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RSCAS 2012/69
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EUI Working Paper **RSCAS** 2012/69

ISSN 1028-3625

Printed in Italy, December 2012
European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy
www.eui.eu/RSCAS/Publications/
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Abstract

The North and Baltic Sea Grid is one of the largest pan-European infrastructure projects raising high hopes regarding the potential of harnessing large amounts of renewable electricity, but also concerns about the implementation in largely nationally dominated regulatory regimes. The paper develops three idealtype development scenarios and quantifies the technical-economic effects: i) the Status quo in which engagement in the North and Baltic Sea is largely nationally driven; ii) a Trade scenario dominated by bilateral contracts and point-to-point connections; and iii) a Meshed scenario of fully interconnected cables both in the North Sea and the Baltic Sea, a truly pan-European infrastructure. We find that in terms of overall welfare, the meshed solution is superior; however, from a distributional perspective there are losers of such a scheme, e.g. the incumbent electricity generators in France, Germany, and Poland, and the consumers in low-price countries, e.g. Norway and Sweden. Merchant transmission financing, based on congestion rents only, does not seem to be a sustainable option to provide sufficient network capacities, and much of the investment will have to be regulated to come about. We also find strong interdependencies between offshore grid expansion and the subsequent onshore network.

Keywords

Electricity, Offshore Transmission, Rent Allocation

JEL-code: D60, L51, L94

1. Introduction[*]

The North and Baltic Sea Grid features very prominently on the agenda for European energy infrastructure development, both by the European Union and its Member States. The North Sea Grid is the No. 1 priority of the "European energy infrastructures for 2020 and beyond", which defines the objective to develop an "Offshore Grid in the Northern Seas and a connection to Northern as well as Central Europe" (European Commission, 2010, p. 10). The objective is "to integrate and connect energy production capacities in the Northern Seas, including the North Sea and North-Western Seas, with consumption centers in Northern and Central Europe and hydro storage facilities in the Alpine region and in Nordic countries" (idem, p. 10). This project is important since it would enable continental Europe to accommodate large volumes of wind and hydropower surplus electricity generation in and around the Northern and Baltic Seas, while connecting these new generation hubs, as well as major storage capacities in Northern Countries and the Alps with the major consumption centers in Continental Europe.

The economic literature[1] and recent engineering studies seem to agree on the benefits of offshore grids, such as the North and Baltic Sea Grid. The economic benefits result from a better use of existing electricity generation resources, higher security of supply and reserve power, and the integration of a higher share of renewable energy generation, mainly wind and hydropower. Thus, European Wind Energy Association (EWEA, 2009a) investigates the integration of 40 GW offshore wind generation capacity into the European electricity network by 2020 and 150 GW by 2030, while by 2020 most of the additional cables are still point-to-point. By 2030 the study assumes the realization of a really meshed offshore grid with offshore connectors parallel to the British east coast connecting to offshore hubs at the Belgian, the Dutch and finally the German part of the North Sea. The TradeWind study (EWEA, 2009b) is the first analysis of the proposed offshore grid designs with a flow based model; the objective function of which is to minimize the total operating costs of the system. In a high wind scenario, annual cost reduction for generation amount to € 326 mn.; investment costs are estimated in the range of € 300-400 mn. per year. The "preliminary analysis indicates a better cost-benefit ratio for the meshed grid than for the radial connection solution" (EWEA, 2009b, p.61). The North Sea Electricity [r]evolution study (Woyte et al., 2008) describes a layout for an offshore grid, allowing for an offshore wind power capacity of 68.4 GW with an annual output of 247 TWh by 2030. The offshore links have a total length of 6,200 km, and estimated investment costs of € 15-20 bn.; the layout consists of mostly direct HVDC connections with few offshore substations. Last but not least, the OffshoreGrid study (Decker and Kreutzkamp, 2011) concludes firstly, that the connection costs of offshore wind farms could be reduced by 14 bn. € in the next 25 years by offshore clustering and secondly, the optimal offshore grid design should include meshed network elements instead of only radial connections. Think (2011) provides a general assessment of engineering and economic analyses of offshore grids.

However, besides the discussion on technical aspects of the North and Baltic Sea Grid, and the general agreement on overall positive welfare effects, little is known on the specific effects of the project on each of the participating stakeholders, countries, potential investors, incumbent energy companies, and consumers. Yet it is precisely these stakeholders who will be the main drivers of the North and Baltic Sea Grid, with political, regulatory, and eventually some financial support from the

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[*] We thank without implying seminar/conference participants at EEM 2012 (Florence), YEEES Seminar 2011 (Madrid), Transatlantic Infraday 2011 (Washington D.C.), Wind Integration Workshop 2011 (Aarhus), Infraday Conference 2011 (Berlin), S.CO.RE. Seminar 2011 (Florence), IAEE International Conference 2011 (Stockholm), Enerday Conference 2011 (Dresden). This paper is based on the Diploma Thesis of Jonas Egerer (2010), the usual disclaimer applies.

[1] See Nooij (2011), Malaguzzi Valeri (2009), and Turvey (2006) for the examples of NorNed between Norway and the Netherlands, of the East-West interconnector between Ireland and the United Kingdom and of the French-English interconnector.

European level. But, so far, there is a lack of understanding how stronger interconnection and different offshore grid designs change the market situation in the affected countries. Indeed one observes somewhat less enthusiasm about the perspectives of the North and Baltic Sea Grid at the level of individual actors, or even outright resistance of a few stakeholders that fear to lose economic ground in the process (see Midttun et al., 2012, for the case of Norway). More generally Supponen (2011) provides a survey of the political economy of transmission investment in Europe.

Rather than to chime into the voices of normative analysis what should be done, be it in favor or against certain pathways, this paper therefore proposes a positive analysis of the micro-aspects of the North and Baltic Sea Grid: we identify several possible pathways how tapping of renewable energy sources in the region can proceed, from national approaches over intensified trade connections, to a fully meshed network. The paper also proposes a methodology to assess the distributional impacts of different scenarios for the North and Baltic Sea Grid.

A second ambition of this paper is to sketch out options for sustainable development for cross-border networks, that go beyond the stylized hypothetical supergrids often promoted. Indeed, the past decade has shown that beyond the rhetoric of pan-European infrastructures, cross-border transmission expansion has been rather modest, and that visions of “supergrids”, e.g. the meshed North and Baltic Sea Grid, or the fully integrated EU-MENA integration (à la Desertec or MedGrid) have had a difficult time in taking off. Whilst maintaining the objective, i.e. large-scale renewable integration, we therefore open up alternative perspectives; in doing so, we follow the scenario classification proposed by Hirschhausen (2012) who distinguishes a fully European, a regional, and a national scenario.

The rest of the paper is structured in the following way: the next section sketches out the methodology and the engineering-economic approach: we use the European electricity market model ELMOD to calculate the effects of different North and Baltic Sea Grid developments on the different actors involved. Section 3 sketches out the three stylized scenarios, i.e. possible trajectories in which future market developments may evolve: these range from a rather nationally focused development to a full European integration. Section 4 then reports modeling results and some interpretation, focusing on the effects of the North and Baltic Sea Grid on welfare, producer and consumer surplus, the electricity flows resulting from different network designs, and the congestion rents emerging on concrete network connections. In Section 5, we also check whether merchant transmission financing, which is sometimes considered as an important lever of infrastructure development, has a role to play in the North and Baltic Sea Grid. The last section provides the conclusions.

2. Methodology

2.1 Model description

We analyze the distributional effects, both in terms of nation-wide effects, and the distribution of benefits between electricity generators and consumers, for different design configurations of a potential North and Baltic Sea Grid. To this behalf, we apply the ELectricity MODel ELMOD (Leuthold et al., 2012), a techno-economic model of the European electricity market. It implements the DC load flow approach (Schweppe et al., 1988) which allows a realistic representation of physical characteristics of electricity networks including Kirchhoff’s laws. The model comprises the high voltage transmission system on a nodal level of the ENTSO-E area, with the objective to maximize system welfare (1) under several constraints, amongst them the balancing equation for each node (2):

$$\max_{\substack{g_{n,s,t} \\ d_{n,t}}} W = \sum\nolimits_{n,t} \left[\left(A_{n,t} d_{n,t} + \frac{1}{2} M_{n,t} {d_{n,t}}^{2} \right) - \sum\nolimits_{s} \left(g_{n,s,t} MC_{n,s} \right) \right] \qquad (1)$$

$$\sum\nolimits_{s} g_{n,s,t} - d_{n,t} - ac\_input_{n,t} - dc\_input_{n,t} = 0 \qquad \forall n, t \qquad (2)$$

The model maximizes system welfare by optimizing nodal generation (g) and demand (d). System welfare (W) is defined as the sum of consumer and producer surplus and corresponds to the area below the inverse demand function minus the marginal generation cost for every network node (n) and for every hour (t). The inverse demand function is determined by the prohibitive price A and the slope M. The model is constrained by the maximum transmission capacity of the AC and the DC lines, respectively. Electricity generation is constrained by maximum installed capacity for every node and technology (s). The energy balance (2) ensures the balance of nodal generation, demand, and in-/outflow through AC and DC lines for every system node. The marginal on the constraint is the cost of an additional incremental unit of electricity at the node and can be interpreted as the locational marginal price. The model is implemented in the General Algebraic Modeling System (GAMS) and solved with CPLEX.

The reference scenario uses market data of the year 2009. The network consists of three non-synchronized networks (Continental Europe, Great Britain and Scandinavia), implemented with the DC load flow approach and connected by DC cables. In total, the system includes 2069 nodes, 2877 AC lines and eight DC lines[2]. It has a line sharp resolution for all countries adjacent to the North and Baltic Seas while neighboring countries are referred to with one generation/demand node and the cross border links.

Generation includes 16 technologies[3] distinguished by different marginal generation costs based on fuel prices and cost for emission allowances. Renewable generation[4] is assumed to have zero marginal generation cost and hourly availability. The hours (t) include 80 different time periods referring to the matrix of season (winter and summer), ten different demand levels and four different wind output levels. Seasonal hydro reservoirs face (in addition to installed capacity) an annual generation budget endogenously allocated by the model to the 80 time periods as flexible generation.

2.2 Estimating the effects on stakeholders

The contribution of this paper is that we differentiate the economic effects of transmission expansion specifically on certain stakeholders, mainly electricity consumers, producers, and transmission companies. Figure 1 shows the methodology for a simplified two-node example: The difference in prices between nodes is a good indicator where upgrading the network might be beneficial. However, transmission capacity causes price convergence and thereby alters the market result as it allows for more trade flows. In node 1, the exports raise overall demand and therefore cause a higher price (p_1) redistributing consumer surplus (CS) to producer surplus (PS) and further decreasing CS_1 by lower zonal consumer demand (q_1). Producers at node 1 (PS_1) benefit from the higher price and the additional exports. In node 2, the imports decrease the price (p_2), leading to increased consumer surplus (CS_2) stemming from redistribution (PS_2 is reduced) and higher quantities (q_2). For producers in node 2 (PS_2) the competition from node 1 implicates lower generation volumes and surplus.

If the transmission capacity between the two nodes is limiting a scarcity rent accrues from the transport of electricity, the congestion rent (CR). It reflects the rent of the line between the two nodes and is quantified by the price difference between the starting and the ending node of the line (price difference of the two nodes) multiplied with the line flow. For the welfare calculation in this paper it is assumed that the congestion rent is allocated evenly between the two nodes for each line. The overall net impact on zonal welfare depends on the specific characteristics of the demand and supply function in the node and the congestion rent. Therefore, losses in CS by a higher zonal price might be lower or higher than the additional income for producers with exports.

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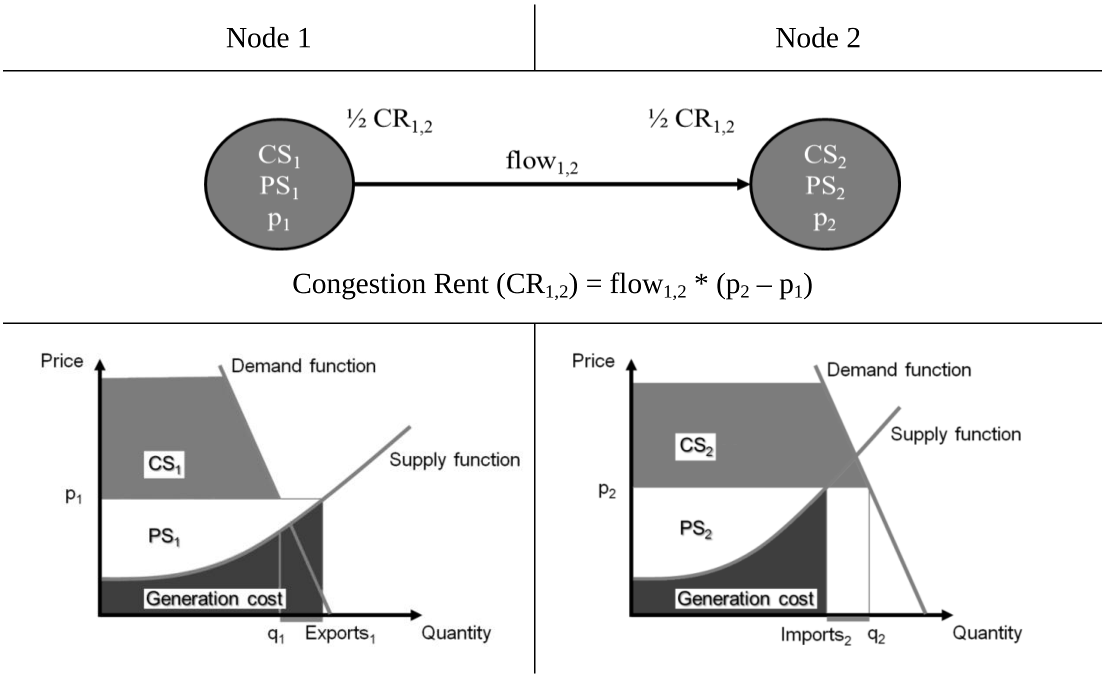
[2] Fenno-Skan, Kontiskan, Swepol, Kontek, Baltic Cable, NorNed, Skagerak, and Cross-Channel.

[3] Nuclear, lignite, hard coal, three technologies for gas, three technologies for oil, pump storage and biomass are the technologies with constant variable generation costs.

[4] Run of river, reservoirs, on- / offshore wind, and geothermal.

In the subsequent analysis, we quantify welfare as well as producer and consumer surplus at a national level. The objective function of the model leads to welfare maximization for the sum of the participating countries, including all countries i and their consumer surplus (CS_i), producer surplus (PS_i) and congestion rents in the network (CR_i). The national congestion rent is distinguished in internal CR_i on all lines within the country and in cross-border CR_i for all lines connecting it to other countries. We thus are able to obtain welfare values, CS, PS and internal and external congestion rents of the transmission system, analyzed at the national level for all countries adjacent to the North and Baltic Sea.

Figure 1: Welfare and rental distribution in a two node example



3. Three Scenarios: "Status quo", "Trade", and "Meshed"

3.1 Stylized development scenarios

In a highly meshed network as the European electricity transmission system, the expansion of transmission capacity can relieve congestion in one place but is likely to increase congestion in another, thus moving congestion rents from one line to another. Therefore, the effects of transmission expansion on national welfare and surpluses are not obvious and subject to scenario based evaluation. A major argument of this paper is that the development paths of the North and Baltic Sea Grid can not be forecasted ex ante, neither that full integration is the default case. Rather, economic history and recent experience with transmission expansion teaches us that a variety of development options are possible, and that it is impossible to forecast a "most likely" scenario.

We propose a trias of political-institutional scenarios that were initially sketched out in Hirschhausen (2012): i) continuation of the status quo, where electricity markets develop decentrally, focusing on the national level, with purely nationally focused policies of supply security, and the absence of further European harmonization; ii) move towards stronger regional cooperation, i.e. integration of local or national energy markets, relying more on bi- or trilateral contracting, under the umbrella of some European framework ("Regional" scenario); and iii) rapid completion of the internal energy market with a perfectly functioning, EU-wide market system and with European-wide energy superhighways (“Europe centralized” scenario in Hirschhausen (2012)).

Although these stylized scenarios can not be transferred one-to-one to the North and Baltic Sea Grid, they provide some orientation for what may happen in the region. Therefore, three different scenarios are subsequently described taking into account firstly the stylized scenarios of Hirschhausen (2012) and secondly the characteristics of the national power system in the investigated North and Baltic Sea region. Furthermore, for each scenario, we distinguish the situation in 2009, with no offshore wind parks connected to more than one country, and a hypothetical scenario “Wind+” which reflects a situation where additional offshore wind generation close to shore (and assumedly to be connected by AC cables) is added to the nearest onshore node. The offshore wind parks more than 80 km from shore are connected with HVDC cables to the country of the respective wind farm. The capacities for on- and offshore wind in the Wind+ scenario[5] are taken from the regional 2020 installation figures of the OffshoreGrid (2010) project. This implies additional cables of 2,600 km * 1 GW transmission capacity[6], most of it installed in the North Sea.

3.1.1 Status quo

The Status quo scenario refers to a case in which the potentials of the North and Baltic Sea are mainly used to supply in the national electricity markets, i.e. the UK harnesses wind offshore the UK coast, Norway and Sweden use their storage potential for domestic balancing, and Germany, the Benelux, France, Poland, etc. develop wind parks and connect them mainly to their national territory. With some exceptions, this scenario corresponds to the status quo in 2012, with few lines connecting the North and Baltic Sea riparians.

The Status quo scenario is sketched out in the first line of Figure 2, both for the base year 2009 and a future “Wind+” situation. Besides very few bilateral connections, all offshore wind parks are connected “only” to the next (national) shore; there are neither bilateral exploitations, let alone multilateral or meshed connections.

3.1.2 Trade scenario

Another possible scenario focuses on bi- or trilateral coordination: the Trade scenario is characterized by point-to-point trade cables that connect two countries, respectively. This structure is foreseen by the ten-year network development plan (ENTSO-E, 2010), amongst others. The Trade scenario thus extends the Status quo scenario by five new connectors and the expansion of the already existing offshore links in the North Sea. In the Baltic Sea the transmission capacity of all existing connectors is extended. In addition to the radial lines for offshore wind integration, an equivalent of 5,300 km of 1 GW in transmission capacity is built. The Trade scenario is a state of the art offshore grid design of point-to-point HVDC cables without multi-terminal solutions.

In the parlance of the European stylized scenarios (Hirschhausen, 2012), the Trade scenario corresponds most closely to the “Regional” scenario: bilateral trade links are in fact nothing else but a way to exploit the existing potentials regionally, between two (or few more) countries.

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[5] For 2009 the installed wind capacity is for onshore 73.6 GW and for offshore 0.3 GW. In the Wind+ scenarios it increases to 177.2 GW and 47.2 GW.

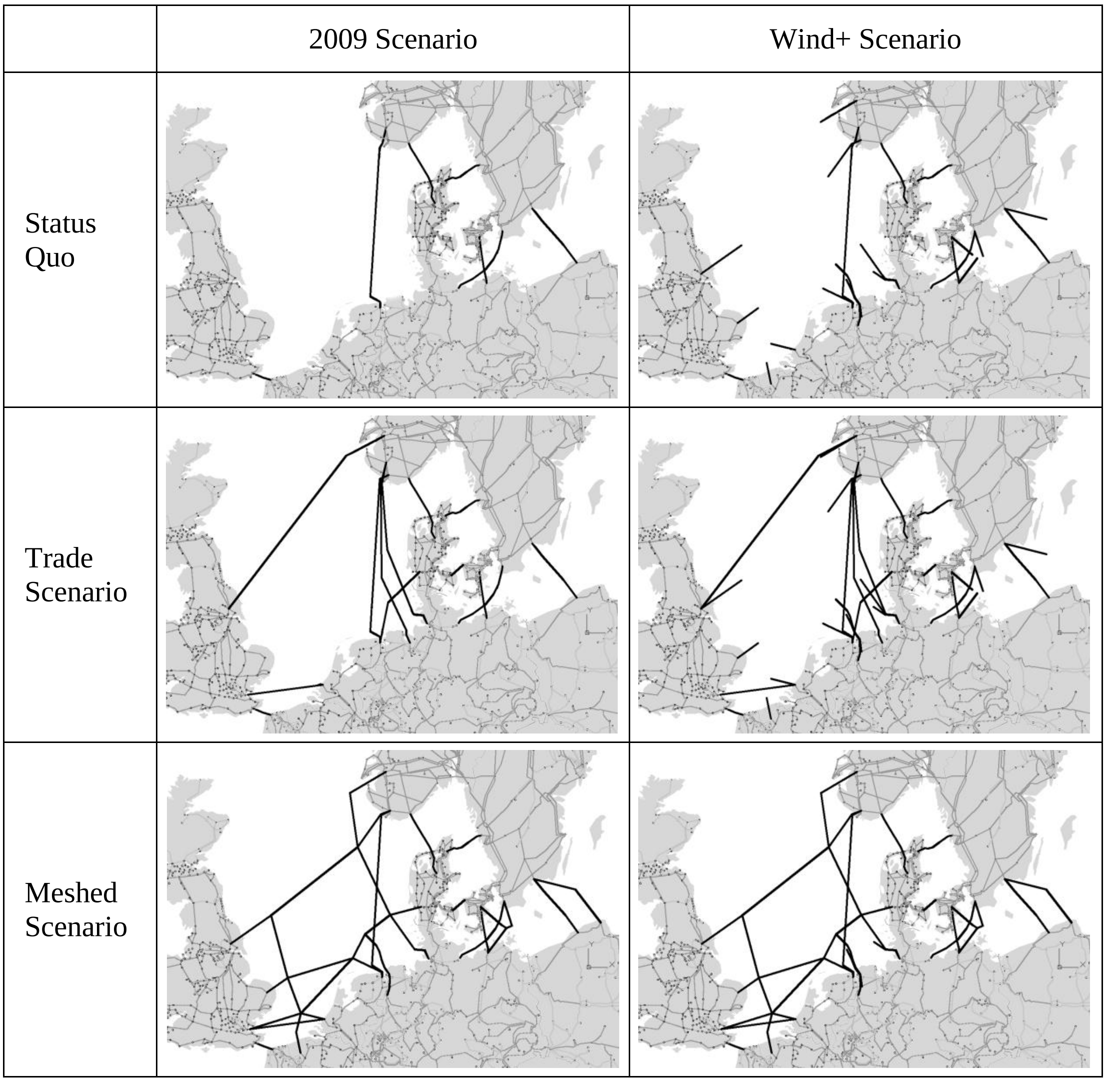
[6] The figure of length [km] * capacity [GW] provides an aggregated investment volume. It combines the capacity of individual lines (which can be different from 1 GW) multiplied with their length.

3.1.3 Meshed scenario

On the contrary, the Meshed grid design stands for an integrated approach for wind feed-in and trade links for the future offshore grid expansions. The concept is derived from the meshed offshore grid proposal in the TradeWind (EWEA, 2009b) and similar studies. Thereby, the hubs of the main offshore wind generation fields in the North Sea are connected with each other by additional connectors. In the Baltic Sea Kriegers Flak is realized. Existing trade links are not extended so that the overall exchange capacity between the three non-synchronized electricity networks (Great Britain, Scandinavia and continental Europe) almost equals the Trade scenario. Due to the existing wind integration the meshed system is embedded in, the overall expansion is only slightly higher (5,500 km * 1 GW) but has to share some of its trade capacity with wind integration. Some technology development is necessary to realize the Meshed design, notably multi-terminal connections that the current HVDC technology does not deliver thus far. However, gradual technological innovations are expected to make such a Meshed scenario feasible within the considered time span.

With respect to the stylized scenarios sketched out above, the Meshed scenario corresponds to “European centralized”, tending towards full integration. In that sense, it can be regarded as representing a “supergrid”, a vision shared by many of the existing studies. Figure 2 shows the network implications of the Status quo case 2009 and the scenarios developed thereupon. One clearly distinguishes the nationally segmented offshore connection in the Status quo “Wind+” scenario, and the point-to-point connections in the Trade scenario, from the intensive interconnection in the Meshed scenario.

Figure 2: Offshore Grid and Wind Scenarios



4. Results and Interpretation

This section first shows the change in electricity trade flows, as calculated by the model; we then move on to provide and interpret the social welfare implications, both at the national level and the level of specific stakeholders (electricity producers, consumers and transmission operators). Finally, we sketch out the perspectives of using the congestion rents to finance transmission expansion commercially ("merchant transmission"). Note that the Status quo scenario is the benchmark, to which the results of the Trade and the Meshed scenarios are compared (in absolute differences). Therefore, we focus on the results from the Trade and the Meshed scenario, referring to the Status quo scenario where appropriate.

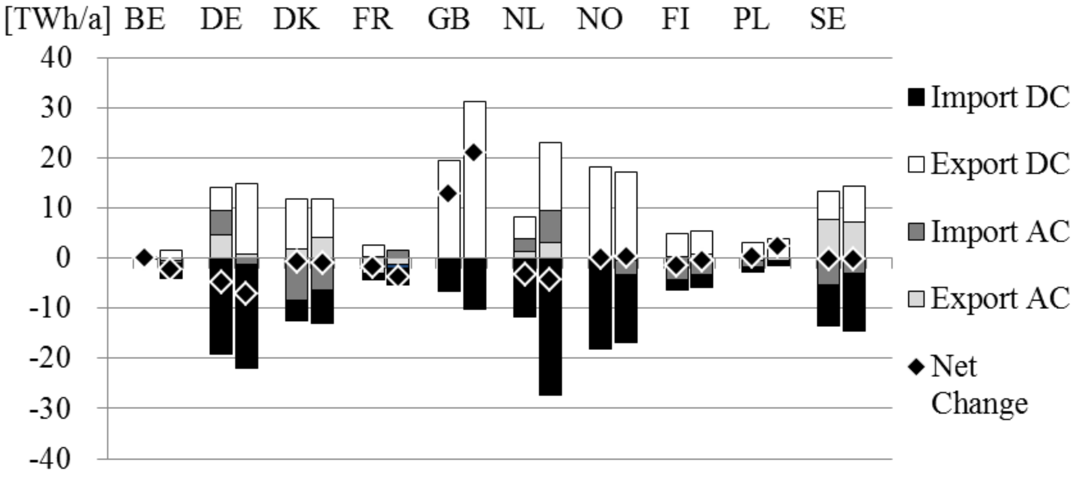
4.1 Changes in trade flows and volumes

International trade flows increase with additional offshore connectors (see Figure 3). In the North and Baltic Sea Grid, cross-border flows increase from 40 TWh/year in the 2009 Status quo scenario to 110 TWh/year in the Trade scenario and to 140 TWh/year in the Meshed design. Thereby, the annual electricity flow increases in both directions for all countries as the North and Baltic Sea Grid allows for a more efficient usage of generation capacities regarding the specific demand needs and fluctuating wind output.

Note that the results are mainly driven by a better integration of Great Britain, which even dominates the effect of additional transmission capacity to Scandinavia. This is caused by lower gas prices and an increase in offshore wind expansion plans in Great Britain. The electricity exported from Great Britain mainly replaces more expensive generation from Germany, France and the Netherlands where the net trade balance decreases. Scandinavia might have cheap hydro generation but the current annual generation output is calibrated to supply the domestic markets and can even be insufficient in dry years. Therefore, the supply curve of generation in this region starts at low prices, but becomes very steep for additional capacity.

The flexibility of the seasonal hydro reservoirs is used in the welfare maximization to increase production and exports in hours with high prices (low wind, high demand). This exported energy has to be imported back in hours with sufficient generation so that exports as well as imports increase significantly for Norway and Sweden. The Meshed design does not lead to increased trade between Scandinavia and continental Europe, as its design allows for more flexible distribution of imports to the Netherlands mainly from Great Britain. Note also that except for the case of Great Britain and the Netherlands, there is no noticeable difference between the Trade and the Meshed scenario with respect to trade flow changes. In fact, the net changes for most other countries appear to be minor, which is a surprising and perhaps even counterintuitive result.

Figure 3: Change in Trade Flows with Trade (left) and Meshed (right) Scenario for 2009[7]



4.2 Overall system welfare and national welfare

Before providing the analysis at the level of the participating countries and stakeholders, we discuss the overall system benefits to society, i.e. the sum of national welfare gains. As the value for total welfare includes the area below the inverse demand function it is reasonable to discuss changes in welfare rather than absolute values.

With respect to the Status quo, the Meshed scenario increases total social welfare by € 210 mn. per year. In the Trade scenario, the increase is only half that amount (~ € 100 mn.). The welfare gains result mainly from a cheaper electricity generation dispatch. The generation dispatch becomes cheaper

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[7] Positive values reflect an increase in exports and decrease in imports (vice versa for negative values).

and location marginal prices decrease.[8] In the Wind+ scenario, the offshore grid designs (compared to status quo of Wind+) create about 20% less welfare increase, due to the fact that more local wind feed-in reduces the inter-regional price differences.[9]

What happens to national welfare, e.g. the sum of producer surplus, consumer surplus, and congestion rents, in the scenarios? Figure 4 presents the major trends in the Trade and Meshed scenarios, when compared to the Status quo scenario which we maintain as reference. Clear bright and dark shades indicate an improvement of national welfare, whereas shaded content indicates a deterioration of national welfare. The main finding is that smaller isolated markets can increase their welfare as they are better integrated in the internal European electricity market. This is the case for Great Britain which has new trade connectors to the Netherlands and Norway in both expansion scenarios. Compared to the 2009 network where only trade with the low price zone of France is possible, the new export markets allow for an increase in national welfare. The highest welfare gains are realized in the Meshed scenario where north-south onshore congestion in the British transmission network is bypassed by the additional offshore connectors alongside the British east coast.

On the contrary, traditional exporting countries suffer losses from the North and Baltic Sea Grid, either by exports or by lower prices; this applies particularly to the traditionally large producing countries Germany and France. The effect is even stronger in the Meshed scenario, with additional supplies from Great Britain and Scandinavia.

A positive welfare effect is observed for importing countries that benefit from lower prices induced by additional low-cost supplies of electricity. This is the case, e.g. for the Netherlands, that changes the structure of its imports, away from the traditional suppliers France and Germany, towards lower price countries like Great Britain and Scandinavia. The increase in consumer welfare largely overcompensates the loss of producer welfare due to lower prices. This development is stronger in the Meshed scenario, where import options are even extended.

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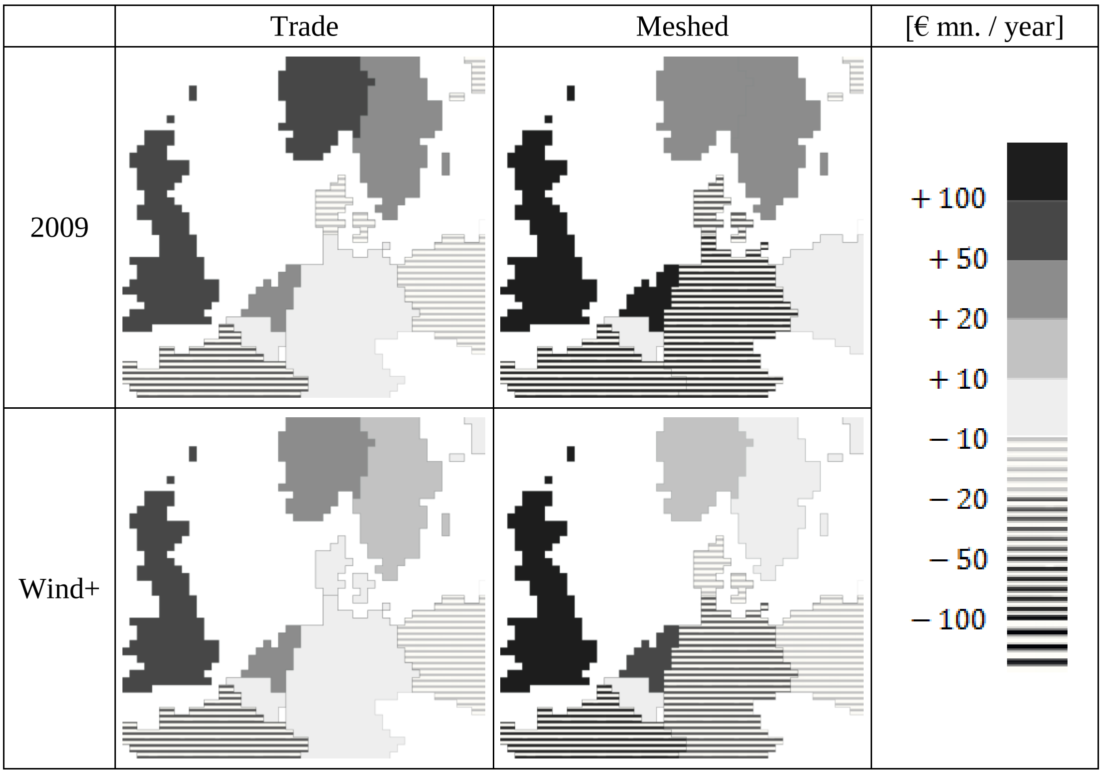
[8] Note that the paper makes no statement on the profitability of the implemented offshore grid scenarios. The focus of this work is to examine the effect of different offshore grid designs on specific stakeholders in the market. However, we only discuss general scenarios of offshore grids which are not optimized but represent possible developments towards point-to-point and meshed designs of the North and Baltic Sea Grid.

[9] New wind generation enters the markets with all other generation still available which shifts the merit order to the right.

Figure 4: Development of National Welfare Compared to no Offshore Extensions



Countries with significant levels of seasonal hydro reservoir capacity can create more national welfare without increasing the net exports; this is notably the case for Norway and Sweden. Hours with high levels of wind generation in the markets connected by the North and Baltic Sea Grid allow for buying cheap electricity to replace domestic hydro reservoir generation. In hours with low wind generation the higher price for electricity allows for additional export profits by increasing hydro reservoir generation. Competing with the transmission capacity of the North and Baltic Sea Grid, transit countries lose welfare by the decrease in congestion rents on their national transmission lines. For Denmark this causes lower welfare values, especially in the Meshed scenario.

In most countries the benefits and losses created by the North and Baltic Sea Grid in the Trade scenario increase when moving to the Meshed design. Except for France, all directly connected countries see welfare gains (GB, NO, SE, NL), are indifferent (BE, DE) or only suffer small losses (DK) in the Trade scenario. This statement does not hold for the Meshed scenario as Germany and Denmark suffer higher losses. To recover the higher gains in system welfare of the Wind+ scenario the willingness to cooperate among countries requires a mechanism to redistribute welfare gains among the participating countries.

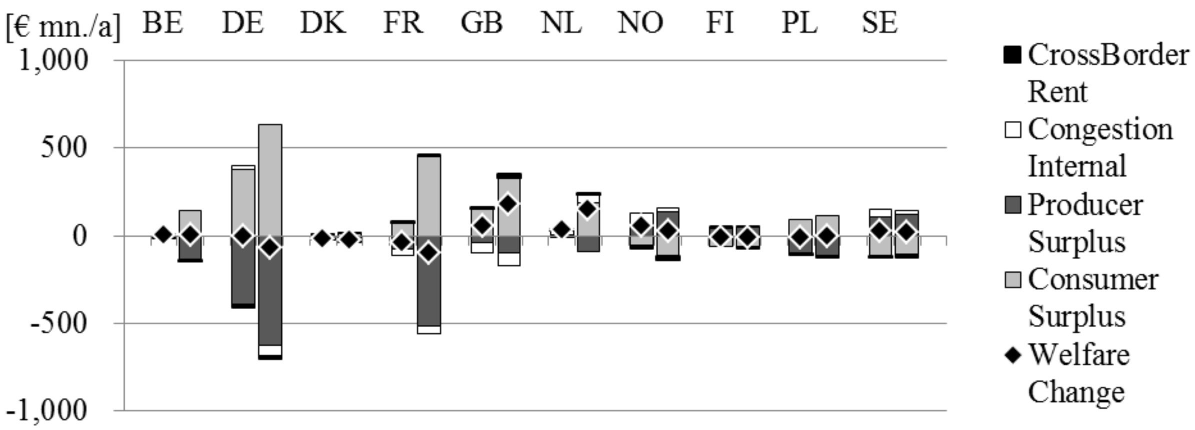
4.3 Changes in national consumer and producer surplus and congestion rents

We now turn to the most sensitive political economy results, in terms of distributional issues of consumer and producer surplus. Even if the national welfare increases for a certain network expansion scenario, higher electricity prices can raise public and political opposition. Candidates for this argument are mainly the Scandinavian countries. The national welfare gain in Norway and Sweden is positive, but consumers have to pay an additional € 100-150 mn. per year. This argument is discussed in detail for the Norwegian case by Midttun et al. (2012) on the national debate about the future of offshore connectors.

Figure 5 shows that for most countries the changes of consumer and producer surplus are significant, even though the aggregate welfare effects seem to be modest. Consumers in continental Europe benefit due to lower electricity prices. These benefits can be substantial, such as in the case of Germany and France with several hundred million Euros. The amount is generally higher in the meshed offshore design. Producer surplus in these countries significantly decreases in the same dimension. With increasing shares of renewable generation capacity, market prices become more sensitive to hourly renewable generation output. Countries with more flexible generation benefit from that development. However countries with large and rather inflexible conventional plants could have an interest in limiting the share of renewable generation. One option is a limitation of new interconnector capacity with countries that have a high share of fluctuating generation.

Note that the Scandinavian countries that are instrumental to the success of the North and Baltic Sea Grid integration “earn” significant losses of consumer welfare; this is particularly the case in Norway, a pivotal country for the North Sea Grid. In the Trade scenario, consumer welfare losses are mainly matched by internal congestion rents, and a little gain in producer surplus; however, in the Meshed scenario the loss of consumer welfare almost equalizes welfare benefits. It is unclear how the discrepancy between beneficiaries and losers from higher market integration plays out in the case of Scandinavia.

Figure 5: Rent Shifting with Trade (left) and Meshed (right) Network Design for 2009



5. Congestion Rents and Interconnector Financing

Congestion rents, i.e. price differences between countries or within countries due to fully used transmission capacity, are an important element of the political economy of transmission expansion. This section therefore analyses the level and the distribution of congestion rents in more detail; in addition to the welfare considerations we are also interested in the financing implications of these rents.

The congestion rent in the onshore systems is highly interdependent with the offshore congestion. Depending on where the bottlenecks are located in the system, a strong expansion of offshore connectors without onshore investment moves the congestion to the onshore links. Vice versa, a good hinterland connection of the offshore connectors can result in the offshore cable as bottleneck in the system. The analysis of the offshore congestion rent should be considered in this context.

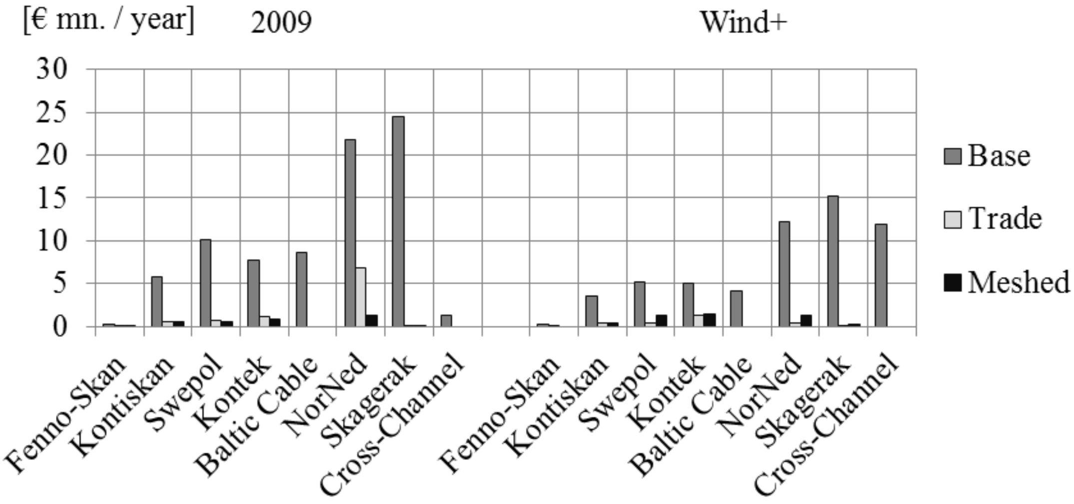
The national congestion rent is an indicator for internal transmission scarcity within the country. Figure 5 above has already shown that the onshore congestion is affected by the offshore grid design. Some countries see more severe internal congestion as a consequence of the offshore connectors (NL, NO and SE) indicating an increasing need for onshore AC extensions. Others have internal congestion relieved with the offshore links (DE, FR and GB). In the Trade scenario the internal congestion rent of all countries together increases by about € 75 mn. per year. In comparison, the Meshed scenario causes lower internal congestion rents in the AC grid for all countries than the Trade design, with an overall decrease of € 175 mn. per year. Comparing these values to the overall annual welfare benefits (see section 0) from the North and Baltic Sea Grid, the importance of the onshore network becomes obvious.

We now consider the offshore network and its congestion rent which is measured by the trade flows on each connector multiplied with the price difference between the starting and the ending node. For the 2009 Status quo scenario there are three offshore connectors in the North Sea and five connectors in the Baltic Sea. The sensitivity of their congestion rent with increasing offshore transmission capacity is illustrated in Figure 6 for the different scenarios.

The congestion rent on the three interconnectors in the North Sea sums up to € 48 mn. per year for the Status quo scenario in 2009. Thereby, the Skagerrak cable between Denmark and Norway (€ 24.5 mn. per year) and the NorNed cable between Norway and the Netherlands (€ 21.8 mn. per year) collect high congestion rents while the Cross-Channel interconnector experiences only low congestion rents (€ 1.2 mn. per year). The most important result is that with the additional offshore cables of the Trade and Meshed scenario these values collapse, indicating that with additional trade connectors, the effect of price convergence outweighs the additional trade flows leading to lower congestion rents. The Skagerrak and Cross-Channel cable are not congested anymore and only for the NorNed cable some congestion rent remains: In the Trade scenario € 6.8 mn. per year and in the Meshed scenario € 1.3 mn. per year. In the Baltic Sea the four connections between Scandinavia and continental Europe have an annual congestion rent of € 5 to 10 mn. each in the 2009 scenario. This value is also reduced significantly by more than 90% with the additional transmission capacity in the Trade and Meshed design.

For the Wind+ scenario the congestion rents start from lower initial values without additional offshore transmission. As wind generation is added to the markets at zero marginal generation costs the model sees lower locational marginal prices and price differentials compared to the 2009 scenario causing lower congestion rents. Still, the intense impact of additional offshore capacity on congestion rents remains. Although there is a certain variance around these figures, the sensitivity of the congestion rent to additional transmission capacity modeled for the North and Baltic Seas suggests that merchant investments relying on these returns face high risks by consecutive network extensions; in fact, in the light of the drastic changes of congestion rents merchant transmission investment does not appear as a feasible option.

Figure 6: Congestion Rent for the Existing Offshore Links in Trade / Meshed design



6. Conclusions

The "North and Baltic Sea Grid" has become a metaphore for diverse ideas of harnessing renewable energy in the region, and transporting it somehow to electricity consumers located near or far from generation. While the region is in the core of energy network infrastructure development in Europe, the assessment of its benefits and costs is quite at its infancy. The main purpose of this paper is to provide a methodology to assess the future potential welfare and distributional issues, and to apply this methodology to a set of concrete scenarios. While traditional network planning is generally based on technical considerations, this paper also puts forward the usefulness of a combined engineering-economic approach.

While the traditional literature focuses on the search of "optimal" transmission investment, often suggesting the move towards pan-European supergrids, a look at the critical issues of transmission investment suggests a variety of possible development paths, with very different implications on individual states and stakeholders. We provide three stylized scenarios (without providing any normative judgement on the feasibility neither the probability of these scenarios to become reality): i) Status quo, including a national focus; ii) Trade with a regional focus; and iii) Meshed, with a pan-European focus.

The main focus of the papers is on the welfare implications of the different scenarios and grid designs, in particular the effects on producers and consumers. This is a main driver for political support of, or resistance to, the project. There is clearly a distinction between the overall benefits of the North and Baltic Sea Grid project, and the individual national gains. While the gains in social welfare are significant in all scenarios, the benefits that each individual country obtains vary with the network design, the regulatory approach, and the assumptions on supply and demand. Thus, there is a high variance in the expected benefits for each country, which may limit their enthusiasm to engage in such a multilateral project. Also, the scenarios have very different cost implications.

We show for the case of the North and Baltic Sea Offshore Grid that different designs create different beneficiaries and losers on national level but also within the countries. While exporting countries suffer losses through additional competition combined with rent shifting from producers to consumers, lower flexibility of the chosen offshore design limits this development but also creates lower overall welfare gains. Balancing the interests of different participating parties is a critical element of any transmission expansion strategy. In this case, the exporters of low-cost electricity, i.e. Norway and Great Britain, are winners of a grid expansion, since they obtain higher prices in the region they export to, continental Europe, than in their respective domestic markets. Continental European consumers also gain from the developments due to the price decrease. On the other hand, electricity producers in the more expensive region, continental Europe, lose market share and producer surplus, while the consumers in the lower-price region also lose (consumer) rent: after the installation of the infrastructure, they may have to pay a higher price than before.

We thus find a relation between the regulatory rules and the emerging grid design. The grid development is not exogenous to the institutional setting. The Status quo scenario has the benefit of well-know income streams and rents, though it is suboptimal in terms of welfare. For the near to medium future, the current institutional setting would favor bilateral point-to-point connections in a Trade scenario; the Meshed, while yielding higher aggregate welfare, is more difficult to bring about.

Far from being a panacea for the large-scale integration of renewables, the North and Baltic Sea Grid highlights the challenges of large-scale transmission expansion; rather than to provide simple answers (e.g. “supergrids”), the paper highlights the interaction between different drivers of network development, and provides a methodology for quantifying these drivers. While it is relatively easy to show the overall welfare gains of such a project, “the devil is in the details”, and the study highlights important interdependencies between planning, regulating, financing, and pricing offshore transmission infrastructure. There are many pathways to tap the renewable potential of the North and Baltic Sea region, and at this point in time it may neither be urgent nor necessary to press for a specific network design.

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