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# The role of natural gas in Europe – focus on the power markets


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# Outline

- Transition to near zero emission power systems
- The EMPIRE model
  - case 1: With our without CCS
  - Case 2: CCS transitional support measures
- NCCS - ambitions
- References

# The Zero Emission Power system

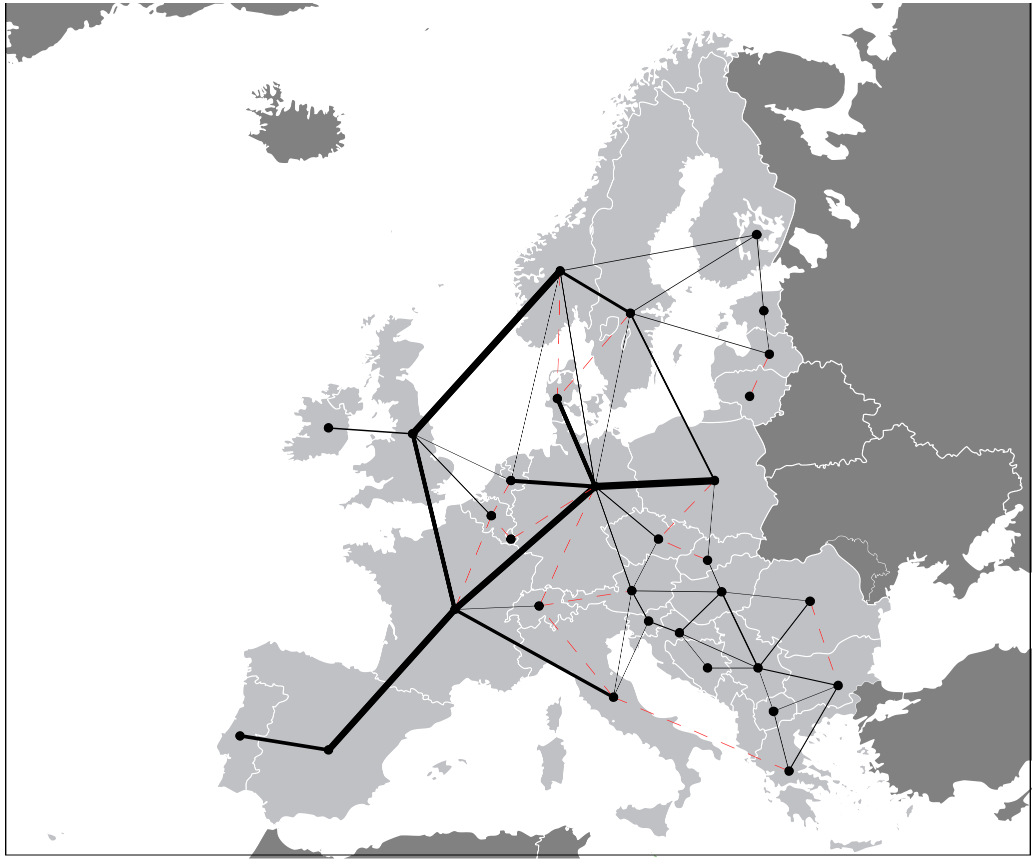
What is needed to achieve 90%emission cuts in 2050?

- Transmission versus storage
- How does the role of gas develop
  - With CCS?
  - Or without.
- The “winter package”: Active consumers and demand response. An alternative to transmission?

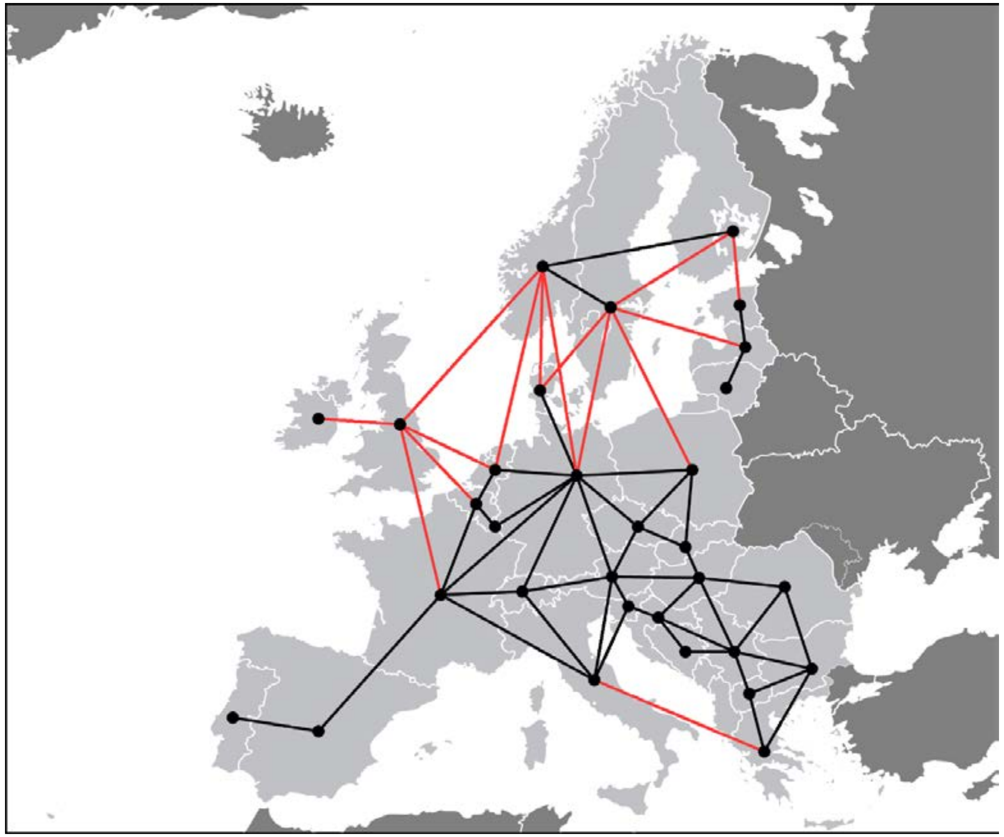

# Zero Emission Power systems

- Challenges: intermittency and variation
- Technology choice
  - Large scale solutions/transmission/renewables
  - Distributed systems/storage/demand response
  - A combination of all

- Analyses using the EMPIRE model
- Power system design and operation
  - Time horizon until 2050 – investments in 5 year steps
  - Model operational time periods: demand, supply (stochastic wind and solar PV) and optimal dispatch.
- Provides a cost minimization capacity expansion plan for Europe, detailed for each country



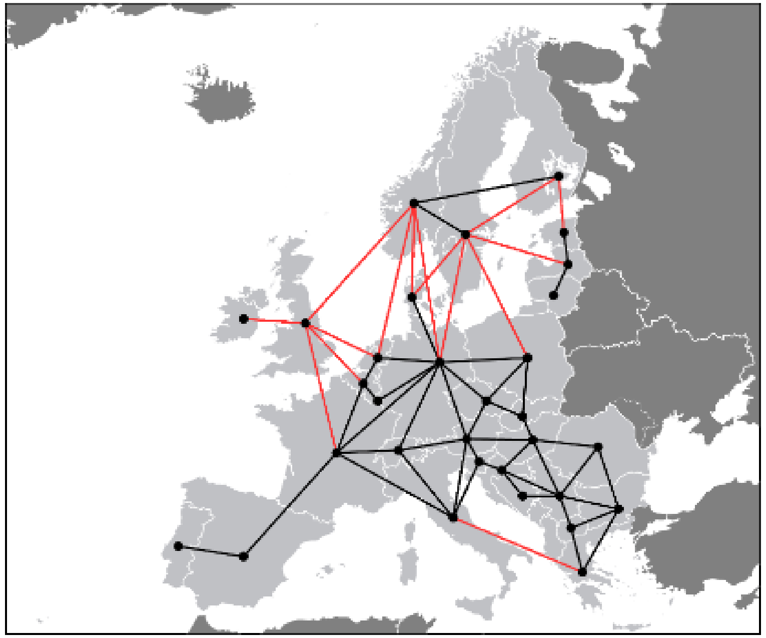
# EMPIRE modeling assumptions



- Perfect competition
- Inelastic demand
- Generation capacity aggregated per technology (do not model individual plants)
- Investments are continuous
- Lines are independent (transportation network)
- Perfect foresight in terms of fuel prices, carbon price, and load development

# The challenge for Zero Emission Power Systems
# - Intermittent generation and variable load

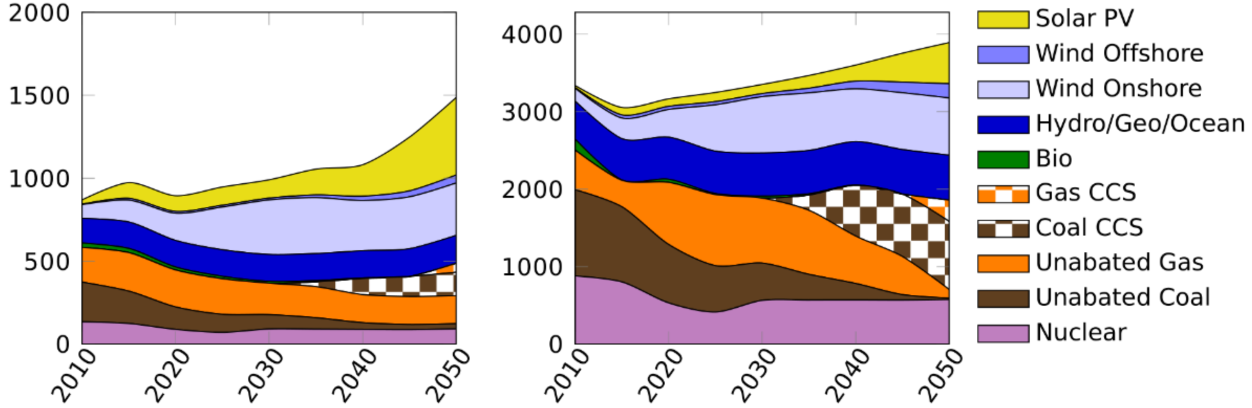
# CO-OPTIMIZATION OF STRATEGIC AND OPERATIONAL DECISIONS



Optimal investment strategy 2010-2015

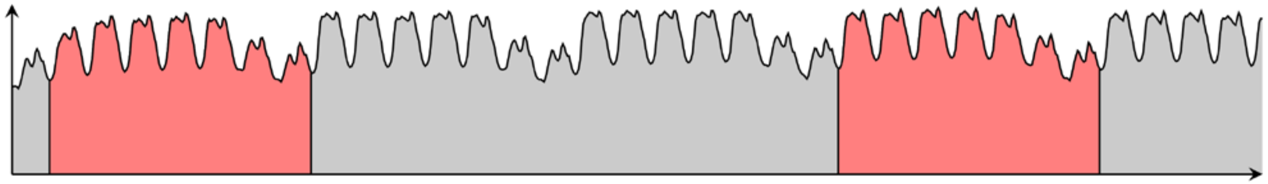
Capacity [GW]

Generation [TWh]

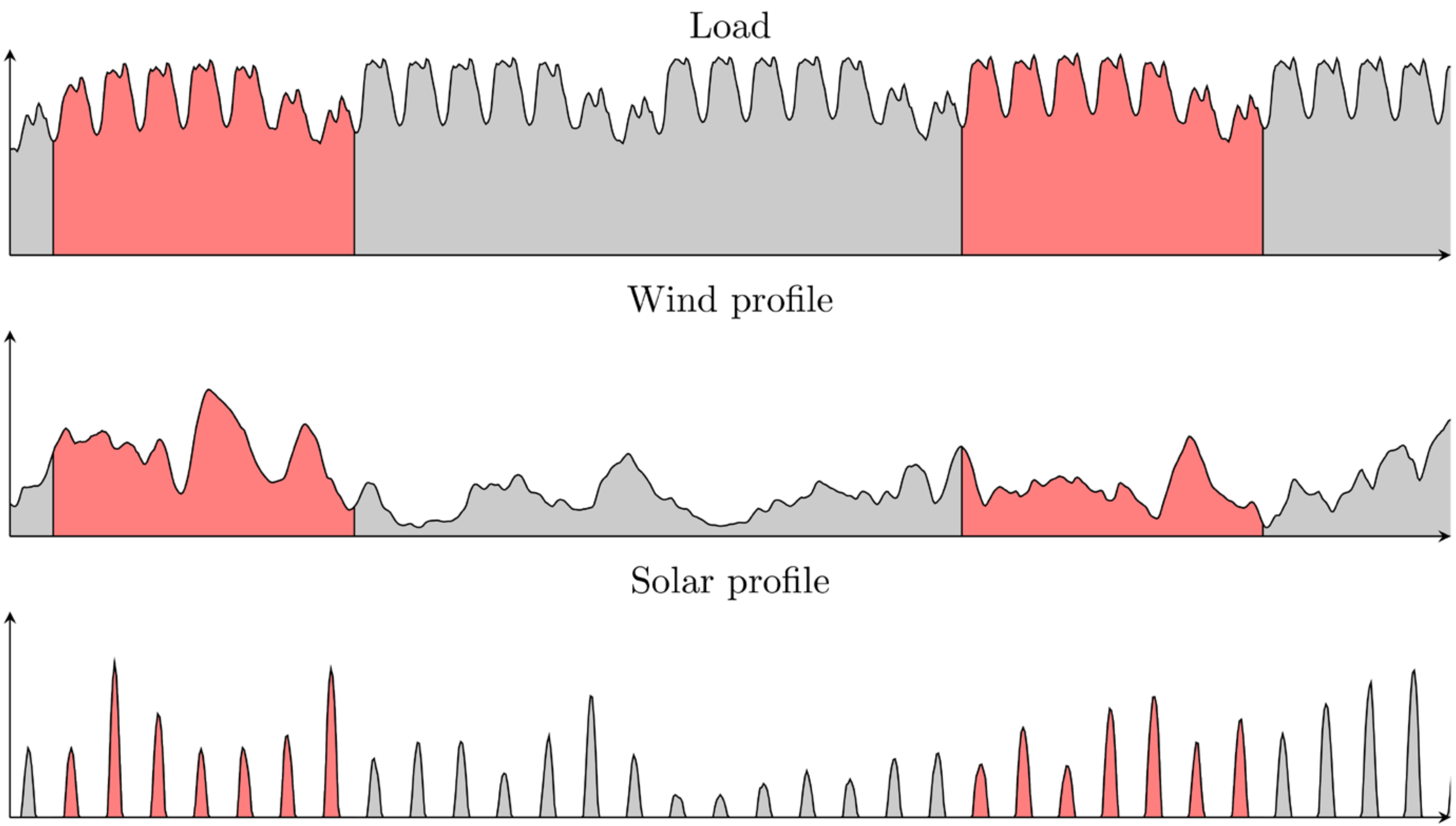



Coupled optimization problem to minimize total system costs

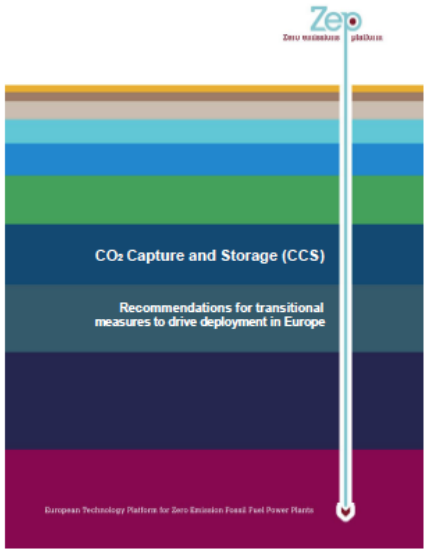
Optimal dispatch for representative 168-hour blocks

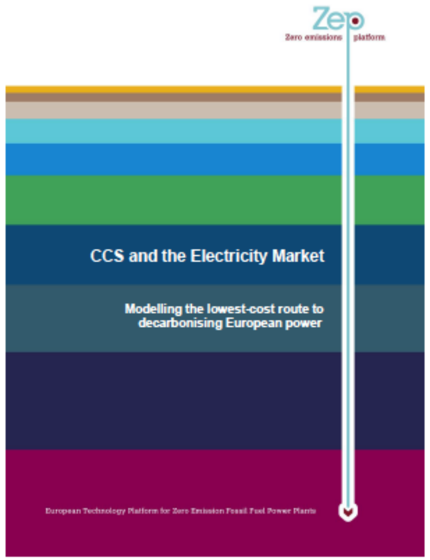


# Operational data – slicing



# Use of EMPIRE in Zero Emissions Platform (ZEP)





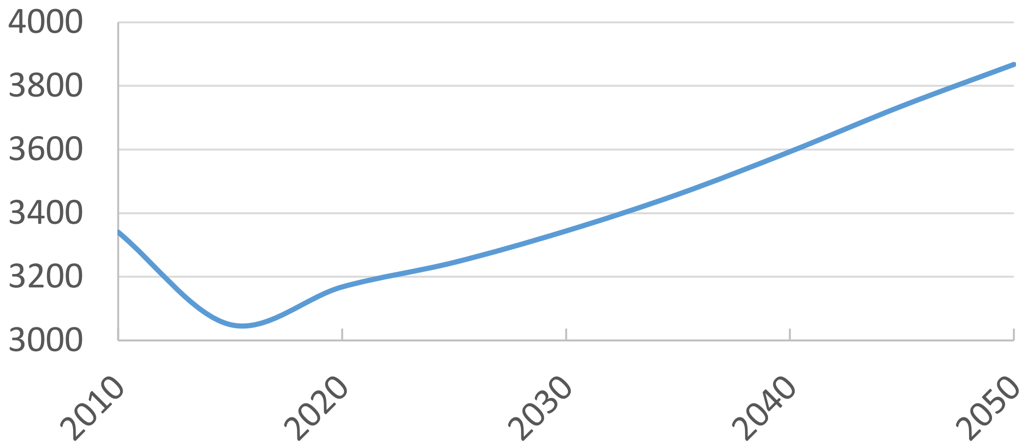
- Published November 2013
- Transitional measures for demonstration CCS

- Published November 2014
- Decarbonization scenarios for the European power system

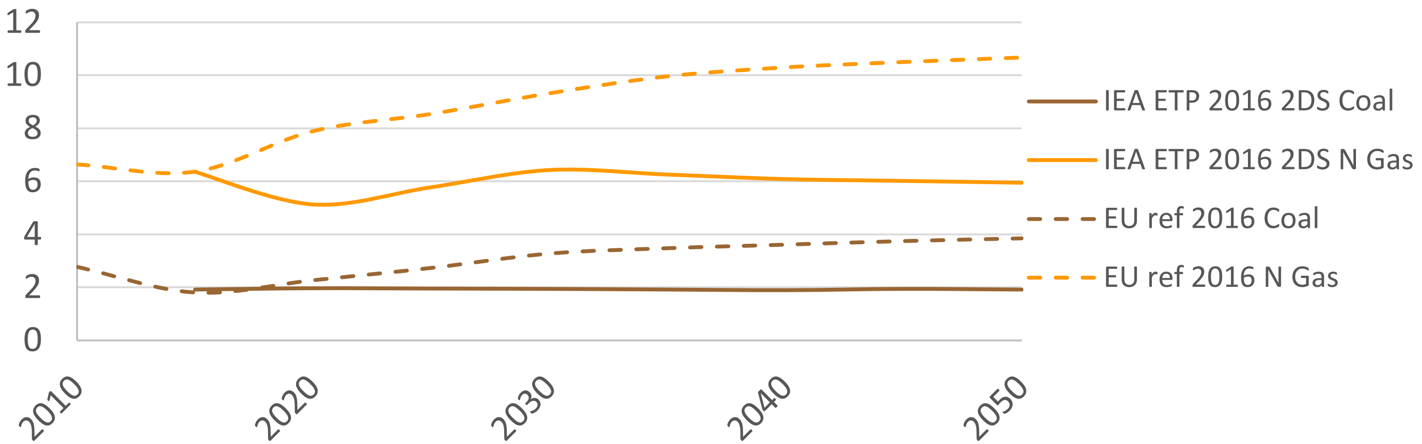
- Published December 2015
- CCS and industry in Europe

# Background

European demand for electricity [TWh/an]

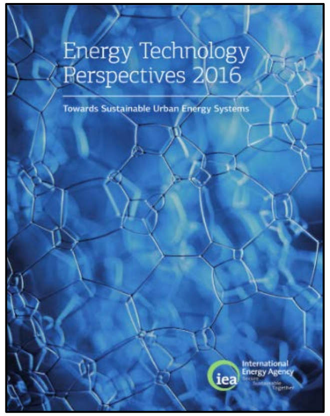



Fuel Prices [€2010/GJ]




EU reference scenario 2016


IEA Energy Technology Perspective 2016



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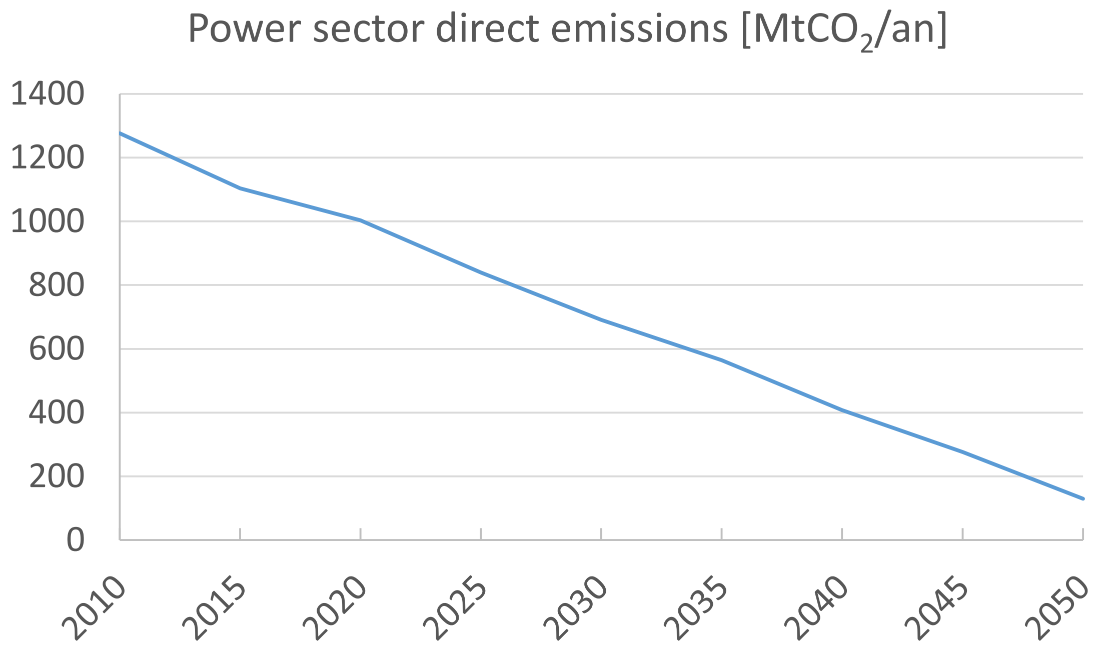
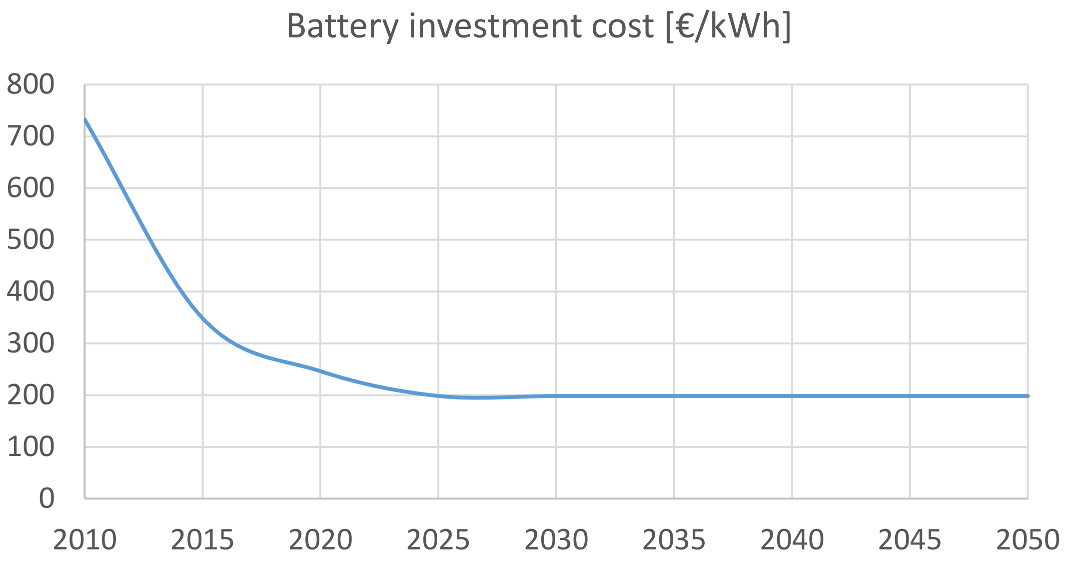
# Scenario assumptions

1. Baseline decarbonization: **90 % emission reduction from 2010 to 2050**
   i. Grid expansion towards 2020 fixed to ENTSO-E's 2016 TYDP reference capacities.
      i. Beyond 2020: expansion limit of 4 GW for each interconnector every five year period
   ii. Capacity limits for selected technologies
      i. Wind onshore capacity potential from IEA's NETP 2016.
      ii. Solar limited to cover no more than 14% of a country's area (assuming 150 $W/m^2$)
      iii. Nuclear capacities limited
   iii. RES targets defined for Germany, France, Great Britain and Spain
   iv. Development of Norwegian hydro power predefined

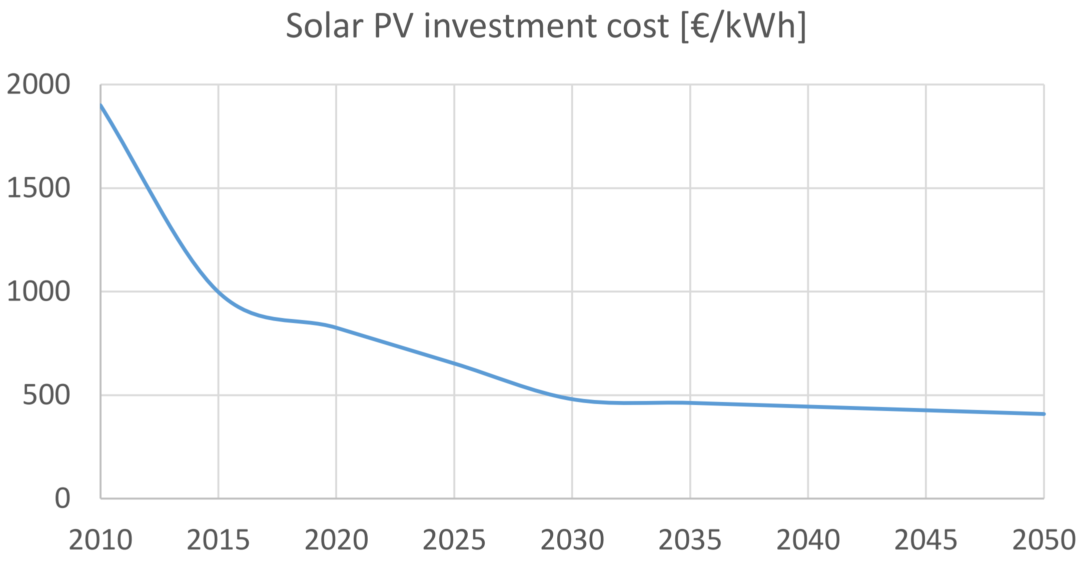
2. Alternative scenario NoCCS: same as baseline but no carbon capture and storage available



# Medium optimistic assumptions for “decentral” technologies




**Source:** Cole, W. J., Marcy, C., Krishnan, V. K., & Margolis, R. (2016). Utility-scale lithium-ion storage cost projections for use in capacity expansion models. DOI:doi.org/10.1109/NAPS.2016.7747866




**Source:** PV: Fraunhofer ISE. (2015). Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems. Agora Energiewende.

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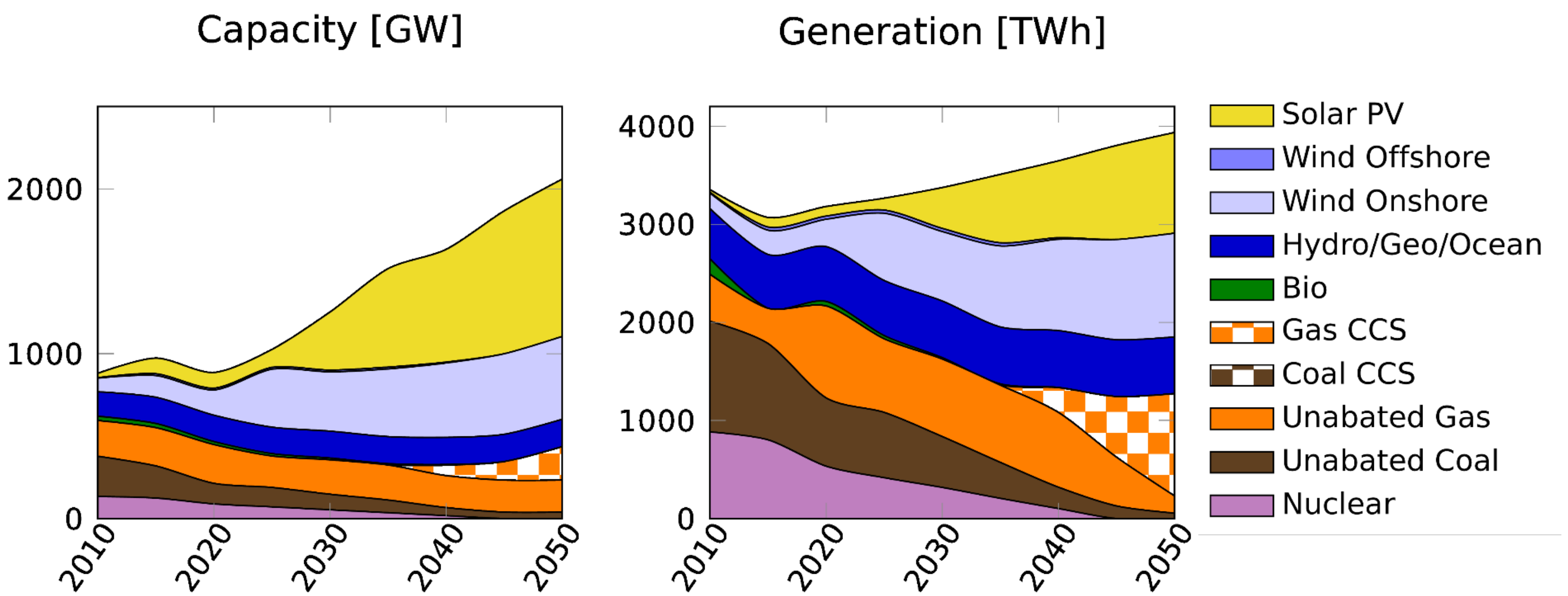
# Baseline scenario: 90 % emission reduction




| Technology/fuel (2050) | Capacity [GW] | Generation [TWh] |
|---|---|---|
| Solar | 954 (46%) | 1026 (26%) |
| Wind | 503 (24%) | 1057 (27%) |
| Gas CCS | 204 (10%) | 1043 (26%) |
| Coal CCS | 0 (0%) | 0 (0%) |
| Fossil unabated | 233 (11%) | 231 (5%) |
| Others | 166 (8%) | 578 (15%) |

Battery energy storage by 2050: 99 GWh

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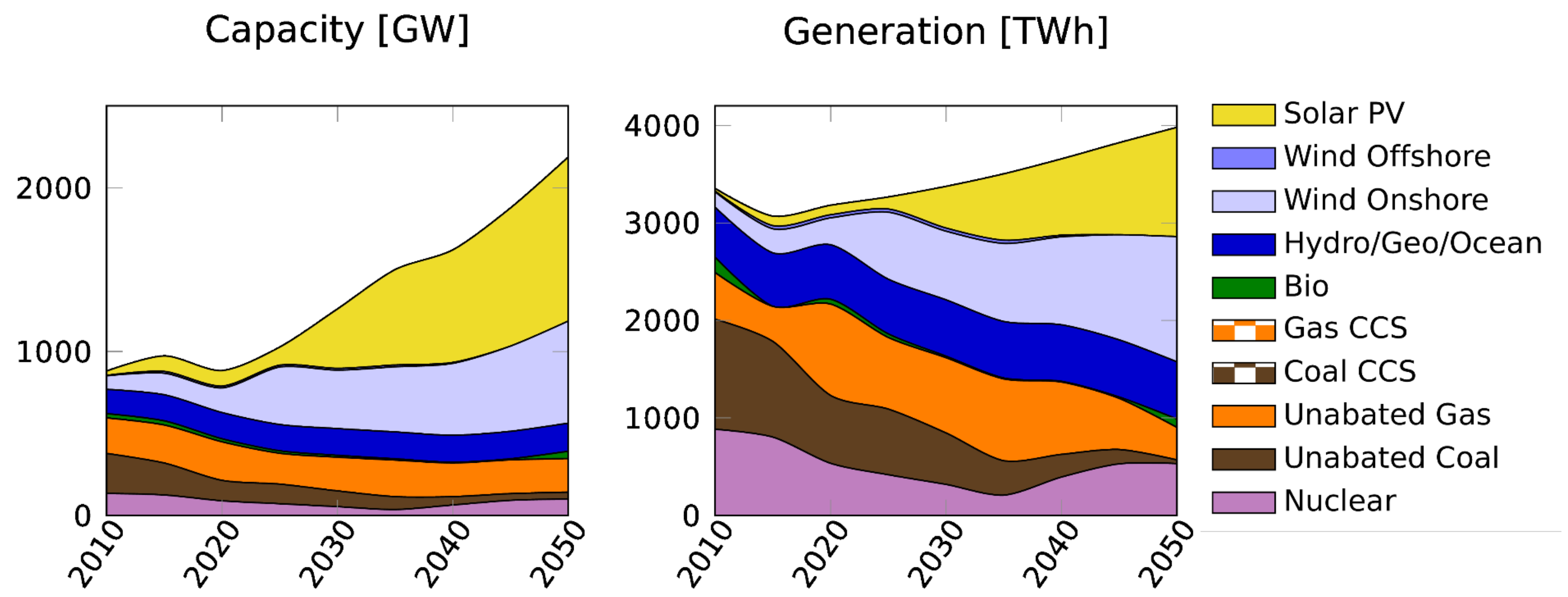
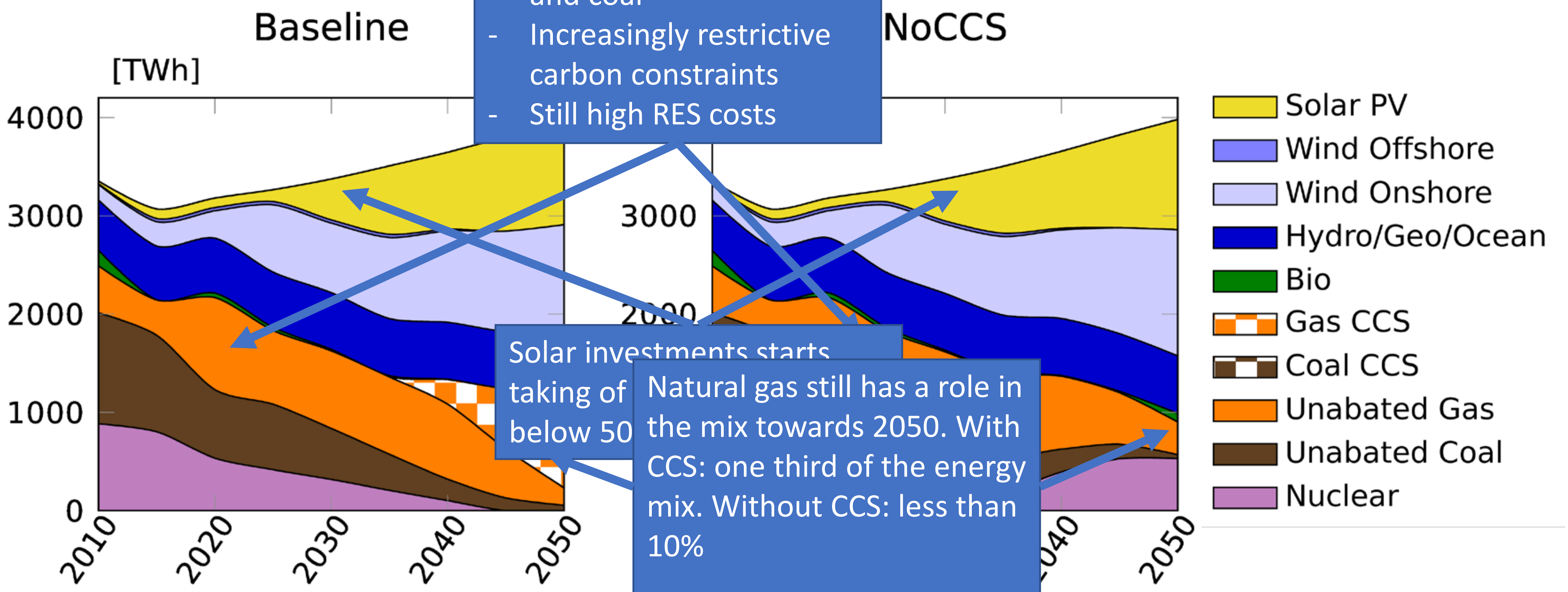
# NoCCS scenario: 90 % emission reduction




| Technology/fuel (2050) | Capacity [GW] | Generation [TWh] |
|---|---|---|
| Solar | 1001 (46%) | 1120 (28%) |
| Wind | 623 (28%) | 1284 (32%) |
| Gas CCS | 0 (0%) | 0 (0%) |
| Coal CCS | 0 (0%) | 0 (0%) |
| Fossil unabated | 247 (11%) | 371 (9%) |
| Others | 316 (15%) | 1204 (30%) |

Battery energy storage by 2050: 339 GWh

# Transition to a low- … n power sector




Increased shared of unabated natural gas in the medium term. Due to

- Retirement of nuclear and coal
- Increasingly restrictive carbon constraints
- Still high RES costs

Solar investments starts taking of … below 50 …

Natural gas still has a role in the mix towards 2050. With CCS: one third of the energy mix. Without CCS: less than 10%

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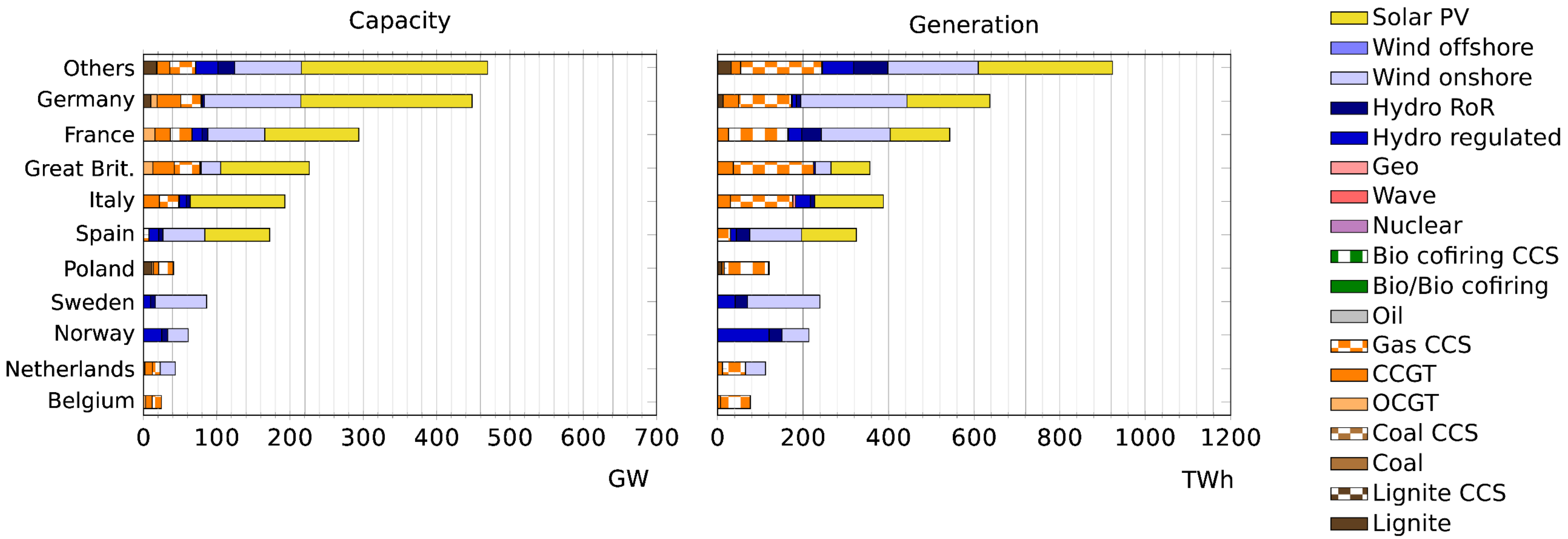
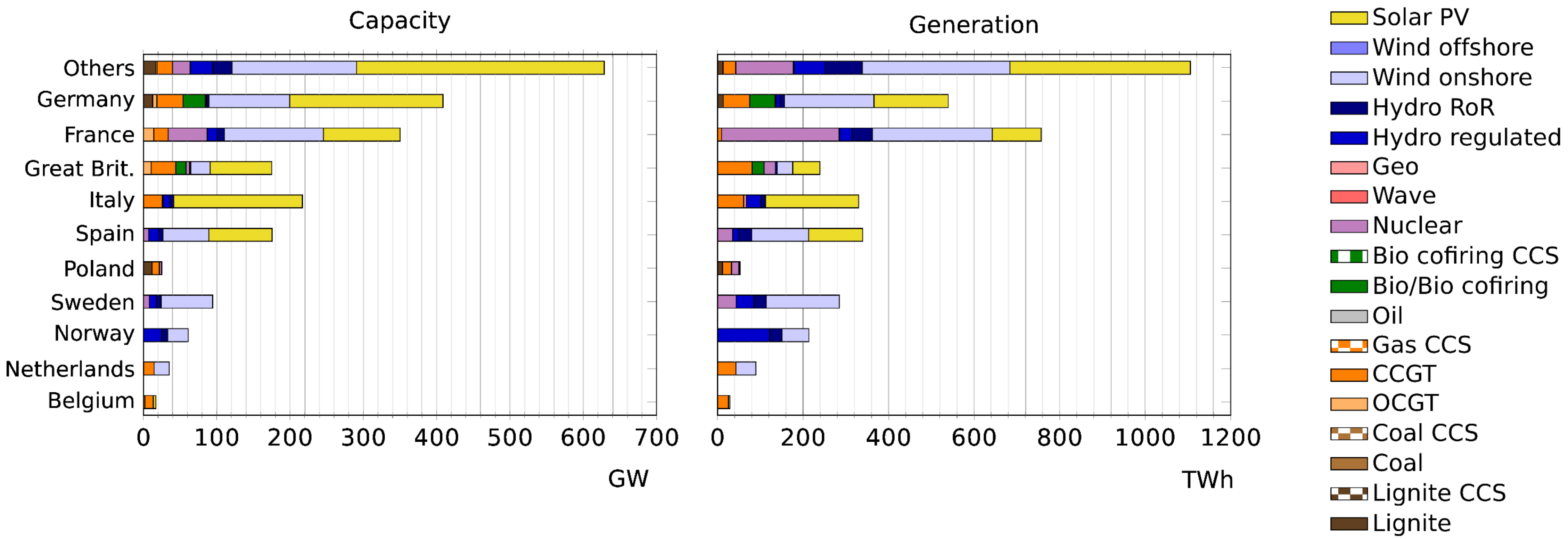
# Baseline country results 2050




Source: CenSES position paper Norway as a flexibility provider to Europe, in preparation.

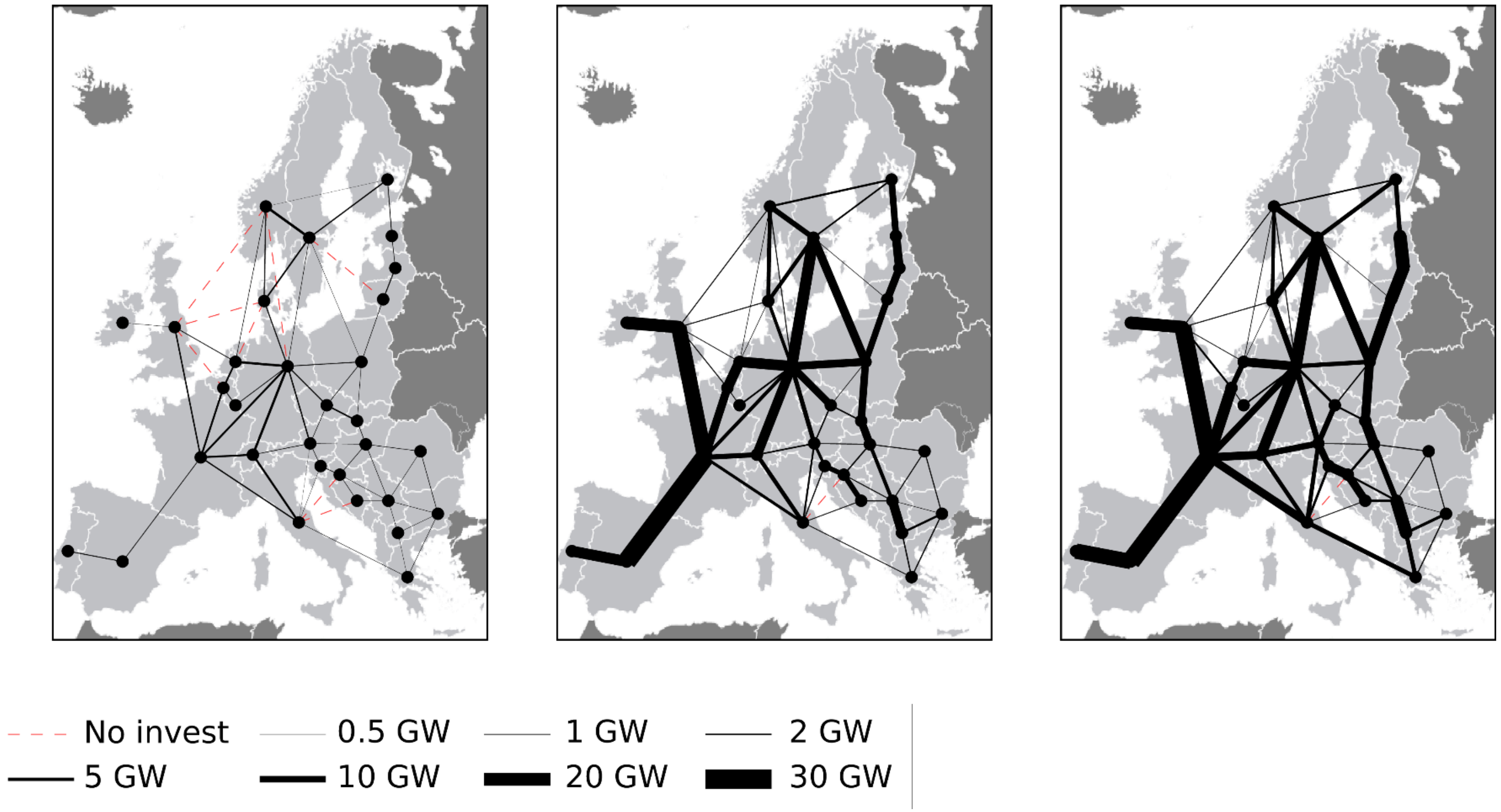
# NoCCS country results 2050




Source: CenSES position paper Norway as a flexibility provider to Europe,
in preparation.

# Transmission

2010 | Baseline 2050 | NoCCS 2050




**Baseline**
European cross-boarder interconnector expansion: capacity increases by 644 % from 2010 to 2050

**NoCCS**
Capacity increases by 826 % from 2010 to 2050

# Baseline operation

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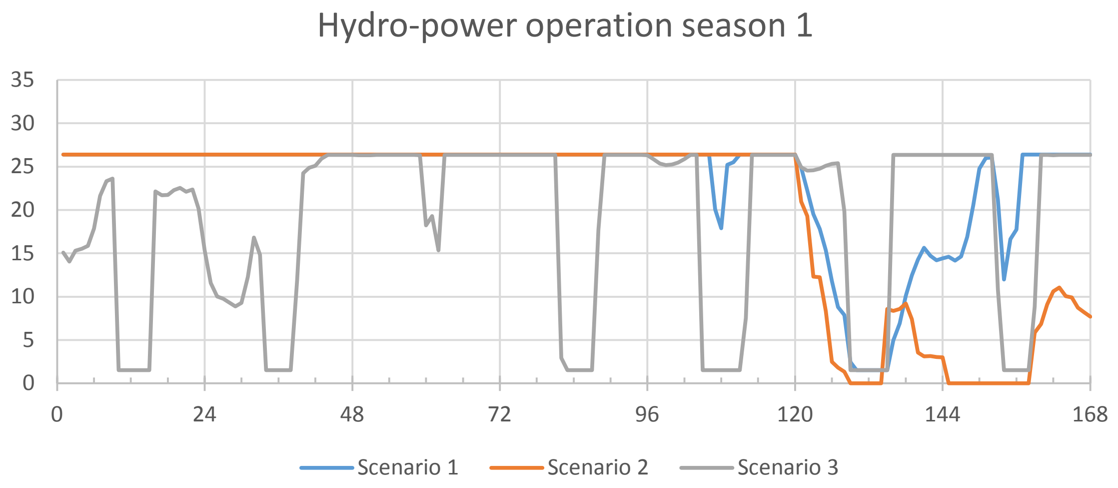
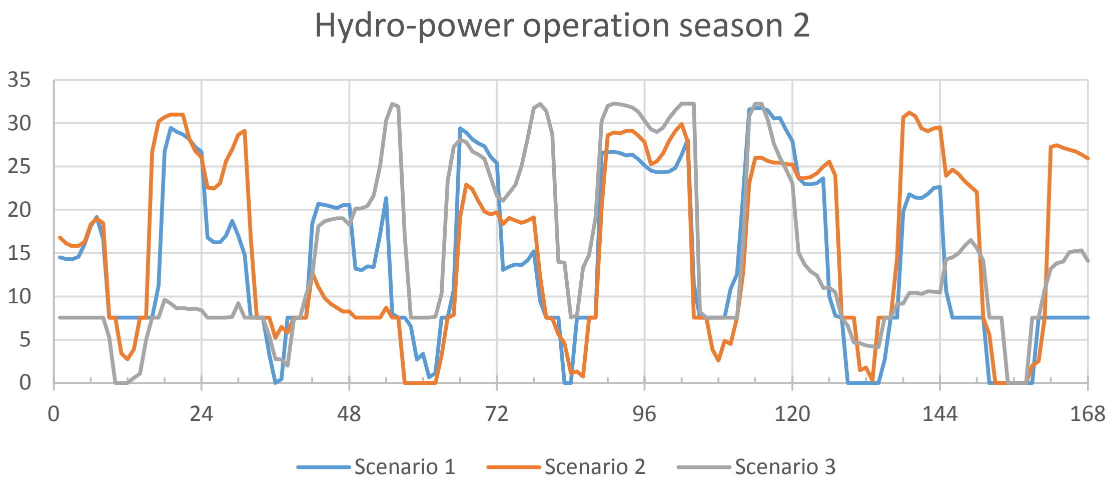
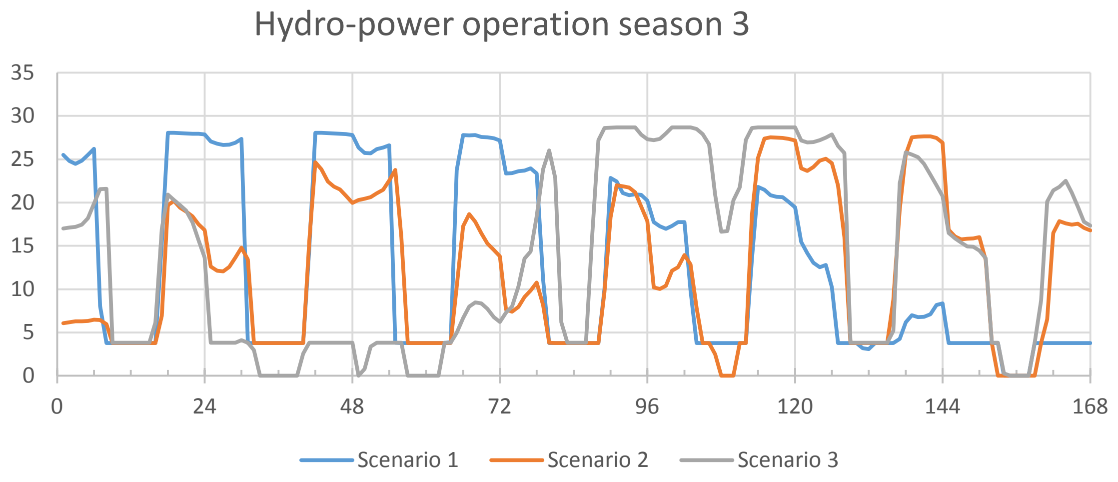
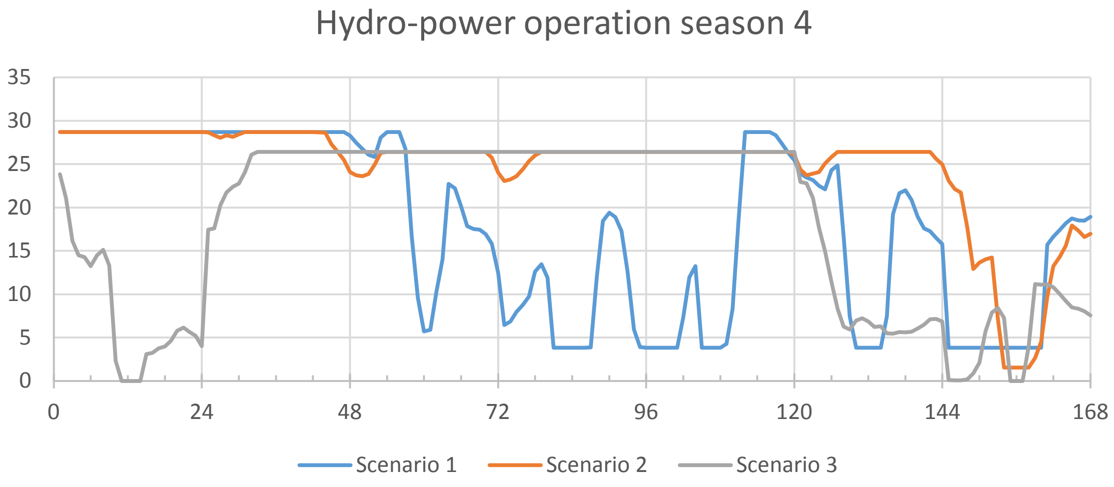
# Hydro-power operation NO 2050



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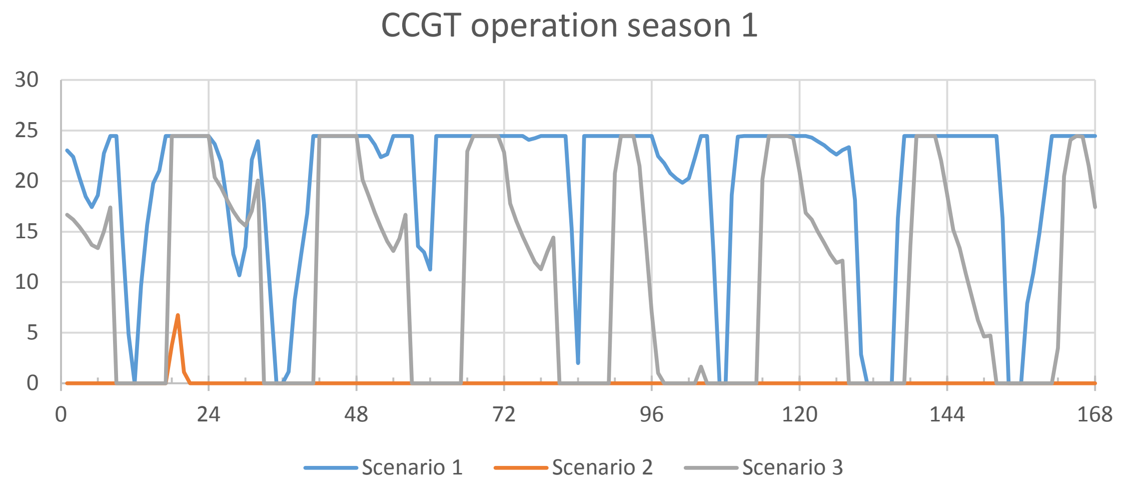
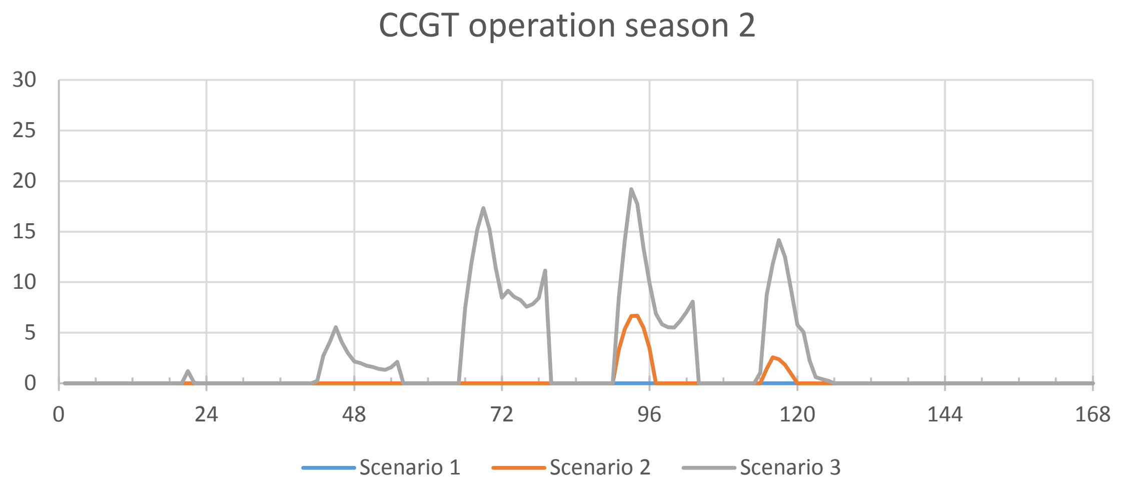
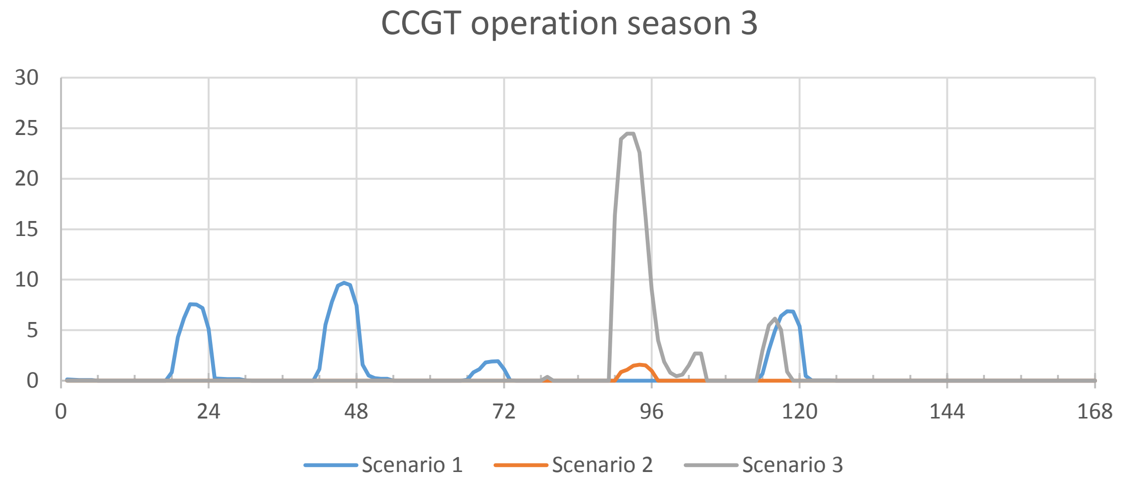
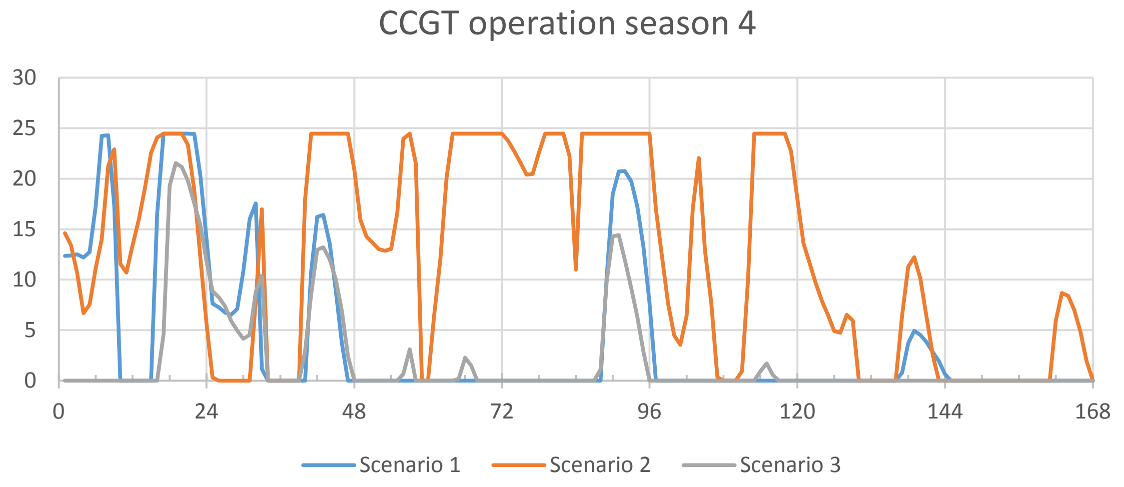
# Unabated gas operation GB 2050



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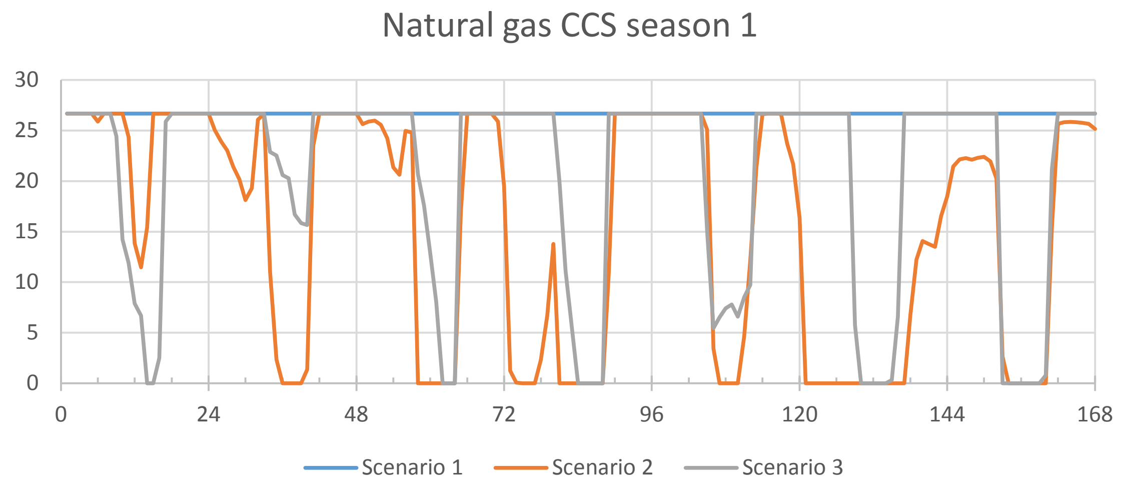
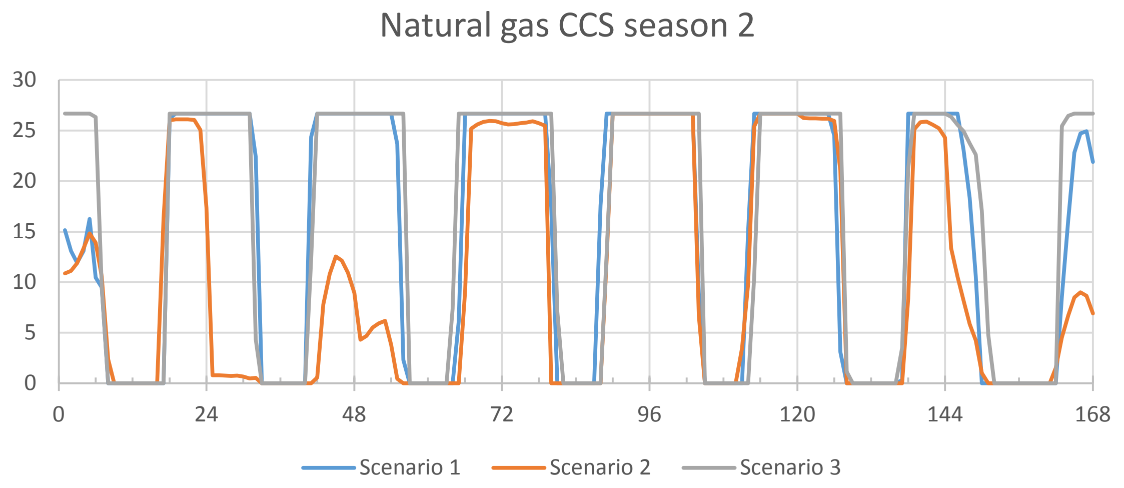
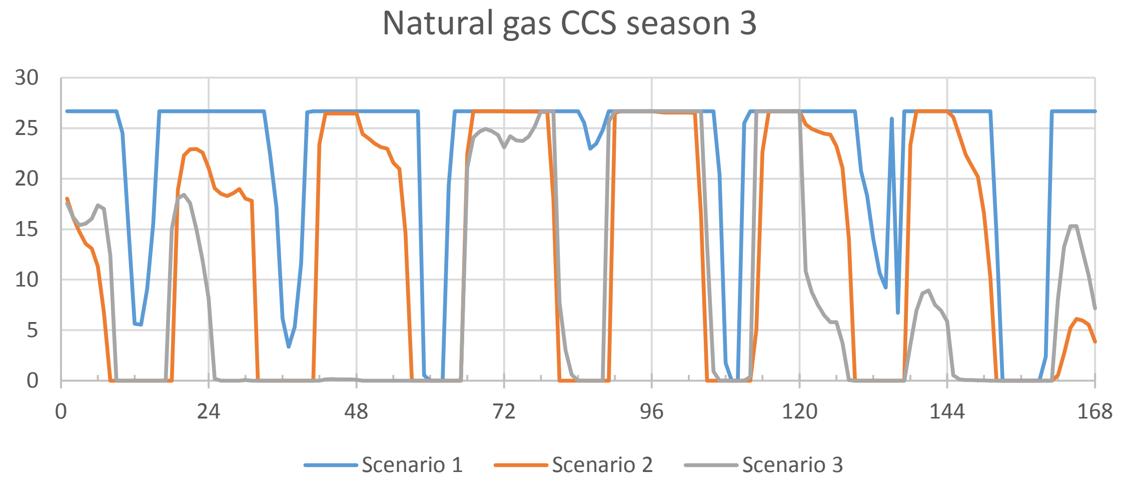
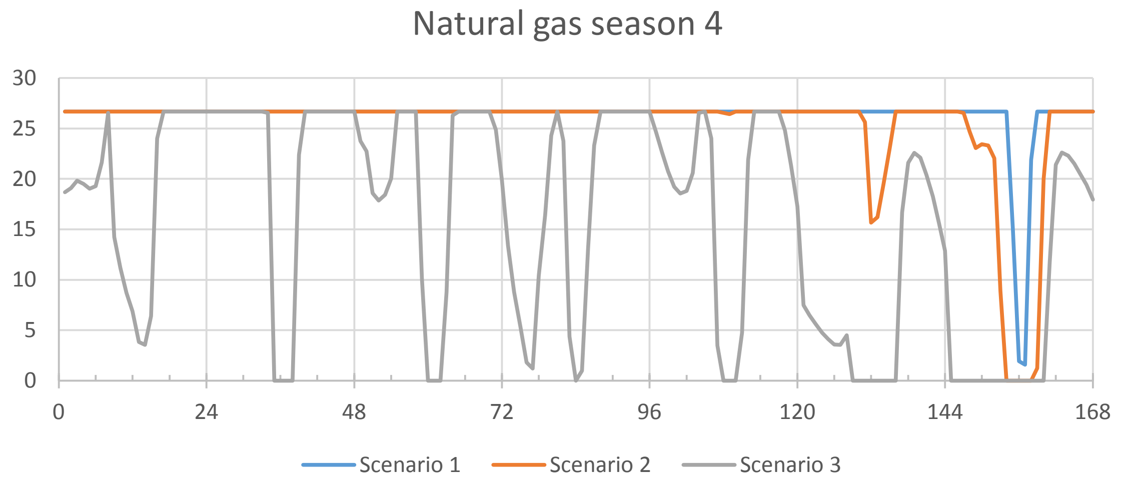
# CCS gas operation GB 2050



# NoCCS case: operation details

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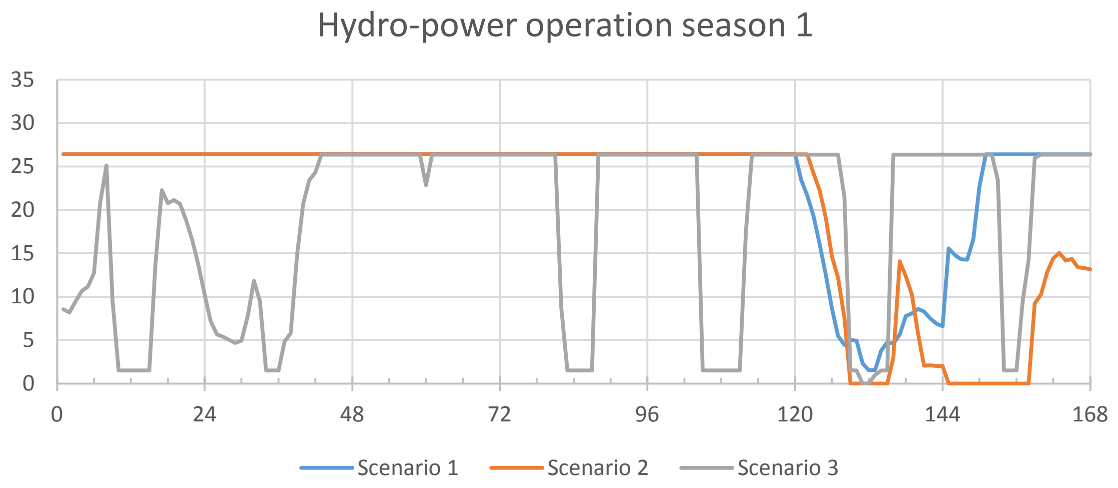
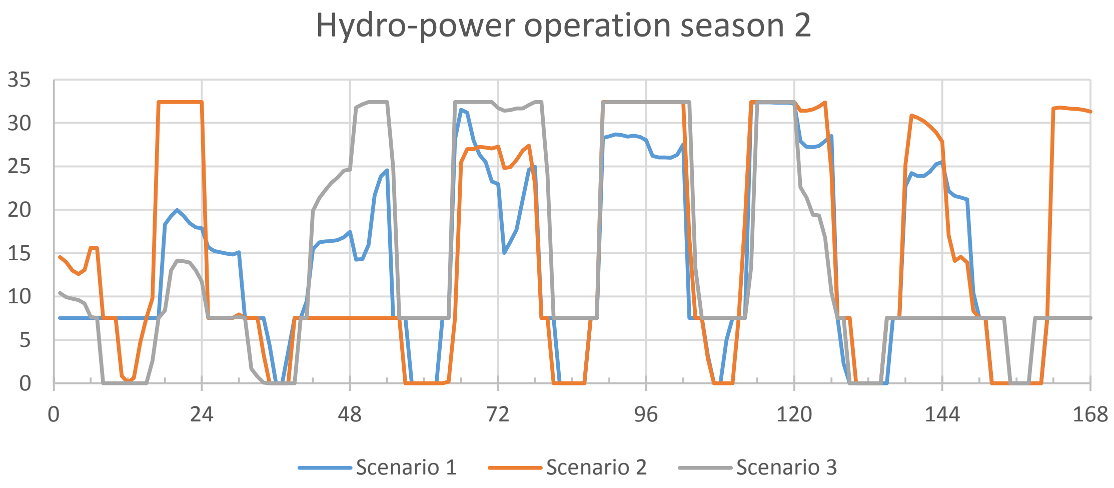
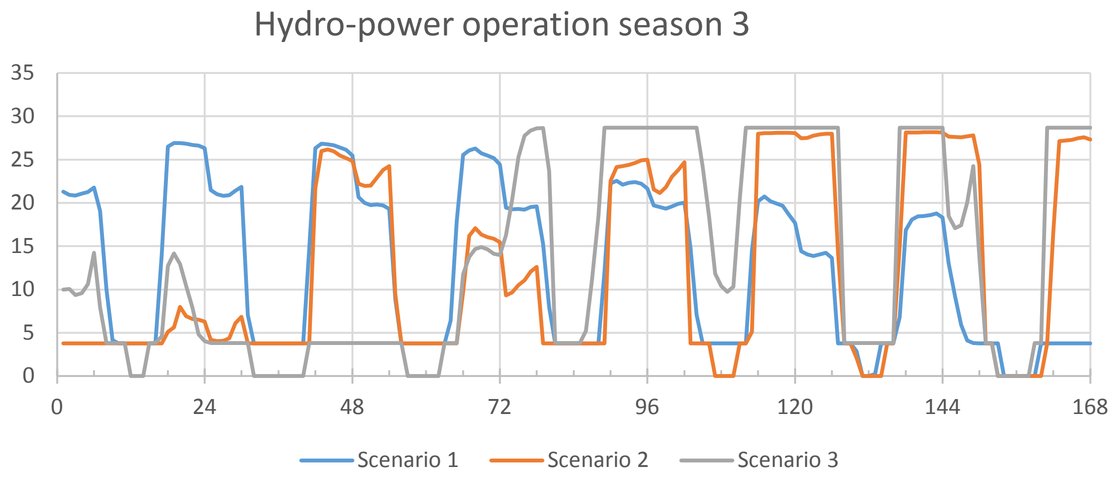
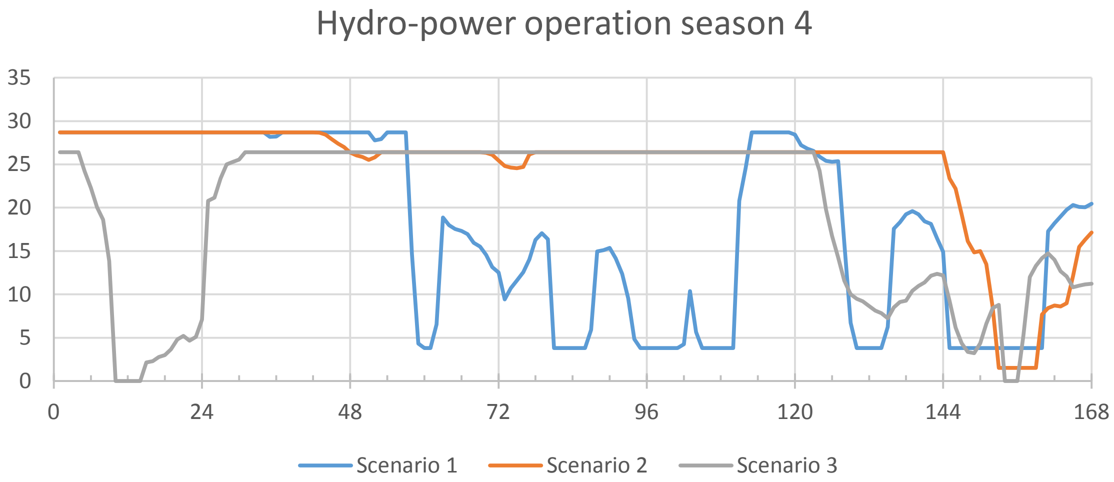
# Hydro-power operation NO 2050



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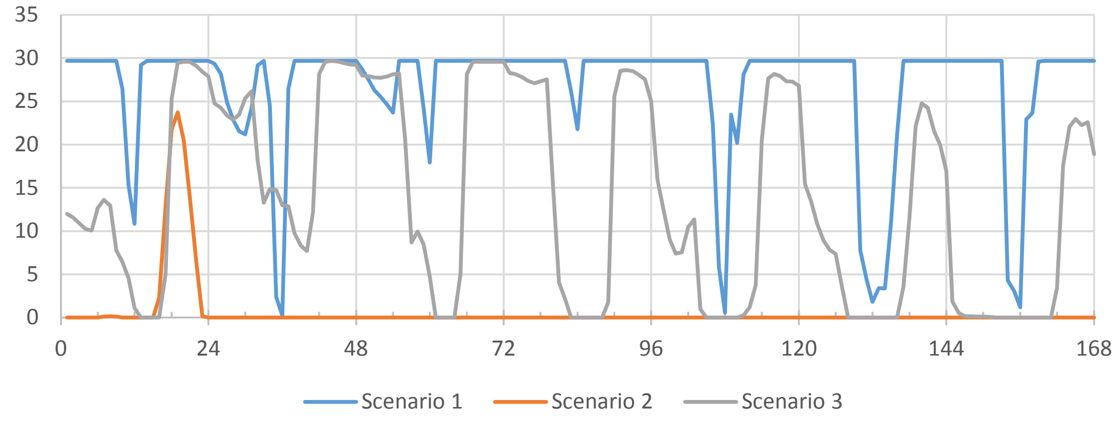
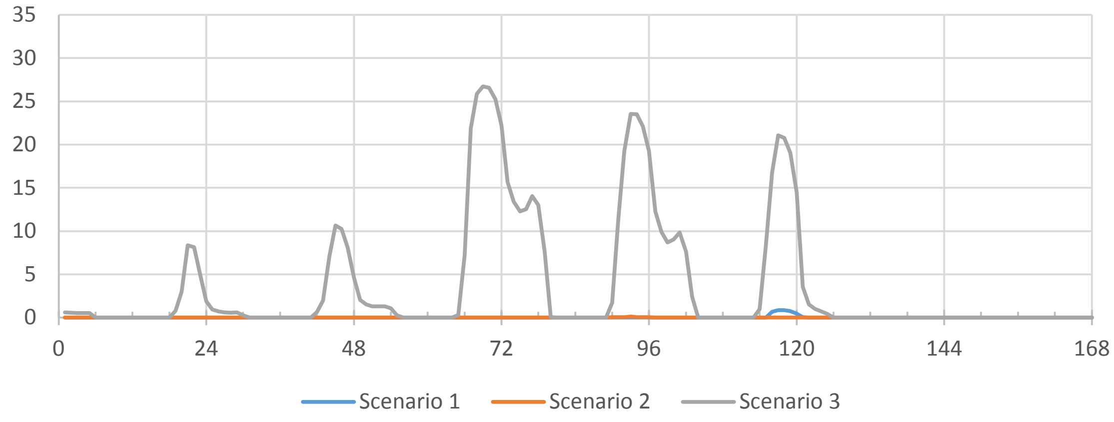
# Unabated gas operation GB 2050

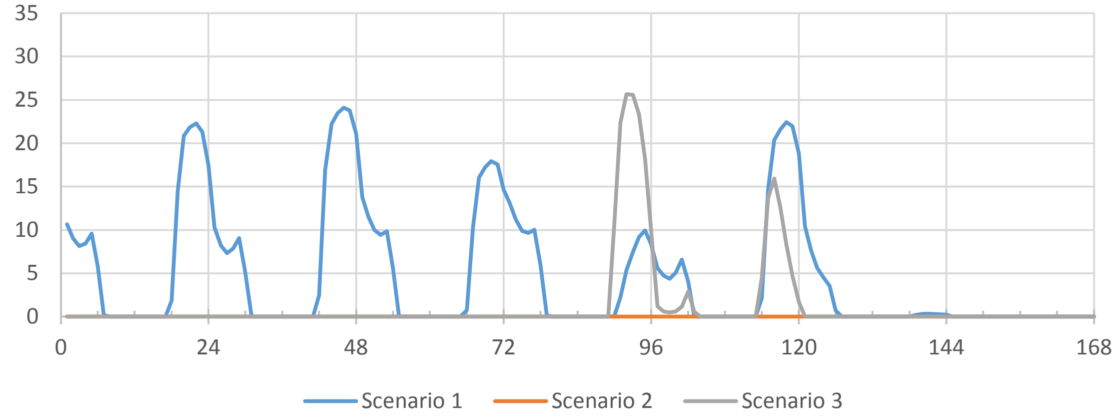
CCGT operation season 1



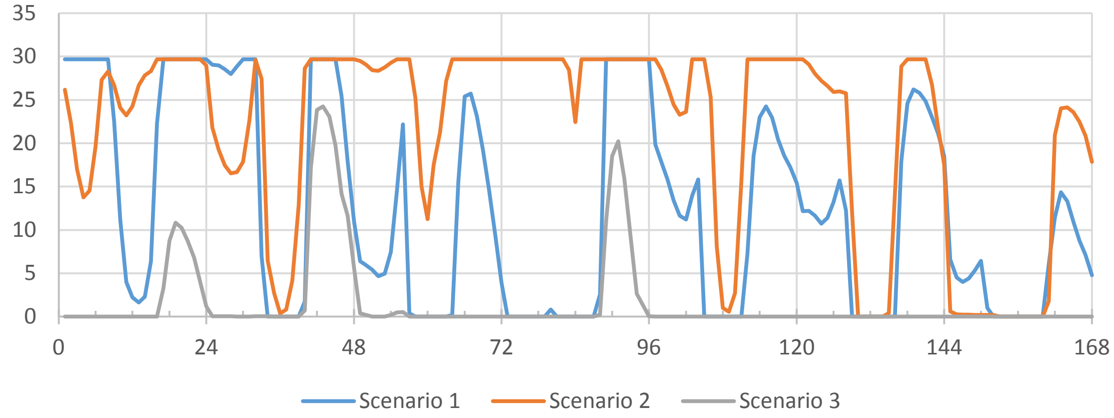

CCGT operation season 2




CCGT operation season 3




CCGT operation season 4



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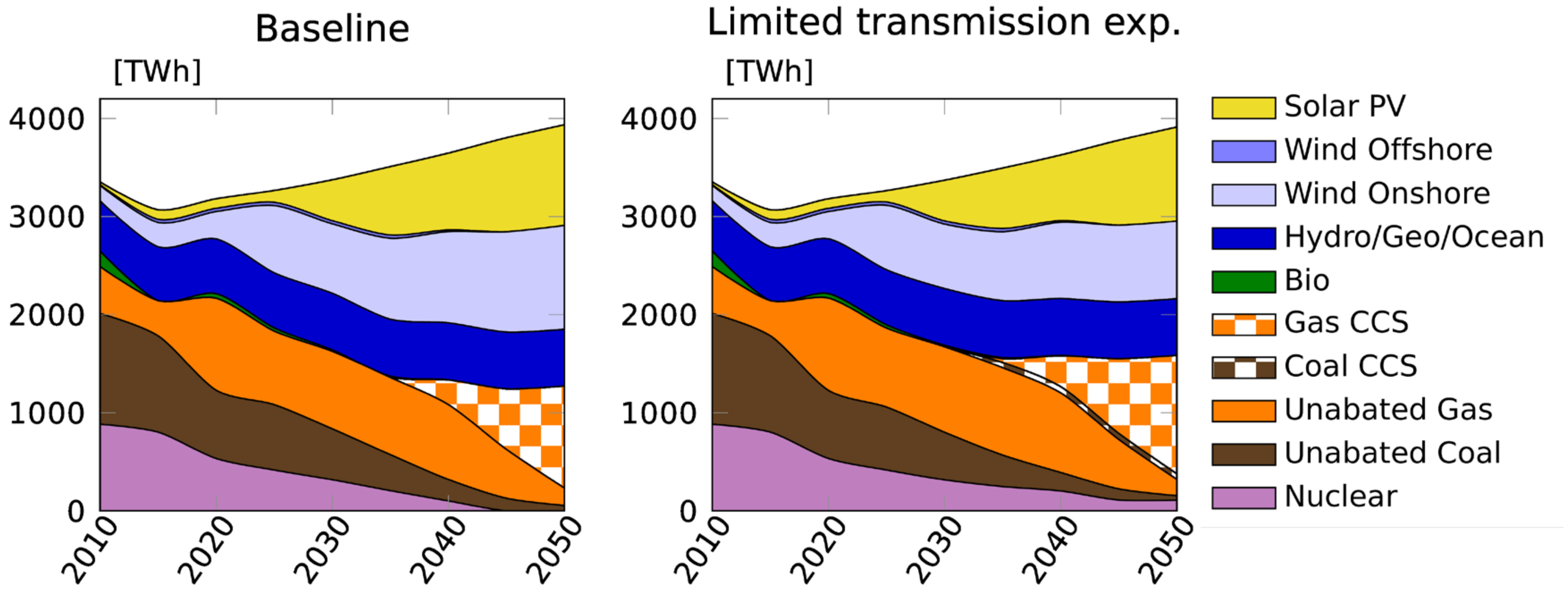
# Selection of flexibility options 2050

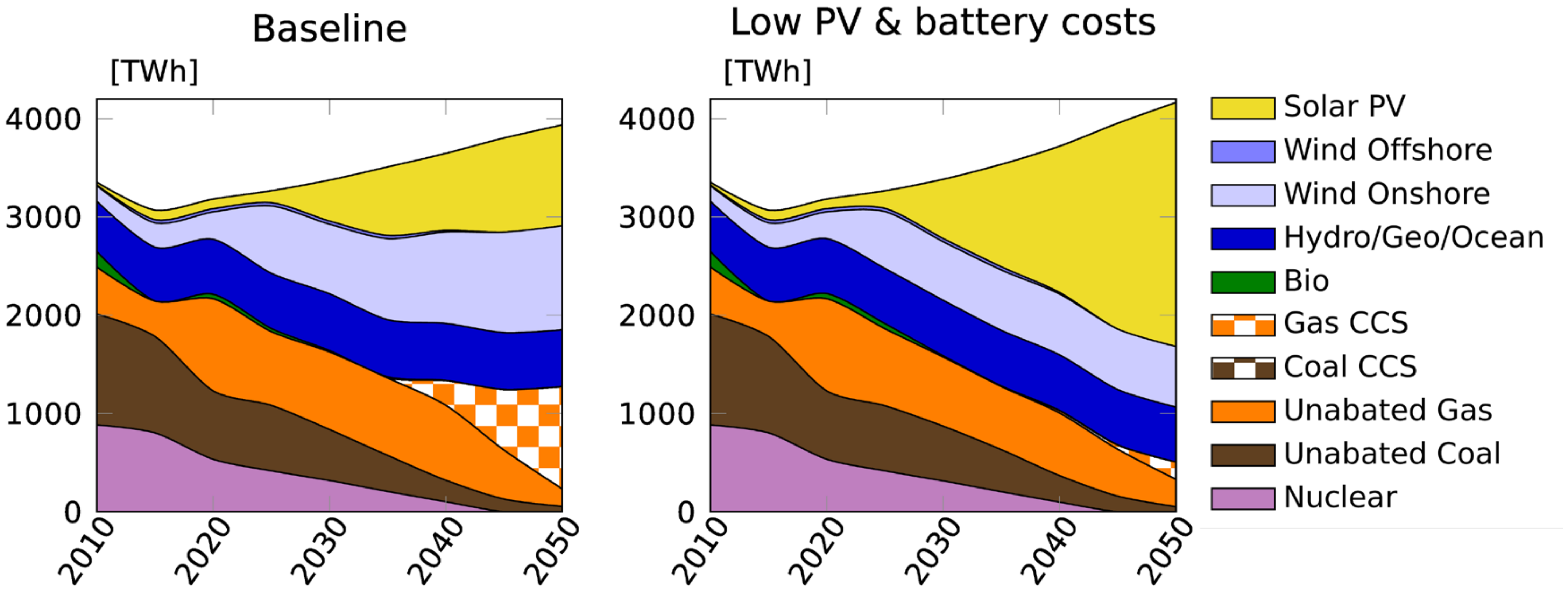
| Scenario | Baseline | | | NoCCS | | |
|---|---|---|---|---|---|---|
| | Gas (GW) | Trans. (GW) | Battery (GWh) | Gas (GW) | Trans. (GW) | Battery (GWh) |
| With transmission exp. | 398 | 416 | 99 | 206 | 533 | 339 |
| Limited transmission exp. | 442 | 121 | 86 | 247 | 121 | 646 |

| Scenario | Baseline | | NoCCS | |
|---|---|---|---|---|
| | Curtail energy (TWh/an) | Avg. elec. Cost (€/MWh) | Curtail energy (TWh/an) | Avg. elec. Cost (€/MWh) |
| With transmission exp. | 60 | 51 | 74 | 56 |
| Limited transmission exp. | 83 | 54 | 104 | 64 |

# Sensitivities: Transition to a low-carbon European power sector



# Sensitivities: Transition to a low-carbon European power sector



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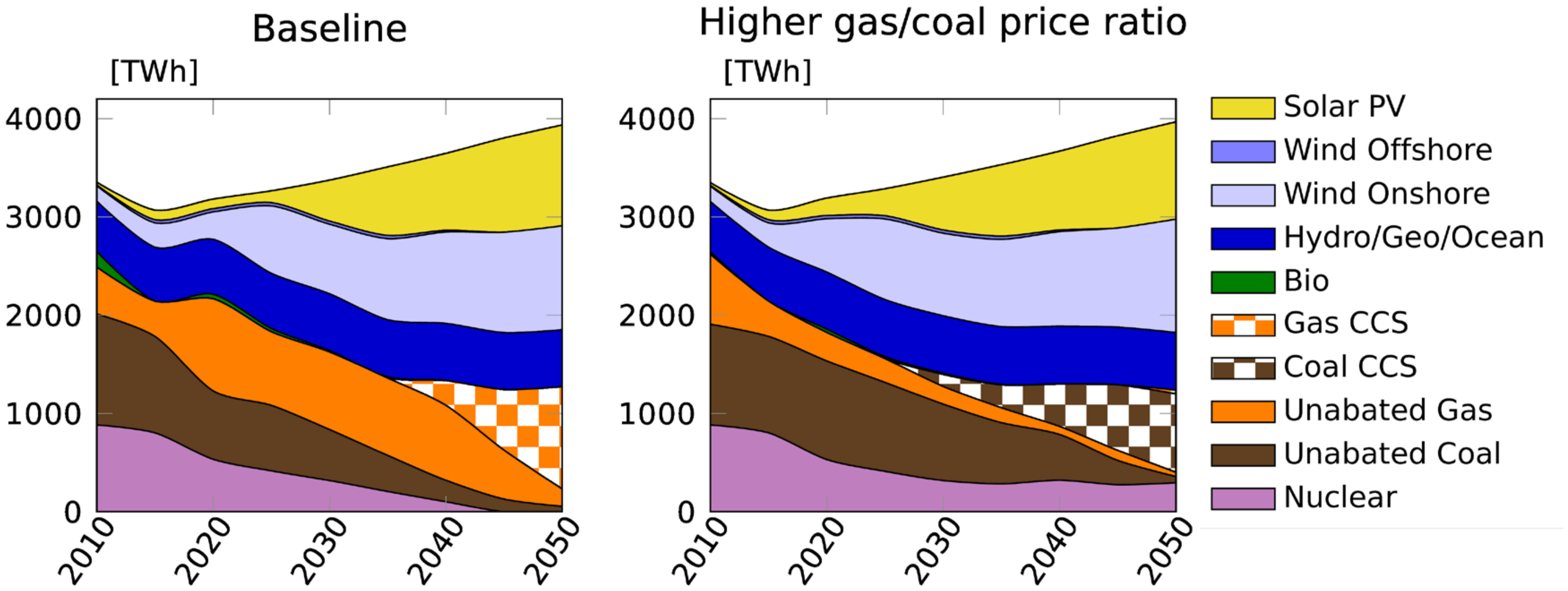
# Sensitivities: Transition to a low-carbon European power sector



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# Some insights

- Availability of CCS makes a significant difference in the cost-optimal transition to a low carbon European power system
- The role of natural gas depends on availability of CCS and on the gas/coal price ratio
    - With CCS: natural gas with CCS is used for baseload, unabated for balancing. Total share 31%.
    - Without CCS: natural gas is mostly used for balancing. Total share 8%.
- Without CCS a combination of options are used to achieve low-carbon power generation, including solar, wind and (some) bio, but also nuclear and unabated natural gas
- If solar PV and battery costs follow the most optimistic cost reduction curves available solar can become the dominant technology in the mix (share almost 60%)

# CCS transitional measures

# Possible technological development

## CCS assumptions

| | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|
| **Capital cost [$€_{2010}$/kW]** | | | | | | |
| Lignite CCS | 2600 | 2530 | 2470 | 2400 | 2330 | 2250 |
| Coal CCS | 2500 | 2430 | 2370 | 2300 | 2230 | 2150 |
| Gas CCS | 1350 | 1330 | 1310 | 1290 | 1270 | 1250 |
| **Efficiency [%]** | | | | | | |
| Lignite CCS | 37 | 39 | 40 | 41 | 42 | 43 |
| Coal CCS | 39 | 40 | 41 | 41 | 42 | 43 |
| Gas CCS | 52 | 54 | 56 | 57 | 58 | 60 |
| CCS T&S cost [$€_{2010}/tCO_2$] | 19 | 18 | 17 | 15 | 14 | 13 |

Contingent on deployment of demonstration plants

## Demonstration CCS

| Project Until 2020 | Capital cost [$€_{2010}$/kW] | Efficiency [%] | Post-demo 2025 | Capital cost [$€_{2010}$/kW] | Efficiency [%] |
|---|---|---|---|---|---|
| Lignite CCS | 2600 | 31 | | 2600 | 37 |
| Coal CCS | 2500 | 33 | | 2500 | 39 |
| Gas CCS | 1350 | 48 | | 1350 | 52 |

# Three types of measures investigated

- Capital grants
  - capex support, public co-funding of investment costs
- Feed-in premium
  - opex support, fixed payment to producer for every MWh generated
- Emission performance standard
  - limit on specific emissions
  - Tested both an EU-wide portfolio limit and a limit for individual generators

# Capital grants (CAPEX support)

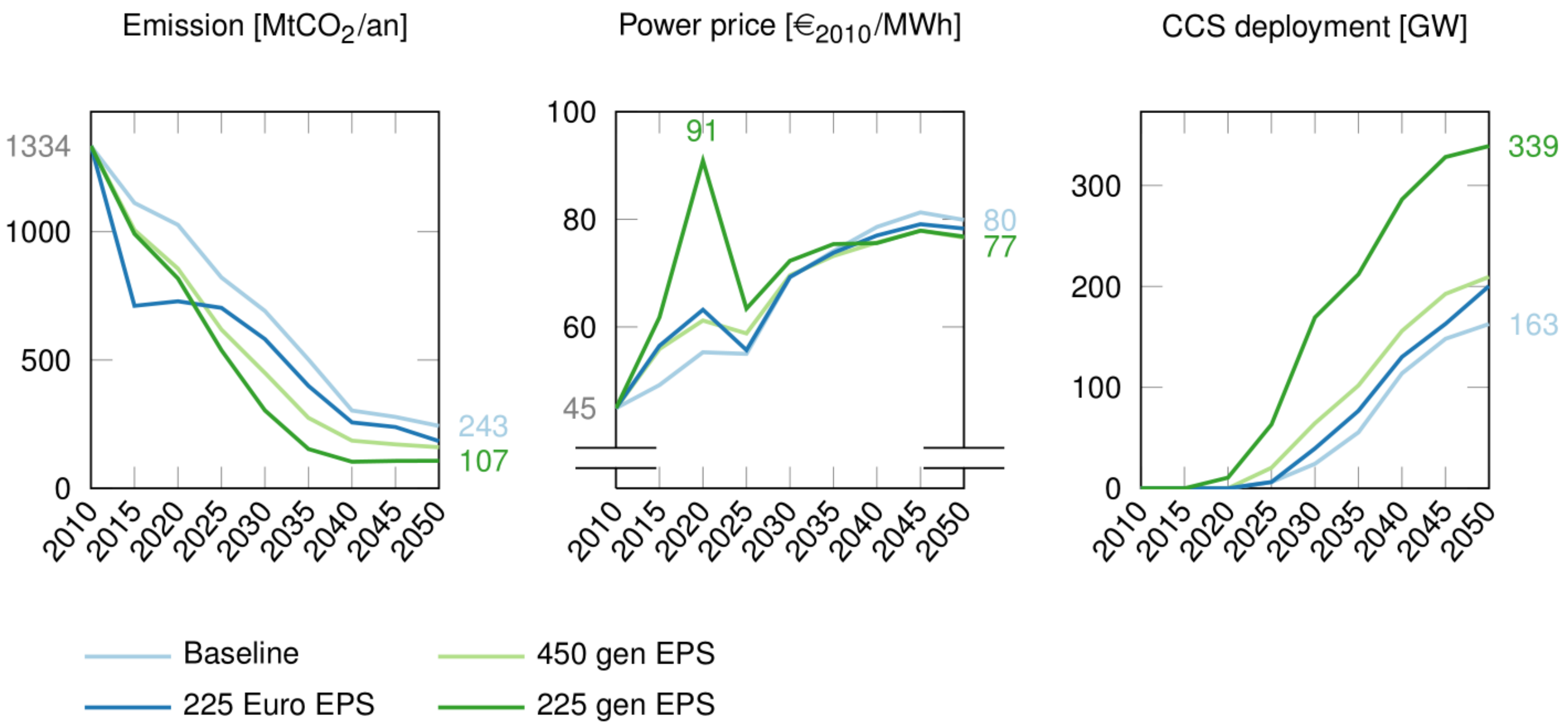
- Design: given share of the capital costs covered
- Different levels tried
- Result: a support level of 2000 $€_{2010}$/kW needed to spur investments
- Result: 4.1 GW of lignite CCS deployed. Cost: 6.5 bn € (NPV in 2015)

# Feed-in premium

| Type | | End | Gas | Lignite | Total | 2015 NPV | LCOS |
|---|---|---|---|---|---|---|---|
| Flat [€/MWh] | SRMC [%] | | [GW] | [GW] | [GW] | [bn€] | [€/MWh] |
| | 45.0 | 2030 | No deployment | | | | |
| | 50.0 | 2030 | 1.9* | | 1.9 | 6.6 | 40.0 |
| | 55.0 | 2030 | 5.0* | | 5.0 | 20.9 | 43.7 |
| | 30.0 | 2050 | No deployment | | | | |
| | 35.0 | 2050 | | 5.0 | 5.0 | 12.6 | 31.3 |
| 20.0 | | 2030 | No deployment | | | | |
| 25.0 | | 2030 | | 4.1 | 4.1 | 6.2 | 15.8 |
| 10.0 | | 2050 | No deployment | | | | |
| 15.0 | | 2050 | | 2.8 | 2.8 | 4.0 | 15.0 |
| 17.5 | | 2050 | | 4.1 | 4.1 | 6.6 | 17.5 |
| 20.0 | | 2050 | | 5.0 | 5.0 | 9.4 | 20.0 |
| 20.0 | | 2030 | No deployment | | | | |
| (L) 15.0 | (G) 32.5 | 2050 | 1.2 | 2.8 | 4.1 | 6.9 | 18.8 |
| (L) 17.5 | (G) 32.5 | 2050 | 0.9 | 4.1 | 5.0 | 8.7 | 18.8 |

- SRMC: short-run marginal cost
- Fuel + variable O&M + carbon price + CCS transport and storage
- Determines the dispatch!
- (L) – lignite CCS, (G) – natural gas CCS

# Emission performance standard




**Specific emissions for unabated generation**

- Coal: 786 $gCO_2$/kWh
- Gas CCGT: 336 $gCO_2$/kWh
- Gas OCGT: 505 $gCO_2$/kWh

# Some insights

- CCS can be a major contributor to cost-efficient decarbonization of European power
- Without CCS decarbonization will be more expensive– even for less emission reduction (given the same ETS price)
- Support schemes needed to secure deployment of demonstration CCS
  - CAPEX support can help CCS with low fuel costs
  - OPEX support needed for gas CCS
- Emissions performance standard (EPS) is an effective emission reduction mechanism
  - A limit of 225 g$CO_2$/kWh for generators drive down emissions
  - Results in a transitional period with high prices

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NCCS

NORWEGIAN CCS RESEARCH CENTRE

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*b: SINTEF Energy*

# NCCS Task Meeting

## Optimal Design and Operations of a CCS Value Chain

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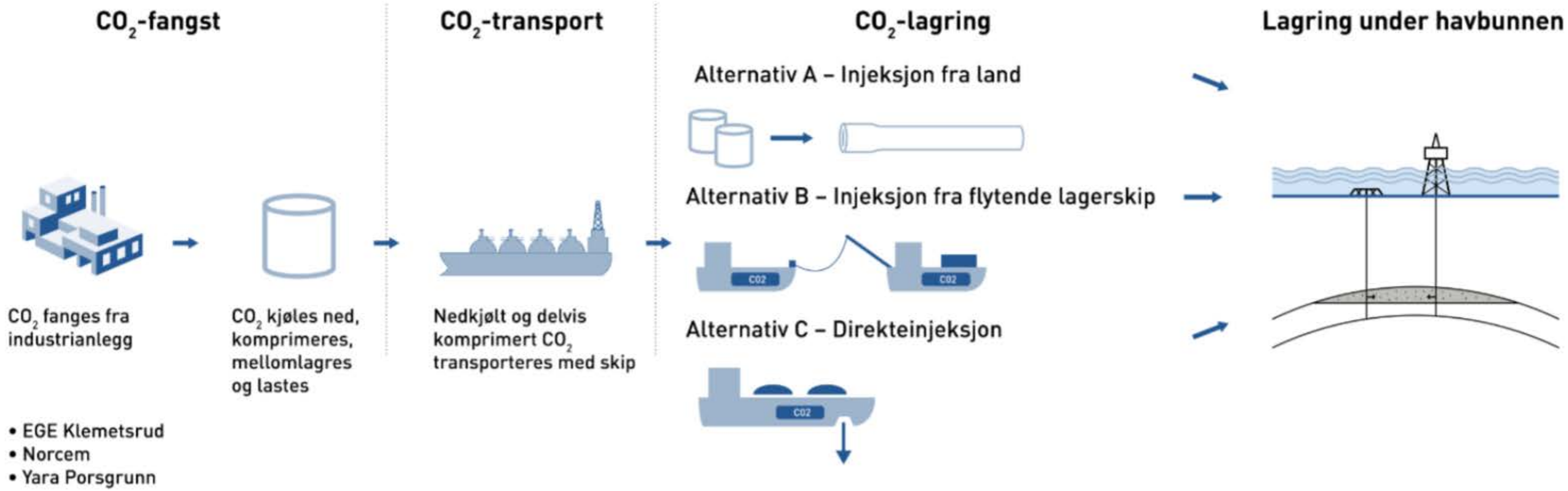
# A Norwegian CCS Value Chain




- Decarbonizing industry in eastern Norway
- Transport by ship or pipelines
- Store carbon offshore on the west cost

# Research question and discussion

- Focus on optimal strategic and operational decisions.
- Value chain design
  - From subsidised transition to well functioning markets
- How do the firms in the value chain get the right signals?
  - Transform the technology from system optimal and climate friendly to investor friendly
  - Expectations of costs, profit and acceptable risks for the firms
    - Who carries the burden?

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