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Copernicus Institute of Sustainable Development

Least-cost options for integrating intermittent renewables

Anne Sjoerd Brouwer

27-11-2015

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Introduction

- Stricter climate policies increasingly likely
- Power sector in a state of change
  - More intermittent renewables: wind and solar PV
  - Large CO_2 emission reductions: only a role for low-carbon power plants

- Effect of intermittent renewables?
- Role of emerging technologies?
  - Carbon Capture and Storage (CCS)
  - Demand response
  - Increased interconnection capacity
  - Electricity storage

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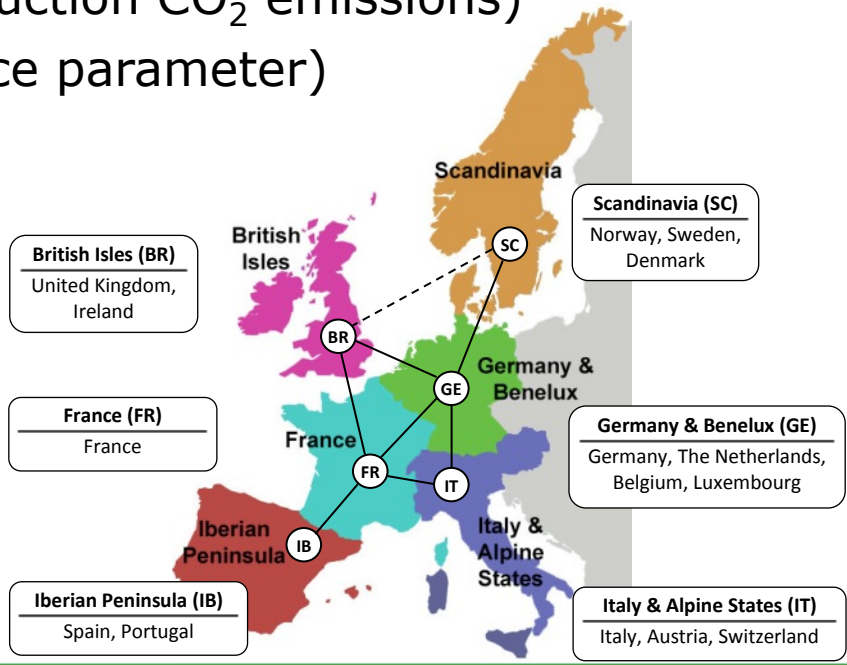
Study methods

- Goal of our research: identify which technologies may be part of a centralized power system with:
  - High reliability (LOLP <0.1 day/year)
  - Low emissions (>96% reduction CO_2 emissions)
  - Low costs (key performance parameter)
- Europe in 2050
- Three scenarios:

RES	40%	60%	80%
iRES	22%	41%	59%



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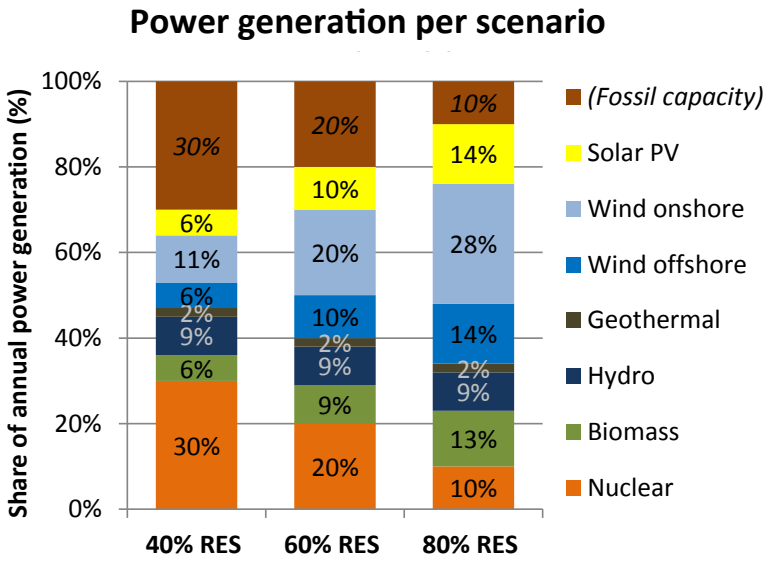
Study methods

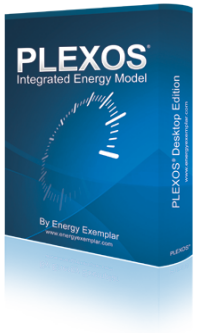
1. Define **non-fossil** capacity per scenario

2. Define capacities of **complementary** options

3. Optimize **fossil** capacity per scenario [PLEXOS]

4. Run **hourly simulations** [PLEXOS]





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Study results – power generation

- Two aspects can reduce total system costs
  - Least-cost power generation
  - Efficient system operation

- First: what is the cheapest way to generate power in low-carbon power systems?

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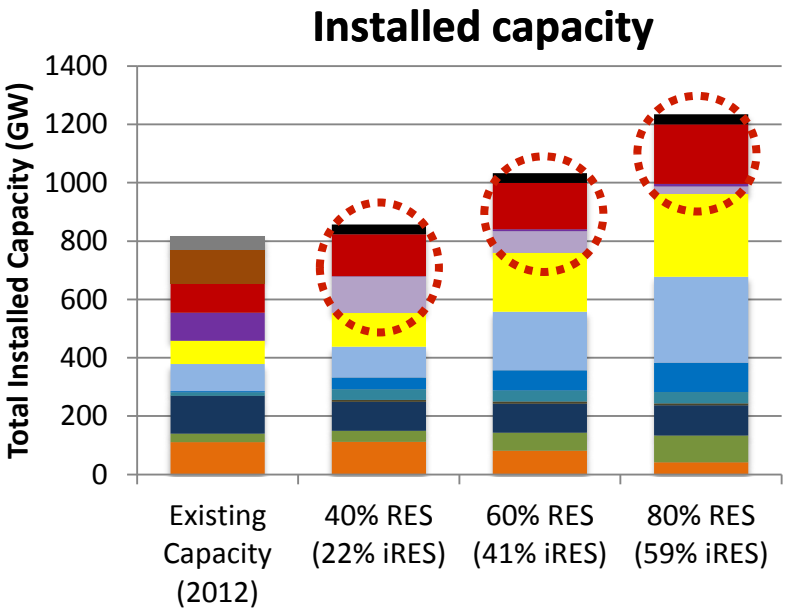
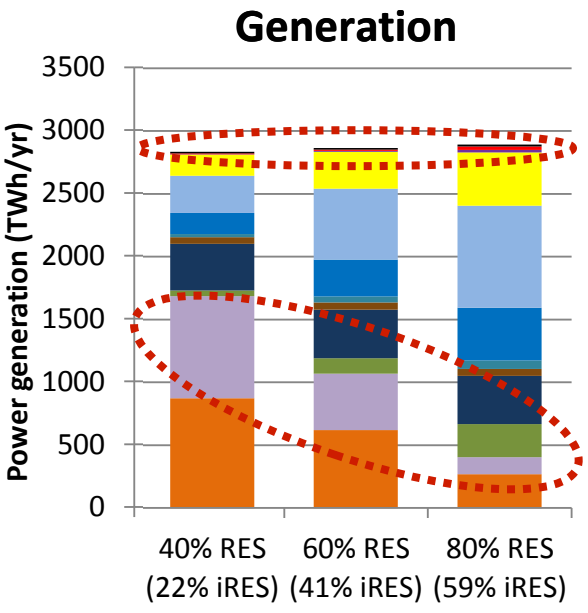
Study results – power generation

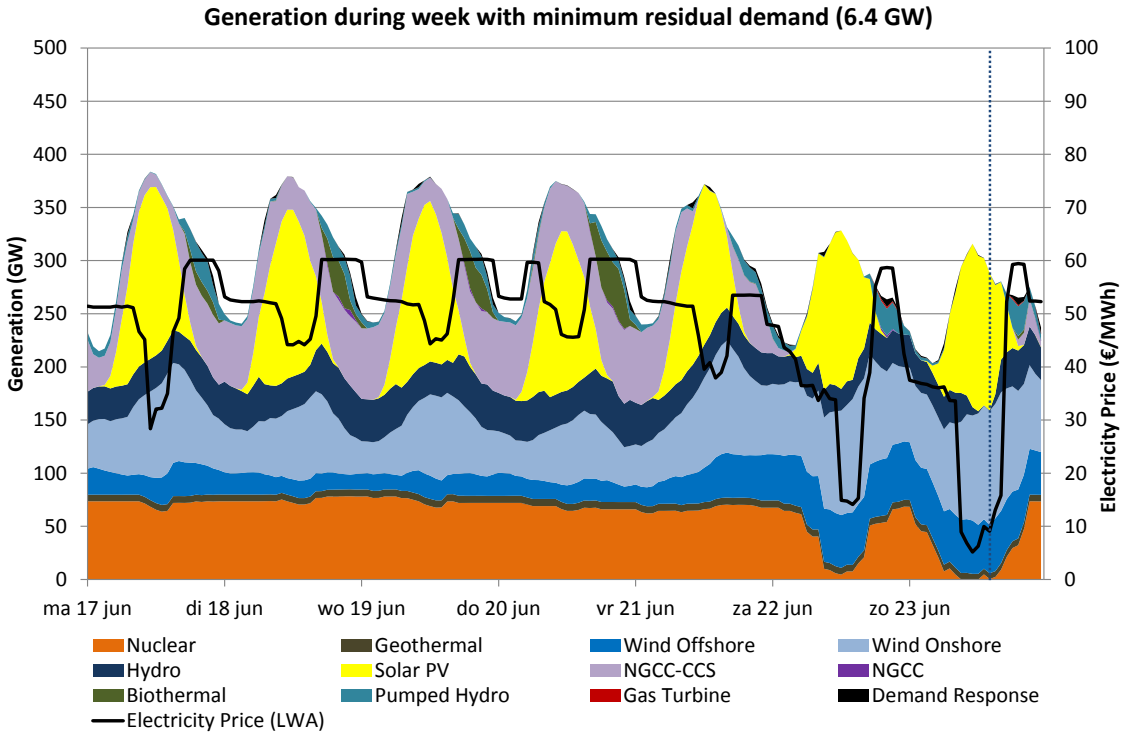
- Fossil capacity optimization: only natural gas capacity
  - Combined cycle with CCS
  - Gas turbines





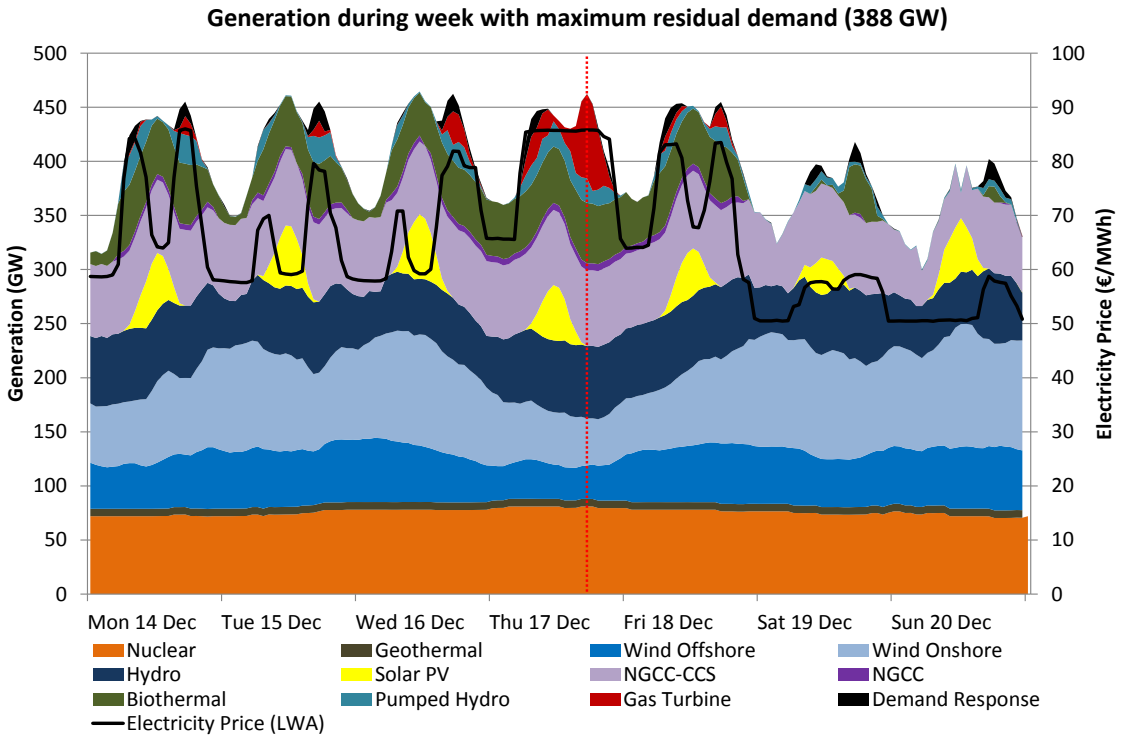
Study results – power generation

- NGCC-CCS generates power during the night in the summer



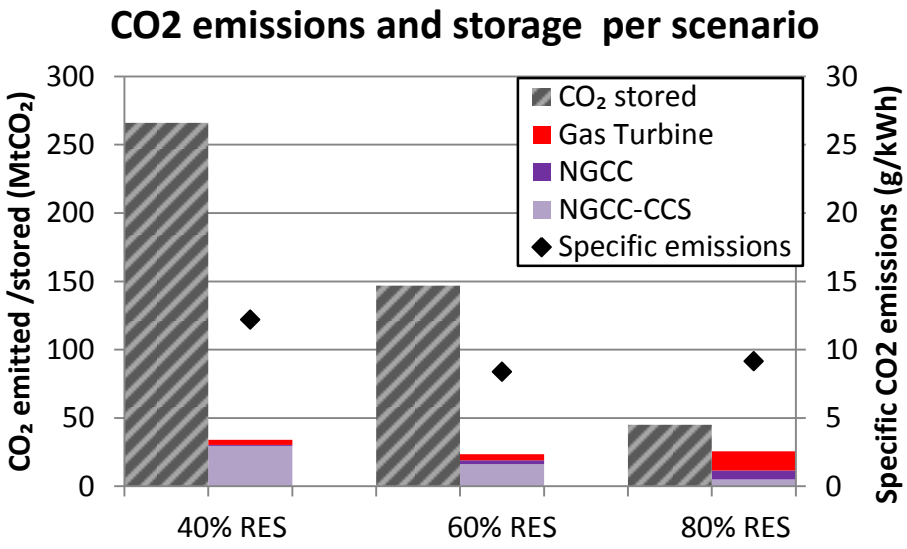
Study results – power generation

- NGCC-CCS baseload generation during winter time
- Gas turbines supply peak demand



Study results – power generation

- CO_2 emission reduction target is met in all scenarios
  - Specific emissions of <13g/kWh correspond to a >96% reduction in CO_2 emissions



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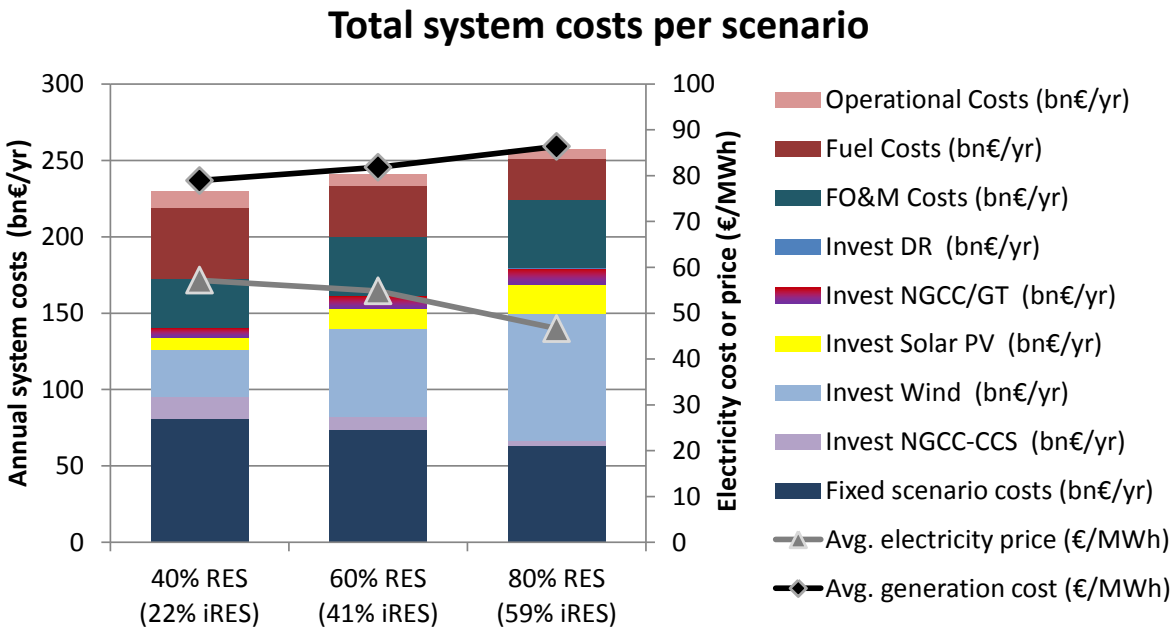
Study results – power generation

- Effect on costs: intermittent renewables increase total system costs
  - 12% higher capital costs
  - 18% reduction in electricity price



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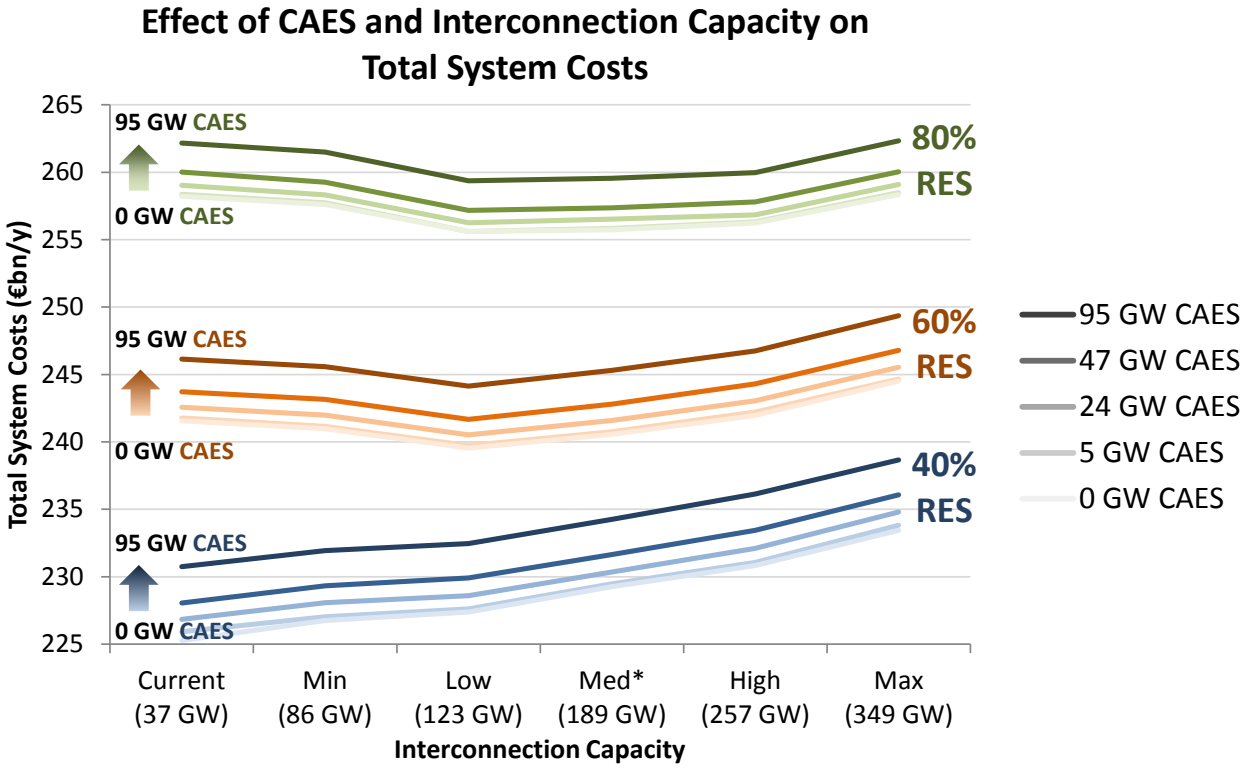
Study results – system operation

- Which options can decrease system costs by improving “system efficiency”?
  - More efficient use of power plants
  - Less curtailment

Study results – system operation

- Interconnects reduce costs up to a 'sweet spot'
- Storage increases total system costs
- Demand response reduces costs by 2-3%



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Conclusions

- Intermittent renewables affect the operation of power systems, but their impacts are manageable.
  - Larger reserves, effect on capacity factors of other generators
- Low-carbon power systems can be realized with various generation portfolios
  - Intermittent renewables increase total system costs
  - Natural-gas fired generation important in all scenarios
  - Demand response & interconnections least-cost options
  - Electricity storage too expensive

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The bigger picture

- Future power systems will become increasingly complex
  - New technologies
  - More decentralized generation
  - Cross-sectoral integration
  - More uncertainty for investors
- Necessary investments in power plants will not be made with the current energy-only market design
  - Business cases are unsound.
  - Generation adequacy may become a key issues of future power systems

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Recommendations

- Support demonstration projects
  - No regret options
- Investigate the effects of cross-sectoral integration
- Investigate how future capacity can be delivered
- Develop stochastic power system simulation models

Thank you for your attention

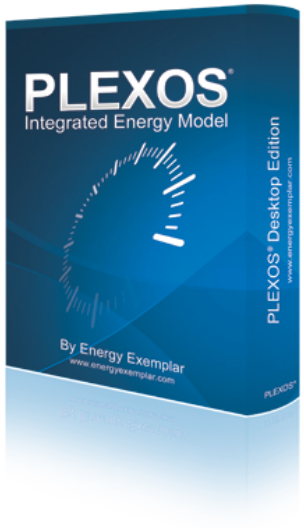
Any questions?

Anne Sjoerd Brouwer
asbrouwer@gmail.com

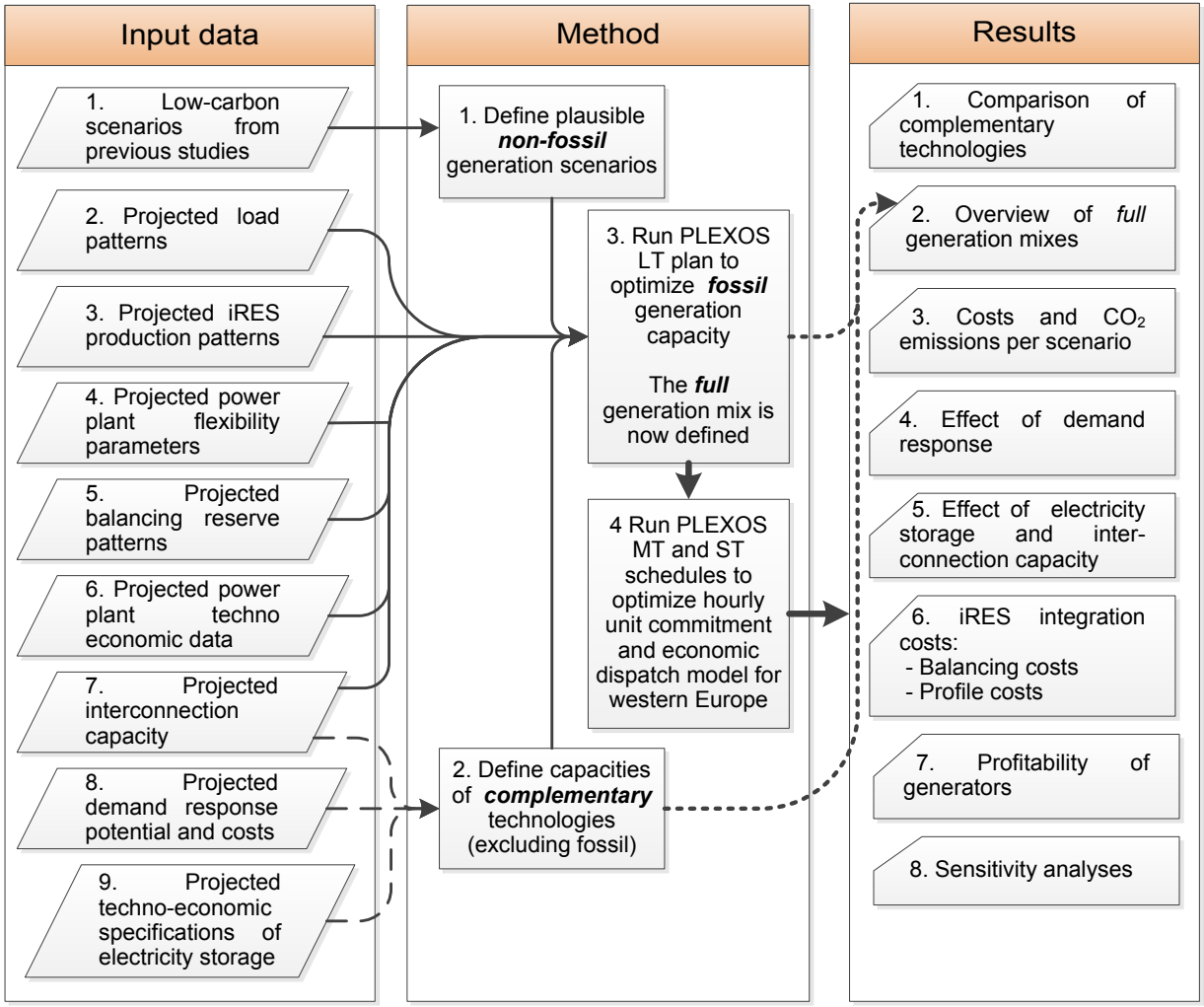
Will Zappa
w.g.zappa@uu.nl

Brouwer, A.S., Van den Broek, M., Zappa, W., Turkenburg, W.C., Faaij, A., 2016. *Least-cost options for integrating intermittent renewables in low-carbon power systems*. Applied Energy 161, 48–74. doi:10.1016/j.apenergy.2015.09.090

Supplementary slides



Overview of method



Key input parameters

€/GJ	Coal	Natural gas	Uranium	Biomass
Fuel price	1.7	6.5	1	7.2

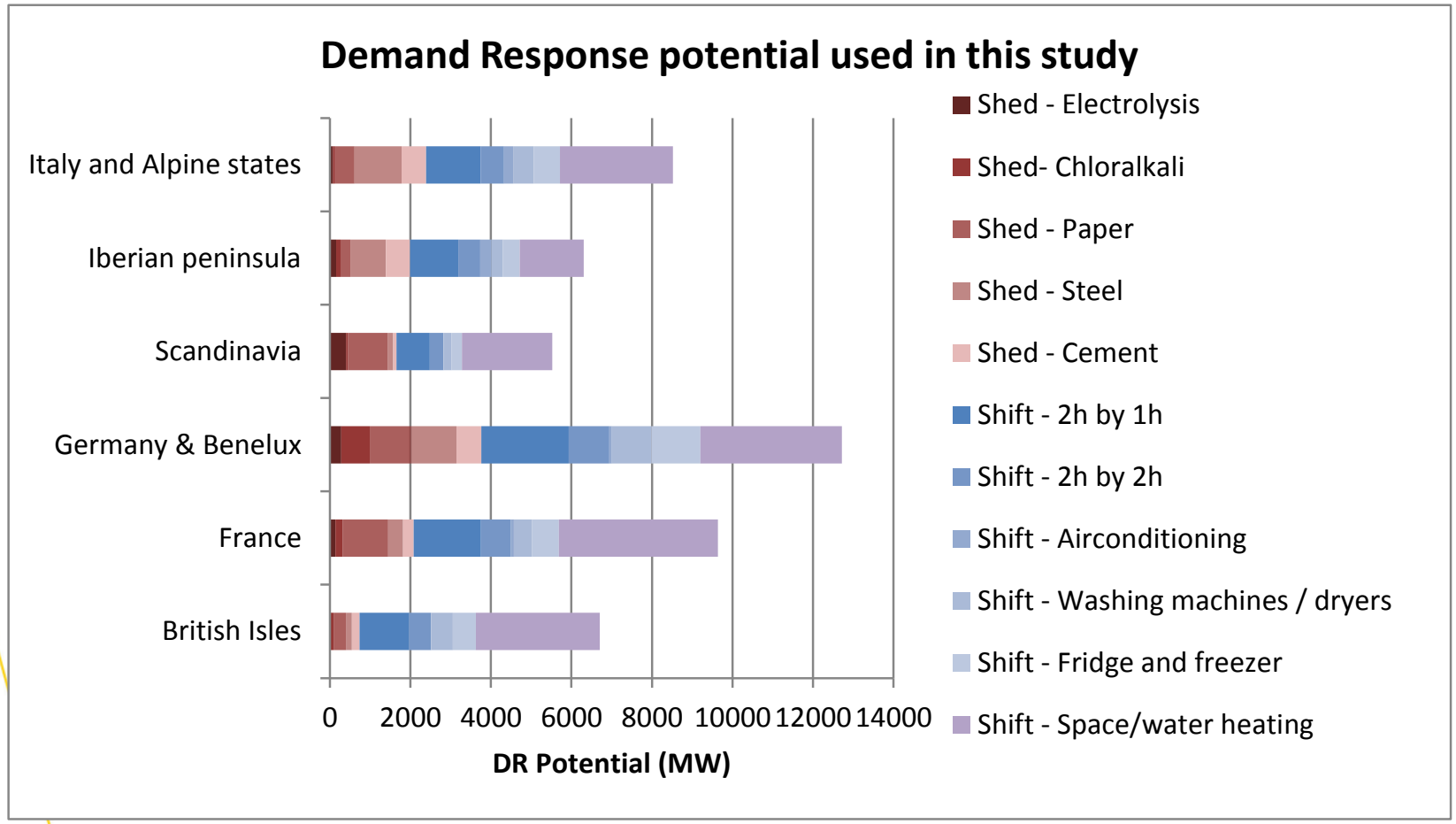
€/tCO_2	Transport and storage
CO_2 costs	13.5

TWh/yr	Britain	Scandi-navia	France	Ger-many +	Iberian pen.	Italy+
Load	415	368	602	811	358	525

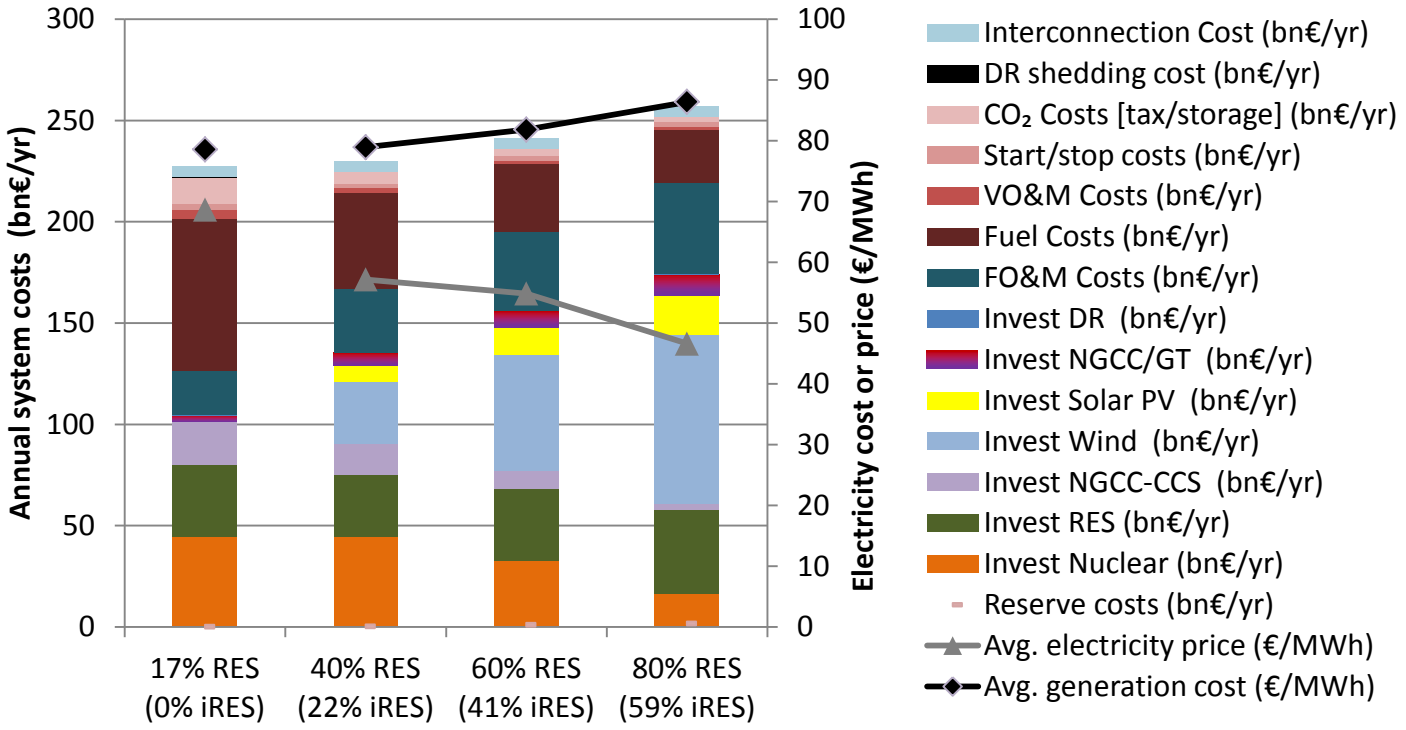
Input parameters of generation technologies

Generator	Investment (TCR, €/kW)	Fixed O&M (€/kW/yr)	Variable O&M (€/MWh)	Efficiency	Remarks
Nuclear	4841	103	1	33%	
PC-CCS	2847	33	5.6	41%	90% CO_2 capture
NGCC-CCS	1349	15	2.1	56%	90% CO_2 capture
NGCC	902	11	1.2	63%	
Biothermal	1949	37	3	45%	100% biomass fired
Geothermal	2657	44	0		
Hydro	3037	52	0		
Wind onshore	1402	37	0		CF: 22-26%
Wind offshore	2655	83	0		CF: 40-43%
Solar PV	700	17	0		CF: 11-21%
Gas turbine	438	10	0.8	42%	
Pumped hydro	2079	58	0.23	80%	80% round trip η
Demand resp.	3-100	1-11	0	100%	1-2 hrs of "storage"

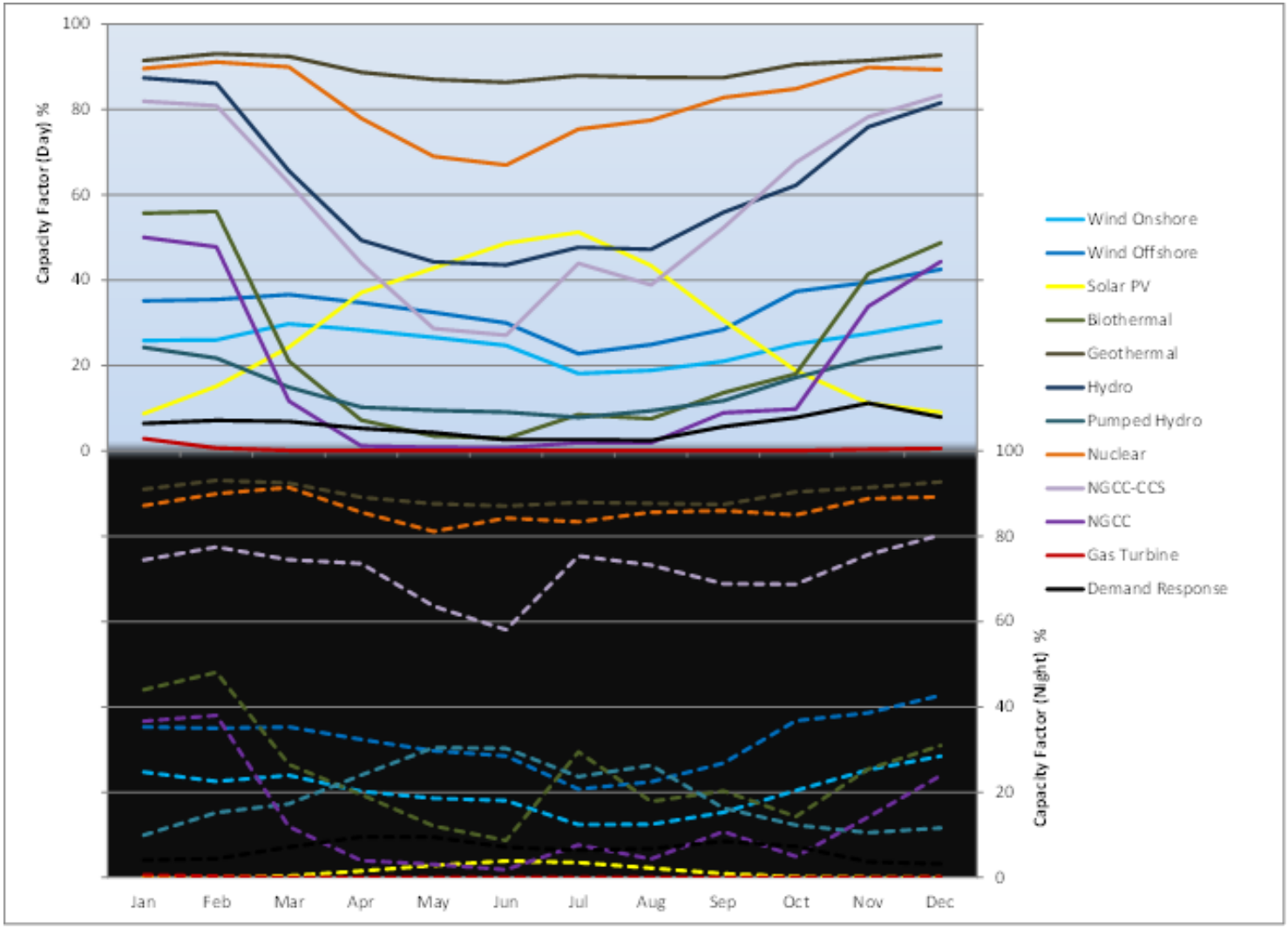
Demand response potential



Detailed total system costs



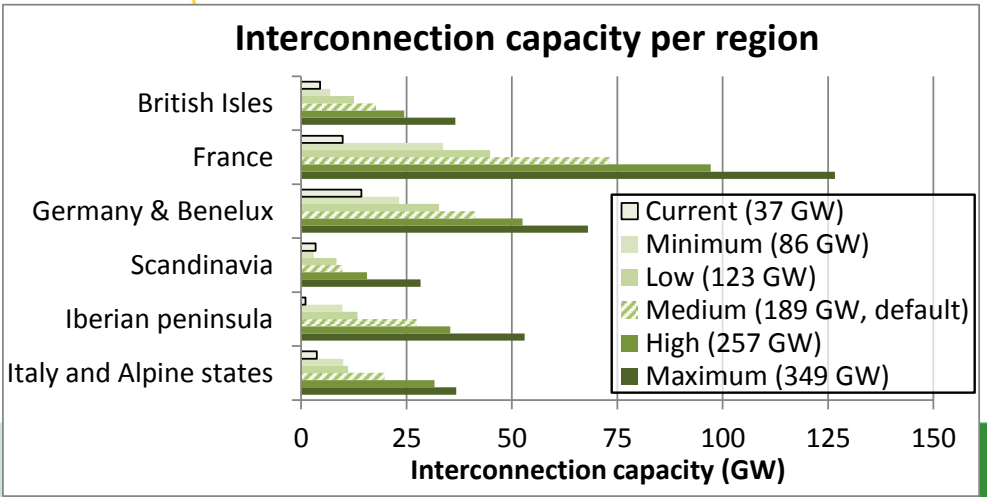
Capacity factors per month

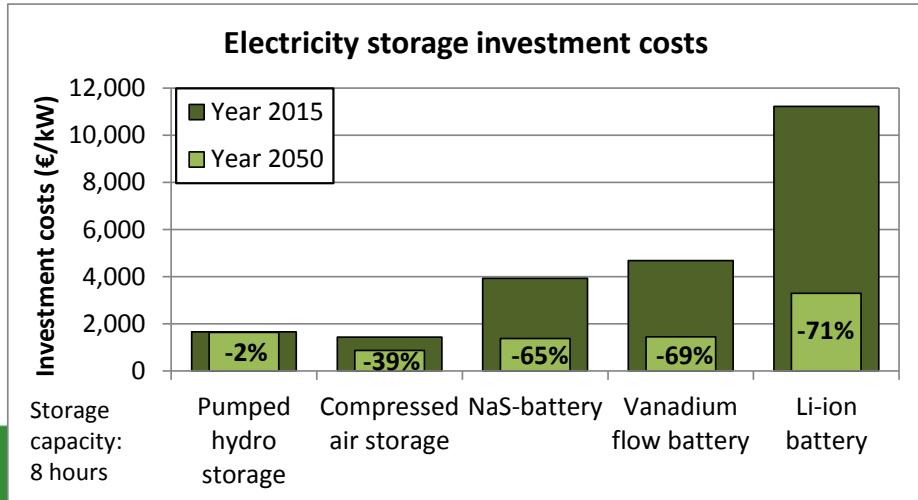


1. Define **non-fossil** capacity per scenario
2. Define capacities of **complementary** options
3. Optimize **fossil** capacity per scenario [PLEXOS]
4. Run **hourly simulations** [PLEXOS]

2. Methods

- Interconnection capacity
  - Deployment based on previous studies
  - Costs of 28 k€/MW/yr
- Demand response
  - Potential based on other studies (11 categories)
  - Crude costs of 200-5000 €/MWh (shedding) and 2-100€/kw (shifting)





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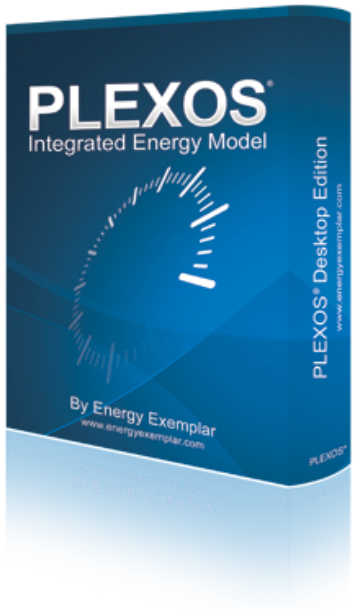
2. Methods

- Two optimizations with PLEXOS
  - Power system simulation and optimization tool

- Optimization of fossil capacity
  - IEA projections of specifications
  - 6 generator types

- Hourly simulations
  - Chronological simulations with 8760 steps
  - Account for flexibility constraints
  - Auxiliary reserves also included
  - Curtailment of RES allowed



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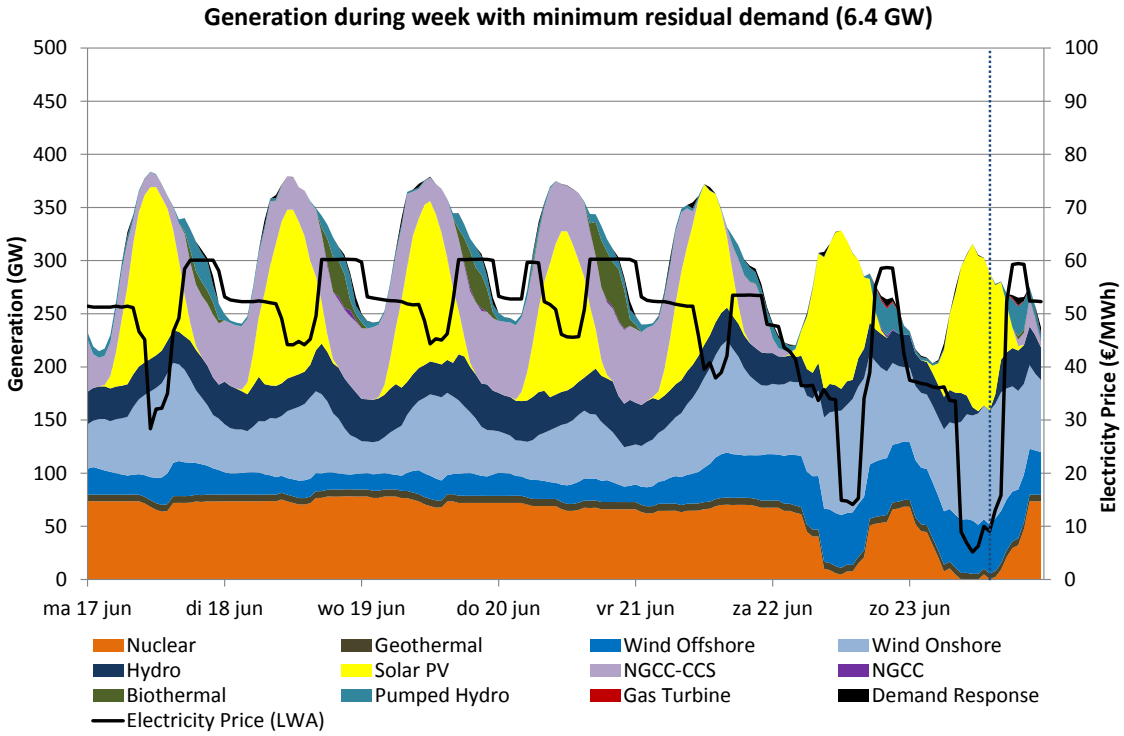

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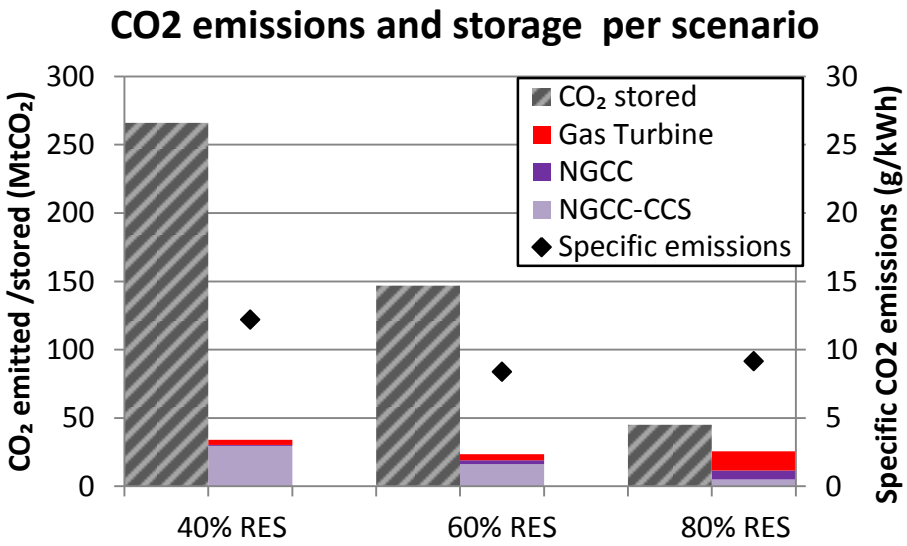
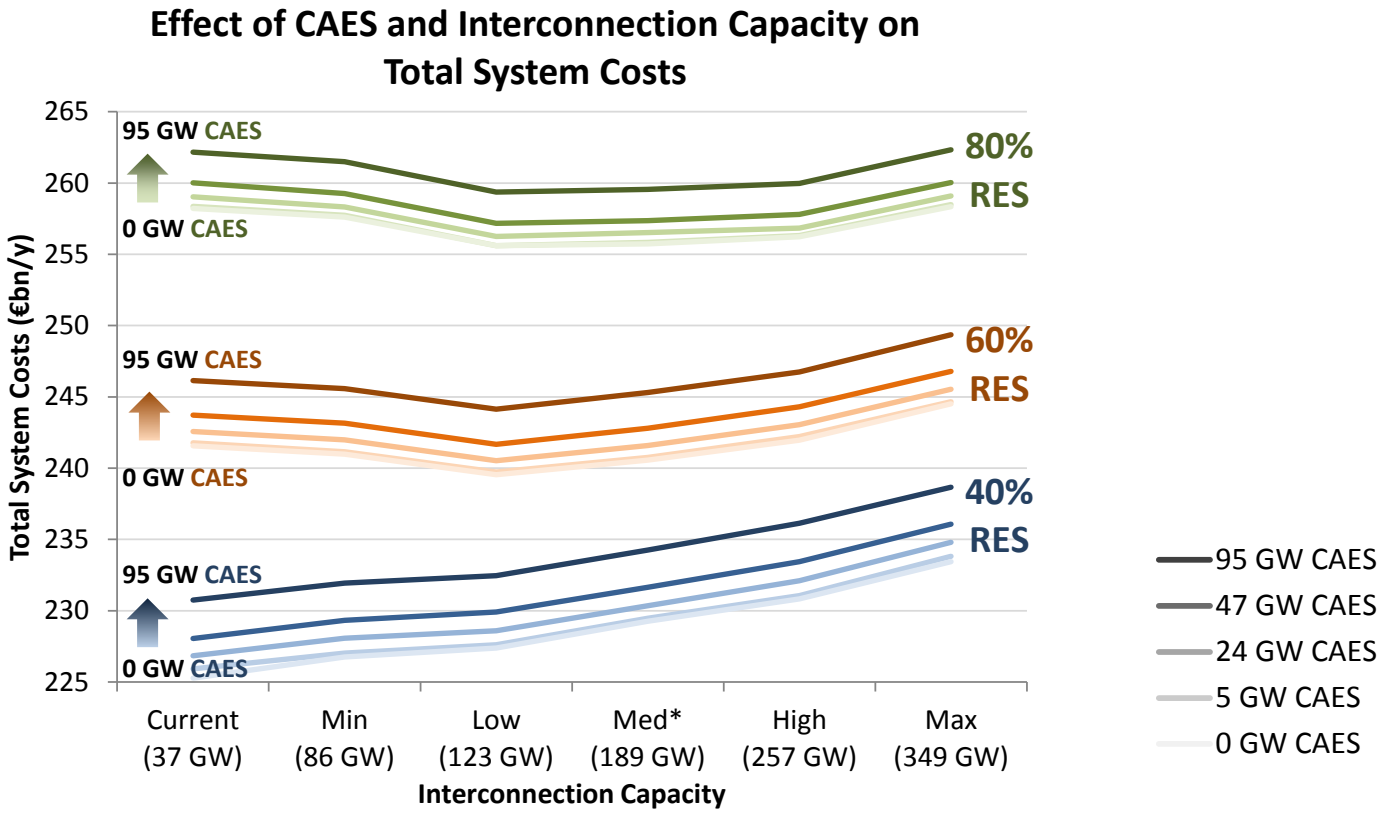
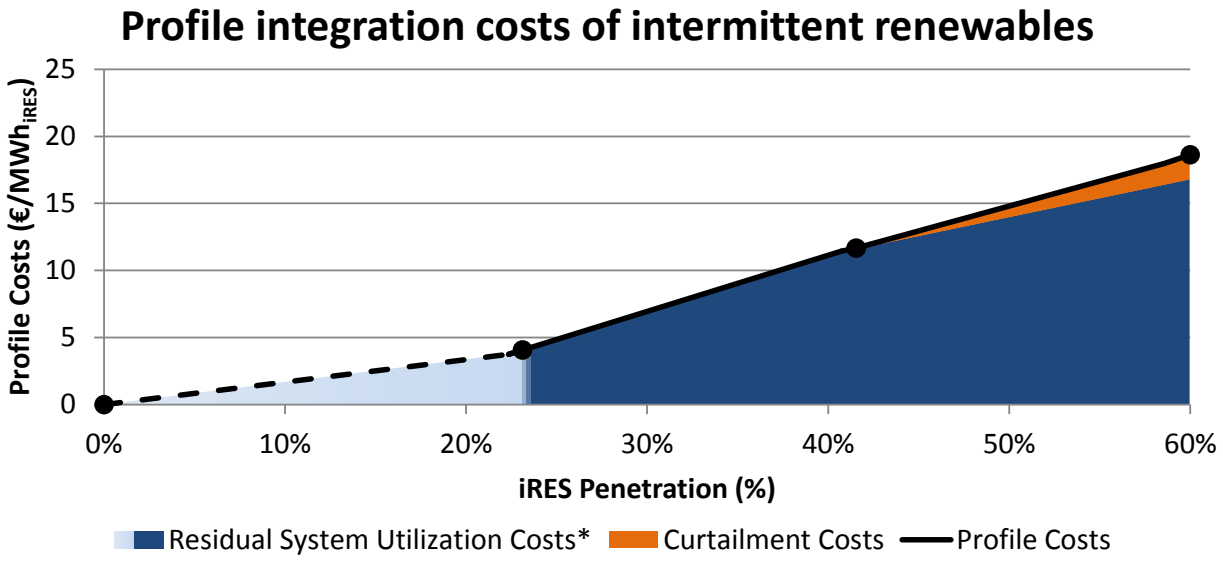


Study results – system operation

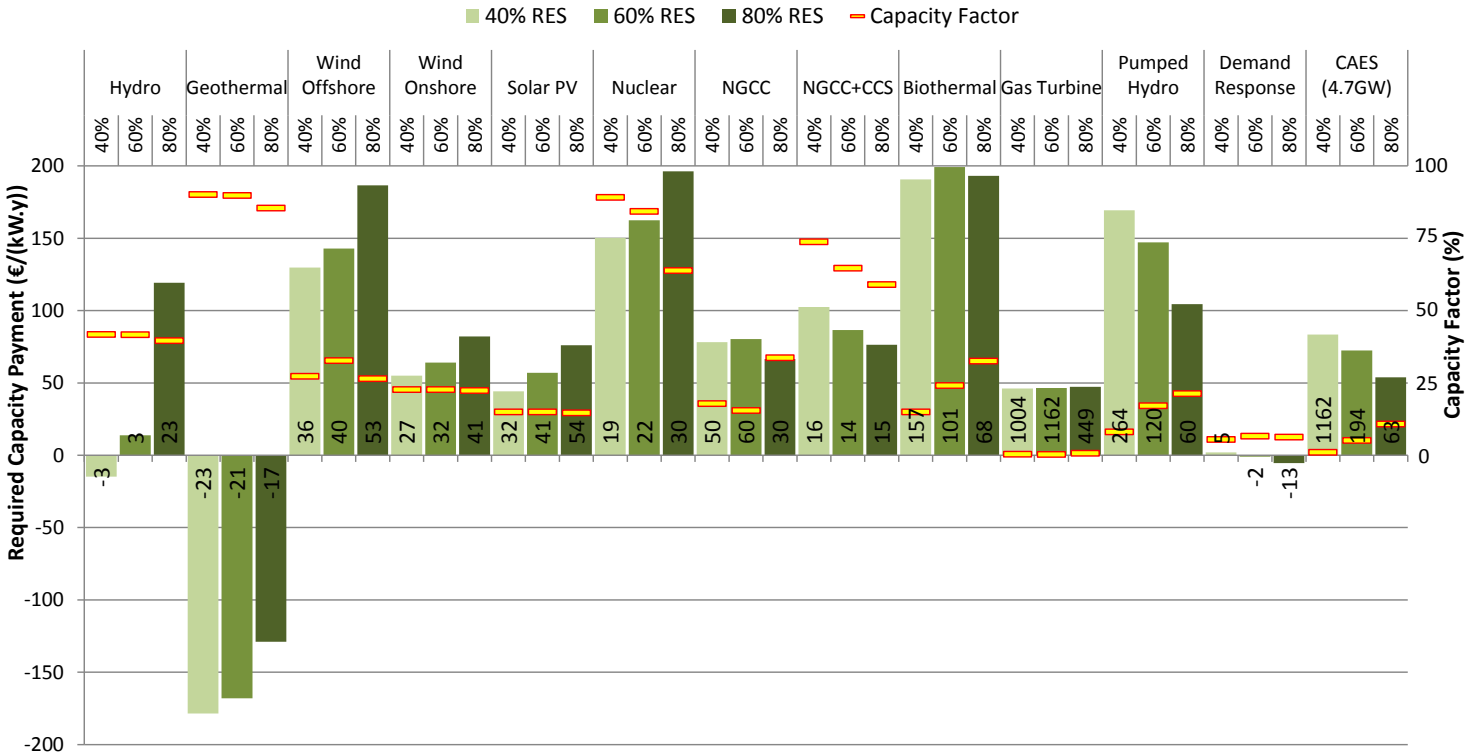


3. Results – power generation

- Total system costs are also increased by the integration costs of intermittent RES:
  - Profile costs
  - Balancing costs, grid costs



(3. Results – economics)



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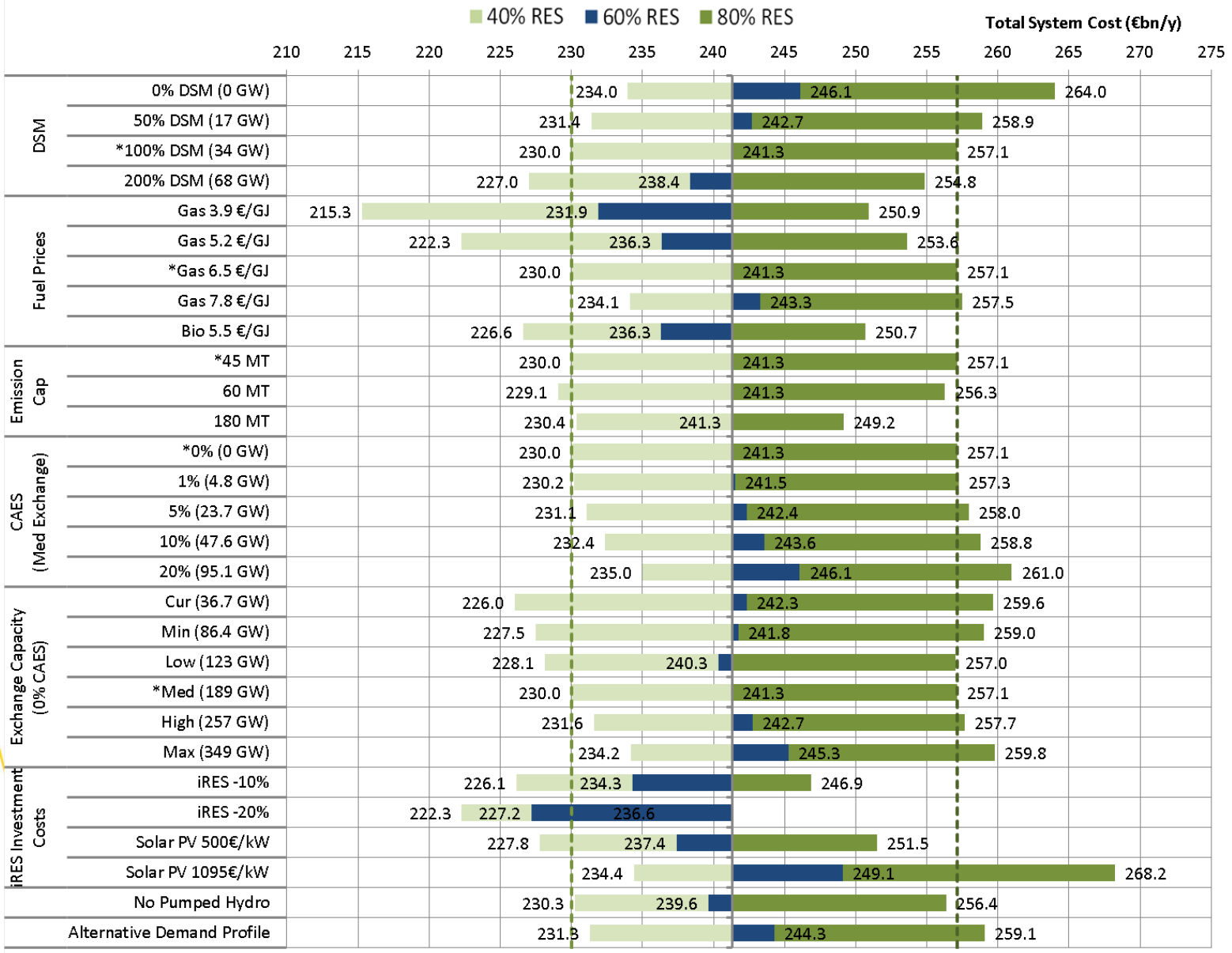
(4. Sensitivities – key findings)

- Results are overall robust. Results are only considerably affected by:
  - High gas price (7.8 €/GJ) → shift of NGCC-CCS to PC-CCS
  - Cheaper biomass (5.5 €/GJ) → biomass early in merit order
  - Higher CO2 cap (180 Mt) → shift of NGCC-CCS to NGCC
  - Lower investment costs of iRES → lower system costs
- More flexibility in systems resulting from interconnections, DR or CAES leads to
  - More base-load generation
  - Less GT capacity being installed and used
- Investment costs of iRES are a key factor.
  - Reduction in iRES investment costs has a large impact
  - Overall iRES cost reduction of >31% required to make 80% RES the cheapest scenario

Total System Cost

60% RES Base = 241.3 €bn/y

**60% RES, Cap 45MT ,CAES 0% , Exch 189 GW, DSM 34 GW , NG 6.5 €/GJ, BIO 7.2 €/GJ*



4. Discussion – scope, assumptions

- This study only considers snapshots of possible future power systems in 2050. No consideration is given to the dynamic transition from the current system
- Starting points of this study are pre-set emission reduction and reliability targets.
- Heating (demand, generation, storage) is not included.
- No transmission constraints are simulated within regions
- Assumed properties of DR capacity
  - 49 GW of DR potential
  - Shedding costs in this study: 200-5000€/MWh
  - Shifting investment cost in this study: 2-100 €/kW

4. Discussion - caveats

- The scenario approach fixes 50-65% of the costs exogenously leaving less room for optimization. Thus systems are plausible, not necessarily optimum. This may be reflected in the costs.
- Capacity credits of iRES are fixed. This assumption:
  - Underestimates the benefits of interconnections (interconnectors can increase the capacity credit by spatial smoothing);
  - Underestimates the profile costs in the 80% RES scenario compared to the 40% RES scenario (capacity credits decrease with higher iRES capacity, requiring more firm capacity with low capacity factors).
- Significant uncertainties remain about the potential and costs of DR
- The model does not include specialized VOLL-values, or a detailed representation of super-peak generators (e.g. backup generators). These could improve the profitability of power plants by causing price spikes, which lead to big profits in a small amount of time.