UNIVERSITA' DEGLI STUDI DI ROMA

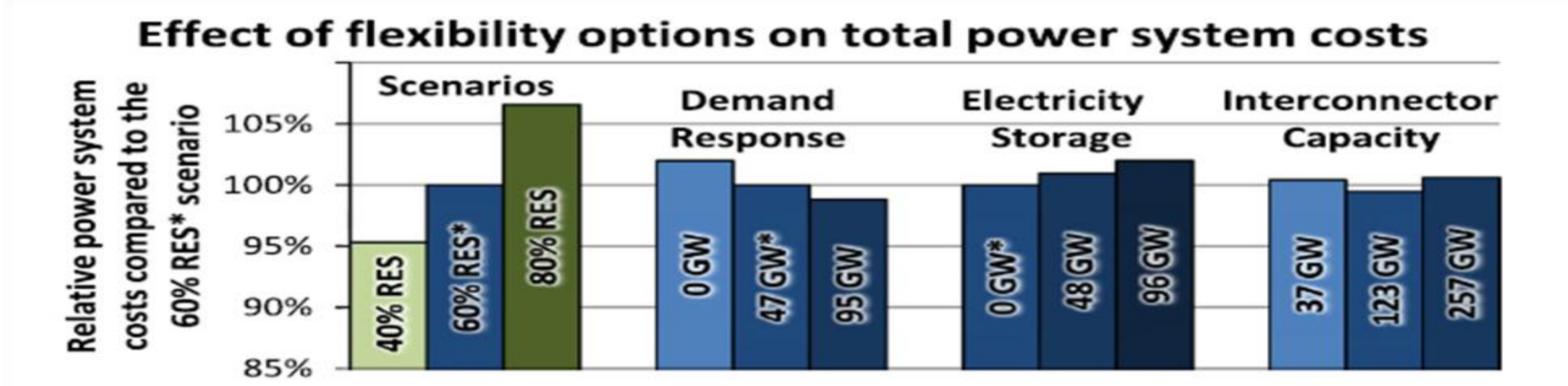
Tor Vergata

Degree Candidate: *Sohail Khan*

Supervisor: *Prof. Vincenzo Mulone*

Least-Cost options for integrating intermittent renewables in low carbon power systems

Introduction



• West- European power system simulation with defined scenarios of 40%, 60%, 80% intermittent -RES scenario that contribute to 22%, 41% and 59% of annual energy generation .

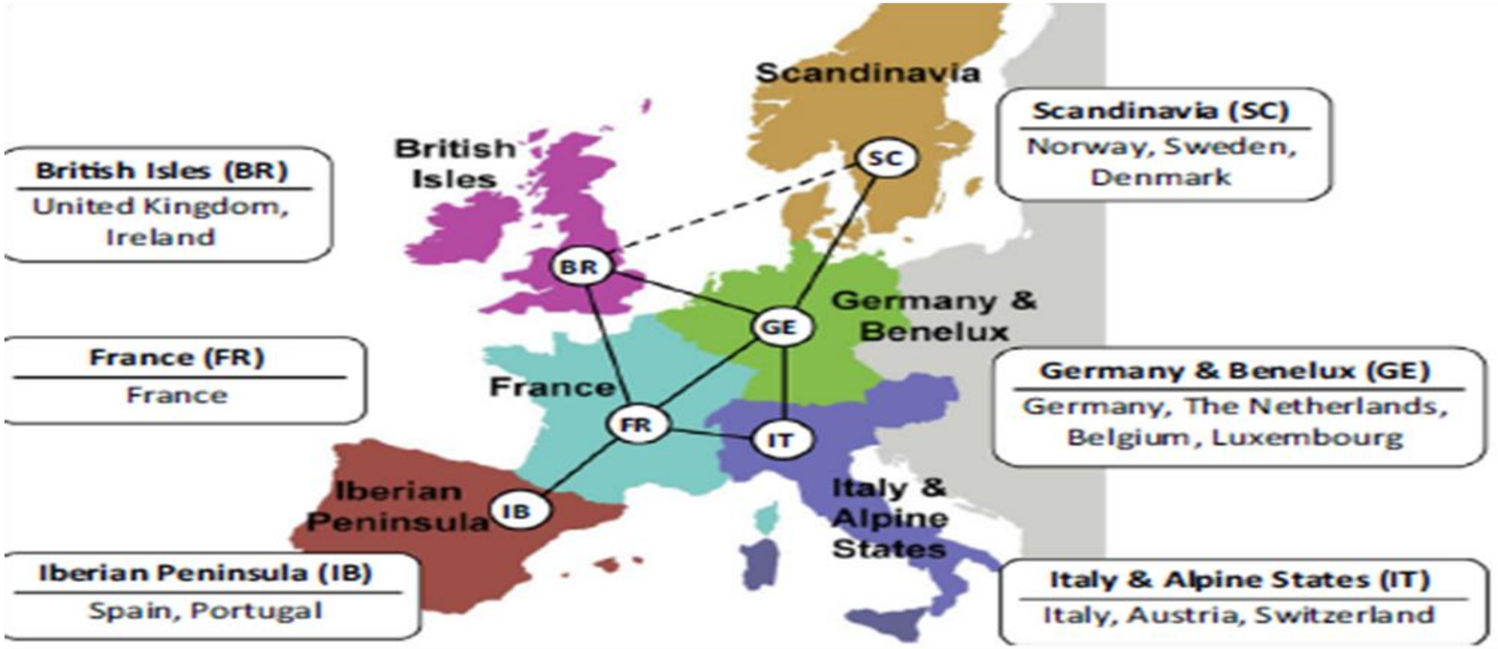
• CO_2 emission reductions up to 96% to meet long term climate change targets.

• Five options can complement intermittent RES with lower total system cost,
I-e Demand response DR, Carbon capture and storage CCS, Increasing interconnection capacity, Curtailment, Electricity storage

• *Which complementary option should be deployed in low-carbon systems with high share of intermittent RES to minimize total system costs?. **

*Brower AS ,van de Broek , Seeregts A.Faaij. Operational flexibility and economics of power plants in future low carbon system. Apply Energy**

Introduction



- Each region is distinguished by their prevalent type of intermittent –RES potential.

Methodology

❖ *Step 1: Plausible non fossil generation scenarios*

- *40%; 60%; 80% RES- penetration that contribute to a 22%; 41%; 59% of annual energy generation*

❖ *Step 2: Capacities of complementary options*

three option are

- *Five type of electricity storage*
- *Demand response DR, which can either shed or shift load.*
- *Six level of interconnection to balance load.*

❖ *Step 3: Optimize fossil generation capacity with PLEXOS tool*

- Fossil generation capacity for the year 2050 is optimized with PLEXOS tool.
- It run three modules LT, MT,ST.

❖ *Step 4 : Run hourly simulation with PLEXOS tool*

- Base case for intermittent-RES integration cost calculations.

Methodology

❖ ***Integration costs of intermittent-RES***

These are considerable components of total generation cost:

- ***Balancing costs equation (1)***

$C_{\text{Balancing, specific}} = \Sigma\,(\text{Shadow price}_{t,r,rt}^{\text{reserve type}} * \text{Requirement}_{t,r,rt}^{\text{reserve}})/E_{iRES}$

- ***Utilization costs equation (2)***

$C_{\text{utilization, specific}} = ((\Sigma_{rg}\, C_{rg} / \Sigma_{rg}\, E^{rg\ 0\%iRES}/) - (\Sigma_{rg}\, c_{rg}^{0\%iRES} / \Sigma_{rg} E_{rg}^{0\%iRES})) * E_{resid} / E_{iRES}$

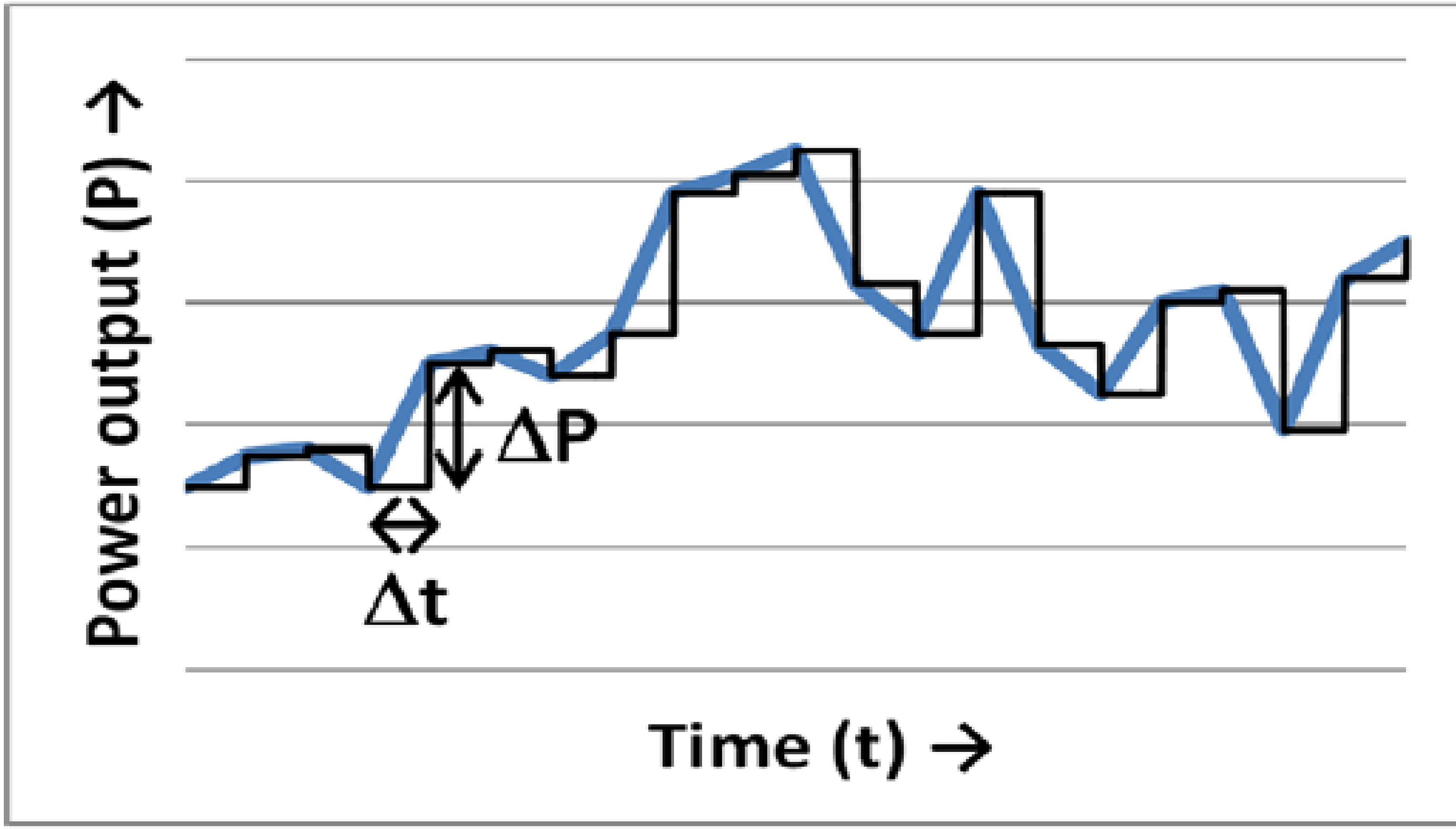
- ***Over prodution cost equation (3)***

$C_{\text{overproduction ,specific}} = \Sigma_{IRES}\, c_{iRES}^{\text{specific}}\, {}_{*}(1 - E^{\text{delivered}}_{iRES} - E_{IRES}^{\text{curtailed}} / E^{\text{deliverd}}_{iRES})$

- ***Profile costs equation (4)***

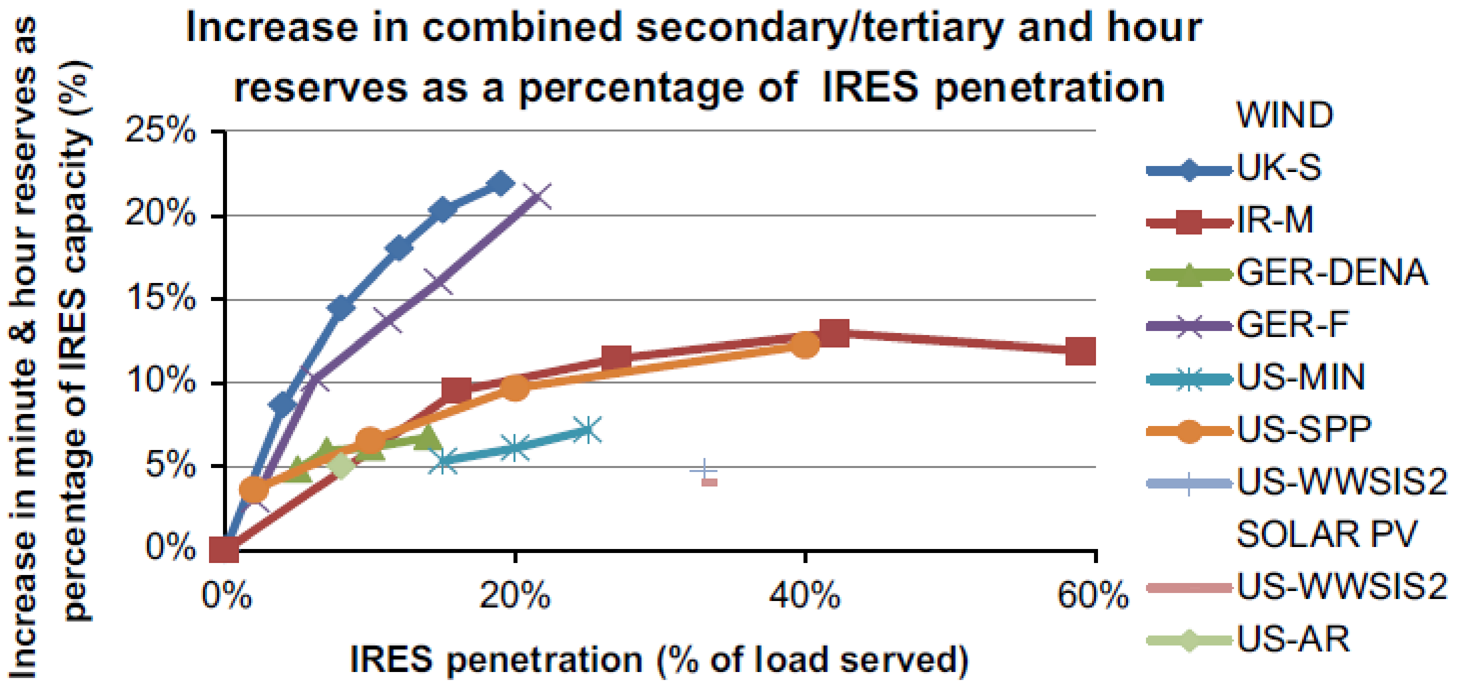
$C_{\text{profile, specific}} = C_{\text{utilization, specific}} + C_{\text{overproduction, specific}}$

Modeled power system



Variablity of power production on single intermittent IRES generator power blues line. Delta are black line.

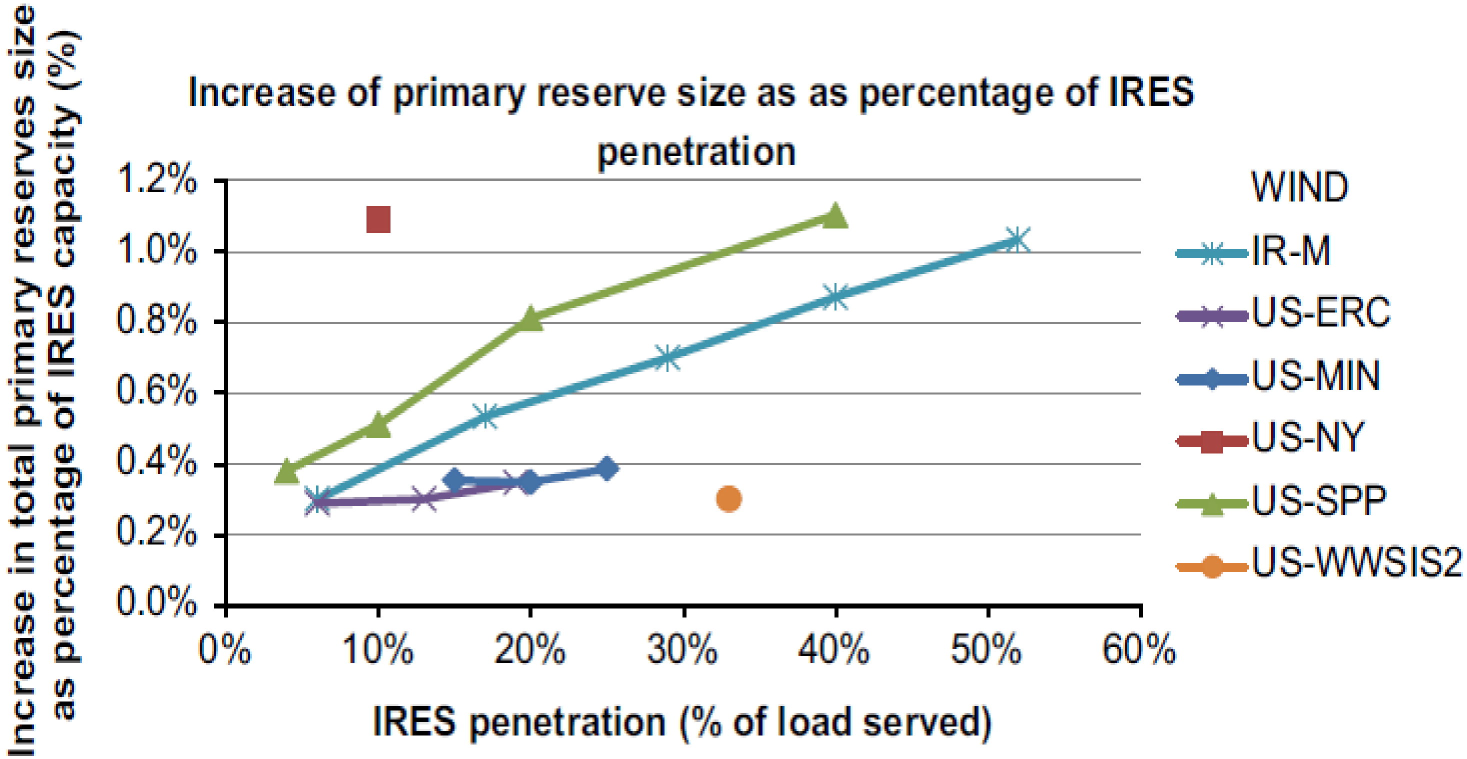
Impact modeling- increased reserve size**



US-MIN ,IR-M : Stat-B-Val approach hourly reseve size 6% and 9%
UK-S, US-SPP,GER-F : Stat-B-Var approach

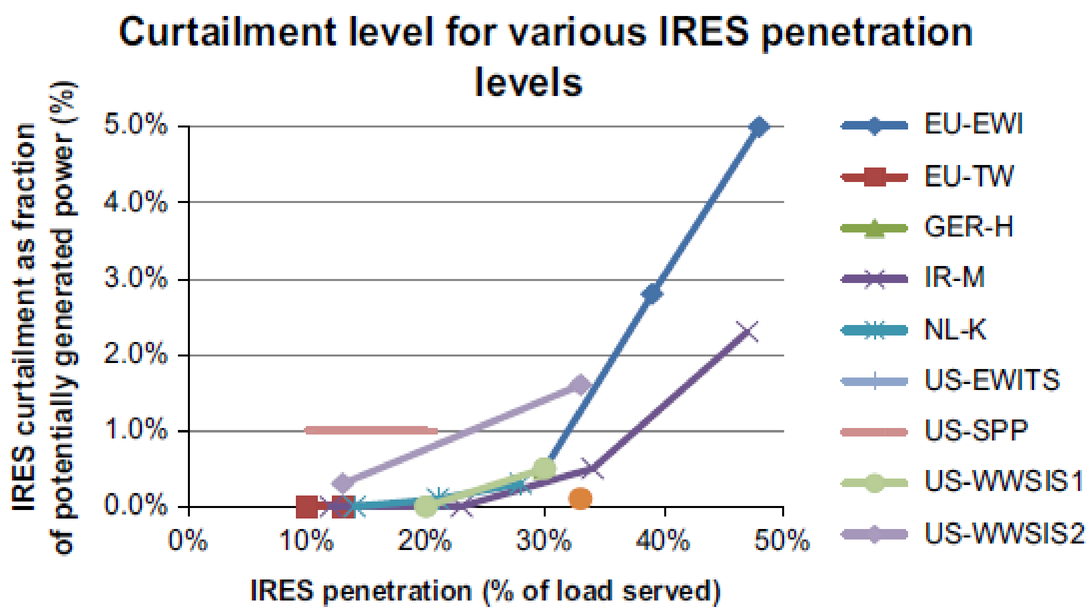
**Brower AS , van de borek M , Faaij A . Impact of large-scale Intermittent Renewable Sources on electricity , and how these can be modeled .

Modeled power system**



US-MIN,US-NY :Stat-B-VAR Approach wind varability 2MW per 100 MW
US-SPP: Stat-B-WLP approach wind and forecast errors

Observed IRES curtailment**



Insufficient transmission capacity and surplus IRES production.

US-SPP,US-WWSISI,US-EWITS: *Transmission constraints*

IR-M,GER-H: No interconnection

EU-EWI,IRM: Oversupply of wind

Input Data

❖ ***Fuel price***

- based on the low carbon 2DS scenario of the IEA Energy Technology Prospective 2014

❖ ***Load and intermittent RES patterns***

- are based on historical load pattern per country of 2013; it increases by 0.25 % per year to 2800 TWH

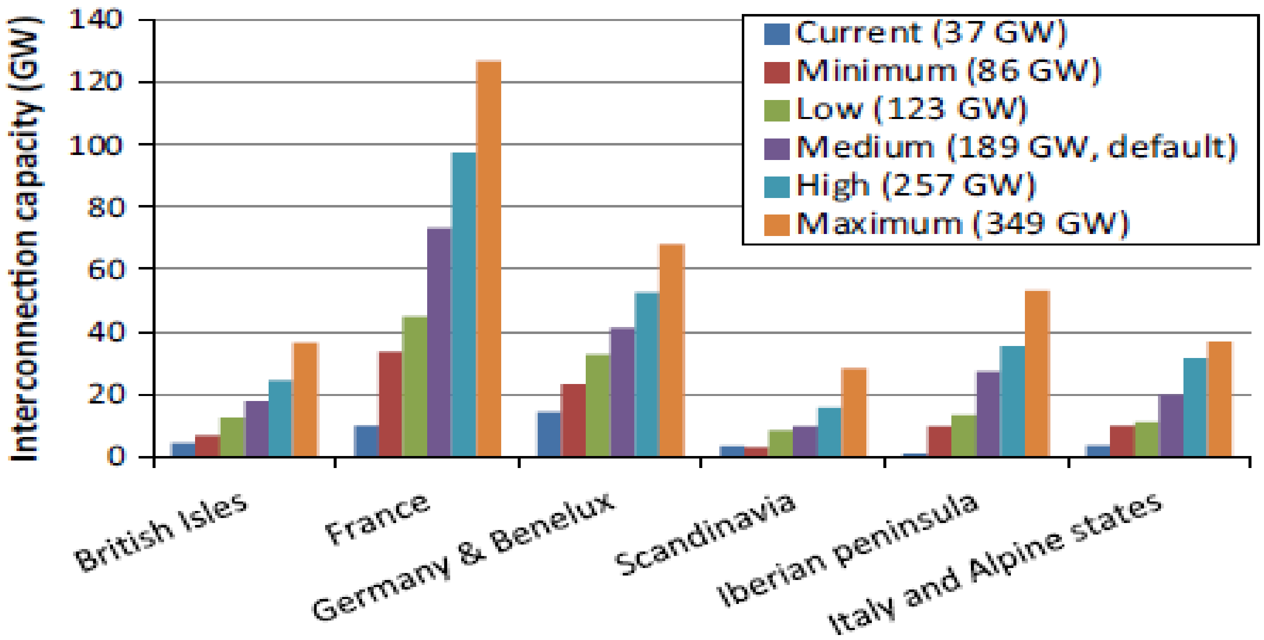
❖ ***Power plant parameters***

Twelve type of power plants along with their techno- economic parameters.

Input Data

❖ ***Interconnection capacity.***

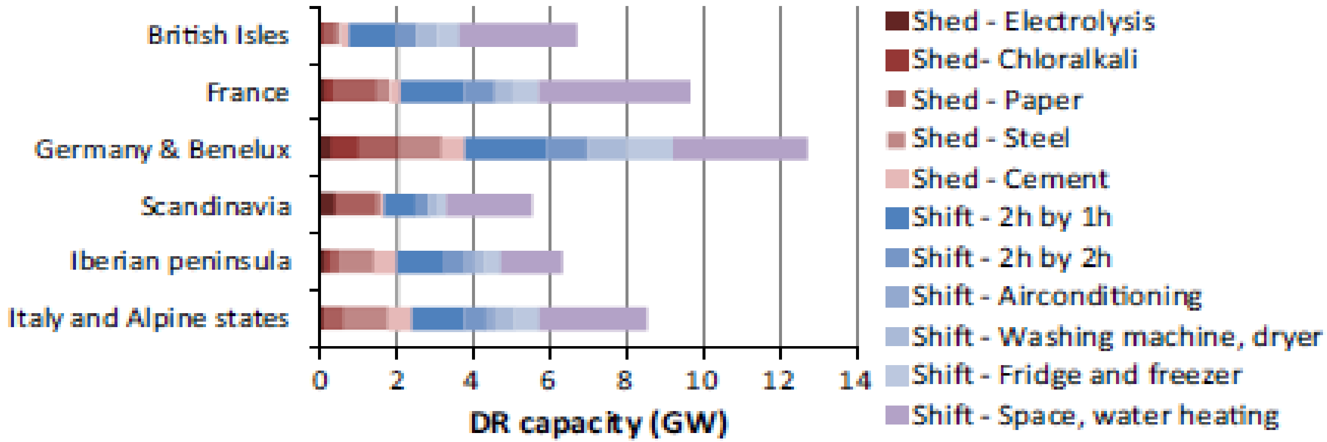
- Six interconnection cases ranging from the installed capacity of 37 GW in 2014 up to 349 GW for 2050 .
- Annual cost of 28,000 €/MW h are used to assess benefits .



Input data

❖ *Demand Response DR*

- Cost of load shedding range between 200 and 5000 €/MW h .
- Investment cost of load shifting range from 2 to 100 €/KW .
- Composition of 47 GW are shown in the Fig .



Results

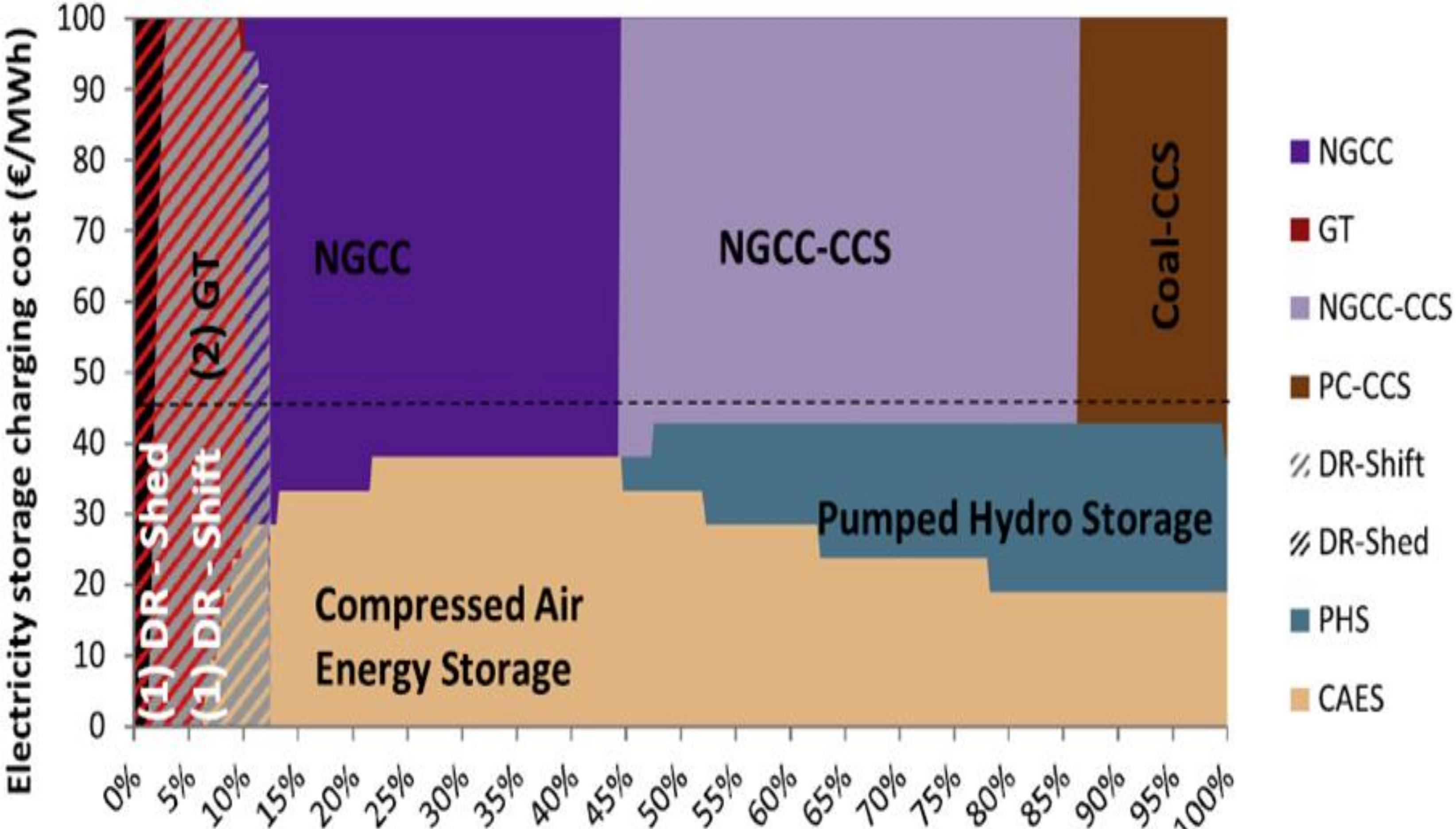
❖ *Overview of full generation mixes*

- As intermittent capacities increases nuclear decreases.
- Inceasing RES capacity lower the residual load.
- Bulk of energy generation is provided by intermittent-RES, nuclear, hydropower and NGCC-CCS.

❖ *Comparison of complementary option*

- Lowest levelized cost of electricity (LOCE)is effected by capacity factor x-axis.
- LOCE of storage technologies is effected by average cost of charging Y-axis.
- Low fixed cost perform better at lower capacity factor.
- DR-shed and DR-shift are effective only at limited technology.
- Coal had lowest LOCE at high capacity factor (>86%).
- CAES is lowest cast storage technolog y at 10% (200-400 €/MW h).
- Fossil fuel fired generator supply interseasonal flexibility. (See Fig below)

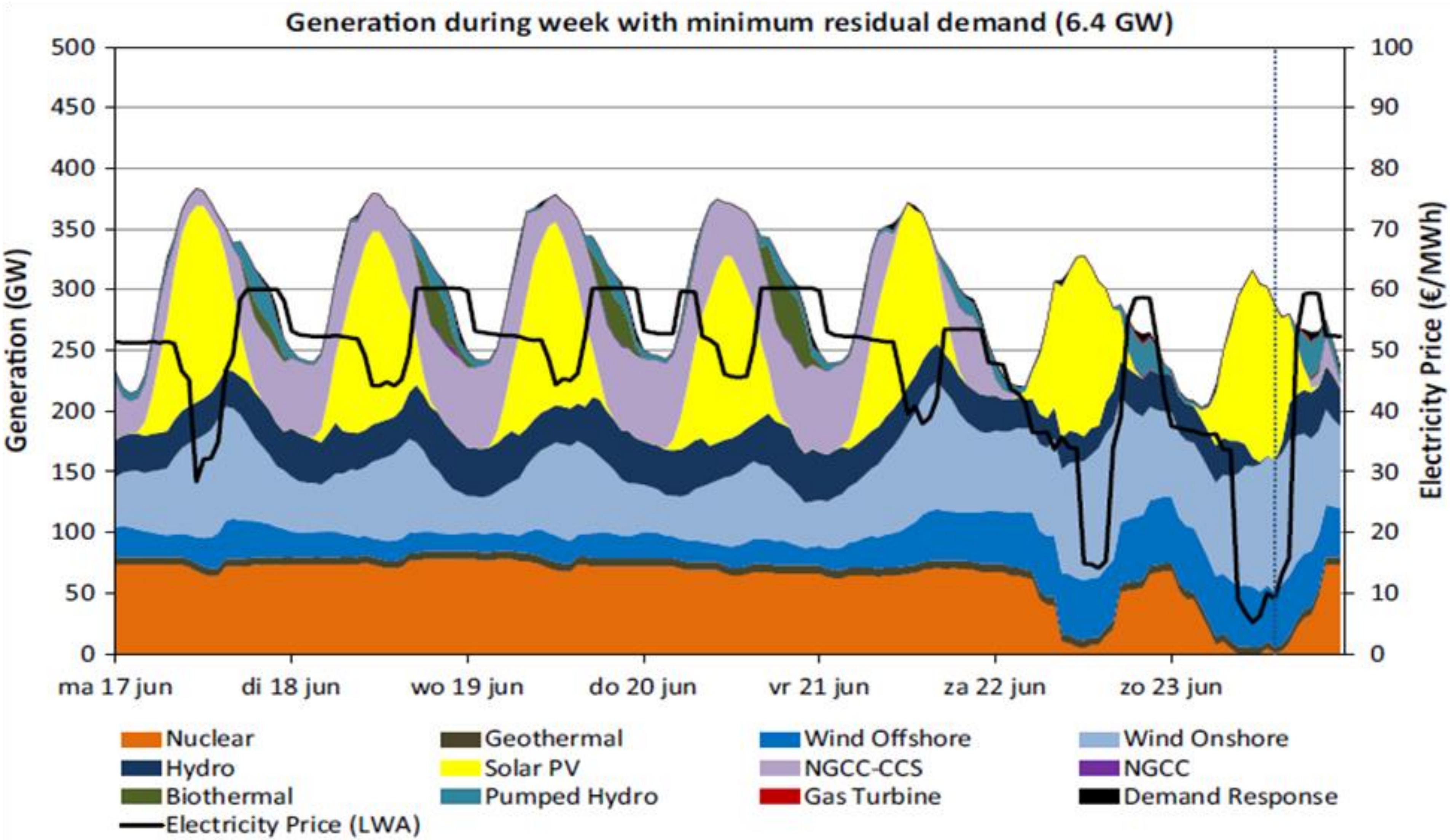
Results**



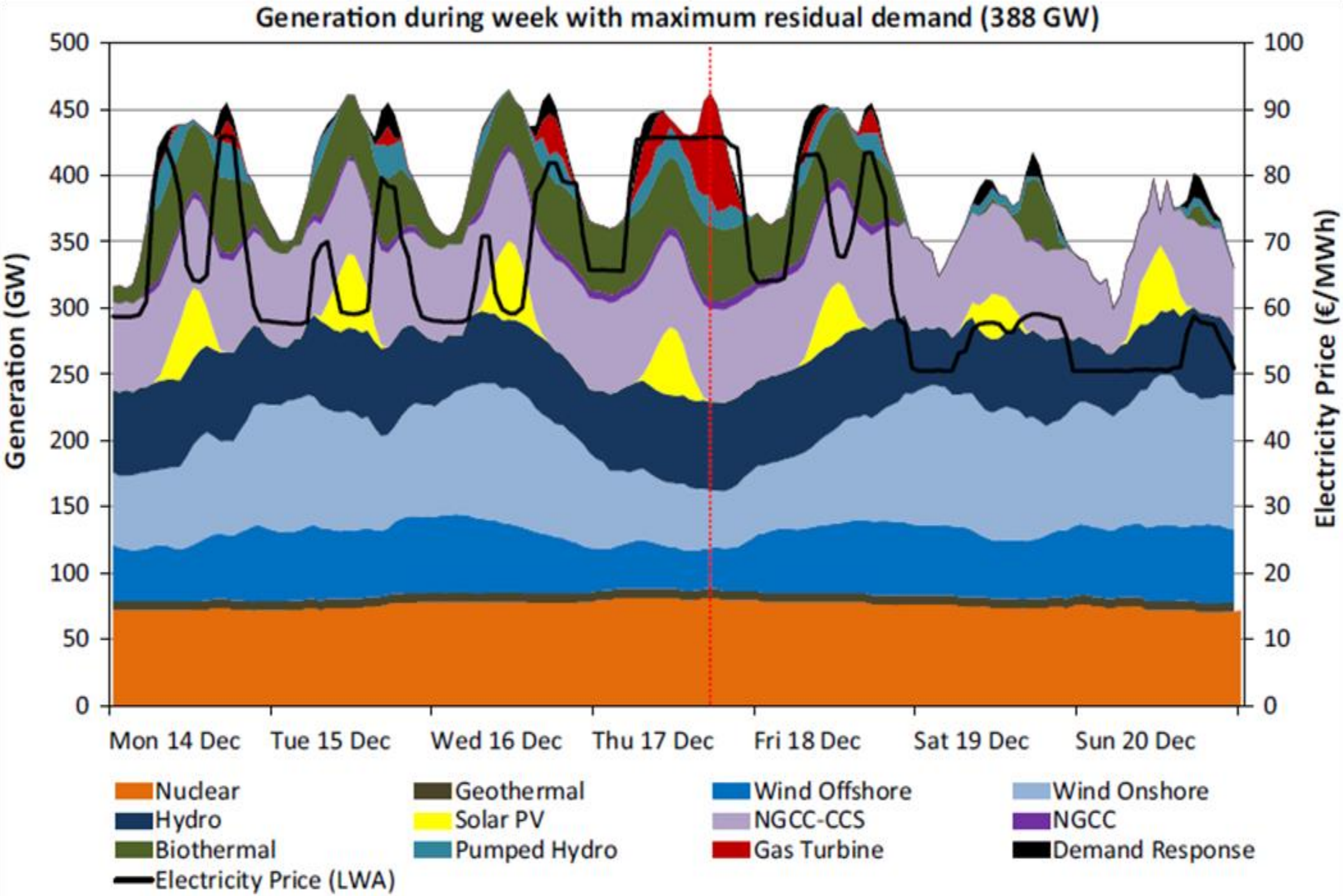
At low capacity factors, DR is cheaspest, but its potential is limited. GT is next cheapest.

The dotted line shows the typical charging cost (p90 of 60% RES electricity price)

Results**


Generation during week with minimum residual demand (6.4 GW)
Generation (GW)
Electricity Price (€/MWh)
500
450
400
350
300
250
200
150
100
50
0
100
90
80
70
60
50
40
30
20
10
0
ma 17 jun
di 18 jun
wo 19 jun
do 20 jun
vr 21 jun
za 22 jun
zo 23 jun
Nuclear
Geothermal
Wind Offshore
Wind Onshore
Hydro
Solar PV
NGCC-CCS
NGCC
Biothermal
Pumped Hydro
Gas Turbine
Demand Response
Electricity Price (LWA)

Results**



Generation during week with maximum residual demand (388 GW)
Generation (GW)
Electricity Price (€/MWh)
500
450
400
350
300
250
200
150
100
50
0
100
90
80
70
60
50
40
30
20
10
0
Mon 14 Dec
Tue 15 Dec
Wed 16 Dec
Thu 17 Dec
Fri 18 Dec
Sat 19 Dec
Sun 20 Dec
Nuclear
Geothermal
Wind Offshore
Wind Onshore
Hydro
Solar PV
NGCC-CCS
NGCC
Biothermal
Pumped Hydro
Gas Turbine
Demand Response
Electricity Price (LWA)

Università di Roma
Tor Vergata

Results

❖ ***Effect of demand response***

- DR reduce total system cost in range of 1.7 -2.5% in the 47 GW DR core scenario.

❖ ***Effect of intermittent capacity and electricity storage***

- Higher interconnection capacity decrease overall system costs.
- Least cost deployment of intermittent capacity is 37 GW for the 40% RES scenario, to the low case (123 GW) for the 60% and 80% RES scenario.

❖ ***Intermittent RES integration cost***

- Two types of costs Balancing and profile cost are quantified.

❖ ***Profitability of complementary technologies and other generators***

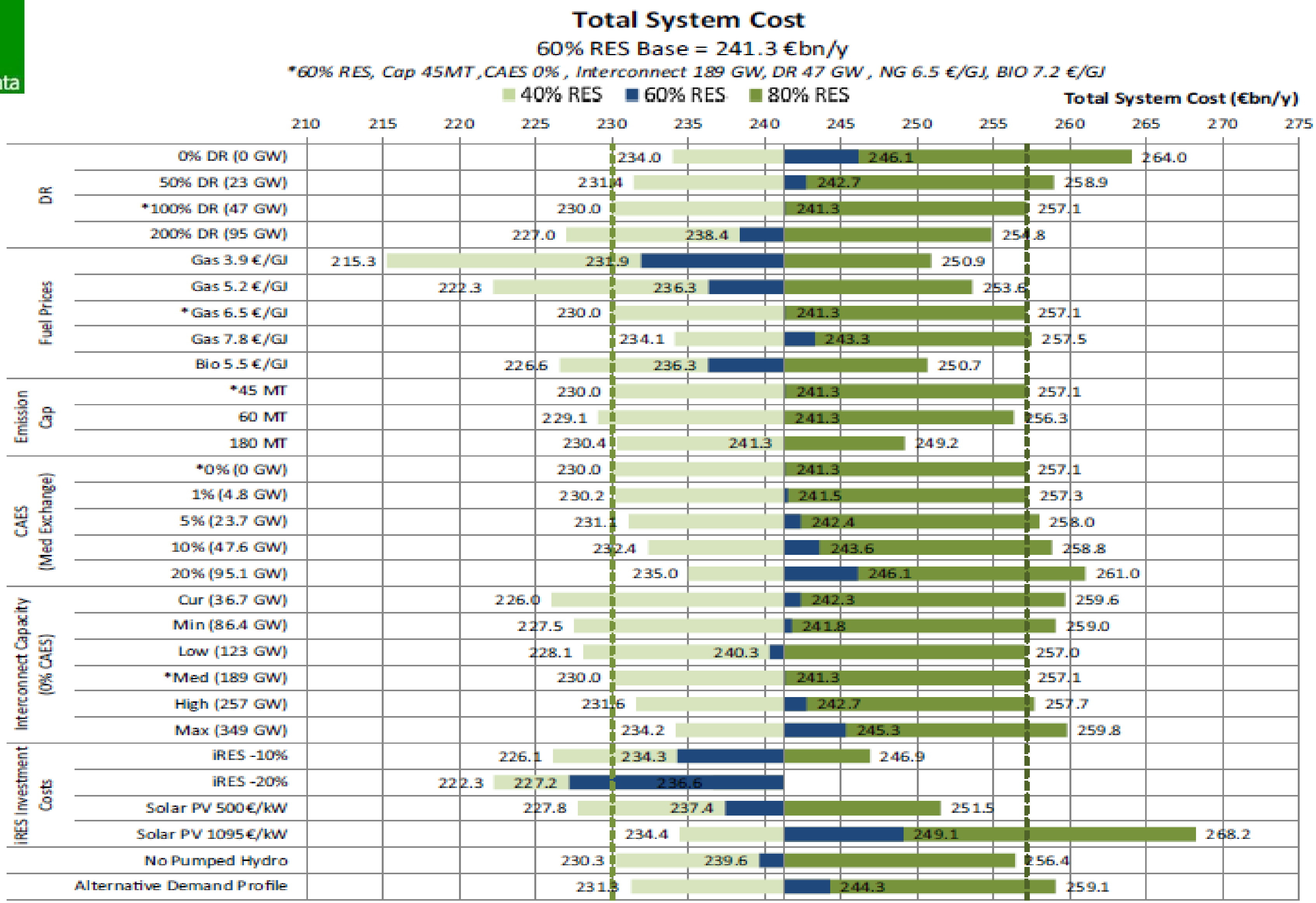
- Revenue and total cost comparison.
- All installations run at a loss.
- Curtailment and DR are only profitable because of low investment costs.

Results

❖ Sensitivity Analysis

- Total costs are determined by defined 40%,60%,80% scenarios.
- Lowest investment of RES lead to lower total system cost.
- High gas price (7.8€ GJ) shift NGCC-CCS to PC-CCS
- Cheaper biomass (5.5€/GJ) places bio thermal generator before natural gas.

Total annual system cost



Total annual system cost as simulated in sensitivity runs. Bars with reference to 60% RES core secnario. Left 40% RES and right 80% RES core secnario.**

Discussion

❖ ***Limitation of the study***

- Heat and transport sectors are not included.
- Regions are relatively large.
- 12 types of power generators
- DR potential and costs are uncertain.
- Price premium is not included.
- Cost gas distribution, transmission and storage infrastructure has not been included.

Discussion

❖ *Consistency in study assumption and outcomes*

- Technological and modeling deployment does not match.
- Investment in most power system is unjustified.

❖ *Profitability of generators*

- Intermittent –RES appear to drive down the electricity price and capacity of thermal power plants.

❖ *Comparison to literature*

- Natural gas generators are an important source of flexible mid- merit and peak load capacity.
- Demand response is a promoting technology with many uncertainties.

Università di Roma Tor Vergata

Conclusions

- *40%, 60% and 80% RES are simulated that meet predefined reliability (LOLP < 0.2 d/yr) and CO_2 emission (96% emission reduction) targets.*
- *Demand response lowers total system costs in range 2-3%.*
- *Natural gas fired generators can provide low-carbon electricity.*
- *Interconnection capacity reduces system costs in range 1%.*
- *Curtailment reduces cost up to 2%.*
- *Electricity storage is expansive.*

Conclusions

- *96% CO_2 emission can be reduced with higher shares of RES (80% RES).*

  or with

- *(96% CO_2 can be reduced) with a combination of Natural gas fired generation plus nuclear power and 40% RES.*
- *Total system costs increases with high levels of renewable from 230 (40%RES) to 275bn€/yr for (80%RES) respectively.*
- *High share decrease electricity price from 57 to 47 €/MW h at (40%, 80%) respectively.*
- *Difference in total system cost of 40% and 80% IRES is only 12%.*

Thanks !