Expansion Governance Simulation for the Northern Seas Offshore Grid

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Sara Lumbreras
Andrés Ramos
The Northern Seas offshore grid

- Two functions: **interconnection and offshore wind connection**
- **HVAC** and **HVDC** transmission
- Conventional and integrated links
The Northern Seas offshore grid

- Two functions: **interconnection and wind connection**
- HVAC and HVDC transmission
- Conventional and integrated links

**Main drivers**
- Offshore wind power
- HVDC technology
- European energy & climate policy
The Northern Seas offshore grid

- Two functions: \textit{interconnection} and \textit{wind connection}
- HVAC and HVDC transmission
- Conventional and integrated links

- Main drivers
  - Offshore wind power
  - HVDC technology
  - European energy & climate policy

- Main barriers to an integrated grid
  - \textbf{Regional governance} and cooperation
  - Costs & benefits distribution
  - Regulatory differences
Governance of Expansion Planning
Governance of expansion planning

1. Expansion planning: **Identify adequate investments in generation and transmission** to guarantee future reliability given other energy & climate policy objectives

2. Governance: **Heterarchical (non-hierarchical) mechanisms and institutions** for decision making in networked, multi-level, multi-actor systems

3. OGEM aims to **analyze governance constraints for the expansion planning of the Northern Seas offshore grid of Europe**

Gailing and Röhring, 2016; Goldthau, 2014; IEA, 2010; Maggetti and Gilardi, 2014; Rhodes, 1996; Szulecki, 2016; Treib et al., 2007
OGEM: The Offshore Grid Exploratory Model
Multi-period myopic (sequential static) MILP simulation

Offshore generation and transmission investment and system operation cost minimization

Governance constraints:
- **Pareto**: welfare must increase for any country building integrated links
- **Integrated links**: Limit to number of integrated links per node
Data: e-Highway2050

- 430+ transmission candidates
- 10+ generation techs
- 123 nodes
- 9 offshore nodes
Results
Costs & Benefits

• 2030-2050 offshore **investments** of 19.5-176.9 €\(_{2030}\) (transmission: 28%)

• **Net benefits**: 1.1-15.0 €/year

• Welfare losses average of **3.7%** for the Pareto welfare, **4.3%** for complex planning and **5.7%** for disintegrated planning
  • Equivalent to a maximum of 1.0 €/year

• **Distribution**:
  • **Consumers and offshore wind benefit**, while onshore renewables and conventional producers lose
Costs & Benefits

100% RES

Big & Market

Small & Local

Fossil & Nuclear

Large-scale RES

- Consumer surplus
- Conventional producer surplus (PS)
- Offshore wind PS
- Onshore renewable PS
- Congestion rent
- Offshore wind investment
- Offshore transmission investment
- Unconstrained
- Pareto welfare
- Complex integration
- Disintegrated planning
- Net benefits
Technology
Technology & layout

- Multiterminal HVDC is the main tech

Multiterminal grids:
  - Unconstrained: True meshed offshore grid for large expansion scenarios, local grids otherwise
  - Disintegrated: Interconnect onshore grids and farms to shore, often with other techs

Tech functions:
  - HVAC: Connects Danish and British wind farms onshore, and FR to GB
  - Multiterminal HVDC: Grids, connection of HVAC grids, with possible KVL decoupling
  - Point-to-point HVDC: Exogenous grid, long distance single-purpose interconnections
Disintegrated planning
Disintegrated links combination
KVL decoupling & multiterminal leveraging
An integrated (unmeshed) offshore grid
What drives different grids?
Conclusions

1. We analyze governance constraints in a detailed open-source simulation model

2. Net benefits change significantly per scenario (1.1-15.0 B€/year)

3. Significant governance constraint losses of up to 5.7%

4. We highlight with more detail than in Dedecca et al., 2017 path dependence, welfare and distribution, technology and link type

5. OGEM supports expansion planning governance framework design and evaluation
Thank you!

João Gorenstein Dedecca

homepage.tudelft.nl/w67e1
TU Delft / Technology, Policy & Management (TBM)
Transmission link types

- **Conventional**
  - Shore-to-shore interconnectors
  - National farm-to-shore

- **Integrated**
  - Cross-border farm-to-shore
  - Farm-to-farm
## Transmission technologies

- **HVAC**
- **HVDC**
  - Point-to-point
  - Multiterminal

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Li et al. in van Hertem et al., 2016
References


Pareto welfare

- **For each country**
  - consumer payments
  + congestion rent
  + producer surplus
  - investment cost
  $\geq \text{base state welfare} - (1 - \text{cooperation}) \times \text{Big M}$

- **Iteration convergence conditions**
  - Constant objective function value
  - Pareto welfare constraint satisfied with new duals
  - Congestion rents split equally among nodes
OGEM

- **Multi-period myopic (sequential static) MILP simulation**
- **Offshore generation and transmission investment** and operation cost minimization

- **Governance constraints:**
  - **Pareto:** welfare must increase for any country building integrated links
  - **Integrated links:** Limit to number of integrated links per node

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**Base system**

- **Full-year operation**

**Snapshot selection**

- **k-medoids on nodal prices**

**Investment and operation**

- **100 snapshots**

**Expanded system**

- **Full-year operation**
Offshore wind will grow globally

Adapted from IEA-RETD, 2017
Offshore wind is cheaper than forecast

Adapted from IEA-RETD, 2017
E-Highway2050 scenarios

- Demand
- Nuclear
- Fossil with CCS
- Exchanges
- Renewables

Legend:
- Large-scale RES
- 100% RES
- Big & Market
- Fossil & Nuclear
- Small & Local

Challenge the future
Governance constraints

- Pareto welfare
  - Constraint: Welfare increase for countries with integrated links
  - Solve for investment and operation
  - Input nodal prices
  - Check: Constraint satisfaction Constant objective
    - Iterate if necessary

- Planning integration
  - No integration limit
  - Complex: 1 link per node
  - Disintegrated
Costs & Benefits

- 2030-2050 offshore investments of $19.5-176.9 \text{ B\euro}_{2030}$ (transmission: 28%)
- Net benefits: 1.1-15.0 B\euro/year
- ROI increases with investments, but with low correlation (36-202%)
  - e.g. ROI of 100% RES much higher than Large-scale RES
- Welfare losses average of 3.7% for the Pareto welfare, 4.3% for complex and 5.7% for disintegrated planning
  - Up to 1.0 B\euro/year
- Distribution:
  - Consumers and offshore wind benefit, while onshore renewables and conventional producers lose
  - DE, GB and NL generally benefit
  - NO and SE losses due to hydro
## Costs & Benefits

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Unconstrained
Graph characteristics

Degree

Node Centrality

Shortest Paths

Edge Centrality
# Costs

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<td>Concentrated solar power</td>
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<td>Offshore wind</td>
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<td>VOLL</td>
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</table>
Disintegrated planning
Complex planning

100% RES  Big & Market  Fossil & Nuclear  Large-scale RES  Small & Local

2030

2040

2050

Load-weighted average nodal price

Link type

AC + multiterminal  AC  multiterminal + point-to-point  initial  multiterminal  AC + multiterminal + point-to-point  AC + point-to-point  point-to-point
Unconstrained
What is governance?

Main categories from Mekonnen et al., 2016
Caveat Emptor

- Limitation of comparisons to e-Highway2050
  - Grid parameters
  - OW potential
  - VOLL
  - 2030 MCs
- Flat transmission
- Transmission compatibility & standardization
- Short-term detail
- (In)flexibility and unit commitment
- Forecast errors and short-term markets
- Stochastic renewables
- Realistic hub placement
- Impedance modelling
- Components investment cost
- Nordic and British DC grid modelling
Recent research

- **Case studies: Modelling of projects for CBA and regulatory analysis**
  - NorthSeaGrid (E3G et al., 2015): Three North Sea cases
  - Jepma, 2015: Combination of offshore wind and oil & gas
  - Flynn, 2016: NSCOGI case study applying the MLP framework

- **Regulation and governance: Qualitative frameworks**
  - PWC et al., 2016: Energy model CBA followed by a regulatory analysis framework
  - Meeus, 2014: Regulatory principles and adequacy of different developer models
Grid is beneficial, but estimates vary

Net benefits = welfare (surpluses and congestion rent) - investment and operation costs

Dedecca et al., 2016
Wind growth of up to 150GW by 2030, but uncertain

Dedecca et al., 2016
Energy modelling

Adapted from Jägemann et al., 2013
Main barriers

- Jay and Toonen, 2015: Collaboration has progressed but is still slow and limited
  - Regulatory complexity and misalignment
  - Project difficulties
  - Soft legal approaches at the European level
  - Lack of involvement of civil society

- Fitch-Roy, 2016: Increased wind development model convergence
  - Mixed contribution of the European Union
  - Not necessarily reflected in an effective cooperation for grid development

- Flynn, 2016: Importance of the national level and national differences in renewables development
  - Contrast between ambitious visions and the reality of the national or bilateral development
From 1 to 12GW in 10 years

GLOBAL CUMULATIVE OFFSHORE WIND CAPACITY IN 2015

ANNUAL CUMULATIVE CAPACITY (2011-2015)

GWEC, 2016
Figure S8: Anticipated timing and importance of innovations in offshore wind technology, 2016-2045

IRENA, 2016
Recent developments

- **Energy Union winter package**
  - MEPs manifesto (Belet et al., 2016)
  - Review of market design, renewables directive, ACER regulatory framework

- **Offshore wind auctions**
  - Feb/16 - DK Horns Rev 3: 400MW @ €103/MWh
  - Jul/16 - NL Borselle I & II: 760MW @ €72.7/MWh
  - Sept/16 - DK nearshore Vesterhav Syd & Nord: 350MW @ €60/MWh

- **US**
  - Deepwater commissioning in Nov/16 (30MW in Rhode Island)
  - US DoE national offshore wind strategy (US DoE et al., 2016)

- **Asia**
  - Offshore wind in China, Taiwan, Japan, Korea, India
  - Asia supergrid (Ohbayashi, 2016)
### 1st version findings

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mechanisms</th>
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<tbody>
<tr>
<td>Cost structure</td>
<td>Different cable costs favor expansions with different lengths</td>
</tr>
<tr>
<td></td>
<td>Different terminal costs favor expansions with different terminal capacities</td>
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<tr>
<td>NPV types</td>
<td>The NPVa favors the maximum net benefit, independent of the investment cost</td>
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<td></td>
<td>The NPVr favors investment efficiency by maximizing net benefits over investment costs</td>
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<tr>
<td>NPV scopes</td>
<td>Kaldor-Hicks and Pareto scopes rule out expansions which may have a higher social net benefit</td>
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<tr>
<td>Multiterminal links</td>
<td>Multiterminal links have reduced investment costs but parallel links may restrict flows</td>
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<td>Path dependence</td>
<td>Expansion investments in earlier periods affect the selection for the following ones</td>
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<tr>
<td>Wind farm installation timing</td>
<td>Expansions connecting new installations provide higher benefits due to cheaper system operation</td>
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<tr>
<td>Candidate exhaustion</td>
<td>There can be no expansion with a positive NPV due to previous expansions or higher investment costs</td>
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<td>Expansion characteristics</td>
<td>Capacities and lengths of specific expansions</td>
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<tr>
<td>Grid functions integration</td>
<td>Higher integration of interconnection and wind connection may lead to higher link utilization (and possibly congestion) as well as lower investment costs</td>
</tr>
<tr>
<td>Terminal capacities levels</td>
<td>Higher terminal capacities require higher investments</td>
</tr>
</tbody>
</table>
Myopic optimization

- **Myopic optimization**: An optimization problem with a restricted horizon
  - E.g. In time (single period optimization in a multi-period simulation) or in space
  - E.g. In space (local optimization in a larger geographical area)
Pareto welfare for each country

**Consumer payments**

\[
\sum_{s_n} \sum_{b} B_{b,sn} \ast \lambda_{b,it} \ast D_{b,sn} - \sum_{l \in L^{CL}} C_{b,l}^{CL} \ast K_{l}^{LI} \ast \overline{f}_{l,sn}
\]

**Producer surplus**

\[
\sum_{s_n} \sum_{g} p_{g,sn} \ast (\lambda_{b,it} - K_{g}^{G}) + \sum_{s_n} \sum_{s} p_{s,sn} \ast \lambda_{b,it} - \sum_{s_n} \sum_{s} s_{s,sn} \ast \lambda_{b,it}
\]

**Congestion rent**

\[
\sum_{s_n} \sum_{l} C_{b,l}^{CL} \ast f_{l,sn} \ast (\lambda_{j,it} - \lambda_{i,it})
\]

**Transmission investment**

\[
\sum_{l \in L^{CL}} C_{b,l}^{CL} \ast K_{l}^{LI} \ast \overline{f}_{l,sn}
\]

**Generation investment**

\[
\sum_{g \in G^{OW}} C_{b,g}^{OW} \ast K_{g}^{OWI} \ast (\overline{p}_{g}^{OW} - \overline{P}_{g}^{0})
\]