The Role of Cross-Border Power Transmission in a Renewable-Rich Power System

– a Model Analysis for Northwestern Europe

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Yi-kuang Chen (yi-kuang.chen@nmbu.no), Jon Gustav Kirkerud, Torjus F. Bolkesjø
Hardi Koduvere
Philipp A. Gunkel, Klaus Skytte
Hans Ravn

Norwegian University of Life Sciences, Norway
Tallin University of Technology, Estonia
Technical University of Denmark, Denmark
RAM-løse, Denmark
Background

- Northwestern European energy systems feature in various characteristics
  - NO, DK, UK: wind
  - NO, SE: hydro
  - UK, DE, FR: large demand

- Geographical integration creates a more stable energy system.

Source: [Global Wind Atlas](#) - capacity factor IEC class I
Nevertheless...

- Increasing opposition against power lines
  - Visual, health impacts
  - Environmental impacts
  - Increased power prices (in low price areas)

Objective

- To quantify how increased cross-border transmission capacities affect the power system and the power market in a decarbonized future towards 2050 in Northwestern Europe.

Source: ABB
Methodology

• Balmorel
  • Bottom-up approach
  • Partial equilibrium optimization model
  • Endogenous generation capacity investments

• Transmission modelling
  • Existing as of 2016: FB approach for HVAC lines
  • New lines: NTC approach

• Two scenarios of transmission capacities
  • Planned: exogenously given
  • Optimal: model-determined

Table. Fuel and emission price assumptions

| Unit | Fuel | Emission |
|------|------|----------|
|      | €/ MWh | €/ t CO₂ |
| Year | Coal | Lignite | NG | Biomass |
| 2016 | 7.6  | 4.5     | 15  | 22–31   | 5     |
| 2020 | 8.3  | 2.7     | 20  | 22–31   | 17    |
| 2030 | 9.6  | 3.7     | 30  | 30–38   | 26    |
| 2040 | 9.9  | 3.6     | 33  | 37–45   | 40    |
| 2050 | 10.1 | 3.5     | 37  | 39–47   | 54    |
Model Results
Optimal transmission capacity

Aggregated; Cross-border only

Transmission Capacity (MW)
- 1 - 2000
- 2000 - 4000
- 4000 - 6000
- 6000 - 8000
- 8000 - 10000
- 10000 - 12000
- 12000 - 14000
- 14000 - 16000

Installed cross-border transmission capacity, GW

- 2050 Optimal investments
- 2040 Optimal investments
- 2030 Optimal investments
- 2020-2030 Planned
- 2016 Existing

NORTH
WEST
Power generation capacity

Planned Scenario

- Wind
- Solar PV
- Bioenergy
- Gas
- Coal

Difference between Optimal and Planned in installed power generation capacity, GW Year 2050

West

North

- Coal
- Gas
- Nuclear
- Bioenergy
- Hydro
- Solar PV
- Wind
- Others

Year 2020 to 2050
Emission impact and system costs

-25% - 46% - 65%

-1 bn€ - 7 bn€
Welfare distribution
- Change in producer revenues (2050)
Welfare distribution
- Change in consumer prices (2050)
Conclusions

• The optimal scenario suggests additional 76 GW of cross-border transmission capacity expansion from 2030 to 2050

• More wind power substitutes fossil fuel based energy
  • Further emission reduction
  • Lower system costs

• Benefits asymmetrically distributed
  • 😊: Northern wind power producers, Northern hydro power producers, Western consumers
  • 😞: Fossil-fuel-based power producers, Northern consumers

 Barrier and/or opportunity?
Thank you for your attention!

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Transmission assumptions

- Investment cost data derived from or estimated by established projects
  - a pay-back period of 40 years with 3.25% discount factor
- O&M cost: 0.1 EUR/MWh
- Efficiency: 95.8%
- Capacity rating: 90%

| Table showing transmission capacity costs [Monthly/MWh] |
|-------------------------------------------------------|
| D02 | D41 | D61 | SE1 | SE2 | SE3 | SE4 | NO4 | NO8 | NO1 | NO2 | H4 | DE6-S | DE6-E | DE6-N | DE6-W | UK | EE | LV | LT | PL | NL | FR | BE |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|------|------|------|------|----|----|----|----|----|----|----|----|
| 2016-06-2 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-1 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-2 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-3 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-4 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-5 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-6 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-7 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-8 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-9 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-10 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-11 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |
| 2016-06-12 | 509,574 | 568,371 | 421,375 | 695,000 | 568,371 | 1,195,000 | 942,000 |

- Table showing transmission capacity costs [Monthly/MWh]
| Country     | Export_P | Import_P | NetE_P | Export_O | Import_O | NetE_O |
|------------|----------|----------|--------|----------|----------|--------|
| BELGIUM    | 29 860   | 45 017   | 15 157 | 43 234   | 56 000   | -12 767|
| DENMARK    | 39 457   | 34 421   | 5 036  | 66 265   | 57 130   | 9 135  |
| ESTONIA    | 7 859    | 5 145    | 2 714  | 12 070   | 7 960    | 4 110  |
| FINLAND    | 14 887   | 16 326   | -1 438 | 26 579   | 16 568   | 10 011 |
| FRANCE     | 103 727  | 11 512   | 92 214 | 166 450  | 4 840    | 161 610|
| GERMANY    | 155 686  | 259 035  | -103 348 | 183 005 | 336 647  | -153 642|
| LATVIA     | 7 871    | 7 104    | 766    | 12 885   | 8 506    | 4 379  |
| LITHUANIA  | 6 125    | 13 564   | -7 439 | 6 266    | 17 329   | -11 063|
| NETHERLANDS| 60 058   | 43 489   | 16 569 | 30 060   | 85 467   | 55 407 |
| NORWAY     | 113 355  | 62 916   | 50 439 | 157 398  | 96 089   | 61 309 |
| POLAND     | 16 865   | 23 285   | -6 420 | 52 377   | 40 101   | 12 276 |
| SWEDEN     | 102 217  | 118 651  | -16 434 | 191 242 | 161 541  | 29 701 |
| UNITED_KINGDOM | 20 431 | 37 933   | -17 502 | 35 170   | 94 823   | -59 653|

Net export (GWh)

-150
-100
-50
0
50
100
150
>150

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Sample aggregated wind profiles for two onshore generation areas