Technische Universität Berlin
*Fachgebiet **W**irtschafts- und **I**nfrastruktur**p**olitik*

North Sea Offshore Grid Design

A Techno-Economic Analysis for Market Impacts in the North and Baltic Sea Region

Transatlantic Infraday - Washington D.C.

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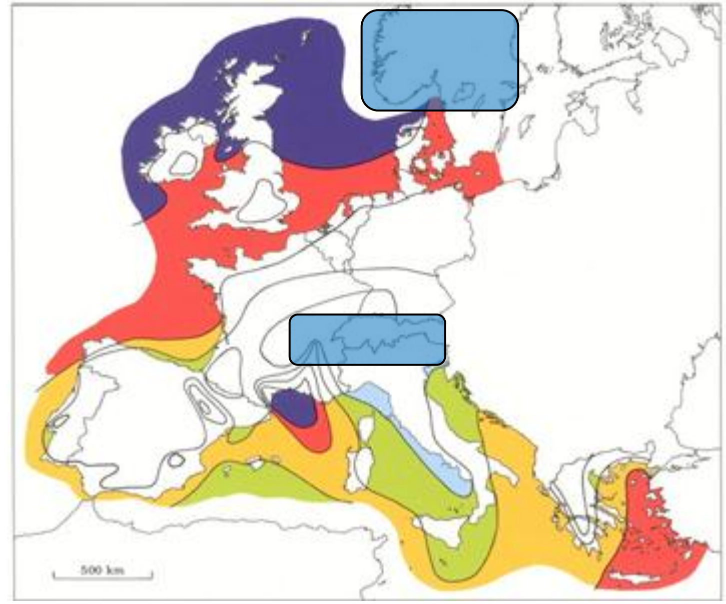
Agenda

1. Introduction and Motivation
2. Modeling Approach
3. Scenarios
4. Results
5. Conclusion

Introduction and Motivation

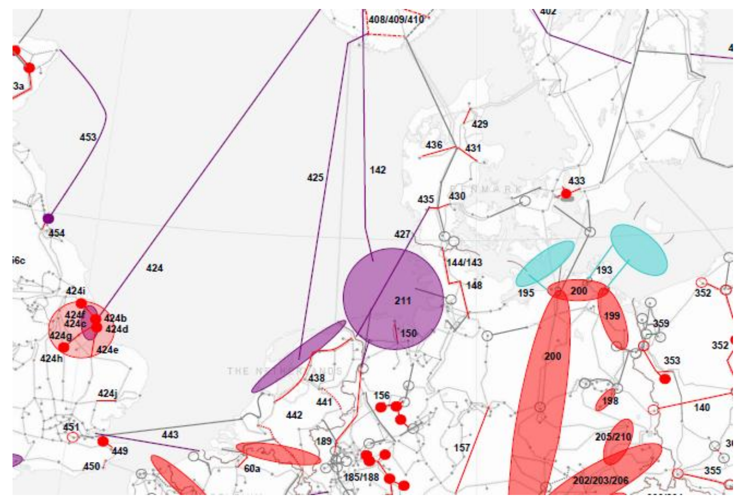
Electricity Markets in North and Baltic Sea Region:

- Separated markets (non-synchronized)
- Different generation portfolios
  - \- Thermal generation
  - \- Renewable capacity
  - \- Hydro reservoirs
- Increasing share of wind generation



Offshore network between markets:

- Several HVDC connectors
- Planning status for more capacity:
  - \- NO ←→ GB / DE / NL / DK
  - \- DK ←→ NL
- Point-to-point transmission connectors



Source: European Wind Atlas (1989), ENTSO-E (2011).

Introduction and Motivation

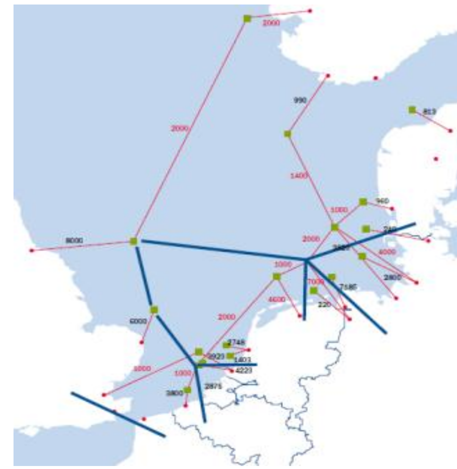
TradeWind (2009):

- Zonal modeling approach with system cost minimization
- Quantification of offshore grid layouts (meshed design with cost of €300-400M/year)
- Meshed offshore grids design economically most beneficial (+ €326M/year)
- European wind generation data:

  2005: 42GW

  2020: 200GW

  2030: 268GW



OffshoreGrid project (2009-2011):

- Follow-up project
- Preparation of blueprints for an offshore grid
- Cost-benefit calculation for detailed offshore grid designs

What is the welfare and rental impact on the national electricity markets?

Source: EWEA (2009).

Relevance of Research Question?

Network Planning:

Technical Network Planning → Security of Supply / n-1 Security

Cost Optimal Planning → Minimize operation cost plus investments

Welfare Optimal Planning → Maximize welfare minus investments

BUT:

- How about the national perspectives (e.g. EU - nations, PJM - states)?
- Allocation of welfare and investment costs?
- Socio-economic implications on national level?

Agenda

Modeling Approach

DC Load Flow Model

with welfare maximization (ELMOD)

$$\max_{\substack{g_{n,s,t} \\ q_{n,t}}} W = \sum_{n,t} \left[\left(A_{n,t} * q_{n,t} + 0.5 * M_{n,t} * {q_{n,t}}^2 \right) - \sum_s \left(g_{n,s,t} * MC_{n,s} \right) \right]$$

$$|flow\_ac_{ac,t}| \leq Flow\_AC\_max_{ac}$$

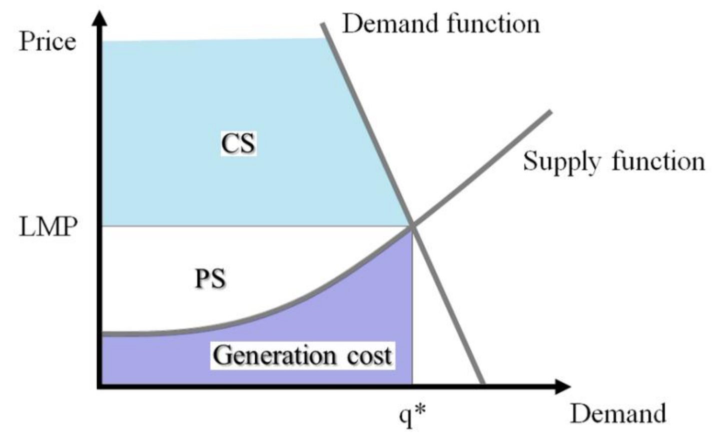
$$flow\_ac_{ac,t} = \sum_n \left(H_{ac,n} * delta_{n,t} \right)$$

$$|flow\_dc_{dc,t}| \leq Flow\_DC\_max_{dc}$$

$$g_{n,s,t} \leq G\_max_{n,s} * Availability_{n,s,t}$$

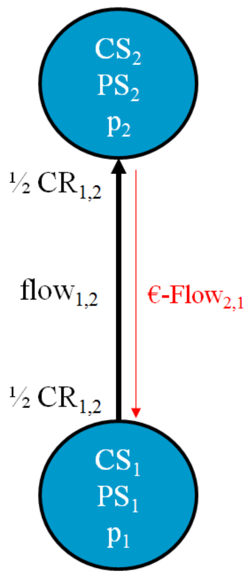
$$\sum_{t=1}^{m} \left(g_{n,s,t} \right) \leq Res_n * G\_max_{n,s} * m$$

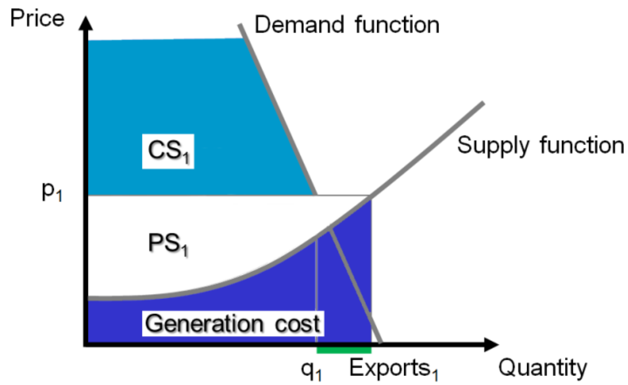
$$\sum_s g_{n,s,t} - demand_{n,t} - ac\_input_{n,t} - dc\_input_{n,t} = 0$$



Source: Leuthold et al. (2011).

Two Zone Example – Welfare and Surpluses

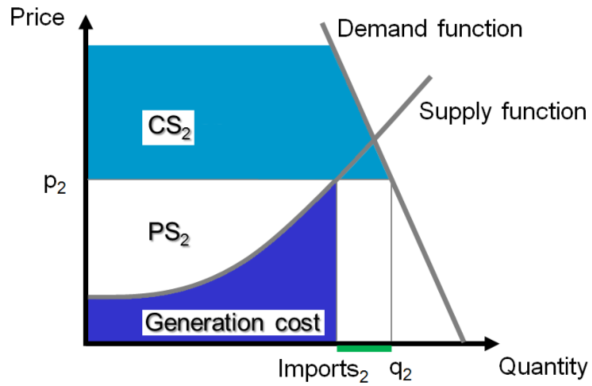




Zone 1: *$Exports_1$* increase p_1 → higher PS_1 and lower CS_1

Zone 2: *$Imports_1$* decrease p_2 → lower PS_2 and higher CS_2

Congestion Rent ($CR_{1,2}$) = $flow_{1,2} * (p_2 - p_1)$



Modeling Approach

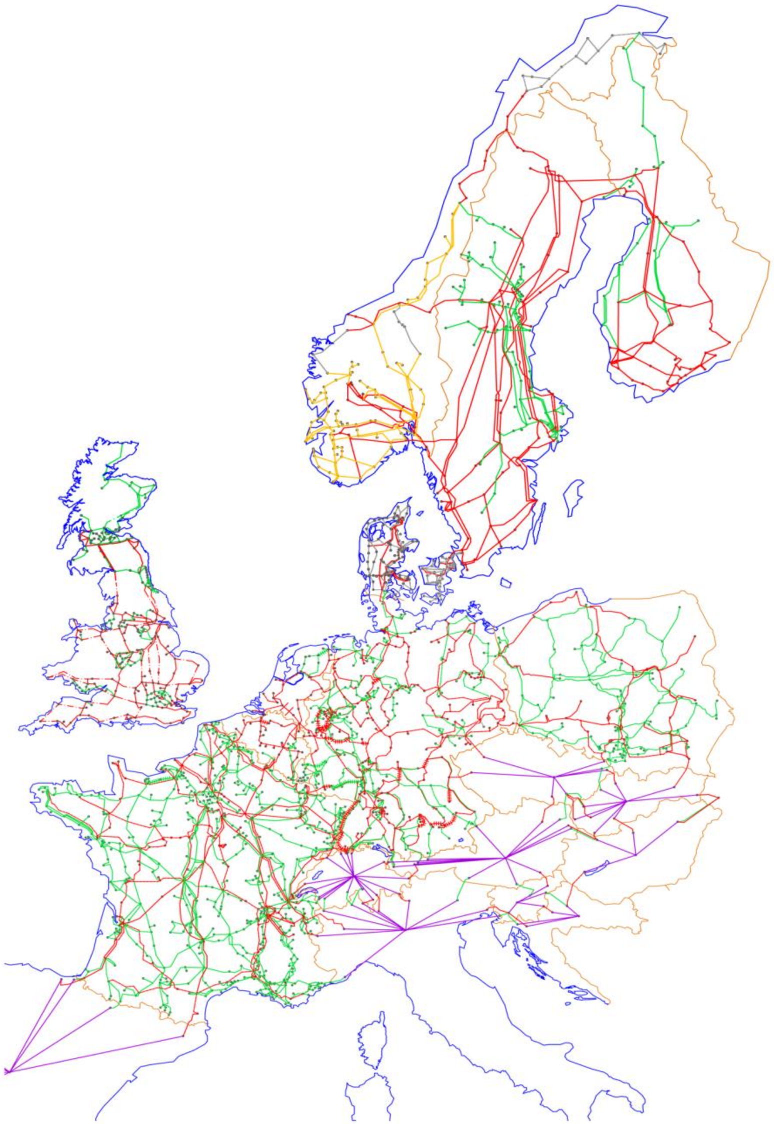
Model Scope:

- Three separated AC control zones
- Connected by HVDC offshore grid
- Reference year: 2009

- Nodes 2069
- AC lines 2877
- DC lines 8

Time resolution:

- 80 non-consecutive reference hours
- Season (2x), demand (10x), wind (4x)
- Free allocation of hydro reservoir generation



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Scenarios

Trade scenario:

- Separate wind integration and trade connectors
- Point-to-point connectors between two countries

Meshed scenario:

- Combined wind integration and trade capacity
- Meshed offshore system

Wind+ scenario:

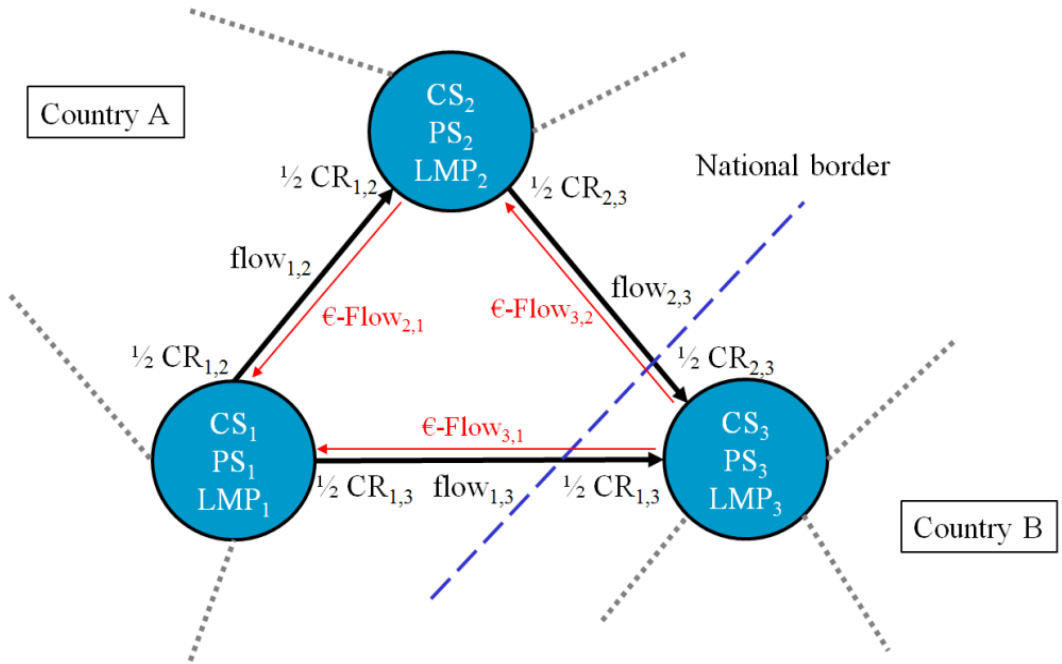
- Additional on- and offshore wind generation capacity
- Data based on 2020 figures of OffshoreGrid Project

Agenda

Results

Model outputs:

- System welfare (objective)
- Nodal consumer surplus (CS)
- Nodal producer surplus (PS)
- Locational marginal prices (LMP)
- Line flows on each link



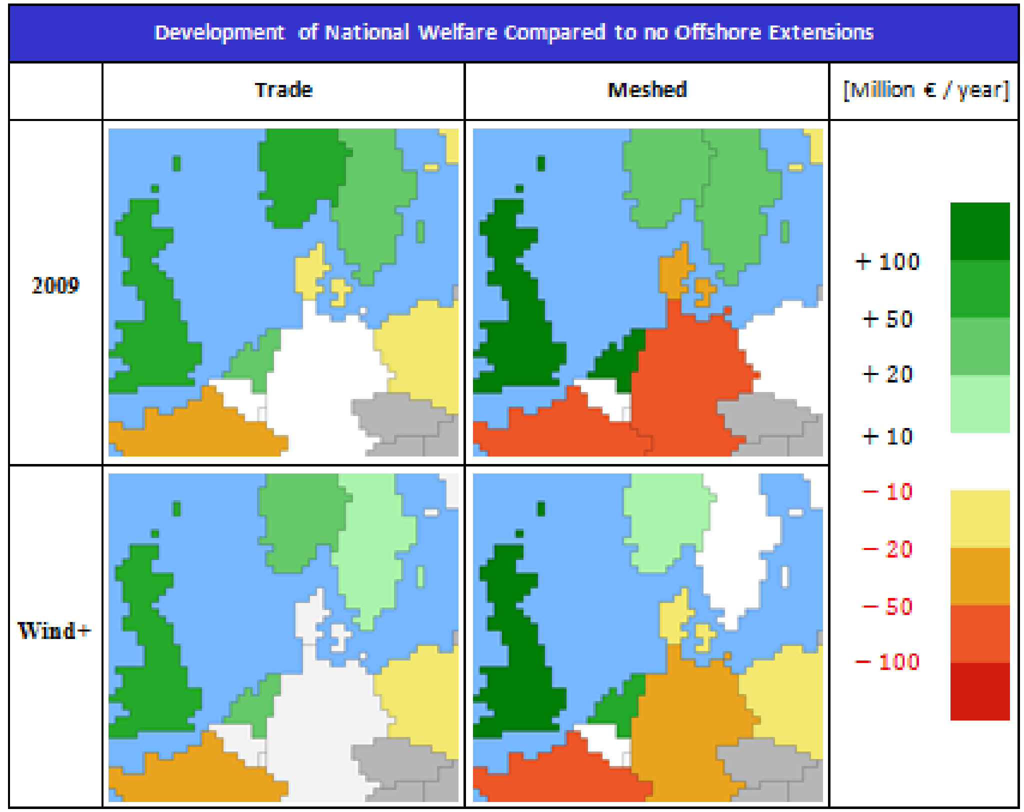
Calculated output results:

- National consumer surplus
- National producer surplus
- National congestion rent
- National welfare (=sum of previous ones)

Results

National welfare implications:

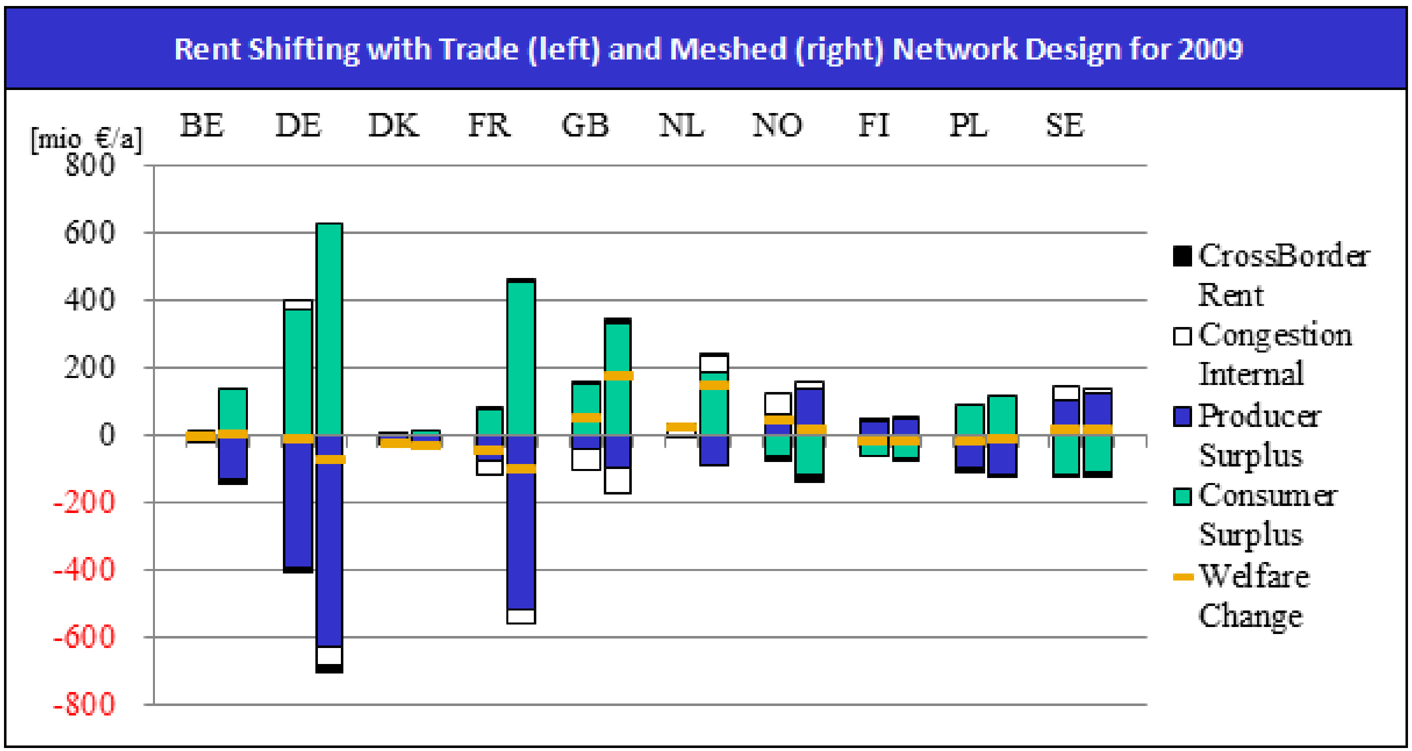
- Different designs have strong impact on welfare gains/losses
- Meshed network sees higher overall welfare gains than trade scenario
- Tendency of winners and losers for all scenarios
  - Isolated countries with excessive and flexible generation capacity gain welfare (GB, NO, SE)
  - Largest net importer (NL) gains by lower prices
  - Traditional exporting countries lose some export share (FR, DE)



Results

Change in national consumer and producer rents:

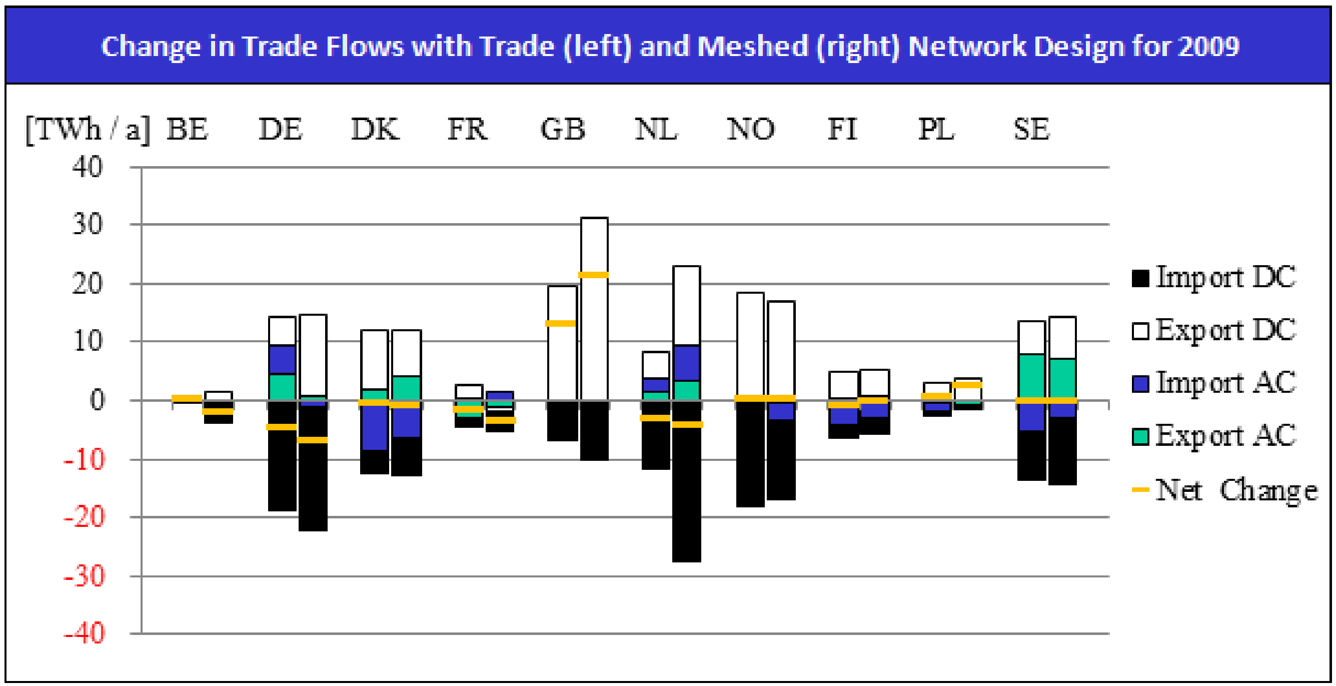
- Strong national rent shifting effects in most countries
- Meshed network leads to higher rent shifting (stronger price convergence)
- Some countries experience higher internal congestion with offshore connectors
- More wind in the system creates similar results (reservoirs!)



Results

Change in trade flows:

- Net balance only changes in GB (+) and DE & NL (-)
- Balancing renewable generation between Scandinavia and UCTE is realized in the modeled scenarios (national imports and exports increses)
- Meshed network → more trade between NL and GB



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Conclusion

- Different network designs have quite different effects on social welfare and on distributional aspects → **inter-national objectives**

- Effect of national rent shifting between consumers and producers is a lot higher than national welfare changes → **intra-national objectives**

- Congestion rents on offshore connectors seem to be highly sensitive to additional transmission capacity in the offshore grid → **regulated network planning**

- Results driven by market integration and balancing different wind generation levels with hydro reservoir generation (no geographic deviation in wind generation) → **modeling issue**

- Meshed offshore grid (more onshore connections) decrease onshore congestion to a stronger extend then point-to-point links → **hinterland analysis**

Thank you for your attention

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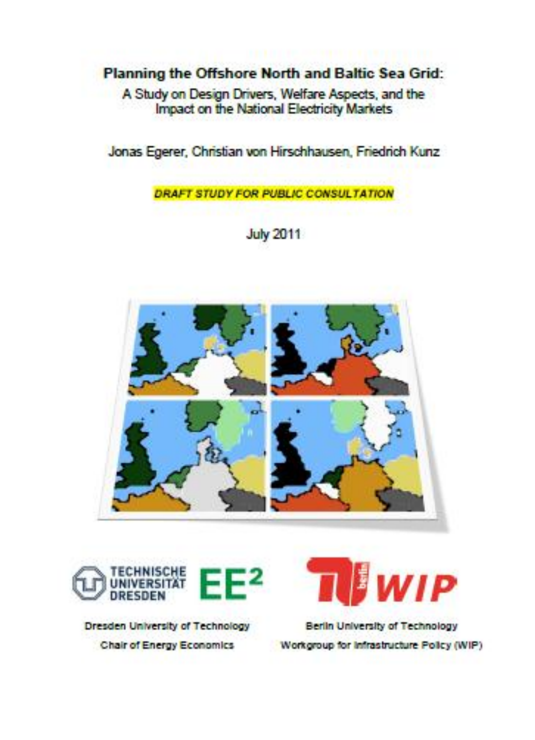
Planning the Offshore North and Baltic Sea Grid:
A Study on Design Drivers, Welfare Aspects, and the Impact on the National Electricity Markets

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