Modeling low carbon scenarios for the European power sector

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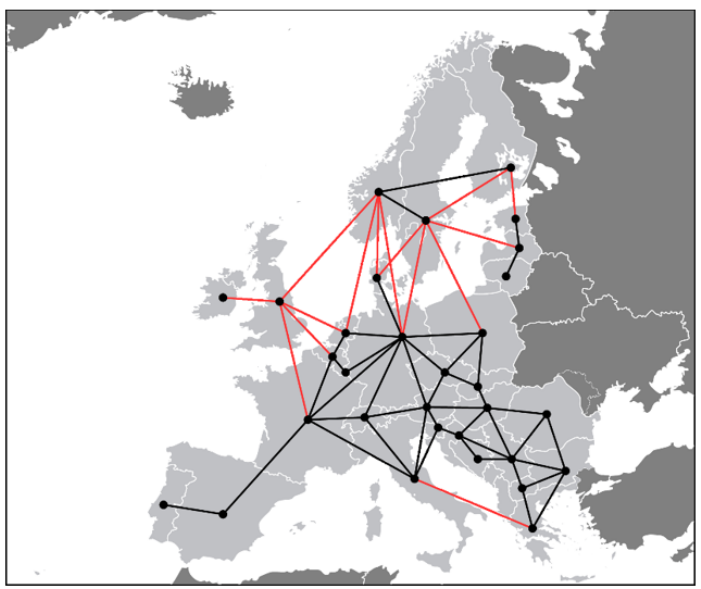
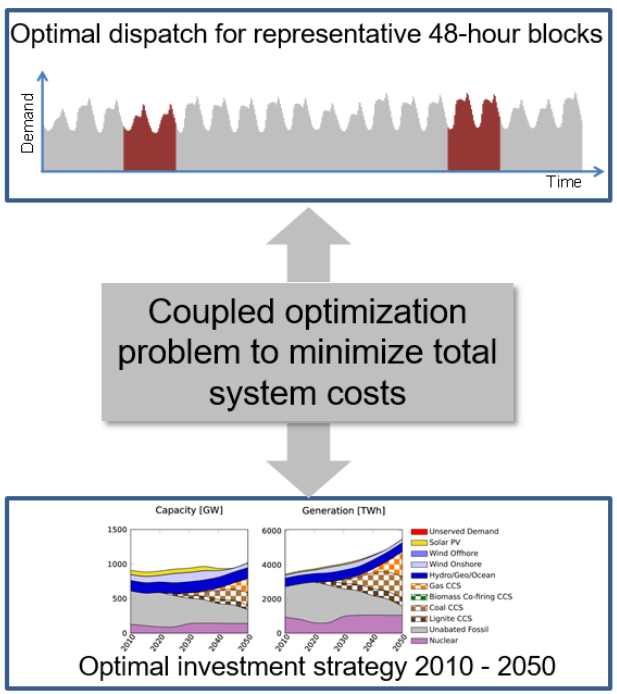
EMPIRE

EMPIRE: European Model for Power system Investments with Renewable Energy

- Capacity expansion model for the European power market
- Investments are made under uncertainty about operational conditions
- Embedded calculation of hourly optimal system operation
- Five year time steps
- Developed at NTNU

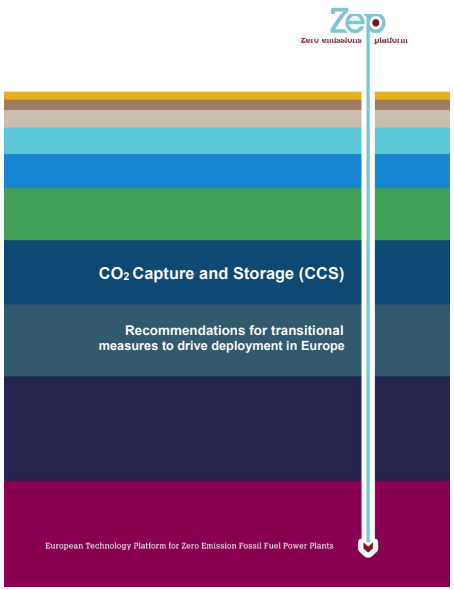




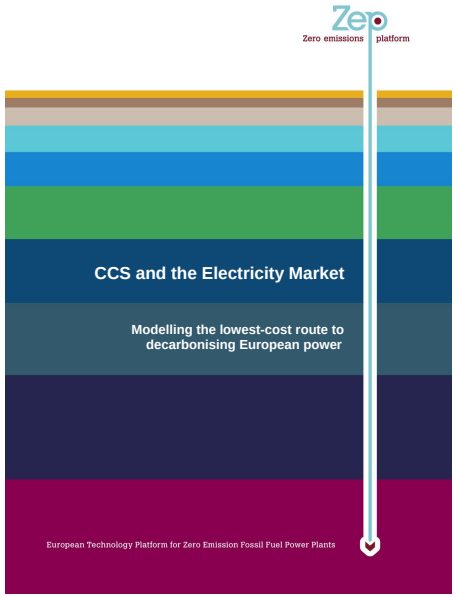
EMPIRE modeling assumptions

- Generation assets modeled per technology
- Investments are continuous
- Loop flows are not considered
- Integrated European electricity market
- Perfect competition
- Load and production from intermittent renewables based on historical data
- Ramping constraints enforced, but start up costs and part load efficiency not considered

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

Recent NTNU studies

- Transmission expansion
- Role of CCS in Europe decarbonization
- Using fuel prices, electricity demand and CO_2 prices from the EU 2013 reference scenario
- The generation technology parameter data is the same as used for the previous ZEP studies.
- Recent study done at NTNU

Using the EU reference scenario:

Disclaimer

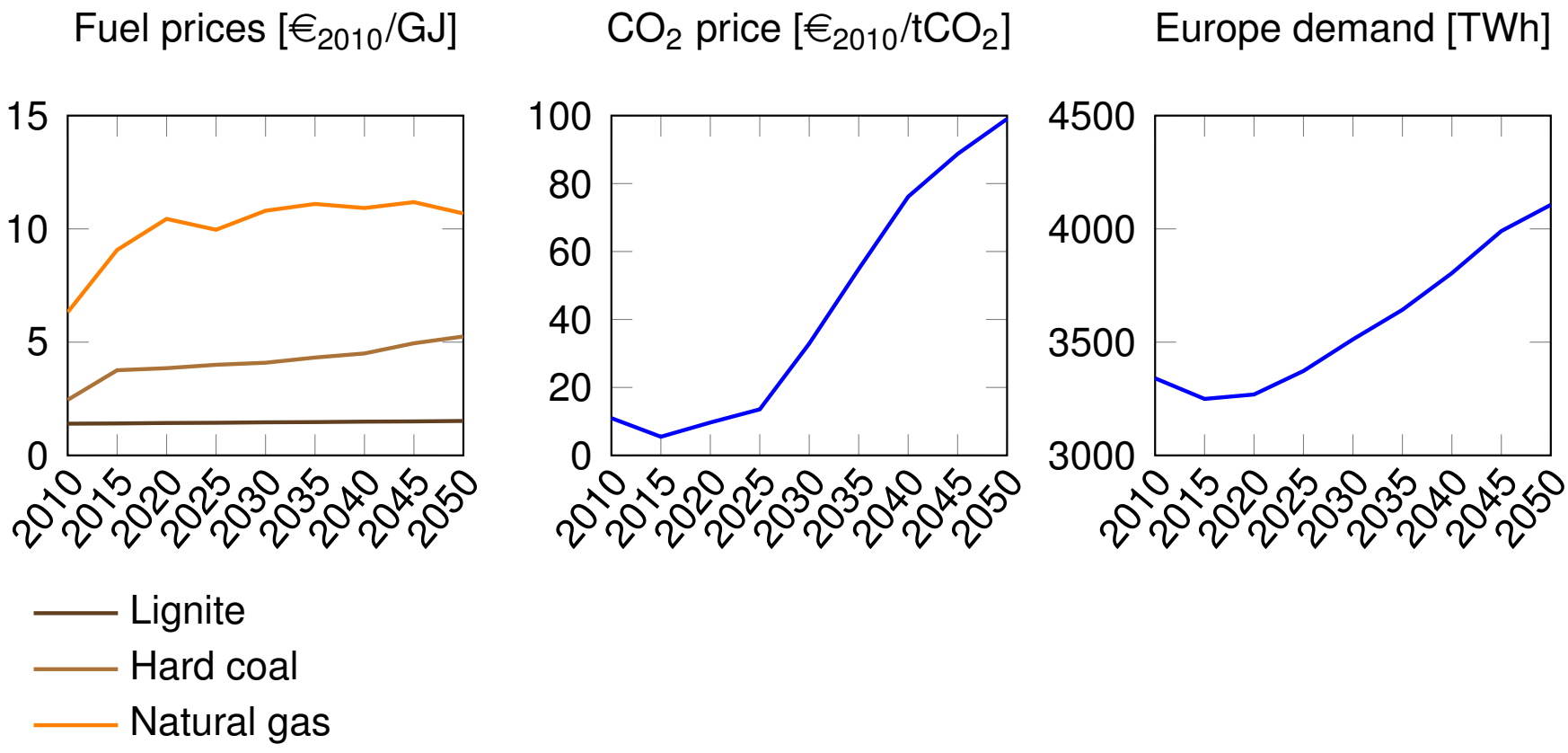
This is not a ZEP study. Members of ZEP have not yet had the opportunity to comment on the analysis, nor the results, and the following part of the presentation is solely the responsibility of the authors.

Decarbonizing European power (carbon price)

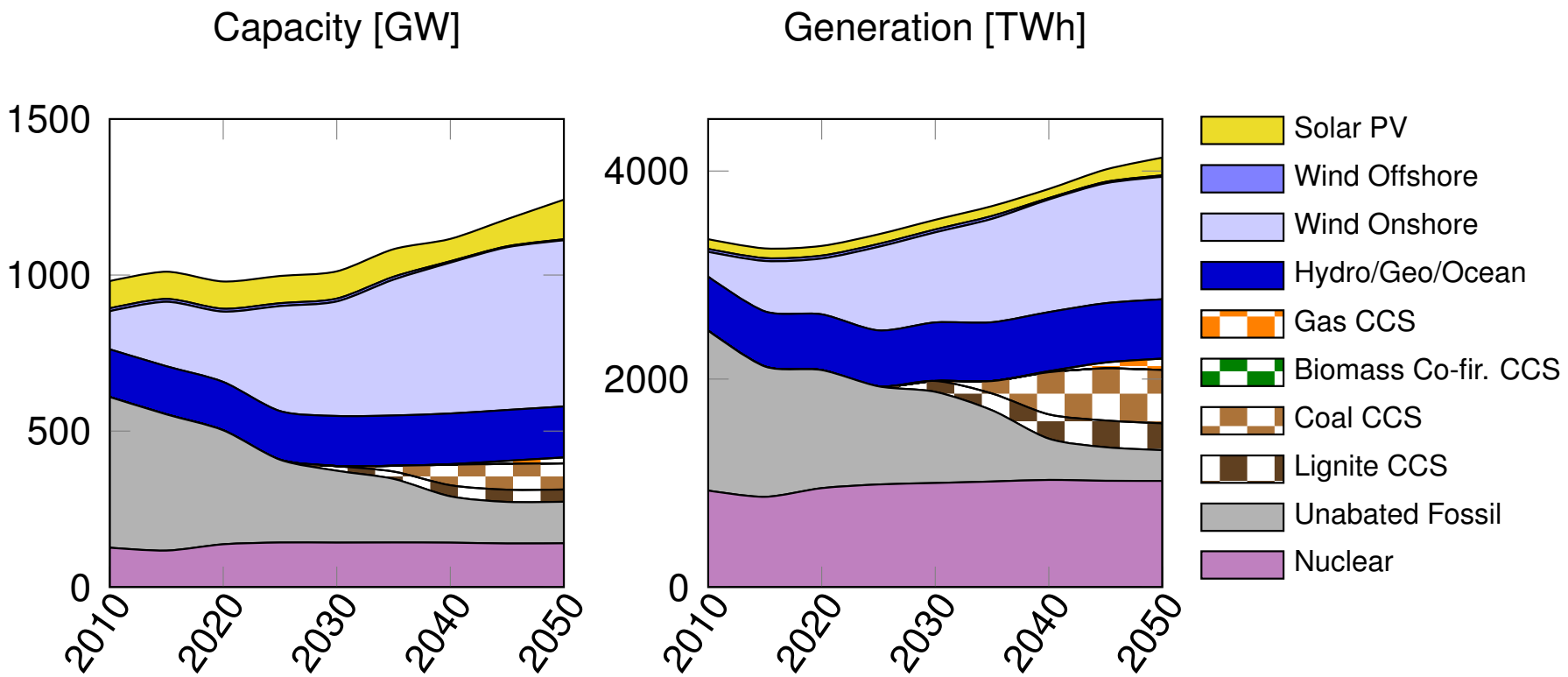
Reference

Skar, C., G. L. Doorman, G. A. Pérez-Valdés, and A. Tomasgard. 2016. “A multi-horizon stochastic programming model for the European power system.” CenSES Working Paper, March 2016.

Major assumptions



Capacity and generation mix in Europe



2050 results

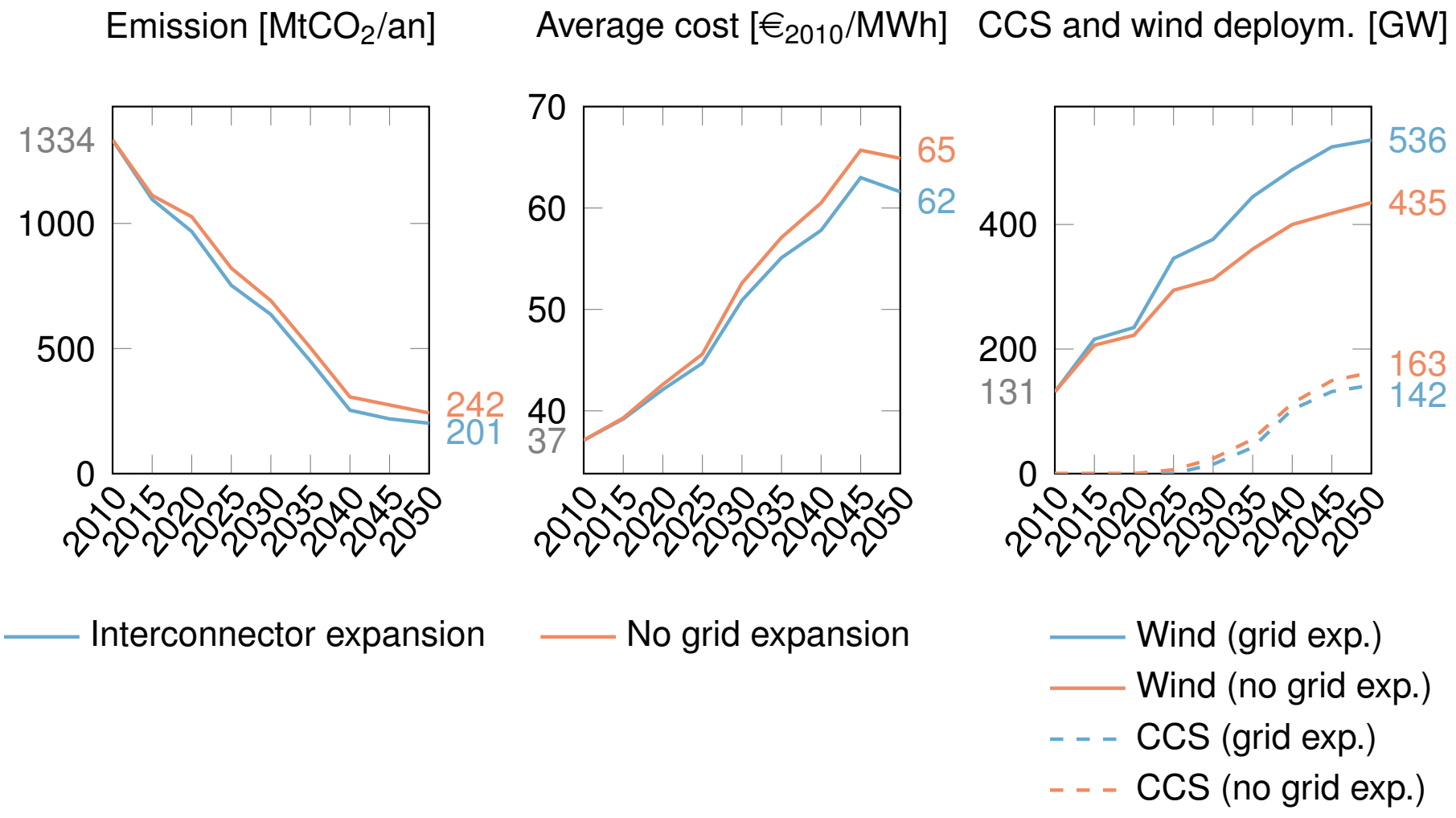
Capacity

- CCS: 142 GW (11 %)
- Wind: 536 GW (43 %)
- Nuclear: 140 GW (11 %)
- Unabated fossil: 133 GW (11 %)

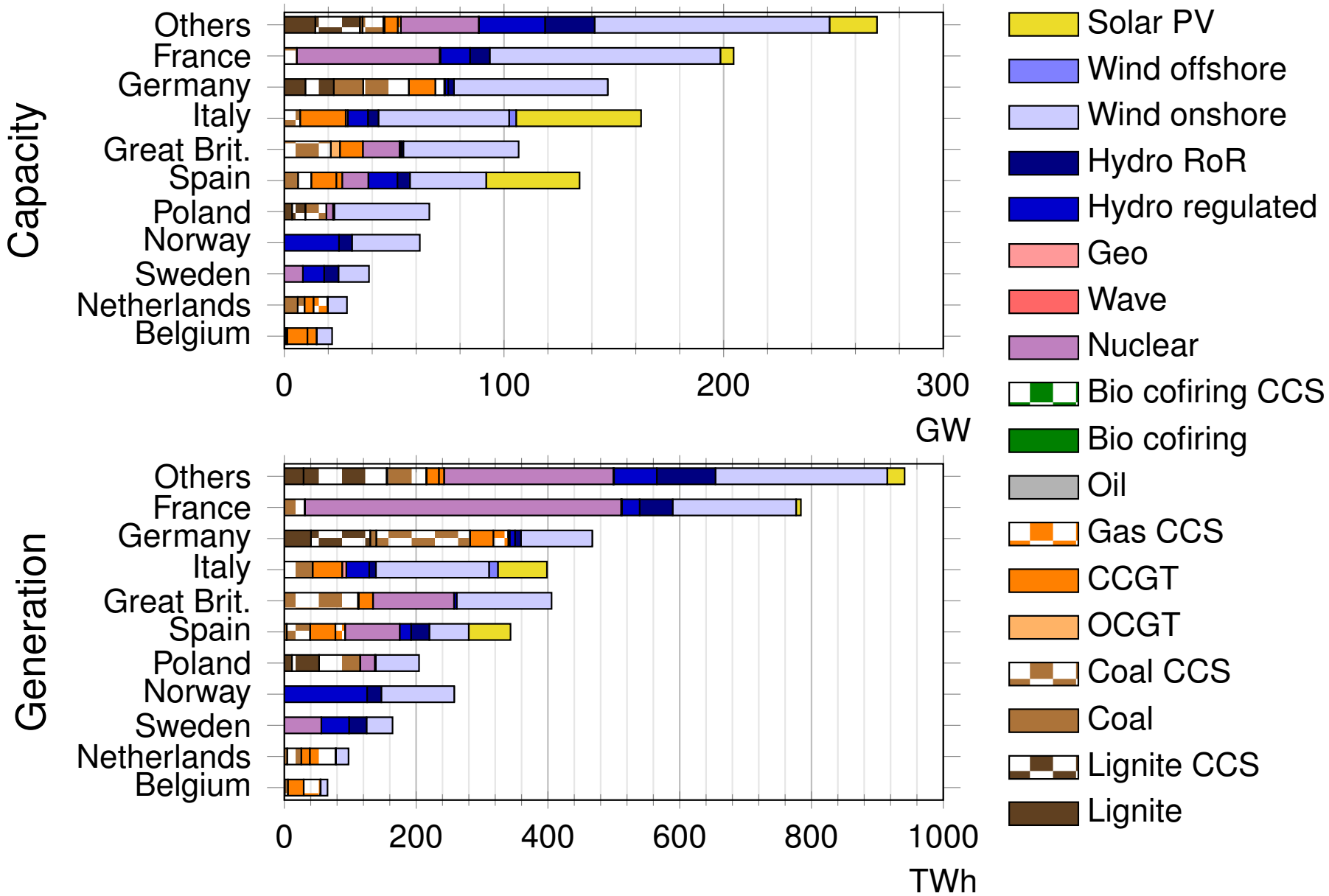
Generation

- CCS: 879 TWh (21 %)
- Wind: 1191 TWh (29 %)
- Nuclear: 1021 TWh (25 %)
- Unabated fossil: 396 TWh (7 %)

Transmission expansion vs no expansion

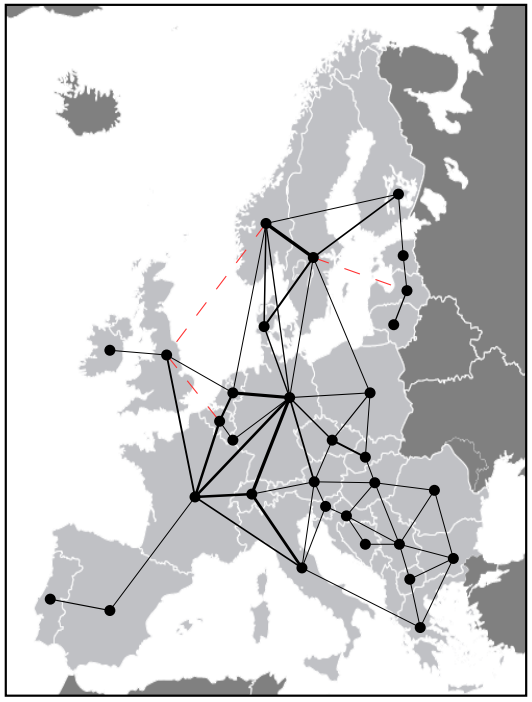


Country results 2050: Transmission expansion

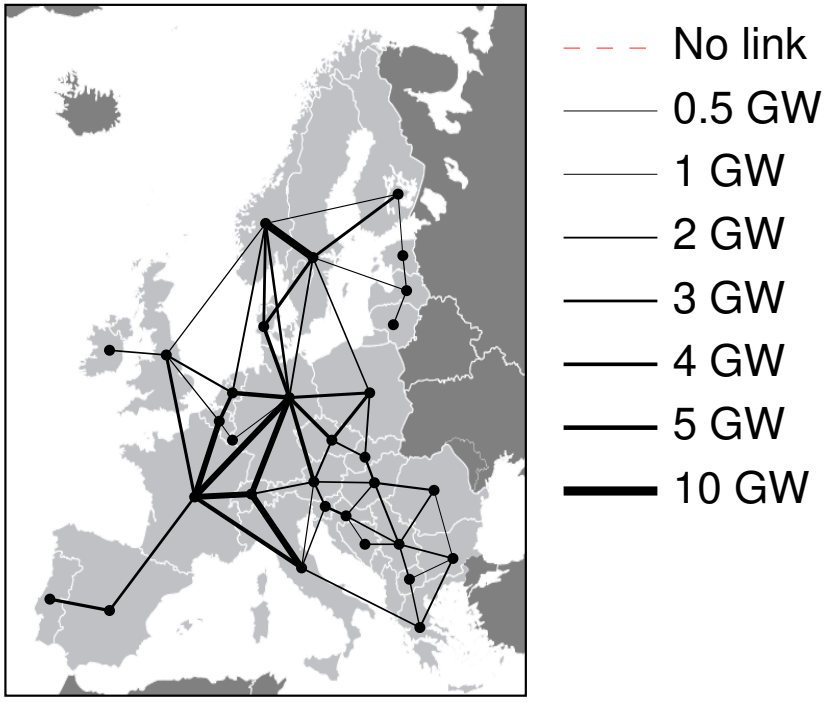


Transmission expansion

Initial system 2010



Interconnector capacities 2050



Capacities

- Initial capacity: 67 GW
- New capacity by 2050: 96 GW
- Total capacity 2050: 163 GW

Conclusions

- Driven by the EU ETS price from the European reference case 2013 an emission reduction of more than 80 % is achieved displacing unabated fossil fuel generation with onshore wind and CCS
- By allowing interconnector expansion, more wind power was deployed, which significantly reduces the system operational costs
- Only small differences are observed for the total emissions

The role of CCS in Europe and support policies

Reference

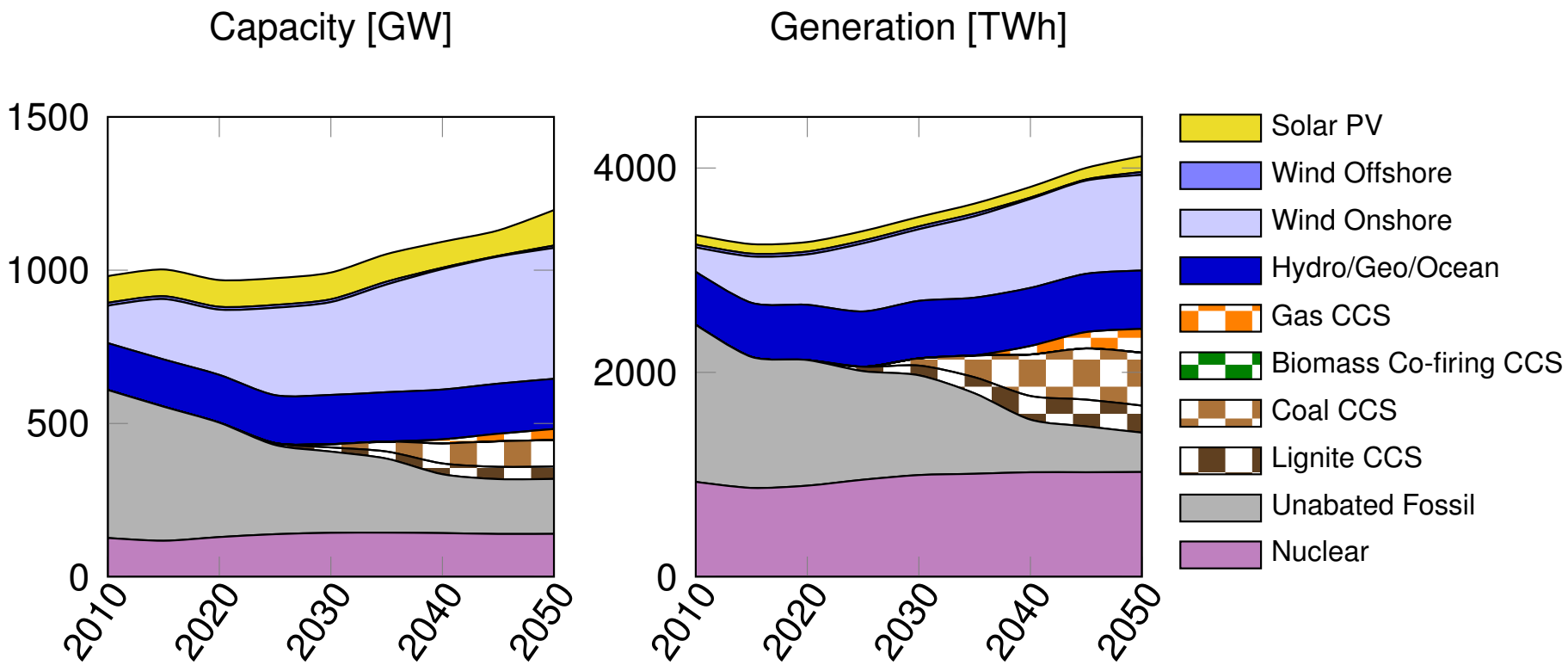
Skar, C., G. L. Doorman, G. Guidati, C. Soothill, and A. Tomasgard. 2016. “Modeling transitional measures to drive CCS deployment in the European power sector.” CenSES Working Paper, March 2016.

Carbon catpure and storage cost and technological data

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

Capacity and generation mix in Europe



2050 results

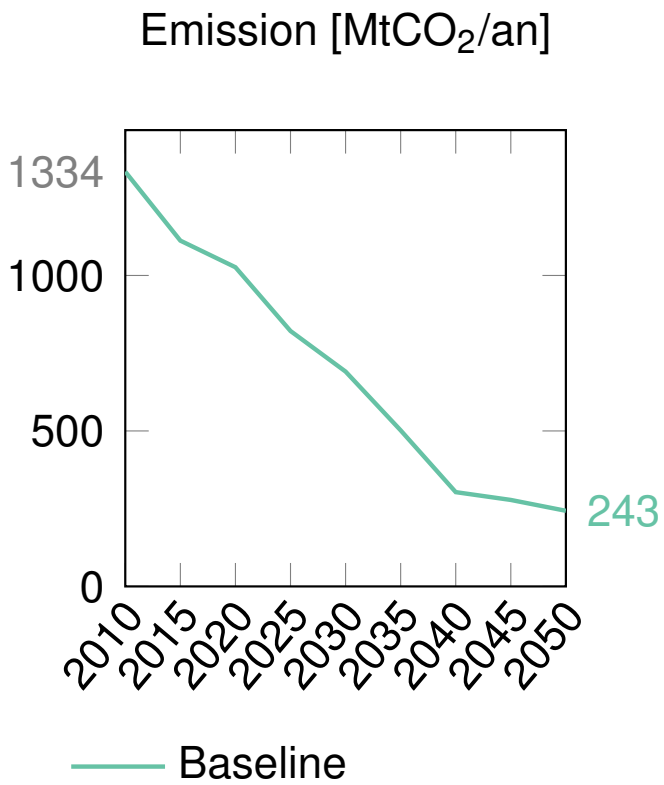
Capacity

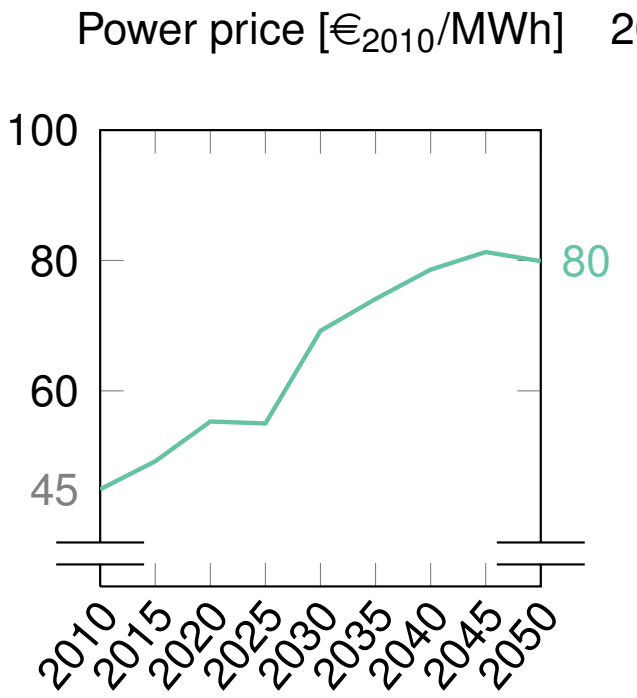
- CCS: 163 GW (14 %)
- Wind: 435 GW (14 %)
- Nuclear: 140 GW (12 %)
- Unabated fossil: 180 GW (15 %)

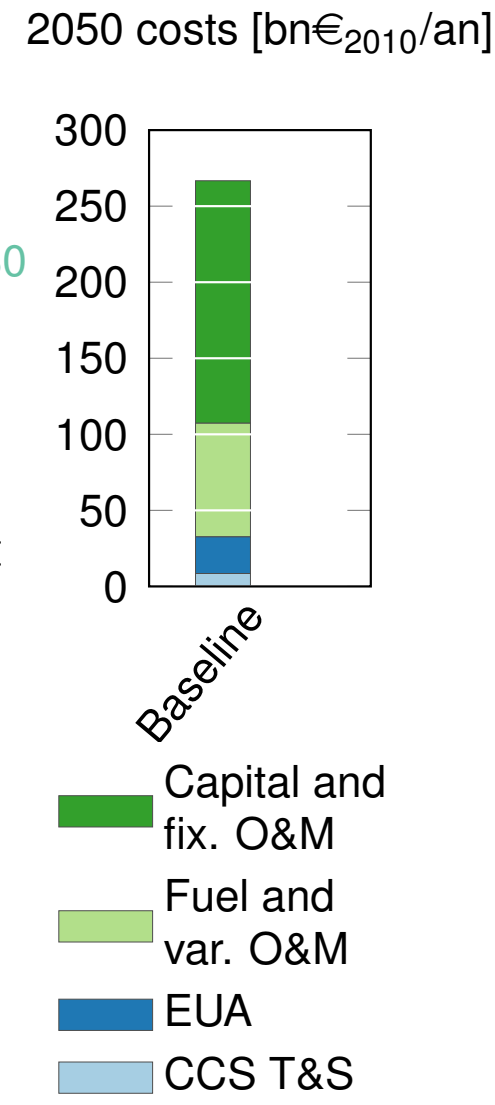
Generation

- CCS: 1014 TWh (25 %)
- Wind: 964 TWh (23 %)
- Nuclear: 1025 TWh (25 %)
- Unabated fossil: 385 TWh (9 %)

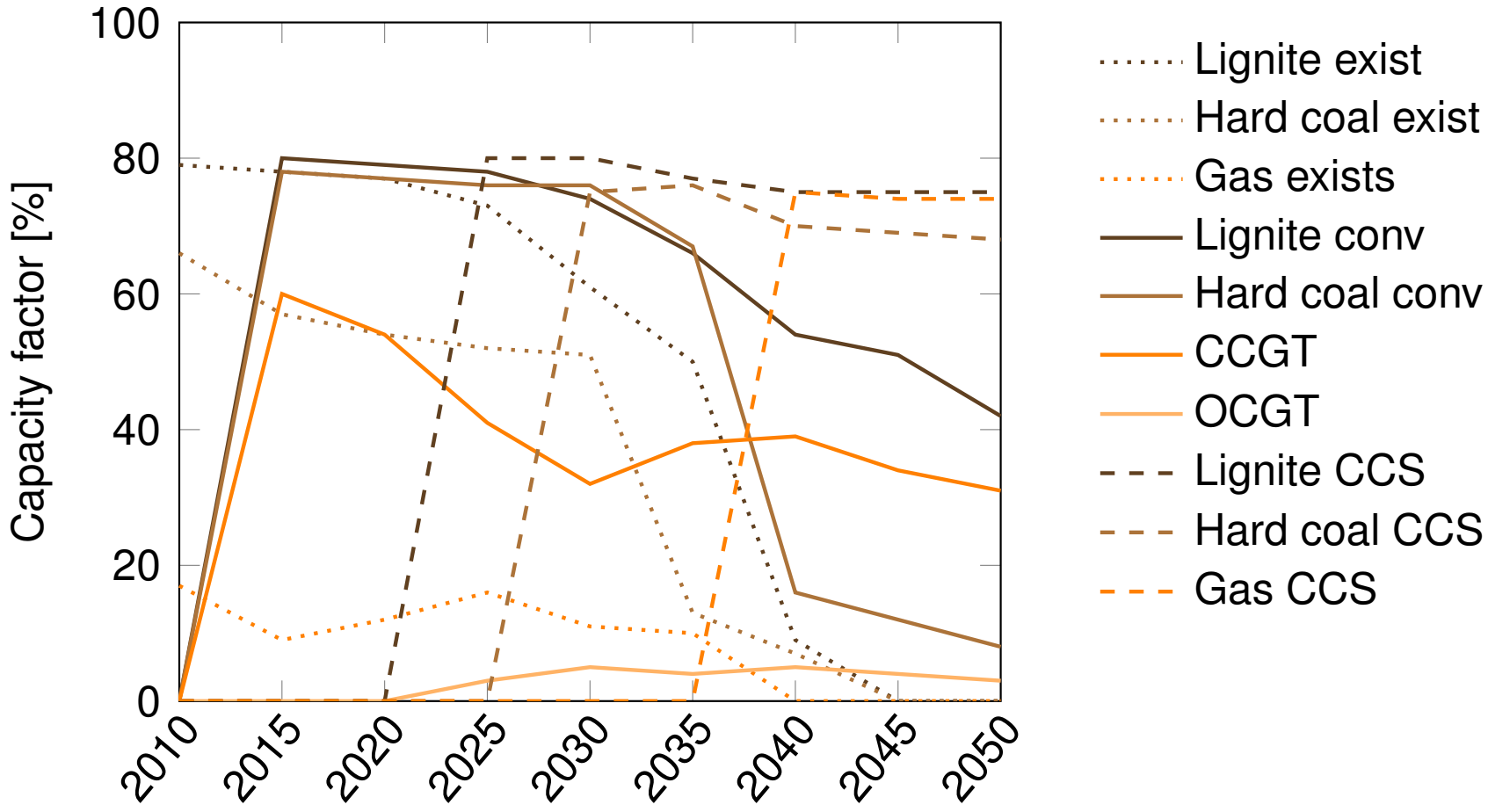
CO_2 emissions, power price and 2050 annual costs



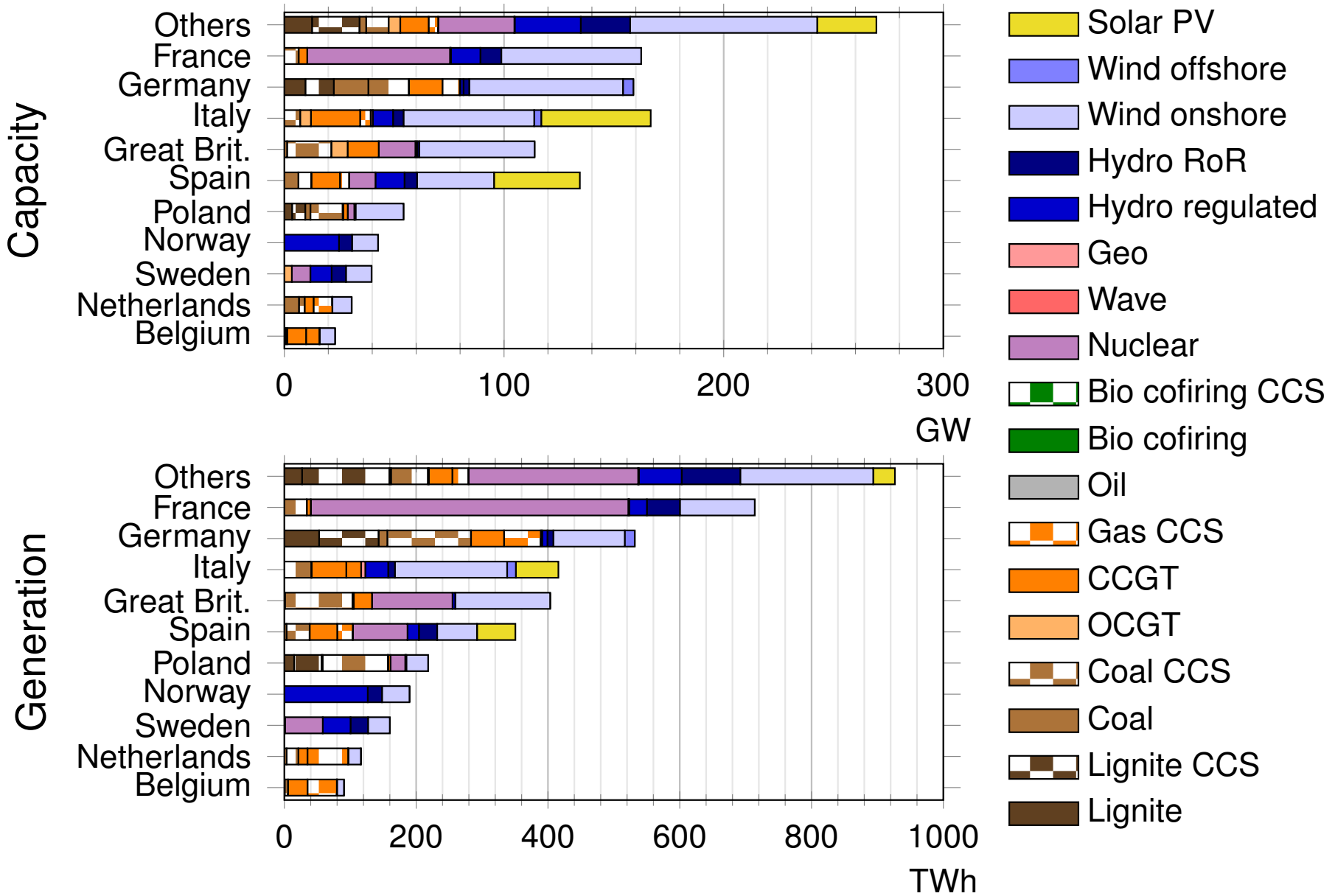




Capacity factors



Country results 2050



Motivation

What if we cannot use CCS?

theguardian

News | Sport | Comment | Culture | Business | Money | Life & style

Environment › Carbon capture and storage (CCS)

Not under our backyard, say Germans, in blow to CO2 plans

German carbon capture plan appears to be a victim of 'numbyism' - not under my backyard

Terry Slavin and **Alok Jha**
theguardian.com, Wednesday 29 July 2009 10.40 BST

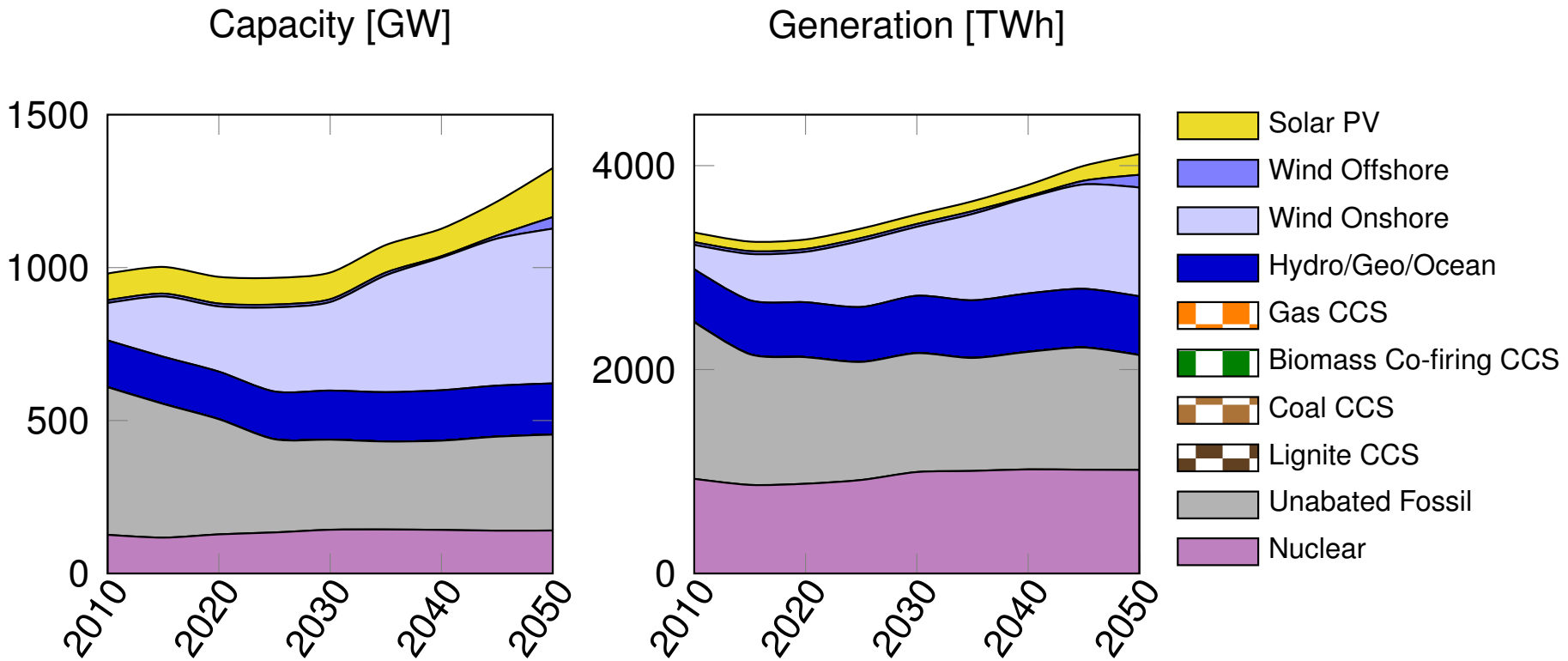
It was meant to be the world's first demonstration of a technology that could help save the planet from global warming – a project intended to capture emissions from a coal-fired power station and bury them safely underground.

But the German carbon capture plan has ended with CO_2 being pumped directly into the atmosphere, following local opposition at it being stored underground.

The scheme appears a victim of "numbyism" – not under my backyard.

- Nuclear has a public relations issue in Europe
- Only leaves renewable energies as low carbon solution
- What is the cost?

Capacity and generation mix in Europe, No CCS



2050 results

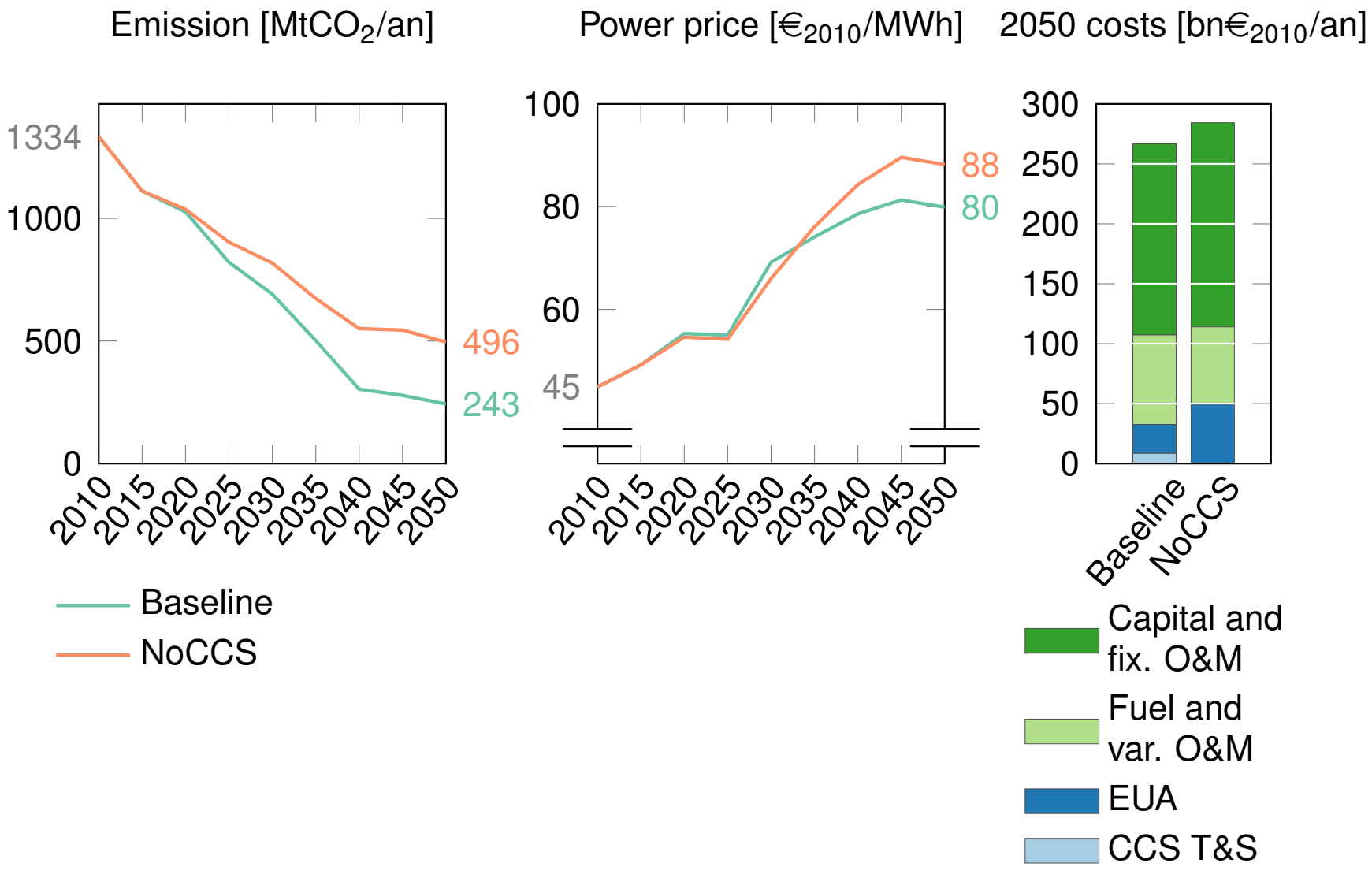
Capacity

- Wind: 544 GW (41 %)
- Nuclear: 141 GW (11 %)
- Unabated fossil: 313 GW (24 %)

Generation

- Wind: 1191 TWh (29 %)
- Nuclear: 1016 TWh (25 %)
- Unabated fossil: 1126 TWh (27 %)

Comparison: CO_2 emissions, power price and 2050 annual costs



CCS demonstration projects for power generation

What stands in the way?

- No successful CCS project for power generation exists in Europe
- Needs to be proven
- Challenges:
  - High capital cost
  - Transport and storage infrastructure needed
  - Low price in EU ETS
- Support programs (EERP, NER300, UK competetion for CCS) unsuccessful or canceled

First CCS for power: Boundary Dam Power Station in Estevan, Saskatchewan, Canada.

photo by SaskPower on Flickr

Transitional measures to inscentivize demonstration projects

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

Schemes evaluated

- Capital grants
- Feed-in premiums
- Emission performance standard

Capital grants (CAPEX support)

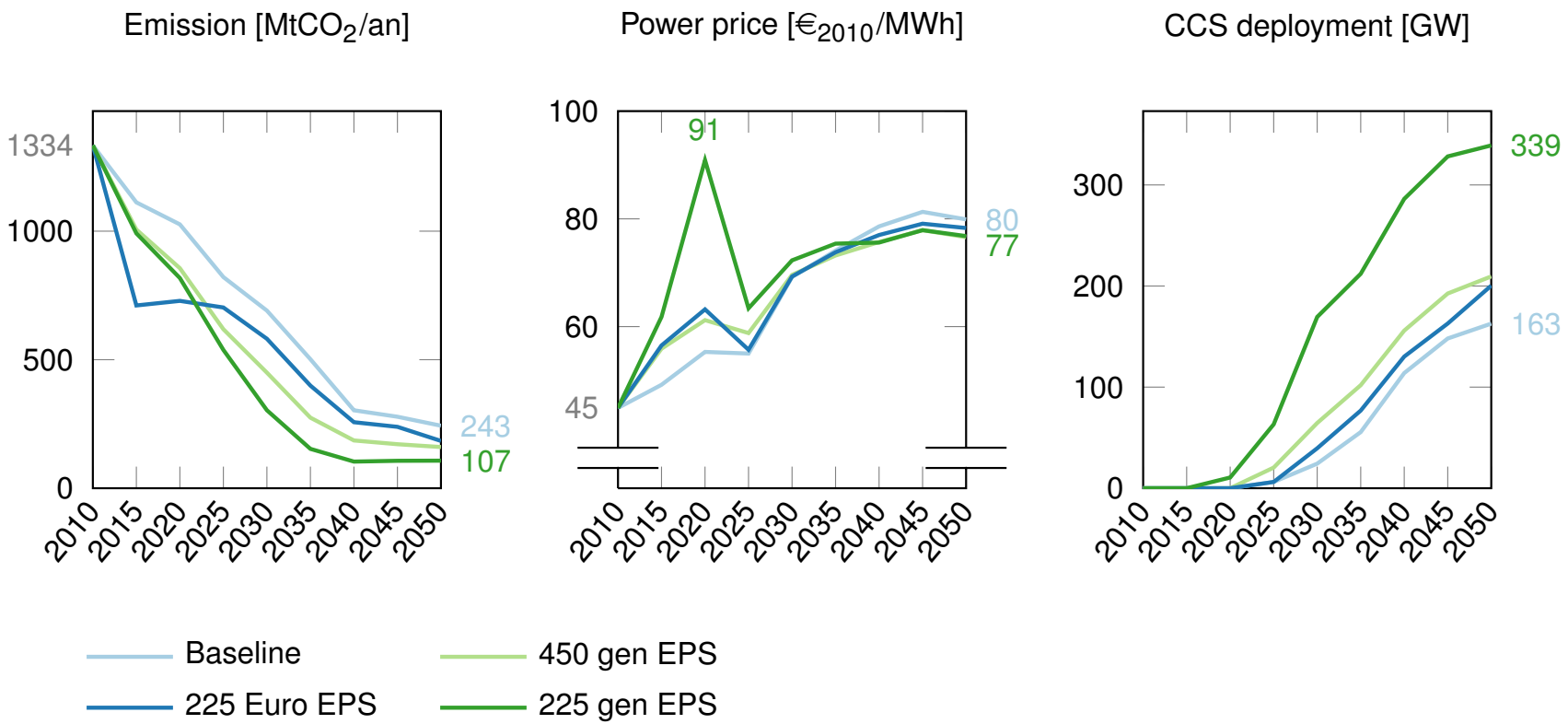
- Design: given share of the capital costs covered
- Different levels tried
- Result: a support level of 2000 €$_{2010}$/kW needed to spur investments
- Result: 4.1 GW of lignite CCS deployed. Cost: 6.5 bn€(2015 NPV)

Feed-in premiums (OPEX support)

Type							
Flat [€/MWh]	SRMC [%]	End	Gas [GW]	Lignite [GW]	Total [GW]	2015 NPV [bn€]	LCOS [€/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 from 2015



Specific emissions for unabated generation

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

Conclusions

- 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
- 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 gCO_2/kWh for generators drive down emissions
  - Results in a transitional period with high prices

Thank you for your attention

Questions?