How to Specify Storage Systems Needed in Our Future Electric Grid

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Structure

1) Structure of German electricity system
2) Overview on storage technologies
3) Case study: Adiabatic Compressed Air Energy Storage co-located with wind energy
   - Modeling
   - Operational regime
   - Economics
4) Conclusion

*RES: Renewable Energy Sources

Projected installed generation capacity in Germany

according to BMU Leadscenario 2010

→ ratio of inst. Capacity with intermittent to dispatchable power feed-in:

- 2005: 1:5
- Today: 1:2
- 2020: 1:1
- 2040: 2:1

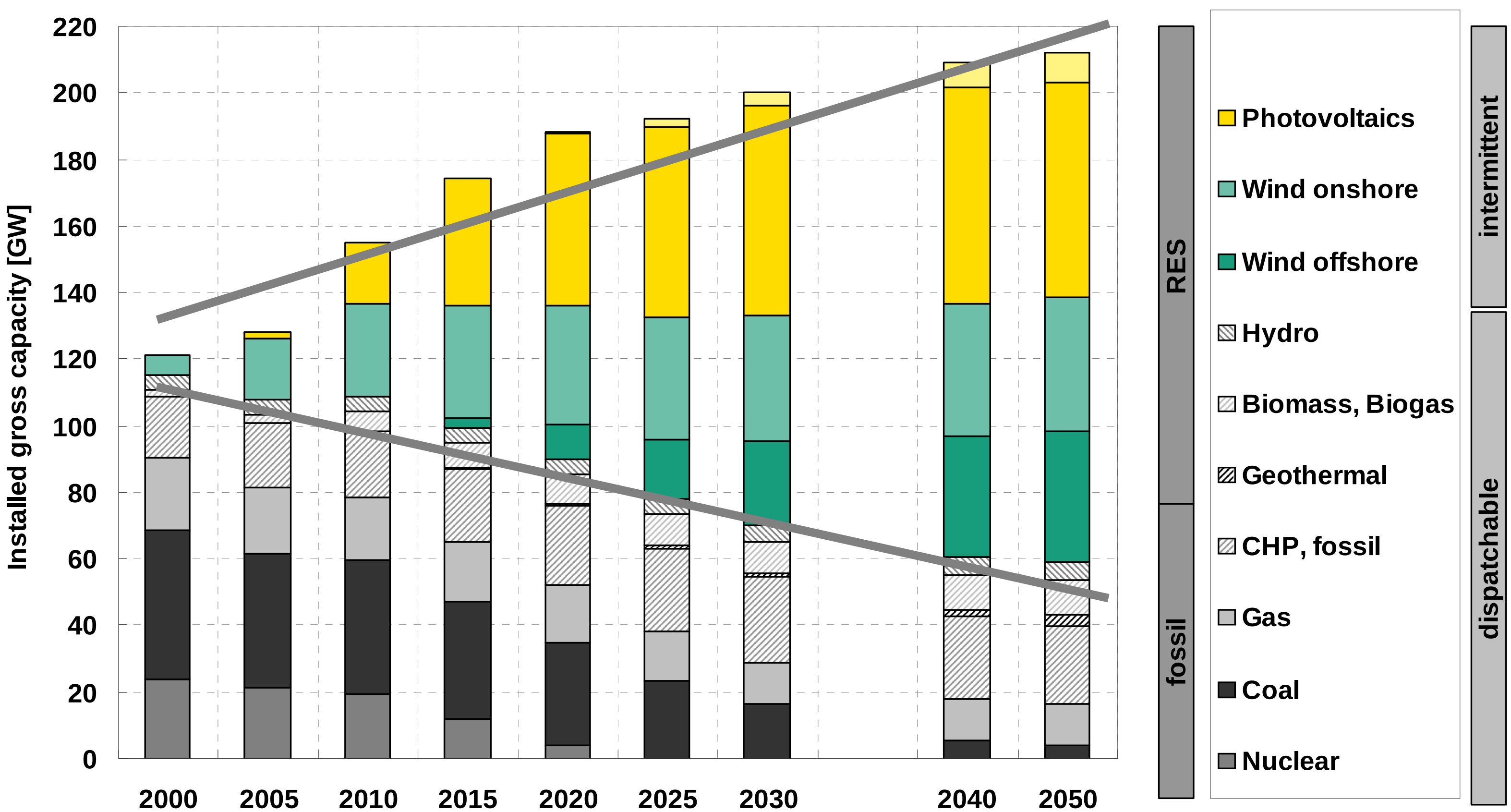
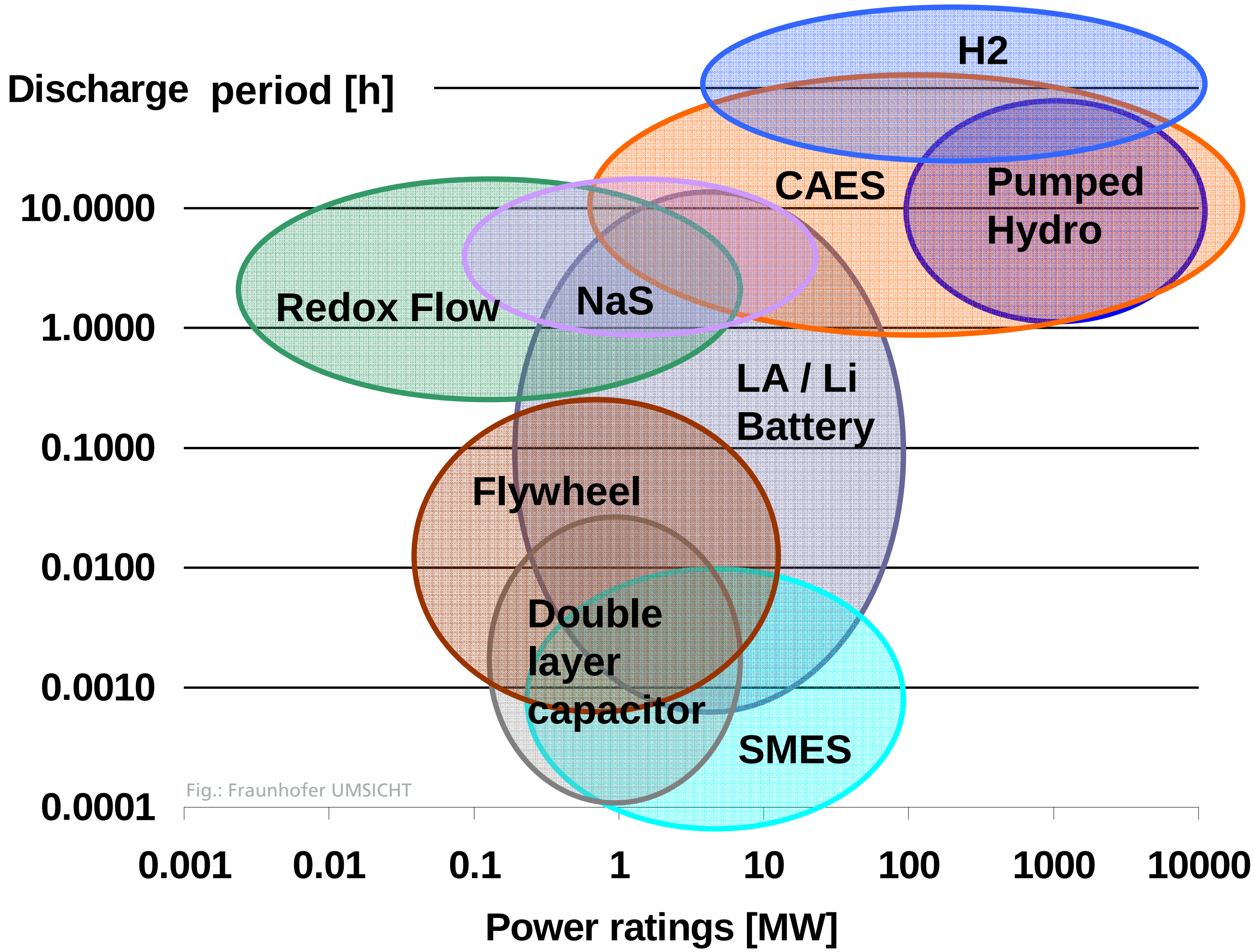


Fig.: Projected developmet of inst. generation capacitiy in Germany according to BMU Leadscenario 2010

Comparison of storage technologies and services

Storage Technologies



Services

- Long-term wind compensation
- Spot market trading
- Tertiary reserve
- Secondary reserve

- Primary reserve
- Voltage sag correction

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Compressed Air Energy Storage

only in Germany and the USA

Huntorf, Germany (1978)

- 60 MW_{komp} / 320 MW_{exp}
- Storage volume: 560 MWh_{el}

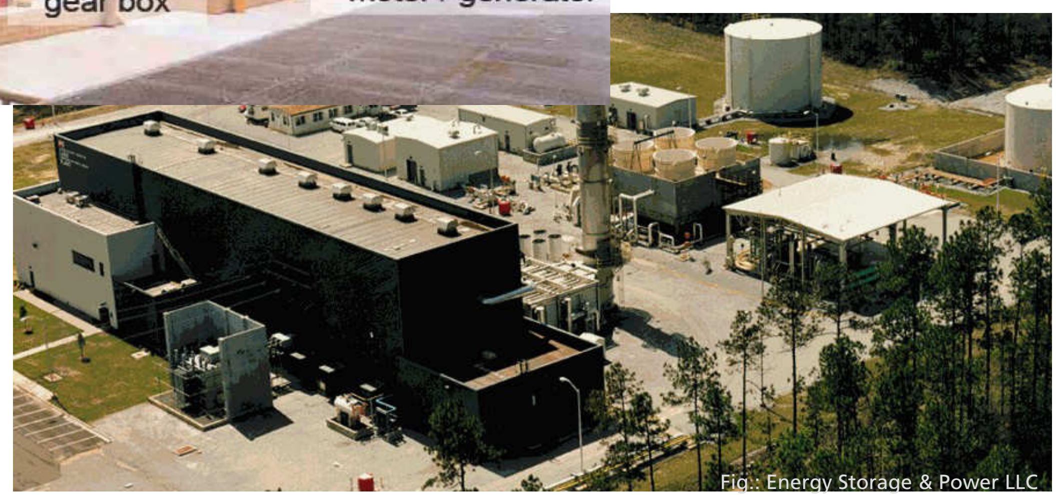

Fig.: Energy Storage & Power LLC

McIntosh, USA (1991)

- 50 MW_{komp} / 110 MW_{exp}
- Storage volume: 2640 MWh_{el}

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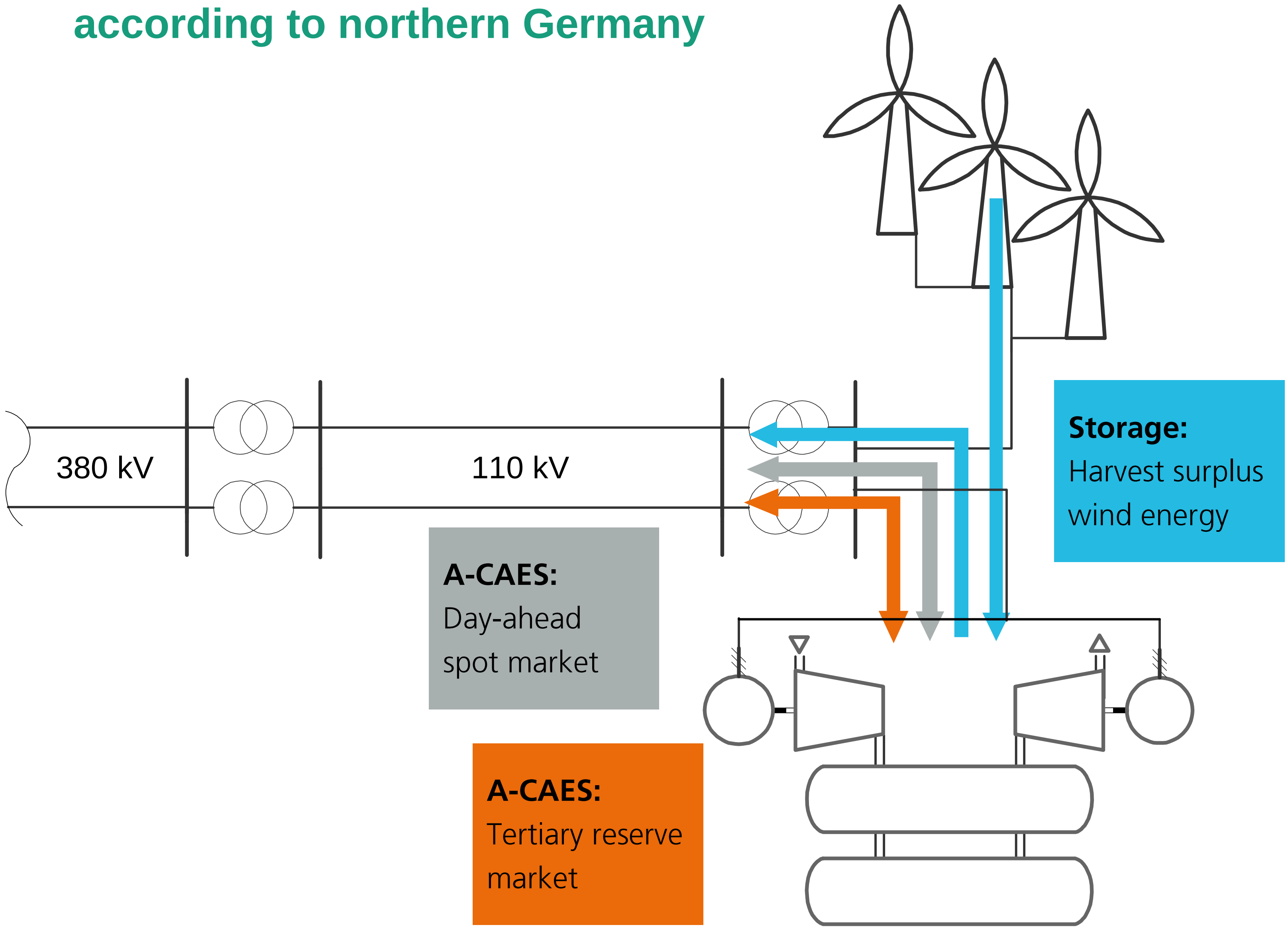
Reference energy system
according to northern Germany



GOMES® - objective function and boundary conditions*

Storage plant parameters	
Constant cycle efficiency	0.68
Stand-by storage losses	0.5%/day
Ramp-rate	300 MW/h
Start-up time (cold start)	15 min
Part load ability	> 50% P_{max}
Start-up cost	15 €/MW
Variable operation cost	2 €/MWh

revenue:

- Revenue from the storage plant operator point of view

income:

- Income of the storage plant operation

cost:

- Short term marginal cost of storage plant operation

$$revenue = \sum_{T=1}^{365} \sum_{t=1}^{96} \left[income_{T,t} - cost_{T,t} \right] \rightarrow max!$$

*See also: Adiabatic Compressed Air Energy Storage co-located with wind energy—multifunctional storage commitment optimization for the German market using GOMES, Int. Journal of Energy Systems, Springer, 2011, DOI: 10.1007/s12667-011-0044-7

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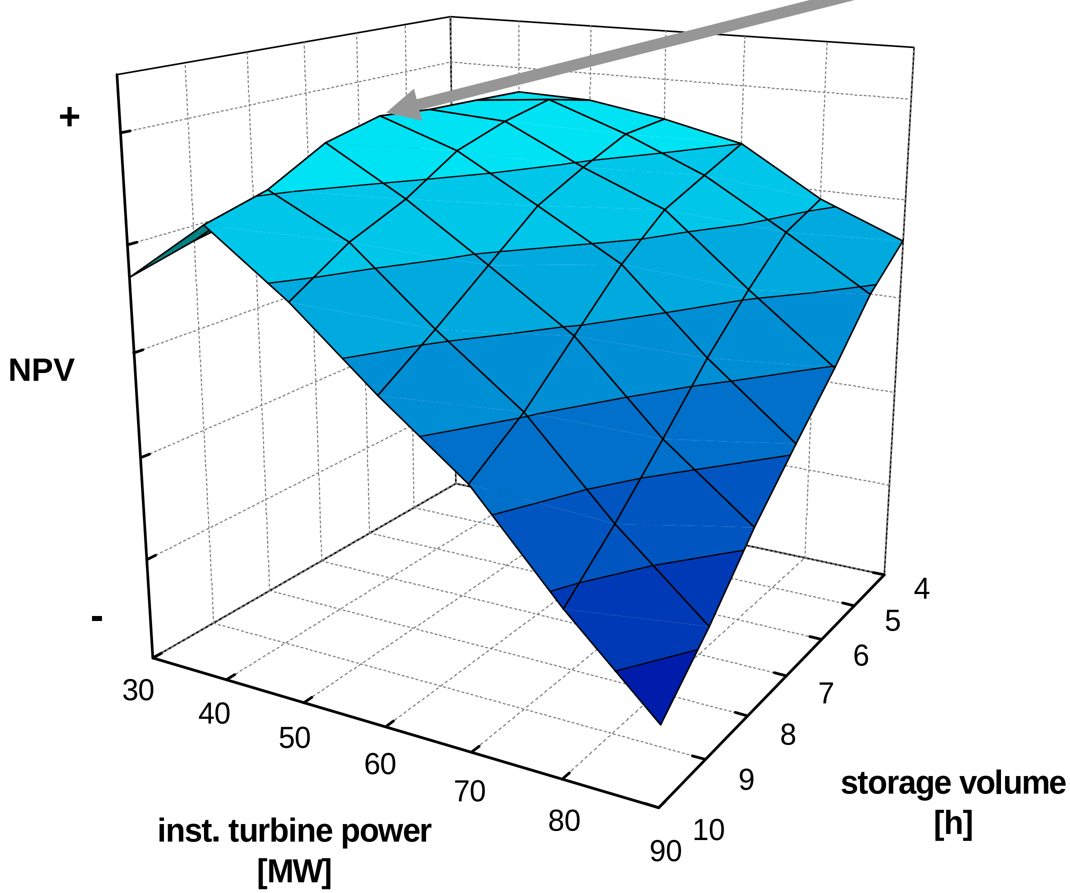
Optimal storage plant configuration

within the reference energy system



Optimal storage plant configuration

given an installed charging power of 70 MW

- Discharging: 40 MW
- Storage volume: 7h

Compressed Air Energy Storage

only in Germany and the USA

Huntorf, Germany (1978)

- 60 MW_{komp} / 320 MW_{exp}
- Storage volume: 560 MWh_{el} / 310.000 m³

McIntosh, USA (1991)

- 50 MW_{komp} / 110 MW_{exp}
- Storage volume: 2640 MWh_{el} / 538.000 m³

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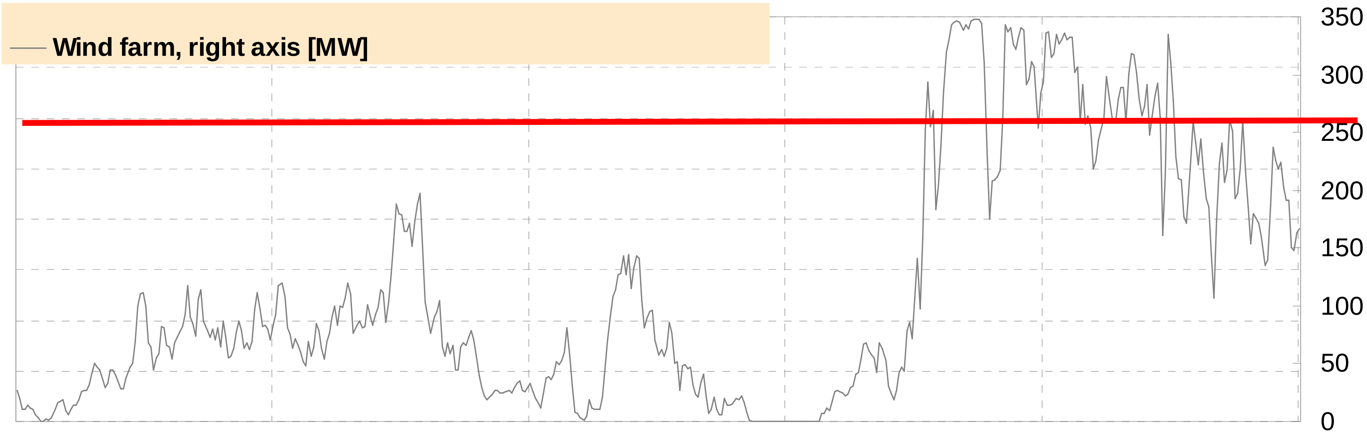
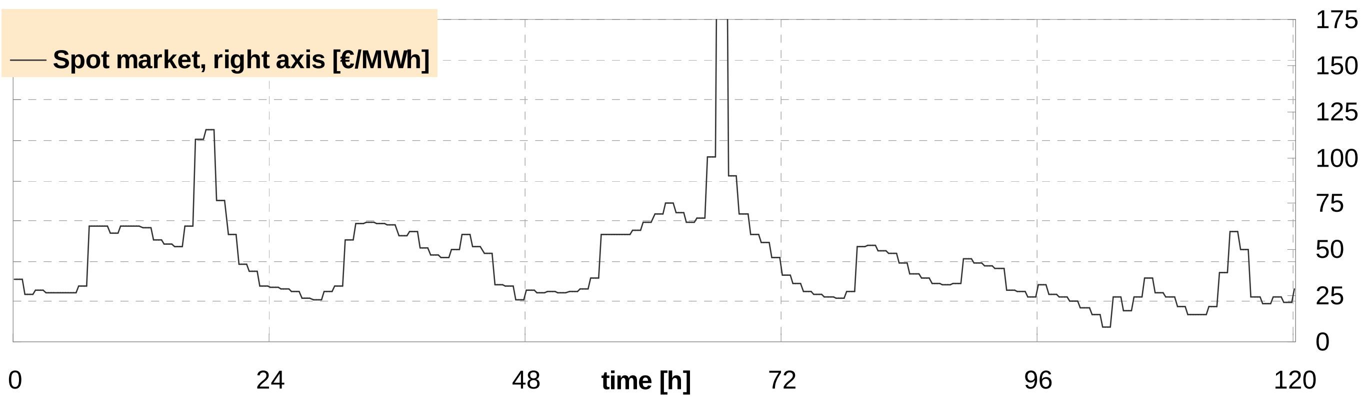
Wind farm output and spot market prices



← 110 kV transmission restriction: 260 MW

Wind farm output

Five-day period within the year 2007



Spot market price

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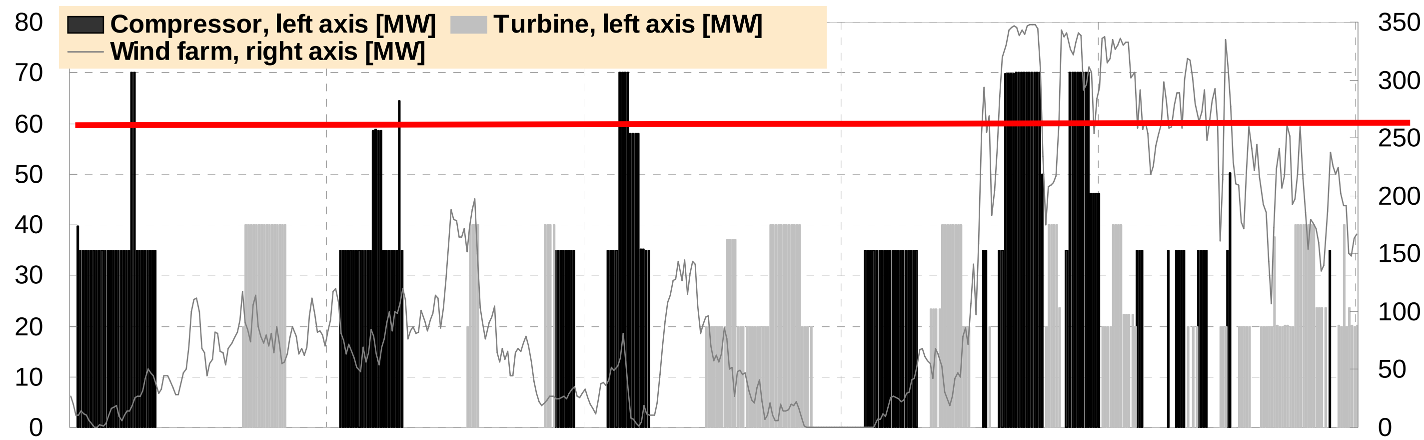
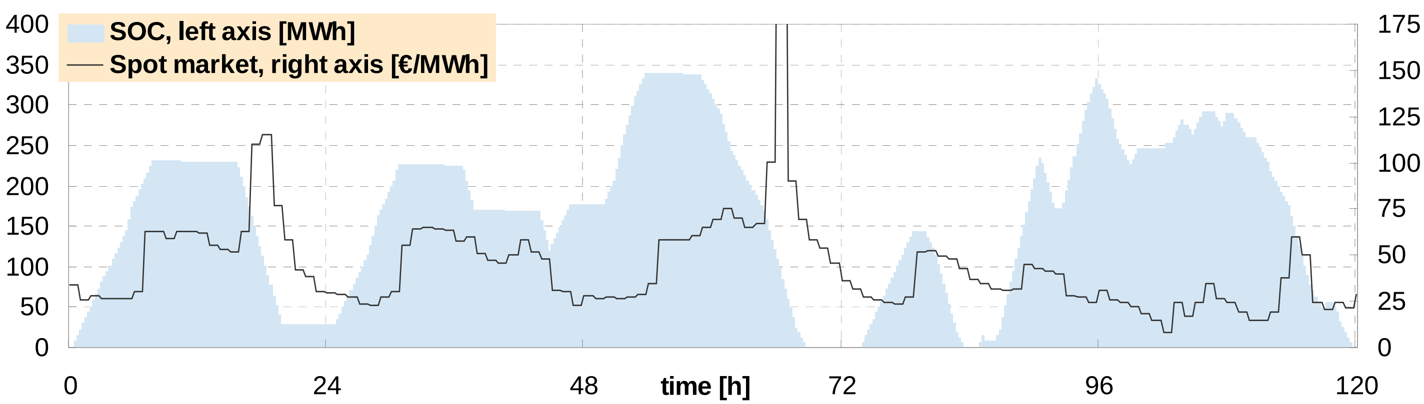
A-CAES operation

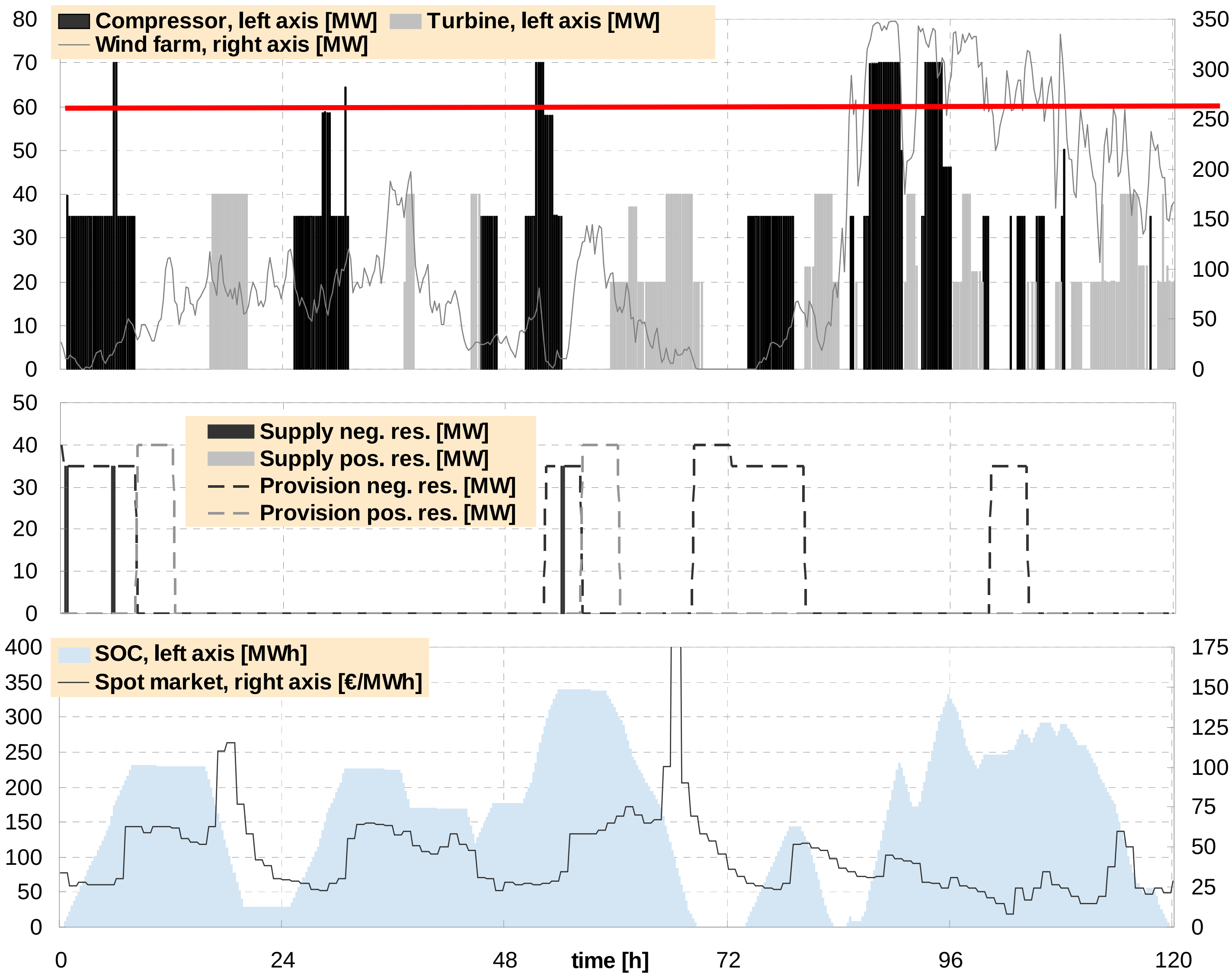




Optimal storage plant operation based on multifunctional application comprising:

- Storage of surplus wind power
- Spot market trading
- Provision of tertiary reserve power

A-CAES operation



Optimal storage plant operation based on multifunctional application comprising:

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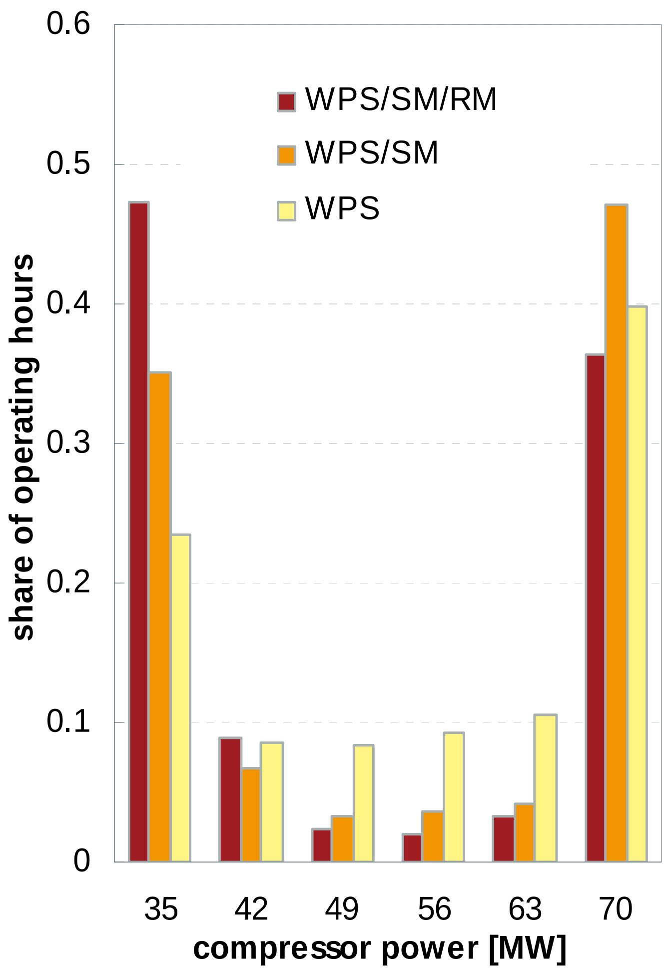
Overview on characteristic operational values



	Multifunction application (WPS/SM/RM)	Dual application (WPS/SM)	Singular application (WPS)
Full load hours total	3402 h	3421 h	286 h
Avg. stand-by period between charging	8.9 h	11.1 h	23.0 h
Number of charging start-ups per year	732	597	123

WPS: Wind Power Storage
SM: Spot Market
RM: Reserve Market

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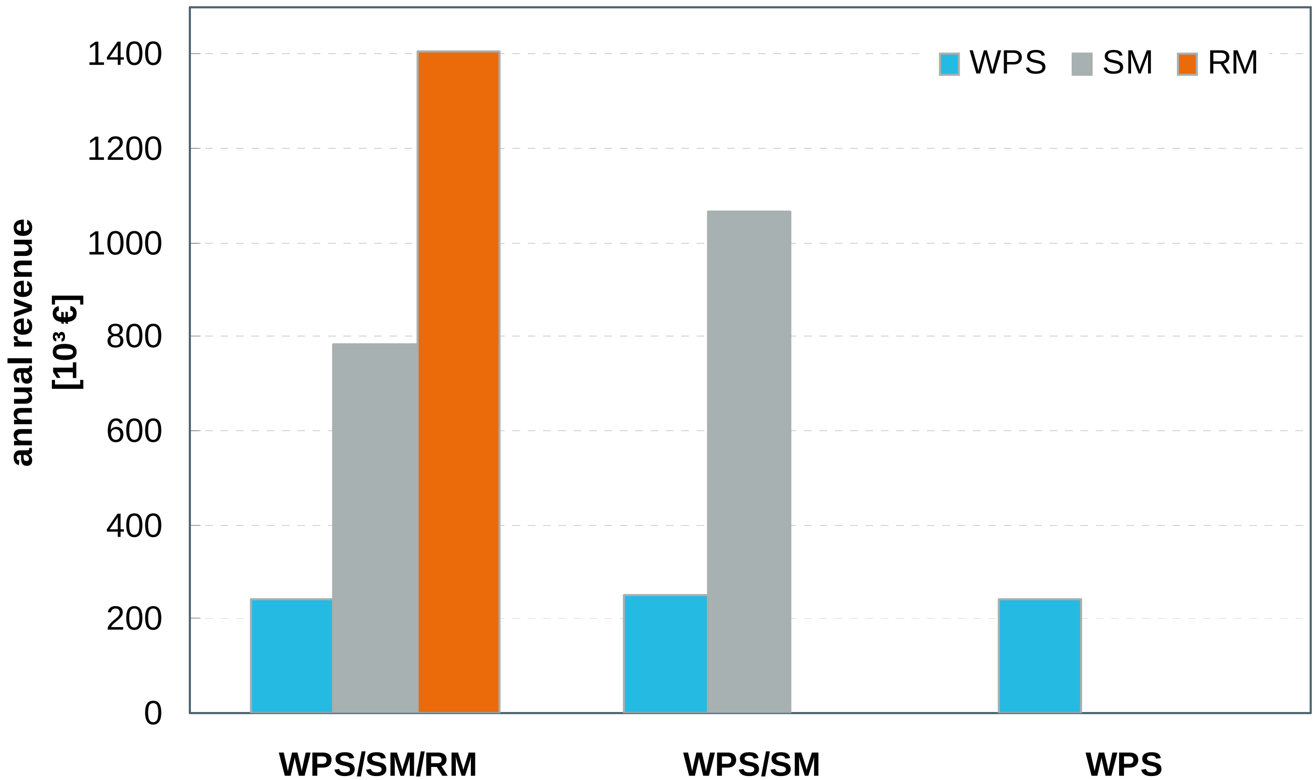
Income streams for different application modes



Rel. annual revenue: **100%** **54%** **10%**

General observations*:

- RM participation decreases SM income
- Neither RM nor SM participation diminish WPS income

WPS: Wind Power Storage
SM: Spot Market
RM: Reserve Market

*See also: Adiabatic Compressed Air Energy Storage co-located with wind energy—multifunctional storage commitment optimization for the German market using GOMES, Int. Journal of Energy Systems, Springer, 2011, DOI: 10.1007/s12667-011-0044-7

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Conclusion

Conclusion

- Energy storage powerful means for intermittent RES integration
- Multifunctional storage application most profitable
- Multifunctional storage application …
  - … leads to high part load shares and
  - … causes more frequent plant start-ups
  - … does not diminish absorption of surplus wind energy

- Which storage technology fits best?
- How much storage do we need in the future?

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