Universiteit Utrecht

Copernicus Institute of
Sustainable Development

Least-cost options for integrating intermittent renewables

Anne Sjoerd Brouwer 22-01-2016

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

Structure

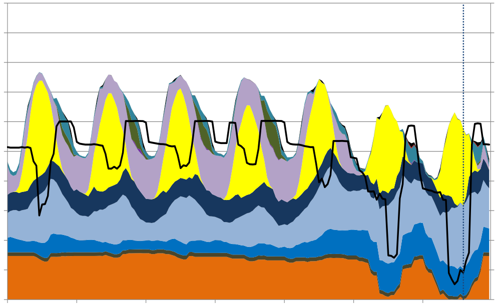
- 1. Background on intermittent RES (iRES)
- 2. Methods
- 3. Results
- 4. Conclusions

Universiteit Utrecht

Background on intermittent RES

- Intermittent RES important component of low-carbon power systems

- Specific properties
  1. Intermittent
  2. Partly unpredictable
  3. Location specific



- Affect the whole power system
  - Operation
  - Economics

Methods

- Some technologies match better with intermittent renewables

- Goal of our research: identify which technologies may be part of a power system with:
  - High reliability (LOLP <0.1 day/year)
  - Low emissions (>96% reduction CO_2 emissions)
  - Low costs

- Power system with high shares of RES and iRES
- Consider a future power system…

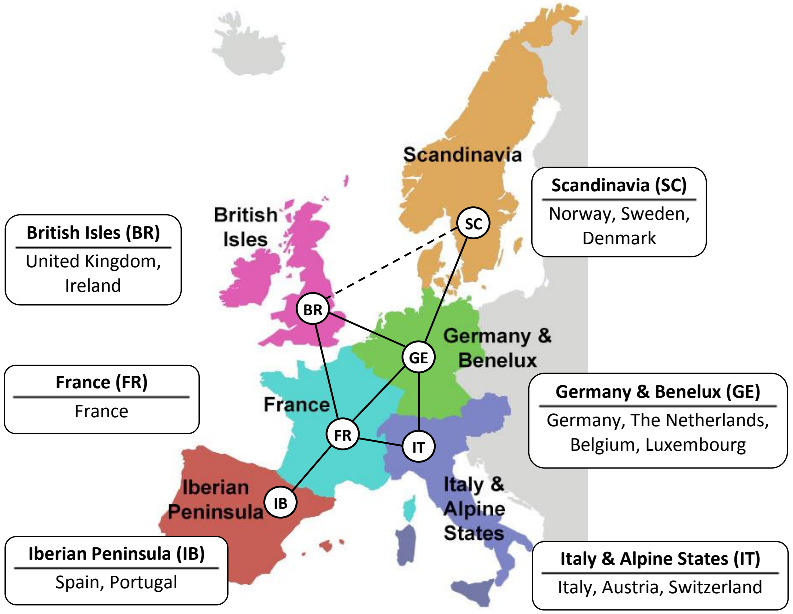
Universiteit Utrecht

Methods

- … in Europe in the year 2050
- Six-node power system simulated with PLEXOS
- Three scenarios evaluated

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

- <u>Quantify system costs</u>



Universiteit Utrecht

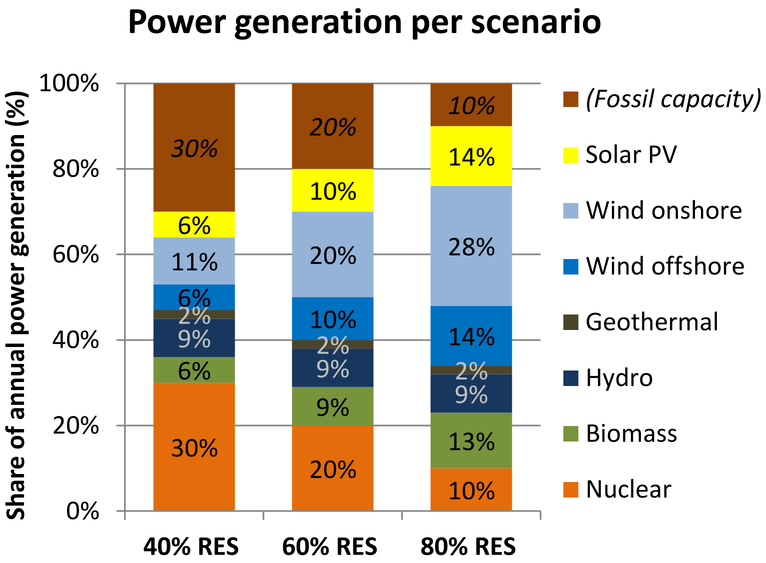
Study methods

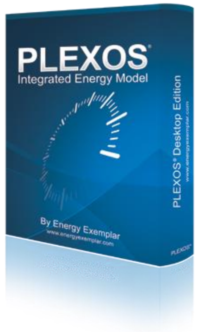
1. Define **non-fossil** capacity per scenario

2. Define capacities of **complementary** options

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

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





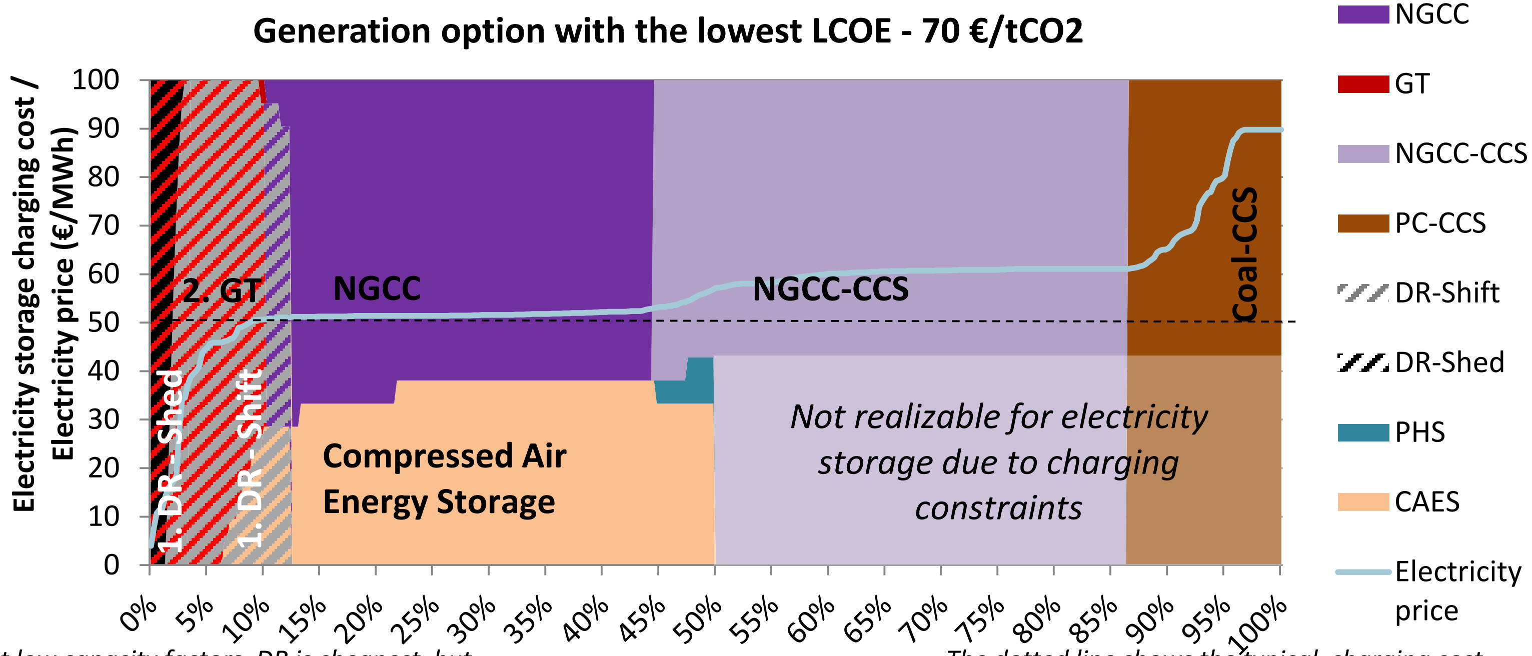
Results – power generation

- 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?

Results – power generation

- Cheapest technology to generate low-carbon power?
  - Demand Response has limited potential
  - Storage can be attractive at low charging costs
  - Electricity storage charging costs are too high

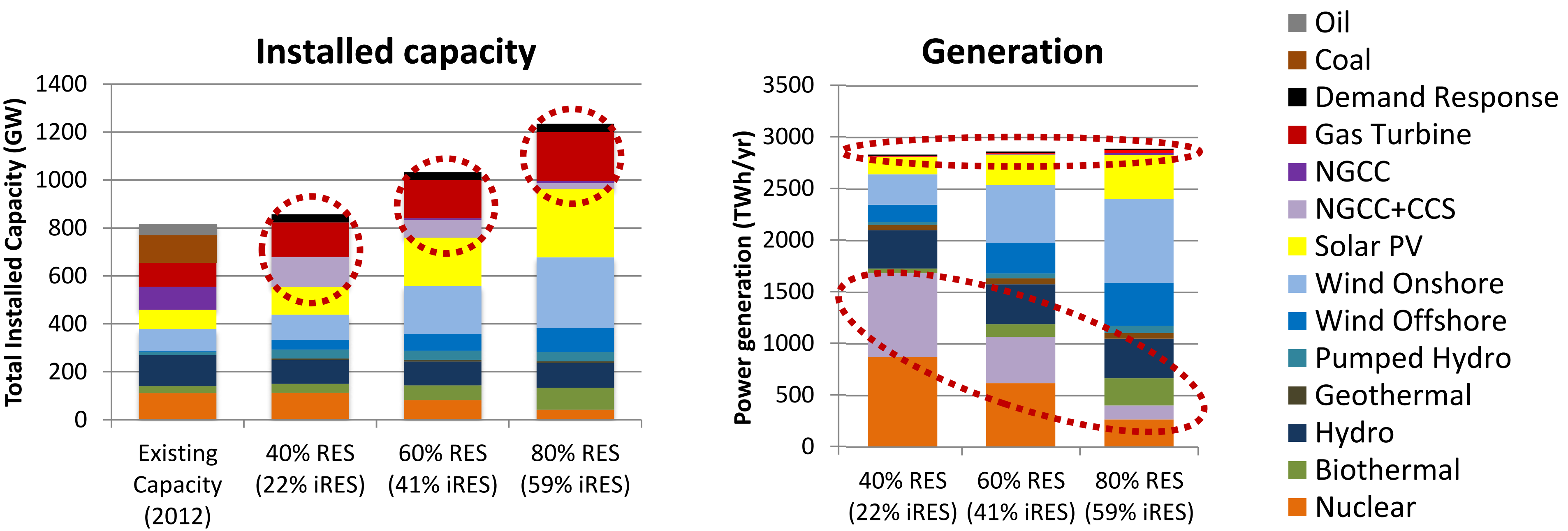


At low capacity factors, DR is cheapest, but its potential is limited. GT is the next cheapest

The dotted line shows the typical charging cost (p10 of 60% RES electricity price)

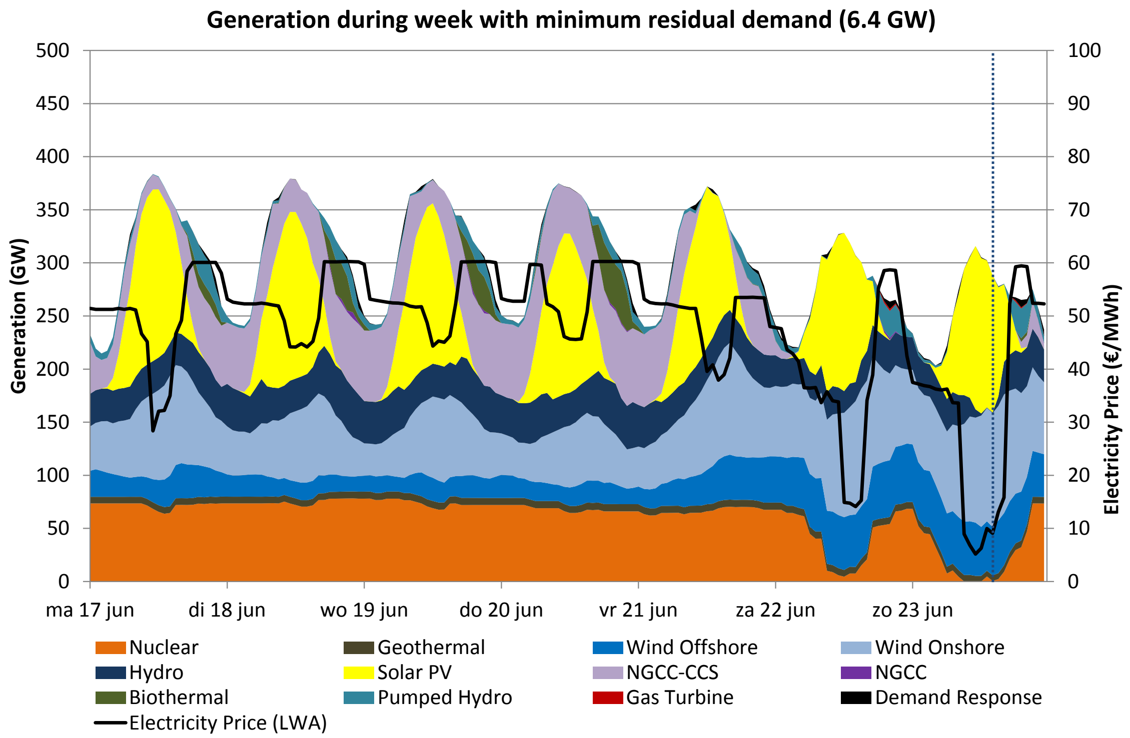
Results – power generation

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



Results – power generation

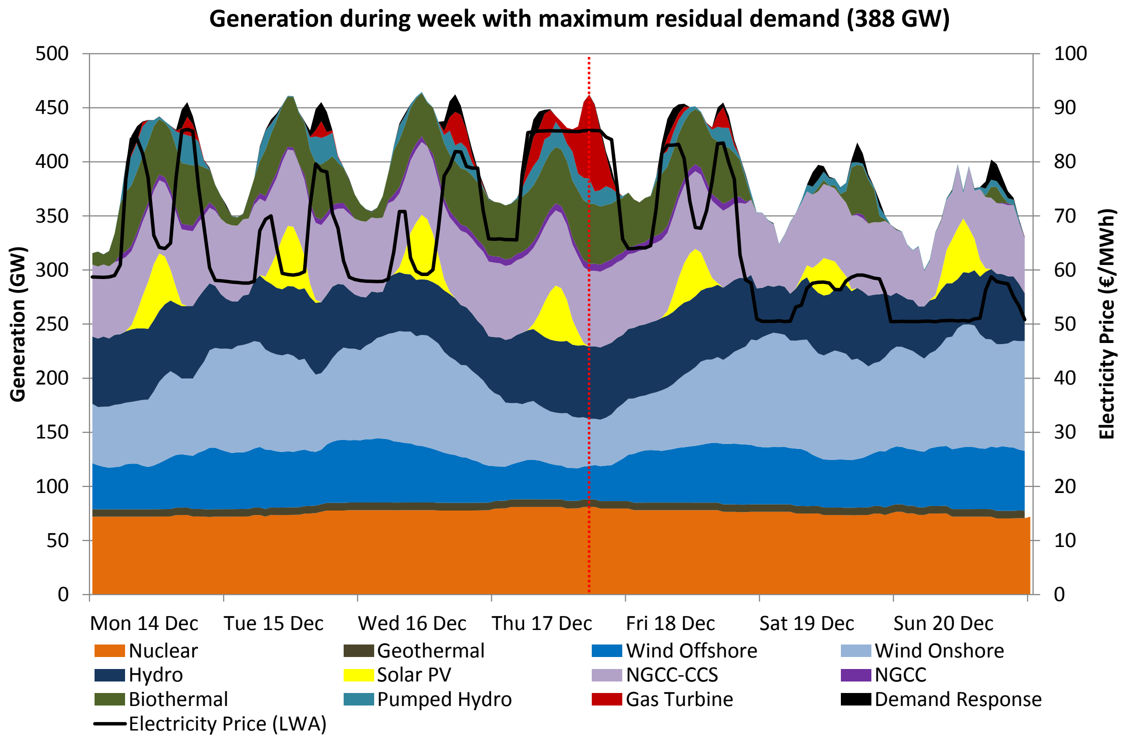
- NGCC-CCS generates power during the night in the summer



Universiteit Utrecht

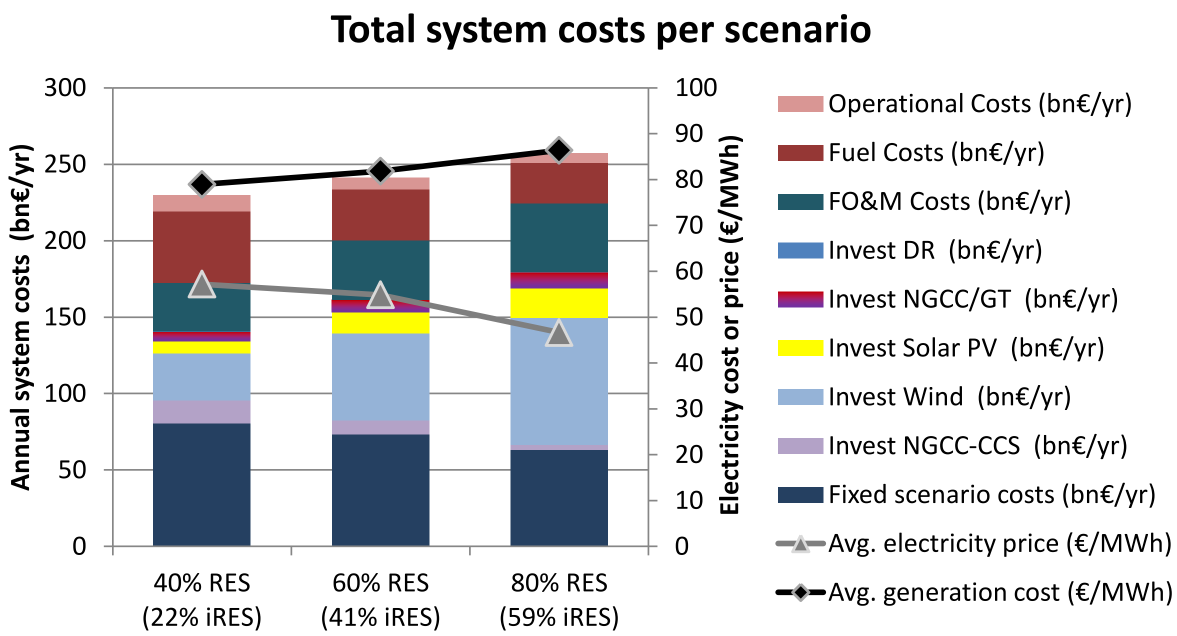
Results – power generation

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



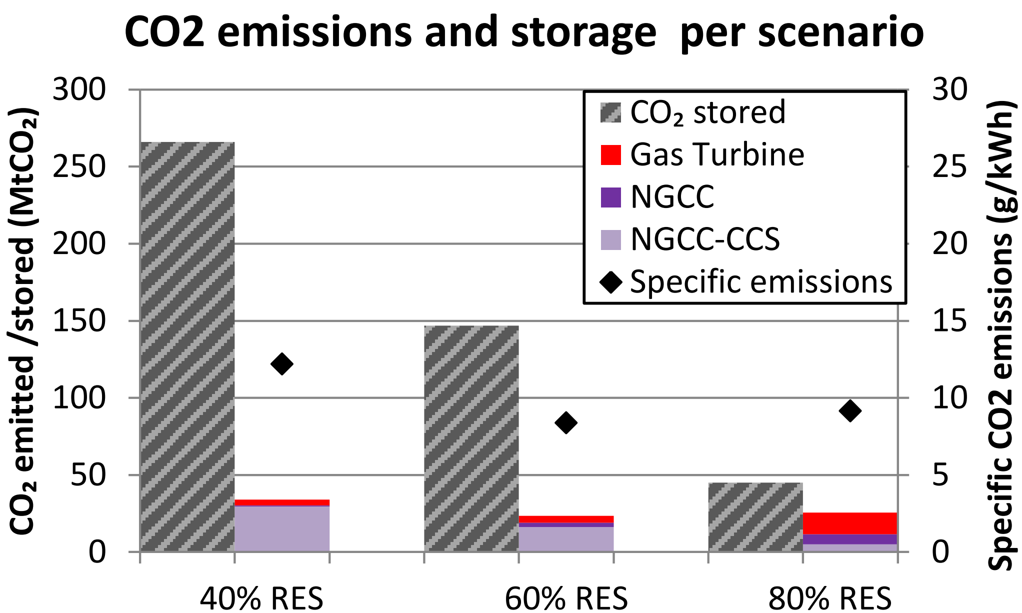
Results – power generation

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



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

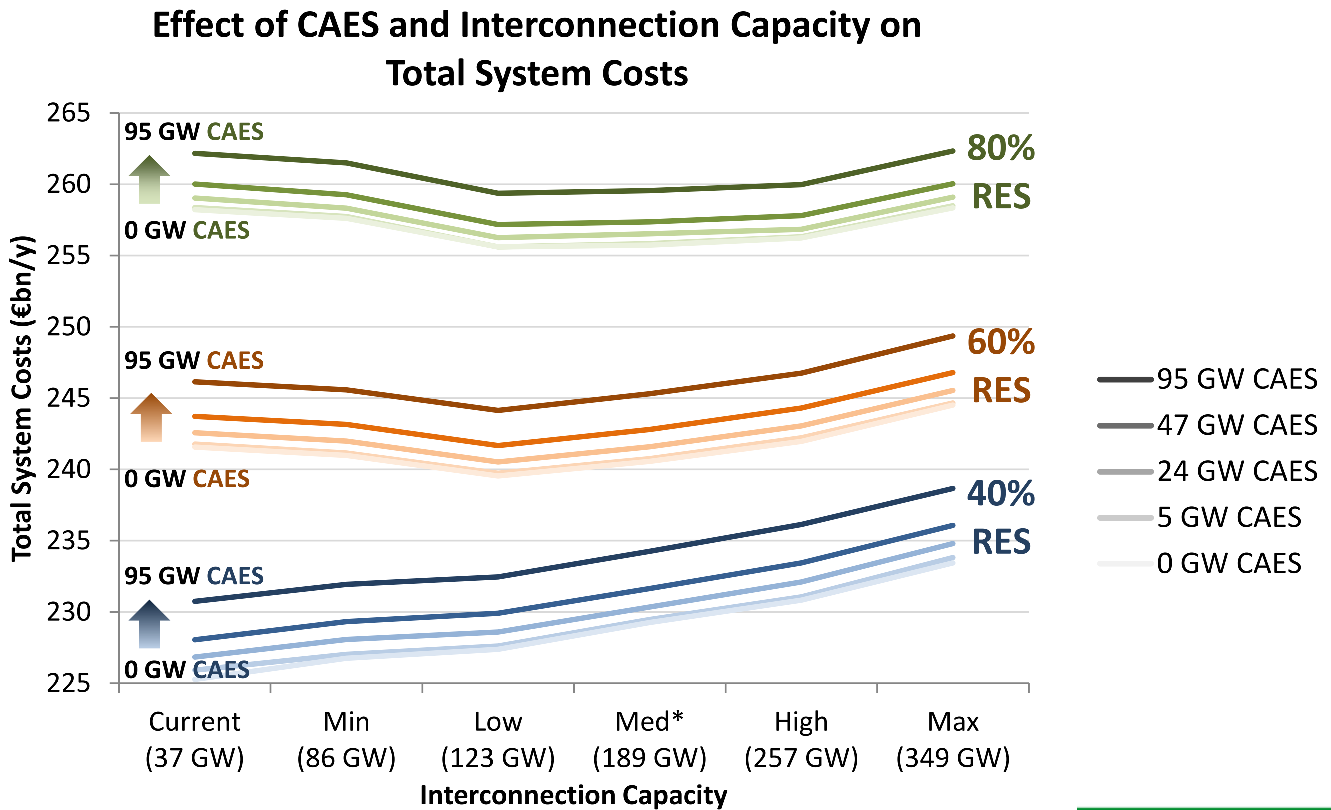


Results – system operation

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

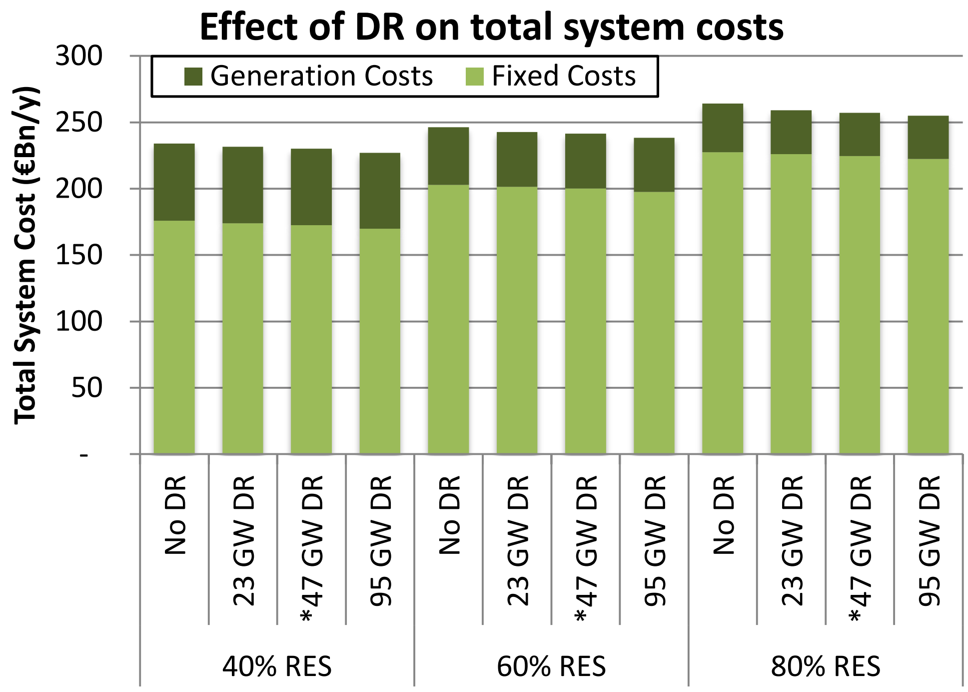
Results – system operation

- Interconnects reduce costs up to a 'sweet spot'
- Storage is expensive



Results – system operation

- Demand response also reduces costs by 2-3%
  - Effect stronger at high RES penetration



Conclusions

- iRES 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
  - iRES increase total system costs
  - Natural-gas fired generation important in all scenarios
  - DR & interconnections least-cost options
  - Electricity storage too expensive

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

Thank you for your attention

Any questions?

Anne Sjoerd Brouwer
a.s.brouwer@uu.nl

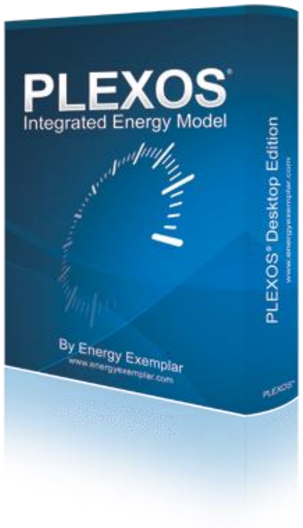
Will Zappa
w.g.zappa@uu.nl

Machteld van den Broek
m.a.vandenbroek@uu.nl

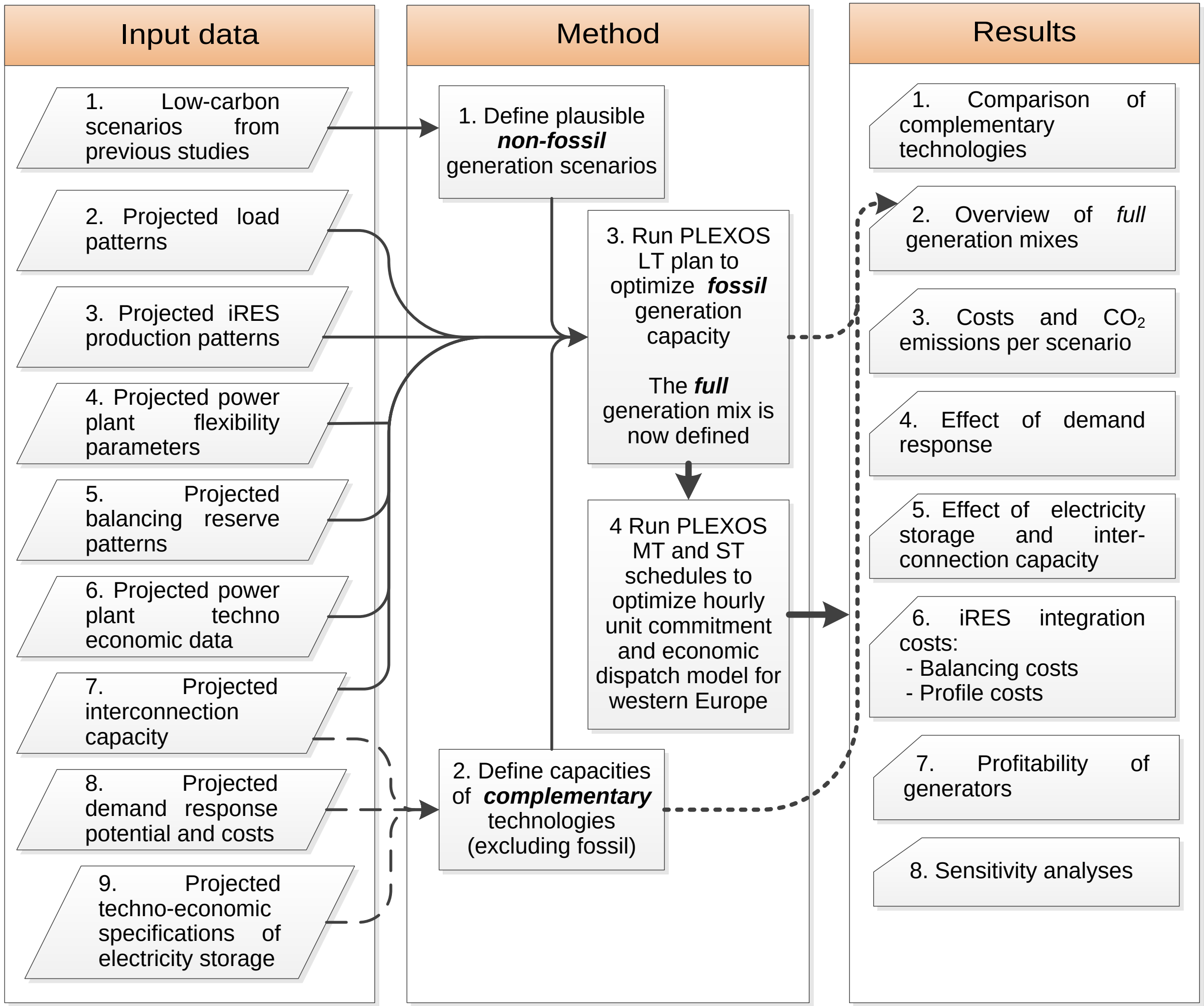
Anne Sjoerd Brouwer, Machteld van den Broek, William Zappa, Wim C. Turkenburg, André Faaij. *Least-cost options for integrating intermittent renewables in low-carbon power systems*. Applied Energy 161, pp 48-74.(2016)

Universiteit Utrecht

6. Supplementary slides



Overview of method



Universiteit Utrecht

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

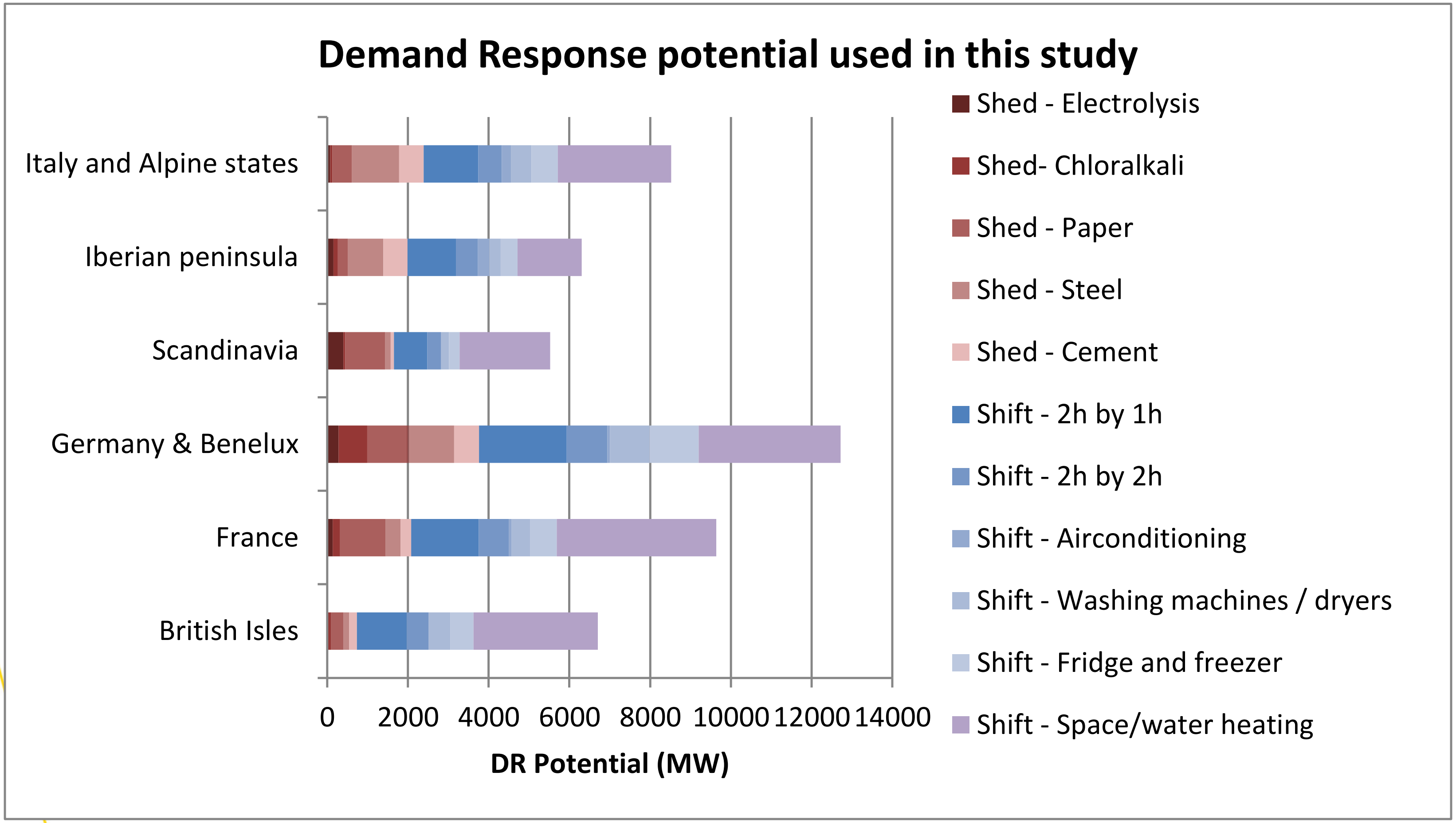
TWh/yr	Britain	Scandi-navia	France	Ger-many+	Iberian pen.	Italy+
Load	415	368	602	811	358	525

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”

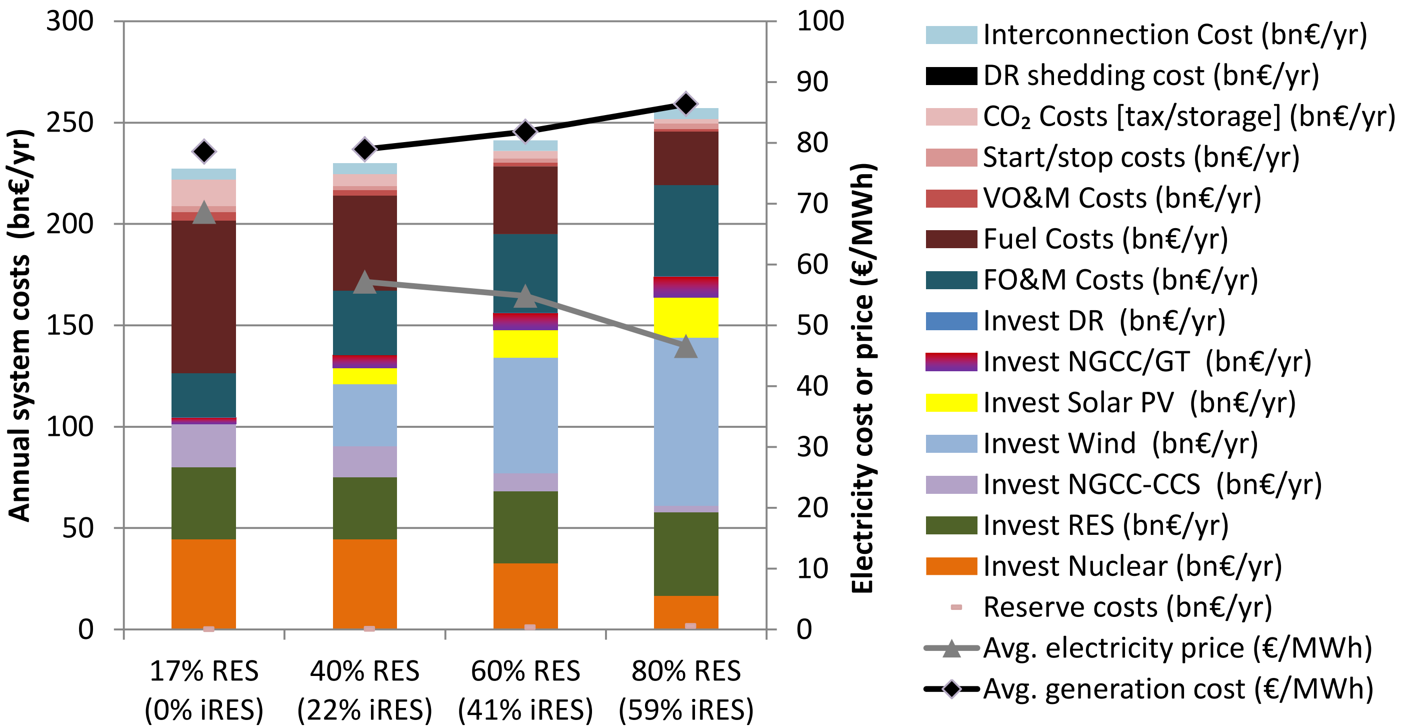
Universiteit Utrecht

Demand response potential



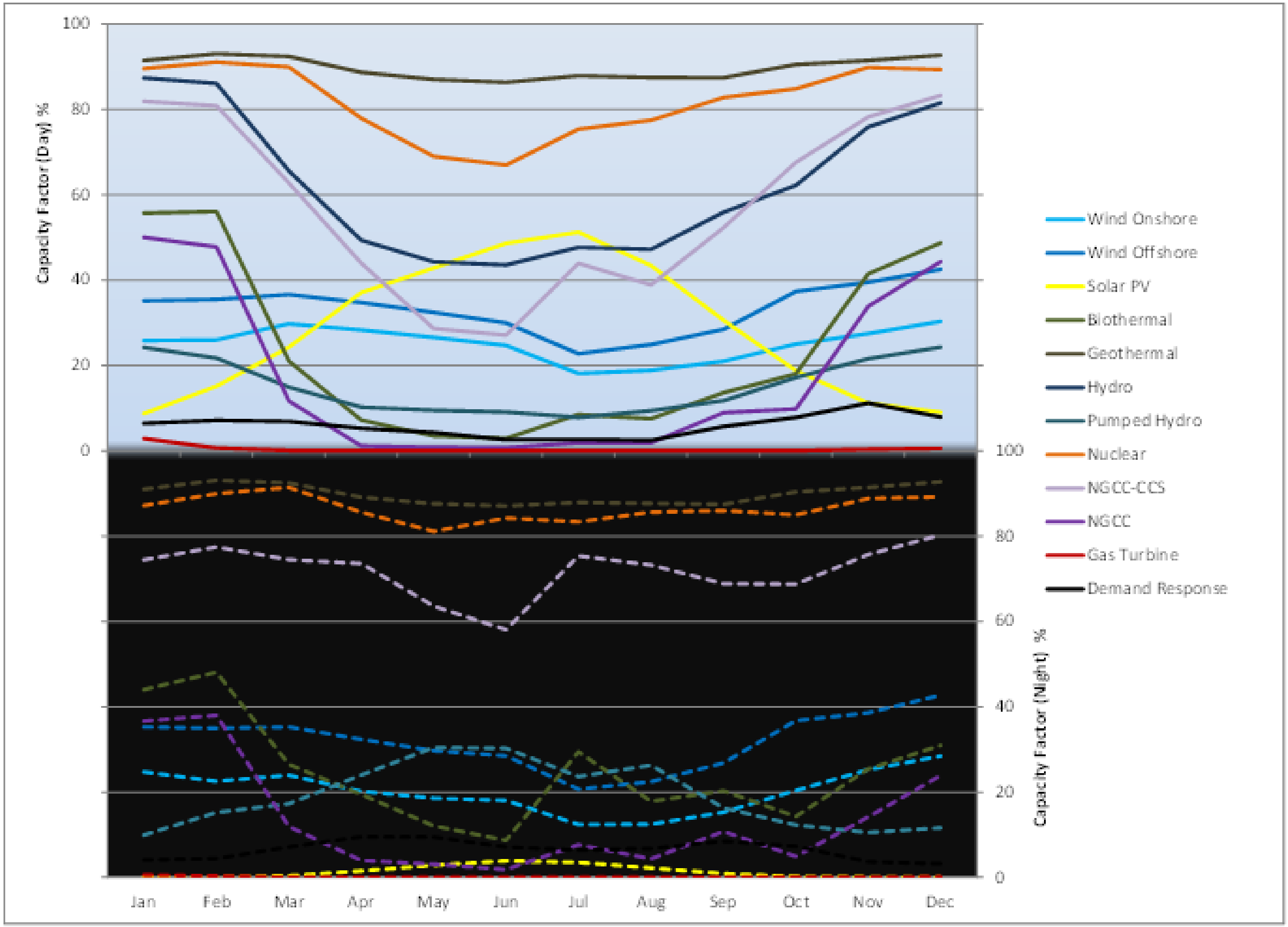
Universiteit Utrecht

Detailed total system costs



Universiteit Utrecht

Capacity factors per month



Universiteit Utrecht

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

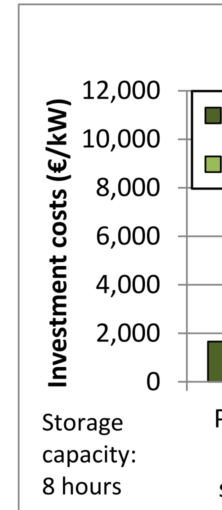
2. Define capacities of **complementary** options

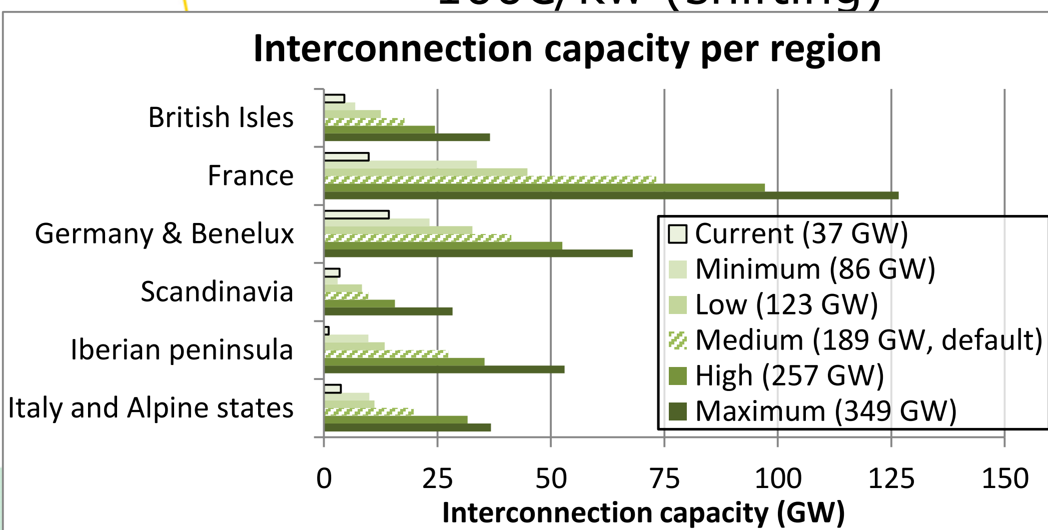
3. Optimize **fossil** capacity per scenario [PLEXOS]

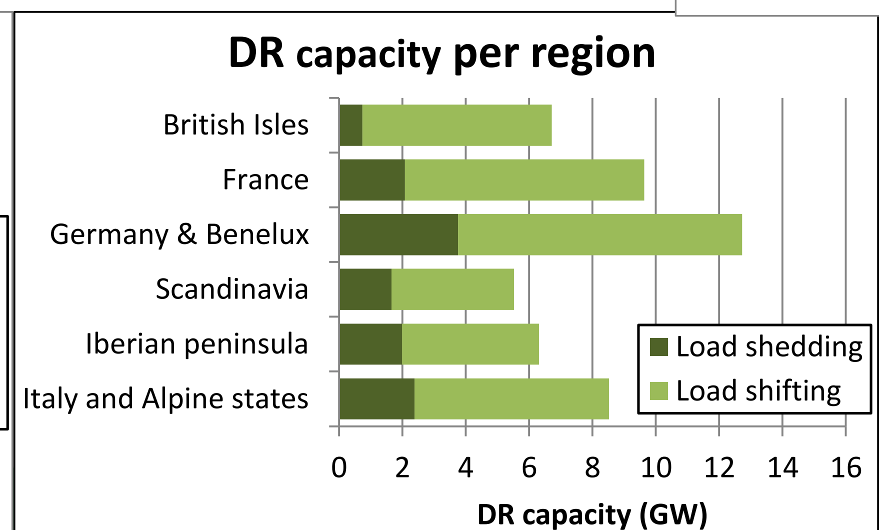
4. Run **hourly simulations** [PLEXOS]

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)



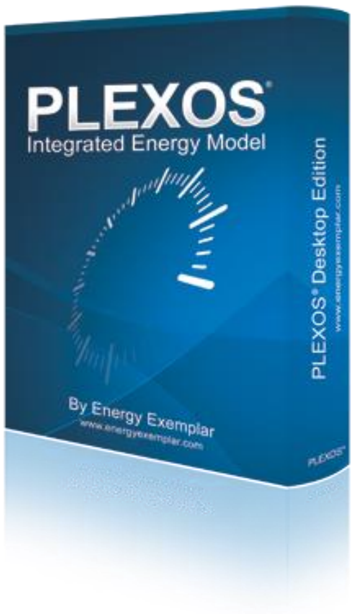




1. Define **non-fossil** capacity per scenario
2. Define capacities of **complementary** options
3. Optimize **fossil** capacity per scenario [PLEXOS]
4. Run **hourly simulations** [PLEXOS]

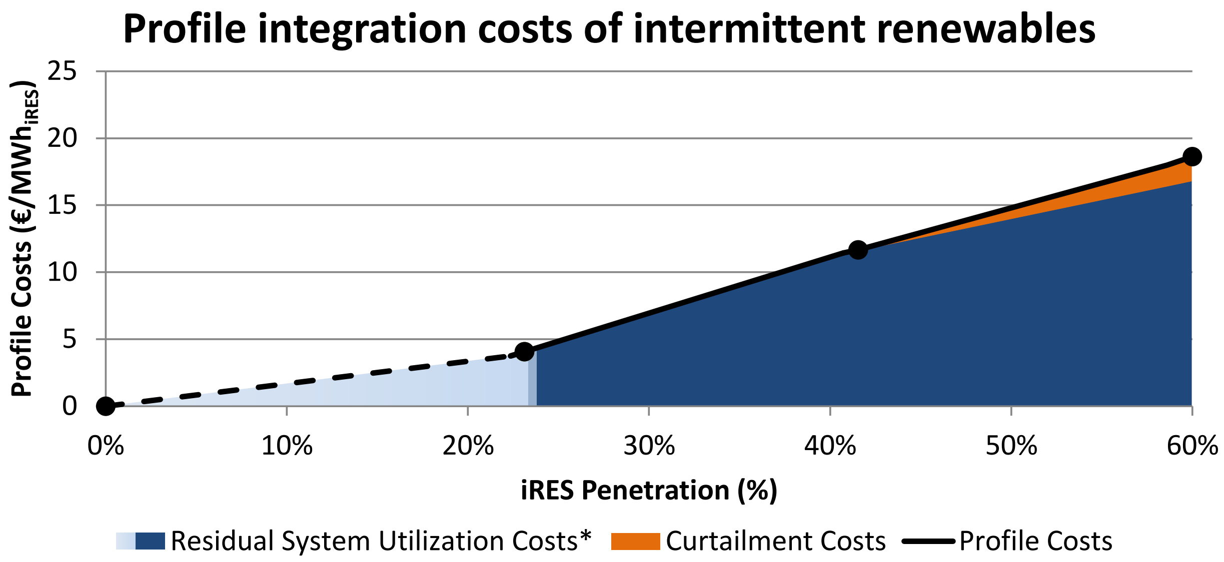
2. Methods

- 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

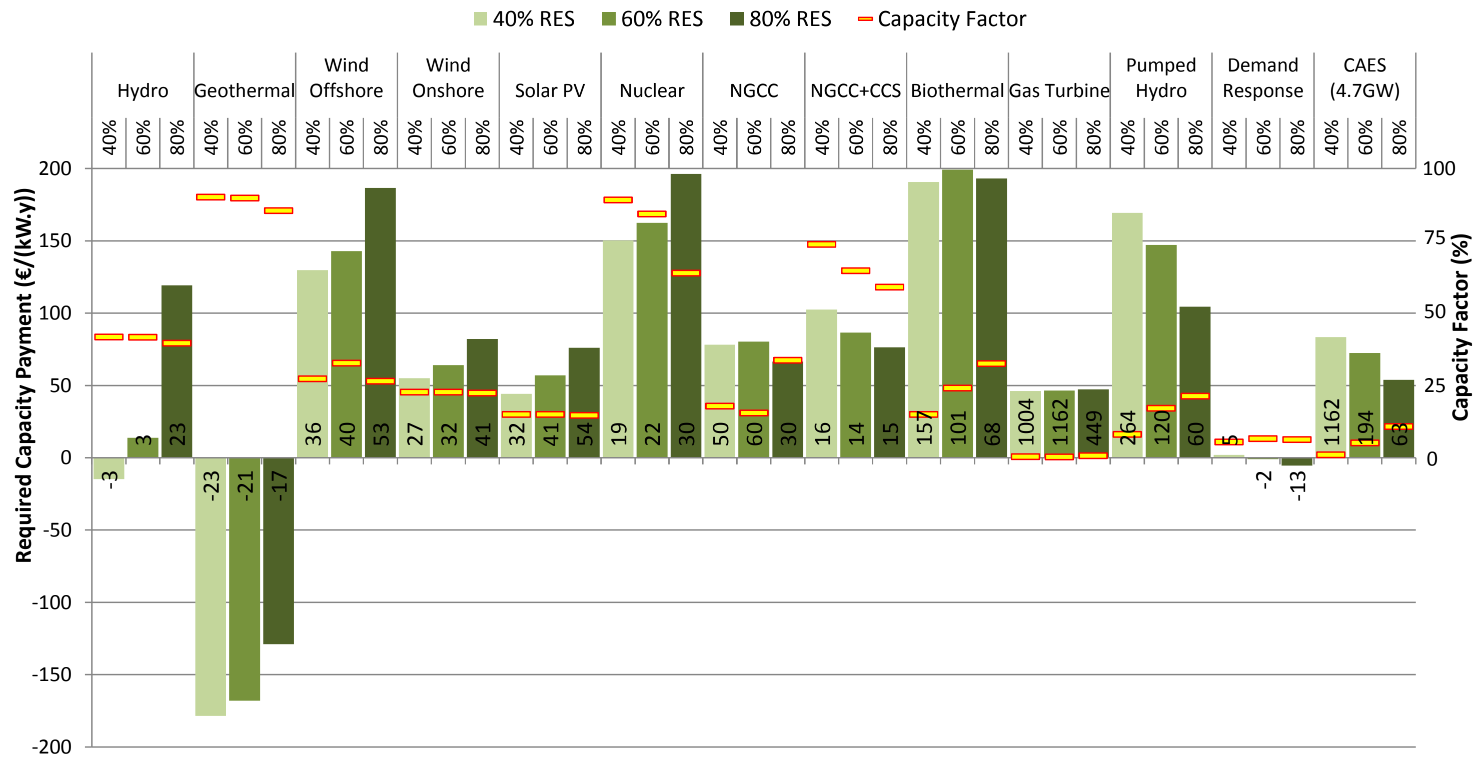


3. Results – power generation

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



(3. Results – economics)



(4. Sensitivities)

- Variations in input parameters are explored, as the input parameters determine the outcome of the study.
- Four tornado graphs depict the effect of variation in input parameters on:
  - Total system costs
  - Fuel use
  - Generation capacities
  - Electricity generation per generator type

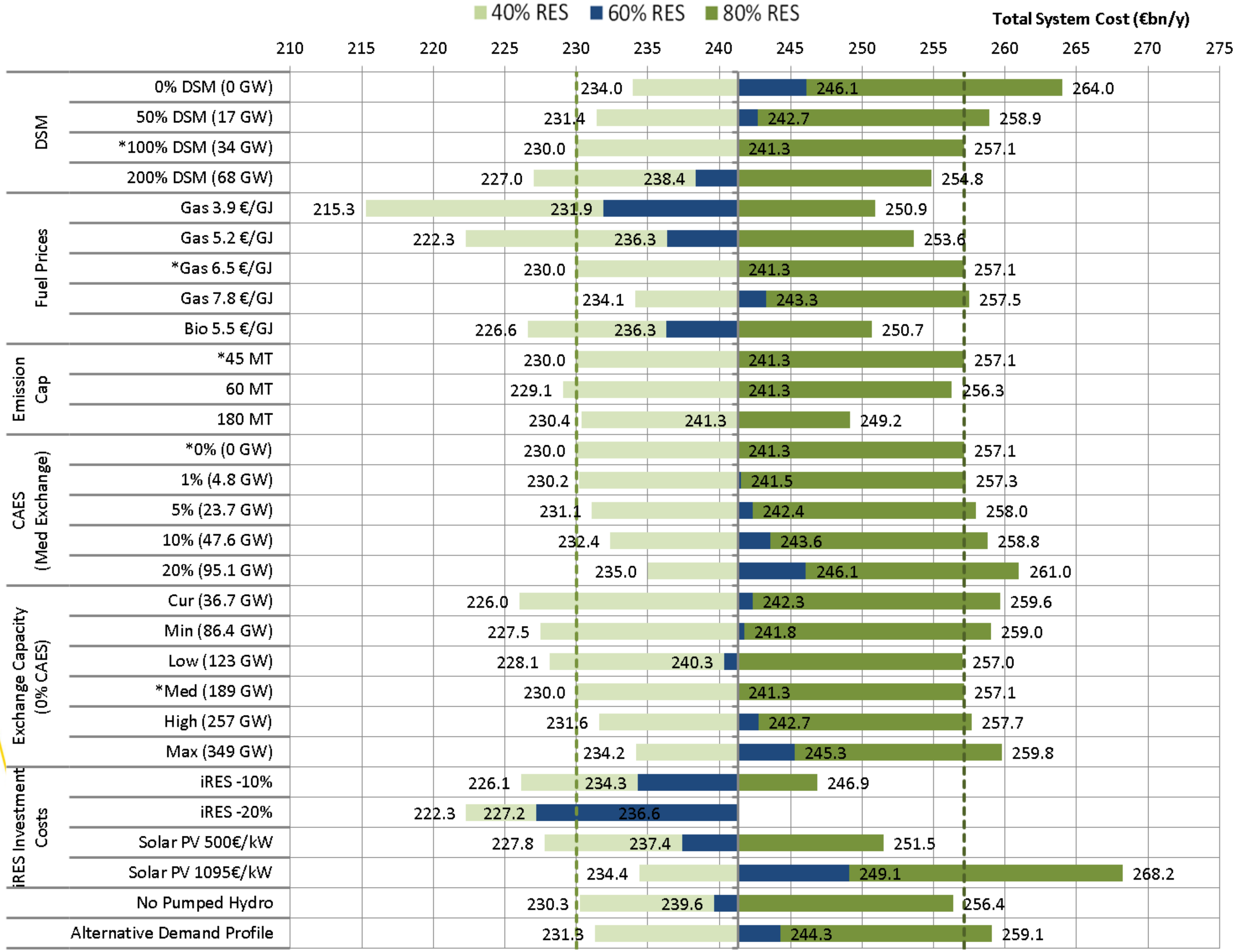
(4. Sensitivities – key findings)

- 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*



Universiteit Utrecht

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

Universiteit Utrecht

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.