NORTHSEAGRID
Offshore Electricity Grid
Implementation in the North Sea

NORTHSEAGRID
Integrated offshore grid solutions in the North Sea

Results from the NorthSeaGrid Project

Co-funded by the intelligent Energy Europe
Programme of the European Union

BACKGROUND

Wind power and cross-border transmission lines - or 'interconnectors' - will become two key pillars of Europe's electricity system if we are to meet the EU's low-carbon targets *cost effectively*. The EU's Energy Roadmap 2050 indicates that 600 to 1,300 GW of wind power will be installed by 2050 – at least twice as much as any other electricity generation technology. Interconnectors improve security of supply and reduce the need for back-up power because they balance the intermittency of wind.

Both onshore and offshore wind can contribute to this increase. Wind conditions are better at sea than on land, however. A wind turbine will generate about twice as much electricity if it is installed offshore. In the North Sea region, both wind turbines and interconnectors will be deployed offshore to a large extent, which suggests the possibility of integrated solutions: a so-called interconnected offshore grid of transmission lines between countries and connections of offshore wind farms to the shore.

Integrated offshore grid solutions represent economic, environmental and technical advantages for Europe's power system that in some cases may outweigh the costs of investment.

Yet up to now, no such project has been planned, let alone built, despite the growing consensus among key stakeholders that integrated solutions can be more beneficial than traditional stand-alone projects.

POLICY CONTEXT

From a policy perspective, such projects are challenging, for at least three reasons:

First, current socio-economic analyses focus on the power sector as a whole. Yet to make progress we need to identify concrete projects, make detailed calculations of their costs and benefits and assess their regulatory barriers.

Second, cross-border projects may be beneficial overall but their benefits are likely to be distributed asymmetrically between the affected countries. This raises the question of suitable cross-border cost-benefit allocation mechanisms to bring all participating countries on board.

Third, the policy and grid regulation of renewables is currently organised on a national level, while interconnectors require agreements between the connected countries. Integrated systems make it harder to differentiate transmission lines used for cross-border trade and grid lines used to connect offshore wind farms to shore.

Recommendations are therefore needed for these policy challenges in order to turn integrated offshore grid solutions into reality. It is in this context that the NorthSeaGrid project has been set up.

> “RATHER THAN INVESTIGATE THE OVERALL POWER SYSTEM, WE LOOK AT THE BARRIERS THAT HINDER THE IMPLEMENTATION OF INTERCONNECTORS”

THE NORTHSEAGRID PROJECT

The focus of NorthSeaGrid is interconnectors that directly integrate offshore wind farms. Rather than investigate the overall power system, we look at the barriers that hinder the implementation of interconnectors and focus on three concrete, carefully selected case studies.

The aims of NORTHSEAGRID are to:

- Identify the main challenges, risks and financial effects for various stakeholders
- Calculate costs and benefits based on sensitivities and risk assessments
- Identify approaches for the cross-border allocation of costs and benefits
- Propose changes to regulatory frameworks
- Prepare recommendations to facilitate the implementation of the first integrated offshore grid solution.

METHODOLOGY - SELECTING THE CASE STUDIES

Based on the locations of planned wind farms and the locations of announced (inter)connection cables, the project consortium drew up a list of possible case studies or projects. This list was then narrowed down to 12 cases by the programme board of NSCOGI (North Seas Countries' Offshore Grid Initiative) and the broad range of stakeholders involved. Following a more in-depth socio-economic cost-benefit analysis, NSCOGI selected three case studies for detailed analysis in this project.

A specially designed pre-validation model was used to estimate costs and benefits. The model compares the potential reduction in infrastructure costs that would result from integrating wind farms and interconnections, with the reduction of trade due to constraints on the cables introduced by sending the wind power to shore.

> “WE FOCUS ON THREE CONCRETE, CAREFULLY SELECTED CASE STUDIES”

Based on the preliminary analysis, the three cases selected by NSCOGI (which may not fully represent currently planned interconnectors) have the following characteristics:

German Bight

- German wind farm connected to both Germany and the Netherlands
- Another German wind farm connected to Denmark
- Hub-to-hub interconnection between the two wind farms

UK-Benelux

- Belgian offshore wind farms connected to two platforms (alpha and beta)
- Interconnection from the UK to Belgium alpha
- Connection between Belgium alpha and beta
- Dutch wind farm connected to Belgium beta
- Interconnection from Belgium beta to the Netherlands

UK-Norway

- Large British wind farm
- Largest part of wind farm connected to UK
- Remaining capacity connected to Norway

The main reasons for this selection are the following:

- All three cases are beneficial, interesting, and provide a high learning potential
- They enable coverage of six North Sea countries (UK, NO, DK, DE, NL, BE) and different geographic areas
- They represent different types of cases: split hub/tee-in connection, hub-to-hub interconnection, three-leg interconnection, and combinations of these
- They enable the investigation of the impact of size (small scale in Benelux vs. large scale for Dogger Bank), and would allow the importance of a cost-beneficial solution for Europe to be demonstrated.

Figure 1
The three case studies selected for NorthSeaGrid

COSTS AND RISKS OF INTEGRATED SOLUTIONS

KEY FINDINGS

The construction of the selected cases in an integrated manner would generally lower the material requirement and costs. This would have a knock-on effect on installation and operation costs. Second, the availability of alternative paths in integrated implementations, if an export cable were to fail, means a greater availability and utilisation of the infrastructure. Third, the technical risks are largely similar for both isolated and integrated developments. Consequently, the net present worth (allowing for the additional benefits and reduced costs) of projects with integrated designs is higher.

> "THE TECHNICAL RISKS ARE LARGELY SIMILAR FOR BOTH ISOLATED AND INTEGRATED DEVELOPMENTS"

RISKS

Two types of risk assessment were carried out: qualitative and quantitative. The qualitative approach helped us to visualise abstract risks; costs cannot be attributed to them at present. The quantitative approach helped us to compare the two options in terms of their reliability, availability, and maintainability.

QUALITATIVE RISK ANALYSIS

NorthSeaGrid considered both the policy and the regulatory issues related to the integrated development of interconnectors and offshore wind farm connections. The qualitative risk analysis focused on and compared the technical risks inherent in these developments. We took a risk factor and analysed for each case whether it would pose a higher risk for the integrated approach than for the isolated design.

We discovered that the technical risks of both options are broadly similar. The most significant technical risk factor is the high-voltage direct current (HVDC) circuit- breaker technology. The integrated approach needs radial multi-terminal HVDC connections which necessitate a rapid, reliable, and selective isolation of the faulty part of the network so that it does not bring down the entire offshore grid.

The second significant risk factor is the offshore HVDC converter station, which acts as a connection between the offshore wind farm AC (alternating current) grid and the interconnector. The experience to date is limited and not encouraging. But the technology is expected to have matured sufficiently by the launch of these projects; the risk is therefore deemed to be lower than that for the HVDC circuit breaker.

QUANTITATIVE RISK ANALYSIS

Offshore repair and maintenance operations are both time consuming and costly. This is because of the nature of the area, the equipment needed and the human resources involved. Many factors, such as weather, waves and currents have to come together to

enable maintenance staff to start work on faulty equipment offshore. The problems posed by bad weather can be compounded by the unavailability of proper offshore support vessels, which are expensive to rent and own. Add to this the idle hours of the maintenance crew, which escalates the overall costs. The cost of the energy supplied can therefore be much higher.

A reliability, availability, and maintainability (RAM) analysis can offer insight into how these issues might affect the viability of such projects. Such an analysis was carried out for isolated and integrated options for each case.

The main criteria selected were:

- Expected energy not supplied from the offshore wind farm
- Number of hours for which transmission capacity is not available and power production from offshore wind farms has to be curtailed
- Expected energy not delivered via trade over the interconnector
- Number of hours when transmission capacity is not available for trade

The results indicate that reliability is greater with the integrated approach in each case. Isolated designs have non-redundant sets of cables connecting the two ends of both interconnectors and grid connections of offshore wind farms. The supply of energy over the connection is discontinued once a cable fails and can only resume after proper repair, which can take a long time. Laying redundant cables for such connections is not economically viable. Instead, the integrated approach allows energy supply to be continued by selectively isolating the faulty paths. This redundancy would benefit the export of offshore wind power to a higher degree than trade, because even though there are optional routes available for power exchange, the connections to the shores still do not have redundant sets of cables. If a line to one country fails, the power can no longer be rerouted to that country but it can flow to another country that has a healthy cable. Offshore wind power would therefore have to be curtailed to a lesser degree.

COSTS

Cost calculations are crucial to any comparison of integrated and isolated developments. The final savings would be the savings in costs added to the additional operational benefits obtained with the integrated approach. This would determine the cost of energy supplied to consumers. The net present value (NPV) method was used to compare the alternative solutions for each case, which brings all the costs and benefits occurring during the lifetime of these projects (25 years; 5 for construction and 20 for operation) up to date.

Uncertainty was modelled in the cost calculations based on available information and interviews with suppliers and experts. The major cost components are the capital expenditure (CAPEX), which includes items such as design, supply, and installation and operational expenditure (OPEX), which includes costs associated with operation, maintenance, and repairs etc.

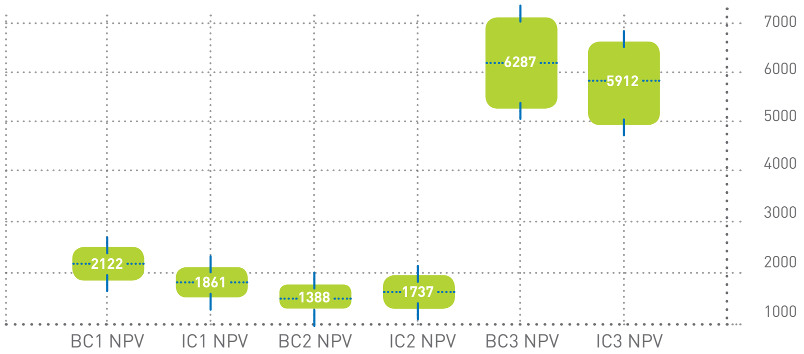
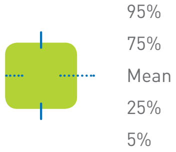


Figure 2
Cost NPV in M€ for base and integrated options



BC NPV: BaseCase NVP
IC NVP: Integrated Case NVP

For all the cases, the costs with associated uncertainties are given in *Figure 2*. Two of the three selected cases (1 and 3) are almost certain to cost less when built in the integrated manner. Conversely, the cost NPV for case 2 is higher with the integrated design due to the comparatively high level of interconnection for integrated design compared to the isolated design in this case. The major cost elements are the cables, high-voltage direct current (HVDC) converter platforms, and HVDC converter stations offshore and onshore. The lower cost of integrated design is largely achieved through a reduction in cable quantities and converter stations.

Uncertainties do not increase when integrated designs are implemented. The major uncertainty drivers are the market and basic materials, such as copper and steel.

SYSTEM BENEFITS AND DISTRIBUTIONAL EFFECTS

KEY FINDINGS

The system benefits of the proposed integrated North Sea Grid development are quantified using the state-of-the-art investment optimisation model.*

We conclude that:

- System benefits in the selected NorthSeaGrid cases amount to:
  - German Bight: (€34 to €64) million per annum
  - UK Benelux: (€30 to €141) million per annum
  - UK Norway: (-€2 to €1) million per annum.
- In the German Bight and UK-Benelux cases, the benefits are primarily driven by the increased level of interconnection between the NorthSeaGrid countries. For the UK-Norway case, there is a small reduction in the capacity leading to a marginal increase in the system cost;
- The level of benefits of the integrated cases is sensitive to characteristics of the next-generation European system. A higher penetration of renewables tends to increase the benefits, while lower fuel and carbon prices and increased system flexibility supported by demand-response reduce the benefits.

ASSUMPTIONS

The following four scenarios are used in the study:

- Main scenario with renewables covering 50% of the European electricity demand;
- Scenario with a 60% contribution of renewables ('Higher RES');
- Lower fuel and carbon price scenario where the fuel and carbon prices are around 50% from the central projection;
- Scenario where the potential of demand-side response (DSR) has been utilised to improve the economic efficiency of the system operation and to maximise the use of capacity.

The benefits are expressed as savings in generation investment and operating costs, which are achieved by integrating offshore grid and interconnection when compared to the North Sea Grid offshore wind farms being connected directly to the onshore grid of the respective country, and hence do not form part of the interconnection.

RESULTS

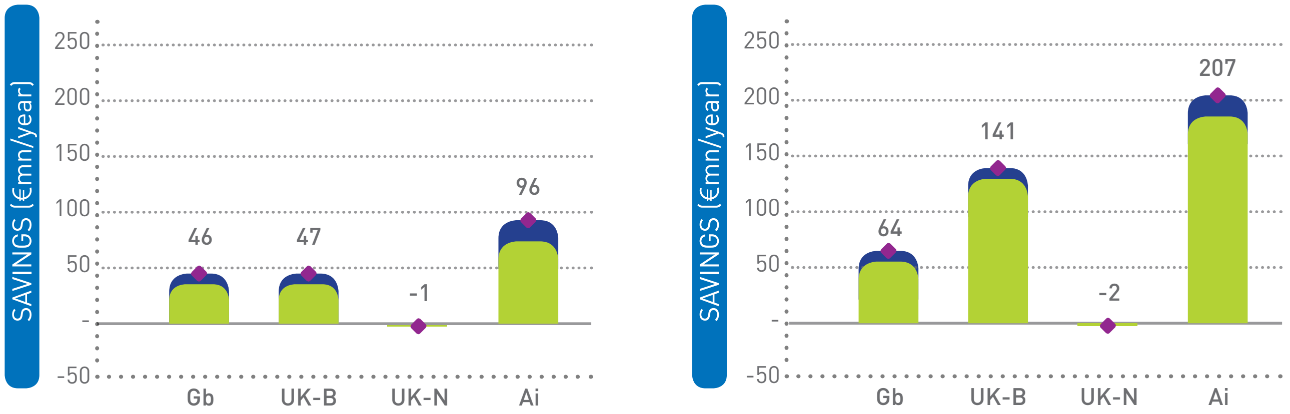
The system benefits for all scenarios are shown in *Figure 3*. In all cases, with the UK-Norway case as an exception, the integrated configurations lead to reduced operating costs and the cost of generation infrastructure.

> “OPTING FOR THE INTEGRATED DESIGN IS BENEFICIAL IN ALL THREE CASES”

***Figure** 3*
The system benefits of integrated solutions under different 2030 system development scenarios

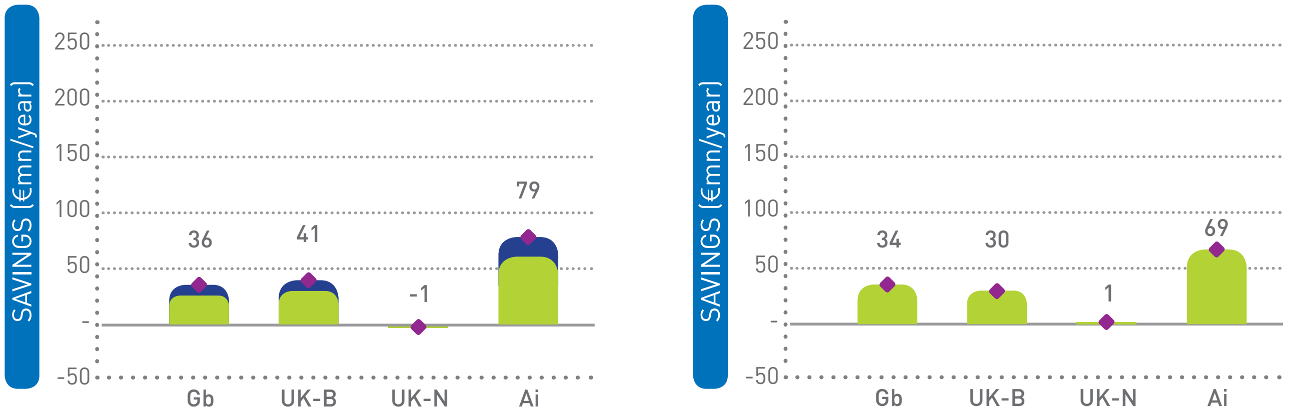
Main scenario

Higher RES (60%)



Lower fuel and carbon price scenario

DSR

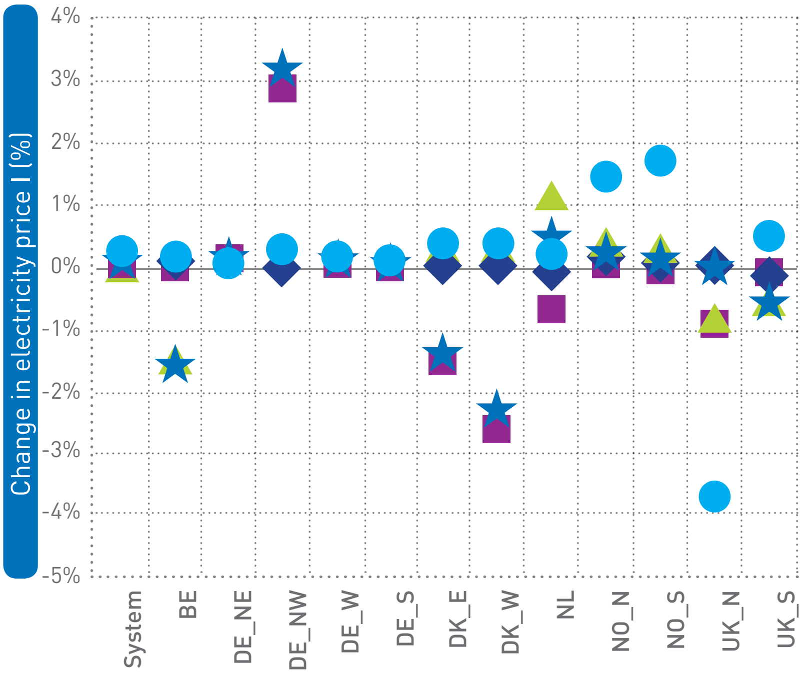


***Gb**: German bight*
***UK-B**: UK-Benelux*
***UK-N**: UK-Norway*
***Ai**: All integrated*

🟦 *Gen Capex*
🟩 *OPEX*
◆ *Total*

The impact of integrated solutions on consumers and generators across regions is asymmetric. On the one hand, some may obtain the benefits in the form of lower electricity prices, increased generation and network revenue, but on the other hand, some may face increased costs and reduced profits. Quantitative results are presented in *Figure 4*. The changes are expressed as the percentage of increased/decreased average wholesale electricity prices relative to the average electricity prices in the base case.

Zones with a large amount of renewables which initially enjoy low electricity price will see increase in prices



Other zones see reduction in prices as the increased interconnection allows access to lower cost generation

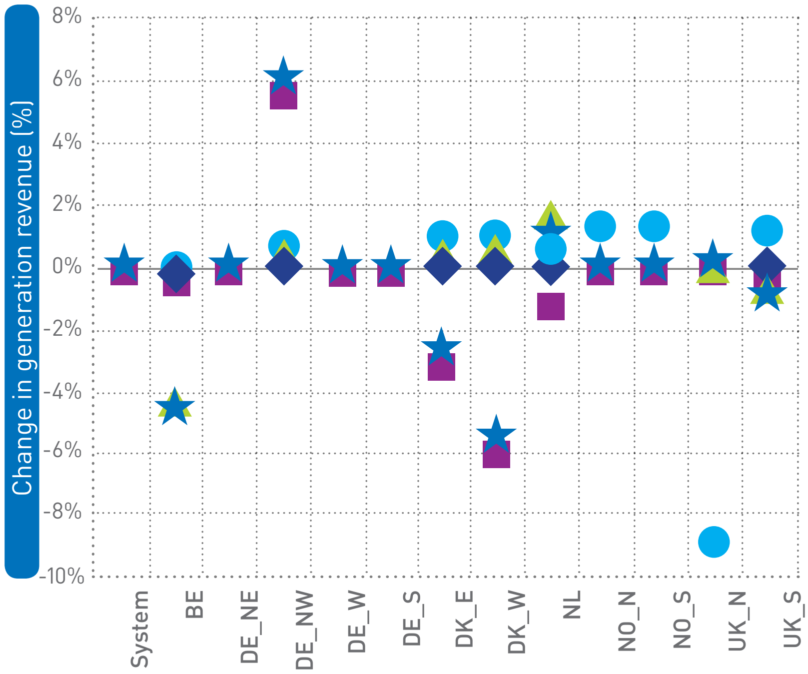
Figure 4
Changes in wholesale electricity prices as a result of NSG integrated development

Asymmetrical impact on the change of electricity prices across regions

For example, the electricity price in North West Germany (DE_NW), which has a high share of renewables, increases in the cases 'German Bight' and 'All integrated', as more renewables can be exported to other regions. By contrast, electricity prices in Denmark (DK_E and DK_W) and the Netherlands (NL) decrease, as these regions would import more generation with low marginal costs. The impacts are asymmetrical across regions. In any case, the impact of integrated solutions on electricity prices, and hence on consumers' electricity bills, is relatively modest, i.e. up to around +3%. It is also noted that the development of an interconnector between two countries may have an impact on third countries, although generally with less intensity.

Figure 5
Changes in the revenues of generators resulting from integrated offshore grid solutions

Generation revenue follows the changes in electricity prices but the impact on generation and demand customers is assymetrical



In the regions with reduced electricity prices (as a result of the increased level of integration), generators would experience reduced profits and vice versa. However, as the level of regional electricity production is different from regional electricity demand, the impact of electricity price changes on consumers and generators is likely to be different. Generators in DE_NW would obtain the highest benefit from the proposed integrated solutions. Their revenue increases by approximately 6%, while generators in DK_W would lose 6% of their annual revenue. This is demonstrated in *Figure 5*, above.

Another finding is that integrated solutions tend to expose the offshore wind farms to the zones with lower electricity prices. Offshore wind farms are always at the exporting zone and therefore at the low price end of the network constraints when the network is congested. However, this does not necessarily mean that the revenue would be lower because in the case of increased integration the wind farms may be exporting to countries with higher electricity prices (*see Figure 6*).

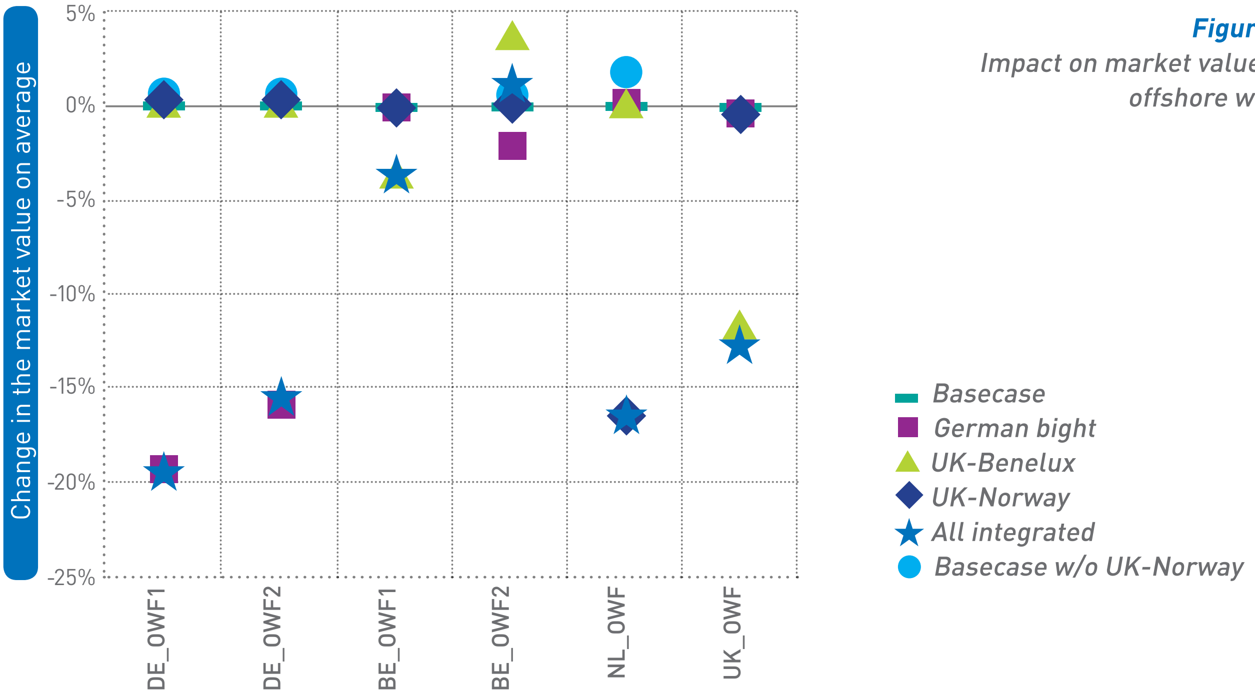


Figure 6

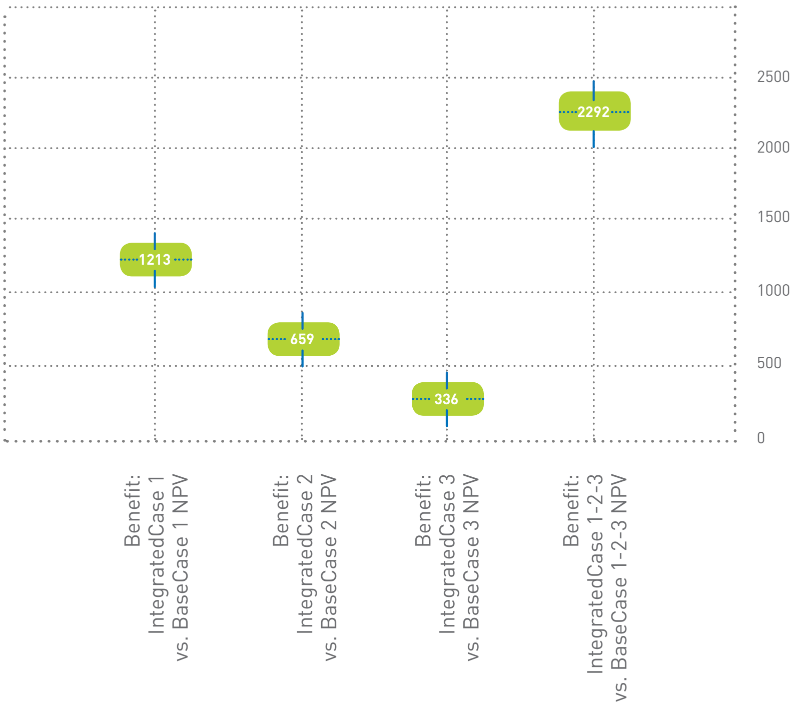
Impact on market value of offshore wind

The integrated development also improves the utilisation of the network assets. The offshore-to-onshore connection can be used both to transport energy from the offshore wind farms and to be part of an interconnector across the countries in the North Sea. The integration of the offshore grid with interconnection tends to increase network congestion revenues, which may stimulate further development of the integrated solutions in the North Sea.

OVERALL SAVINGS

The analyses of additional** benefits for each case were carried out so that the case under consideration would be built in the integrated manner and the rest of the projects implemented with isolated design. The NPV simulations of the overall savings were therefore performed considering all these options. See the results of these simulations in *Figure 7*. The net NPV for all the selected projects are positive, implying that opting for the integrated design is beneficial in all three cases.

***Figure** 7*
Overall savings NPV in M€



Various sensitivity studies were also conducted.

The results show that:

- Increased material costs would boost the justification to build the projects in the integrated manner because of their generally lower material requirements;
- The benefits increase with a higher penetration of renewables; and
- The project value of integrated solutions decreases with lower fuel prices or more demand flexibility. Yet this value remains positive; suggesting that integrated solutions are more beneficial than isolated point-to-point implementations.

> THE *SO-CALLED POSITIVE NET BENEFIT DIFFERENTIAL* METHOD IS FULLY CONSISTENT WITH THE *BENEFICIARIES PAY* PRINCIPLE

SHARING COSTS AND BENEFITS OF INTEGRATED OFFSHORE GRID STRUCTURES

KEY FINDINGS

Conventional methods to allocate the costs and benefits of cross-border projects sometimes result in highly unbalanced outcomes, making it less likely that hosting countries decide to build such projects. Instead, the so-called Positive Net Benefit Differential method should be applied consistently as a pivotal point of departure for negotiations on the financial closure of investments in cross-border (integrated) offshore infrastructures. This method is fully consistent with the *beneficiaries pay* principle; it mitigates free riding. Compensation transfers in line with the proposed method may improve the global political acceptance of such projects and create the financial leeway to compensate stakeholders that would otherwise sustain an economic loss (a negative net benefit).

OVERVIEW OF DIFFERENT CROSS-BORDER ALLOCATION MECHANISMS

Three cross-border cost allocation (CBCA) mechanisms have been considered in this project, applied to cross-border cost allocation of integrated offshore grid structures for renewable generation and cross-border trade, respectively:

1. Conventional. The conventional method stands for CBCA practices prevailing to date. It assumes :

- An allocation for financing an interconnector on a 50/50 basis by the national TSOs of the two interconnected countries (and a 1/3 : 1/3 : 1/3 basis for three interconnected countries, etc.).
- The same applies to the allocation rule for interconnector congestion rents among the national TSOs
- Cost allocation within countries is based on national regulations regarding, notably, support schemes, responsibility for connecting offshore wind farms, internal congestion rents and network tariffs.

2. Louderback: Allocate to the entity concerned its directly attributable costs (direct costs) and its part in the total non-directly attributable costs (common costs) proportionally to one variable, i.e. its share in the difference between stand-alone costs minus direct costs. The allocation of the direct costs can be regarded as an application of the *Beneficiaries Pay* principle, whilst the *Louderback* allocation of the common costs can be regarded as an application of the *Postage Stamp* principle.

3. Positive Net Benefit Differential (PNBD): Establish the Net Present Value of differential costs and benefits of the Integrated Infrastructure investment proposal, compared to the applicable base case. Allocation of the total investment and operating costs of the Integrated Case will then be related to the respective Net Present Value for each entity. Entities with a negative net benefit then need to be compensated according to pre-set rules by entities with a positive net benefit until (at least) the negative values turn zero. The crux is which pre-set compensation rules should apply.

Regarding the PNBD method, four variants of the compensation rule are being explored. *The first compensation variant* determines net benefit impacts on both hosting countries and third countries. Positive net benefit is transferred up to the (Pareto-optimal) point where all countries with net benefit values are compensated up to the level that the net benefit values concerned become zero. Under *the second compensation variant* only hosting countries with a 'significant' positive net benefit (default 10%) provide compensation to hosting countries with a negative net benefit pro rata with their share in the sum of positive net benefit above the threshold for all 'significantly' benefiting from the Integrated Project. In principle, under the second variant some hosting countries 'win' and other hosting countries end up with a neutral net benefit position, at best.

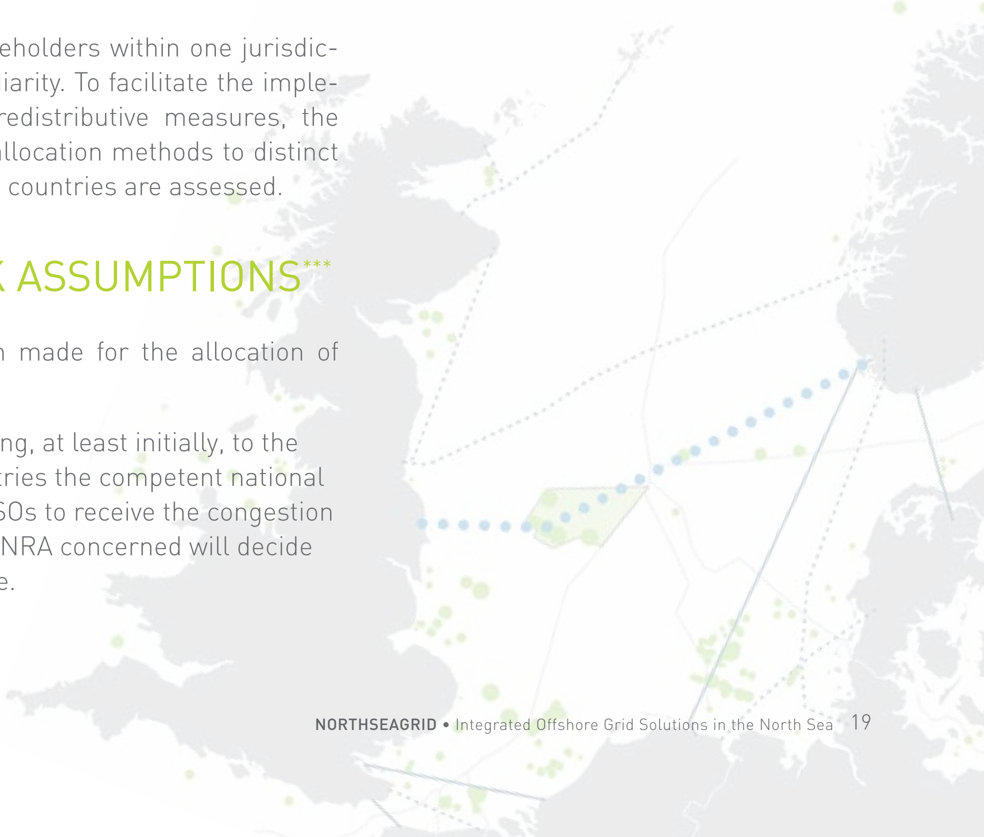
To shorten the negotiation time between member states, in *the third compensation variant* it is proposed as well to negate the net benefit impacts on third countries. As in the first variant, but only applied to hosting countries, 'winners' will compensate 'losers' up to the point where the net benefit value of each of the latter will reach a zero value. *The fourth compensation variant*, again exclusively between hosting countries, will assume that all countries for which there is a net benefit 'return' below a pre-set positive value (default floor value: 10% of global net benefit) will be compensated up to the pre-set minimum net benefit threshold as a maximum, whilst the net benefit of initial winners above the threshold will not sink below the threshold value after compensation contributions.

Compensation transfers between stakeholders within one jurisdiction are complex and subject to subsidiarity. To facilitate the implementation of possible intra-country redistributive measures, the propagation of the cross-border cost allocation methods to distinct stakeholder categories within (hosting) countries are assessed.

GENERAL FRAMEWORK ASSUMPTIONS***

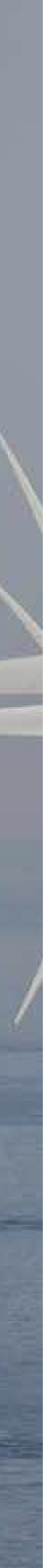
The following assumptions have been made for the allocation of costs and benefits:

- Typically, congestion rents are accruing, at least initially, to the TSOs. It is assumed that within countries the competent national regulatory agency (NRA) will allow TSOs to receive the congestion rents under a separate account. The NRA concerned will decide on the final destination of this income.



- Generation Use of (transmission) System (GUoS) charges as a percentage of total (transmission) system charges in accordance with national regulations. The country-specific share of GUoS charges in total use of system charges ranges from 0% to 38%. The Load Use of System charges are the complement of GUoS charges (both adding to 100%).
- Production support benefits for offshore wind farm operators, defined as support in excess of the average *ex post* commodity price, have been normalised in an approximate way for 20 years and range from €60 per MWh to €90 per MWh, depending on country-specific regulations.
- Support cash flows to the operators of offshore wind farms located in the exclusive economic zone of country A will be ultimately passed on to network users of country A by way of a volumetric surcharge (i.e. as a function of their electricity consumption volume on a per MWh basis) on their energy bill.
- In case (part of) the electricity produced by an offshore wind farm in the exclusive economic zone of interconnected country A is physically evacuated to the shore of interconnected country B, country A remains responsible for support payments over the volume of exported electricity concerned. In other words, country A is responsible for support over the total offshore wind energy production in its exclusive economic zone, regardless of which jurisdiction the electrons concerned flow into.
- Consistent with the previous assumption, offshore wind farms in the exclusive economic zone of a certain country have to bid to the applicable bidding zone of that country, even if the anticipated commodity prices in (one of) the other interconnected country (countries) is higher and/or the physical flow is in another direction than towards the aforementioned zone.
- In the case of congestion on offshore interconnector structures offshore wind farms have priority access for the notified power injection capacity at the intraday gate closure time. In line with current regulations in most NSCOGI countries, offshore wind farms are assumed to be given a waiver to pay for access to the transmission network; even in the event of congestion.
- The allocation tool used in the NorthSeaGrid project considers impacts in terms of net benefit differentials for the countries included in the ICON model, notably the ones participating in NSCOGI, i.e. Belgium, Denmark, France, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom. The tool builds on the cost-benefit analysis explained previously, including base case definition.
- Within the hosting countries, for each case study the following stakeholder categories are being distinguished:
  - Consumers
  - Offshore wind farm operators
  - Other producers
  - TSOs.

> “EU MEMBER STATES SHOULD FACILITATE THE FEED-IN OF WIND FARMS THAT ARE NOT LOCATED ON THEIR TERRITORY”



REGULATORY CHALLENGES AND SOLUTIONS

KEY FINDINGS

Regulatory challenges may arise when an offshore wind farm is directly connected to more than one country, as is the case for integrated offshore grid solutions. EU member states should therefore facilitate the feed-in of wind farms that are not located on their territory but directly connected to it. Regarding support systems (i.e. payments for renewable generators), a practical solution would be the following:

- The generator receives the remuneration of the country in which it is located, irrespective of which country the produced electricity is flowing into. This would ensure a high certainty for investors in renewable energy projects.
- Monetary compensation mechanisms between the affected countries are set up to ensure a fair distribution of the costs between the countries involved.
- Renewable energy targets are currently national. Additional compensation mechanisms are therefore set up between the affected countries to ensure that the country that pays for the support receives the credit that counts for achieving the target.

OVERVIEW OF REGULATORY CHALLENGES FOR A MESHED OFFSHORE GRID

The following is an overview of the main regulatory challenges for various fields.****

SUPPORT SCHEMES

The participation in the support system of a neighbouring country is not possible at the moment, or only to a very limited degree. An important aspect in this regard is how the income for the renewable energy generators is set. Here, tendering creates a barrier if it is not possible to participate in the tender from outside the respective Exclusive Economic Zone (EEZ). Generally, if an offshore wind farm is connected to two countries, different amounts of remuneration in the respective countries could affect the preferred feed-in of electricity in the direction of the higher remuneration, potentially causing unexpected congestion.

GRID ACCESS RESPONSIBILITY

The main barrier in the area of grid access responsibility occurs if an offshore wind farm is located in the EEZ of country A and is intended to be connected to country B. The responsible party for the connection to shore in country A would deny responsibility to connect the offshore wind farm to the grid of country B, because the offshore wind farm is not connected to their grid. The responsible party in country B would also reject responsibility because the offshore wind farm is not located in their EEZ, thus creating a barrier.

CONNECTION DESIGN (hub vs. radial)

At the moment, the connections to shore are realised using a hub or radial connection design. Planning starts many years in advance and the location of the cables and converter stations are planned respectively, especially for the hub design. If an offshore wind farm were to be integrated into an interconnector project and the foreseen capacity on the hub design not used (or used to a lesser extent), this could lead to stranded investments.

PRIORITY GRID CONNECTION

Grid connection rules with different priorities could lead to a non-aligned completion of the connection to shore. This could be a barrier, notably where the offshore wind farm is operational and needs the connection to two countries – one with a priority grid connection to the offshore wind farm and one without – to match the capacity of the offshore wind farm. The entire capacity of the offshore wind farm cannot be used until the missing connections are complete. In this case the question of compensation also arises.

DEFINITION OF THE CONNECTION TO SHORE

The definition of the connection to shore (part of the transmission system or of the offshore wind farm) is not a barrier, because in all analysed countries the connection to shore is part of the transmission system.

BALANCING RESPONSIBILITY

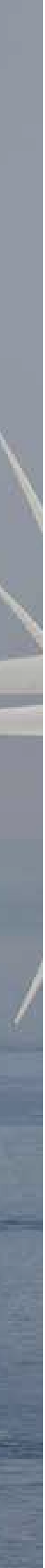
In the case of balancing responsibility only the lack of a suitable regulation in one of the analysed countries creates a barrier. If only one country requests a balancing of responsibility, unequal treatment of the offshore wind farm operators would result.

ANCILLARY SERVICES

In the field of ancillary services, which offshore wind farms have to provide, the main barrier emerges from differing Low Voltage Ride Through (LVRT) requirements. The national TSOs expect that all offshore wind farms that feed into their grid fulfil the respective national requirements. But offshore wind farms that are connected to two countries can only fulfil the LVRT requirements of one country. With regard to the other country a disruption could occur, which is a technical barrier.

TRANSMISSION CHARGES

National regulations covering transmission charges show several different regulatory settings regarding the amount of charge or indeed whether a charge is applied at all. The consequence would be that, where possible, the offshore wind farm would feed into the



countries with no or low transmission charges. This could then lead to congestion in these grids.

PRIORITY FEED-IN

Different regulations regarding the priority feed-in of renewable electricity production and the compensation in the case of curtailment could lead to a barrier. The preferred feed-in would be into the direction of the countries, where the curtailed production would be compensated. As a consequence, congestion could increase even further. In the end, this also leads to the unfair distribution of costs between the different TSOs due to compensation of curtailment in some cases.

The question is now whether offshore wind farms, which feed-in a country outside their respective borders, would also receive the compensation in the case of curtailment. This could lead to a barrier that affects the feed-in flow and would lead to an unequal treatment of offshore wind farm operators outside and inside national borders.

CROSS-BORDER CAPACITY ALLOCATION

Different national mechanisms need to be coordinated due to the increased interconnection of the interconnected offshore grid. But this is already done and the interconnected grid would only add interconnections that have to be taken care of (thus no major barrier).

GATE CLOSURE TIMES

Different national arrangements regarding gate closure times lead to the unequal treatment of offshore wind farm operators, because the closer the gate closure times are to real time the clearer the situation. The responsible balancing offshore wind farms will therefore know better if they are to produce according to their submitted schedule or if they have to become active in the intraday market. This leads to the unequal treatment of the different offshore wind farm operators in the six countries analysed.

IMBALANCE PRICE

One offshore wind farm, if connected to two countries, could be subject to two different price-setting models. But the usage of different imbalance price calculation methods is not evaluated as a barrier because the imbalance price is influenced by the different national supply and demand characteristics. External factors therefore influence the imbalance price as well, which leads to uneven imbalance prices anyway. A uniform imbalance pricing method thus seems unnecessary because different imbalance prices for the individual offshore wind farm operators could still occur.

CLASSIFICATION OF THE BARRIERS

The different areas described above were also individually assessed on a case-by-case level. The classification of barriers is shown below in *Figure 8*. The magnitude of the barrier is indicated by a traffic-light system, whereby a green light indicates no barrier, an orange light a medium barrier and a red light a strong barrier.

Topic/Case	Case 1 German Bight	Case 2 UK-BeNeLux	Case 3 UK-Norway
Support Schemes	🟠	🟠	🟢
Grid acces Responsibility	🟠	🟠	🟠
Connection Design (Hub vs. Radial)	🟠	🟠	🟢
Priority Grid Connection	🔴	🔴	🔴
Definition of the connection to shore	🟢	🟢	🟢
Balancing Responsibility	🟢	🟠	🔴
Ancillary Services	🟠	🔴	🔴
Transmission Charges	🟠	🔴	🔴
Priority Feed-in	🔴	🔴	🔴
Cross Border Capacity Allocation	🟠	🟠	🟠
Gate Closure Time (Intraday) and Settlement Period	🟠	🟠	🟠
Imbalance Price	🟢	🟢	🟢

Figure 8
Overview of the magnitude of the barriers per case

🟢 *No barrier*
🟠 *Medium barrier*
🔴 *Strong barrier*

SOLVING REGULATORY CHALLENGES STATUS QUO

BARRIERS ADDRESSED AT EU LEVEL

After assessing the barriers on a cas-by-case basis the second step was to double-check these barriers with regard to EU-level legislation. Legislation in place and under development has been taken into account; this also included the network codes.*****

If all regulations and network codes are implemented into the national regulation, several strong and medium barriers could be mitigated, as shown in *Figure 9*.

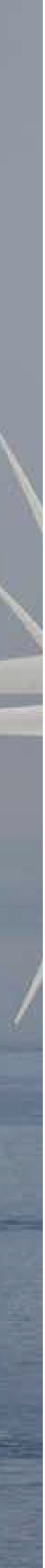


***Figure** 9*

Magnitude of barriers per case taking new EU legislation into account

🟢 *No barrier*
🟠 *Medium barrier*
🔴 *Strong barrier*

Topic/Case	Case 1 German Bight	Case 2 UK-BeNeLux	Case 3 UK-Norway
Support Schemes	🟠	🟠	🟢
Grid acces Responsibility	🟠	🟠	🟠
Connection Design (Hub vs. Radial)	🟠	🟠	🟢
Priority Grid Connection	🟢	🟢	🟢
Definition of the connection to shore	🟢	🟢	🟢
Balancing Responsibility	🟢	🟢	🟢
Ancillary Services	🟢	🟢	🟢
Transmission Charges	🟠	🟠	🟠
Priority Feed-in	🟠	🟠	🟠
Cross Border Capacity Allocation	🟢	🟢	🟢
Gate Closure Time (Intraday) and Settlement Period	🟢	🟢	🟢
Imbalance Price	🟢	🟢	🟢

Note that the fact that the barriers are addressed at EU level does not mean that they are already fully overcome. Transposing EU legislation into national law takes time and national amendments are also possible.

BARRIERS NOT / OR ONLY PARTLY ADDRESSED AT EU LEVEL

Barriers not addressed at EU level are:
- Grid access responsibility
- Connection design (hub vs. radial).

Partly addressed by the analysed EU regulations are:
- Transmission charges
- Priority feed-in.

Moreover, there is so far no EU approach that specifies how to participate in the support scheme of another country. Finally, it is worth noting that not all barriers need to be addressed at EU level.

> INTEGRATED OFFSHORE GRID SOLUTIONS REPRESENT ECONOMIC, ENVIRONMENTAL AND TECHNICAL ADVANTAGES FOR EUROPE'S POWER SYSTEM THAT IN SOME CASES MAY OUTWEIGH THE COSTS OF INVESTMENT

POLICY RECOMMENDATIONS

In order to meet the EU's long-term decarbonisation targets cost effectively, offshore wind power will have to play a greater role. In this context, integrated offshore grid solutions provide an opportunity to exploit the potential of offshore wind at lower overall costs. But policy action is required to realise such infrastructure projects.

From a technology point of view, the capacity of the supply chain is currently not sufficient for large undertakings. There are several manufacturers operating outside Europe that could enhance supply chain capacity if brought in early. The high-voltage direct current (HVDC) technology forms an essential part of integrated offshore grid solutions. Yet this is a fast developing technology that has so far remained proprietary. There is a strong case for standardisation. Point-to-point HVDC connections to connect offshore wind farms to the shore have experienced delays, cost overruns and operational problems. The involvement of independent third parties at various stages during the design, engineering, and construction period may help to alleviate this situation.

Integrated offshore grid solutions typically involve two or more countries. Bilateral or multilateral collaboration mechanisms involving wind farm developers, transmission system operators and regulators may help to bring about such projects earlier.

Regarding the cross-border allocation of costs and benefits, we recommend using Positive Net Benefit Differential methods as a starting point for negotiations on the financial closure of investments in cross-border (integrated) offshore infrastructures. This method is fully consistent with the beneficiaries pay principle; it mitigates free riding. Compensation transfers in line with the proposed mechanism to or from third countries may improve the global political acceptance of such projects and also create financial leeway, within all the countries involved, to compensate stakeholders that would otherwise sustain an economic loss (a negative net benefit).

On the regulatory side, if all EU regulations and network codes were implemented in national regulation, several barriers could be mitigated. Special attention is required by the European Commission and ACER (Agency for the Cooperation of Energy Regulators) to speed up this process. National support systems for renewables could also be re-designed to facilitate the realisation of integrated offshore grid solutions. To this end, renewable generators should receive the remuneration of the country in which it is located, regardless of which country the electricity produced is flowing into. This ensures a high degree of certainty for investors in renewable energy projects. Monetary compensation mechanisms between the affected countries should be set up to ensure that the country in which the renewable electricity is consumed funds the support for it. Additional compensation mechanisms could be set up between the affected countries to ensure that the electricity produced is counted towards the national target of the country that funds the support.

BRIEF OVERVIEW OF NORTHSEAGRID

Duration:

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€1.4 m, of which 75% is funded

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ENDNOTES

* *The model was developed by Imperial College London for a set of 2013 system development. scenarios. It is pan-European; electricity flows are modelled on a zonal resolution. The ENTSO-E ten-year network development plan was used to determine the capacity of the European grid.*

** *Considering the costs and benefit in the preceding sections, a net saving NPV analysis was carried out. Put simply, it is a subtraction of the additional benefits (benefits with integrated design – benefits with isolated design) and additional costs (costs with integrated design – costs with isolated design). This would then give the net additional worth of the projects in NPV terms when implemented with integrated designs.*

*** *The reader is referred to a separate Policy Brief for further information on the resulting allocation of cost and benefits, available on the NorthSeaGrid website.*

**** *This case-specific analysis was conducted under the following assumptions: due to continuous changes to the regulatory framework the support schemes and regulations in place in August 2014 were taken into account to have an equal benchmark for all countries. In addition, it was assumed that wind power producers can participate in the support schemes and electricity markets of neighbouring country.*

***** *Legislations and network codes taken into account: guidelines on state aid for environmental protection and energy 2014-2020, Directive 2009/28/EC, Directive 2009/72/EC, Regulation 714/2009 and relevant network codes.*