Global Unit Generation

# New perspectives – revenue and cost optimized pumped storage concepts

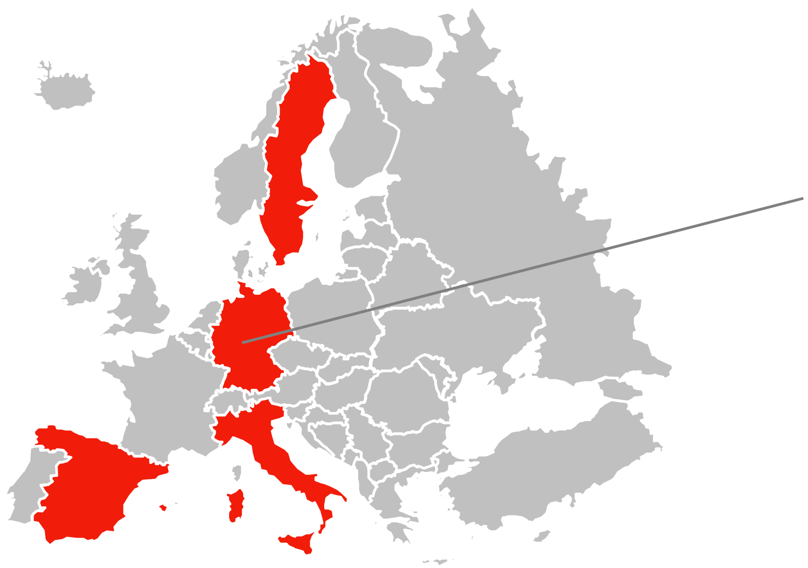
Dr. Klaus Engels
Louisville, KY – July 19, 2012

# Future system demands require highly flexible PSP with optimized revenues and cost structures

- Currently, pumped storage plants (PSPs) are the only mature large scale option to store energy and react flexible on system demand.
- Considering all revenue streams – wholesale market, ancillary services and portfolio effect – PSPs are profitable, even in tough market environment.
- The remaining optimization lever is cost of a PSP – beside other positions, the machine set is a main cost driver, which can be optimized.
- To display the value contribution of a PSP – technically and economically - the optimal dispatch needs to be simulated with modern tools.
- As the plant flexibility becomes more important, the majority of the revenues come from the ancillary services (secondary reserve).
- Thus, the optimal machine concept is highly flexible at minimal costs and has the right size in the market portfolio.

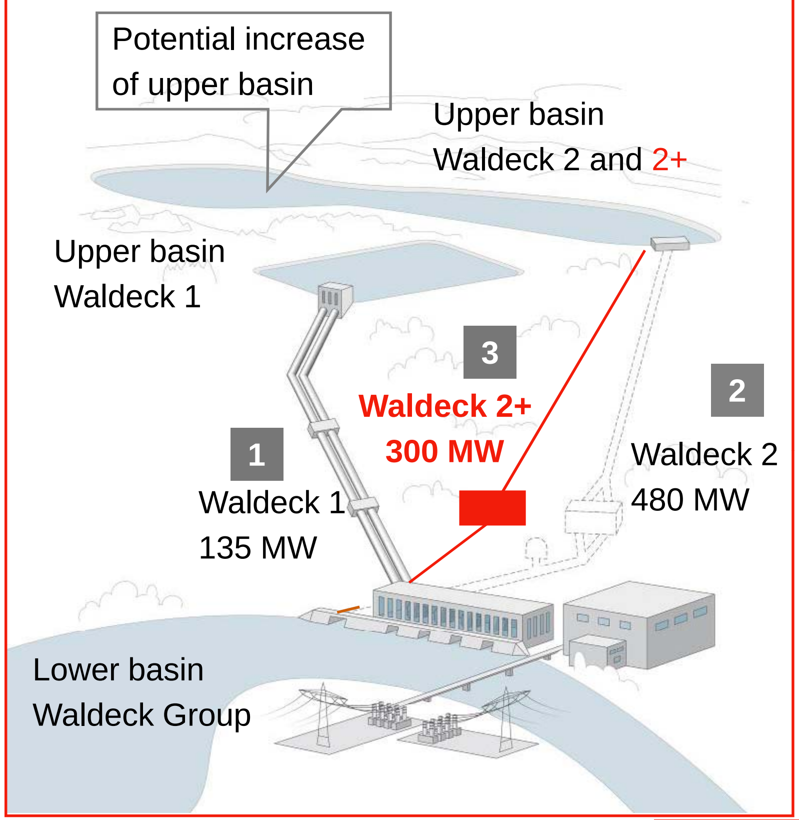
# E.ON's Waldeck 2+ project is an extension of the existing interconnected Waldeck Group

**European hydro power portfolio**



| | |
|---|---|
| No. of operated hydro plants | **212** |
| Efficient capacity | **6.161 MW** |
| Annual net generation | **18,5 TWh** |

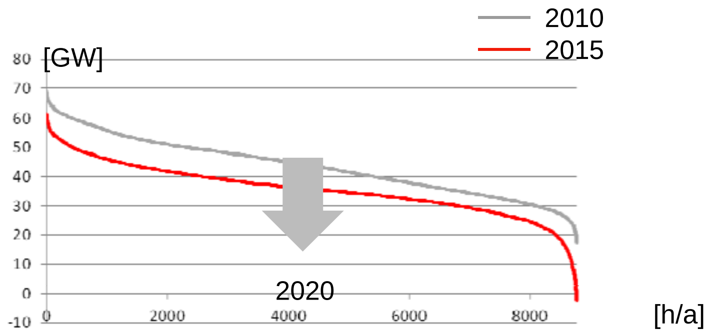
**The Waldeck Group in central Germany**



# Demand for flexibility will permanently increase within the next years due to growing share of renewables feed-in

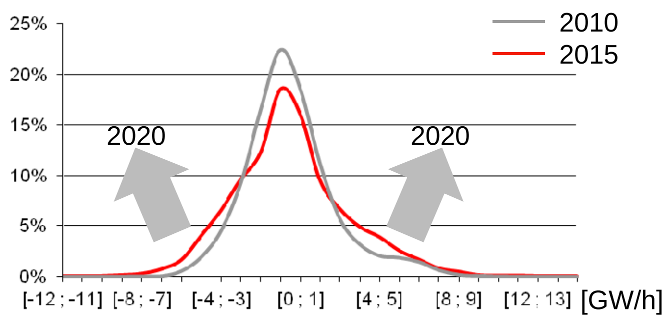
## Annual residual load

**Decrease of** residual load

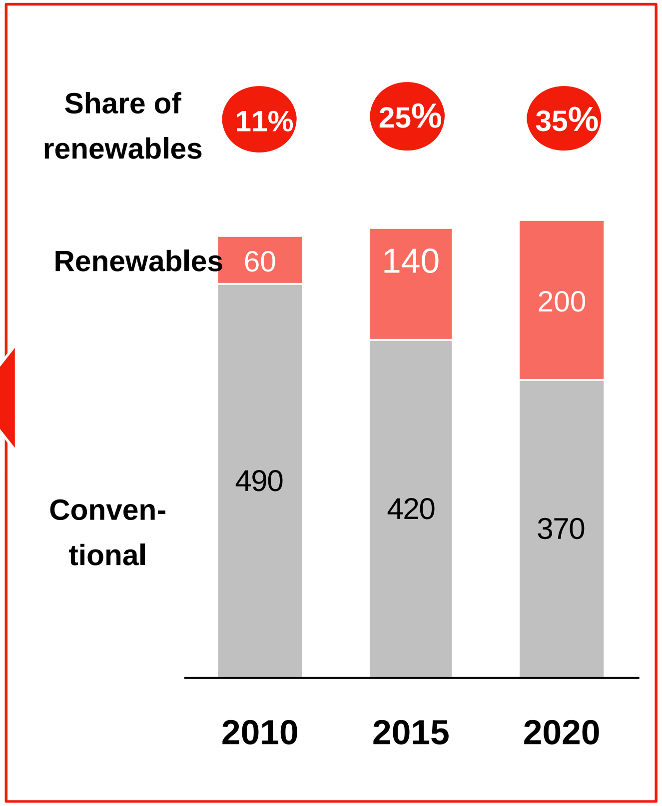



## Relative frequency of load changes of annual residual load

**Increase of** fluctuation

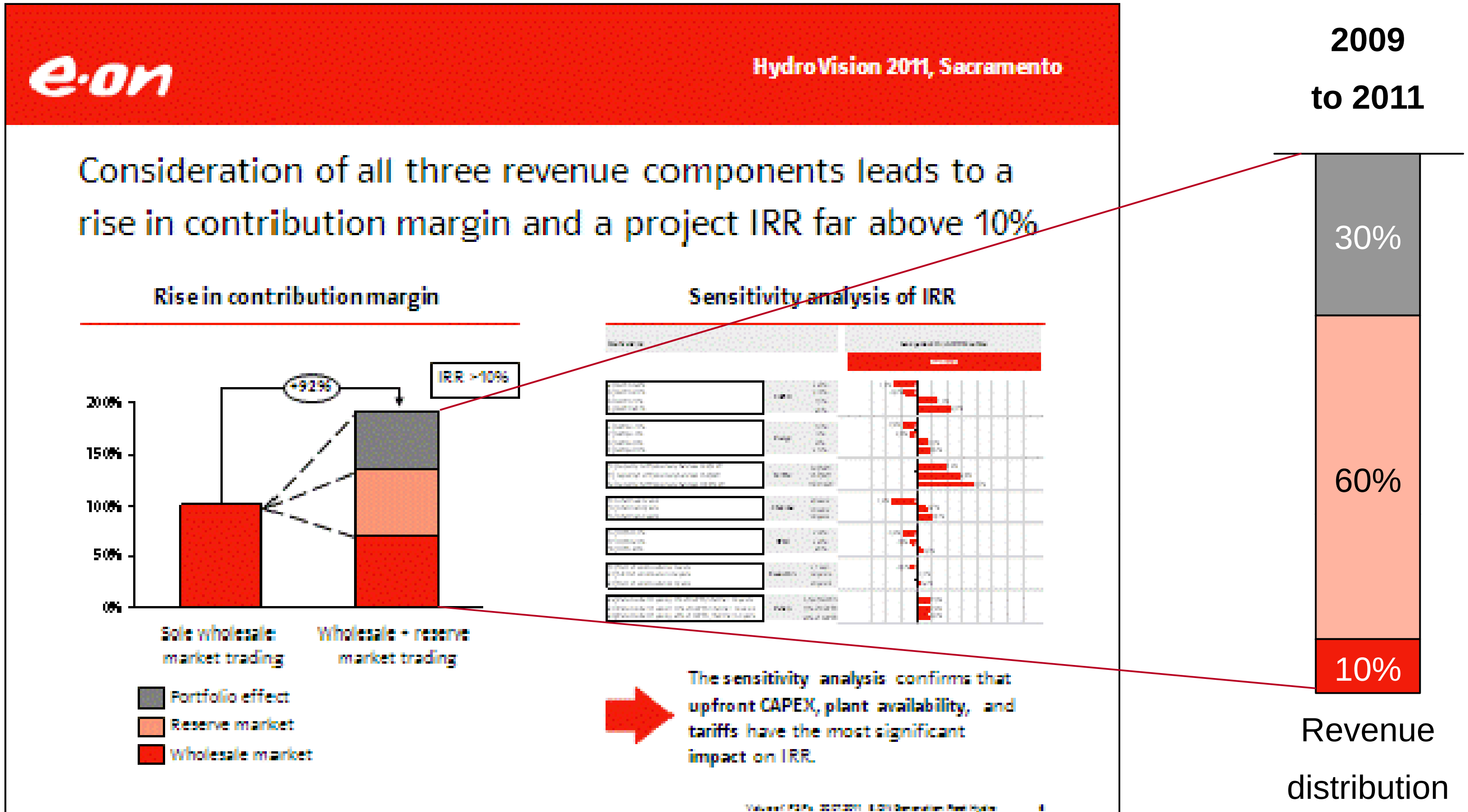



## Energy production* [TWh]




*) Germany/ input for simulation without export, direct industry, railway or auxiliary consumption

# Profitability of PSP is supported by high demand of ancillary services – increasing revenue share accordingly



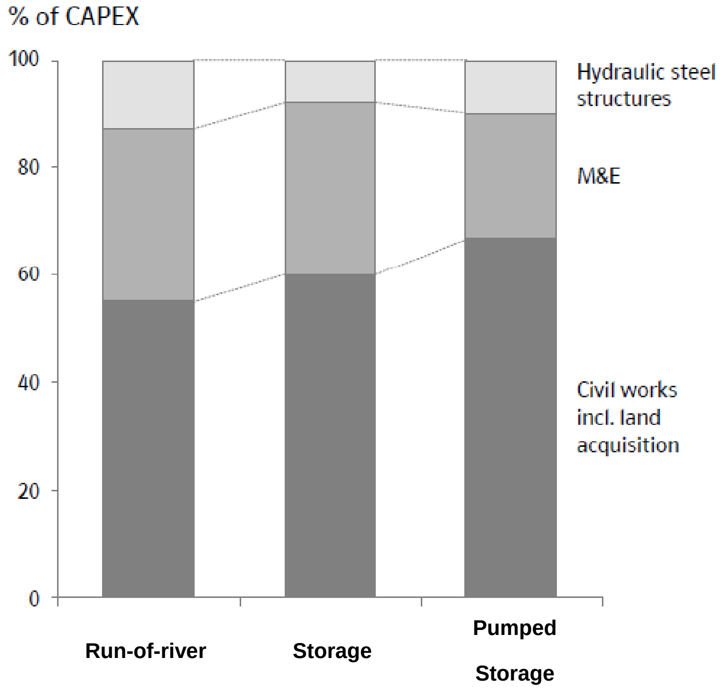
# Typical investment cost structure for new build projects of hydropower plants incl. pumped storage plants

## Basic CAPEX set

| Head – driver for CAPEX | Plant type – driver for revenues: Run-of-river | Storage | Pumped storage |
|---|---|---|---|
| High Head >150m | 1,400–2,800 | 1,850–4,600 | 700–3,200 |
| Medium Head 50–150m | 1,600–3,400 | 2,100–4,800 | |
| Low Head <50m | 1,900–3,800 | | |

CAPEX (€/kW)

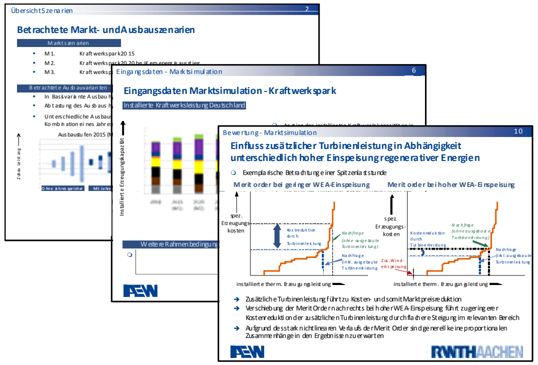
## Split of CAPEX




**General note:** depending on the real project, individual cost structure may be different!

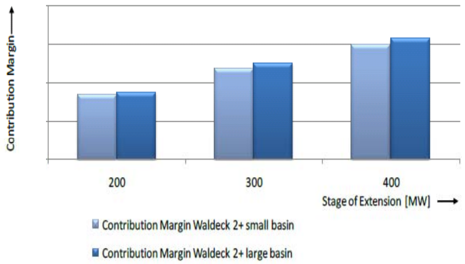
# To optimize the technical concept a comprehensive three-step evaluation approach has been applied

## New Build Potential



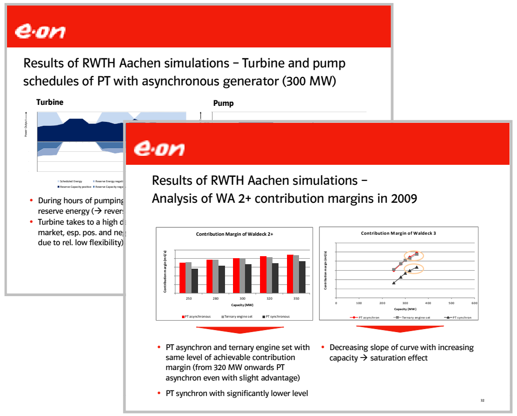

How much additional pumped-storage capacity fits into the German market?

## Extension Stage




What is the market optimal capacity and upper basin size?

## Machine Concept

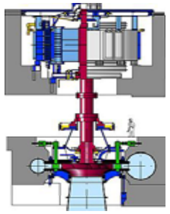



**How much flexibility is required in today's market? → Which machine type should be applied?**

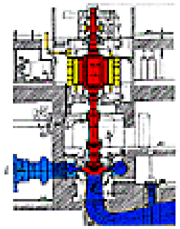
# Machine types differ in their flexibility to participate in the reserve markets and in their investment cost

**Three technical alternatives are available:**

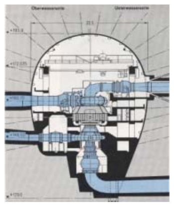
1 Pumped turbine with synchronous generator



2 Pumped turbine with asynchronous generator



3 Ternary machine set



**Two main flexibility parameters of given machine types were simulated:**

Controllability in pumping mode

Minimum load of turbine

1 Limited flexibility (no controllability of pump, high min. load of turbine)

2 Medium flexibility (variation of power output of pump possible, medium min. load of turbine)

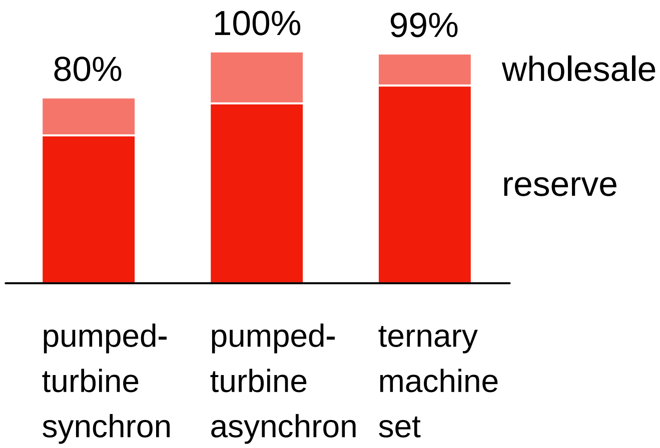
3 Maximum flexibility (hydraulic short circuit can be applied, low min. load of turbine)

**Investments required:**

Capital Expenditure €/kW

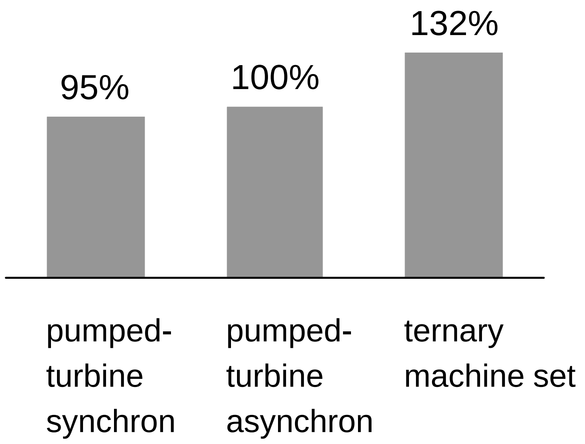
# An asynchronous pump-turbine is proposed as optimal machine concept – dependent on the individual situation

## Simulated contribution margins:




Asynchron pumped-turbine and ternary machine set reach same level of contribution margin, whereas synchron pumped-turbine remains 20% behind.

## Capital expenditure assumptions *:




Cost-benefit-analysis with consideration of capital expenditure reveals pumped-turbine with asynchronous generator to be the most beneficial solution.

* Source: Lahmeyer International, only M&E part (approx. 20% of total budget)

# Backup

# Contact details and CV

## Contact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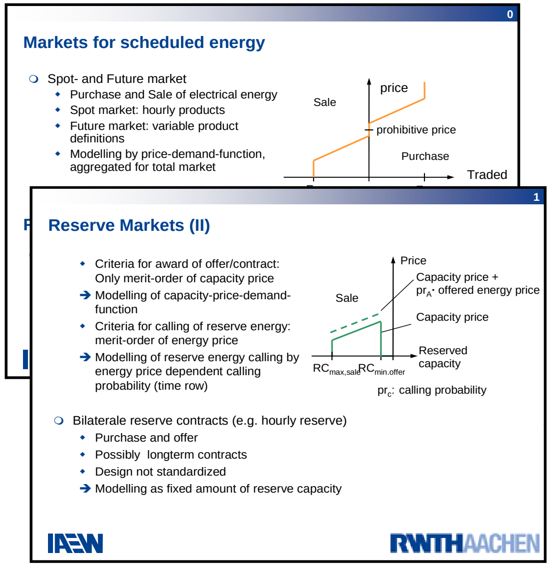
## Curriculum Vitae

- University Degree in **Electrical Engineering**, RWTH Aachen University, Germany
- University Degree in **Economics**, FernUni Hagen, Germany
- 1997 – 2002 Academic assistant and **PHD studies** at RWTH Aachen University
- 2002 – 2004 **Asset Manager Transmission Grid** RWE Energy AG, Dortmund
- 2005 – 2008 **Project Manager** Roland Berger Strategy Consultants, Dusseldorf/Munich
- 2008 – 2010 **Head of Business Development** E.ON Wasserkraft, Landshut
- since 2010 **Vice President Asset Risk and Governance Hydro**, E.ON Fleet Management Generation
- Recently invited to **Advisory Working Group for the study "Modeling and Analysis of Value of Advanced Pumped Storage Hydropower in the U.S."** of DoE

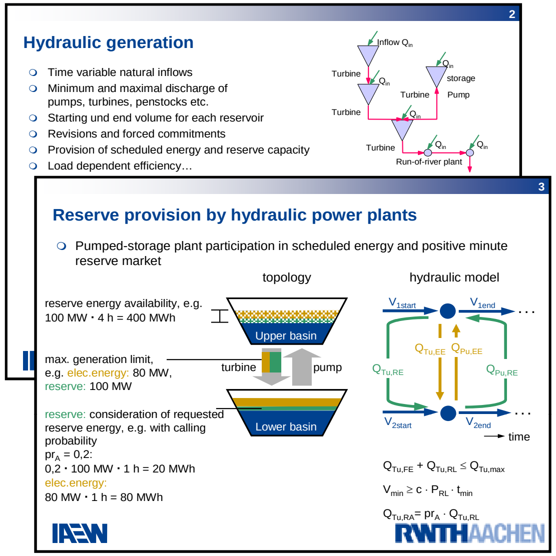
# The energy-economic modeling of pumped-storage plants must address both wholesale and reserve markets

## Wholesale & reserve market



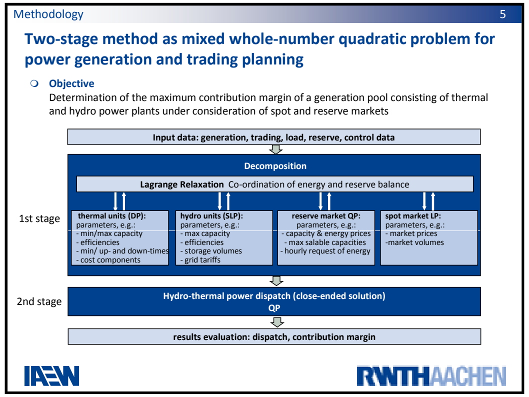

Particularities for scheduled energy and reserve markets (prices, sellable reserve capacities, calling signals…)

## Thermal & hydraulic systems




Hydraulic constraints and technical restrictions in the considered system (incl. thermal plants → portfolio approach)

## Evaluation method




- An **integrated algorithm** optimizes the power plant scheduling on wholesale and reserve market
- **Results:** optimized **dispatch** of portfolio and **contribution margin** of PSP (incl. portfolio effect)

# Additional restrictions needed to be defined in simulation model to reflect machine type characteristics

$B^i_{SP,m} = 0$, else $B^i_{SP,m} = 1$

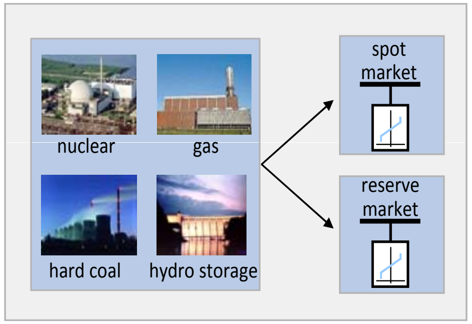
$B^i_{ST,m} = 0$, else $B^i_{ST,m} = 1$

$B^i_{ST,}$

$$E^i_{SE} + \sum_{j=1}^{n} P^i_{Res,j} + \sum_{j=1}^{n} E^i_{Res,j} - SC_{max,pos} = 0$$

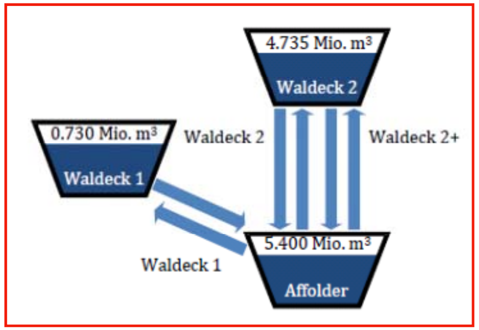
$$E^i_{SE} - \sum_{k=1}^{m} P^i_{Res,j} - \sum_{k=1}^{m} E^i_{Res,j} - SC_{max,neg} = 0$$

- With re-definition of optimization problem complexity increased tremendously
- **Simulation approach needed to be split into two steps** to limit calculation times




**Step 1:**

**Portfolio-simulation without restrictions** in order to conclude how much reserve capacity is provided by Waldeck Group if part of the portfolio.



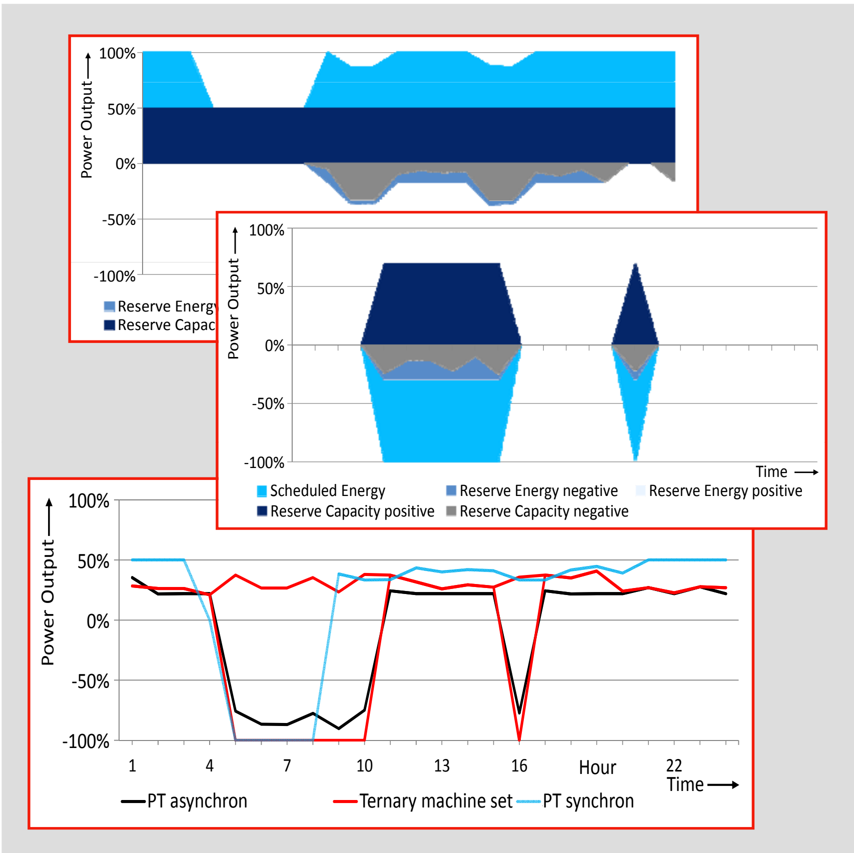

**Step 2:**

**Machine type simulation on stand-alone basis for Waldeck-Group** with portfolio-simulated reserve capacity provision as input and 2009 actual prices

**Waldeck 2+ extracted from group results**

# Analysis of run-of-day schedules showed that machine type specifics were captured well in simulation

## Exemplary 24-h-schedules




## Take-aways

- **No full load operation in wholesale market**, irrespective of machine type
- Large amount of **capacity sold to reserve market**
- Increasing **flexibility of machine types fosters reserve market participation**
- **Hardly any standstill times** to be able to participate in PCR market, which is very lucrative in Germany
- Simulated energy output schedule looks **different from a traditional PSP schedule of today**