Modeling low carbon scenarios for the European power sector

Christian Skar and Asgeir Tomasgard

NTNU – Trondheim
Norwegian University of Science and Technology

Department of Industrial Economics and Technology Management

CREE model forum April, 2016
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

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

Major assumptions

Fuel prices [€\textsubscript{2010}/GJ]

- **Lignite**
- **Hard coal**
- **Natural gas**

\textbf{CO\textsubscript{2} price [€\textsubscript{2010}/tCO\textsubscript{2}]}

Europe demand [TWh]
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

Emission [MtCO₂/an]

Average cost [€2010/MWh]

CCS and wind deployment [GW]

- Interconnector expansion
- No grid 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
Carbon capture and storage cost and technological data

### CCS assumptions

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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 %)
CO₂ emissions, power price and 2050 annual costs

**Emission [MtCO₂/an]**

- Baseline

**Power price [€2010/MWh]**

- Baseline

**2050 costs [bn€2010/an]**

- Baseline
- Capital and fix. O&M
- Fuel and var. O&M
- EUA
- CCS T&S
Capacity factors

[Graph showing capacity factors for various energy sources over time (2010-2050)].

- Lignite exist
- Hard coal exist
- Gas exists
- Lignite conv
- Hard coal conv
- CCGT
- OCGT
- Lignite CCS
- Hard coal CCS
- Gas CCS
Country results 2050

### Capacity
- **Others**
- **France**
- **Germany**
- **Italy**
- **Great Brit.**
- **Spain**
- **Poland**
- **Sweden**
- **Netherlands**
- **Belgium**

### Generation
- **Others**
- **France**
- **Germany**
- **Italy**
- **Great Brit.**
- **Spain**
- **Poland**
- **Sweden**
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- **Belgium**

- **Solar PV**
- **Wind offshore**
- **Wind onshore**
- **Hydro RoR**
- **Hydro regulated**
- **Geo**
- **Wave**
- **Nuclear**
- **Bio cofiring CCS**
- **Bio cofiring**
- **Oil**
- **Gas CCS**
- **CCGT**
- **OCGT**
- **Coal CCS**
- **Coal**
- **Lignite CCS**
- **Lignite**
Motivation

What if we cannot use CCS?

**the guardian**

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 CO₂ 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

**Emission [MtCO$_2$/an]**

- Baseline
- NoCCS

**Power price [€2010/MWh]**

**2050 costs [bn€2010/an]**

- Capital and fix. O&M
- Fuel and var. O&M
- EUA
- CCS T&S
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 competition 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 insentivize demonstration projects

**Demonstration CCS**

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**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 €\textsubscript{2010}/kW needed to spur investments
Feed-in premiums (OPEX support)

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- 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 gCO₂/kWh
- Gas CCGT: 336 gCO₂/kWh
- Gas OCGT: 505 gCO₂/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?