NORWAY AS A FLEXIBILITY PROVIDER FOR A LOW-CARBON EUROPEAN ENERGY SYSTEM

Christian Skar
Department of Industrial Economics and Technology Management
Norwegian University of Science and Technology (NTNU)

Co-authors: Kjetil Midthun (SINTEF Technology and Society)
Asgeir Tomasgard (NTNU)

15th IAEE European Conference 2017, Vienna, Austria, 06.09.2017

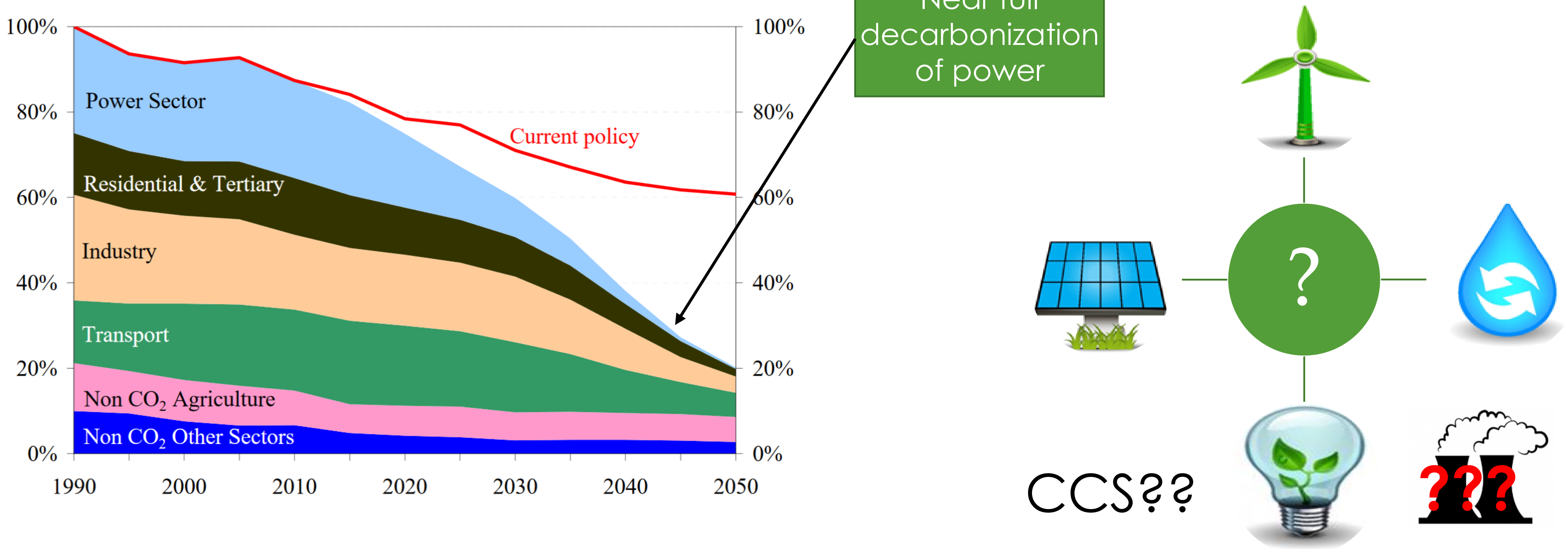
FME FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

IAEE INTERNATIONAL ASSOCIATION for ENERGY ECONOMICS
WWW.IAEE.ORG

CenSES
Centre for Sustainable Energy Studies

Backdrop: European Decarbonization

Figure 1: EU GHG emissions towards an 80% domestic reduction (100% =1990)



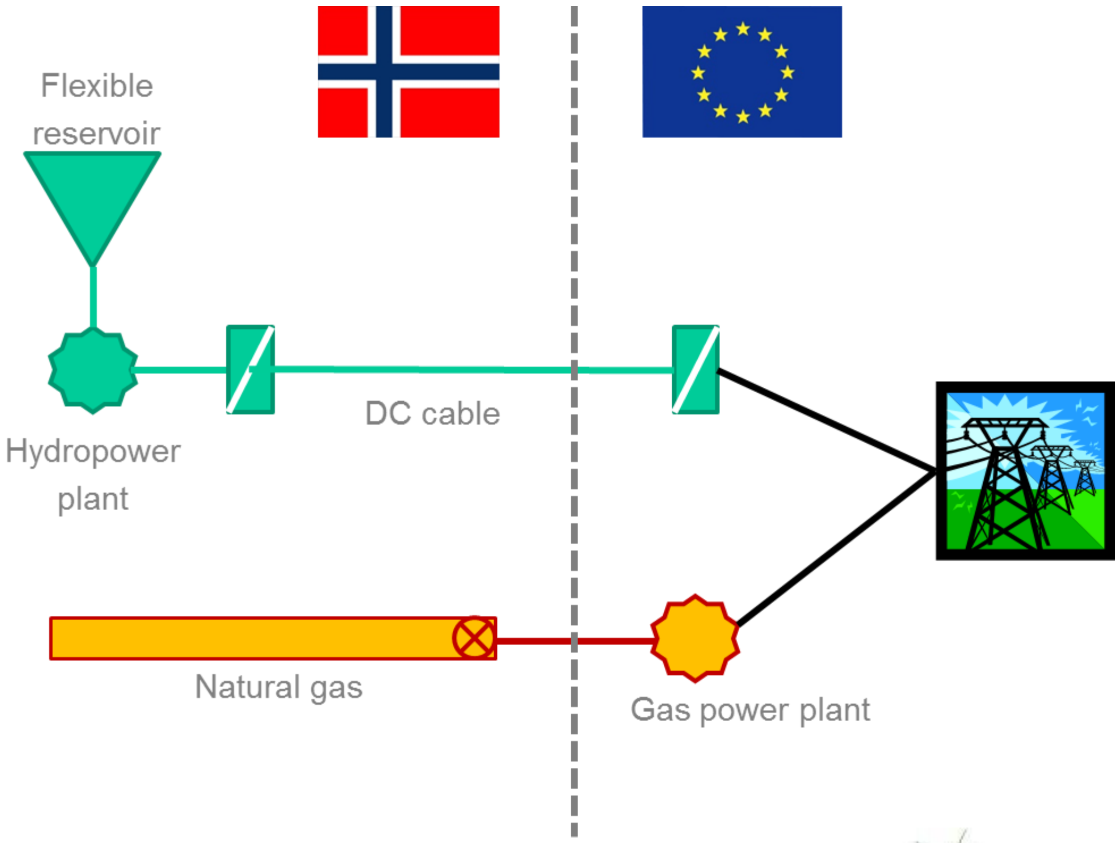
Source: European Commission. (2011). A Roadmap for moving to a competitive low carbon economy in 2050. *Communication from The Commission to The European Parliament, The Council, The European Economic and Social Committee and The Committee of The Regions, COM(2011).*

FME Forsknings-senter for miljøvennlig energi
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

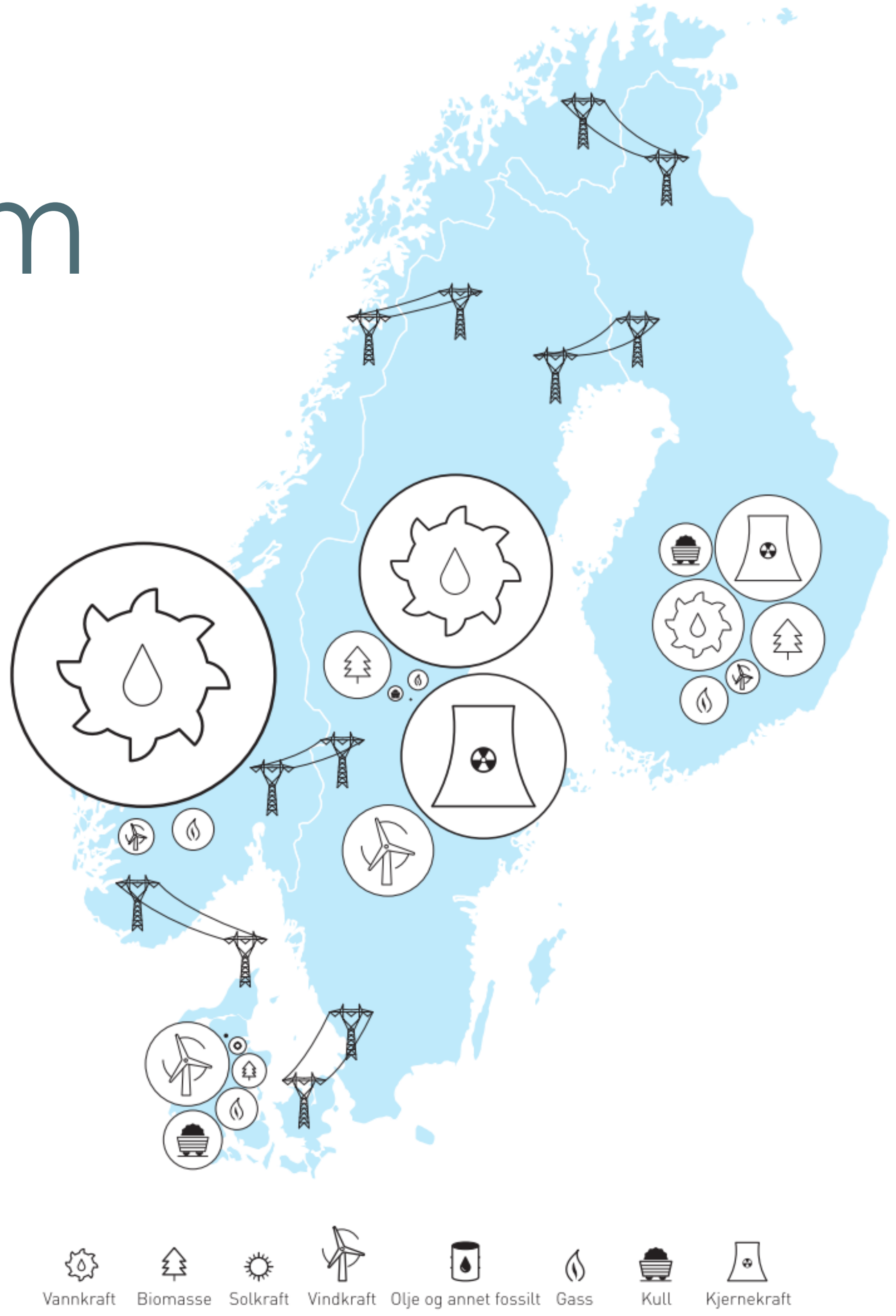
Norway as a flexibility provider for a low-carbon European energy system

- Techno-economic study of the transistion to a low-carbon European power sector
- Look at mix of low-carbon technologies, interconnector expansions and use of energy storage
- Focus on Norwegian **results**
  - Optimal expansion of interconnectors
  - Power exchange
  - Use of natural gas for power generation in countries to which Norway exports



Nordic power system

- **Norway**
- Annual production: 138 TWh (>95% hydropower)
- Reservoir capacity 85 TWh
- Largest reservoir 8 TWh
- Between 5 and 11 TWh surplus
- Cabels to the Denmark and the Netherlands (Germany and UK cables are under way)



Source: Olje- og energidepartementet. (2016). *Meld. St. 25 (2015–2016) - Kraft til endring — Energipolitikken mot 2030* (Vol. 25).

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

ES
able Energy Studies

Norwegian natural gas trade (2015)

First delivery country	Share of total
France	15.1 %
UK	24.5 %
Germany	42.3 %
Belgium	12.3 %
LNG	5.3 %

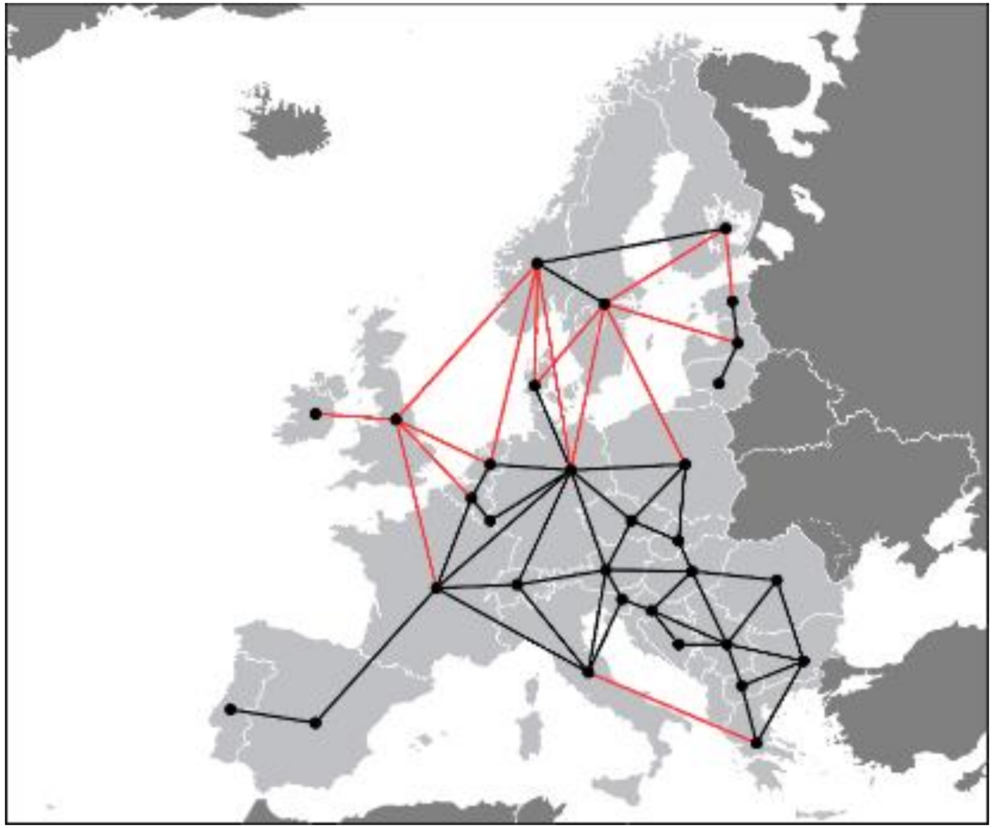
Norway is the 3rd largest exporter of natural gas and supplies about 25 % of the European gas demand (2016)

Source: Norwegian Petroleum Directorate, Gassco

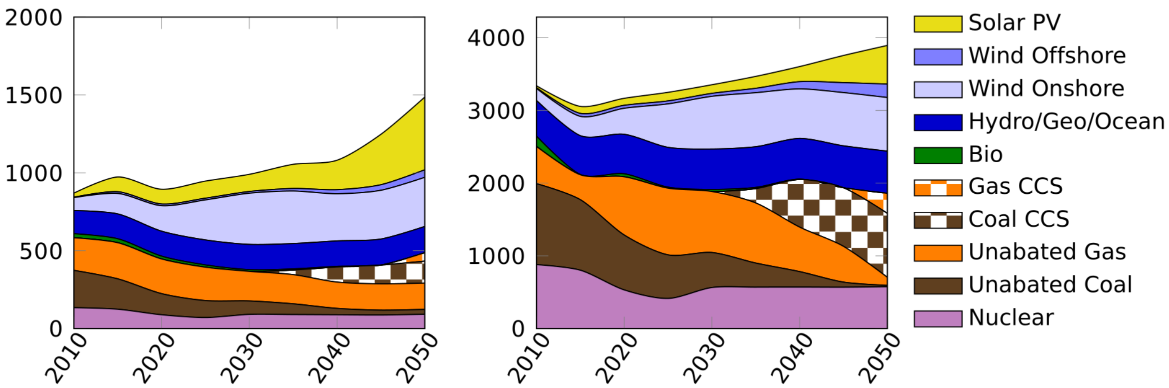
FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Co-optimization of strategic and operational decisions

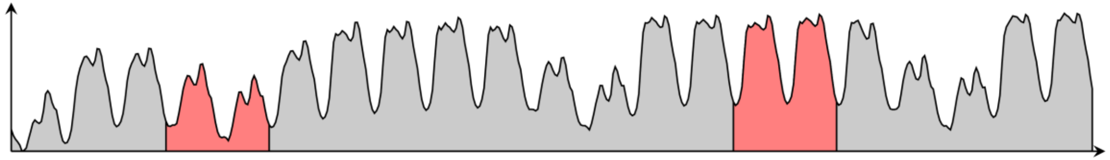


Optimal investment strategy 2010-2015



Coupled optimization problem to minimize total system costs

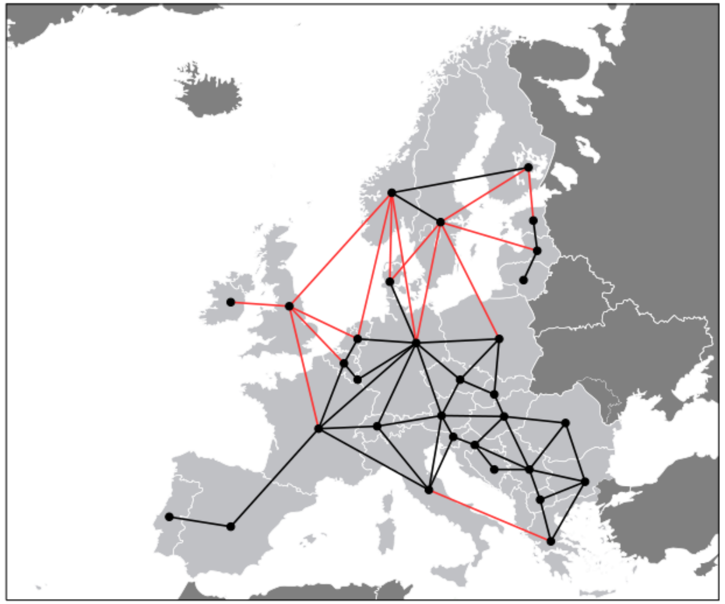
Optimal dispatch for a number of representative 48-hour blocks



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

Energy Studies

European Model for Power system Investment with (high shares of) Renewable Energy (EMPIRE)



Multi-horizon Stochastic Program

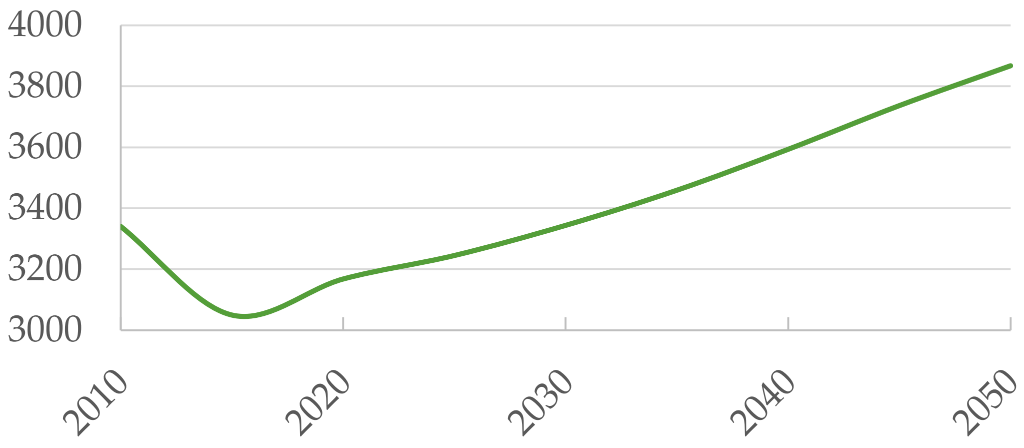
- Long-term dynamics (multi-period investments)
- Short-term dynamics (multi-period operation)
- Short-term uncertainty

Modeling assumptions

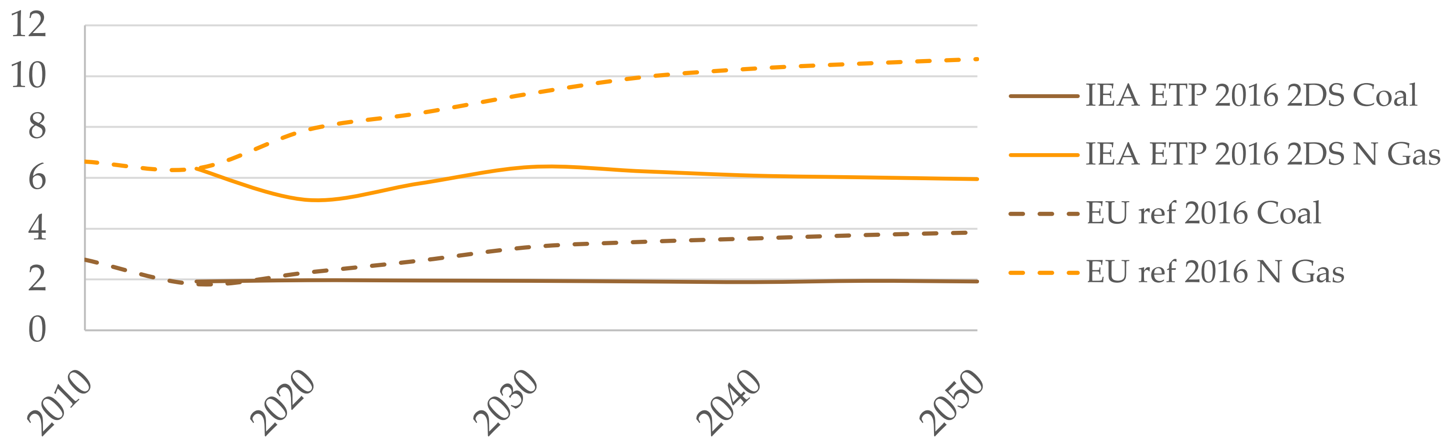
- Perfect competition (system cost minimization formulation)
- Inelastic demand
- Generation capacity aggregated per technology (i.e. do not model individual plants)
- Investments are continuous
- Lines are independent (i.e. transportation network)
- Perfect foresight about fuel prices, carbon price, and load development.

Assumptions

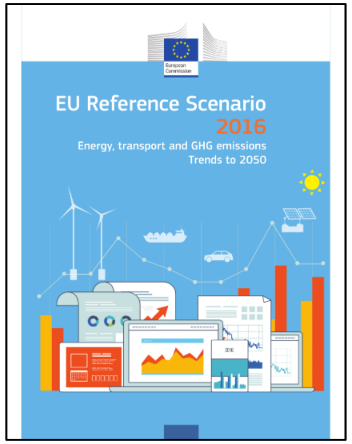
European demand for electricity [TWh/an]



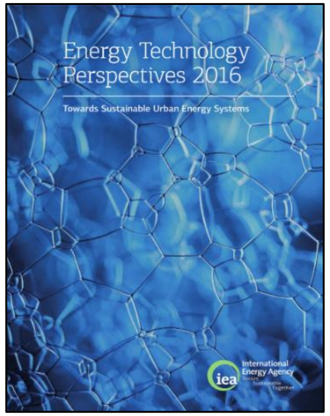
Fuel Prices [€2010/GJ]



EU reference scenario 2016

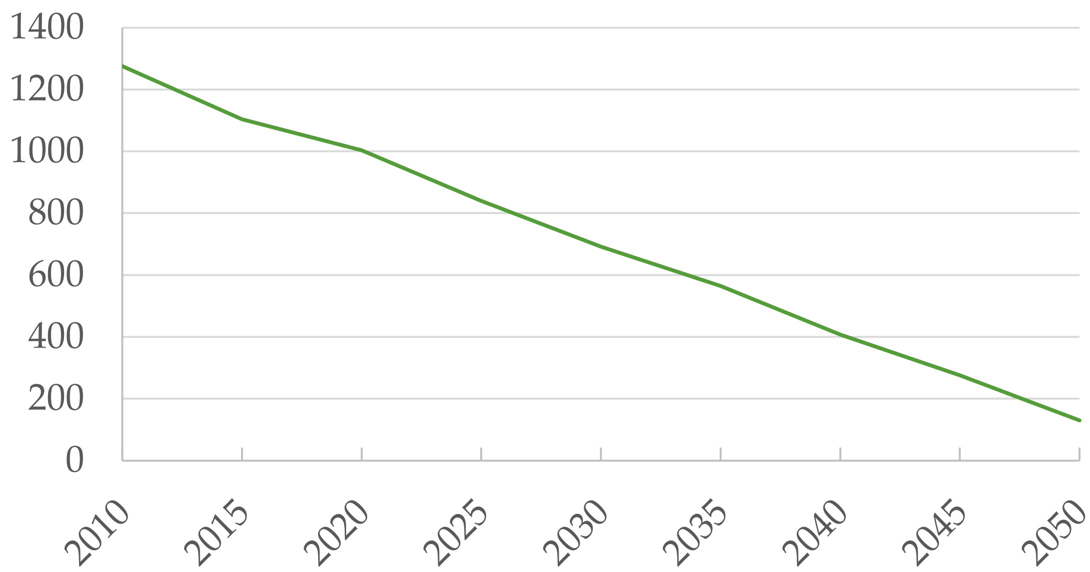


IEA Energy Technology Perspective 2016



Scenario assumptions

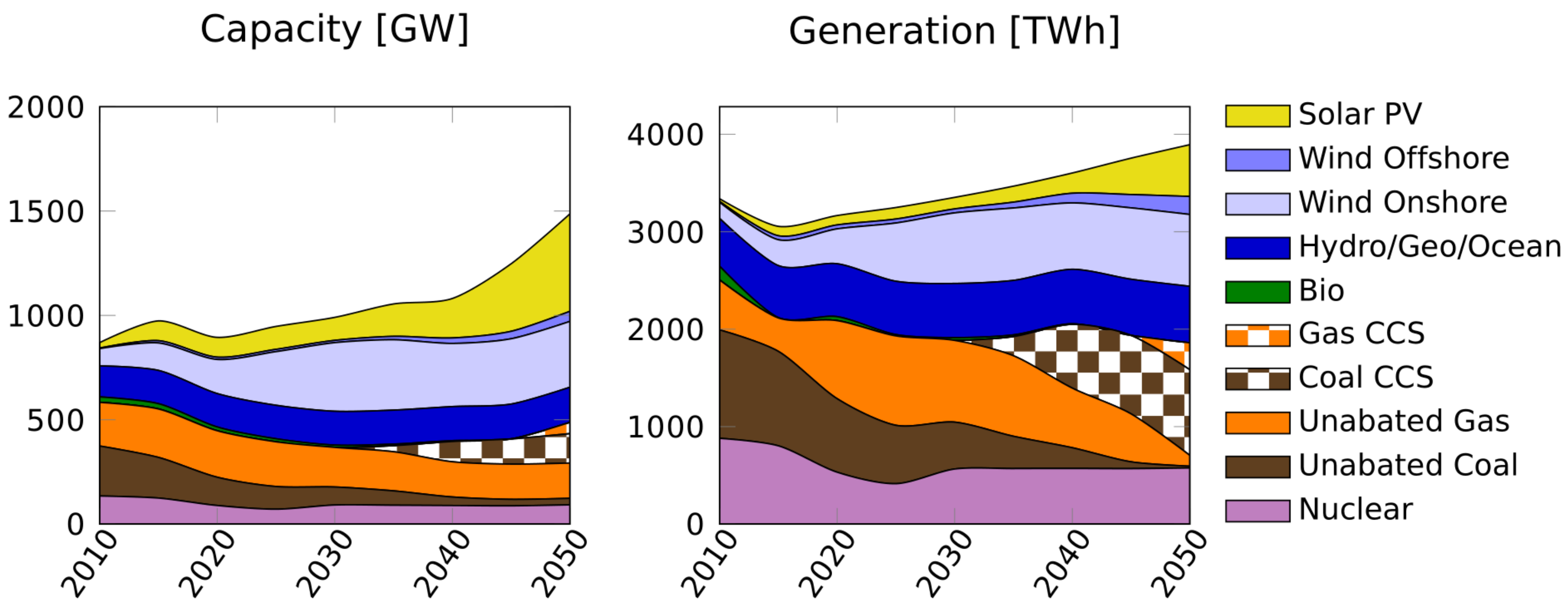
1. Baseline decarbonization: **90 % emission reduction from 2010 to 2050**
   i. Nuclear capacities limited to the ENTSO-E vision 1&2 (medium nuclear) scenarios in the 2016 Ten Year Development Plan (TYDP) .
   ii. Grid expansion towards 2020 fixed to ENTSO-E's 2016 TYDP reference capacities.
      i. Beyond 2020: expansion limit of 4 GW for each interconnector every five year period
   iii. Development of Norwegian hydro power predefined
   iv. Renewable electricity generation targets set for Germany, France, Spain and the UK.
   v. Wind onshore capacity potential from IEA's NETP 2016
2. Alternative scenario NoCCS: same as baseline but no carbon capture and storage available



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

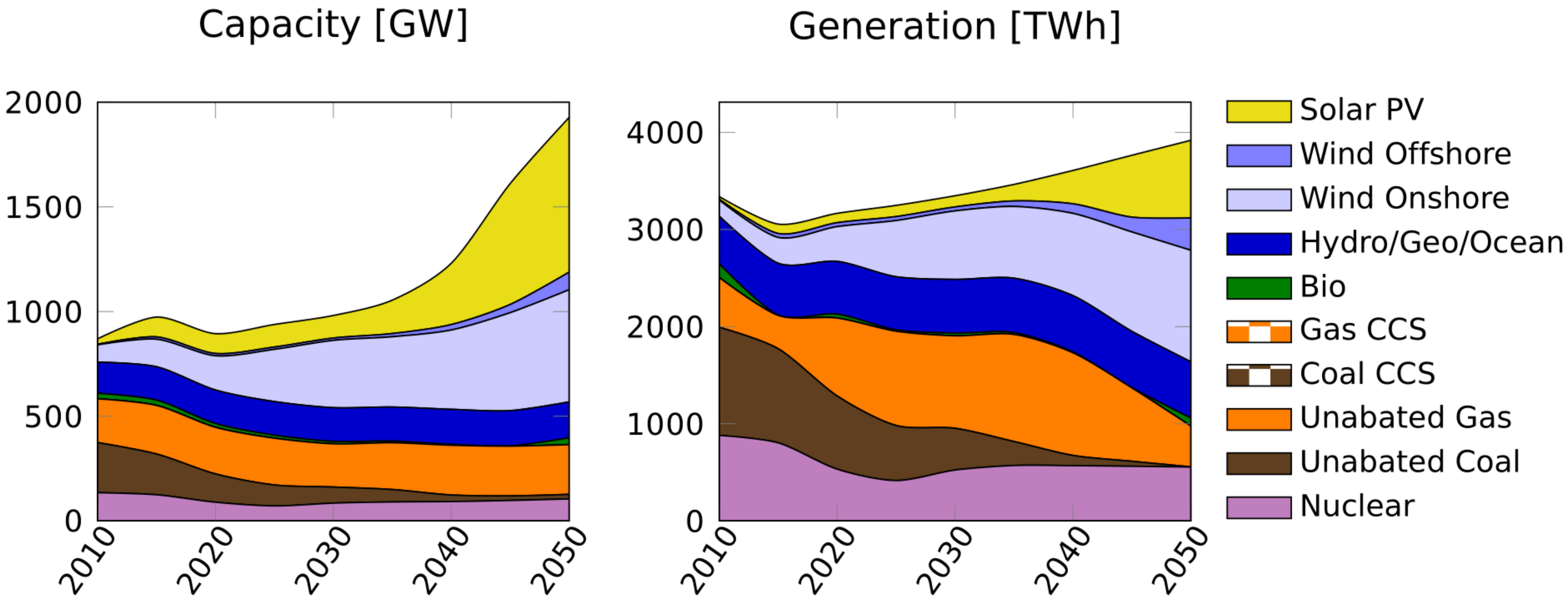
CenSES
Centre for Sustainable Energy Studies

Baseline scenario: 90 % emission reduction



Technology/fuel (2050)	Capacity [GW]	Generation [TWh]
CCS	196 (13%)	1155 (30 %)
Wind	364 (24%)	922 (24 %)
Solar	467 (31%)	532 (14 %)
Coal (unabated)	31 (2%)	18 (0%)
Natural gas (unabated)	169 (11%)	111 (3%)

NoCCS scenario: 90 % emission reduction

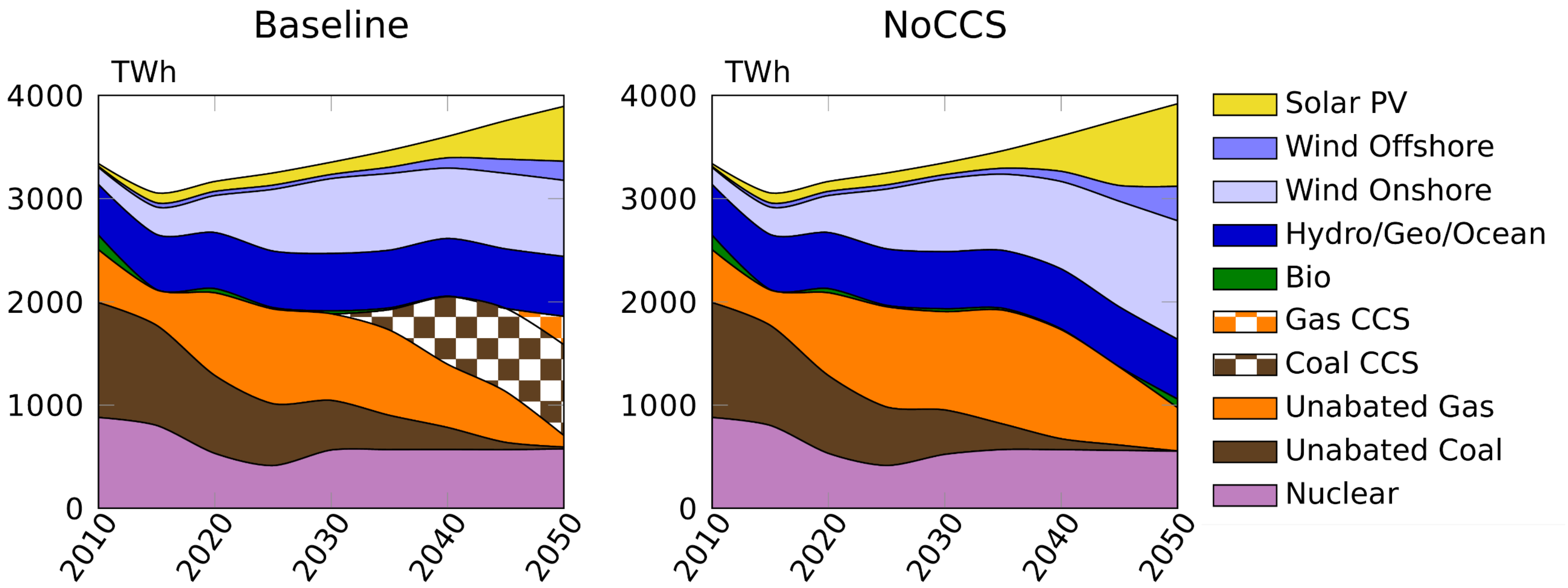


Technology/fuel (2050)	Capacity [GW]	Generation [TWh]
CCS		
Wind	620 (32%)	1481 (38%)
Solar	739 (38%)	800 (20 %)
Coal (unabated)	22 (1%)	2 (0%)
Natural gas (unabated)	238 (12%)	420 (11%)

FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

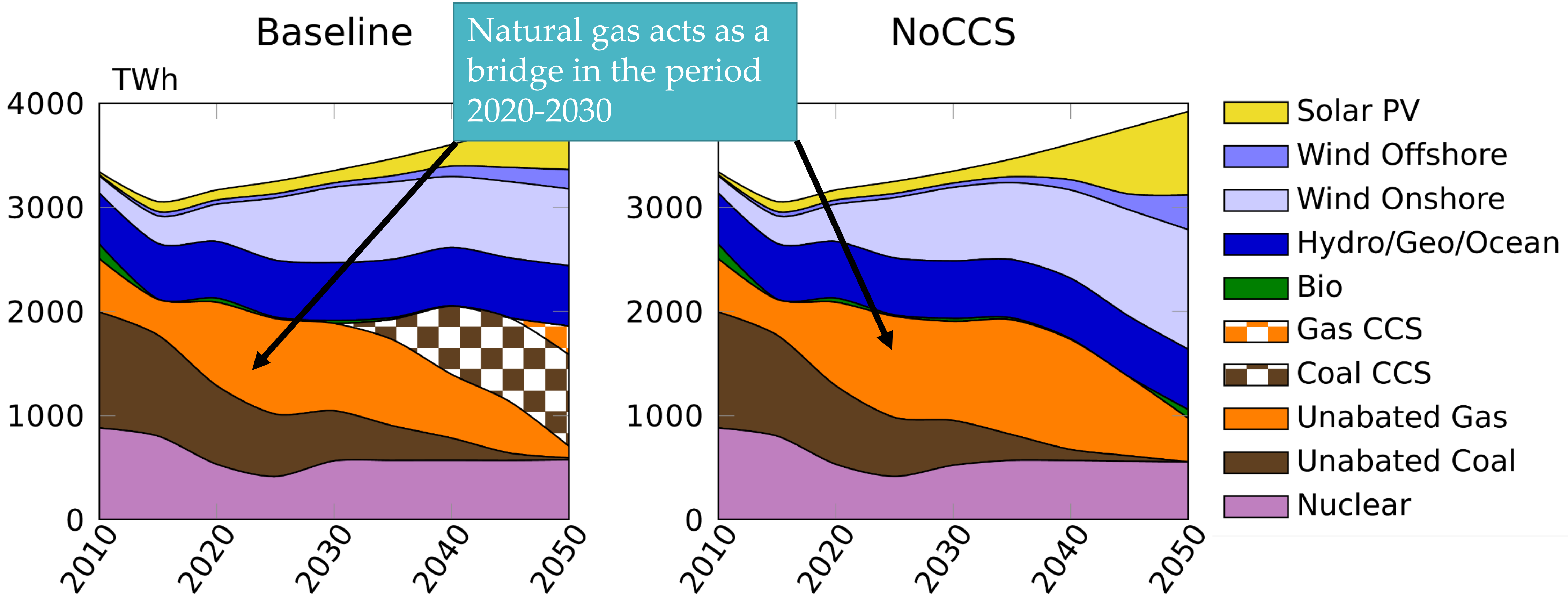
Transition to a low-carbon European power sector



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

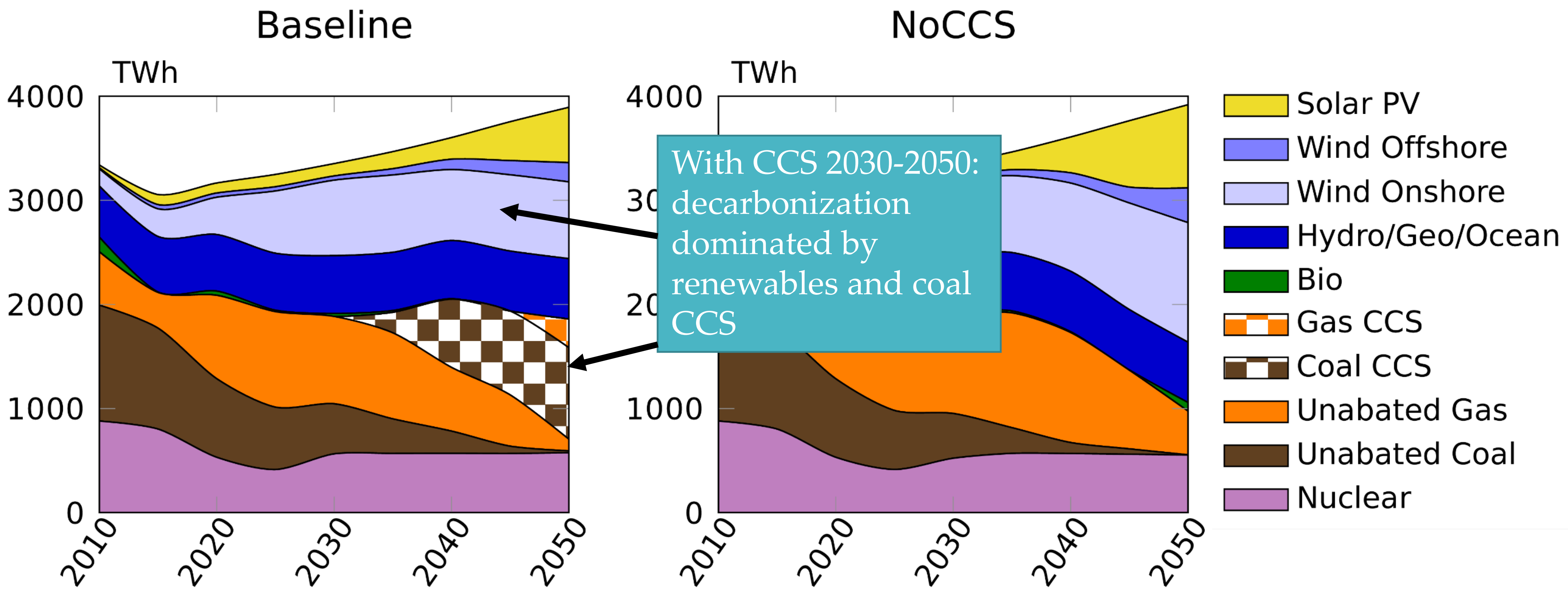
Transition to a low-carbon European power sector



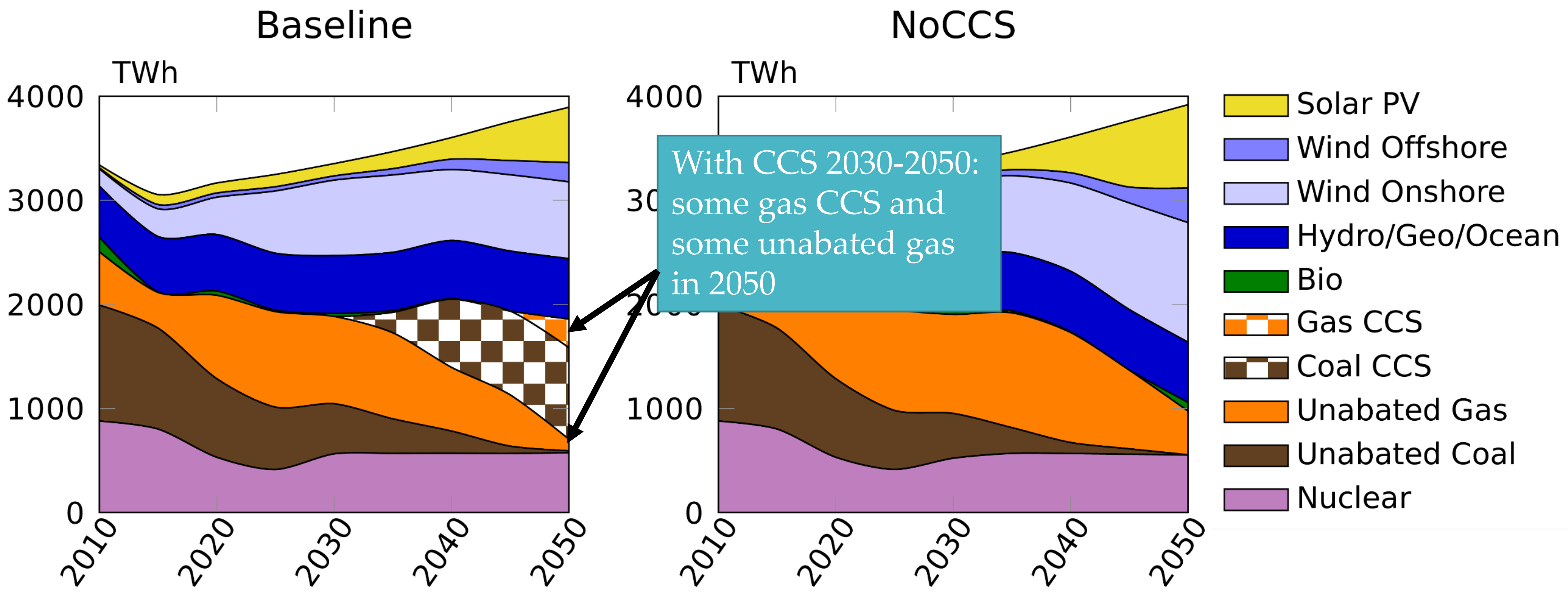
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Transition to a low-carbon European power sector



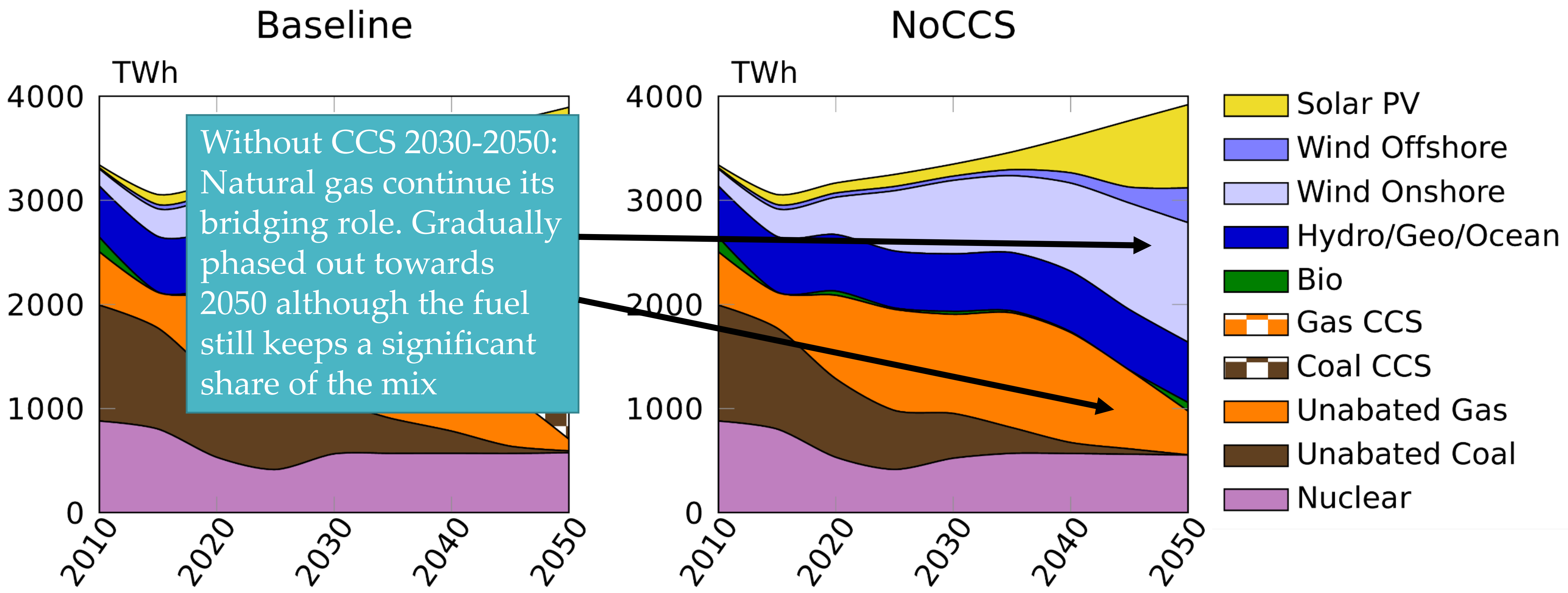
Transition to a low-carbon European power sector



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Transition to a low-carbon European power sector

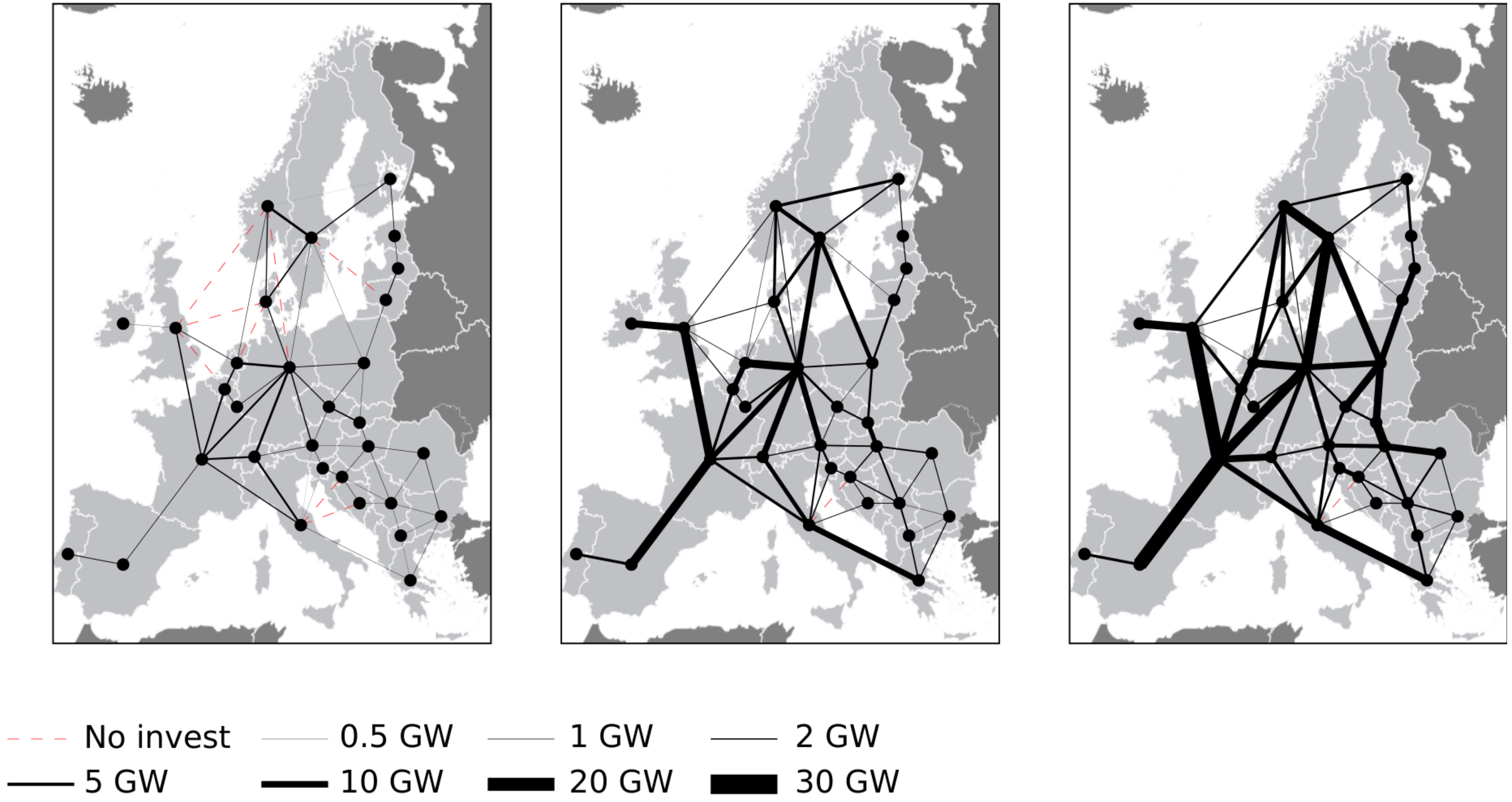


FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Transmission

2010 Baseline 2050 NoCCS 2050



Baseline
European cross-boarder interconnector expansion: capacity increases by 370 % from 2010 to 2050

NoCCS
Capacity increases by 640 % from 2010 to 2050

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Norwegian power system 2050

Type	Baseline [TWh]	NoCCS [TWh]
Demand	152	152
Production	206	265
Reservoir hydro	*117*	*118*
Run-of-the-river hydro	*33*	*32*
Onshore wind	*56*	*55*
Offshore wind		*59*
Export	74	144
Import	21	33
Net export	53	111

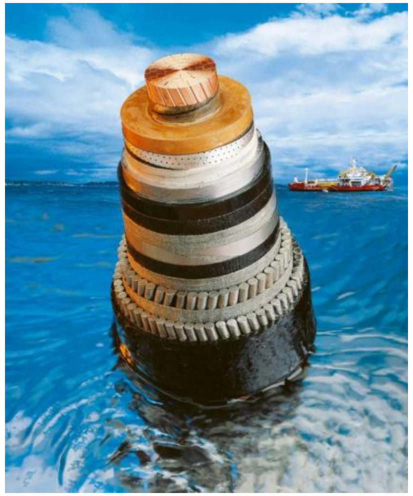
Photo: GE, from t-a.no/

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Norway interconnectors

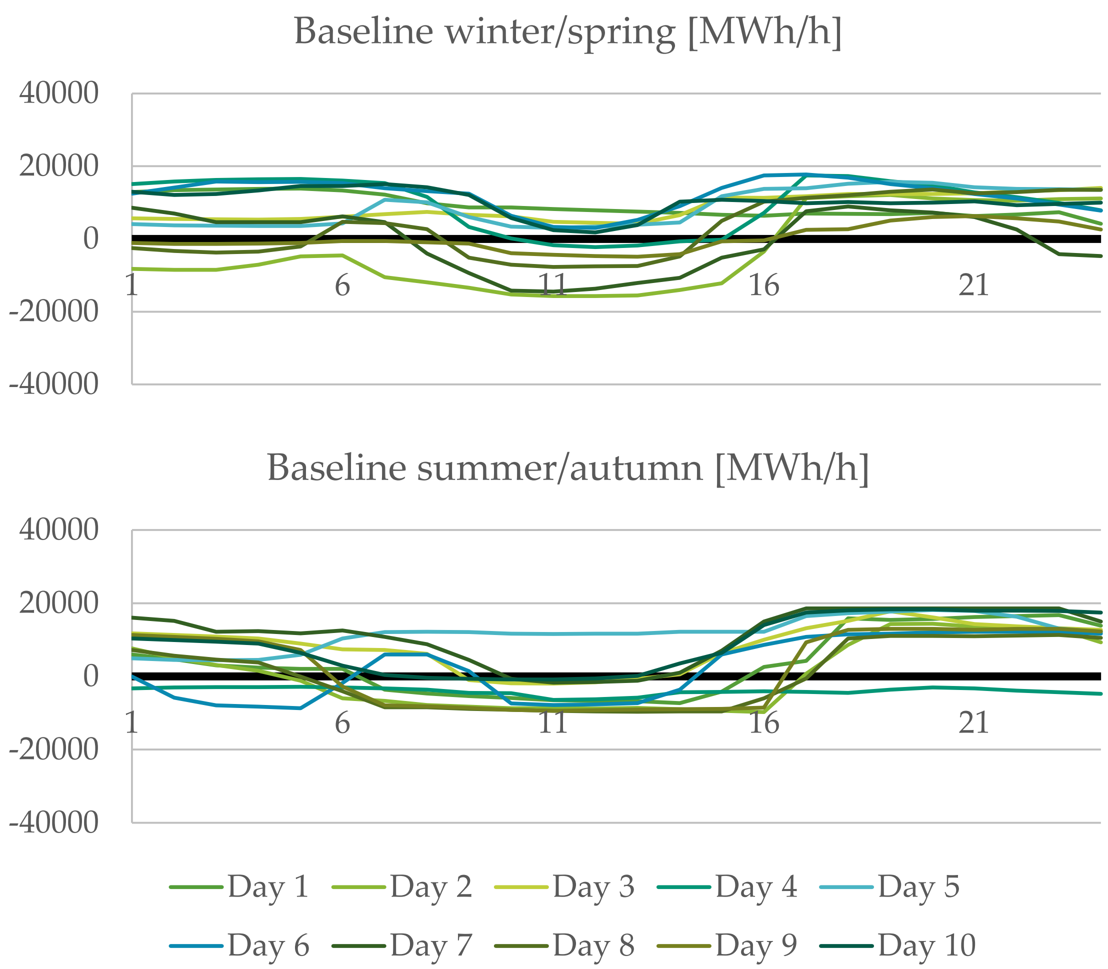
Inteconnector [MW]	2020 (ENTSO-E TYNDP 2016)	Baseline 2050	NoCCS 2050
Sweden	4 000	6 300	14 600
Denmark	1 600	4 200	6 700
Finland	100	4 600	3 900
Germany	1 400	1 400	1 400
Great Britain	1 400	1 400	4 200
Netherlands	700	700	7 600
Total	***9 200***	***18 600***	***38 400***

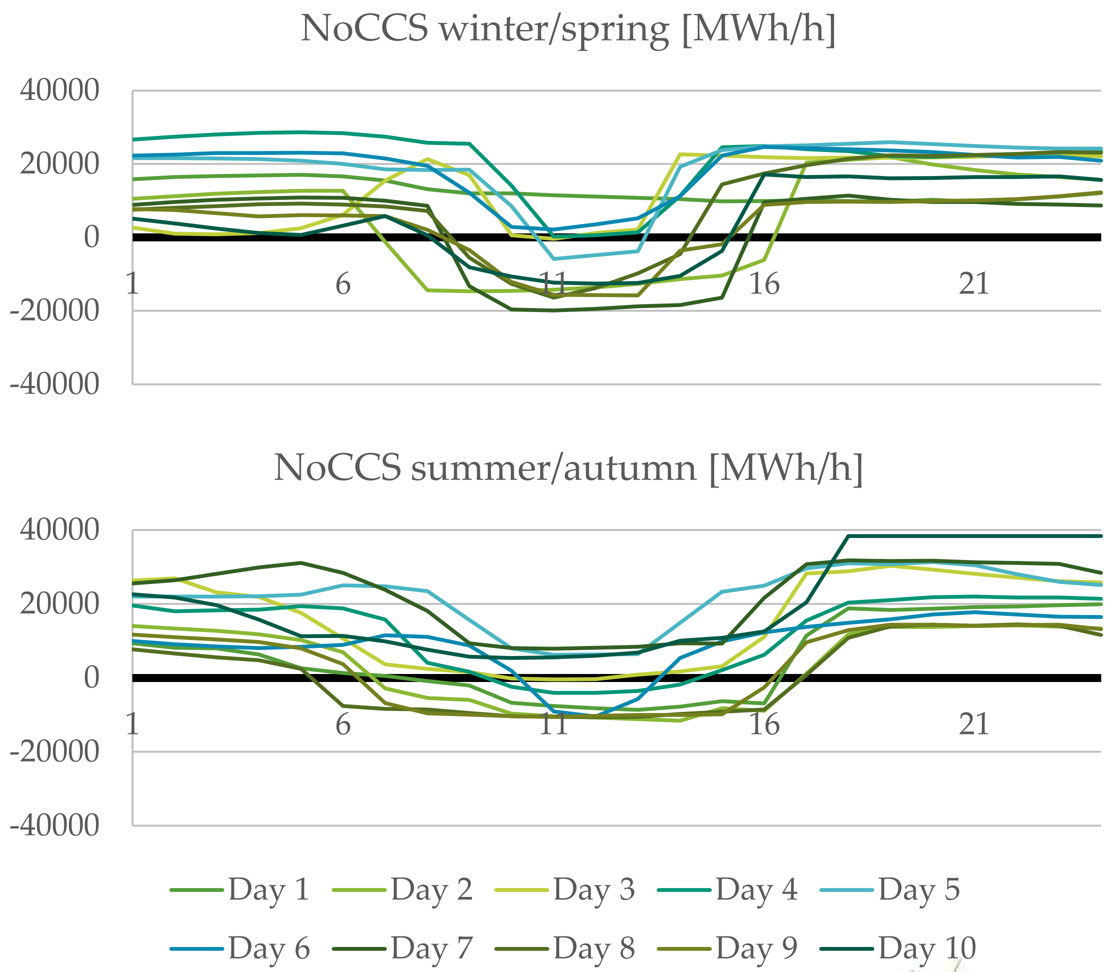


FME FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Norwegian power exchange 2050: Baseline (left) vs NoCCS (right)

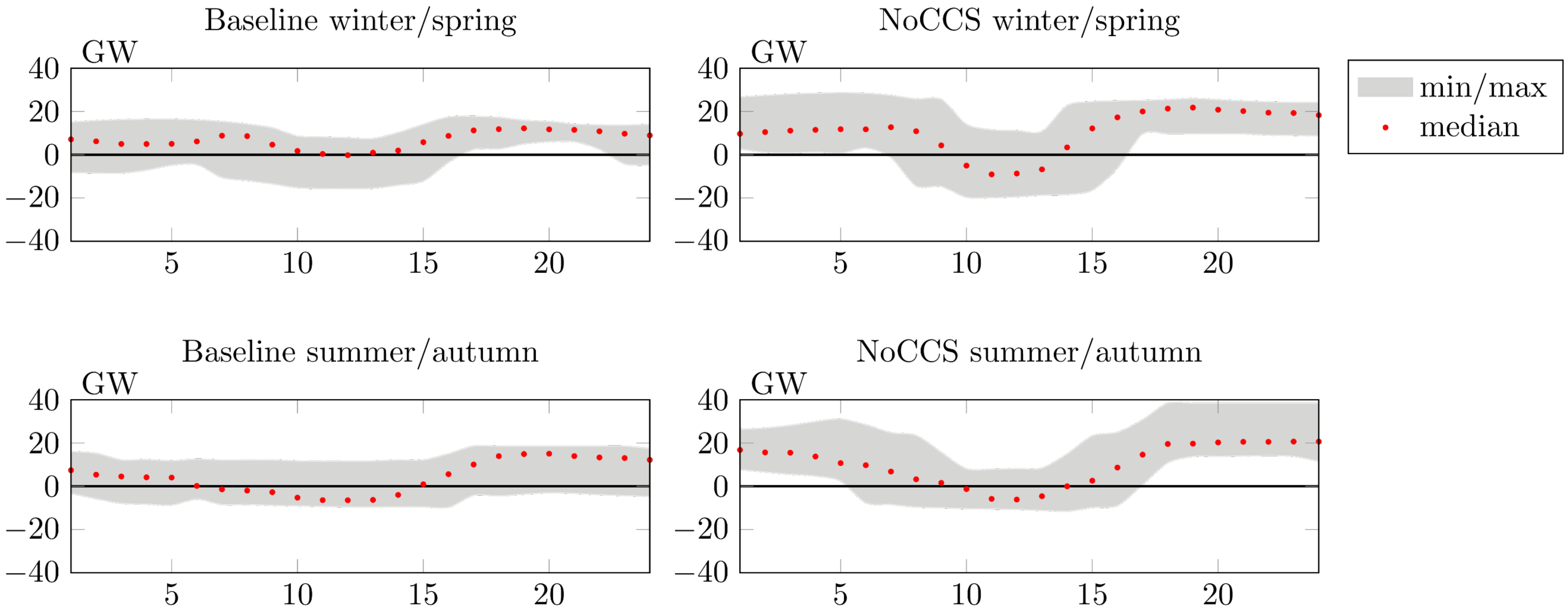




FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

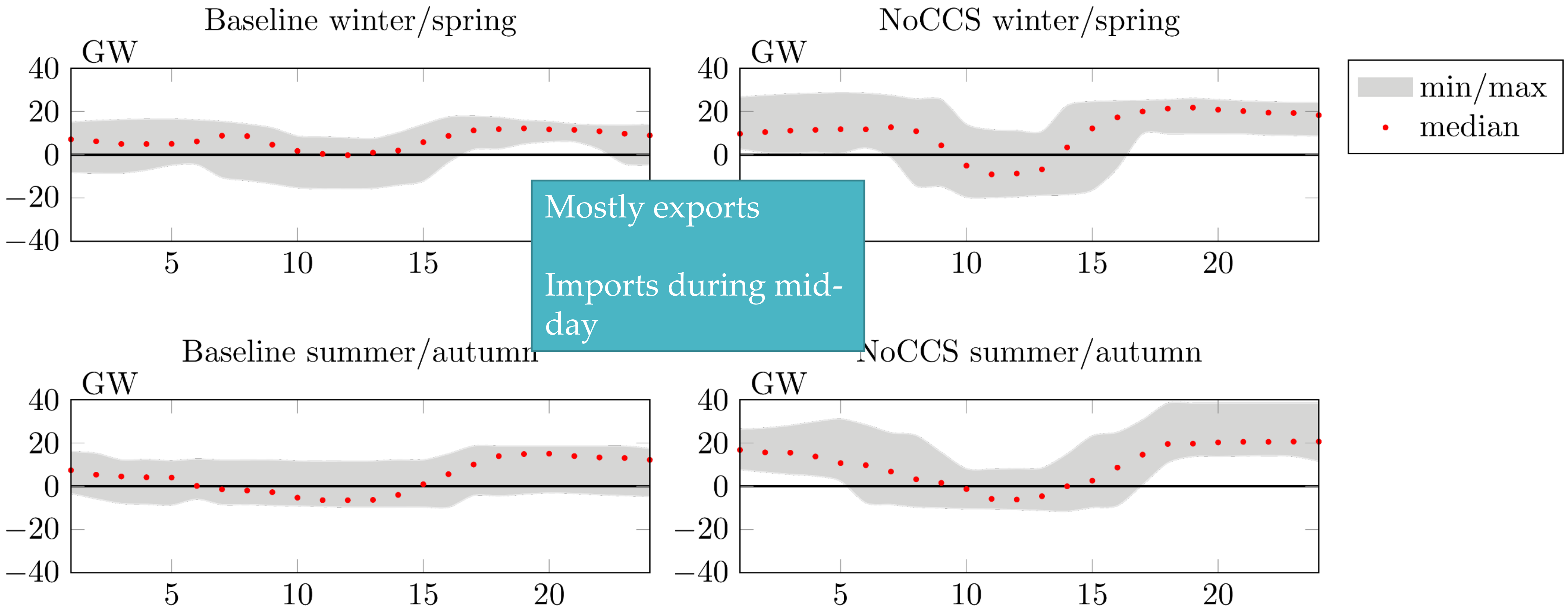
Norwegian power exchange 2050: Baseline (left) vs NoCCS (right)



FORSKNINGS-
SENTER FOR
MILJØVENNLIG
ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Norwegian power exchange 2050: Baseline (left) vs NoCCS (right)



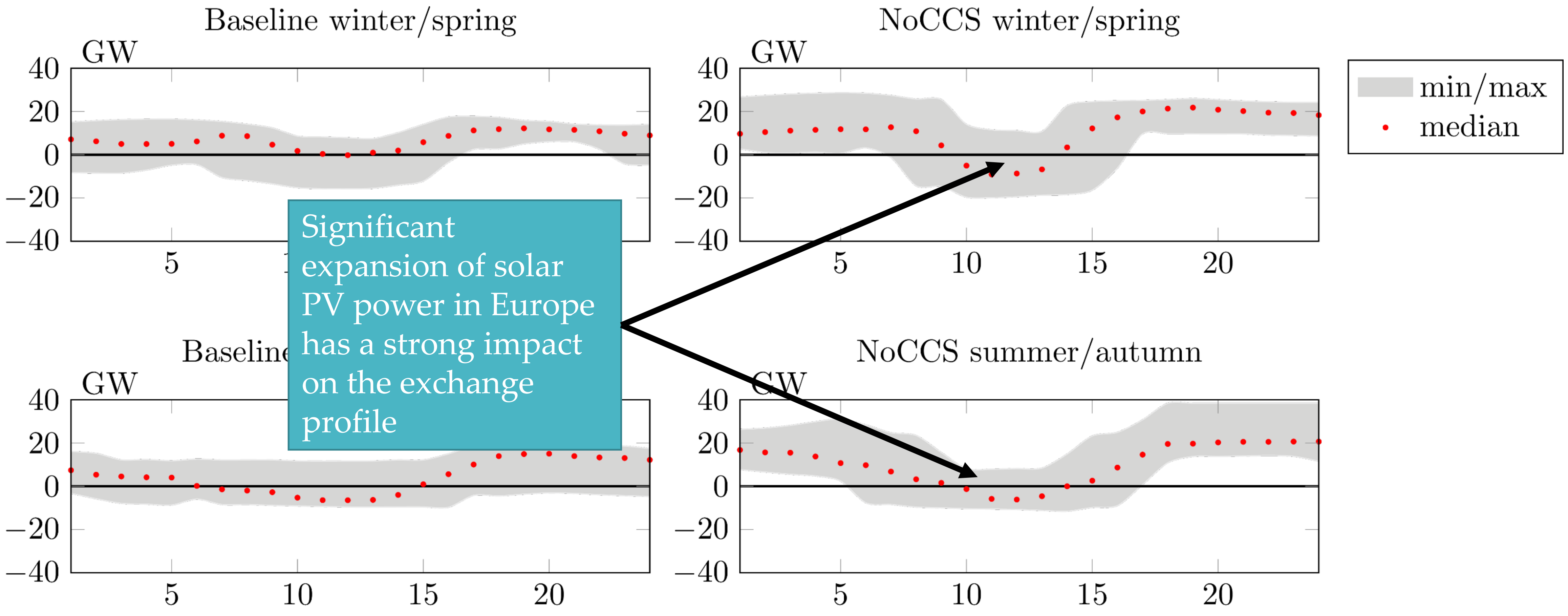
Mostly exports

Imports during mid-day

FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

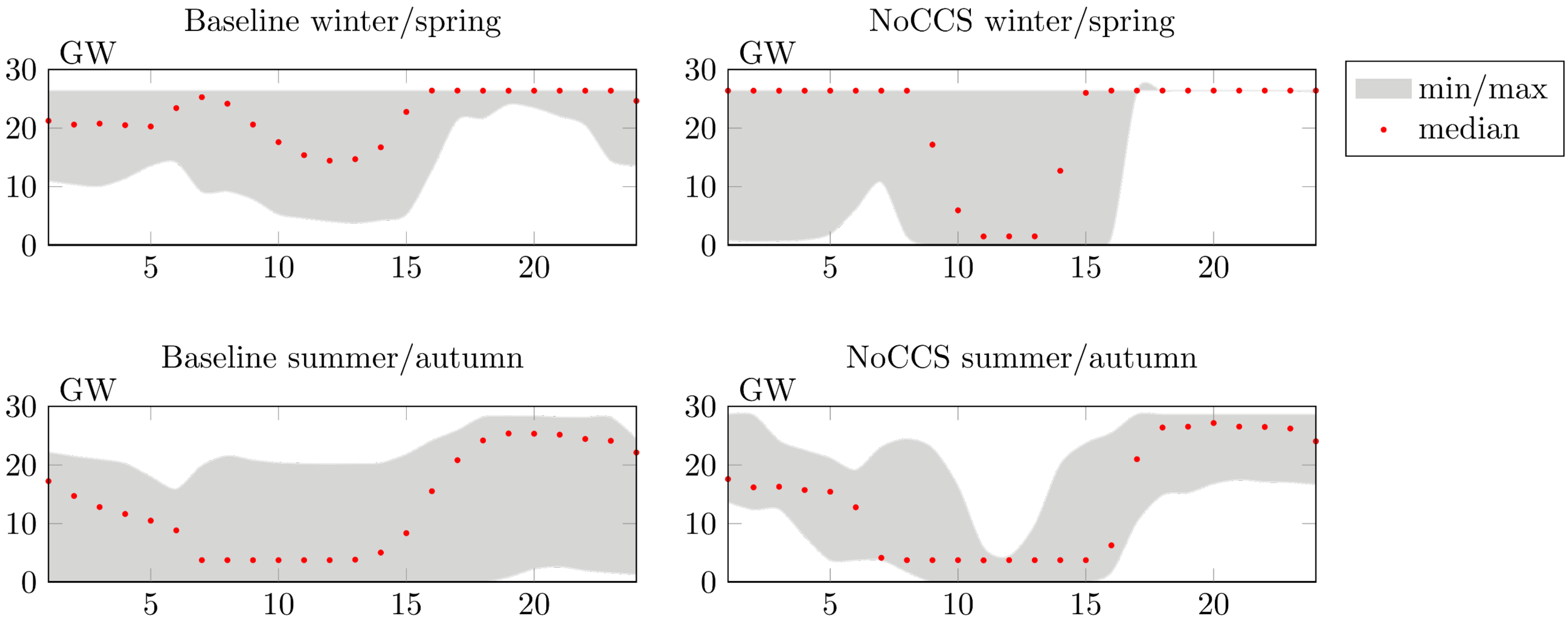
Norwegian power exchange 2050: Baseline (left) vs NoCCS (right)



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

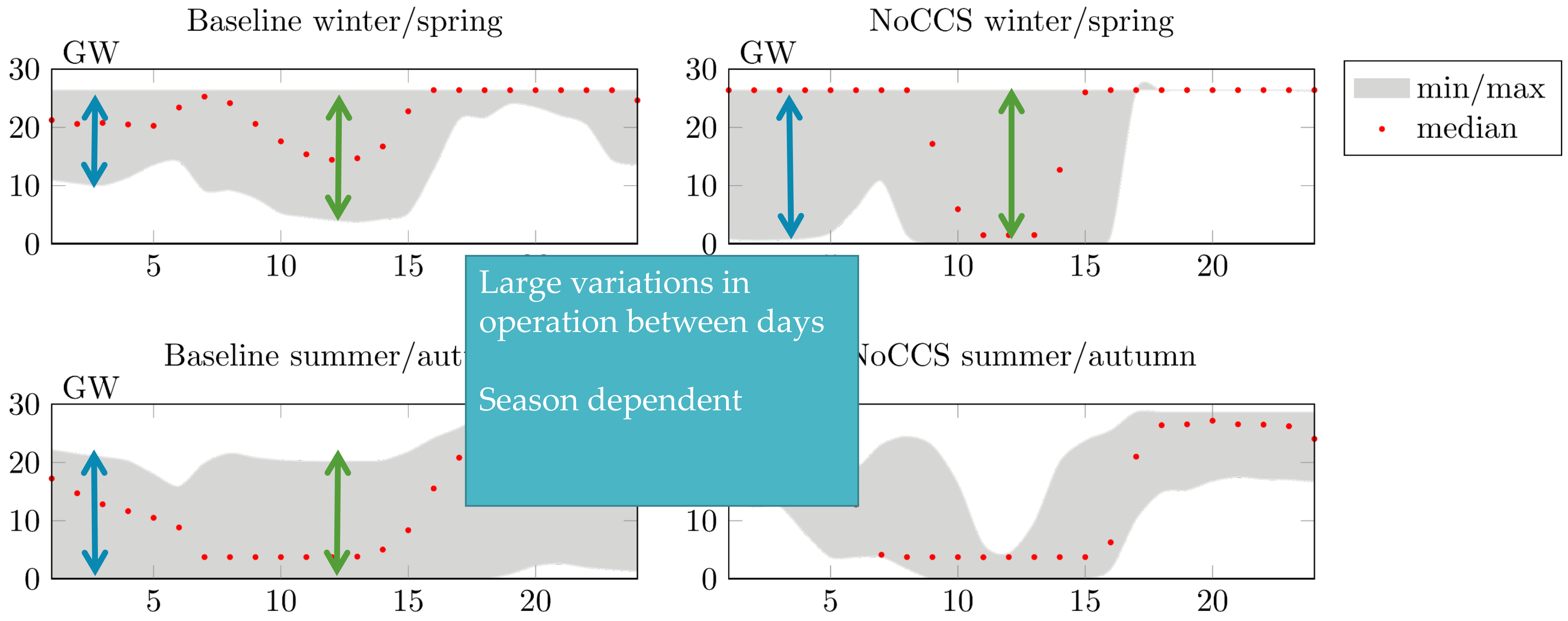
Operation of Norwegian hydro power 2050: Baseline (left) vs NoCCS (right)



FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Operation of Norwegian hydro power 2050: Baseline (left) vs NoCCS (right)



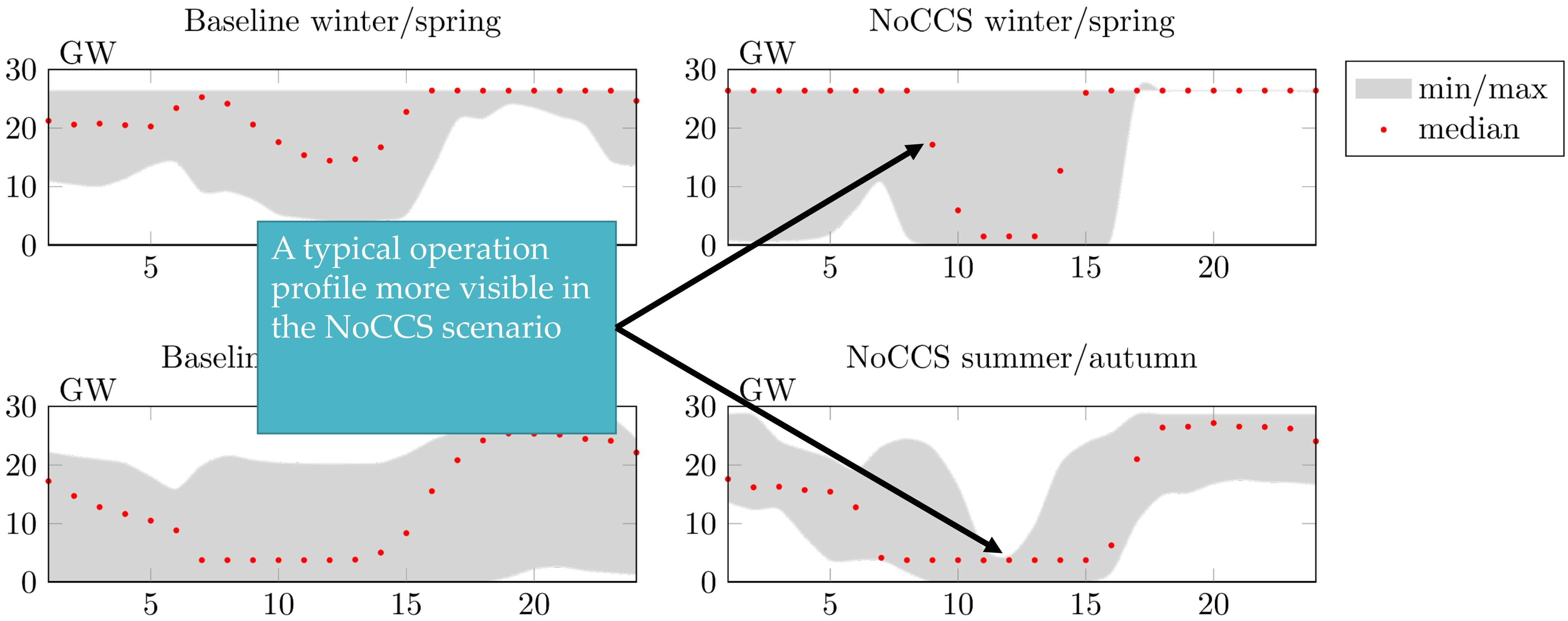
Large variations in operation between days

Season dependent

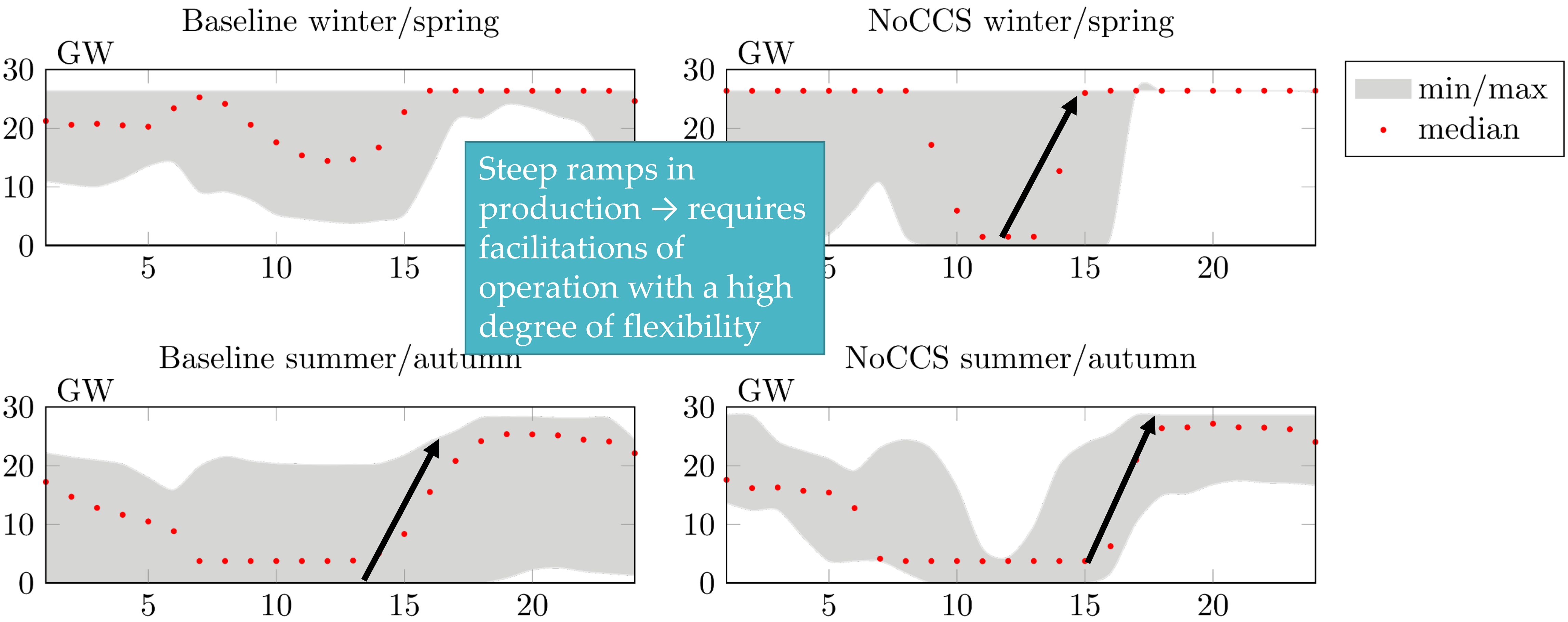
FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies

Operation of Norwegian hydro power 2050: Baseline (left) vs NoCCS (right)



Operation of Norwegian hydro power 2050: Baseline (left) vs NoCCS (right)



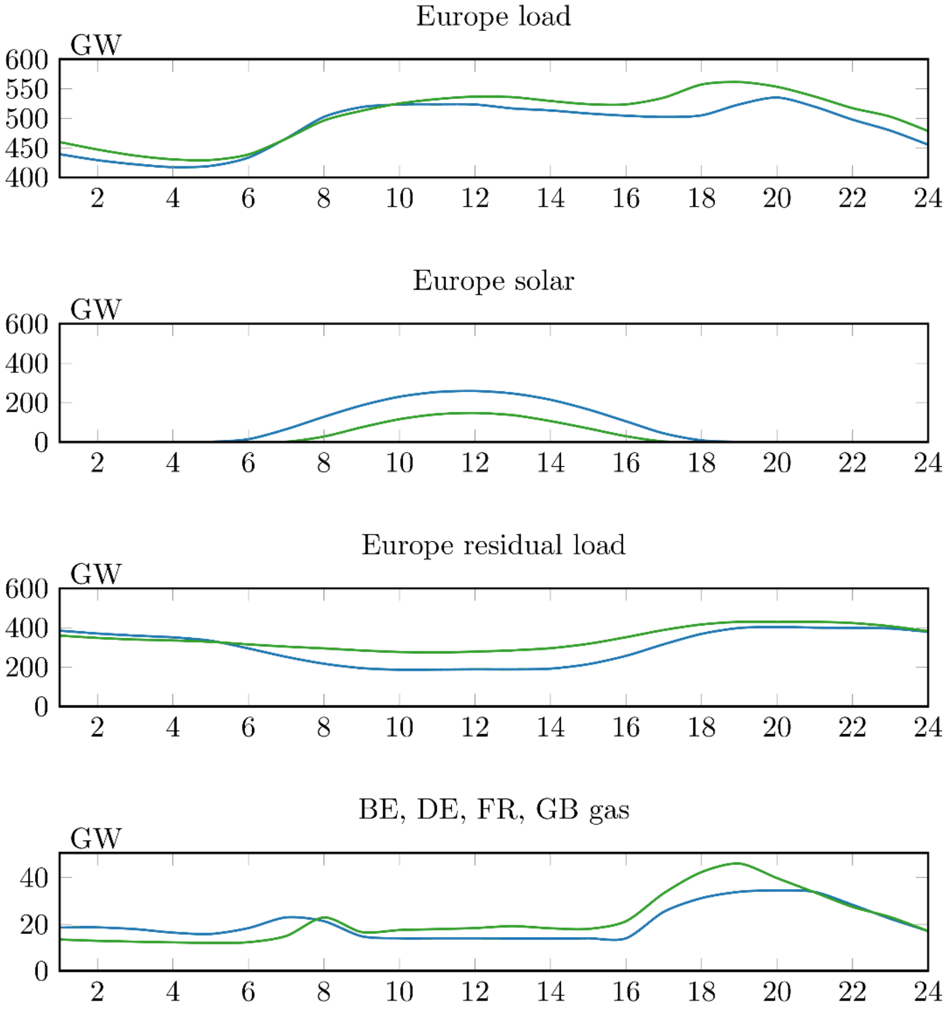
Steep ramps in production → requires facilitations of operation with a high degree of flexibility

Norges forskningsråd

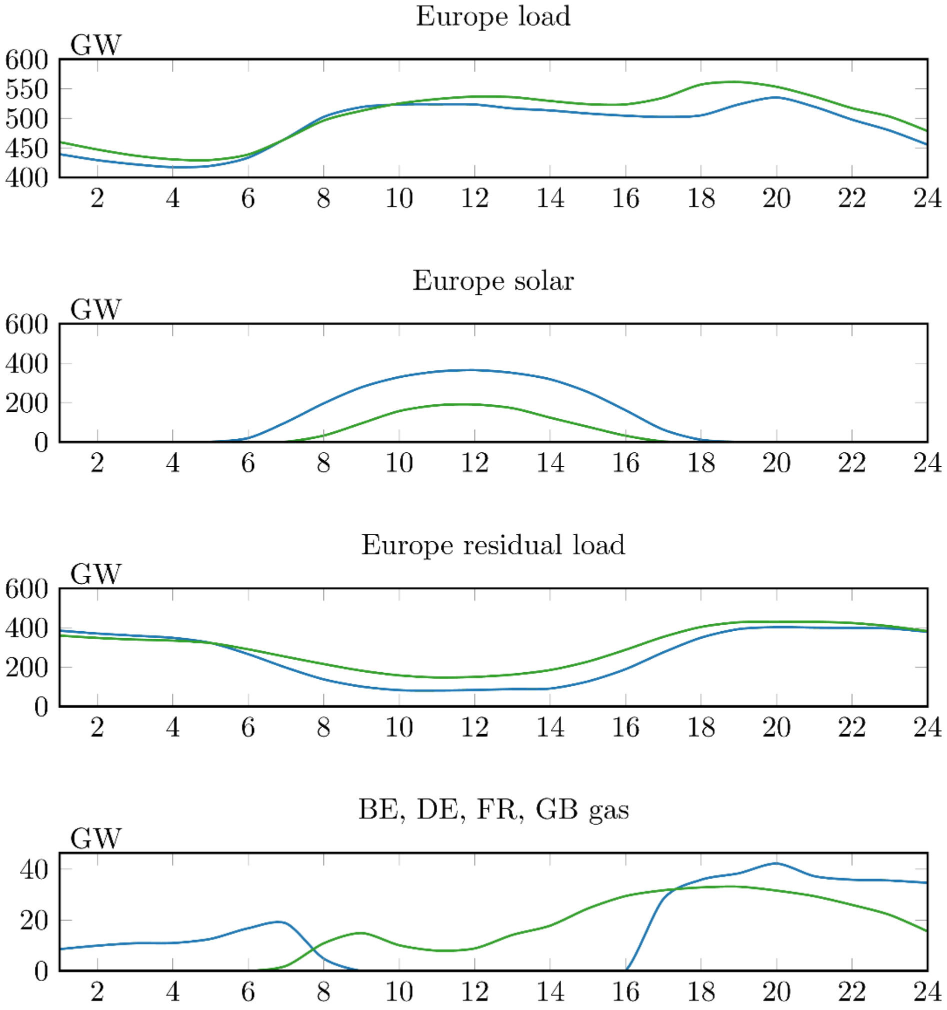
Centre for Sustainable Energy Studies

Daily operation of natural gas power generation in 2050

Baseline



No CCS



FORSKNINGSSENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

SES
stainable Energy Studies

Summary and conclusions

- Availability of CCS has a great impact on the optimal generation technology mix in Europe
  - With CCS: substantial amounts of onshore wind, and coal with CCS
  - Without CCS: large amounts of wind and solar PV, some unabated natural gas for balancing

- Deployment of wind and solar at this scale requires a strong transmission grid
  - Especially when CCS is not available – our results indicate a doubling of interconnector capacity in the optimal system design from the Baseline to the NoCCS scenario

- Norwegian (reservoir) hydropower is an efficient source of flexible generation
  - If large amounts of solar PV is built across Europe Norway can absorb the peak generation during mid-day and export power outside these hours

- Without CCS Norway can play an even larger role in decarbonizing European power
  - Expansion of offshore wind → potential to further increase export of renewable electricity
  - This is conditioned on increased interconnector exchange capacity with continental Europe and Great Britain

- The natural gas infrastructure has to be able to deliver fuel for a highly fluctuating operation.

Thank you!

Kontakt: christian.skar@ntnu.no

Web: http://www.ntnu.edu/employees/christian.skar

FORSKNINGS-SENTER FOR MILJØVENNLIG ENERGI
Norges forskningsråd

CenSES
Centre for Sustainable Energy Studies