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Reliability and Efficiency Considerations for an Energiewende Market Design

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Research Questions

- How do equilibrium solutions look like with high RES shares?
- How much demand response (DR) is required in high RES scenarios?
- How does uncertainty affect the results of an EOM?
- What are the differences between EOM and capacity market (CAPM) solutions?
- How does the capacity mix change if CAPM product definitions change?
- How do CAPM perform with higher RES shares?

Methodology

- Two-stage stochastic investment and dispatch problem
 - Parallel high performance computing
 - Avoiding regional effects – we analyse a single market
 - Avoiding transitional effects – we analyse equilibria
-
- We isolate the particular effects of uncertainty and RES increase on costs and DR market participation in EOM and CAPM designs

2-stage Stochastic Decomposed Approach

Master problem:

$$\begin{aligned} \min_C! \quad & T = \sum_t f_t C_t + \alpha \\ \text{s.t.} \quad & \alpha \geq \sum_s \pi_s (\bar{d}_s + \sum_t \lambda_{s,t} (C_t - \bar{c}_t)) \quad \text{„Benders Cut“} \\ & \sum_t C_t \geq p \quad \text{In case of CAPM: „Capacity target“} \\ & \quad \quad \quad \text{(dropped in EOM)} \end{aligned}$$

Stochastic subproblem:

$$\begin{aligned} \min_G! \quad & D_s = \sum_{t,h} v_t G_{s,t,h} \\ \text{s.t.} \quad & \sum_t G_{s,t,h} = l_{s,h} \\ & G_{s,t,h} \leq \bar{c}_t \end{aligned}$$

Stochastic subproblems run in parallel mode

Scenario Matrix

	0% RES	30% RES	50% RES	70% RES
EOM perfect foresight	1 realisation	1	1	1
EOM uncertainty	3 realisations	3	3	3
CAPM 1h DR	3	3	3	3
CAPM 2h DR	3	3	3	3
CAPM 4h DR	3	3	3	3
CAPM 6h DR	3	3	3	3
CAPM 8h DR	3	3	3	3
CAPM 10h DR	3	3	3	3

RES shares:

- 50% Wind
- 50% Solar

Realisations:

- Estimation (550 TWh demand, x% RES)
- +5% Demand - 10% RES
- -5% Demand + 10% RES

Duration of peak demand:

- At 95% of peak demand: 5h
- At 90% of peak demand: 14h

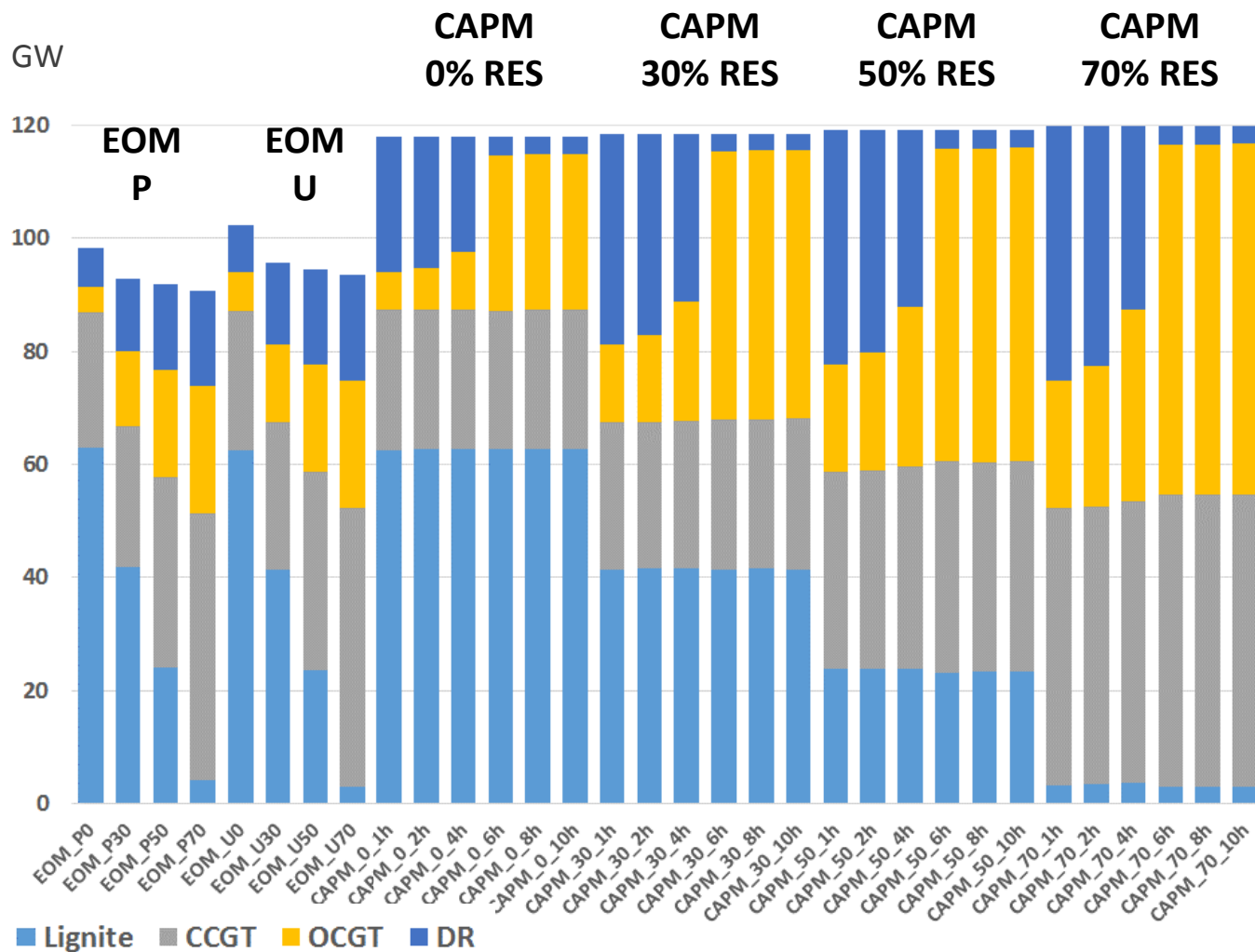
Assumptions

- Capacity target according to high demand scenario and no RES capacity credit – conservative regulator
- CO₂: 40 EUR/t

Technology	Annual fixed costs (kEUR/MW _a)	Variable costs (EUR/MWh _{th})
Lignite	242	1,4
Coal	203	11
CCGT	107	30
OCGT	74	30
DR	17	400 (el)

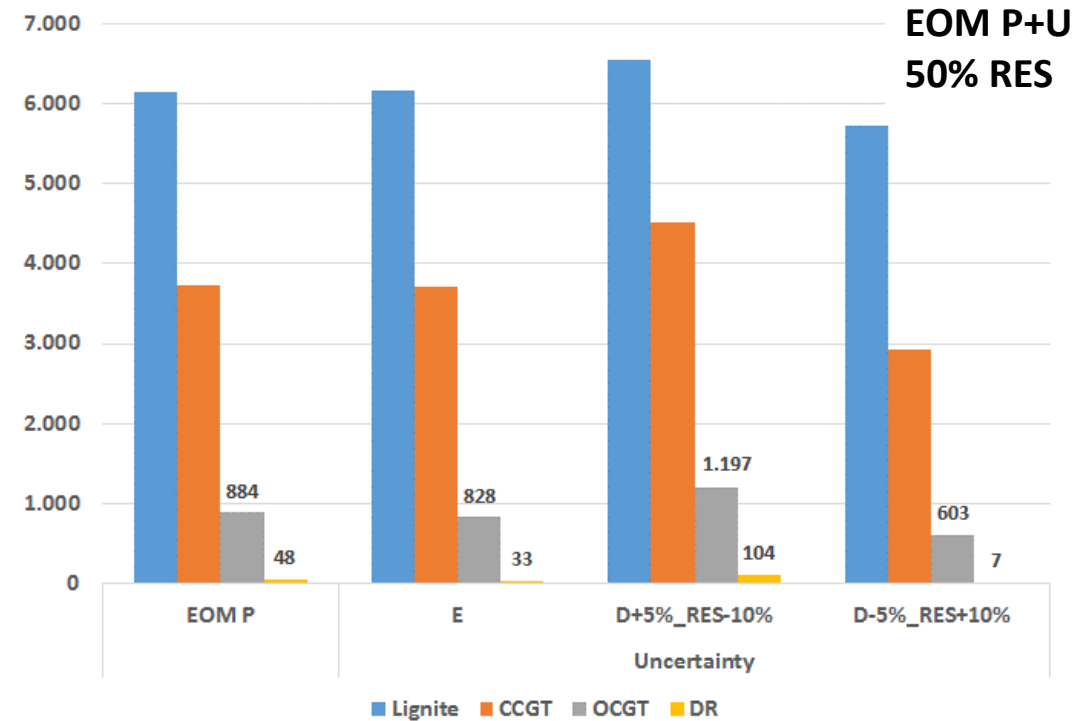
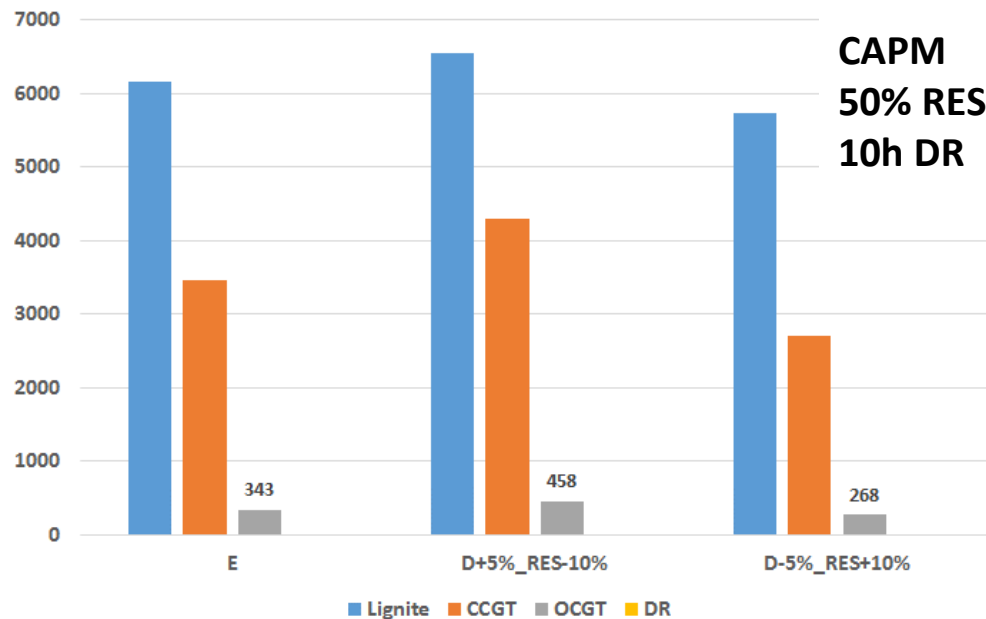
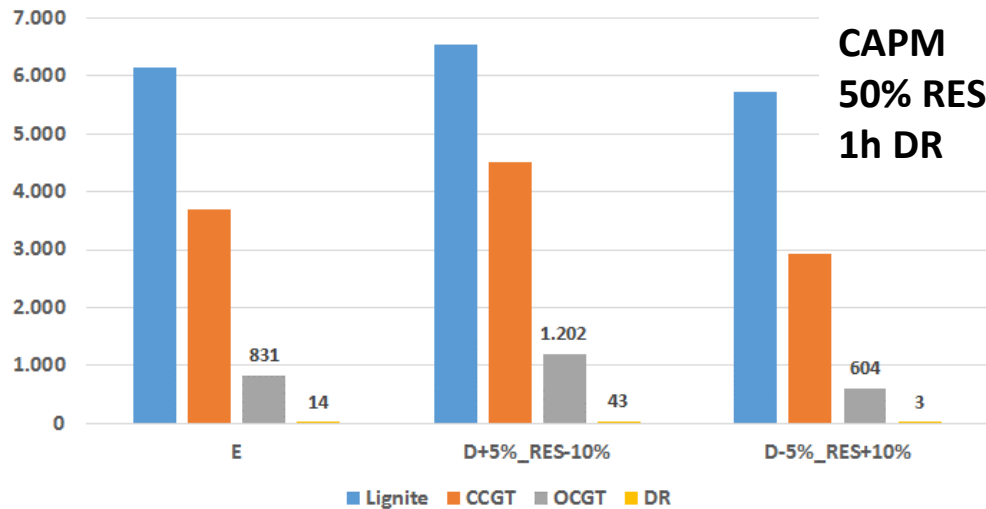
- DR-Law (Abschaltverordnung)
 - Capacity payment: 30.000 EUR/MW_a
 - Energy payment: 100 – 400 EUR/MWh_{el}

Capacity Mix



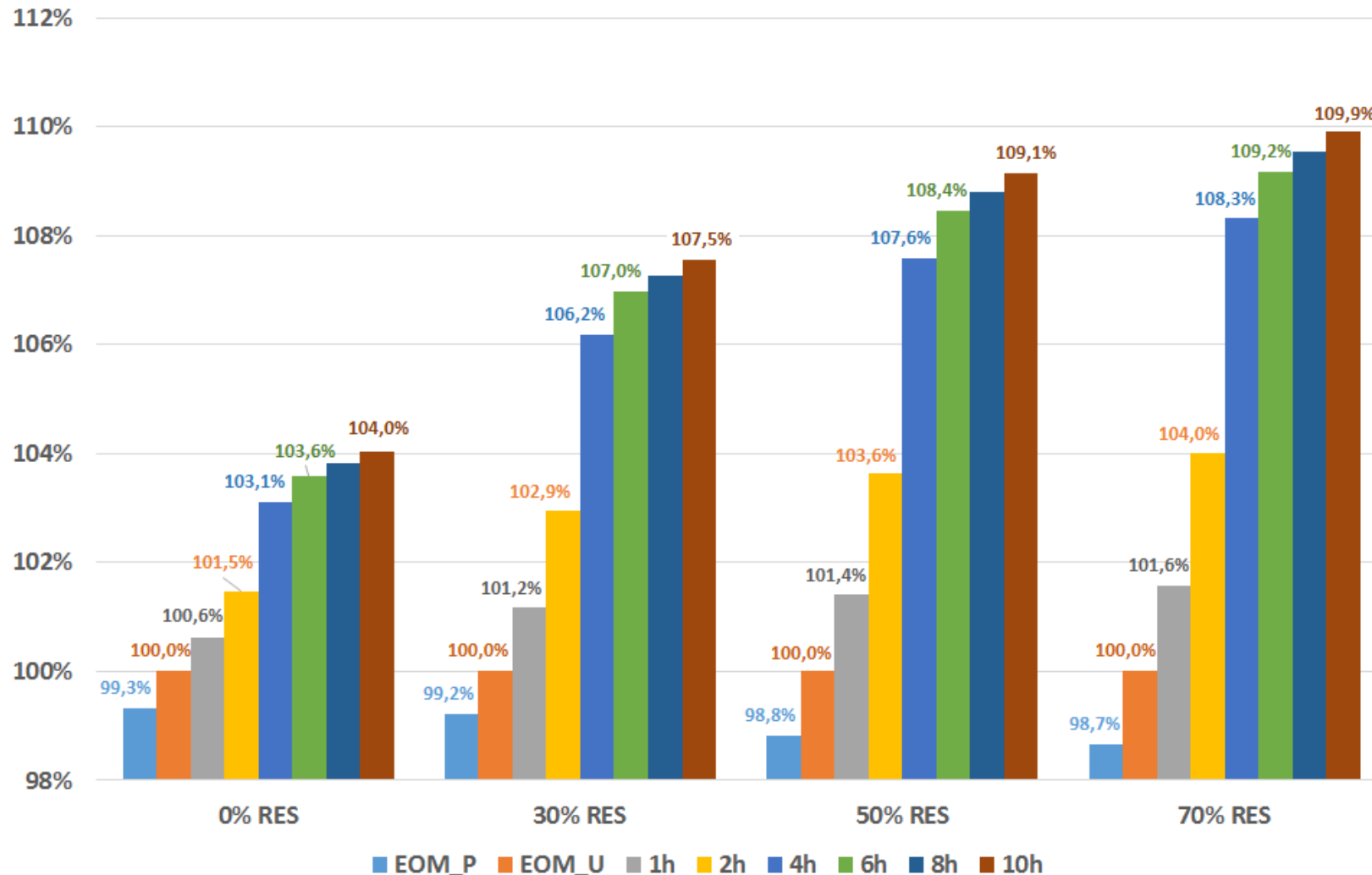
- Higher RES share leads to more peak and DR capacity and less base load capacity
- Uncertainty leads to more capacity
- CAPM scenarios have more total capacity due to capacity target
- DR contribution depends on product definition
- Challenging to meet criteria which enable efficient level of DR and ensure adequacy at the same time

Utilisation



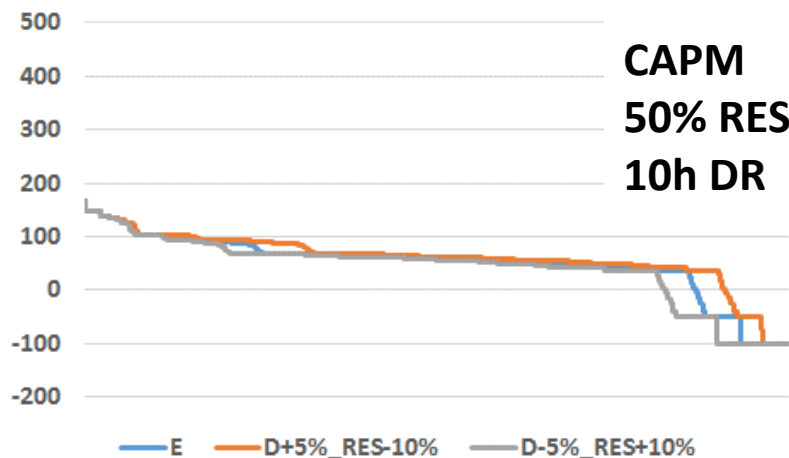
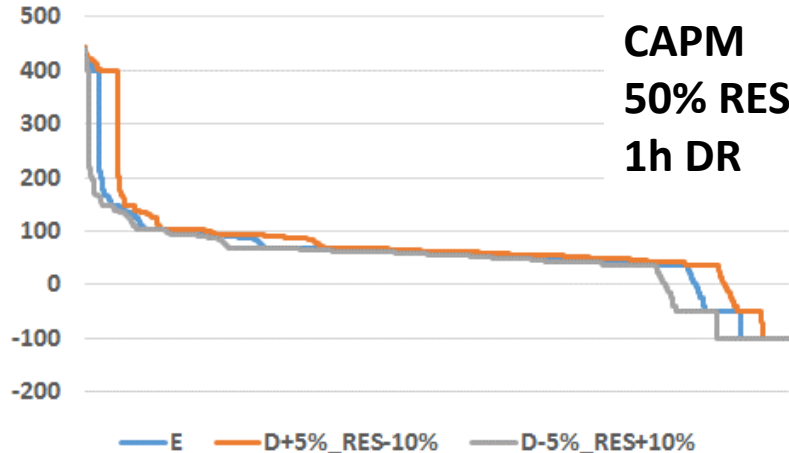
- Utilisation of peak capacity in CAPM scenarios depends strongly on product definition and capacity target
- CAPM could lead to unnecessary costs for consumers due to either windfall profits for industrial consumers or due to conventional overcapacities

Total System Costs

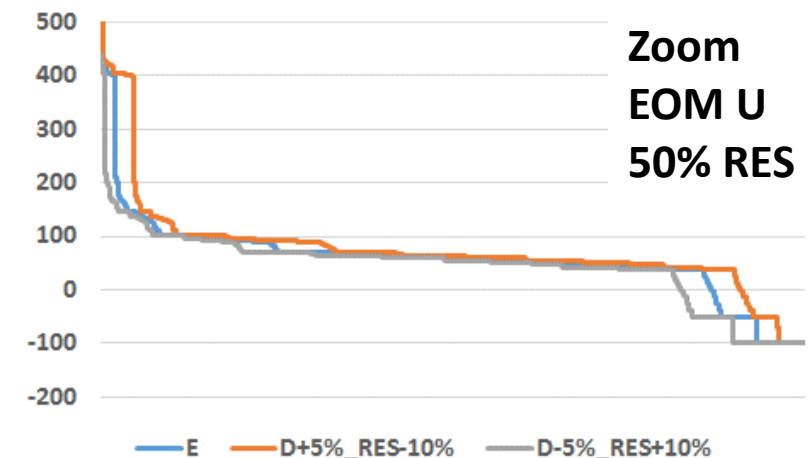
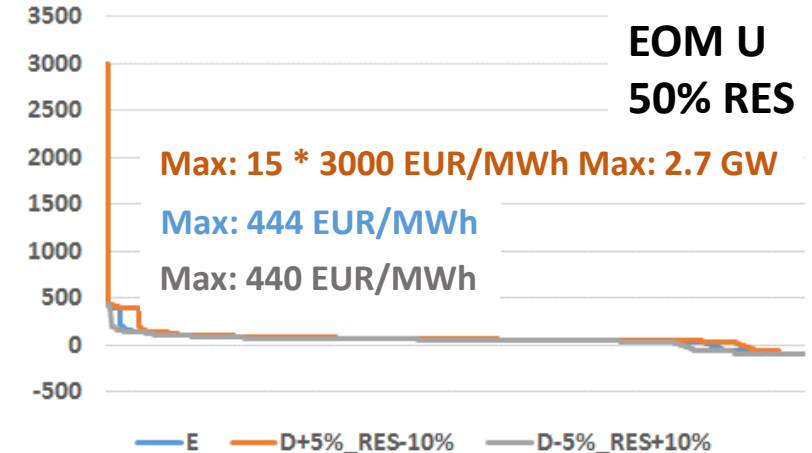


- Perfect foresight has a value
- The value of perfect foresight increases with an increasing RES share
- The higher the DR requirements, the higher the additional costs of a capacity target
- The higher the RES share, the more additional costs occur due to higher DR requirements

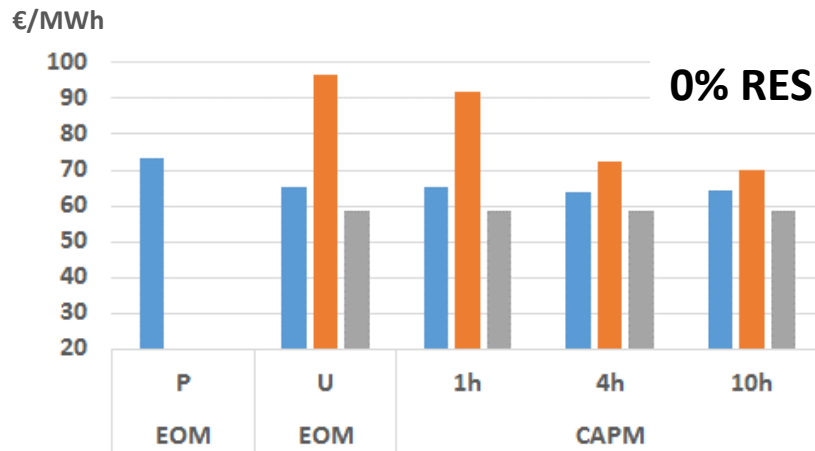
Price Duration Curves



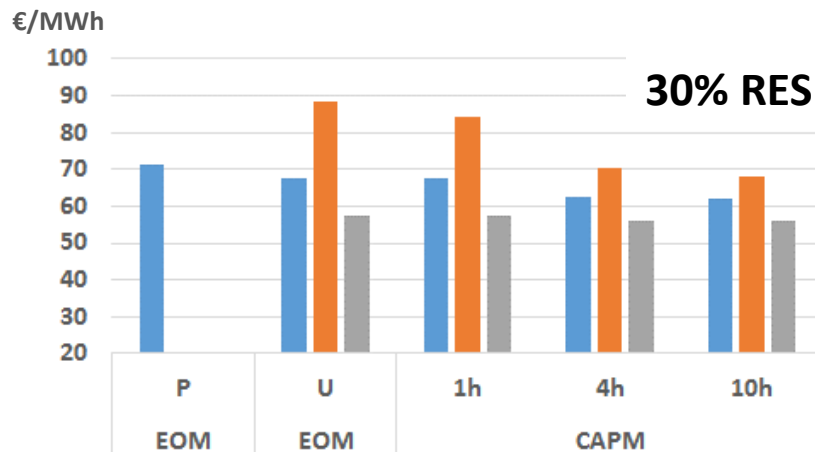
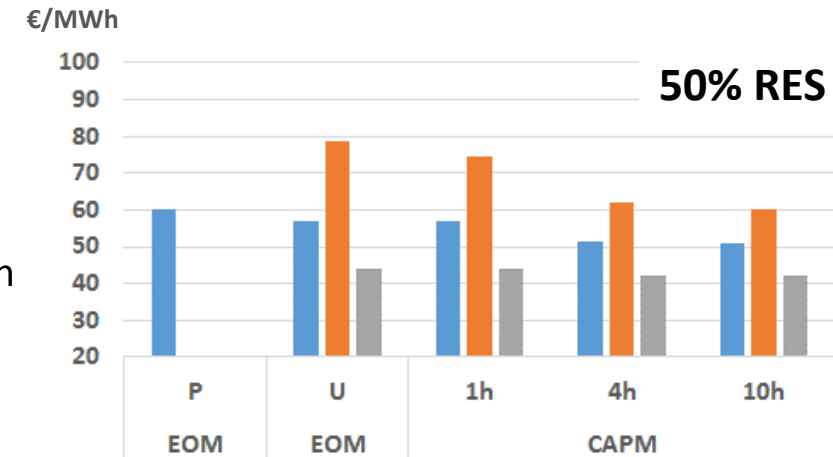
- In EOM, Strategic Reserve could be necessary in extreme years
- DR utilisation increases price volatility
- In CAPM, if DR is not part of the solution, price volatility is significantly decreased
- DR utilisation in CAPM lower than in EOM
- In EOM, max SR call is 2.7 GW (3 GW new OCGT SR would cost 222 mill. EUR/a)



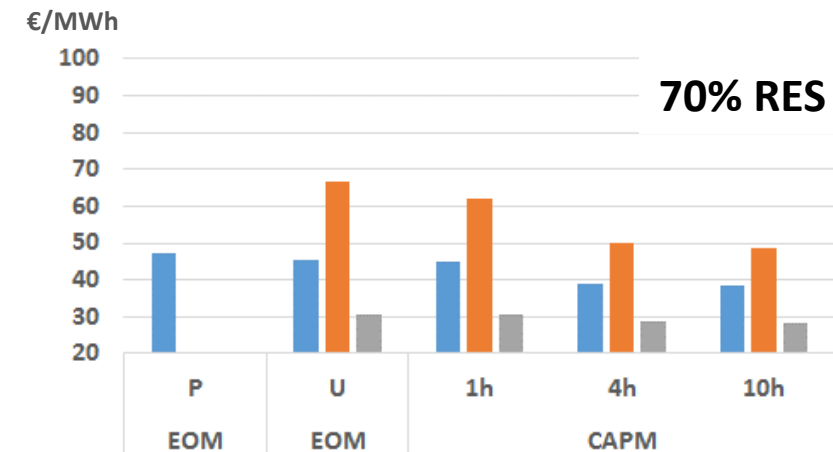
Average Wholesale Prices



- The degree of DR affects price volatility
- Price volatility in high RES scenarios increases between years and within years
- Increase of RES depresses average wholesale prices



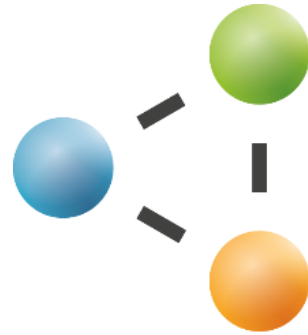
- In EOM, due to price spikes, capacity is profitable
- In CAPM, due to lack of price spikes, reliance on CAPM increases with high RES shares



Conclusions

- Uncertainty increases total capacity (including DR) and costs
- The value of perfect foresight increases with RES share
- CAPM „product definition“ is crucial – hardly a chance to get it „right“
- Additional costs of DR-unfavourable „product definitions“ increase with RES share
- Distributional disputes are likely between consumers and producers as well as between different consumer groups

- In CAPM: Trade-off between reliability and efficiency due to target and product definition
- High risks of designing a CAPM which is inefficient and causes distribution risks
- Likely CAPM lock-in due to low price level caused by overcapacities



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