Making green energy affordable

How the offshore wind energy industry matured – and what we can learn from it

Ørsted

At Ørsted, our vision is a world that runs entirely on green energy

Not only is this necessary to avoid catastrophic changes to the conditions of life on our planet Earth, it is also possible.

Today, green energy is the economic choice. Life-time costs of new solar, onshore and offshore wind energy generation are lower than those of new-build coal, gas and nuclear power plants. For offshore wind energy alone, the cost in Europe has dropped by 63% since 2012.

This paper tells the story of how offshore wind energy went from a prototype to a mature and competitive technology at industrial scale. It demonstrates how industrial innovation – and ultimately the birth of a new large-scale energy technology – can happen when industry and government collaborate. While industry can research, demonstrate and deploy new energy solutions at scale, governments must set the framework for the market that enables industrial development, learning and growth of new and promising technologies.

Across the world, countries increasingly act to address climate change by transitioning their energy systems to green energy. Solar, onshore and offshore wind power can provide the backbone of the world's new green energy system.

However, other complementary technologies will be needed to build a world fully powered by green energy, for instance, to make use of growing renewable power production in decarbonising heating, industry and transport, and to store excess energy for when the demand is higher. Such technologies can be developed and matured faster, if governments and industry collaborate effectively, enhancing the world's chance of mitigating climate change.

Offshore wind energy has played a defining role in Ørsted's strategic transformation and will continue to do so. As the global market leader in offshore wind energy, we are proud at Ørsted to have been the first mover in maturing a green, scalable and very powerful renewable energy technology. From its birthplace in Europe, we will in the years to come help offshore wind energy go global, as we deploy offshore wind at scale across countries that want to decarbonise their energy systems.

For the past decade, we have been on a radical decarbonisation journey ourselves. At the end of 2018, 75% of our energy generation was green, up from just 17% in 2006, and we will continue to drive out fossil-based energy generation of our own energy mix as we move towards our target of 99% green energy by 2025.

In Ørsted, our ambition is to continue leading the deployment of green energy. In 1991, we installed the world's first offshore wind farm. Today, more than 12 million people are powered by offshore wind farms built by us. And by 2030, our ambition is to have an installed renewable energy capacity of more than 30GW, enough to power more than 50 million people across the world.

We are happy to share our insights on what has made offshore wind energy innovation happen and what it takes for offshore wind energy to go truly global with the potential to power hundreds of millions of people worldwide.

Executive summary

Over three decades, offshore wind energy has emerged as a mature, proven and competitive green energy technology.

In just three decades, offshore wind energy has gone from a demonstration concept powering 2,200 households in Southern Denmark to a large-scale energy technology that is now powering millions of people across three continents.

Offshore wind power holds the potential to power hundreds of millions of people in a sustainable way.

It has become cheaper to produce energy from newly constructed offshore wind farms than from newly built coal or gas-fired power plants, and vast areas are readily available at sea.

The global offshore wind energy industry matured in four phases. In each phase, steps were taken that pushed offshore wind energy towards increasing competitiveness:

1991 – 2001: The first offshore wind farms were built, mainly as demonstration projects in a few European countries.

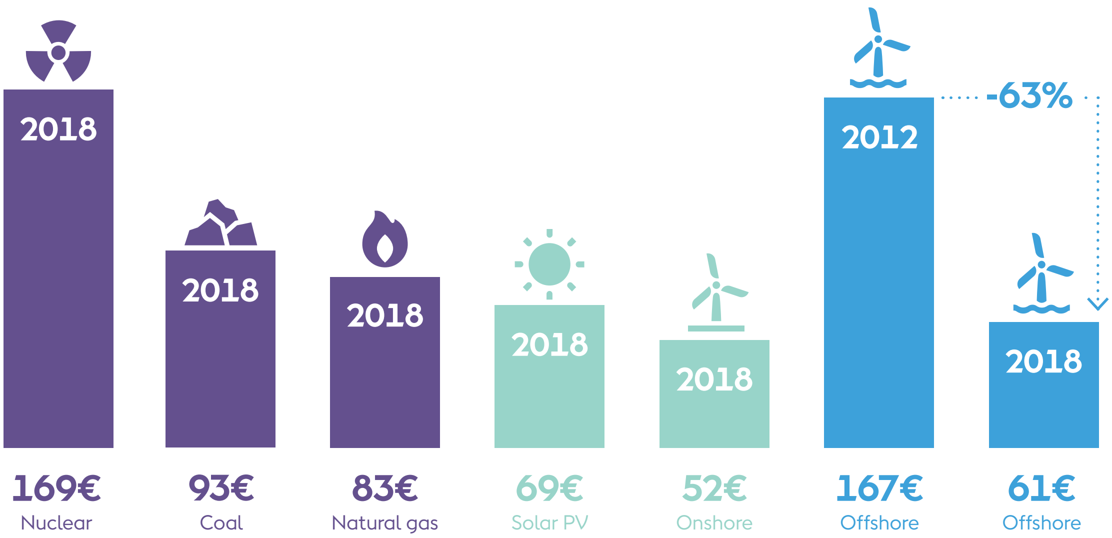
2002 – 2011: Scaling up. The second phase saw the first modern offshore wind farm, Horns Rev 1, in 2002. After that, projects' size and complexity grew, but the supply chain had yet to be developed. Short-term, this combination led costs to increase.

2012 – 2017: Driving down costs. In the third phase, industry committed to a hard push for cost reductions, which led to a 60% cost reduction, making offshore wind energy cheaper than new coal, gas and nuclear-based power generation.

Since 2018: In the fourth, current phase, we see offshore wind energy maturing and going global, moving beyond Europe into North America and Asia-Pacific.

In just six years, newly built offshore wind has become cheaper than black energy

Levelised cost of electricity for different energy technologies (LCOE).
EUR/MWh, 2018 prices, North Western Europe[1]



1. Source: Bloomberg New Energy Finance / Ørsted

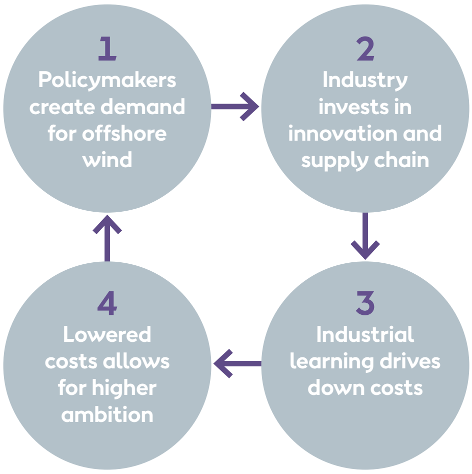
The development of offshore wind power over the past three decades was made possible by the constructive interplay between visionary policymakers and industry. Governments ensured demand and volume through ambitious green energy targets, political support, funding of public research and dedicated offshore wind policies.

This created a long-term market outlook, enabling industrial developers to take the leap and commit to developing offshore wind parks at an unprecedented scale, which unlocked the financial resources needed to drive innovation and supply chain build-out, to mature the technology and ultimately to make it competitive.

The increasing volumes of offshore wind energy deployment has been instrumental in driving costs down. Historically, each time installed capacity of offshore wind power has doubled, the levelised cost of electricity has declined by approximately 18%.

The drivers have been larger market volume, which has allowed for economies of scale, growing competition, investment into new technologies and technological improvements and a continuous maturation of the supply chain. The positive feed-back loop – by some labelled an ambition loop – between government policy and business dynamics is a clear example of how new technologies can be matured.

The Ambition Loop for offshore wind energy

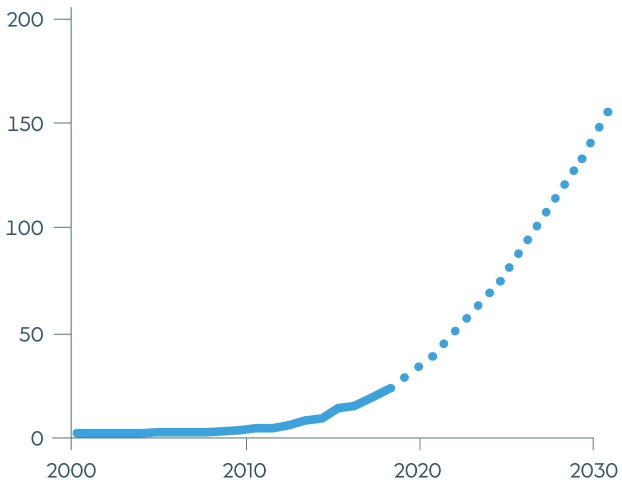


The story of the maturation of offshore wind energy as a large-scale, cost-competitive green energy technology holds important lessons. That can be applied as we work to develop offshore wind energy in new markets and strengthen other new technologies, such as hydrogen or battery storage, that can complement solar and wind energy in a fully decarbonised energy system. It shows the importance of scale in facilitating innovation and bringing down costs, enabling still higher ambitions and even larger scale.

As more offshore wind capacity is installed, costs are decreasing

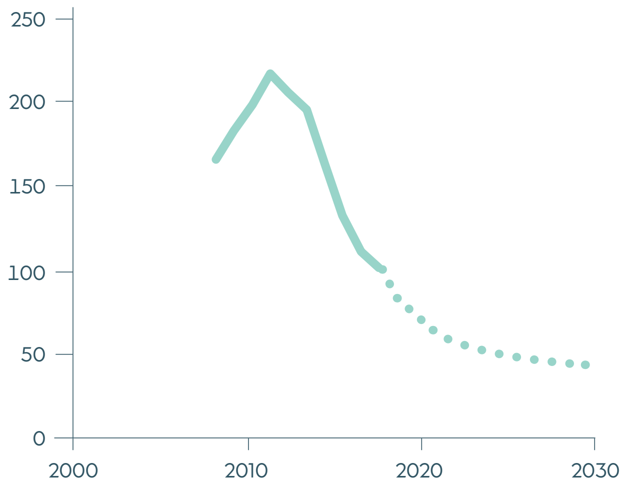
Global installed offshore wind capacity

GW



Global LCOE benchmark

EUR per MWh



Source: Bloomberg New Energy Finance

The drivers and indicators of the offshore wind energy cost-out journey

Phase	1991 – 2001 The first offshore wind farms	2002 – 2011 Scaling up
Key political drivers	• Political wish to develop the national wind energy industry and fiscal concerns over energy imports leads to the first offshore wind farms	• Emerging political demand for climate action and new EU targets • More countries implement policies to promote and accelerate offshore wind energy build-out
Key industry developments	• No specialised supply chain. • Few, scattered and relatively small demonstration projects • Turbines growing from 0.5 up to 2.3MW	• Increased scale and complexity without a firm supply chain in place increases costs • Operations and maintenance by specialised vessels. Helicopters used routinely • Turbines growing from 2.3 up to a typical 3.6MW
Markets	Denmark, United Kingdom, Sweden, the Netherlands	Denmark, United Kingdom, Sweden, the Netherlands, Finland, China, Belgium, Germany
Market volume	0.25GW	6.4GW
Annual industry investment	< EUR 0.1 bn	~ EUR 2 bn
Typical project size	~20MW	~100MW
Global deployment rate	~ 1 turbine / 28 days	~ 1 turbine / 2 days
Cost (LCOE)[2]	No reliable data available	EUR ~90-167 per MWh

2. In north-western Europe. The cost might differ in geographies where a local supply chain has yet to materialise

2012 – 2017 Driving down costs	**Since 2018** Going global
• Governments and industry shift focus to bringing down costs • Renewed governmental support key to developing the industry • In the UK, the FID-enabling contracts scheme allows developers to place large orders for upcoming projects	• Costs have come down • Offshore wind energy is going global as more countries turn to offshore wind energy as means to transform their power system
• Industrialisation of supply chain • Cost reduction programmes • Flexible service operation vessels introduced, O&M increasingly done remotely, using drones, cameras and new digital technologies • Offshore wind farm clusters effectively reduce O&M costs • Turbines growing from a typical 3.6 up to 8MW	• Floating foundations being piloted • Turbines growing from 8 up to 12MW, with expectations for even larger turbines
Denmark, United Kingdom, Sweden, the Netherlands, Finland, China, Belgium, Germany, Taiwan, Japan, USA	Denmark, United Kingdom, Sweden, the Netherlands, Finland, China, Belgium, Germany, Taiwan, Japan, USA, South Korea, Ireland, France, Poland, India +
12.3GW	100+ GW
~ EUR 10 bn	~ EUR 10 bn
~400MW	800+ MW
~ 1.5 turbines / day	2+ turbines / day
EUR 167-65 per MWh	EUR <61 per MWh

1991-2001
The first offshore wind farms

When the 11 turbines of the world's first offshore wind farm, Vindeby in Denmark, were commissioned by Ørsted in 1991, not many believed that it was practical – or even possible – to operate wind turbines at sea.

In Denmark, a wind energy industry with an established home market emerged following the oil crises of the seventies. Initially seen mostly as a demonstration project to underpin the wind energy industry and its growing export, Vindeby was installed off the coast of Denmark. Totalling 5MW, it covered the annual consumption of 2,200 Danish households.

After the commissioning of Vindeby in 1991, the growth in new offshore wind farms was slow. Over the next ten years, only a few more offshore wind farms – in Denmark, Sweden, the Netherlands and the UK – were constructed, the largest being 40MW. Since the farms were considered pilot projects, the political focus was on technical feasibility rather than on comparing costs to other sources of renewable energy.

The first offshore wind farms were relatively simple; onshore turbines based on concrete foundations in shallow water. They were typically ordered by governments and constructed by utilities, sometimes with companies entering into consortia.

While not at industrial scale by any standards, the first offshore wind farms provided valuable learnings. Fundamentally, the projects proved the feasibility of the concept of offshore wind power, despite being harder to install and access. Some early wind farms had positive surprises by producing more energy than expected. This, along with growing political concern over climate change, resulted in an appetite for more offshore wind energy.

Increased national ambitions

In 1998, the Danish Government announced plans for five new offshore wind farms of 150MW each. The same year, in the UK, the Government, The Crown Estate and the British Wind Energy Association held talks to set guidelines for offshore wind energy development in UK waters. This led to the first offshore wind leasing round by The Crown Estate in the UK, which was completed in 2001.

In sum

Key political drivers	• Political wish to develop the national wind energy industry and fiscal concerns over energy imports leads to the first offshore wind farms
Key industry developments	• No specialised production chain. • Few, scattered and relatively small demonstration projects. • Turbines growing from 0.5 up to 2.3MW
Markets	Denmark, United Kingdom, Sweden, the Netherlands 
Market volume	0.25GW
Annual industry investment	< EUR 0.1 bn
Typical project size	~20MW
Global deployment rate	~ 1 turbine / 28 days
Cost (LCOE)	No reliable data available

Example of wind farm from this phase

Vindeby

Market	Denmark
Construction	1990-1991
No. of turbines	11
Total capacity	5MW

2,200

Vindeby was powering 2,200 Danish homes

2002-2011
Scaling up

By the turn of the millennium, a sizable pipeline of upcoming projects in north-western Europe started to emerge.

The technology was moving forward. In 2002, Horns Rev 1 was commissioned in the North Sea west of Denmark. At 160MW, Horns Rev was a significant technological milestone, marking the transition from the demonstration phase to utility scale offshore wind power plants. It was the first offshore wind farm to use steel monopile foundations 18km from the coastline, and the first to have its own designated offshore substation.

Pipeline emerges in the UK

The UK's first seabed leasing round, launched by The Crown Estate in 2000, made the UK the leading offshore wind energy market overnight. The result was a total of 1,100MW to be installed across 11 projects in the following years. The UK model let developers propose sites for new projects, which allowed for competition in scoping and pre-development of projects.

In 2003, The Crown Estate in the UK completed its second leasing round for offshore wind, this time awarding capacity consent to 15 projects, with a previously unseen capacity of 7,200MW. And in 2008, The Crown Estate surpassed the capacity of the first two leasing rounds. In this third round, nine development zones were awarded a cumulative capacity of up to 32,000MW. Offshore wind energy developers were now looking at building multiple farms in the hundreds of MW scale, typically situated 20km from the coast or further. While the projects had yet to secure subsidies and take final investment decisions, the second and third rounds indicated future build-out at an unprecedented scale. The growing pipeline also motivated several turbine manufacturers to enter the market for dedicated offshore wind turbines.

National renewable energy targets

Towards the late 2000s, European politicians responded to an increasing demand for action on climate change. In 2007, the European Commission proposed the '20-20-20 targets', calling for 20% reduction in greenhouse gas emissions, 20% renewable share of gross final energy consumption and the EU using 20% less energy compared to business as usual – all by 2020.

The targets were adopted by the European Parliament and EU member states in 2008 and implemented in the Renewable Energy Directive of 2009, mandating national binding targets for renewable energy build-out. This led more countries to formulate or increase their own targets for offshore wind power, increasing market volume further.

Offshore Wind Farms have grown big

Today, offshore wind farms are constructed at the size of large cities

1991
Vindeby

5 MW
0.45 km²

Powering 2,200 homes

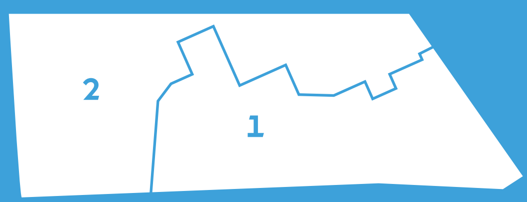
2013
Anholt

400 MW
88 km²

Powering 400,000 homes

2020
Hornsea Project One

1,218 MW
407 km²



Powering more than 1 million homes

2022
Hornsea Project Two

1,386 MW
462 km²

Powering up to 1.3 million homes

New York City

Size comparison
784 km²

Securing finance through partnerships

Along with the increasing size of offshore wind farms, utilities began partnering with each other on a project-by-project basis, to gather know-how in offshore wind energy projects and share risk.

Utilities also began to enter partnerships with institutional investors to secure capital. This helped developers finance new projects and to diversify their risk, while offering investors a stable and predictable return.

For instance, London Array, which was awarded in 2003 as part of the second leasing round and was the world's largest offshore wind farm at its commissioning in 2013, was financed by a group of utilities and institutional investors, including Ørsted, and the Canadian pension fund CDPQ.

Gradually, institutional investors such as Danish PKA and Pension Danmark entered into project partnerships at earlier stages of the development, where risks of delays and budget overruns are at their largest. This demonstrated a growing understanding of offshore wind farms as a new asset class and greater confidence in the projects being delivered on time and on budget.

The combined national build-out plans in north-western Europe laid the foundation for needed investment in upgrading the supply chain.

With this newfound visibility, turbine manufacturers announced larger turbine platforms, and throughout the industry, production facilities were put in place for a new generation of blades, towers, nacelles, substations and the foundations needed to support them.

However, the market was still new. Some suppliers were reluctant when investing in production facilities and sought to secure their returns quickly. This meant a premium was generally required for the first farm in an area, or for the first farms using a new and larger turbine model to help finance procurement of installation vessels, dockside facilities and factories for large components.

Increasing complexity and cost

Increased project scale demanded new production lines and installation methods and called for turbines, foundations and electrical systems all to be specifically designed for large scale offshore generation. Concurrent with their growing size, offshore wind farms moved further from shore to benefit from stronger winds and in response to public preferences for reduced visual impact.

This added complexity of the new and larger projects, wind farms moving further offshore and the need to build up a new and larger supply chain all meant higher costs. While some of the increase could be offset by mass production and economies of scale, the second phase of offshore wind power saw costs of energy (LCOE) increasing from around EUR 90 per MWh to EUR 167 per MWh, with some projects going even higher.

Highlight:

Bulk purchasing

In 2009, Ørsted entered into a framework agreement with Siemens to supply up to 500 of its newly developed 3.6MW turbines. It was the largest single order for offshore wind turbines to date and provided a base for investment in production facilities for Siemens, while delivering procurement cost synergies for Ørsted's future offshore wind energy projects.

In sum

Key political drivers	• Emerging political demand for climate action and new EU targets • More countries implement policies to promote and accelerate offshore wind energy build-out
Key industry developments	• Increased scale and complexity without a firm supply chain in place increases costs • Operations and maintenance by specialised vessels. Helicopters used routinely • Turbines growing from 2.3 up to a typical 3.6MW
Markets	Denmark, United Kingdom, Sweden, the Netherlands, Finland, China, Belgium, Germany
Market volume	6.4GW
Annual industry investment	~ EUR 2 bn
Typical project size	~100MW
Global deployment rate	~ 1 turbine / 2 days
Cost (LCOE)[3]	EUR ~90-167 per MWh

Example of wind farm from this phase

London Array

Market	UK
Construction	2011-2013
No. of turbines	175
Total capacity	630MW

560,000

London Array powers 560,000 UK homes

2012-2017
Driving down costs

On one hand, by 2012, the ambitious national build-out policies had created a dedicated offshore wind energy industry. Developers were learning and generally completing projects with fewer delays and on budget.

On the other hand, in the light of austerity policies following the financial crisis, it became clear that costs for offshore wind energy had to be reduced to ensure continued political support.

Governments and industry entered into a dialogue to outline the possibilities and prerequisites of cost reductions. In the UK, Ørsted was first to propose an ambitious cost reduction target in 2012 of driving down the levelised costs of offshore wind energy to EUR 100 per MWh by 2020, in effect setting an ambition to cut the cost by roughly one third. The UK Government set a similar target of GBP 100 per MWh.

This GBP 100 per MWh target was later adopted as an industry-wide target in the UK.

Cost reduction programmes

As market volume increased, new suppliers of turbines and other components entered the market, and competition to offer the best and most cost-effective solutions increased. Both industrial suppliers and project developers worked hard to optimise energy production and reduce their costs.

Developers individually sought to develop their competitive edge, but in some areas also joined forces to reduce costs collectively through industry-wide innovation. For instance, through programmes such as the UK-based Carbon Trust Offshore Wind Accelerator, which was jointly funded by the main developers of offshore wind energy, the sector aimed to advance best practice, overcome market barriers and reduce costs.

Lighter foundations – lower cost

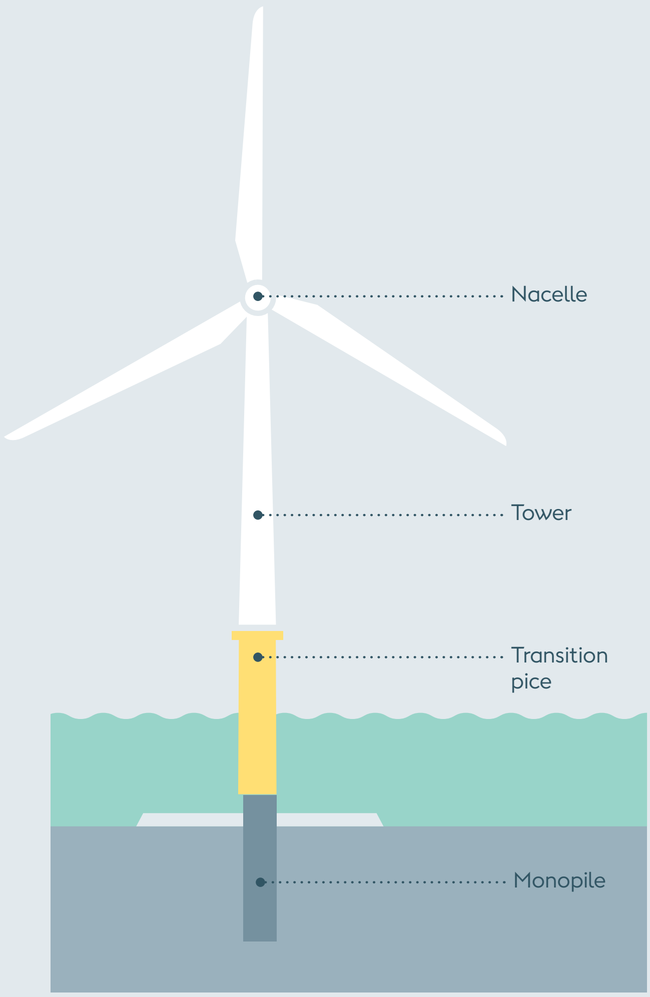
The monopile is the most common offshore wind turbine foundation today, supporting more than 80% of all installed turbines.

Initially, the industry leveraged design principles developed for the US oil and gas industry in the 1970s and 1980s.

In 2013, Ørsted – together with 10 major industry partners and three universities – initiated the so-called PISA study to develop new design principles for monopile foundations.

In 2016, the study resulted in new design models, enabling foundations using significantly less steel. This new design made foundations cheaper to produce, transport and install – yielding improved economics for offshore wind farm development.

As experience with machinery and materials generally grows, new opportunities for optimisation emerge and costs can be reduced even further. This is the case for foundations as for other components such as towers, electrical systems and turbines.



For turbine manufacturers, the drive to reduce costs was a strong incentive to develop larger turbines with longer blades and higher output – a particularly important development, as larger turbines mean fewer installations, fewer foundations and fewer units to service, all leading to reduced costs.

The increased competition transformed the industry. All along the offshore wind energy value chain, processes were streamlined, turbines and other components became standardised, and remote monitoring and simulation was being implemented. All of which helped reduce costs.

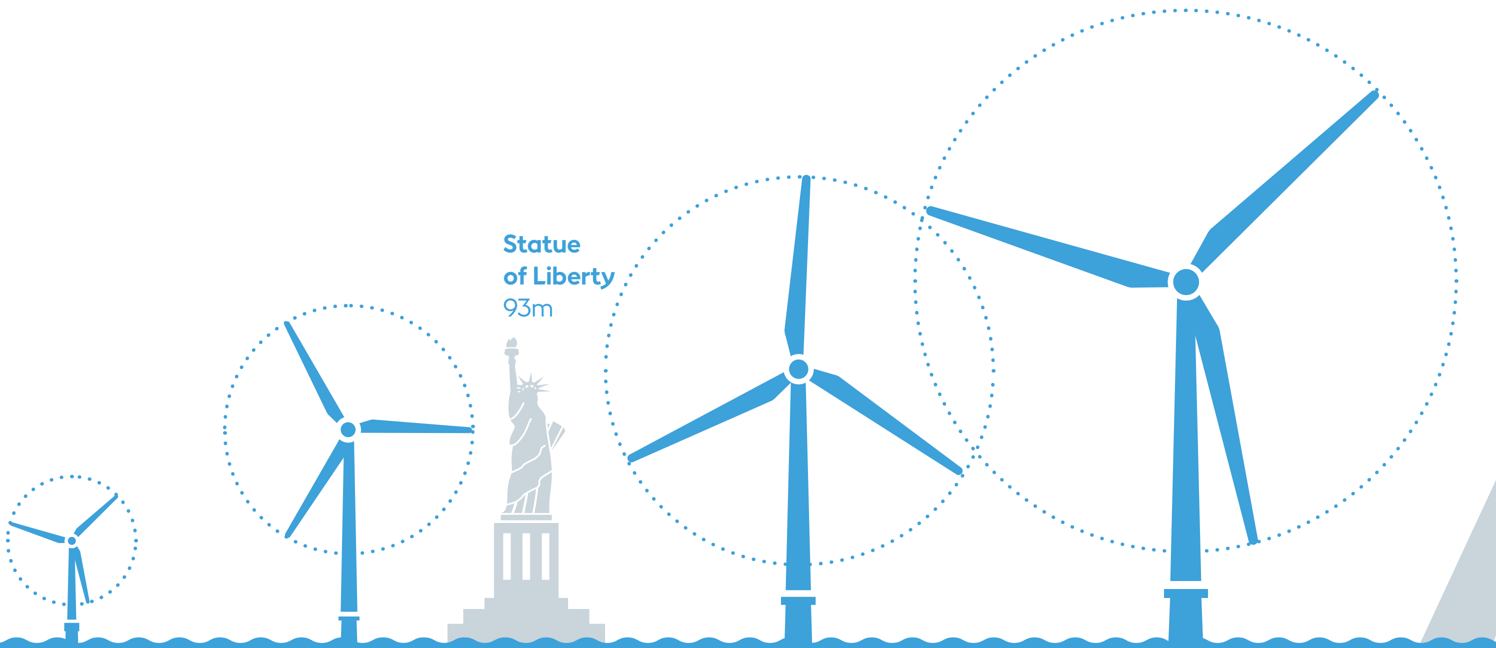
From 2012 and for the next couple of years, turbine manufactures launched new turbines, reaching 6, 7 and even 8MW – effectively quadrupling the 2.0MW-turbines installed in 2002 at Horns Rev 1 in Denmark. To put this scale into perspective, a single 8MW turbine can cover the electricity demand of more than 7,000 UK households.

Policy framework increases competition

In 2013, the UK government carried out an important reform of the electricity market. Until then, renewable energy had been promoted through the Renewables Obligation Certificates (ROCs), whereby renewable energy

The evolution of offshore wind farms 1991-2021

Approx. number of UK homes powered



1991
Vindeby
0.4MW
Height 54m
200

2000
Middelgrunden
2MW
Height 102m
1,500

2013
London Array
3.6MW
Height 147m
3,100

2017
Burbo Bank Extension
8MW
Height 195m
7,100

producers would receive certificates for their generation, to be sold to utilities to cover their mandated quota. Instead, the government wanted to strengthen competition through auction rounds, while increasing security for the projects with a guaranteed strike price. Ultimately, the governmental decision, in 2013, to shift to Contracts for Difference (CfD) was instrumental in reducing the cost of build-out.

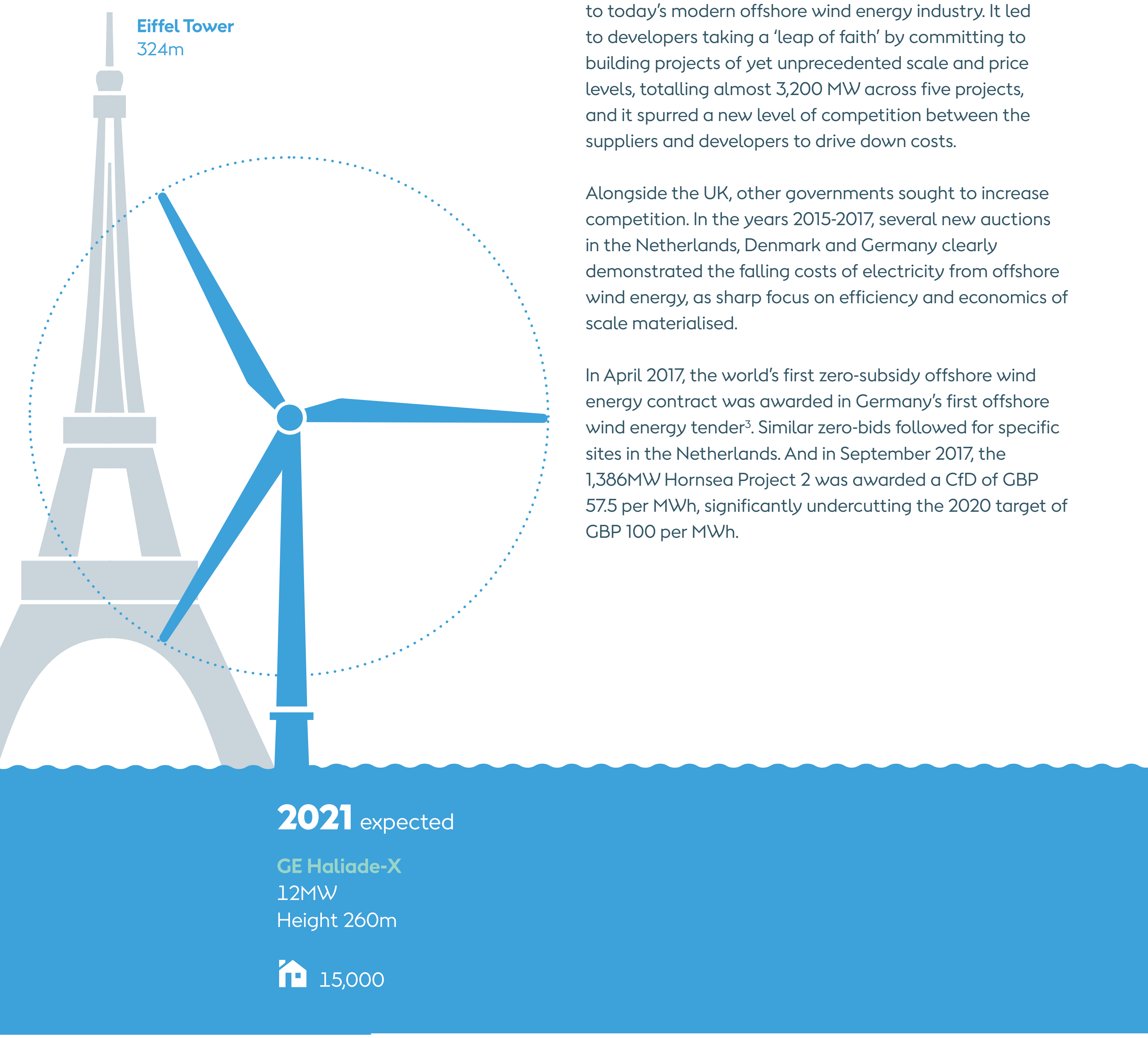
This change to a new support regime risked inhibiting the industry's momentum given the uncertainty the transition period which could have resulted in an investment hiatus.

To counter this, the FID enabling contracts scheme was put in place, offering advanced projects a CfD, conditional on the market reform being ratified. This enabled selected projects to proceed with development and proved of paramount importance in securing an uninterrupted build-out rate, thereby underpinning the industrial build-up.

The reform was an important milestone on the journey to today's modern offshore wind energy industry. It led to developers taking a 'leap of faith' by committing to building projects of yet unprecedented scale and price levels, totalling almost 3,200 MW across five projects, and it spurred a new level of competition between the suppliers and developers to drive down costs.

Alongside the UK, other governments sought to increase competition. In the years 2015-2017, several new auctions in the Netherlands, Denmark and Germany clearly demonstrated the falling costs of electricity from offshore wind energy, as sharp focus on efficiency and economics of scale materialised.

In April 2017, the world's first zero-subsidy offshore wind energy contract was awarded in Germany's first offshore wind energy tender[3]. Similar zero-bids followed for specific sites in the Netherlands. And in September 2017, the 1,386MW Hornsea Project 2 was awarded a CfD of GBP 57.5 per MWh, significantly undercutting the 2020 target of GBP 100 per MWh.



3. The contracts do not include transmission assets, which are provided by German and Dutch transmission system operators, respectively.

Research and standardisation

The historic advancements within the offshore wind sector is owed to the effort of both public and private research, forming of partnerships to address specific challenges, and to governments working with academia and industry to enhance/accelerate the technological development. This has led to both the technology of a modern offshore wind power plant and shared industry norms and standards, enabling economies of scale.

From its outset, offshore wind technology relied heavily on advances made in the much larger onshore market, which had emerged in north-western Europe following governments' effort to diversify energy production after the two major oil crises of the 1970's.

When market volume grew, so did offshore wind energy as a specialised research area. Initially, the focus was to develop technical norms and standards for offshore wind turbines and to ready the turbine models for harsh offshore conditions.

As offshore wind projects reached utility scale in the early 2000's, the research scope expanded to the entire offshore wind power plant. Norms and standards were now developed at farm level. Research in seabed, waves and wind conditions enabled improved foundations and farm layout to increase yield. And by 2014, the first projects using dedicated offshore wind turbine platforms were commissioned, following years of research and development.

Today, research and development projects on grid integration and sector coupling have emerged, as energy markets are increasingly dominated by renewable generation.

Development through pragmatic collaboration

Industrial players have generally been pragmatic in partnering together and with research institutions on a project-by-project basis. And to optimise resource allocation, industry associations and governments established fora to identify strategic challenges in order to target public and private research spending towards overcoming these challenges. This coordination helped creating a pull demand for innovation and facilitating technologies as they moved towards commercialisation.

Long-term commitments by governments to underpin the research in offshore wind also allowed for common large-scale test facilities, where components and even entire turbines could be tested in full scale.

In sum

Example of wind farm from this phase

Walney Extension

Market	UK
Construction	2017-2018
No. of turbines	87
Total capacity	659MW

590,000

Walney Extension powers 590,000 UK homes

Key political drivers	• Governments and industry shift focus to bringing down costs • Renewed governmental support key to developing the industry • In the UK, the FID enabling contracts scheme allows developers to place large orders for upcoming projects
Key industry developments	• Industrialisation of supply chain and cost-cutting programmes • Flexible service operation vessels introduced, O&M increasingly done remotely, using drones, cameras and new digital technologies • Turbines growing from a typical 3.6 up to 8MW
Markets	Denmark, United Kingdom, Sweden, the Netherlands, Finland, China, Belgium, Germany, Taiwan, Japan, USA
Market volume	12.3GW
Annual industry investment	~EUR 10 bn
Typical project size	~400MW
Global deployment rate	~1.5 turbines / day
Cost (LCOE)	EUR 167-65 per MWh

Since 2018
Going global

The cost of energy from new offshore wind energy farms is now lower than new-build coal, gas or nuclear power plants in Europe, and the lead time for offshore wind in mature markets is typically shorter. This makes offshore wind energy a competitive option to policymakers seeking to bolster their national efforts to decarbonise. A fact which can be seen directly in national build-out plans and future scenarios.

In Europe, for instance, national policy targets add up to more than 70GW by 2030. And in late 2018 the European Commission proposed a strategic roadmap for a European net-zero carbon economy by 2050, including up to 400GW of offshore wind power – more than 20 times today's installed base. And in fact, the economically feasible potential for offshore wind power in north-western Europe exceeds 600GW – enough to cover more than 80% of the EU's power demand[4].

Europe is no longer alone

But the most illustrative element of offshore wind energy's amazing development is its rapid globalisation. Apart from China, which for some years now has invested in the technology, north-western Europe has long been the only home of offshore wind energy. This is changing rapidly, as governments in India, Japan, South Korea, Taiwan and the US are all deploying or looking to deploy offshore wind energy at large scale. And more countries are expected to join in the future.

Countries looking into offshore wind energy for the first time can benefit from the experience of both developers

Technical highlight:

A floating hotel for technicians

When installing or servicing an offshore wind farm, every hour counts. Downtime or delays equal missed opportunity to generate energy.

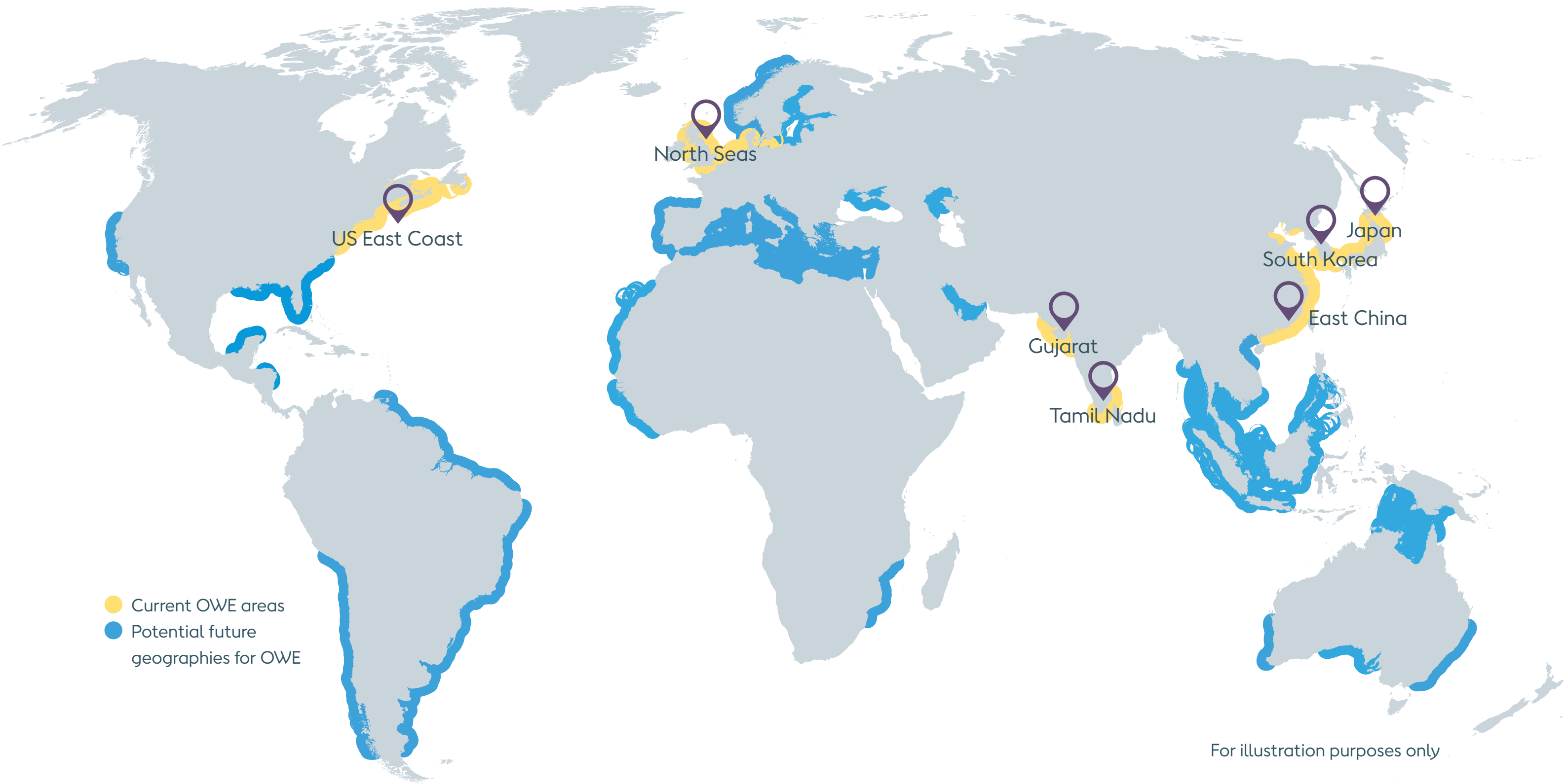
As offshore wind power plants move further from the coastline, sailing technicians to and from the wind farm takes up more time. And going by helicopter is expensive.

But as offshore wind farm clusters are beginning to form, new options present themselves. In Germany, for instance, Ørsted operates two permanent service operations vessels – one for construction and one for servicing the Borkum Riffgrund 1 & 2 and Gode Wind 1 & 2 farms.

The vessels can accommodate crew living offshore for up to two weeks, saving precious travel time from shore, thereby cutting costs significantly and improving working conditions.

4. BVG Associates for Wind Europe, 2017. Offshore wind energy potential in NW Europe with a cost equal to or lower than EUR 65 per MWh by 2030.

Global offshore wind energy
Current and potential areas



and governments from those first generations of offshore wind energy. They are 'greenfielding' a mature technology.

And with regional political demand for renewables boosting market volume, operational synergies and economies of scale can be achieved far faster than historic European developments. For instance, by designating larger areas for multiple neighbouring projects with a well-known timeline, the utilisation of ports, vessels and other facilities may be optimised.

This can be seen, for example, on the east coast of USA and in Taiwan. Here, policymakers work on creating a political framework and a mass of projects to secure economies of scale and attract industry developers.

However, countries which develop their first offshore wind farms will generally see somewhat higher project costs than in north-western Europe, until a supply chain and a pipeline of projects are in place. When a market reaches 'critical mass', regional investment and localisation of the supply chain can reduce costs. This typically occurs when projects totalling a few GW are under way[5].

With the global build-out rate of offshore wind energy accelerating further in the years to come, the decline in cost is expected to continue so that offshore wind energy will continue to outcompete fossil fuels across the globe.

Key questions when opting for offshore wind energy

Modern offshore wind farms are massive infrastructure projects, encompassing years of development, billions of EUR investments and a plethora of suppliers and sub-suppliers.

This takes diligence from governments and industry. For policymakers and regulators considering expanding or including offshore wind energy in their country's energy mix, the first task is to consider what the political goals are, and then to design a political framework to meet this end. In this deliberation, several key questions emerge.

5 BNEF (2018)

Four of the most important ones are:

How to reach critical mass of the build-out?

A credible pipeline of opportunities makes it attractive for the industry and developers to invest locally at scale, as future return on investments is more certain. This can also lower the overall cost of the build-out if a critical mass of projects to localise parts of the supply chain is attained. Of course, this requires patience to set out and stick to the build-out plans.

Which role can developers and other actors play?

Developers are increasingly expanding the scope of their competences to gain a competitive advantage. This can be leveraged by exposing more elements of an offshore wind farm to competition. For instance, by letting developers target multiple potential sites, or by including the transmission system up to the onshore grid interface point in a tender to make developers compete for the lowest overall cost of the project.

How to design the right support scheme?

Long-term fixed price off-take contracts reduce risk significantly for the developers and thereby lower the cost of energy. Opting for Contracts for Difference (CfDs) or a power purchasing agreement is therefore a tool to reduce costs. The choice of contract defines the risk profile for developers, which again impacts cost of energy, as higher risk demands higher return.

How to capture a potential for regional coordination of build-out plans?

Depending on geography and existing infrastructure, offshore wind farms can be planned in cooperation between more utility service areas and even countries. This way, the utilisation of supply and infrastructure can be optimised on a regional basis, and offshore wind power can even be deployed in connection with other infrastructure projects, lowering total cost.

In sum

Example of wind farm from this phase

Bay State Wind

Market	US
Under development	-
No. of turbines	-
Total capacity	up to 2,000MW

1.25 million

Enough to power 1.25 million Massachusetts homes

Key political drivers	• Costs have come down • Offshore wind energy is going global as more countries turn to offshore wind power as a means to transform their power system
Key industry developments	• Offshore wind farm clusters effectively reduce • operation and maintenance costs • Floating foundations being piloted • Turbines growing from 8 up to 12MW, with expectations for even larger turbines
Markets	Denmark, United Kingdom, Sweden, the Netherlands, Finland, China, Belgium, Germany, Taiwan, Japan, USA, South Korea, Ireland, France, Poland, India + 
Market volume	100+GW
Annual industry investment	+ EUR 80 bn
Typical project size	~800+MW
Global deployment rate	2+ turbines/day
Cost (LCOE)	EUR <61 per MWh


BX
M05
BX
M05

Milestones

1991
Denmark
Vindeby, 5MW – The world's first offshore wind farm.

1998
Denmark
Political requirement to build five offshore wind farms of each 150MW before 2008. This results in construction of the first large-scale offshore wind farm in the North Sea Horns Rev 1 and the Nysted offshore wind farm south of Lolland. The remaining three offshore wind farms were not progressed further.

2000
Germany

New German Renewable Electricity Law continues support for offshore wind energy through fixed payments per kWh of output over 20 years.

2001
UK
The Crown Estate announces award of 18 sites with a capacity of up to 1.5GW in Round 1.

The Renewables Obligation is one of the main support mechanisms for large-scale renewable electricity projects in the UK.

2002
UK
First UK wind farm in Blyth.

Denmark
Horns Rev 1, 160MW – The first modern utility scale offshore wind farm.

2010
Germany
First large-scale offshore wind farm in Germany – Alpha Venus.

2011

Germany

In the wake of the Fukushima nuclear power plant disaster, Germany announces plans to shut down all nuclear plants by 2022 and to double the country's share of renewable energies, including offshore wind energy.

2012

UK

London Array world's largest windfarm with 175 turbines at 630MW.

UK

UK government and industry target of GBP 100 per MWh by 2020.

2013

UK

Electricity Market Reform; introduction of CfD mechanism.

2014

UK

CfD Allocation Round 1 announced.

2016

UK

First commercial deployment of 8MW turbine at Burbo Bank Extension.

Paris agreement signed following United Nations Climate Change Conference in Paris.

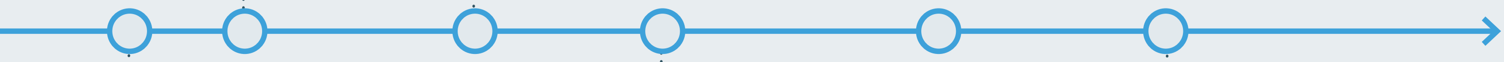
The Netherlands

Ørsted wins Dutch tender for Borsele 1 and 2 offshore wind farms of 700 MW total.

2017

Germany

First German offshore wind energy auction bid marks EUR 0 per MWh subsidy.



What we can learn from the offshore wind energy cost out journey

Less than 30 years after Vindeby started to deliver energy to 2,200 Danish households in 1991, offshore wind power has become a competitive, scalable and powerful source of renewable energy. Today, offshore wind power, together with onshore wind and solar power, is becoming the cornerstone in the quest to create a world that runs entirely on green energy.

With costs decreasing, renewable power production makes electrification an increasingly attractive option, enabling large scale phase out of fossil fuels in transport, heating and industry. And as electrification becomes increasingly feasible in more sectors, the energy system will also be able to utilise even more energy from renewable power sources.

In a fully renewable energy system, other technologies will play a role alongside solar and wind power. On the supply side, renewable energy sources such as biogas and advanced biofuels must be utilised. Energy storage solutions such as batteries or hydrogen must be developed and deployed. And on the demand side, large-scale heat pumps and electric cars can make use of growing renewable power generation. These technologies are at different stages of their development, however, with none of them being as mature as solar and wind energy are today.

All have the potential to become competitive and scalable green solutions that can contribute significantly to a world fully powered by green energy. But it requires a well-orchestrated collaboration between governments and industry. And to this end, the offshore wind energy experience is instructive.

The positive loop

By creating clear and credible market volumes for offshore wind energy, and by sticking to ambitions in times of economic hardship, policymakers allowed for scale. The stable framework conditions made it possible for the industry to invest, build, learn and thereby innovate across the value chain, which in turn lowered costs.

And every cost reduction by industry in term enabled the increase of political ambitions for offshore wind development, creating even more market volume, and stronger incentives to invest. Moreover, economies of scale allowed for even further technological and industrial developments, locally and regionally and further cost reductions.

For offshore wind energy, the concerted effort between public and private actors spurred a self-reinforcing loop, leading to an accelerated roll-out of a new green technology. That is how innovation happens and how new energy technologies are brought to life.

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