deep reservoir) and GPK1 (upper reservoir) without pumps
  - ⇨ System is working
  - ⇨ Temperature decrease of ~7 °C due to new concept



Comparison ORC and Kalina

ORC

Commercial available

Organic, pure fluid as working fluid

Isotherm evaporation and condensation

Higher exergetic loss

Less complex, no separators

Source G.E.I.E, 2010

Kalina

Currently only few power plants

Zeotropic mixture of Ammonia/water as working fluid

non.- isotherm evaporation and condensation

Better adaption of the cycle to the heat source

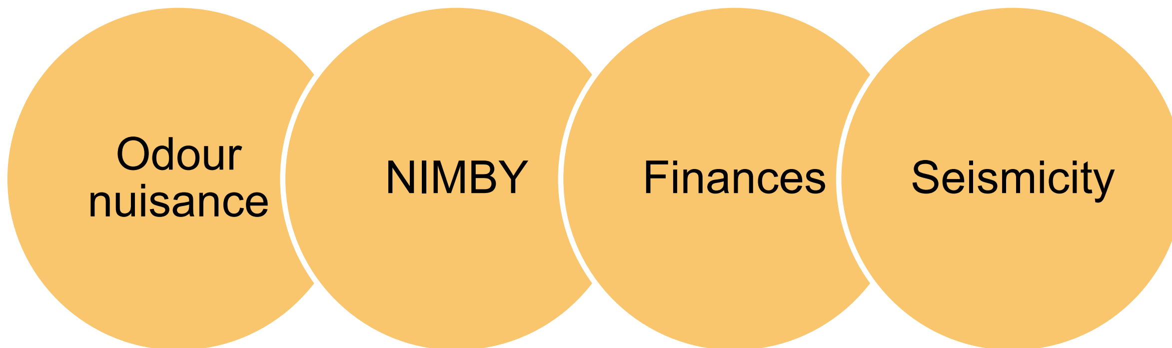
Separators necessary

Experience: operation is manageable

Engineering and design seems to be challeging

Social Acceptance – Fears

Research projekt: “PR für Tiefengeothermie” (BMU; enerchange; EIFER; Risikodialog St. Gallen; EnBW)



- Financial damage at people's property
  - Loss of value through a power plant in the neighbourhood
  - Damages through the operation of a geothermal power plant (Basel)
  - Noise (mainly through the cooling towers)
  - Nuclear pollution – natural nuclear particles in the brine
  - Not trustworthy investors in a local area
  - Economic feasibility and social compatibility

Social Acceptance – Steps towards success

Research projekt: “PR für Tiefengeothermie” (BMU; enerchange; EIFER; Risikodialog St. Gallen; EnBW)

Social Acceptance

Strategic

- Keep your attention focused on your opponents
- Don’t try to solve emotional situations
- Convince the indifferent public and try to make the supporters visible
- Try to identify with the local community
- Make your PR independent from third parties

Structural

- Strategic communicate with a clear concept
- Put as much effort in communication as in technical questions

measurements

- Understand information as an obligation towards the public
- Create direct, crossmedial communication-channels
- Events should be moderated by professionals

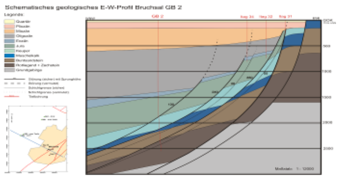
Projectdesign

- Be prepared for a crisis
- Settle damages unbureaucratic and fast
- Create possibilities for participation and benefits
- Try to involve heat utilisation in your project

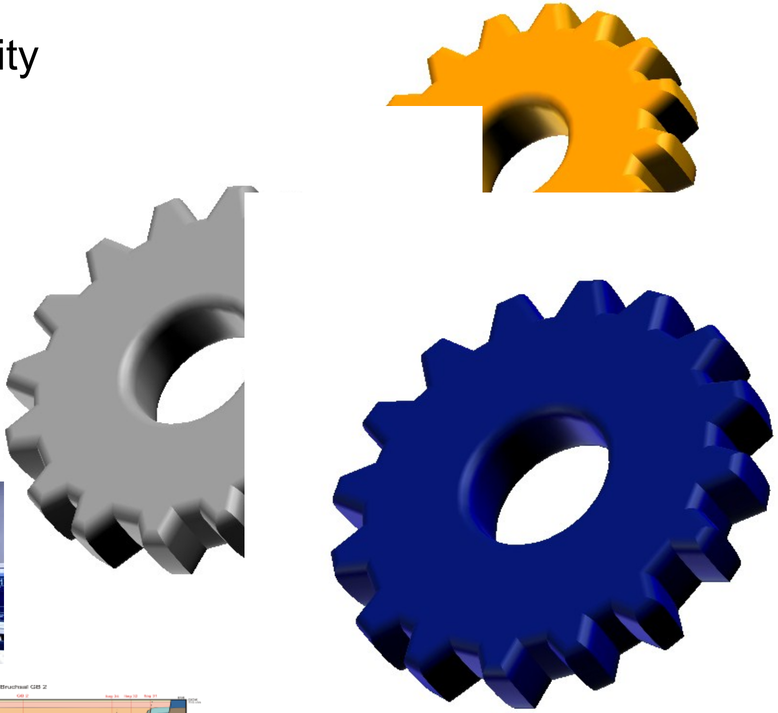
Outlook: Research in the field of deep geothermal energy

Environmental influences

- noise
- Natural radioactivity
- Optical influences
- etc.



Quelle: AGW am KIT



Power plant technology

- corrosion
- scaling
- Aqueous chemistry
- Plant operation
- etc.

eservoir

Reservoir management

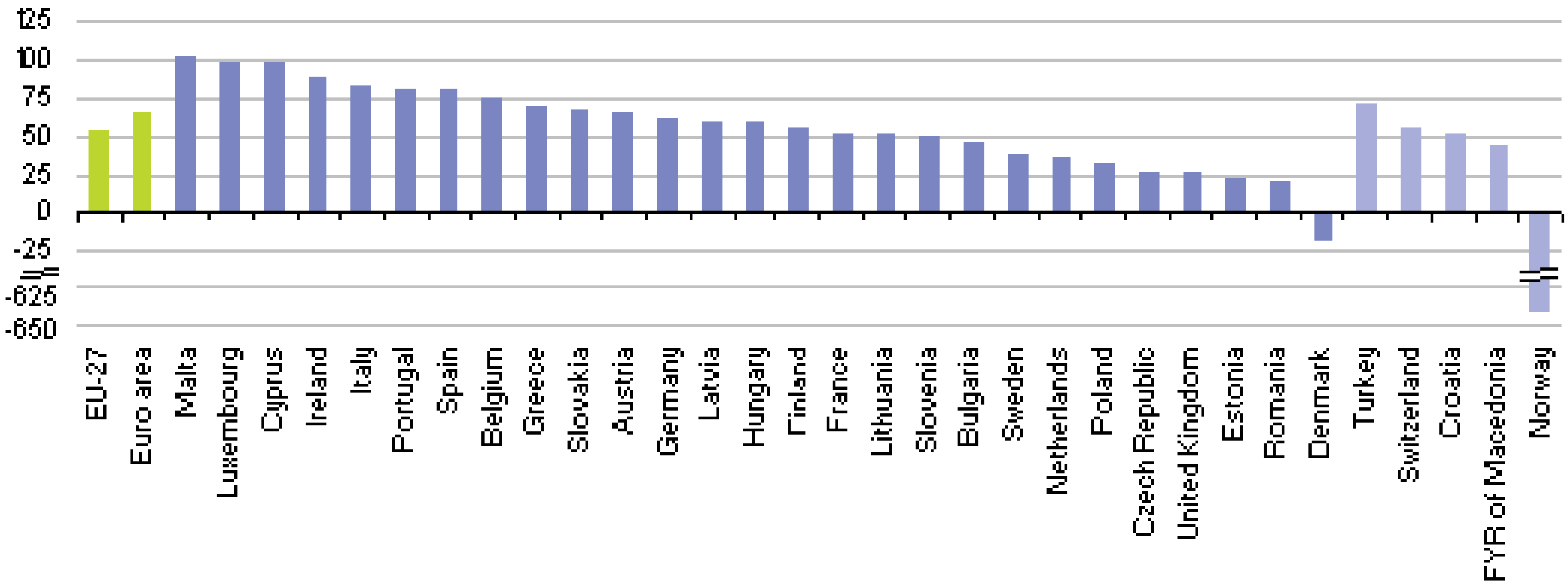
seismicity

Hydraulic behaviour of bore holes

- etc.

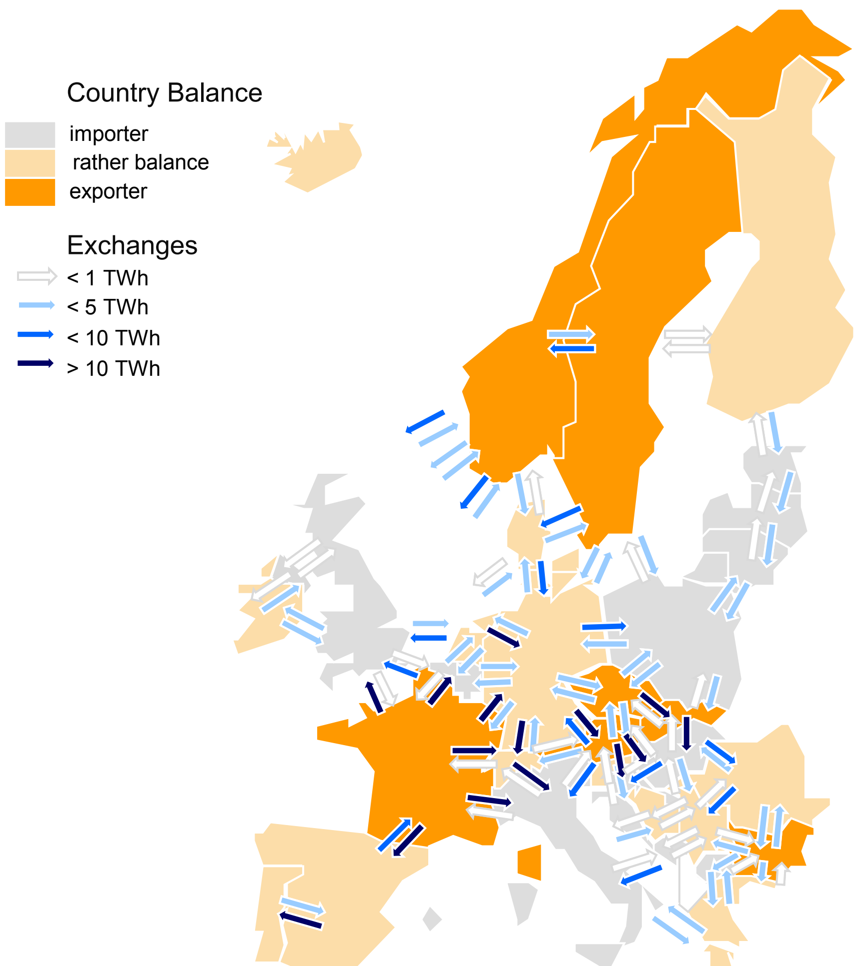

Geothermal Power...
...inexhaustible!
EnBW
Thanks for your kind attention!

Energy dependency of the EU



Source: Eurostat (online data codes: tsdcc310 and nrg_100a)

Cross-border exchange 2020

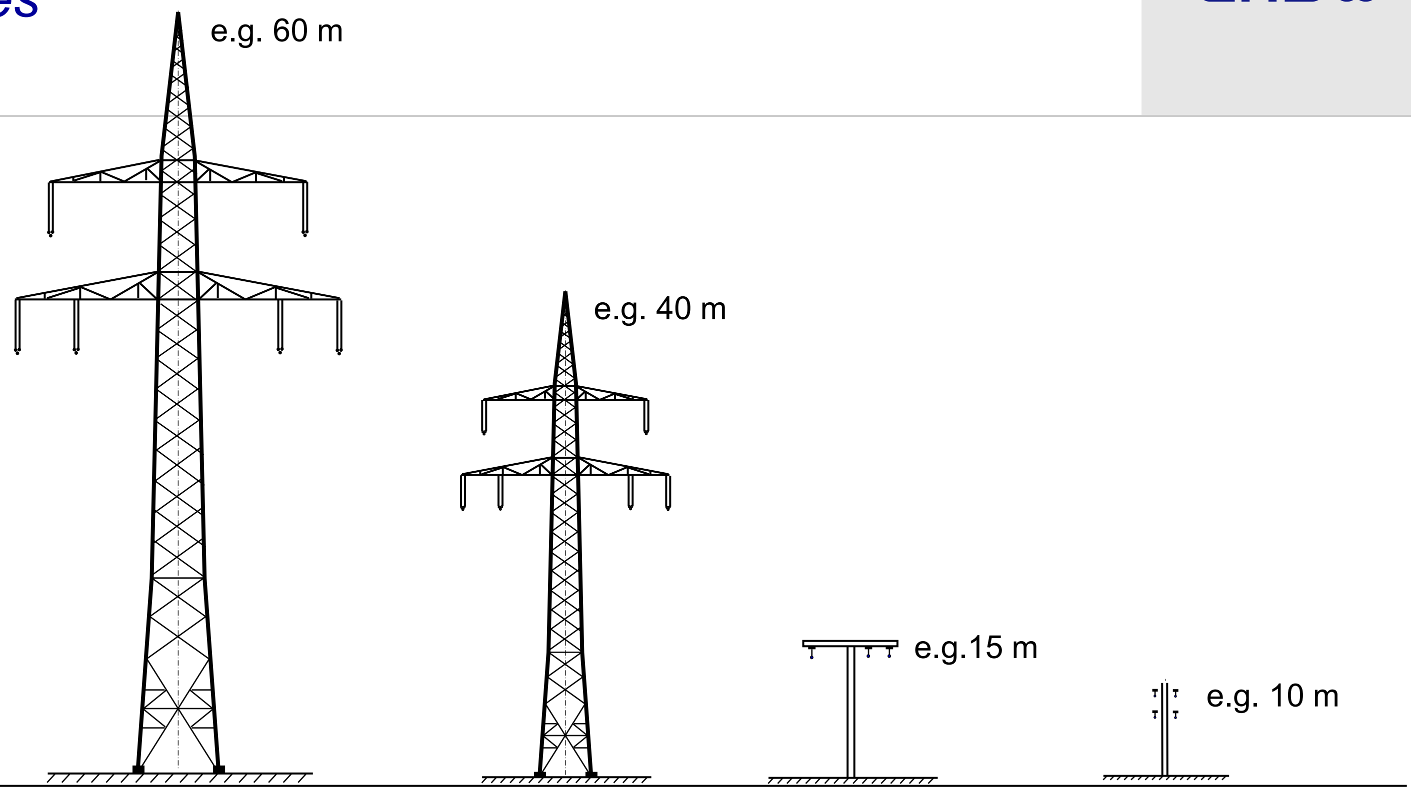


- Challenges for future grid development
  - 80 of 100 identified bottlenecks arise through RES
- The capacity will increase by 250 GW
  - 220 GW will be RES,
- Decommissioning of power plants
  - 25 GW nuclear power (16 Germany, 7 UK)
  - 9 GW coal-fired power plants in UK
  - Decommissioned power plants are close to highly populated regions (security of supply)
- 51500 km new or refurbished power lines
  - + 17 % additional power lines
  - 104 billion € investment in the coming 10 years
    - 80 % new lines/ 20 % refurbishment

ENTSO-E 2012

The electricity network

electricity poles

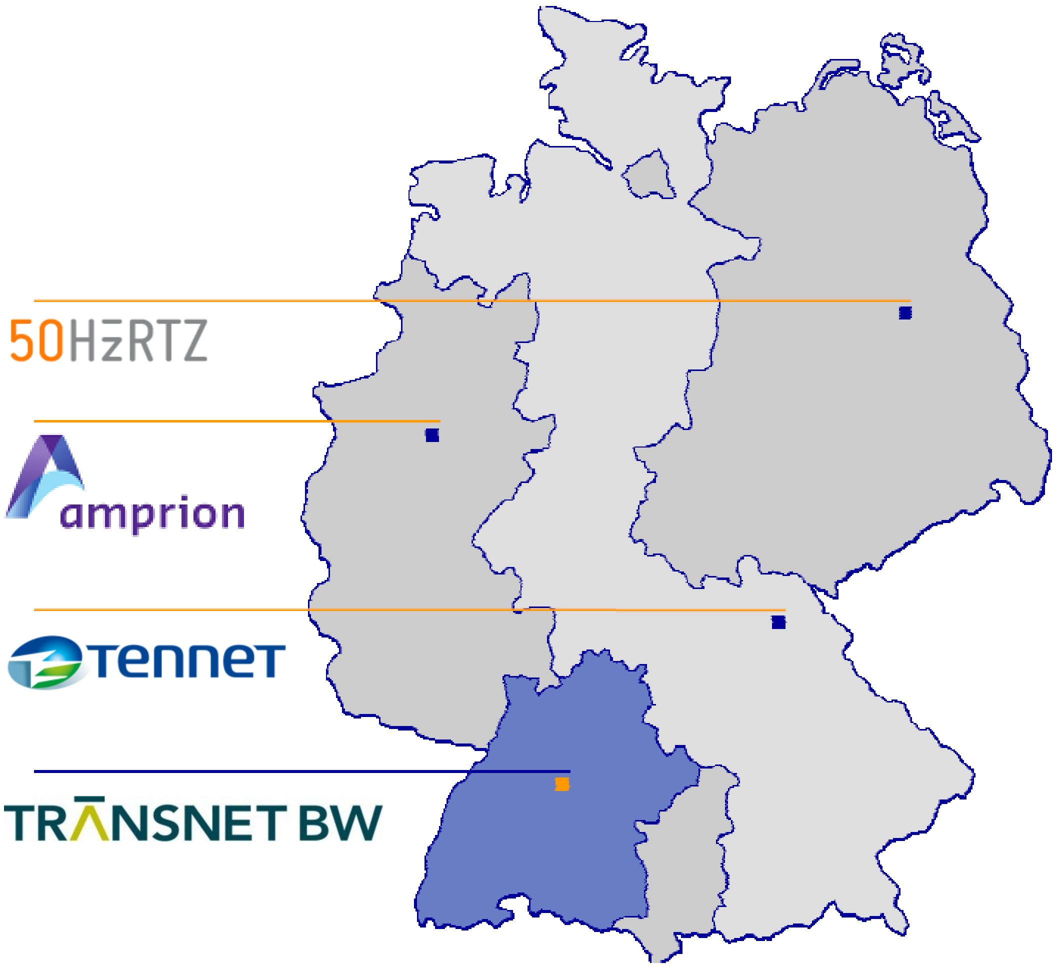


Voltage level:	Extra high Voltage	High Voltage	Middle voltage	Low voltage
	380 kV	110 kV	20 kV	0,4 kV
Network level:	Transportation	Distribution	Distribution	Distribution
Transportable power:	ca. 2 x 1400 MW	ca. 2 x 100 MW	ca. 10 MW	ca. 0,4 MW
Citizens:	ca. 2,8 Mio	ca. 200 000	ca. 10 000	ca. 400

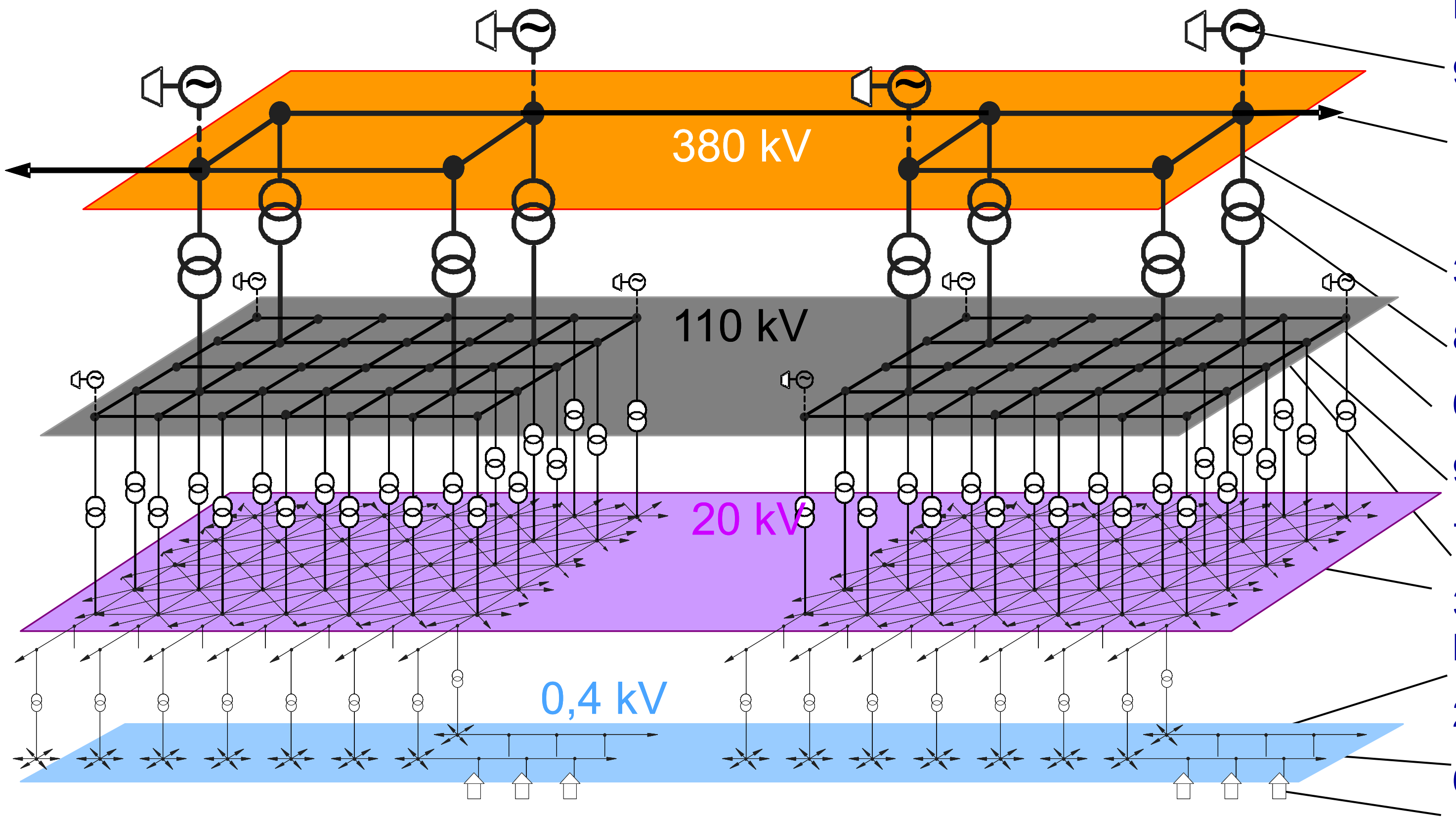
The German transportation network

Overview on the control zones

EnBW



The electricity network
network structure

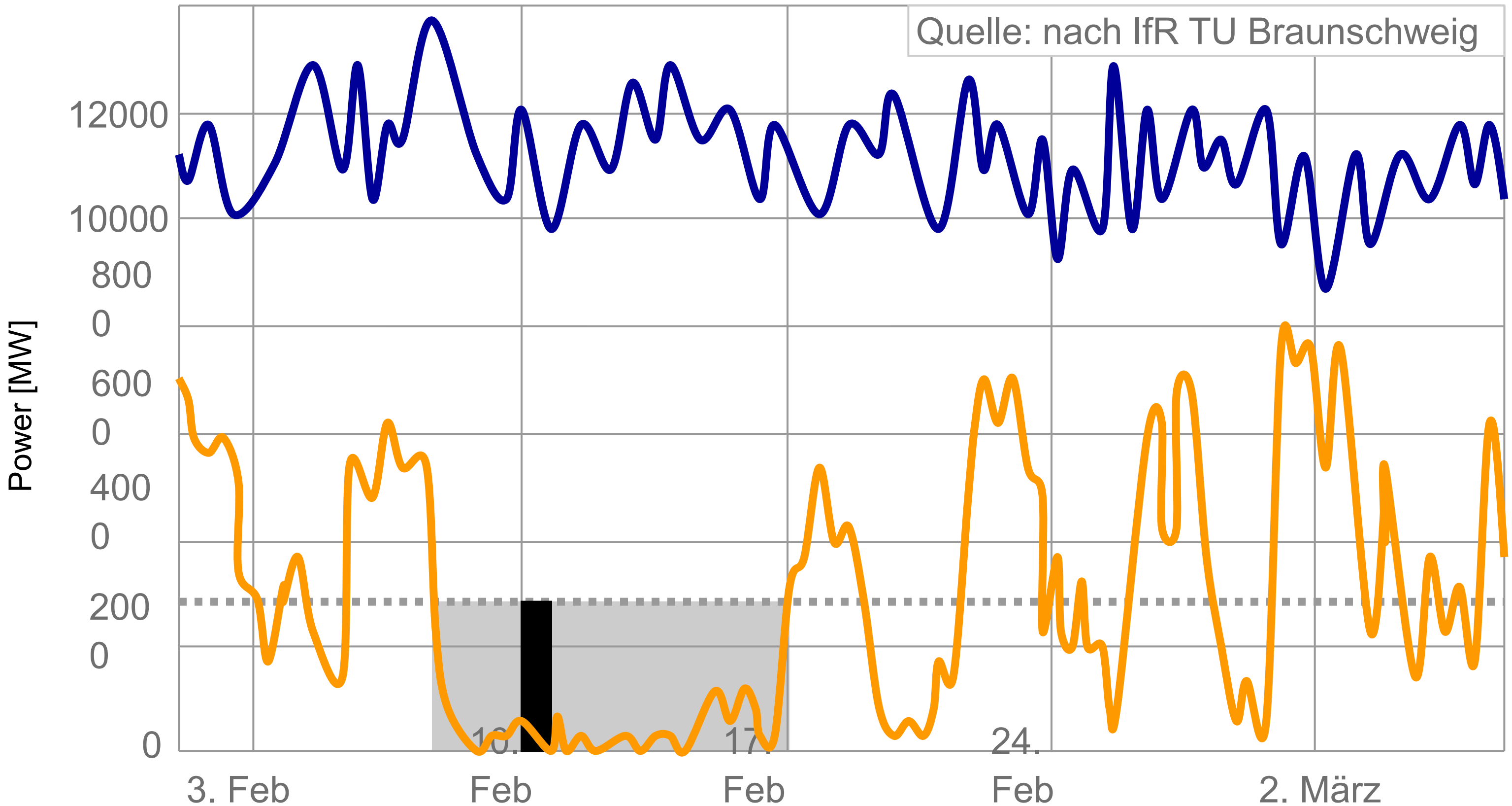


EnBW-network

- 9 Large-scale-PP
- 19 interconnection points
- 3,200 km EHV
- 80 Transformers
- 67 run-of-river-PP
- 9 storage-PP
- 7,620 km 110 kV
- 30,200 km 10-30 kV
- 26,500 substations
- 66,700 km 0,4 kV
- 120.000 Renewable -PP

Market situation in a «lack-of-wind»-situation Feb. 2008

Load curve in the 50-Hertz High-Voltage electricity grid (approximated)



Necessary storage capacity to keep the average wind capacity: ~ 540 GWh

Capacity of all German pump storage power plants ~ 40 GWh

Fast restoring of power
What did EnBW do?

- Immediately after recognizing the frequency drop the network control centre in Wendlingen reacted through the energy-dispatch-centre in Karlsruhe
  - Shutting of all the working pump storage facilities
  - Synchronization of all available and fast-startable power plants (pump-storage-power-plants; gas turbines)
- The automatic, frequency controlled shut-down of pumps (water supply) reduced the burden on the network by 148 MW.
- In the EnBW control-zone a power plant capacity of 1100 MW was started
- Through such additional started power plants in the UCTE-network it was possible to increase the frequency within the secondary regulation (15 min) to the desired level of 50 Hz
- The reason for the frequency drop was a maintenance measure in the Amprion control zone, which wasn't done under the n+1-criteria

Smart grid – what is that ?

Smart grid without customer

Integration of customer and network operator

Smart grid without network operator

Use of ICT and innovative solutions for the requirements of:

- **Grid operation**
- **Plant management**
- **Regulation**

e.g.:

- Remote control
- Monitoring
- Use of equipment for the load flow management
- Automated changes in the control system
- Use of dynamic load capacities

controllability of customers plants in accordance with grid requi.:

e.g.:

- Temporary reduction of feed-in
- Intelligent exchange for ripple control (heat pumps, e-mobility)
- Congestion management for customer plants
- Provision of reactive power by decentralised power plants

Integration of customer plants in the regulation of the balance of load and production:

e.g.

- Time variable tariffs for the schedule optimisation according to the demand prognosis
- Use of customers plant for the provision of balance and reserve power
- Virtual power plants
- Sm@rt home for the automated adjustment to variable tariff systems

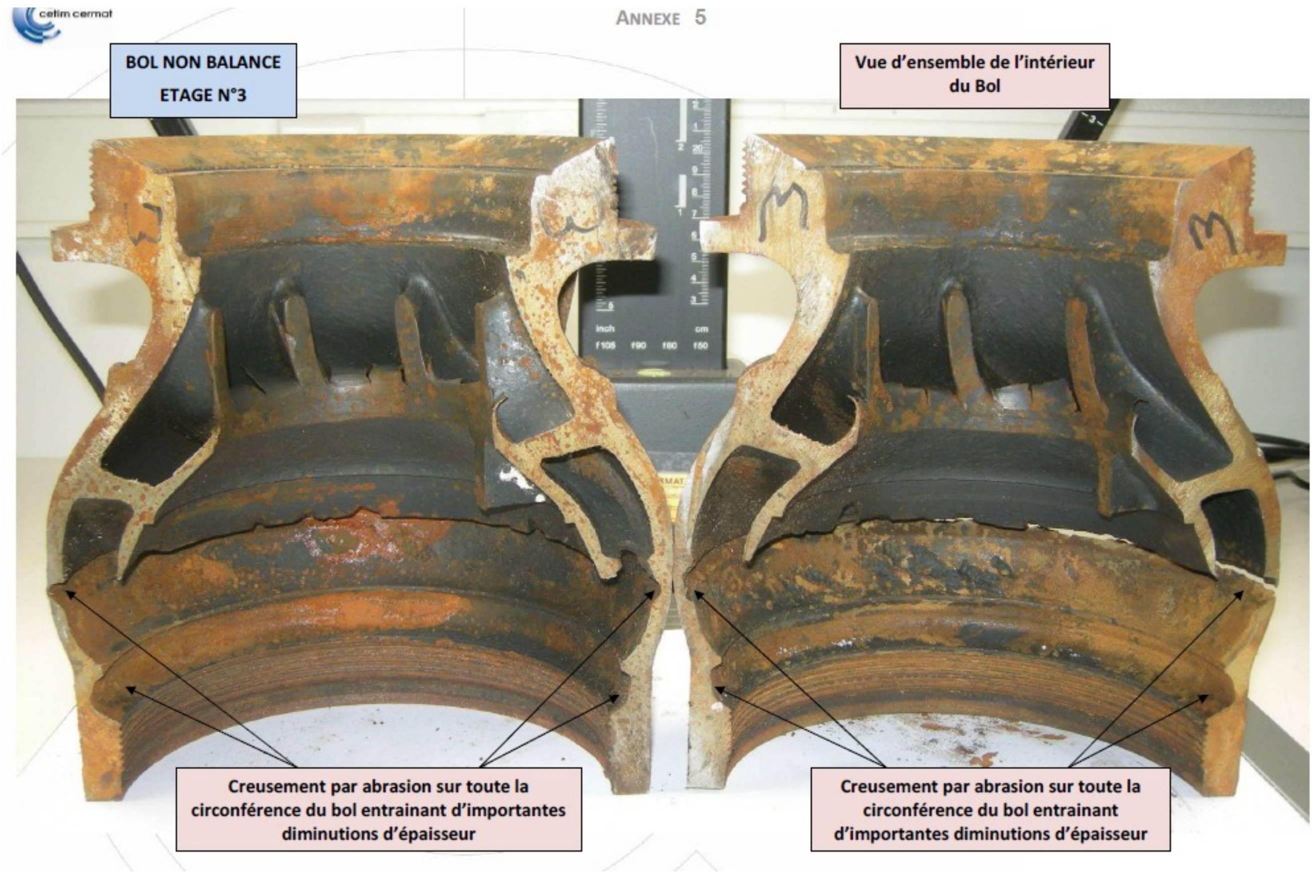
Injection pumps

- Two pumps in noble material (uranus) delivered by EBARA
- Max power 500 kW
- Flow rate between 60 to 120 m³/h and 35 to 80 bars (limitation by seismic issues)
- Variable speed drive for regulation

Closer look at damage of April 2011

- Cause of stop:
- Destruction of the hydraulic part of the pump
  - Loss of bowl N°1
  - Destruction of all bearings inside the hydraulic part
  - Destruction and cutting of the housings within hydraulic part until bowl N°5
- Damage caused by the combination of high rotation speed (2200 rpm) and abrasive particles inside the water
- Analysis of damage was done by CETIM/CERMAT laboratory

Damage of pump housing (damage April 2011)



Damage of impellers and housing (damage April 2011)

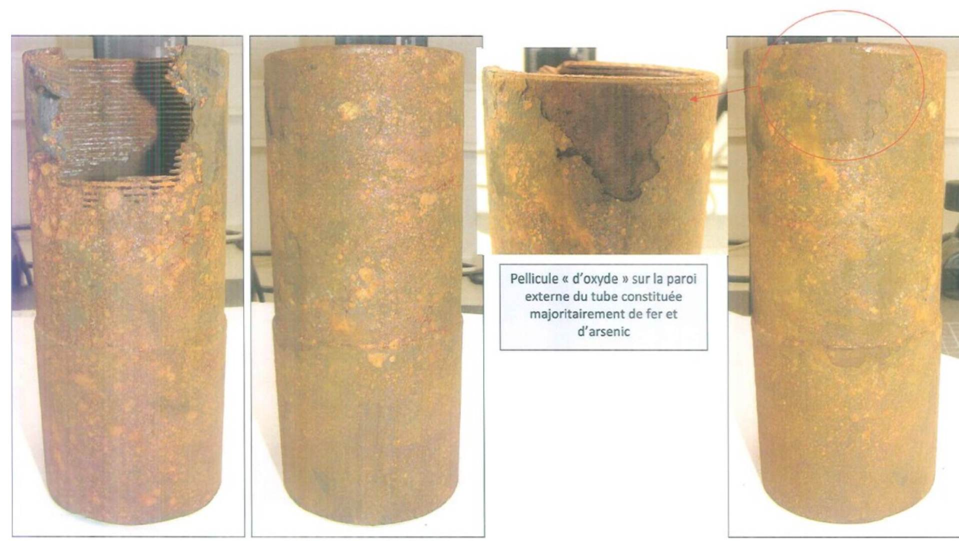
- Damage due to collision of rotor and housing at the pump inlet (highest stress on stages)
- Local cavitation & abrasion

Closer look at damage of October 2011

- Cause of stop:
- Damage caused by high vibration, linked to high rotation speed and initial damage to the centralizer
  - Destruction of the centralizer
  - Destruction of the lubrication string N°4
  - Destruction of the Teflon bearings
  - Destruction of the shaft bearings
  - Destruction of the sealing surfaces of the impellers inside the pump (non boronized surface)
- Destruction of the centralizer due to local under load of the centralizer material (arsenic corrosion)
- Analysis of damage was done by CETIM/CERMAT laboratory

Damage of centralizer, impeller and piping (damage October 2011)

EXAMENS MACROGRAPHIQUES D'UN DES CENTREURS DÉGRADÉS – N°1

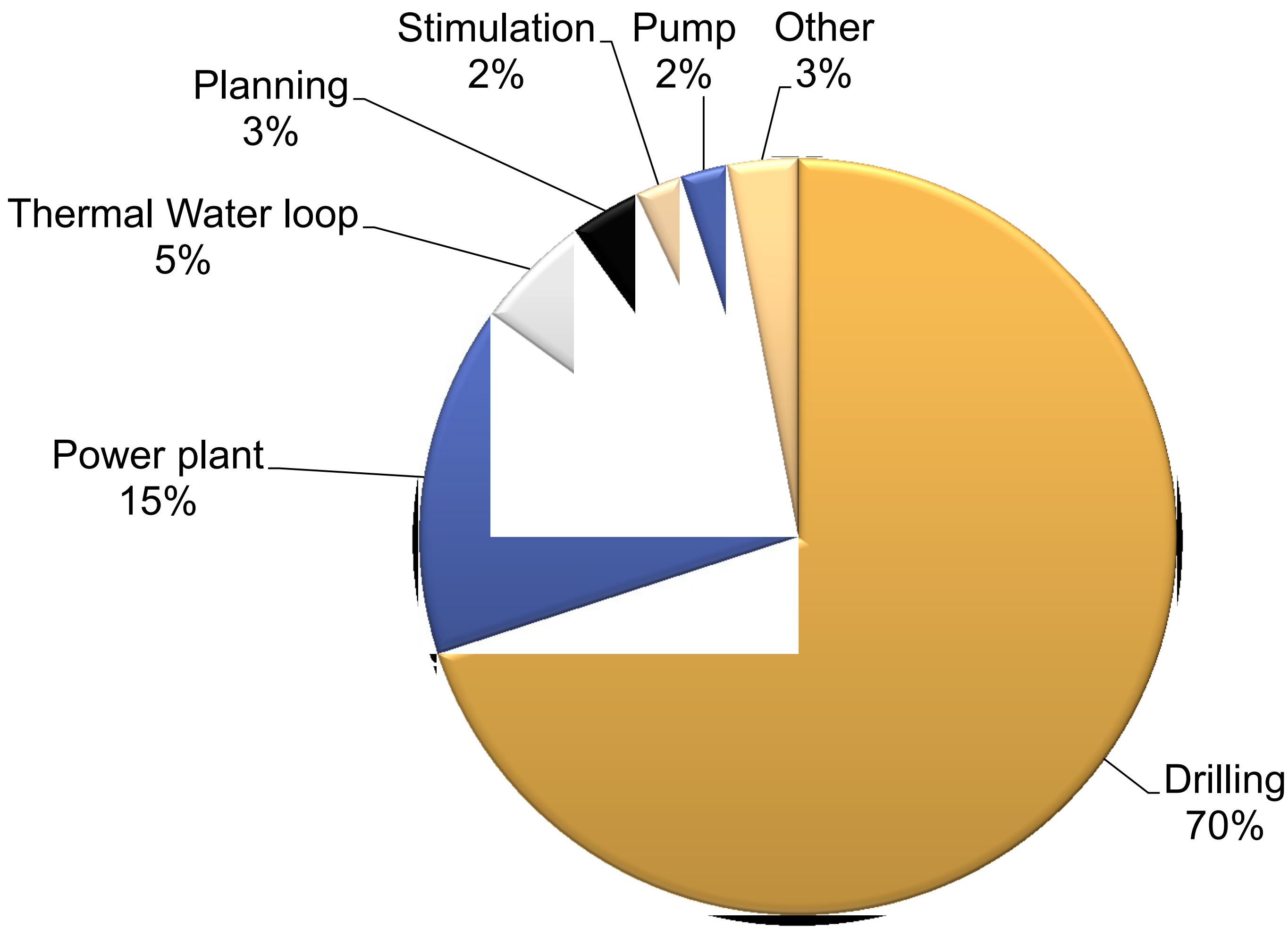


Côté diamétralement opposé à la corrosion

Installation of ESP in November 2008

EnBW

Average Invest Costs of a Geothermal Project



Source: GtV

Allowances

- Mining law (concentrated in one authority)
  - Authorization for the production of resources below the earth
  - Main operation plan (central operation permission)
  - Permission on basis of the water law to extract thermal water
- Construction permit
  - Fire protection
- Organisation of the operation
  - Responsibilities
  - Duties
  - Skills

Seismic Monitoring