The Institut français des relations internationales (Ifri) is a research center and a forum for debate on major international political and economic issues. Headed by Thierry de Montbrial since its founding in 1979, Ifri is a non-governmental, non-profit organization.

As an independent think tank, Ifri sets its own research agenda, publishing its findings regularly for a global audience. Taking an interdisciplinary approach, Ifri brings together political and economic decision-makers, researchers and internationally renowned experts to animate its debate and research activities.

The opinions expressed in this text are the responsibility of the author alone.

ISBN: 978-2-36567-913-8
© All rights reserved, Ifri, 2018

How to cite this publication:

Ifri
27 rue de la Procession 75740 Paris Cedex 15 – FRANCE
Tel. : +33 (0)1 40 61 60 00 – Fax : +33 (0)1 40 61 60 60
Email: accueil@ifri.org

Website: Ifri.org
Michel Cruciani is Associate Research Fellow at the Ifri Centre for Energy, focusing on support policies for renewable energies and the functioning of the European electricity systems. He is also Senior Advisor at the Centre of Geopolitics of Energy and Raw Materials (CGEMP), University Paris-Dauphine, since February 2007. He contributes in particular to studies, the organization of conferences, publications, and provides teaching on Renewable Energy for students in the Master "Energy, Finance, Carbon".

Michel Cruciani graduated from the École Nationale Supérieure d’Arts et Métiers. Prior to the CGEMP, he shared activities between Gaz de France (Technical Services, then Economic Studies), CFDT (Member of the Board of Gaz de France, then Deputy Secretary General of the Federation of Gas and Electricity), and finally within Électricité de France (Department of European Affairs).

In these jobs, he followed the liberalization of the gas and electricity industry in the United States and in Europe, as well as the rise of environmental concerns, leading to the adoption of climate policies, a new role for nuclear energy and the promotion of renewable energy.
Executive Summary

The North Sea has provided an enabling environment for designing the world’s first offshore wind turbines. Its southern part has an excellent wind regime and shallow water. Public policies have gradually encouraged the development of this sector in the five best-located countries: Belgium, Denmark, Germany, the Netherlands and the United Kingdom. At the end of 2017, these countries had 15.5 GW of installed capacity, or 82% of the world’s offshore wind power. Outside Europe, only China has developed a significant fleet so far, with 2.8 GW in service in 2017 (15% of global capacity).

European industrial players have managed to safeguard this market for their products and services, sometimes at the cost of a strong concentration, with two manufacturers supplying 84% of installed turbines, for example. The acquired know-how puts European stakeholders in a good position to enter the global offshore market, whose growth potential is significant. They have already been successful abroad, especially in Taiwan. However, the competition is only beginning and many non-European entities, especially Chinese ones, have taken stakes in the North Sea projects, acquiring the necessary skills to spread to other shores. The shallow continental shelf, specific to the North Sea, has brought project developers to favour installations laid on various types of foundations. But these are hardly adapted to many oceanic areas, much steeper in the vicinity of the coasts; floating wind technology would be more suitable. European territories facing this situation are trying to develop the floating technology (in Scotland, France, Norway, Portugal) before their possible competitors (China, United States, Japan...).

Around the North Sea, support policies for offshore wind have been adjusted over time, partly under the influence of the European Commission (EC). They have moved towards competitive procedures, through calls for tenders. Combined with growing technological expertise, this approach has led to a remarkable fall in announced costs, for projects likely to be completed after 2018 in already equipped countries. Most of the latter have paid around 150€/MWh for their first units, from 2009 to 2017 (France will still be at this level for its first achievements, around 2022); whereas the winners of the latest tenders are now bidding on prices between 50€ and 100€/MWh for 2018-2025. Some projects were even selected with a remuneration at the market price alone and no additional payment.
The improved competitiveness of offshore wind opens up considerable opportunities for development in the North Sea, but these stumble over the difficulties and costs observed in strengthening the electricity transmission network, essential for the evacuation of the generated electric current. The need to almost double the interconnection capacity by 2040 between the countries concerned illustrates the complexity of the issue. The overall cost could be reduced by a good coordination between States, but no regional body has the appropriate levers. Each government defines its objectives and policies independently. In the absence of a good coordination, there are concerns that Norway’s hydropower resource, for example, is not optimally integrated into the electricity system, whereas this resource is highly complementary to wind power. Uncertainty is heightened by the decision of the UK, a major North Sea country, to leave the EU, creating uncertainty about its future participation in common bodies.

If the success story of offshore wind power in the North Sea has to be underlined, it is also necessary to anticipate potential side-effects. Good results certainly provide lessons for States wishing to develop the offshore wind industry; they will usefully learn from the procedures being implemented by their successful neighbours. But the region has non-reproducible assets: besides the quality of the wind and the seabed, it benefits from numerous ports and companies which were already turned towards offshore activities, due to the gas and oil history of the area, an advantage which can be found nowhere else in the EU. While preserving the dynamics of offshore wind in the North Sea, it is therefore up to the EU institutions to balance it by paying attention to less favoured regions. This means supporting efforts on floating wind for difficult ocean areas and providing other forms of aid to landlocked countries, without seafront. Optimistic forecasts indicate that the North Sea could supply up to 50% of all electricity consumed in the EU; it seems unlikely that this can be achieved without involving all the Member States in harvesting this new resource.
# Table of Contents

## INTRODUCTION

INTRODUCTION ............................................................................................................. 9

## INDUSTRIAL ASPECTS OF OFFSHORE WIND

The North Sea, cradle of offshore wind in the world ......................... 11
An area dominated by European companies ....................................... 14
A possible starting point for a global development of offshore wind .. 15
Non-European stakeholders, especially Chinese, in ambush? .......... 16
A platform for innovation, still incomplete .............................................. 18

## ECONOMIC ASPECTS: LOWER COSTS, BUT GRID CONNECTION ISSUES

A fluctuating business model ................................................................. 21
Competitiveness levers ........................................................................ 22
The results: more and more competitive projects ............................. 24

## THE GEO-ECONOMIC AND STRATEGIC STAKES

A considerable potential ................................................................. 31
Coordination issues ........................................................................ 32
The North Sea, Mare Nostrum? .................................................... 35

## CONCLUSION AND RECOMMENDATIONS

CONCLUSION AND RECOMMENDATIONS ..................................................... 37
Introduction

The European Union (EU) wants to lead by example in the implementation of the Paris Agreement on Climate. At the European Council of 22 March 2018, the Heads of State and Government required that the European Commission (EC) prepares a proposal for a strategy to reduce the EU’s greenhouse gas emissions in the long term, consistent with the Paris Agreement.1 While the 2011 version of this "2050 roadmap" aimed to reduce emissions by 80% from the 1990 level, the draft to be presented end of 2018 should bring forward the more ambitious goal of carbon neutrality by 2050. Such an aspiration implies a massive use of renewable energy to replace fossil fuels; given the continent’s limited bioenergy resources, wind and solar power is expected to play a critical role in our energy supply over the next decades.

The wind and solar sectors have been developing for more than 20 years now. In particular, the EU is a pioneer in offshore wind power, holding 84% of the 18 GW of installed capacity worldwide by the end of 2017.2 The North Sea has been the cradle of offshore wind and still offers an exceptional potential. The recently installed port infrastructure, expertise and equipment from the oil industry and the rapid decline in prices for electricity produced in this area suggest that it will gain a prominent place in the future electrical geography of the EU. The acceleration of achievements in recent years strengthens the case for a real upturn.

This study focuses on this predictable rise in offshore wind generation in the EU, focusing on the North Sea, which will continue to be the hotbed of the industry. A first chapter deals with the industrial and technical aspects, observing the specificities of this marine source, the stakeholders already in place and the technical solutions implemented; this section also examines the prospects opened to international export of the acquired know-how. The second chapter outlines the economic side, in terms of costs and their recent evolution. This chapter integrates the issues raised by the necessary adaptation of the electricity transmission network in order to evacuate the volumes produced. Finally, the third chapter addresses the geopolitical consequences of the North Sea offshore wind developments.

They impact on the one hand relations between the States surrounding the North Sea and on the other hand relations between these countries and other EU regions, maritime or not. As regards the States surrounding the North Sea, two of them will play a crucial role: Norway, because of its hydropower potential, which is complementary to variable energy sources, such as wind power, and the United Kingdom, which holds the most important development reserves for offshore wind in the North Sea.

The study presents conclusions based on observations collected in these three chapters and gives some recommendations.
Industrial aspects of offshore wind

The North Sea, cradle of offshore wind in the world

The North Sea links together a large number of European countries. As from the sixteenth century, its many ports have drained a major share of shipping between Europe, America and Asia, justifying the permanent modernization of their equipment. In the last quarter of the twentieth century, these port infrastructures enabled the development of oil and gas exploration and production using offshore platforms.

With the exception of the Norwegian shore, surrounded by pits, it is a shallow sea; in all the southern part, south of a diagonal linking Denmark to the English coast, the depth remains less than 50 meters. Under the influence of the North Atlantic Oscillation, sustained winds sweep the region with good regularity.

**Figure 1: Simplified bathymetry of the North Sea**

*Source: Météo France.*
These characteristics made it easier to install offshore wind turbines. The first offshore wind farm in the world was built in 1991 in Vindeby, Denmark, with 11 turbines each delivering 0.45 MW of power. For a decade, the pace of development remained modest, until the jump in 2002 with the commissioning of the Horns Rev 1 fleet, still in Denmark, with 80 turbines with a unit capacity of 2 MW. The same machines equipped the first British farm, North Hoyle, commissioned in 2003. It took until 2008 for the inauguration of the first marine wind farm in the Netherlands (Egmond aan Zee), 2009 in Belgium (Thorntonbank) and 2010 in Germany (Alpha Ventus). The last country to enter the game, France, has been preparing several projects since 2011, including one on its short North Sea coastline, off Dunkirk (see box).

In recent years, there has been a real surge. Installed capacity in the North Sea tripled between 2012 and 2017; it reached 15.5 GW at the end of December 2017, and accounted for 98% of all EU offshore wind energy. This ratio explains why this study is mainly devoted to the North Sea.

![Figure 2: Offshore wind capacity worldwide](source)

North Sea here includes the Irish Sea and the Kattegat (between Denmark and Sweden).

---

Box: Offshore wind in France

The French government chose the Atlantic Ocean and the Channel for the first projects. 3 GWs were offered on five sites, in two calls for tender (2011 and 2013) defining a guaranteed purchase price over 20 years (feed-in tariff). Each offer was scored from 0 to 100, with 40 points awarded based on the requested price and the other 60 points based on industrial and environmental criteria. The three winners received a remuneration between 200 and 220€/MWh, the costs of connection to the transmission network remaining at their expense:

• "Eolien Maritime France” (joint venture between EDF-EN and the Canadian group Enbridge) for Courseulles sur Mer (450 MW), Fécamp (498 MW) and Saint-Nazaire (480 MW), the first two in partnership with the WPD group. They will be equipped with Haliade turbines of 6 MW (General Electric).

• Engie, EDP-R and CDC for Dieppe & Le Tréport (496 MW) and Iles d’Yeu & Noirmoutier (496 MW), with Siemens-Gamesa turbines of 8 MW.

• "Marine Wings” consisting of Iberdrola, Eole-RES and CDC for Saint-Brieuc (496 MW), with Siemens-Gamesa turbines of 8 MW.

The results were subject to three lawsuits from discarded contenders. Technical, economic and environmental studies remained the responsibility of the winners, who were also required to obtain a series of authorizations (occupation of the public maritime domain, authorization to operate, compliance with the water law, etc.). Almost all authorizations have been contested in court by associations of residents. The courts took between one and two years to deal with each case, and most of the decisions at first instance gave rise to an appeal, again requiring about one year, and then a cassation complaint to the State Council... A similar hostility can be observed in France onshore wind farms projects. The government which took office in 2017 wishes to avoid these situations, which cause very long delays. Among the measures envisaged is the single authorization, grouping all licenses into a single administrative act. However, the same government demanded that the winners review the granted purchase price. At the end of negotiations (June 2018), the price is around 150€/MWh, the cost of the connection being transferred to the transmission system operator, RTE.

A new call for tenders is planned for a site in the North Sea, off Dunkirk. For this site, public authorities will take over the preliminary studies and the call for tenders will be organised in two stages. The first one, which opened at the end of 2016, resulted in a short list of 10 candidates. A phase of "competitive dialogue" then began between them and public authorities;
it should be concluded with the publication of specifications and submissions of firm offers. The choice of the winner will take place at the end of this second stage.

**An area dominated by European companies**

All wind turbines installed in the North Sea to date come from European suppliers, whose offshore activity has been a natural extension of onshore wind turbine manufacturing. Whether at sea or on land, wind energy is experiencing strong fluctuations in orders, resulting in part from shifts in public support policies.

**Figure 3: Annual and cumulative offshore wind installation in the EU**

![Graph showing annual and cumulative offshore wind installation in the EU](image)


These fluctuations have created difficulties for the most fragile companies, resulting in mergers and consolidations. At the end of 2017, the turbine sector’s concentration appeared clearly, with 84% of the installed capacity coming from a few major players. Whether the data refer to all offshore wind power capacity in operation in Europe, but the North Sea accounts for 71%, and even 87% if the Irish Sea is included.

---

5. The data in this section are from the publication described in note 4 above. These figures apply to all offshore wind power capacity in operation in Europe, but the North Sea accounts for 71%, and even 87% if the Irish Sea is included.
capacity supplied by two manufacturers, the pioneer Vestas (19%) and the Siemens Gamesa Renewable Energy group, hereinafter SGRE, (65%).

Less well-known, European domination is also apparent among foundation builders and cable manufacturers, all of whom have head offices and production sites in Europe. A trend towards concentration appears for the year 2017, with three companies having completed 96% of the foundations and another three 96% of the cable deliveries.

A possible starting point for a global development of offshore wind

The EU has recently adopted a 2030 target of 32% for the share of energy consumption from renewable sources, meaning a share of renewable electricity between 50 and 65%. With such a high level of ambition, it seems very likely that countries around the North Sea will make it a key generation site. A prospective study conducted by Wind Europe focused on the "economically attractive" offshore potential of the North Sea. On the basis of this criterion, the potential of the North Sea seems much higher than that of the Atlantic Ocean or the Baltic Sea (the Mediterranean and the Black Sea were not part of the study).

The prospect of large orders in the North Sea raises questions about the possible entry of new players into this market. Several components remain difficult to export:

- Development studies require a good knowledge of regulations and local stakeholders.
- Foundations and substructure elements as well as the assembly of machines and the laying of electrical connections involve frequent inputs from the nearest ports and use highly specialized vessels and equipment, practicing continuous rotations from the mainland.

---

6. Data for the different facilities listed in the following sections come from the online database of 4C Offshore Consultant (www.4coffshore.com).
7. Press release of the European Parliament of 14 June 2018, announcing the conclusion of the negotiations between the delegates of the Parliament, the Council and the Commission. This agreement must now be formally approved in the coming months.
9. With the terms "economically attractive" the study refers to installations whose projected cost of production does not exceed 65€/MWh. This cost, usually expressed as LCOE (Levelized Cost of Energy), is calculated as a discounted value, based on assumptions on the return on capital and on the load factor (ratio proportional to the annual running time at full power).
10. Wind Europe, Unleashing Europe’s Offshore Wind Potential – A New Resource Assessment, June 2017, page 39. The concept of "economically attractive" potential is defined on page 33.
These components account for approximately 46% of the total cost. The turbine represents about 32%; it could be considered as the most standardized piece, but transportation of the blades requires dedicated ships, of which there are only a few worldwide.

The situation thus differs radically from the photovoltaic sector, in which the modules travel easily around the world, are easy to set up and represent on average 55% of the total cost (for a ground solar farm).

The importance of the market, however, attracted non-European companies, all of which gained a foothold through a financial contribution.

Non-European stakeholders, especially Chinese, in ambush?

To all appearance, a certain number of extra-European industry stakeholders come to acquire knowledge on the spot, before a possible replication on their national territory or in third countries. Several cases seem to fall within this category (the list is not exhaustive):

- In the Netherlands, the Canadian group Northland Power acquired 60% of the capital of the farm Gemini; in Germany it took 85% of the park Nord See One, then 100% of Deutsche Bucht’s capital, becoming the sole developer of this later park.

- The Australian group Macquarie Capital has become the fifth largest investor in EU’s offshore wind energy after its 50% stake in the farm Walney Extension.

- The Masdar Fund, the financial arm of the Abu Dhabi Future Energy Company, has taken 20% of the capital of London Array Farm and 35% of that of Dudgeon, both in Great Britain.

- The Japanese group Sumitomo has committed itself with the Belgian group Parkwind NV, first acquiring 30% of the farm Northwind, then, still in Belgium, being associated with the development of the sites of Belwind 1 and now Nobelwind (of which it holds 39% of the capital). In 2016, Sumitomo took a 12.5% stake in Britain’s farm Galloper Wind.

- A second Japanese group, Mitsubishi Corporation, acquired 50% of the Eneco Luchterduinen fleet in the Netherlands. More recently, Mitsubishi has formed a consortium with the British group HICL Infrastructure, which has just obtained the concession for the Burbo Bank Extension.

The Expansion of Offshore Wind Power…

Michel Cruciani

power line in the United Kingdom.

For these stakeholders, the project of developing the necessary skills seems all the more likely that their countries of origin, like the North Sea, present shallow coastal areas: the western shore of Canada, the Persian Gulf and the Inner Sea of Japan.

Chinese players have also taken hold. For example, the China Resources holding acquired 30% of the capital of the English farm Dudgeon, while China Three Gorges Corporation and China Yangtze Power Corporation share 80% of the capital of the German site Meerwind. But China, the world’s first wind country, had on its soil a know-how allowing it to slip from onshore to offshore with modest foreign aid, such as the call which was made to manufacturers General Electric or Siemens. The Yellow Sea and the South China Sea have a shallow continental shelf and thus provide ideal areas to start; most of the marine wind farms in China are located there. With 2.8 GW of offshore wind capacity in service at the end of 2017 and several GW of new projects announced, we cannot exclude the hypothesis that Chinese equipment manufacturers seek to mass their productions by finding export opportunities and wish to acquire a beachhead in Europe. More likely, this presence reflects the very broad desire to collect all information useful to a country that is coveting the place of world leader in the energy transition.

South Korea also plans to develop offshore wind farms in the Yellow Sea; this country has not committed significant capital in the North Sea, but the Samsung Heavy Industry group has tested the prototype of its 7 MW turbine at the experimental centre of Ore Catapult, Scotland.

For all stakeholders, acquiring know-how in Europe will facilitate the penetration of international markets; such know-how includes technical skills, but also experience in the economic and legal set-up of projects. Several major countries want to develop their offshore resource and will probably rely on experienced industrial groups to launch their own domestic sector: Argentina, Australia, Brazil, India, Taiwan, Turkey, USA, Vietnam...

Active offshore European groups are trying to reach out to these potential customers. For the time being, they have achieved a remarkable breakthrough in Taiwan, whose government targets a capacity of 5.5 GW by 2025. Denmark’s Ørsted, holder of 17% of the EU’s marine wind capacity, is preparing to develop in Taiwan several sites exceeding in total 2.5 GW of installed power. The first parks will be financed in partnership with a local player and the Australian investment fund Macquarie Capital already mentioned. The German group EnBW has also committed with the same partners, for projects totalling 2 GW (EnBW holds 50% of the shares in two
parks in operation in the Baltic Sea and in two others under construction in the North Sea). Finally, other players, from Denmark such as Copenhagen Infrastructure Partners and from Germany, such as WPD and SGRE, as well as the Canadian group Northland Power mentioned above, have signed contracts including contribution to financing, project development, electrical connections, port facilities or the management of establishments manufacturing locally various components.

**A platform for innovation, still incomplete**

In the North Sea, the size of the orders and the fierceness of the competition were two factors stimulating innovation. A particularly spectacular evolution lies in the power of turbines, multiplied by 20 in 25 years: from 0.45 MW at the origin, the power now achieves 8 MW for SGRE and 9.5 MW for MHI-Vestas; the General Electric Group is already announcing a 12 MW unit. The gains in power generation cover the additional costs of the port facilities, vessels and specific lifting equipment that these giant machines require.

**Figure 4: Evolution of the diameters of turbines (metres) and their power (kW)**

![Diagram showing the evolution of turbine diameters and power over time](image)

*Source: IRENA, Wind Europe.*

With the aim of reducing the duration of work at sea, the Ørsted group tested metal lattice foundations (*jacket*) in place of a support consisting in a single central pile (*monopile*). This new type of support has the advantage of
being largely assembled on shore and needs only small boreholes for anchoring. The four-foot jacket technique will be used in the Beatrice project in Scotland (a project in which Red Rock Power Limited, the English subsidiary of the Chinese group SDIC Power of China, acquired 25% of the capital). Another technology, the gravity base foundation, was selected for the Belgian Thornton Bank 1.

An electrical cable connects each wind turbine to an offshore substation. The increase in power of turbines has led manufacturers to step up the voltage in the cable, in order to reduce the diameter of the conductors and electrical losses. Much progress has been made in reducing the size and weight of components operating under these high voltages. Generation is then exported from the substation to the mainland by means of alternative current high-voltage cables, usually 220 kV. This solution suits most existing offshore sites in the North Sea, relatively close to the shore. For distances greater than 200 km, the use of direct current would be more advantageous.

The singularity of the North Sea, providing vast swaths of shallow water, also shapes its limits for innovation. There was notably little incentive to test floating supports, which would exploit wind energy in much larger marine areas than those accessible to foundations.

An American study highlights the importance of markets that will open up when floating wind technology is marketable: 80% of the world’s offshore resources are in waters deeper than 60 meters and this ratio jumps up to 90% for territories bordering the Pacific Ocean. The study reveals that the Asian zone devoted three times more funds to floating wind research than Europe between 2013 and 2015 ($ 305 million and $ 110 million respectively).13 Achieving a technically safe floating wind turbine still requires considerable work: modelling, experimentation, certification of machines...

European pioneers in floating technology belong to two less favoured North Sea zones (Scotland and Norway) or countries with much deeper seas (France and Portugal). Other countries have recently shown interest in this specific sector. Here is a brief overview in late June 2018:

- Industrial agreements: The Danish company Vestas and the Japanese giant Mitsubishi Heavy Industry (MHI) have just created a joint subsidiary dedicated to floating wind turbines. The German group EnBW and the US Company Trident Winds have created a joint venture to launch a floating wind farm off California. The French company Ideol signed an agreement in April 2018 with a subsidiary of the Macquarie

---

Capital group to develop the first commercial scale floating wind farm in Japan.

- **Scotland & Norway**: Hywind Scotland Pilot Park (30 MW) is the only floating farm that is fully operational; its capital is owned by the Equinor group (75%) and the Masdar group (25%).

- **Portugal**: The Portuguese operator Principle Power has developed the WindFloat model, tested during five years in Portugal. Principle Power is currently preparing the WindFloat Atlantic Park (first 25 then 150 MW) off Portugal, along with several other players (Portuguese EDP, French Engie, Japanese Marubeni and Mitsubishi, Spanish Repsol...). No date is given for this future achievement. Principle Power has also signed a partnership agreement with a subsidiary of the Japanese group Mitsubishi Corporation.

- **France**: Four projects were selected by the government, all with a capacity of 24 MW, the first one on the Atlantic Ocean and the other three in the Mediterranean Sea:
  
  - **Ile de Groix**, planned for General Electric 6 MW turbines and for floats designed by Naval Group in collaboration with Vinci. This project is carried by Eolfi associated with the Chinese group CGN.
  - **Faraman**, equipped with 8 MW Siemens turbines and SBM/IFPEN floats, of which EDF Energies Nouvelles is the pilot.
  - **Leucate**, equipped with 6 MW General Electric turbines and Eiffage/PPI floats; this project involves Engie, EDPR and CDC.
  - **Gruissan**, with 6 MW Senvion wind turbines and Bouygues TP & Ideol floats. The lead partner is Quadran.

The EU supports only few research activities dedicated to floating wind under the "Horizon 2020" program; the ELISA, DEEPWIND or NEXUS projects can be mentioned.
Economic aspects: lower costs, but grid connection issues

A fluctuating business model

From the beginning of this industry, regulation aimed at reassuring investors by setting up support mechanisms, either through feed-in tariffs over 10, 15 or 20 years (Germany, Denmark, France, the Netherlands) or through a system of green certificates (Belgium, United Kingdom). In all these schemes, the extra cost relative to the market price is transferred to the final consumer. The 2001 European directive also allowed States to impose a priority of injection for electricity from renewable sources.

In 2009, the EU adopted an ambitious target (20%) for the share of renewable energy in its consumption in 2020 and the priority of injection was made mandatory. Countries with access to the most favourable sea areas have all encouraged the development of offshore wind. As the cost of MWh remained much higher than the market price, the bill became unbearable. Denmark and the Netherlands have then decided to switch to call for tenders and the UK has introduced the "contract for difference". In this mechanism, candidates propose a reference price; the lowest bidders are selected; they sell all generated electricity on the market and receive additional compensation to cover the difference between the market price and the reference price (also called strike price).

The EC has recommended that the call for tenders with additional remuneration (feed-in premium) becomes the rule after 2016. Although this rule now creates a common framework, each State still holds a high degree of freedom to set the parameters, such as:

- The terms of the call for tenders
- The duration of the contract and any indexation clauses
- Authorization procedures

Taxation

Additional costs (preliminary studies, connection to the network, financial guarantees, dismantling obligations, etc.).

It is therefore necessary to distinguish the elements common to all projects from those reflecting local specificities.

**Competitiveness levers**

In all calls for tenders, the selection is based on the MWh price requested by the candidates; it is often the only criterion. To calculate the price, the project leader takes into account:

- Expenses related to the initial investment (CAPEX)
- Operating and Maintenance Expenses (OPEX)
- The features of the project: duration of the contract, cost of capital and quality of the wind on the site

Figure 5 breaks CAPEX into three subsets. The first one, in green, includes only the turbine, whose price remains independent of the project. In the second, in various shades of blue, local conditions largely determine the costs. In brown, we include costs related in part to the site and in part to the quality of the developer.

**Figure 5: Costs breakdown**

We have seen that the offshore turbine market remains highly concentrated in Europe. Competition can be considered insufficient to push prices down; but on the other hand, the gains obtained by manufacturers from the series effects lead to a reduction in costs.

In the second subset, the cost is highly dependent on the depth of the sea and the distance to the coast, specific to each project, as well as costs either charged to the project or partially/fully borne by the consumers.

The proximity of a port with the appropriate equipment plays a role in the initial expenses, because the handling of large elements, such as towers and rotor blades, require adapted platforms; special vessels and lifting equipment are also needed for the transport and assembly of wind turbines. The high density of installations in certain areas of the North Sea allows the formation of "clusters" improving the availability of equipment. The "Transport & Assembly" component of Figure 5 decreases accordingly. The German coast provides a good illustration of this phenomenon, with a dozen ports offering facilities.

**Figure 6: Concentration of wind farms and ports in the German North Sea area**

![Map of wind farms and ports in the German North Sea area](source: Map in free access on the website www.offshore-stiftung.de)

The high level of equipment also makes it possible to consider lower operating and maintenance costs, that candidates have probably included in their bids to the latest calls for tenders. However, there is still uncertainty
about risks linked to accelerated corrosion of some components and to the cost of dismantling.

After estimating CAPEX and OPEX, the project developers will evaluate the price of the MWh to be obtained over the duration of the contract; it is established by the formula known as LCOE (Levelized Cost of Energy). In this formula, the full cost of capital plays a major role. It has decreased thanks to the growing importance of bank loans, which partly explains the fall in the price of MWh in recent calls for tenders. Banks financed an average of 60% of a project until 2007; they increased their share to 75% in 2016, extended the maturity of loans up to 17 years and multiplied the amounts granted by a factor of 1.5 to 2.\textsuperscript{15}

The calculation of the LCOE then takes into account the duration of the contract and the quality of the wind; these two parameters vary depending on the situation. Regarding the quality of the wind, the North Sea offers on average a regular regime, but local peculiarities, such as the coastal relief, cause variations from one site to another. The "load factor", or annual rate of production at full power, also varies according to the density of machines. Each wind turbine disturbs the flow and this wake effect reduces the performance of machines downstream.

**The results: more and more competitive projects**

A general observation can be made: the announced price of the MWh produced in the North Sea has dropped everywhere, as following examples confirm. In several cases, this price falls below 65€/MWh, regarded as the threshold of competitiveness compared to the competing reference power plant, which would be a combined cycle natural gas power station with a CO\textsubscript{2} price of 20€/t. The following list is based on a sample of representative projects.

**Germany:**

For installations connected to the grid before the end of 2019, developers could choose between a guaranteed purchase price of 150€/MWh for 12 years or 190€/MWh for 8 years. These terms will apply in total to 5.2 GW.\textsuperscript{16}

Two tenders were subsequently launched under the additional conditions of a high efficiency guarantee and a CO\textsubscript{2} price of 35€/t.

---


remuneration scheme, the results of which reflect a surprising spread: for the first one (2017), the reference price varies from 0 to 60€/MWh and for the second one (2018), from 0 to 98€/MWh.  

The submission of bids without additional remuneration means that the sale of power at market price will be sufficient to make the wind farms profitable. It should be noted, however, that the farms in question are located in exceptionally favourable wind zones, the concessions are 25 to 30 years in length, and four of these farms have been awarded to the same group, allowing for series effects. Since commissioning is not planned before 2024 or 2025, project promoters are also likely to anticipate a price increase on the power market, from 18€/MWh in 2017 to 65€/MWh in 2025.  

**Belgium:**

Belgium changed the support scheme several times:

- The first farm was placed under a system of green certificates with a guaranteed minimum price for 20 years, estimated on average at 101€/MWh in 2009. This park also received a grant of 25 million euros.
- In the face of investors’ reluctance, the minimum price of the green certificate was raised in 2016 to 124 and then to 130€/MWh.
- Belgium ultimately adopted the principle of additional remuneration awarded after calls for tenders, which resulted in a reference tariff of 79€/MWh for 16 years, for commissioning in 2020.  

**Denmark:**

In Denmark too, several regimes have been successively introduced:

- The first one consisted of a guaranteed purchase price of 140€/MWh for 50,000 hours of full power operation in 2012.
- The country then moved on to a constant additional remuneration (independent of the price of electricity on the market), set at 36€/MWh for 22,000 hours of full power operation.
- Denmark has finally adopted the guaranteed purchase price awarded

---

after calls for tenders, which include a pre-selection phase before the submission of firm offers. The parks to come into service in 2019 will benefit from a guaranteed purchase price of 63€/MWh and the one whose commissioning is scheduled for 2021 will receive 49.5€/MWh.20

**Netherlands:**

The Netherlands also implement tenders:

- In 2015, tenders achieved an estimated guaranteed purchase price of 87€/MWh connection included (commissioned in 2020).21
- In 2017, a winner agreed to build two parks with a remuneration limited to the sole power market revenue. The government, however, takes over grid connection fees and is committed to introducing a floor price for CO2 before generation starts in 2022.

**United Kingdom:**

Two systems were introduced:

- From year 2000 on, the system was based on Crown Estate concessions on the maritime domain, accompanied by Renewable Obligation Certificates (ROCs). Each MWh produced was sold at market price and gave right to two certificates, the price of which depended on the ROC market (53€ on average in 2013).22
- In 2013 the government adopted Contracts for Difference awarded by tenders. The strike prices stood between 148 and 141€/MWh at the 2015 tender and 92-71€/MWh at the 2017 tender.23

---

23. DECC, *Contracts for Difference Allocation Round One Outcome*, 26 February 2015, et UK Department for Business, Energy and Industrial Strategy (BEIS), *Contracts for Difference Second Allocation Round Results*, 11 September 2017. Prices are given in 2012 value. Rate of change for this year: 0.81087€/€ (according to Eurostat database [ert_bil_eur_a]).
The Expansion of Offshore Wind Power...

Michel Cruciani

Figure 7: Evolution of announced prices for a sample of projects

Sources: See footnotes 16 to 23.

Reminder: The values in €/MWh estimated above do not reflect costs verified ex post, but price levels calculated ex ante by the project promoters to achieve their profitability objectives.

Comments

According to Mr. Antoine Rabain (MPrime Consulting) the spectacular fall in MWh costs announced during the last calls for tenders is due to several factors:

- Series effects related to investment volumes: from 1 billion euros per year between 2000 and 2010 to more than 10 billion euros in 2017 (cumulative for all European offshore wind).

- Particularly favourable characteristics of the granted plots: moderate distance to the coast, shallow water, soils favourable to monopile foundations, excellent wind conditions.

- Technological progress made by suppliers, delivering more powerful turbines capturing even light winds.

- Very low profit rates accepted by investors in a strategic perspective of occupying the best sites and squeezing out the most fragile competitors.

For the author of this study, the recent interest of large historical companies in offshore wind energy corroborates the latter point. As most of these players are engaged in a strategic reorientation phase, large North Sea parks look very attractive and we see EDF, EnBW, Iberdrola or Vattenfall.

committing dedicated subsidiaries. However, we cannot rule out the possibility that some projects will never be carried out, especially when the penalty for non-fulfilment of the contract is modest (13 million euros in Denmark for Vesterhav Nord & Syd, for example).  

With regard to the technical conditions, it is also necessary to underline the reduction of oil & gas exploration and production activities in the North Sea, which unlocks port infrastructures and provides competent crews on maritime engineering. To date, 715 offshore platforms still remain in operation for oil & gas, which gives an idea of the technical resources that will subsequently be available. Some of them might be converted into maintenance bases or sites dedicated to the production of hydrogen by hydrolysis, possibly reusing old pipelines for delivery.

The grid issue

While the declining costs for new installations are frequently underlined, there are few mentions of the cost of transmission networks needed to evacuate the growing volumes of electricity, a cost which has an adverse impact on the consumer’s bill. We see even more rarely mentions of the time coordination between the construction of farms at sea and the completion of networks. Finally, there are almost never any doubt about the feasibility of such reinforcements of the grid, whereas the opposition to new lines is a limiting factor in most countries.

Germany gives a striking example of the difficulties encountered. The bulk of the wind source, and in particular the offshore wind fleet (totalling 5.4 GW at the end of 2017), is located in the Northern half of the country, while much of the consumption comes from industries located in the South. High-voltage transmission lines connecting the two halves of the country are proving to be insufficient to transmit wind-generated volumes to areas of high consumption. Since 2009, the federal government has passed several laws to facilitate the construction of new lines, but local oppositions have managed to slow down considerably the works, although the authorities decided to lay large sections of these lines underground rather than overhead, which multiplies the costs by a factor 4 to 8. By the end of June 2018, only 900 km had been completed on an overall program of 7,700 km.

This delay resulted in a total cost of 1.4 billion euros in 2017, consisting of "redispatch" costs and compensations for renewable farms whose production could not be fed into the grid.\footnote{Bundesnetzagentur, Bundesnetzagentur veröffentlicht Zahlen zu Redispatch und Einspeisemanagement für 2017, press release of 18 June 2018.}

A report published in 2018 by ENTSO-E, the coordinating body of network operators, gives an idea of the growing needs: depending on scenarios, the total interconnection capacity between seven countries bordering the North Sea should increase from 19 730 MW (expected level in 2020) to 31,700 MW or 40,000 MW in 2040.\footnote{ENTSO-E, Regional Investment Plan 2017 - North Sea Region, page 33. In other words, the capacity of the interconnection should increase by 50 to 100%. However, the consumption of these countries would only increase by 4% approximately by 2030, if we retain a target of 30% improvement in their energy efficiency.\footnote{Author’s calculation based on the final consumptions of the 6 considered countries which was given in the impact study published by the European Commission in 2015 and 2030: PRIMES, Technical Report on Member State Results of EU CO Policy Scenarios, By E3MLab & IIASA, December 2016, pages 71 to 127. On June 20, 2018, the European legislators announced having adopted an energy efficiency target of 32.5%.} An earlier study published by IFRI has emphasized the fragile economic rationale for network extensions not motivated by increases in consumption.\footnote{M. Cruciani, "Electric Networks and Energy Transition in Europe", Notes de l’Ifri, Ifri, September 2015, available at: www.ifri.org.} ENTSO-E does not indicate the cost of the corresponding investments, as it will depend on the final route as well as the choice between AC or DC and overhead or underground lines. This cost will be apportioned among consumers in the interested countries, and appear in the "routing" section of their invoice.
The geo-economic and strategic stakes

A considerable potential

The measures adopted by countries surrounding the North Sea since the 2000s enabled the building of 15.5 GW offshore wind capacity in this area at the end of 2017. An equivalent volume could be added by 2022 if all current projects at different stages of preparation were succeeding. Areas available in the North Sea remain immense, but two economic parameters come into play. First, a greater distance to the coast considerably increases the cost of the electrical connection. Secondly, when the depth of the sea exceeds 60 m, floating wind turbines should be used, and these are more expensive than those on foundations as the technology is not yet mature.

A glance at the map of exclusive economic zones shows that the United Kingdom holds the greatest potential, far ahead of Denmark, then the Netherlands and finally Germany. Norway has a long sea front, but deep waters.

Figure 8: Exclusive economic zones in the North Sea

A study by consultant BGV Associates estimates at 1,572 TWh the annual production in the North Sea that would be achieved by 2030 if all sites with a production cost below 65€/MWh were equipped with turbines. It would correspond to an installed capacity of 607 GW and account for 49% of the EU’s electricity consumption that year (including the UK). Considering this level as unattainable, particularly because of the difficulties to build a transmission grid capable of channeling such volumes, the same study actually forecasts for 2030 an installed capacity of 64 GW, covering about 8% of European needs.33

**Coordination issues**

Many studies assess the potential role of the North Sea in the prospect of fully carbon-free EU electricity generation by 2050. All studies converge on the absolute need to strengthen interconnections, in order to improve the flexibility of an electrical system that will be subject to significant fluctuations in generation due to wind hazards. A number of interconnection projects aim at linking two countries, United Kingdom for its position as a major producer and Norway for its hydro-electric facilities.

Norway has the largest hydropower capacity in Europe, totalling nearly 32 GW.34 Dams fill up in spring and summer when the snow melts, representing a good complement to wind turbines, which achieve their generation peaks in autumn and winter, seasons of strong winds. Various reports attempt to quantify the benefit that could result for the European electricity system through the development of interconnections with Norway.

Reports also try to assess the profitability of new pumping stations in Norway. Their power is only 1.4 GW so far (against 6.8 GW in Germany and 4.6 GW in France, for example), but the additional available potential is estimated at 10 GW from a strictly technical point of view. In addition to their large "battery" function, pumping stations are well suited to providing services required by grid operators to ensure power continuity and power quality, including frequency regulation, as well as the restart of the system in case of failure (black start).

Currently, all parks are connected directly to the mainland. Could a common "hub" be made for several farms and connected to an interconnection cable? Going further, various actors argue in favour of a meshed network in the North Sea, like a national transmission grid,

---


collecting and routing productions throughout the territory. A consortium is considering the construction of a large hub, which would be located on an artificial island not far from the junction point between the exclusive economic zones of five countries. The consortium presented the project at a meeting of the energy ministers of an enlarged G20 in Malmö on 18 May 2018. Their study shows that a coordinated planning of investments and the use of the central hub would reduce about 30% the total cost of the interconnections.  

**Figure 9**: A possible evolution of the North Sea transmission grid

As soon as 2009, countries involved wanted to have a common vision on the North Sea networks. Nine of them (Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Sweden and the United Kingdom) signed a policy declaration called the North Sea Countries Offshore Grid Initiative (NSCOGI) that year. Joined by Norway, the ten States adopted in December 2010 a memorandum of understanding setting up several working groups. A second political declaration, signed in June 2016, outlined a new work program for the period 2016-2020. For its part, the EC has launched its own studies; a 2014 report estimated that a meshed grid would lead to additional investments between 5 and 10 billion euros, but would then generate between 1.5 and 5 billion euros in annual savings.  

As useful as it is, this work remains outside the decision-makers. The NSCOGI has no power comparable, for example, to the Energy Regulators

---

35. The consortium includes Tennet Germany and Tennet Netherlands, Energinet (Denmark), Gasunie (Netherlands) and the Port of Rotterdam. Source: “The North Sea Wind Power Hub Consortium”, press release of 24 May 2018.

Coordination Agency, a power which would enable it to advance common planning, rules or standards. Left at the State level, coordination of decisions faces a series of obstacles. These are not specific to offshore wind, but take a strong importance in this case:

- Connection expenditures of wind farms are passed on different actors depending on the country.
- Due to the spread of projects over time, the first completed projects prefer an immediate connection to the continent rather than to a sea-hub at an unknown date.
- Renewable energy support schemes differ widely between States. The citizens of a "generous" country do not accept that neighbours are benefiting from a production that they have not financed and they are equally reluctant to finance facilities outside the border.

Coordination of decisions will become even more difficult with Brexit. Given the very strong political line of Brexit activists, it is doubtful that the United Kingdom will follow the example of Norway, which, without being a member of the EU, belongs to the European Economic Area. This membership allows Norway to be fully part of the EU’s internal market, respecting its rules, and to benefit from various Community programs, including research, but without having a say in decision-making. Leaving the EU, the United Kingdom will no longer be subject to common rules on the use of the maritime domain and will no longer be bound by common commitments on renewable energy; its grid operators will no longer participate in the European clearing mechanism for cross-border exchanges; its electricity market may adopt rules different from those in force on the continent, which will complicate transactions (a note was published by Insight-e on this subject). The EU is also losing a very active participant in offshore wind research programs.

It therefore seems likely that innovations in coordination now come from industry rather than political bodies. An ad hoc political structure vested on the North Sea could certainly be proposed, for example by boosting the role of the NSCOGI, but the risk would then be that the British influence is dominant, given its current weight in offshore wind power (53% of the capacity installed in the EU at the end of 2017); the UK might then push for the adoption of rules to its advantage.

Another aspect of co-ordination deserves special attention: the military protection of installations, especially against terrorism, calling for concerted

37. S. Pye (UCL), C. Mathieu (Ifri) and P. Deane (UCC), The Energy Sector Implications of Brexit, Insight-e, January 2017.
38. Idem footnote 37.
surveillance of sensitive structures at sea, such as substations or connection hubs.

**The North Sea, Mare Nostrum?**

The success of offshore wind power in the North Sea and the brilliant prospects it holds paradoxically lead to a risk for the EU, that of further shifting the centre of gravity of energy in Europe to the countries surrounding the sea. Indeed, the economic performance of wind power in the North Sea can largely be explained by local factors. They are found partly in the Baltic Sea, but not in countries bathed by the Atlantic Ocean, the Mediterranean Sea or the Black Sea, due to a greater depth of the continental shelf, less favourable wind patterns, and a lack of port equipment.

*Figure 10: Wind speed and sea depth*

For some countries, the technology of floating wind brings an emerging response. However, its development is still distant and based on public commitments that only certain countries can support (Scotland, France, Norway, Portugal...). Manufacturers are well aware of the opportunities opened to these machines, but in the immediate future the North Sea offers them a large potential for further development for wind power on foundations. The intense competition to win the tenders encourages them to favour only research expenditure benefiting from the leverage provided by public funds.
In addition, the economic weight already acquired by offshore wind operators in the North Sea naturally makes them more influential on policymakers and the latter are sensitive to the contribution made by this sector to achieve the 2020 targets. To date, the installed capacity in the North Sea remains too low to worry States located in the heart of Europe, without sea front, or States bathed by other seas. By 2030, it should hardly exceed 5% of all operating capacity in the EU. In the longer term, in case of a high rhythm of development, resentment can arise in the population of these States, especially if wind spikes cause a standstill of local plants.

Marginalization of countries without access to the sea could be alleviated by setting up a large-scale participative funding mechanism. The size of the required investment would justify its opening to any European citizen, by means of a dedicated vehicle, on the model of a savings book, offering a high liquidity accompanied by a modest but guaranteed income (secured by a common financial institution) below a symbolic ceiling, for example 10,000€. Income and ceiling should remain low to avoid drying up participative financing of local, better-paid projects; the main virtue of the system advocated here remains pedagogical.

39. Computation by the author, retaining 64 GW of offshore wind in the North Sea (see note 33) and 1,125 GW for all installed capacity in the EU in 2030 (source: idem note 31, page 70).
Conclusion and recommendations

Countries neighbouring the North Sea have been able to exploit its particular characteristics to develop a sector that looks promising on a global scale, offshore wind. Its take-off was based on very expensive financial support schemes, but this page is turned, with the generalization of provisions stimulating competition. Combined with the effects of series and effects of learning, this policy is starting to bear fruit, with projects now announcing a competitive MWh cost, sometimes more advantageous than conventional productions, with natural gas for example.

The success factors are not all reproducible, but the procedures in place in countries recording the best results could usefully inspire governments that wish to develop offshore wind. We think here of France, which could certainly accelerate the deployment of its program by reproducing the Danish approach:

- Planning of suitable areas after discussion with involved local parties, lifting of legal risks;
- Preliminary site studies conducted by public authorities;
- Programming reinforcement of onshore power networks prior to tenders;
- Two-stage calls for tenders; negotiations with pre-qualified winners before final bidding;
- Single administrative contact for project developers.

The results observed in the North Sea suggest that further development is likely. Doubling or even quadrupling the installed capacity in the region seems to be within reach from a strictly technical and economic point of view. But if we widen the angle of observation, various concerns emerge. A major difficulty lies with the electrical networks intended to evacuate a production becoming considerable. Interconnections between States are an essential link in these networks. Various studies show that the economic optimum would imply the creation of a real internal network in the North Sea, meshed as a national grid and accepting injections in every way, from hubs common to several wind farms. This solution unfortunately seems out of reach, precisely because the procedures adopted to stimulate competition
are determined by national authorities, with strong differences between countries, without a body having a regional coordination power.

Everything indicates that Brexit will complicate or even make it impossible to set up such a governance scheme. In its absence, and often because of internal obstacles, we cannot exclude the hypothesis of wind farms being built before the completion of electric power lines, or forced to interrupt generation because of a saturated grid, two phenomena observed in Germany in the near past. Similarly, there are fears of new occurrences of negative prices on the spot market; however, the rules advocated by the EC in the "clean energy package" will prohibit any remuneration in these situations in the future. This eventuality will undoubtedly revive the interest for various forms of storage of electricity, either centrally, and all eyes will then turn to Norway, because of its potential in hydroelectric pumping stations, or on the generation sites. In this second case, the conversion to hydrogen could be part of the solution, all the more interesting as it would benefit from the competence of stakeholders from the oil & gas sector, widely present in the region.

The success of offshore wind power in the North Sea has its downside: it is based on exceptional singularities, be they geographical (shallow sea, good wind) or historic (density of port equipment). The advance obtained in this sector by the industry of countries surrounding this sea opens up export possibilities in regions of the world enjoying the same peculiarities, but they are few in number. For European States with good wind but deep sea fronts (Spain, France, Greece...), floating offshore wind technology seems to be the best solution to date. Considerable progress is still needed to reach maturity; the European institutions should ensure a fair sharing of research efforts in this direction. The economic spin-offs could become substantial, because the regions of the world where floating wind would find market opportunity are much better distributed than those accessible to wind farms on foundations. In this view, the technological expertise acquired by European companies in offshore wind power can turn them into targets for groups outside Europe eager to take over these skills. EU and national law to prevent these predatory behaviours apply only to activities considered strategic. Then the question is: should this classification be extended to offshore wind production?

Finally, the EU should pay particular attention to countries with no access to the sea and study any mechanism allowing them to be associated with the development of offshore wind turbines outside their borders, in addition, of course, to strengthening the technical and economic support to stimulate the development of the local renewable resources.