



Teknologi- og kostnadsutvikling

– fagrapport til strategisk konsekvensutredning
av fornybar energiproduksjon til havs

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Teknologi og kostnadsutvikling

Fagrappport til strategisk konsekvensutredning av
fornybar energiproduksjon til havs

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Forord

Ved Stortingets behandling av St.meld. nr. 34 (2006–2007) *Norsk klimapolitikk* ble det oppnådd enighet om at det skulle lages en nasjonal strategi for elektrisitetsproduksjon fra vindkraft og andre fornybare energikilder til havs. Loven ble vedtatt i Stortinget 23. mars 2010 og trådte i kraft 1. juli samme år. Av havenergiloven § 2-2 fremgår det at etablering av fornybar energiproduksjon til havs kun kan skje etter at staten har åpnet bestemte geografiske områder for søknader om konsesjon. Det fremkommer også av samme paragraf at før havområder kan åpnes for søknader om konsesjon skal det gjennomføres konsekvensutredninger i områdene.

Denne rapporten er en av 13 fagutredninger utarbeidet i forbindelse med ”*Havvind – strategiske konsekvensutredninger*” (NVE rapport 47). Fagrapporten er utarbeidet av Multiconsult for NVE.

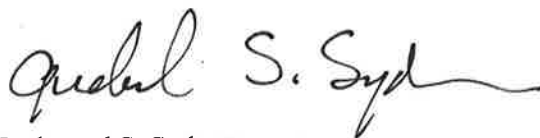
Multiconsult er ansvarlig for innholdet i rapporten.

NVE ønsker å takke fagutredere for et godt samarbeid gjennom hele prosjektperioden.

Oslo, desember 2012



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Fagrappport til strategisk konsekvensutredning av fornybar energiproduksjon til havs – teknologi- og kostnadsutvikling

*Technological and Cost Development Trends of
Renewable Offshore Energy Production*

Date of publishing: 07.08.2012

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About Multiconsult: Multiconsult is one of Norway's leading consulting companies with more than 1400 employees spread in 20 offices in Norway and abroad. The company is involved in a broad range of business areas including: Energy, Oil & Gas, Industry, Buildings & Properties, Environment & Natural Resources, Transportation and Infrastructure. Multiconsult has taken a lead role in supporting offshore wind developments in Norway and has expanded its offshore wind advisory and engineering overseas. The company has built its know how through 100 years of engineering in the power sector combined with 40 years of offshore oil and gas track record.

Contents

Contents	3
Glossary of useful terms	5
1 Executive summary	6
2 Introduction	9
2.1 Background	9
2.2 Study objectives and methodology	9
2.3 Methodology	9
2.4 Limitations & Exclusions	10
3 Technology and cost development trends	11
3.1 Introduction	11
3.2 Offshore wind market and project development trends	11
3.3 Turbine trends	14
3.4 Support structures trends	15
3.5 Other technology trends	17
3.5.1 Assembly and installation	17
3.5.2 Electrical infrastructure	17
3.5.3 Operation and maintenance	18
3.6 Supply chain trends	18
3.7 Cost trends	19
4 Technical assessment of the 15 Zones	25
4.1 Background and Norwegian Context	25
4.2 Methodology	26
4.3 Attractiveness criteria	27
4.3.1 Technical attractiveness criteria	27
4.3.2 Economic attractiveness criteria	28
4.3.3 Take aways	29
4.4 Site definition	30
5 Technical review	31
5.1.1 Technical attractiveness	33
6 Economic assessment of the 15 zones	35
6.1 Methodology	35
6.2 Assumptions for the cost model	37
6.2.1 Technical assumptions	37

6.2.2	Cost assumptions	39
6.3	Results of the cost model	42
6.3.1	CAPEX	43
6.3.2	OPEX	43
6.4	Sensitivity	46
6.5	Economic attractiveness of the 15 zones	49
7	Technical and economic assessment - summary	50
8	Conclusions and recommendations	53
8.1	Summary of findings	53
8.2	Takeaways for the Spatial planning and SEA	55
8.2.1	Scope and selection / attractiveness criteria of an offshore wind site	55
8.2.2	Implications for environmental impact assessments	56
8.3	Recommendations to NVE	56
9	References	58
10	List of Figures	59
11	List of Tables	60
	APPENDICES	61
	Appendix 1: Comparative overview of the 15 zones	62
	Appendix 2: Detailed results of the economic assessment	92
	Appendix 3: More Descriptive Overview of Technology and cost development trends in Offshore Wind	93
	Appendix 4: Detailed overview of used assumptions	94
	Appendix 5: Source of GIS data	95
	Appendix 6: About the authors & contact information	96

Glossary of useful terms

Capacity factor - The net capacity factor (expressed in %) of a power plant is the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full nameplate capacity the entire time. To calculate the capacity factor, take the total amount of energy the plant produced during a period of time and divide by the amount of energy the plant would have produced at full capacity.

CAPEX – Capital expenditure, also equivalent to the initial investment cost.

LCOE – Levelised Cost of Energy in NOK/kWh corresponds to the average lifetime levelised electricity generation cost

Lifetime – Number of years of operations of the offshore wind farm. Typically of 20 years for current project, it could be extended to 25 to 30 years in the years to come.

Load factor – see Capacity factor

MW – Megawatt

MWh - Megawatthour

OPEX – Operational expenditure include operational and maintenance costs.

SEA – Strategy Environmental Assessment

Spatial planning – In the context of this report, spatial planning is a tool that brings together multiple users of the ocean – including energy, industry, government, conservation and recreation – to make informed and coordinated decisions about how to use marine resources sustainably.

1 Executive summary

This report provides an overview of latest trends and outlook for offshore wind in general and specifically assesses the 15 designated zones for offshore wind power development in Norway.

Key takeaways for understanding overall trends in offshore wind

Offshore wind market is taking off. This means that developing offshore wind farms is becoming a less costly and more “conventional” business. In 2011 a total of 140 GW of projects at various stages of planning were identified throughout Europe. A massive wave of construction is expected to take place over the 2015-2020 period thanks to simultaneous market take-offs across Europe (UK round 3, Germany EEZ developments in North and Baltic Seas, France, Netherlands, Denmark among others) – as well as in China and North America.

Most future offshore wind farms will be installed in deep waters. Most installed offshore wind farms are located in waters below 25m. Installation of wind farms in 10-35m water depth is expected up to 2015; with water depths of 20 to 50 meters to be exploited in a 2020 perspective. In a 2030 perspective, larger projects in the 30-70m range using bottom fixed and shallow floating technologies would continue to be built while the deep floating market could accelerate in water depths up to 300m.

Offshore wind power technology will be completely different from onshore wind power. While the maximum onshore turbine capacity now seems to stagnate around 3MW, the capacity of offshore models is increased rapidly: 6MW units are now being deployed. Developing larger units leads to cost reductions and accordingly 10-15MW units are already on the drawing board. The introduction of conventional technologies, such as vertical axis turbines, is expected within 2030. This would have important consequence on environmental impacts as we understand them today.

Of the two basic types of support structures: bottom-fixed (available now) and floating (disruptive technology) – the latter is expected to be competing on cost with the former already in 2020. However there is no universal standard support structure solution for offshore wind as technology choice is site specific. To date, technology selection is essentially driven by water depths and soil conditions. However, future support structure technology will be increasingly based on the overall cost performance of the supply and installation of the foundation and installation of the turbines.

Larger offshore wind farms further away from shore require different electrical infrastructure configurations and systems. All wind farms today employ an AC collection system, and most commonly HVAC for transmission to shore. Larger wind farms further offshore apply HVDC. DC collection and transmission solutions are also under development.

Larger offshore wind farms further away from shore will have on-site installed living and maintenance platforms. Access to such sites from distantly located harbors is highly dependent on weather window and increases O&M costs unless an on-site platform is installed. Benefits from such a platform quickly outweigh its installation cost as it could additionally serve as a substation, on-site storage, living quarters – and in case of using a mothership instead of a fixed platform – even a mobile crane for more extensive repairs.

The Norwegian offshore wind supply chain has gained competitive advantages from its world leading offshore and energy experience. It has the capability to serve the market but its availability will highly depend on the activity level in the Norwegian offshore sector in the years to come. Technological and operational expertise from offshore oil and gas is commonly regarded as the main competitive advantage of Norwegian companies in the offshore wind industry. In the case of shallow water bottom fixed offshore wind farms, foreign supply chains might be suited while deep water areas, floating in particular, are likely to rely on Norwegian capabilities.

Levelised cost of energy is expected to decrease and could be even lower than 1000 NOK/MWh in Norway by year 2020, owing to good wind resources. The average electricity cost of energy (LCOE) for offshore wind has been estimated for a typical project of 500MW in 35 meters water depth at 1370 - 1480NOK/MWh depending on the wind conditions. All offshore wind stakeholders recognize that the current high level of offshore wind cost can only last for a temporary phase as support schemes are unlikely to be sustained over the longer run. In a 2020 perspective, the delivery of the UK 2020 ambition in offshore wind requires, according to market players, a decrease of 30% from current cost levels down to approximately 1000 NOK/MWh.

Comparative overview of the 15 Norwegian zones

The bathymetry in Norwegian waters differs from most other countries in Northern Europe where offshore wind farms are planned, under construction or in operation. The water depths in Norway are highly variable, and except for some parts of the Southern North Sea there are limited shallow areas for bottom-fixed foundations. When it comes to areas with potential for floating wind turbines, the possibilities of offshore wind deployment are much larger.

The drivers for ranking the 15 zones are “distance to grid connection point” and “average depth within the site”. Based on this, the report has grouped 15 zones into three: “near shore - shallow water”, “far offshore-shallow water” and “far offshore - deep water”. “Nearshore - shallow water” zones resemble current developments in Northern Europe. Two zones are “far offshore / shallow waters” in relatively similar conditions as deep zones of the “UK Round 3” such as Doggerbank. Four zones in “far offshore- deep water” will require floating technologies and are thus largely subject to technology risks.

Economic overview of the 15 Norwegian zones

Performed calculations indicate a CAPEX range of 26-31 million NOK per installed MW, with higher CAPEX in far offshore floating sites. Depth of the zone does not seem to be a major driver of CAPEX in such offshore locations. Lowest development costs per MW would be closest to shore, and here depth makes a difference: turbines in relatively shallow waters cost less.

OPEX ranges from 510 to 570 thousand NOK per installed MW. In most zones, OPEX would be at the higher end of the range. There are two reasons for offshore zones to have competitive O&M costs vis-à-vis near-shore zones: (1) all far offshore zones are 1000MW, which allows for economies of scale compared to a 200MW zone – despite increased investments in HVDC conversion station, thicker export cable etc; (2) all offshore zones have an on-site living and maintenance platform.

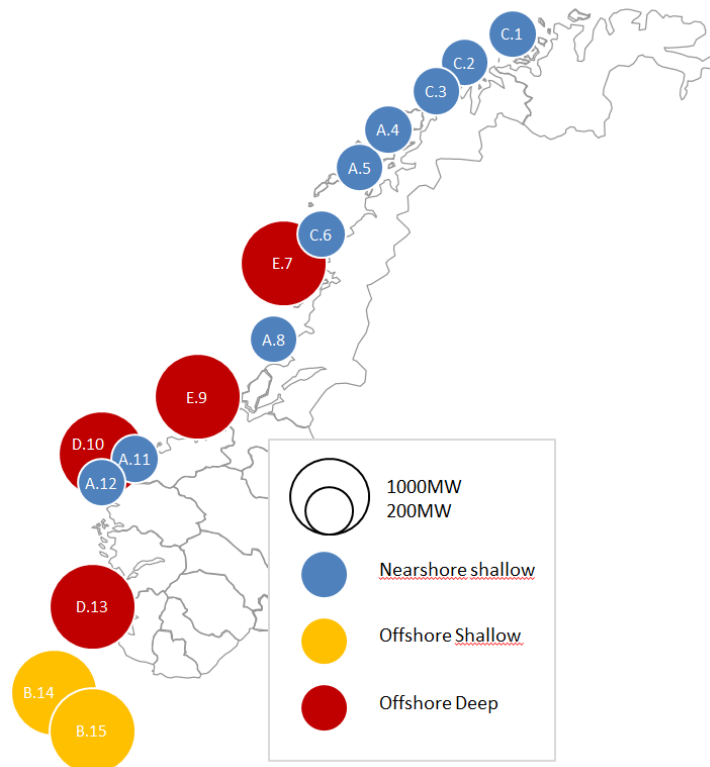
The calculated levelised cost of the 15 zones ranges between 900-1200 NOK/MWh, generally being higher in smaller near-shore zones. Levelised cost of energy considers both lifetime project costs (CAPEX and OPEX) as well as lifetime production. The preliminary analysis conducted under the mandate of this report shows that the near shore zones available for development are less preferred by the investor in year 2020 as far offshore zones have more benefits which outweigh the higher upfront investment costs. Namely, higher production factor is a direct determinant of lower LCOE, whereas depth and distance to shore have no direct correlation to end-costs.

Highest impact on levelised cost estimation would come from expanding the lifetime of wind farm from 20 to 25-30 years and choice of discounting methodology. All base case values used in this report to calculate levelised costs are those believed to be most realistic. The sensitivity analysis of levelised cost performed as part of this report shows that the 860-1030 NOK/MWh range is realistic, although subject to limitations.

Total ranking of the 15 Norwegian zones

The absence of time horizon and detailed data on the zones make it difficult to address the technical and economic attractiveness for each zone. Assuming a base case construction in 2020, a simplified technical and economic analysis provides a comparison and attractiveness ranking of the 15 areas.

The final attractiveness results are summarized in the figure below. The 15 areas have been segmented into 5 categories: in descending order of attractiveness from A to E.



The 15 offshore wind zones and attractiveness ranking
 (Category A is the most attractive while E less attractive)
 Source: Multiconsult, 2012

Suggestions for moving forward

Moving forward, Norway must develop a strategy and roadmap for offshore wind which brings together a vision of the exploitation of its offshore wind resources and the realization of the value creation potential from an offshore wind export market already kicked off. Several offshore wind specific activities must be kicked off well in advanced and executed in a timely manner so as to deploy offshore wind in Norway. Considering the technology and economic uncertainties related to offshore wind, identifying zones to prioritize, defining an optimal spatial planning or implementing a development framework would benefit from the development of a first offshore wind pilot plant in Norway.

2 Introduction

2.1 Background

An assessment of defining suitable areas for offshore wind farms in Norway was carried out in 2010 by a governmental group comprising of the Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Directorate of Nature Management (DN), the Norwegian Directorate of Fisheries (FD), the Norwegian Coastal Administration (KV) and the Norwegian Petroleum Directorate (NPD). The inter-directorate group defined 15 zones to be covered by a strategic environmental impact assessment, and the result of the analysis was presented in the report *Offshore Wind Power in Norway* (2010)(NVE et. al, 2010).

In January 2012, Multiconsult was contracted to deliver a study on the offshore wind technology and cost development trends as a means to assess and compare the 15 zones and rank them according to technical and economic attractiveness.

This report presents the results of Multiconsult's study carried out in 2012.

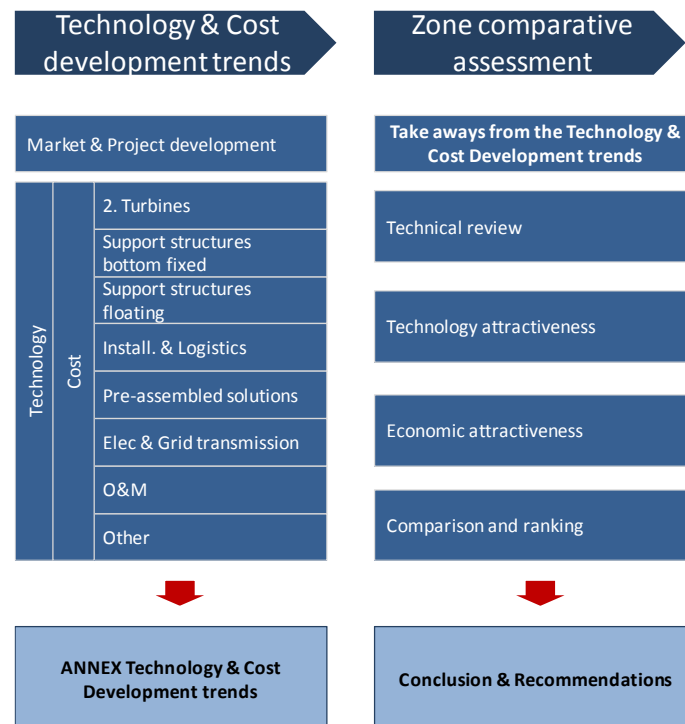
2.2 Study objectives and methodology

Considering the absence of time horizon for deployment of offshore wind in Norway, special attention must be given to the description of the outlook for technology and cost trends that will apply in this case. This report assesses the status and trends of the offshore wind industry in terms of technology and costs and identifies key implications for Norway's offshore wind spatial planning and strategy. The analysis provides the rationale for the assumptions considered for the technical and economic assessments of the 15 areas. The report also indicates data gaps, brings guidelines to overcome these as well as preliminary recommendations regarding spatial planning and offshore wind strategy.

2.3 Methodology

The illustration below presents the overall methodology of the assessment. The research, analysis and compilation of the report were performed from February to April 2012, resulting in a presentation workshop in May 2012. In addition to an in-depth desktop market research, attendance to leading European offshore wind conferences and discussions with key offshore wind players were carried out:

- Turbine manufacturers such as SWAY turbine
- Bottom fixed structure support: OWEC Tower, Seatawer, Windsea jacket (Straum)
- Floating structure support: Hywind (Statoil), Windfloat (Principle Power), Blue H, Windsea floater (Straum)
- Contractors/Installers such as NorWind Installer
- Developers and investors such as Statkraft, Statoil, Vestavind offshore, Lyse
- Financial entities such as Scatec, Export Finance, DNB



This report is an updated version ("REV 1") based on the comments received and information discussed during the workshop held at NVE in May 2012. Major changes include but are not limited to:

- Alignment with net production factor published by StormGeo in "Fagutredning 1"
- More detailed description of how to rank the 15 zones vis-à-vis each other
- Switching of labels "Sørlige Nordsjø I" & "Sørlige Nordsjø II" on all maps

2.4 Limitations & Exclusions

- To date, Strategic Environmental Assessments (SEA) performed in Europe have assessed offshore wind on the basis of conventional turbine technology. This is due to the shorter timeframe for deployment which requires mature technology to be considered in priority. These assessments have therefore not considered in depth the deployment of innovative solutions and disruptive technologies which is of great importance to the Norwegian context. It is thus reasonable to consider the ongoing Impact assessment as a preliminary study ahead of a proper SEA that may be required at a later stage. The study provides an initial characterization of the Norwegian conditions for offshore wind and a high level comparison and ranking of 15 pre-selected areas.
- The report does not aim at giving an exhaustive and detailed state of the art of all different technologies and innovations involved in offshore wind. Rather it focuses on the key trends and their implications on Norway's offshore wind spatial planning and deployment strategy.
- In absence of clear guidelines on the timeline for an offshore wind deployment in Norwegian waters, the report is not aimed at providing precise and restrictive technical recommendations and accurate cost forecast.
- The technical assessment should be considered as preliminary since various site-level data (such as soil conditions) were not available for this study.
- This report does not aim at providing a forecast of costs of offshore wind in Norway by 2020 but to provide a comparative assessment of the costs of 15 zones. Estimating properly the costs of offshore wind requires more detailed information which was not procured during this project.

3 Technology and cost development trends

3.1 Introduction

We explore hereunder technology and economic themes of relevance to the Norwegian offshore wind spatial planning and Strategic Environmental Assessment. A high level description of technology trends is introduced. Key takeaways for the study are indicated.

A broader and more detailed state of the art is available in Appendix 3 as a basis of information for this chapter.

3.2 Offshore wind market and project development trends

After 20 years of relatively slow development, the offshore wind market is finally taking off. As of March 2012, the European Union leads the world with about 4 GW of offshore wind installed. This is only the beginning of a major industrial development. In 2011, a total of 140 GW of projects at various stages of development have been identified throughout Europe as presented in Figure 1 below.

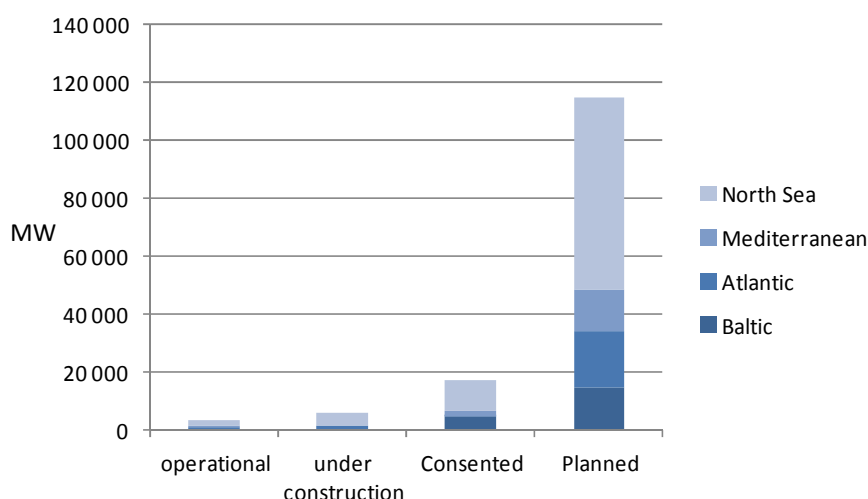


Figure 1. Current European offshore wind project in operation and pipeline. Source: EWEA, 2011

A review of the European National Renewable Energy Action Plans (ECN, 2011) indicates that offshore wind is to play a significant role in Europe's sustainable energy future: by 2020, 12% of the 1217 TWh EU27 renewable energy production is expected to come from about 44 GW of offshore wind. Furthermore EU's "Energy Roadmap 2050" (European Commission, 2011) published late 2011 sets out pathways for an energy sector that is 85% carbon-free by 2050 including a wind power contribution ranging between 32% and 49% of the EU power production. In a recently published plan, Denmark announced the ambitions to build two new offshore wind parks with a total capacity of 1,000 MW by 2020.

Ahead of 2020 targets, a massive wave of construction is expected to take place over the 2015-2020 period thanks to simultaneous market take-offs across Europe (UK round 3, Germany EEZ developments in North and Baltic Seas, France, Netherlands, Denmark among others). Ambitious targets need to be adapted to realistic possibilities, especially in regards to grid constraints or power pooling options. Nevertheless investments are primarily triggered by political willpower and EU's targets send a clear signal to investors.

Outside Europe, new markets will take off in Asia and North America. China alone aims at a cumulative offshore wind installed capacity of 5 GW by 2015 and 30 GW by 2020. Furthermore, a scenario study (Carbon Trust, 2011) forecasts a global cumulative installed capacity ranging between 440 and 1150 GW by 2050.

Challenging project trends - After a decade of exploiting easily accessible sites in shallow water and close to shore, the average project size has been lifted from 60 MW up to typically 300-400 MW today. In 2010, Thanet (300 MW), the world largest offshore wind farm to date, was commissioned in UK but larger projects such as London array (630 MW) and Greater Gabbard (504 MW) are already under construction. The Dogger Bank UK round 3 zone¹ is expected to reach a total capacity of 9-13GW within 2020 through phased deployment of several wind farms.

Most installed offshore wind farms (ref. Figure 2) have been installed in waters below 25m but future projects are located further offshore, in deeper water depths. Earlier projects with favorable sandy and homogenous seabed are progressively replaced by more challenging sites with difficult soil conditions (soft clay or bedrock instead of sand) which may require costly seabed preparation. This implies new design and construction solutions in support structures, installation methods, HVDC transmission technology and remote manned platforms.

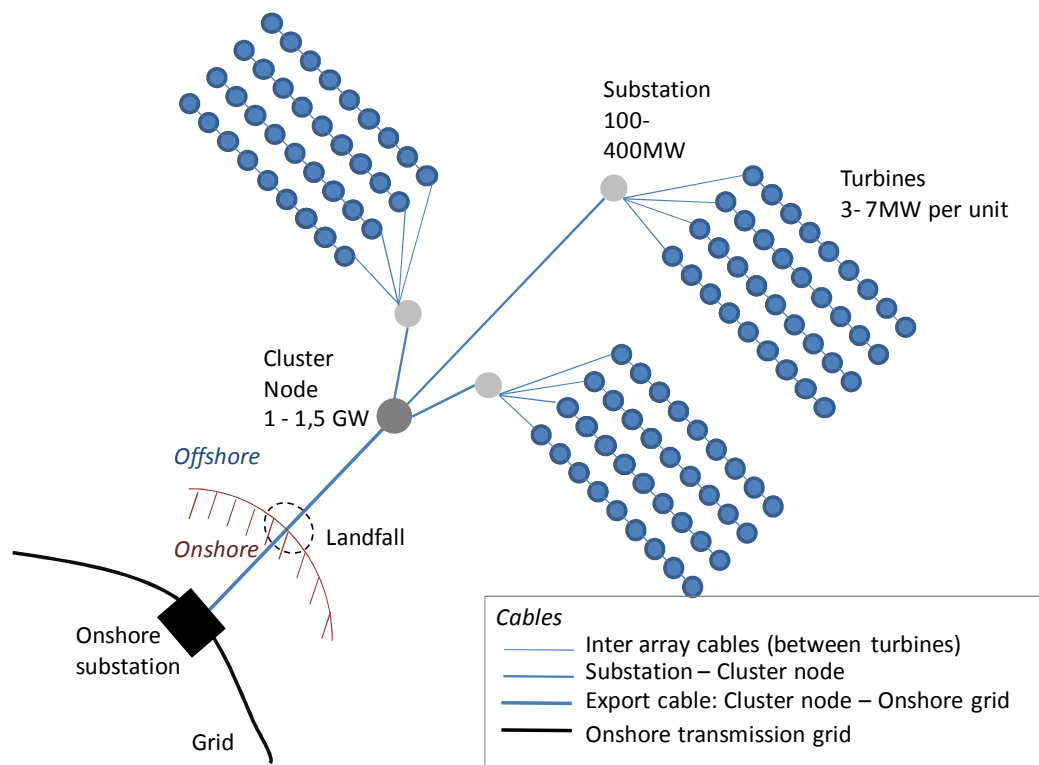


Figure 2. Overview of a typical offshore wind farm cluster (1-1,5GW) in 2012-2015. Source: Multiconsult

Various obstacles need to be overcome in the next five years if Europe is to meet its offshore wind targets (see Figure 3). These are further discussed in Appendix 3.

¹ UK round 3 zones are to be divided in several offshore wind farms



Figure 3. Overview of the key offshore wind obstacles ahead of 2020 ambitions. Source: Multiconsult

Take aways:

- In 2015, offshore wind farms will no longer be developed in 0-10 meter depth and are likely to concentrate on the 10-35 m range. A few bottom fixed projects including deep water pilots and demonstration projects could be built beyond 40m. Possible floating demonstration projects in very deep waters (typically 100-150m where SPAR technologies are optimal) may be constructed.
- Water depths of 20 to 50 meters are expected to be exploited in a 2020 perspective with most of the volume of projects in the 20-40 meter range. Pilot projects for shallow water floaters (semi- submersible or tension-leg platform) could be constructed in the 40-60m range while the first generation of large scale floating offshore wind projects could possibly be built above 100m, not necessarily in Europe (Japan and the USA have already shown interest).
- In the years 2020-25, most sites in the 0-20 meter range could be fully deployed pushing bottom fixed projects in water depths above 20 meters up to 50-60 meters. The first floating commercial projects could then be expected to be deployed in two different water depth ranges using different technologies: 40-60m and deep waters above 100m.
- In a 2030 perspective, large projects in the 30-70m range using bottom fixed and shallow floating technologies would continue to be built while the deep floating market could accelerate in water depths up to 300 (ref. Figure 4).

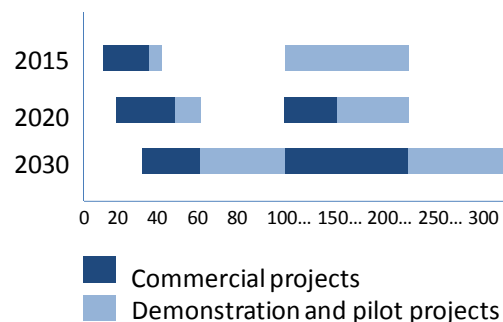


Figure 4. Future project trends: Water depth (m) deployment in 2015, 2020 and 2030. Source: Multiconsult

3.3 Turbine trends

The conventional offshore wind turbine models, based on the 3 bladed, upwind, horizontal axis rotor design were initially developed for onshore purposes. In the latest years, turbines have become specifically adapted to the offshore environment keeping nevertheless the overall design principle of onshore wind turbines.

While the maximum onshore turbine capacity now seems to stagnate around 3MW, the capacity of offshore models is increased rapidly. 3-6MW turbine units are being currently deployed while 7MW are now being commercialized for projects to be built in 2015.

The industry' general assumption so far is that developing **larger units** leads to cost reductions and lower Levelised Cost of Energy (LCOE). Accordingly, larger 10-15MW units are already on the drawing board. Norwegian turbine developer SWAY has received grants to demonstrate in the incoming years an innovative 10MW offshore wind unit on the onshore test site in Norway. Research work² carried out in the past years on turbines up to 20MW with an impressive 252m rotor diameter indicates that technical feasibility is achievable although the economic rationale for upscaling to these dimensions is yet to be proven (ref. Figure 5).

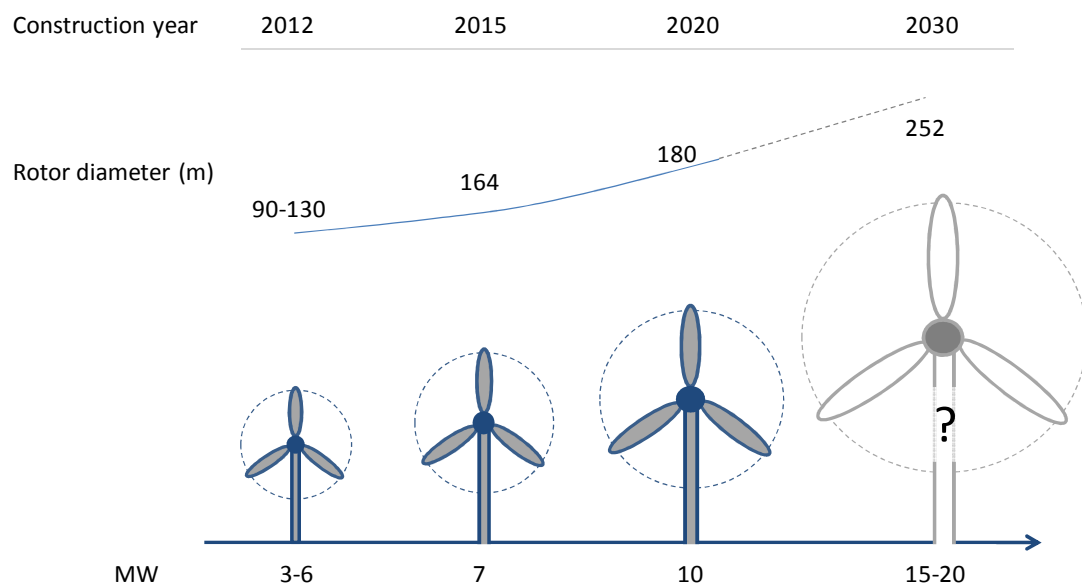


Figure 5. Evolution in conventional turbine dimensioning. Source: Multiconsult

It is commonly accepted in the industry that further scaling up the conventional 3 bladed design may reach its physical and economic limits as other alternative design will compete on cost. The development on **innovative concepts** is now progressing. With the objective of driving down riskiness and costliness of offshore operations innovation on turbines incorporates design features serving other purpose than the increased energy yield and reliability. The main technology trends are variants to the conventional turbines (number of blades, circular lens, downwind), vertical axis turbines and multi-rotor horizontal axis turbines.

Take-aways:

- In order to evaluate the attractiveness of the 15 areas in the 2015-2020-2030 time perspective, a base case quantitative analysis has been modeled on year 2020. Year 2020 assumes a 10MW horizontal axis 3 bladed turbine model although other smaller turbines will be commercialized on larger projects (Table 1).
- The demonstration of innovative support structures requires deployment of smaller turbines during model / small scale demonstration phase (as it was the case at the Hywind and Windfloat floating test sites).

² UpWind EU project, 2008

- Size of conventional turbine and turbine spacing are important for environmental impact assessment, especially on topics such as visual impact, bird impact or radar/aviation. The future deployment of unconventional innovative turbine concepts could impact in more significant manner environmental assessments. Technology watch and environmental monitoring of demonstration projects are necessary.
- Other areas of development concerning conventional horizontal turbine technology relate to reliability, higher yield, lighter turbines as well as extended life time (from 20 to 30 years of operations for instance). These impact to a lesser extent spatial planning activities but are nevertheless taken into account in the following economic assessment.

Table 1. Assumptions used in this report

Timeline / Year of construction	2015	2020	2030
Base case nominal capacity (MW)	7	10	20
Rotor diameter (m)³	164	180	252
Hub Height (m)⁴	104	112	148

3.4 Support structures trends

We can divide the wind turbine support structures into **two main segments: “Bottom fixed” and “Floating”** (for more detailed overview refer to Appendix 3). There is an increasing number of support structure concepts on the table, but only a few solutions have been fully demonstrated. Multiconsult has referenced:

- Above 80 different bottom fixed technology players/concepts such as monopiles, gravity based structure (GBS), tripod, tripile, suction buckets or lattice towers (Jacket).
- About 40-50 different floating technology concepts such as semi-submersible, SPAR or Tension Leg Platform (TLP).

Table 2 below presents used assumptions for foundation type; applicability to different water depths and maturity.

Support structure concepts fall into four technology trends:

- Pre-assembled floating structure applicable down to 25 meter water depths
- Pre-assembled bottom fixed aimed at water depths up to 70 meters⁵
- Deep water bottom fixed transferred from Oil&Gas
- Innovative bottom fixed solutions focused on serial production in deep waters and bedrock installation

There is no universal standard support structure solution for offshore wind. Technology choice is site specific (water depth, soil conditions in particular) and driven by least cost approach which varies from project to project. Shallow water solutions, monopiles in particular, are more mature than deep water alternatives but there remains large room for optimization and innovation of design, fabrication and installation in all water depths.

³ 7MW based on Vestas 7MW; 10 and 20 MW based on Upwind research project

⁴ Assuming 22m clearance between mean sea level and tip of the blade

⁵ 70m is perceived as an economic boundary for bottom fixed solution in a 2030 perspective.

To date, technology selection is essentially driven by water depths and soil conditions. However, future support structure technology will be increasingly based on the aggregated cost of supply and installation of the foundation and installation of the turbines. Other cost drivers such as turbine size may then be determining.

Table 2. Support structure technical feasibility and maturity according to water depth. Source: Multiconsult

Support structure	Foundation/Anchoring	key material	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	> 100
BOTTOM FIXED													
Monopile	Driven/drilled pile(s)	steel											
Monopile	Drilled pile(s)	steel/concrete											
Supported monopiles and guyed towers	Driven/drilled pile(s)	steel											
Gravity Base Structure - concrete	Skirts / Suction	concrete											
Gravity Base Structure - concrete	Seabed preparation for GBS	concrete											
Gravity Base Structure - concrete	Cemented base GBS	concrete											
Lattice towers - Quadripod (jacket)	Driven/drilled pile(s)	steel											
Twisted jacket	Driven/drilled pile(s)	steel											
Tripod	Driven/drilled pile(s)	steel											
Tripile	Driven/drilled pile(s)	steel											
Suction bucket - steel	Suction bucket	steel											
Suction bucket - concrete	Suction bucket	concrete											
FLOATING													
Semi submersible	Depends on soil conditions	steel/concrete											
SPAR	Depends on soil conditions	steel/concrete											
Tension Leg Platform (TLP)	Depends on soil conditions	steel											
Other (Floating barge etc.)	Depends on soil conditions	steel											

color code reflects maturity/exclusion from offshore wind sector.

extensive track record, conventional

limited track record

feasible but not mature

unclear, not investigation for the purpose of offshore wind

not feasible, bottom fixed are excluded from 100 m water depth due to economic reasons

nb: some concepts have been deployed in the offshore oil & gas sector which is not reflected here

Take-aways:

- A limit of 70m water depth was applied in earlier assessment published in *Offshore Wind Power in Norway* (2010)(NVE et. al, 2010) to several “shallow water” areas qualified as “Bottom fixed” areas. This limit does not correspond to the real water depth value observed but to an arbitrary maximum water depth. 70m reflected in 2010 a reasonable limit above which bottom fixed would not be cost competitive.
- In *Offshore Wind Power in Norway* (2010)(NVE et. al, 2010), floating structures were only considered for deeper waters above 100m due to the lack of technology candidates in the market at that time (Hywind from Statoil). Recent technology development achievements in Portugal (Windfloat from Principle Power) demonstrate that floating devices (semi submersible in that case) could be applied in much shallower waters. Some technology developers indicate a minimum water depth of 25m and cost competitiveness with bottom fixed from 40 m.
- Some of the areas referred to as “bottom fixed” in *Offshore Wind Power in Norway* (2010)(NVE et. al, 2010) could very well become mixed type areas where both bottom fixed and floating could in practice be deployed. With this in mind, a different technology neutral segmentation of the areas is thus suggested further in the document to reflect the water depths and distance to shore.
- The high level of activity in support structure innovation may lead to the breakthrough of new standard solutions which will impact supply chain, economics and most probably the scope of environmental impact assessment. Industry and employment will also be impacted as a result (ref. Figure 6).

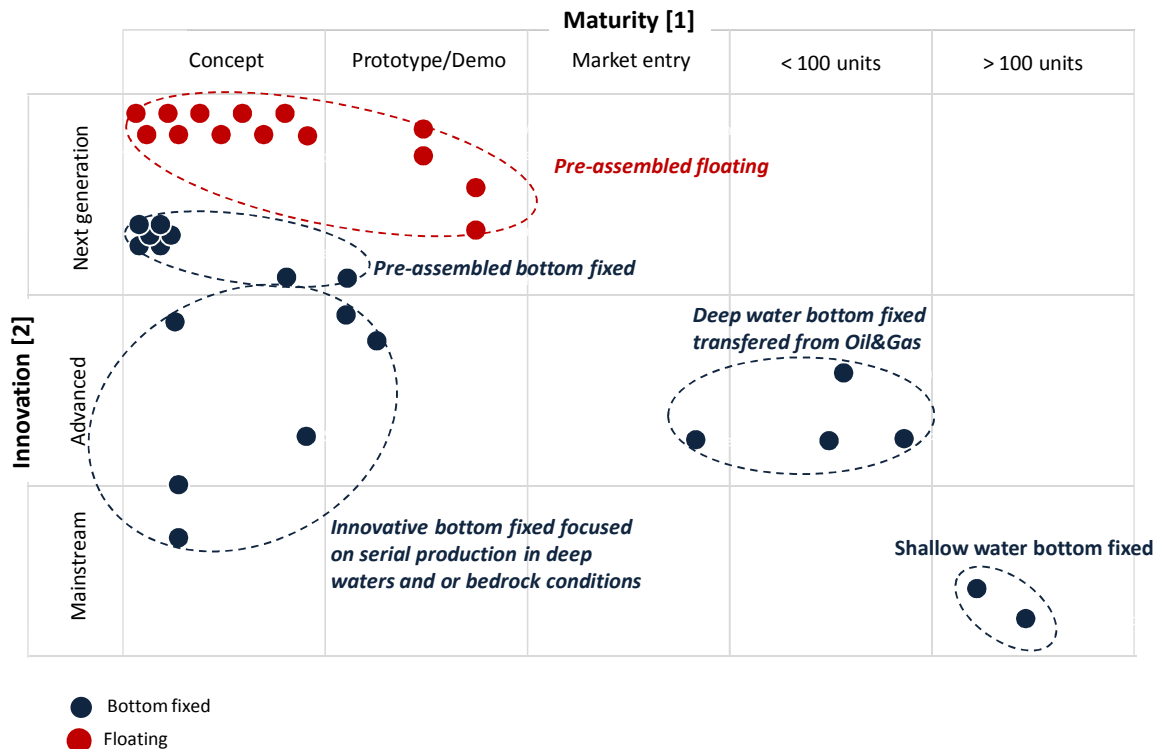


Figure 6. Innovation and maturity for the leading concepts under development. Source: Multiconsult

3.5 Other technology trends

All key trends are described in further detail in Appendix 3.

3.5.1 Assembly and installation

The following trends have no direct impact on the spatial planning and Strategic Environmental Assessment (SEA) but could have strong implications on future cost trends and supply chain requirements:

- Preparation of seabed and pre-installation of foundations
- Pre-assembly of turbines
- Self installing pre-assembled solutions
- Floating dynamic positioning (DP) vessels
- Dedicated support structure installation vessels

Take aways:

For the study, we consider assembly and installation as an influencing factor on cost and risk but we do not discuss in depth the area specific technology requirements and how technology maturity and supply chain readiness may impact the attractiveness of each area.

3.5.2 Electrical infrastructure

All wind farms today employ an AC collection system, and most commonly HVAC for transmission to shore. Larger wind farms further offshore apply HVDC. DC collection and transmission solutions are also under development. The key technology and innovation trends in electrical infrastructure include:

- Clustering of wind farms
- Offshore wind farms as part of an offshore power grid
- Multi-terminal DC grid
- Connection to offshore oil and gas installations

Take aways:

Technologies applicable to electrical infrastructure have impact on the typical offshore wind farm layout to be considered for the study. In a 2020 perspective we consider that large offshore wind developments in the range of 1-1,5 GW will be developed in several phases through distinct offshore wind farms utilizing a common grid collection and transmission infrastructure. Detailed assumptions on electrical infrastructure are provided further in the report.

3.5.3 Operation and maintenance

Turbine reliability remains a problem and offshore cables have shown to be problematic. Recent issues on monopile design (failure of the grouting between transition piece and support structure) have been solved through costly retrofit fixes on some offshore wind farms. Key trends in O&M of importance to the study include:

- Development of dedicated made-for-purpose support vessels
- Development of mother ship vesselshousing both service staff and consumables offshore in order to avoid daily transportation to shore
- Manned offshore platformswith similar aim as mother ship, but with possibility to house the site's substation in addition.
- Supply vessels made for offshore wind purpose to allow simple and safe access
- Floating units to be towed back to shore for maintenance

Take-aways:

A basic layout was prepared for the different offshore wind areas to reflect the likely optimal configuration in 2020 in terms of technology readiness and cost from a CAPEX point of view. An optimal maintenance configuration was also developed. A cost model was then developed to evaluate the relative cost difference between the 15 areas. Important parameters are design characteristics (number of farms, number of units) and site accessibility (distance area-ports, meteorological ocean conditions).

3.6 Supply chain trends

As the **international offshore wind market accelerates**, the high demand for specialized supply chain and skills drives the industry into global competitive arena. The supply chain is primarily being developed in leading offshore wind markets such as Denmark, UK or Germany. Emerging markets such as Netherlands, France and China outside Europe are expected to invest significantly in the supply chain over the next 5 years. These investments are focused on the bottom fixed market rather than floating.

The **Norwegian offshore wind supply chain** has gained competitive advantages from its world leading offshore and energy experience, visualized in Figure 7below. Technological and operational expertise from offshore oil and gas is commonly regarded as the main competitive advantage of Norwegian companies in the offshore wind industry. This expertise is, however, not only about supplying components and services but also in the development of technologies and the management of offshore risks.

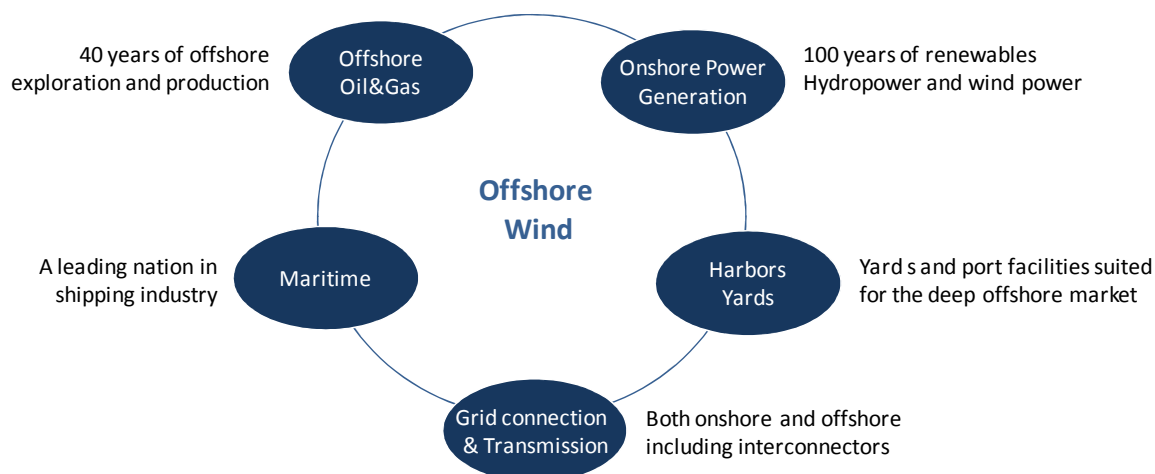


Figure 7. Norway's unique energy, offshore and maritime heritage. Source: Multiconsult

By transferring skills and supply chain assets into the new offshore wind market segment, the potential for diversification and new value creation in the supply chain, services, research and technology is considerable. As illustrated in Appendix 3, several key contracts have already been secured in the manufacturing and installation of inter array and export cables; design, manufacturing and installation of foundations.

Take aways:

- Important upfront investments are currently triggered in the offshore wind supply chain in order to match the timeline of deployment of Northern European bottom fixed markets. No particular attention is given to the future needs of the floating supply chain which may be different.
- Norway has existing supply chain assets that may be utilized for its future domestic market but suitability (e.g. mass serial production rather than single unit fabrication) and availability (versus offshore Oil & Gas market) maybe an issue. In the case of shallow water bottom fixed offshore wind farms, foreign supply chain will be suitable while deep water areas, floating in particular, are likely to rely on Norwegian capabilities.
- Technology innovation on turbines and support structure will have implications on the ability of its supply chain to deliver the first floating large scale offshore wind farms.
- The availability of the Norwegian supply chain will however remain dependant of the level of activity in the offshore oil & gas sector in Norway which is expected to remain more attractive to industry players in the incoming years.
- In order to avoid supply bottlenecks, Norway may need to upgrade or build new facilities to match the requirements of offshore wind in Norway. The realistic phasing of a deployment should take this into account.

3.7 Cost trends

The average electricity cost of energy (LCOE) for offshore wind has been estimated for a typical project of 500MW in 35 meters water depth at 1370 - 1480NOK/MWh depending on the wind conditions. The cost estimation assumes a project lifetime of 20 years, a net capacity factor of 43% (taking into account losses) and an applied WACC⁶ of 9,5%. Grid connection & transmission costs are excluded from CAPEX but considered as a transmission charge as part of the O&M cost (ref. OFTO regime implemented in UK). Detailed breakdown of typical cost is available in Appendix 3.

⁶ WACC – weighted average cost of capital

Development cost ranges between 450 and 1400 kNOK per MW depending on site specifics (size of the site, distance to shore, degree of possible impacts) and national requirements on impact studies and upfront surveys (pre-investment).

Capital expenditure (CAPEX) - As indicated by many reports, CAPEX has increased from 20 to 30 MNOK/MW over the past 5 years and is expected to have stabilized ahead of coming cost reductions. A typical CAPEX (2012) for a 500MW offshore wind farm is presented in Figure 8 below:

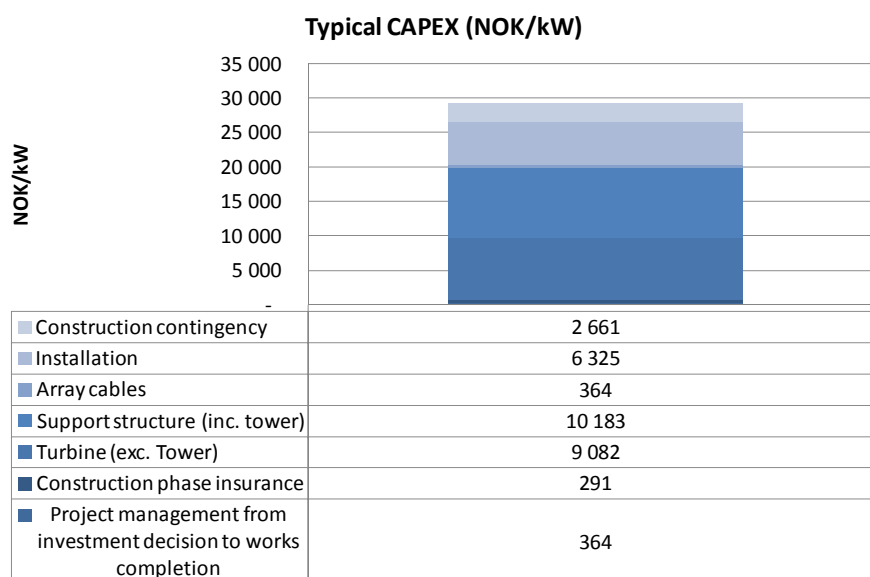


Figure 8. CAPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate (2012)

Operational expenditure (OPEX) - O&M cost estimations vary from one study to another. This clearly reflects the lack of operational and maintenance experience from the industry as a whole, on large projects in particular. Figure 9 below presents typical OPEX (2012) for a 500MW offshore wind farm:

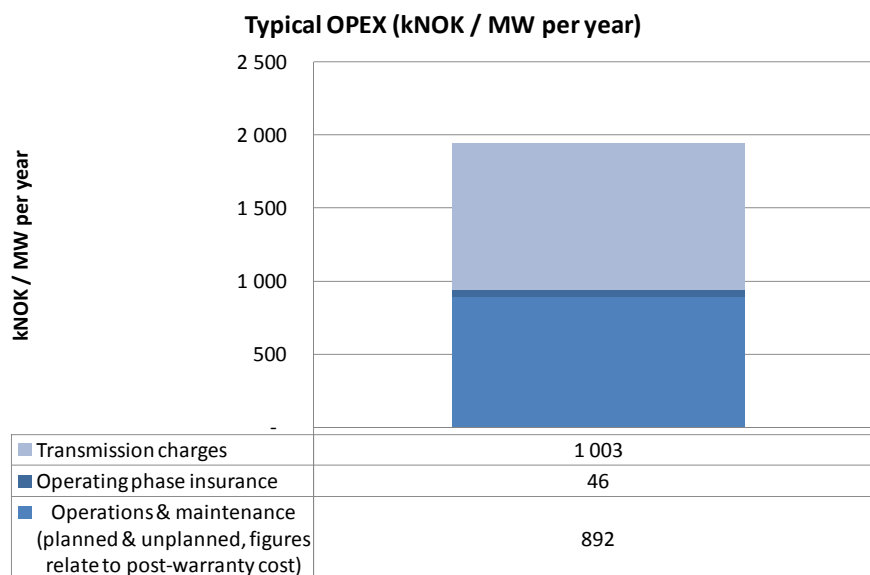


Figure 9. OPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate (2012)

Decommissioning cost is estimated by UK and French authorities to be in the range of minimum 400 NOK per MW for bottom fixed sites. High uncertainties stand behind this number which in practice varies with national requirements, water depth, support structure technology, future heavy lift vessels and processes.

About future cost prognosis - As explained above, offshore wind costs are site specific, subject to various cost drivers and are expected to be reduced through learning, industry competition or innovations. However evaluating the long term cost reduction remains a critical exercise to give vision to policy makers regarding the economic potential and cost competitiveness of offshore wind versus other alternative power generation sources.

A study carried out in 2010 presents indications of expected future levelised cost of offshore wind for the purpose of determining the value creation potential for the UK. Considering the amount of uncertainties in addressing the broad national offshore resources in a single assessment, basic assumptions were made to estimate a min-max cost range. Assumptions were consolidated with inputs from the industry and developers sharing their views on how costs are likely to evolve over time in a 2045 perspective. In Figure 10 below, cost projections for floating structures in water depth down to 30 meters have been removed.

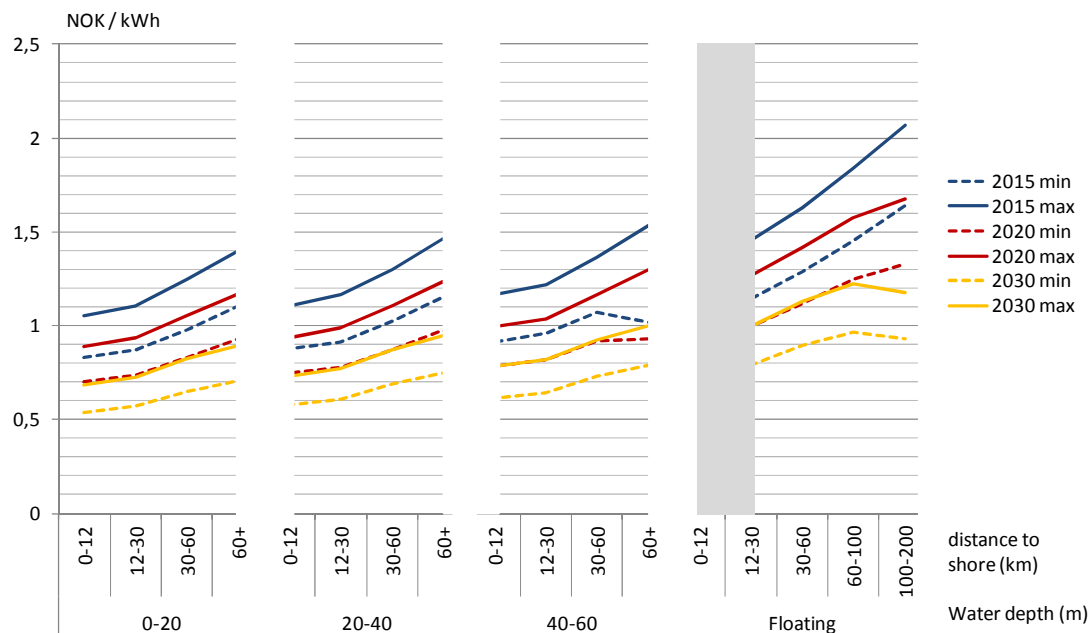


Figure 10. Levelised cost of offshore wind energy (NOK / kWh)⁷. Source: Data from BCG 2010, graph by Multiconsult

Cost reduction - All offshore wind stakeholders recognize that the current high level of offshore wind cost can only last for a temporary phase. The sustainability of the sector relies on its ability to reach grid parity on the long term. Today cost reduction is on the top of the agenda of the offshore wind industry. In a 2020 perspective, the delivery of the UK 2020 ambition in offshore wind requires, according to market players, a decrease of 30% from current cost levels in order to finance the total amount of round 1, 2 and 3 projects. In an effort to accelerate and bring confidence in the market's ability to overcome technical challenges and drive cost down⁸ by 2020, several studies are being carried out to identify the cost drivers and project future cost reduction curves, so far with limited success in matching actual data from executed project.

Aside from the sensitivity to raw materials⁹, Table 3 below indicates internal cost reduction factors to the industry directly addressable by the market players:

⁷ 1 GBP = 10 NOK

⁸ The UK government has recently set the goal of a levelised cost of offshore wind energy of GBP 100/MWh by 2020; corresponding to a 30-40% cost reduction compared to current 2011 levels.

Table 3. Internal cost reduction factors directly addressable by various market participants (Source: Multiconsult)

Technology	Supply Chain	Finance
• Wind farm selection • Wind farm design/layout • Lifetime of the wind farm • Turbine rating and rotor size • Drive train concept • Reliability • Production methods • Support structure type and level of production optimisation • Improved subsea array cable design including robustness • Installation methods for support structures, turbines and subsea cables • O&M strategies and methods of access • Accelerating technology commercialisation	• Risk & contracting approach • Competition • Sourcing – UK v non-UK • Reach (China, mainland Europe, UK) • Supply chain consolidation v. dispersion • Co-operation: co-operative v. hand-off approach to supply chain • Standardisation • Assurance of volume (commitment) • Whole life optimisation approach – trading off CAPEX vs OPEX • Statutory requirements	• Availability of capital and insurance • Perception of and management of risk • Project Sponsors • Participants • Gearing levels • Products (senior debt, senior bonds, subordinated debt / bonds, other risk mitigation instruments such as insurance) • Support (European Investment Bank, Green Investment Bank in UK)

Role of the government - As presented in a recent report¹⁰ from the British Wind Energy Association (BWEA), the likelihood of reducing cost substantially over the next 5 years is highly dependent on whether effective action is taken by Government and industry now. More generally, the national governments' role is key to unleash the potential of cost reduction through giving investors confidence in the market through profitable and stable incentive schemes, implementing reforms towards efficient and stable planning and consenting frameworks, funding RD&D efforts towards cost reduction and stimulating upfront investment in the supply chain through active and sustained regional support. More recently, the UK government has launched a more proactive initiative aimed at challenging the industry through the prospects of reaching specific cost reduction targets as a collaborative effort across all stakeholders¹¹.

Take aways:

Turbine technology and water depth

- Costs foundation supply and installation as well as turbine installation for a 10MW turbine have been estimated for 2012 and reflect a cost reduction due to sole up-scaling of the turbine. The model is further used as basis for the economic model (see Figure 11).

Bottom fixed

- Offshore wind levelised cost varies with wind speed, water depth, distance to shore among other site specific conditions.

¹⁰ BWEA, UK Offshore Wind: Charting the Right Course - Scenarios for offshore capital costs for the next five years, 2009 <http://www.bwea.com/pdf/publications/ChartingtheRightCourse.pdf>

¹¹ Offshore Wind Cost Reduction Pathway development, The Crown Estate, 2011-2012

- Under current trends, offshore wind remains a costly technology and is unlikely to reach grid parity in Norway in the 2015-2030 time horizon considered in this study, especially on deep water sites, and will require appropriate support schemes.
- By 2020, a cost reduction of 30% is expected to be triggered by foreign market players for bottom fixed projects in the 20-40 meter range. Further cost reduction will occur ahead of 2030.
- A share of Norwegian shallow water sites will be directly impacted by this cost reduction but specific site conditions such as the 40-70 water depth range or possible bed rock soil conditions may not be applicable to this cost reduction. Specific technology development and supply chain efforts may be required to overcome associated challenges.

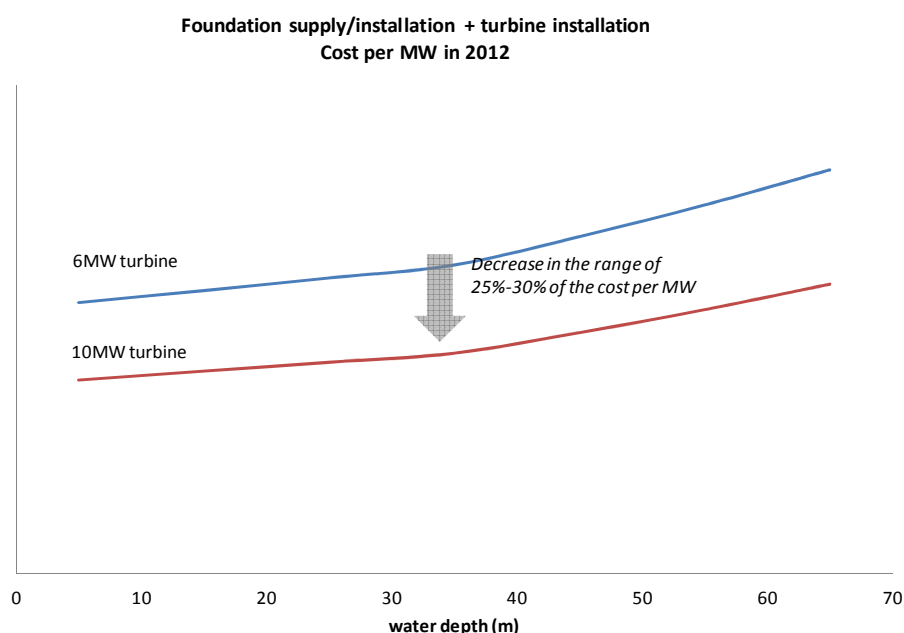


Figure 11. Fabrication and installation of support structure/foundation + installation of turbine. Source: Multiconsult

Floating

- Technology maturity, supply chain readiness and cost reduction are first expected in the bottom fixed segment ahead of 2020. Cost reduction will thus be driven through innovation and supply chain development efforts towards foreign bottom fixed short-medium term markets rather than floating market.
- Despite the acceleration in the early development of floating technology concepts, the financing of demonstrator will remain a key barrier. Governments are expected to play a major role to overcome this, through the set up and financing of demonstration programs for instance.
- The cost effective deployment of floating offshore wind in Norway in a 2020 perspective will be dependent on Norway's governmental and industry efforts in demonstrating, qualifying and reducing the cost of floating offshore wind technology. In a 2030 perspective, foreign countries such as Japan are expected to provide this effort as a means to serve their own domestic floating market and position their industry towards the export market.

Cost competitiveness of floating versus bottom fixed

- In order to assess the competitiveness of bottom fixed versus floating solution, the costs of support structure/foundation fabrication and installation as well as installation of turbine must be summed up. This enables a fair comparison between conventional bottom fixed designs and innovative self installing solutions (including floating).

- The 2015, 2020 and 2030 cost trends presented in Figure 12 indicate that projects are deployed in deeper waters over time.

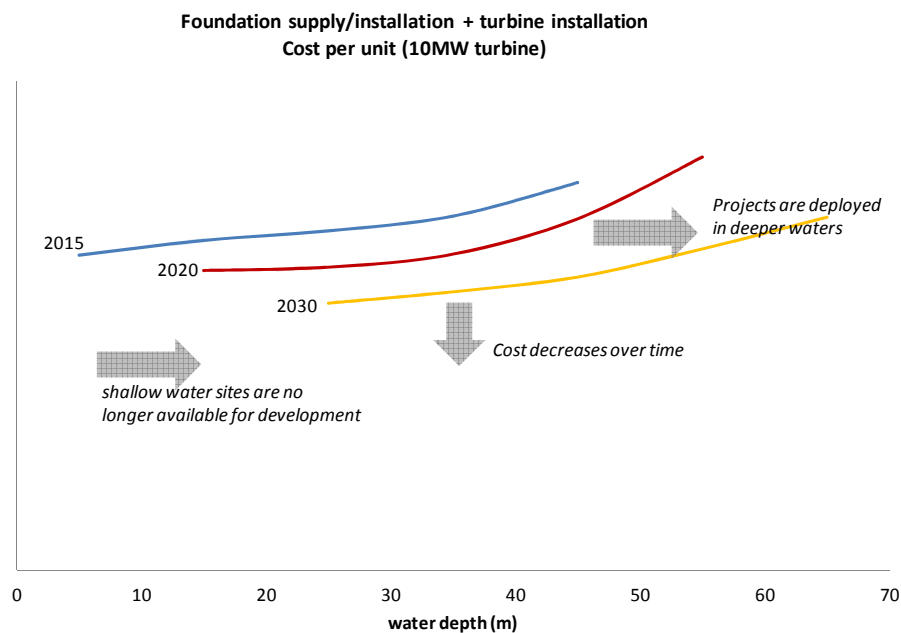


Figure 12. Bottom fixed costs – Foundation fabrication/installation and 10MW turbine installation. Source: Multiconsult

- Figure 13 indicates general cost trends for different water depths over time. The economic model uses 2020 scenario (construction in 2020) and simulate a cost competitiveness of floating with bottom fixed 50-60m by 2020-2025 (optimistic scenario).

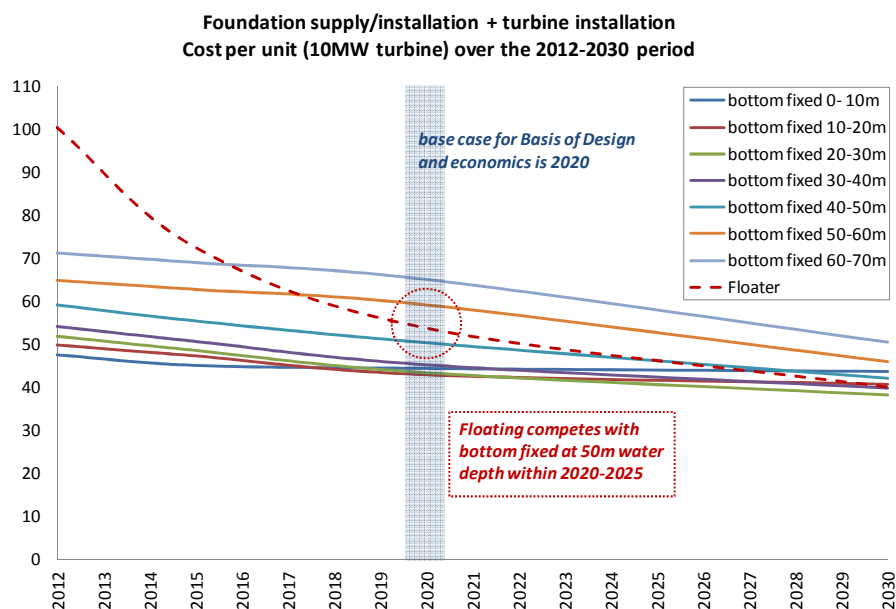


Figure 13. Foundation supply/installation and 10MW turbine installation cost comparison over the 2012-2030 period (optimistic scenario regarding cost reduction for floating) Source: Multiconsult

4 Technical assessment of the 15 Zones

4.1 Background and Norwegian Context

The legal aspects regarding offshore wind development were formalized through the Offshore Energy Act of 1 July 2010. Pursuant to this Act establishment of offshore renewable energy production can in principle only take place after the Norwegian Government has opened defined geographical areas to applications for a license (NVE et. al, 2010). The assessment of defining suitable areas for offshore wind farms was carried out by a governmental group comprising the Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Directorate of Nature Management (DN), the Norwegian Directorate of Fisheries (FD), the Norwegian Coastal Administration (KV) and the Norwegian Petroleum Directorate (NPD). The inter-directorate group defined 15 zones to be covered by a strategic environmental impact assessment, and the result of the analysis was presented in the report *Offshore Wind Power in Norway* (2010)(NVE et. al, 2010).

The zones have different capacity range. For the study, base case capacities have been assumed corresponding to 200MW for small zones and 1000MW for larger ones. Figure 14 below illustrates the 15 areas and base case capacities.

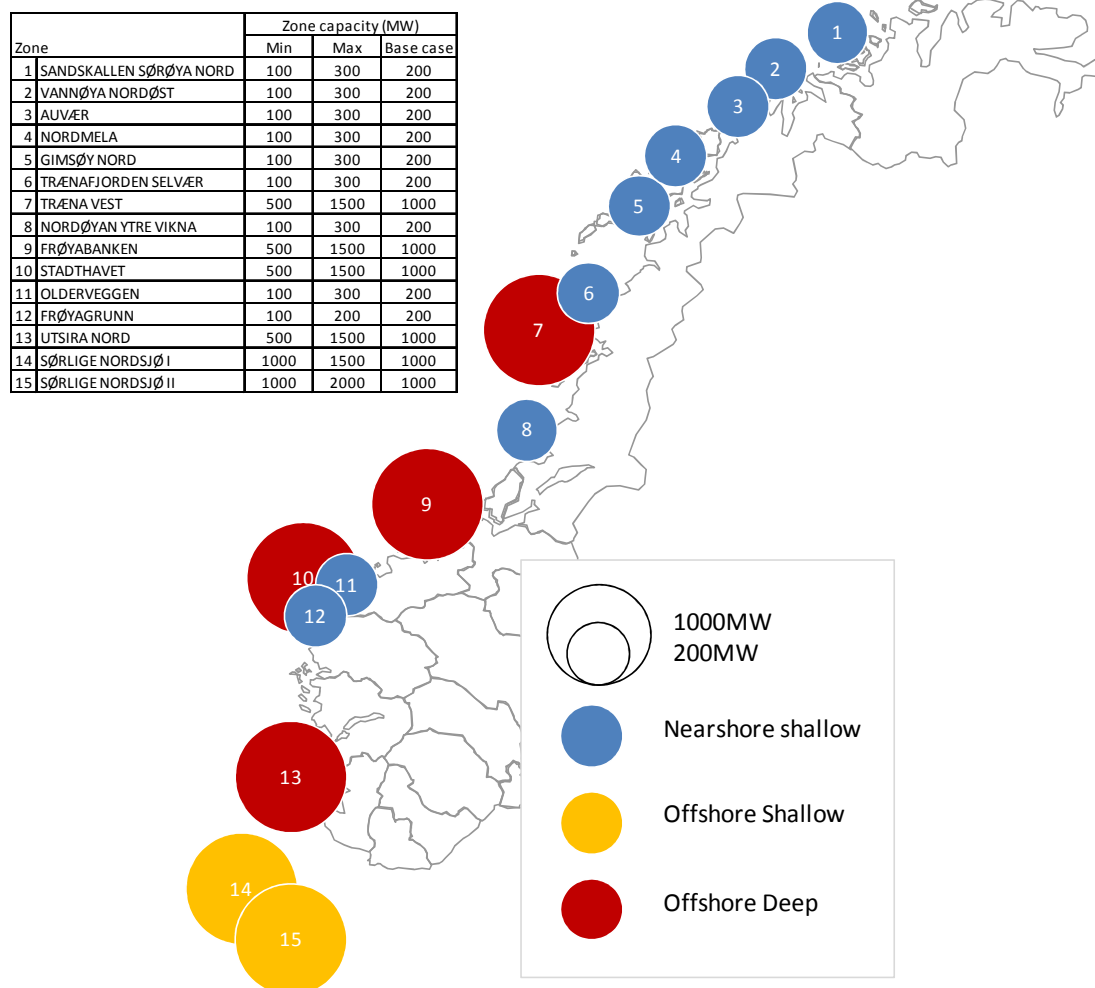


Figure 14. The 15 offshore wind zones: near shore and further offshore; in shallow and deep waters.

Source: Multiconsult based on NVE

Criteria for the selection of the 15 zones have been technical and economic – such as bathymetry and distance to onshore grid connection. In addition, available information of environmental aspects and other users of the sea have been taken into consideration when the final 15 zones were defined.

The 15 zones are spread out along the Norwegian coast, and vary in size, water depth and distance to shore. The bathymetry in Norwegian waters differs from most of the other countries in Northern Europe where offshore wind farms are planned, under construction or in operation. The water depths in Norway are highly variable, and except for some parts of the Southern North Sea there are limited very shallow water sites. The wind conditions in Norway are in general favorable with high wind speeds and high capacity factor (Kjeller Vindteknikk, 2010).

In this report zones will be referred to as the area defined by *Offshore Wind Power in Norway* (2010)(NVE et. al, 2010) meaning there are 15 zones in total; and site as the wind farm within the zone. Consequently, there may be more than one site in a zone, as e.g. 1000MW zones are divided into three 300MW wind farms (sites).

4.2 Methodology



Figure 15. Zone assessment methodology used for this report

The review of the zones enables us to segment the 15 zones in 3 main categories according to water depths and distance to onshore grid connection. The definition of technical attractiveness then provides elements to be further investigated during a site assessment performed for each single zone. An analysis is performed at site level (the zone areas are larger than necessary to develop the expected capacity and water depths must be assessed on smaller sites within each zone). Finally the results of this analysis indicate zone specific features. Technical attractiveness is then assessed at site level while key trends are extracted for each zone segment. Key take-aways for the economic assessment are also presented (Figure 15).

Segmentation of the 15 zones

Plotting the 15 zones on a chart based on their average depth and distance to shore allows the following segmentation (ref. Table 4, Figure 14, Figure 16):

Table 4. Zone segmentation

	Average water depth (m)	Minimum distance to onshore grid connection (km)
Near-shore Shallow (NS)	<70m	<55 km
Offshore Shallow (OS)	<70m	>45 km
Offshore Deep (OD)	>70m	>45 km

The zone segment defined as **Near-shore Shallow (NS)** includes most of the 15 zones. The sites can be described as less than 50km from the coast and in relatively shallow-medium range water depths (20-70m). This category contains wind farms that resemble current developments in Northern Europe. The largest

uncertainty to the NS segment is the complexity of seabed conditions (bathymetry and soil conditions), which is different from the majority of offshore wind farms developed in the rest of Europe. As several of the NS zones are relatively close to archipelagos, bathymetry (i.e. ranging depths) within the zone can mean great variance between minimum and maximum depths of the placed wind turbines. Also, connection cable routing distance can vary significantly depending on where the wind farm will eventually be positioned in a zone, as obstructing islands can mean that the connection cable can be rerouted to the wind farm in more ways than one.

The second zone segment is defined as **Offshore Shallow (OS)**. It comprises two projects in the Southern North Sea. The two projects have a considerable distance to shore but are located at “rather shallow” waters with on average 60 meter depth. This area is near the Ekofisk field and the UK round 3 zone of Dogger Bank on the UK side.

The third zone segment is referred to as **Offshore Deep (OD)**, consisting of larger zones in deeper than 70m waters. The category contains four zones.

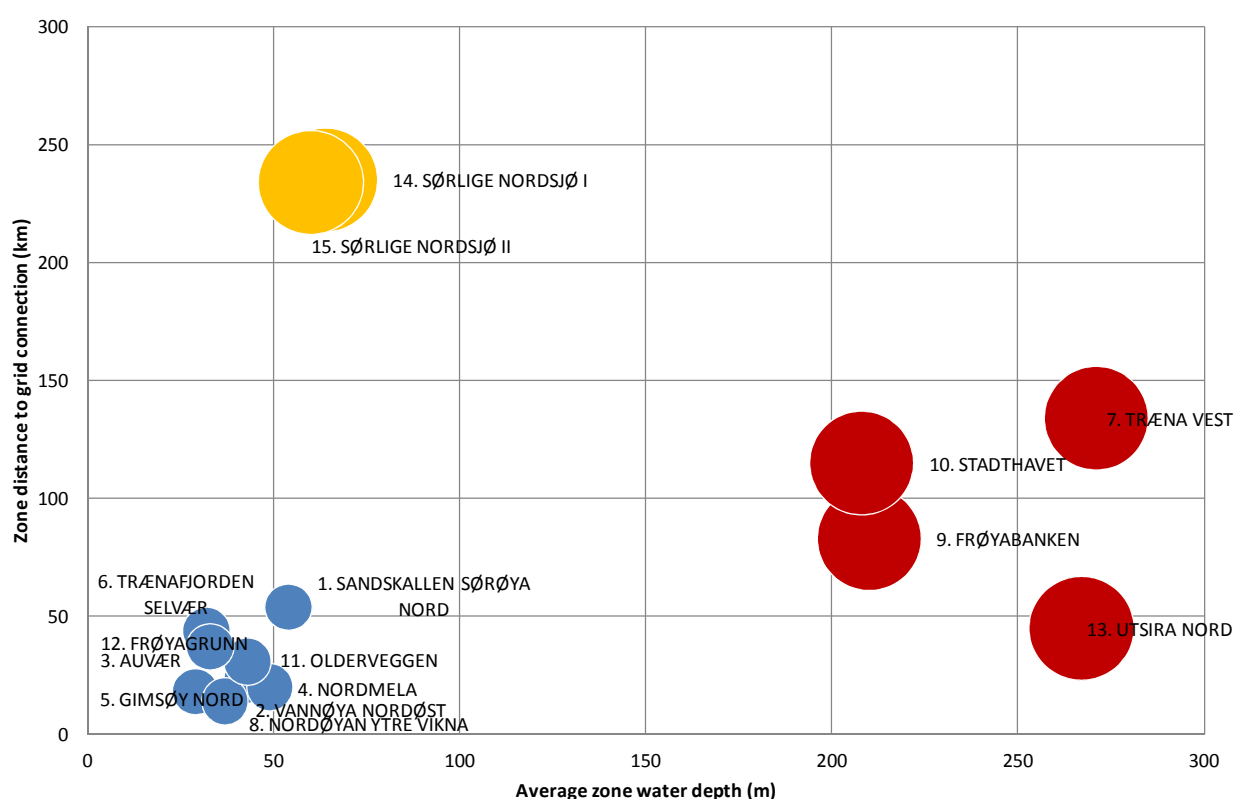


Figure 16. Plotting of the 15 zones based on zone water depth and distance to onshore grid connection: NS (in blue), OS (in yellow), OD (in red). Size of the bubble relates to size of zone (200/1000MW). Source: Multiconsult

4.3 Attractiveness criteria

The study aims at determining the respective attractiveness of the different 15 zones. We distinguish technical from economic attractiveness, both of which will be discussed throughout the report.

4.3.1 Technical attractiveness criteria

Technical attractiveness for this report is based on 3 key drivers. For each of them, some key influencing factors/constraints are to be extracted from the technical review. The main ones taken into account are presented below in Table 5.

Table 5. Three key drivers of technical attractiveness

Key drivers		Influencing factors / constraints
Basis of Design / Site conditions	Has impact on complexity of the engineering required and novelty/risk level associated with fabrication and installation as well as site accessibility issues during both construction and O&M phases.	• Average water depth • Water depth variation • Offshore cable length • Distance to main harbor • Met ocean constraints
Technology maturity	Deep water sites and distance to shore brings technology and construction challenges which will require innovative solutions. This driver reflects the aggregated technology maturity and possible delays associated with the deployment of the concerned zones.	• Expected complexity of support structure delivery • Distance to shore
Supply chain readiness & deliverability	The ability of the supply chain to deliver in due time depends on the volumes and technical complexity of the scope (Deep water support structure in particular).	• Size / Capacity of the zone • Expected complexity of support structure delivery

Technical attractiveness is estimated as a constraint/risk rather than benefit. Its evaluation is based on the weighted average of constraints and risks associated with the 3 key drivers presented above.

4.3.2 Economic attractiveness criteria

Economic attractiveness is evaluated as the relative Levelised Cost of Energy (LCOE) of a given zone in comparison to the other zones. Considering geographical specificities of Norway (deep waters of several areas, complex site bathymetry, harsh ocean conditions, difficult seabed conditions, presence of islands between areas and the onshore substation, complex onshore topography), a list of key cost drivers is presented below in Table 6:

Table 6. Key site condition factors influencing LCOE

Economic impact on		Cost items	Analysis
Water depth	Bottom fixed support structure	Design / Fabrication cost; (Installation & Logistics)	• Uncertainties on current and future costs for sites in waters above 50m. Assumptions have been made. See economic assessment chapter for details.
	Floating support structure	Mooring system cost, (Installation & Logistics related to the subsea foundation & mooring lines)	• Uncertainties on floating technology readiness and costs in a 2015-2030 perspective. Assumptions have been made. See economic assessment chapter for details.
	Maintenance	Inspection and corrective maintenance of subsea equipment	• Uncertainties of unscheduled maintenance in deep water sites above 50m. • The impact of water depths on this item is not taken into account in this study.

Bathymetry spread over the site	Bottom fixed support structure	Design / Fabrication cost; (Installation & Logistics)	Variable bathymetry impacts bottom fixed support structure costs due to the possible need to utilize different construction and installation methods and supply chain. Economies of scale and mass serial production are made difficult.
	Floating	Design / Fabrication cost; (Installation & Logistics)	Cost of floating sites is less impacted to variable bathymetry than bottom fixed support structures.
Seabed conditions	Foundation type	Marine operations related to the site preparation or installation of foundations	- Absence of information on soil condition over the areas. - The study does not consider seabed conditions at this stage.
Met ocean conditions	Wave loads	Dimensioning / Fabrication cost; Installation & Logistics	Cost impact of wave load requires engineering on the basis of a given technology
	Site accessibility / Weather window	Scheduled maintenance	- Absence of detailed met ocean conditions over the sites does not allow detailed assessment. - High level estimates of wave conditions from the Havvind 2010 report have however been taken into account in O&M as well as technical site complexity & risk.
	Power production	(revenue side)	- Absence of detailed met wind conditions does not allow detailed assessment of the sites' capacity factor. - Estimation made by StormGeo has been taken into account.
Distance to onshore grid¹²	Export cable	Power transmission configuration and equipment Cable length – onshore , offshore	- Detailed cable routing is a necessary exercise which cannot be performed in detail at this stage. - High level estimation has been performed assuming a straight line from landfall to substation.
	Power production (revenue side)	Losses due to export cable length	
Distance to O&M base	Site accessibility / Weather window	Scheduled maintenance	Limited information on suited O&M ports
	Site access system; Heavy lifting vessels for repair	Unscheduled maintenance	A cost model OPEX takes this parameter into account. See chapter on Economic assessment.

4.3.3 Take aways

The following parameters should be identified through the technical review:

- Gross capacity Factor (%)
- Distance site to main harbor [km]
- Onshore cable length [km]
- Offshore export cable length [km]

¹² Note: Distance to shore is commonly used as a cost driver, indicating the approximate length of the offshore export cable used for the grid transmission. The analysis of the 15 areas identified in the 2010 Havvind report shows that the distance to shore is a misleading indicators due the presence of islands used as point of onshore reference to calculate the distance to site. Not only it is inaccurate but the presence of islands impacts the length of the export cable.

- Total cable length [km]
- Area of Site (km²)
- Average site depth (m)
- Variation/spread of water depth

4.4 Site definition

First, the small areas are presumed to hold one single wind farm with an installed capacity of 200 MW and the large areas three wind farms with a total installed capacity of 1000 MW (2x300 MW and 1x 400 MW).

As a basis for the further analyses, base case wind farms referred to as 'sites' have been located within the zones. The size of the sites is determined by the spacing between the turbines¹³:

- diameters x 9 diameters, for sites with strong prevailing wind direction
- diameters x 7 diameters, for sites with homogenous distribution of wind (no obvious prevailing wind direction)

In a 2020 perspective, the base case 10MW turbine is used to determine the above spacing and site area. The location of the sites has been driven by distance to grid connection point and bathymetry, where we have focused on placing the sites as close to shore as possible and within reasonable water depths. In order to tell exactly how a different location of the sites will influence the attractiveness of the different zones, a new review/analysis is needed. In general the localization of the sites is flexible within all the zones. Thus, the sites can be located elsewhere, and they probably will, in a more detailed planning phase. One of the least flexible zones seems to be "Træna fjorden – Selvær" where the northernmost area holds several small islands with accompanying shallow water and about half of the southernmost area includes water depths below 150 meters.

Our assessment can be viewed as an illustration of the attractiveness of the 15 zones, and a more detailed analysis is required to give final conclusions. In order to avoid unnecessary debate on site selection at this stage, given the level of detail in the review and for environmental reasons (e.g. fishery), we did not find it appropriate to show the site contours in the public report.

Using a GIS model, different export cables route alternatives from the sites to the grid connection points have been sketched. For the bulk of the areas, several routes have been investigated and an average distance based on the most realistic alternative is calculated (see Figure 17 below). It must be noted that the presence of islands along the coast impacts the cable route for certain zones. As a first approach, we have assumed that offshore cables remain in the marine environment rather than being brought to land and back in the water. In some cases, the estimated export cable length is thus greater than what a direct line route would allow.

Water depth profile is determined by extracting from the GIS model the percentage of different water depth trenches (0-10; 10-20; etc.) over a given site. The average water depths and overall distribution of water depth over a given site is thus determined and later used in the cost model.

In addition, available data on ports and terminals have been added to the GIS database. The distance to nearest port has also a direct implication of the cost of operation and maintenance, and serviceability. For this assessment we have included National Ports (Stamnetthavner)¹⁴ and ISPS Terminals (ISPS Havneterminaler)¹⁵.

¹³For the large areas with several wind farms, the location and spacing between the sites has been driven by bathymetry and distance to grid connection point rather than macro wake losses due to neighboring wind farms.

¹⁴The Norwegian Government has identified 31 such ports, being the most important ports for connecting transport infrastructure in a regional and national context. According to the National Transport Plan¹⁴, the requirement of being defined as a National Port is the

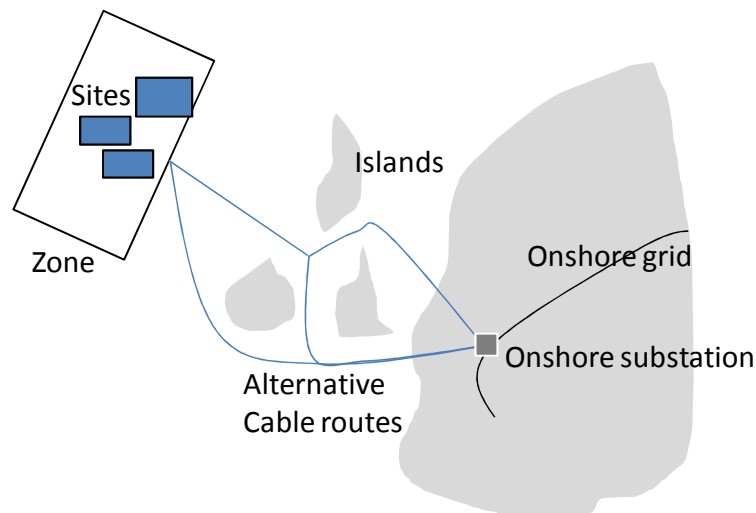


Figure 17. Methodology for determining onshore and offshore cable lengths and relevant water depth on a given zone. Source: Multiconsult

The data are retrieved from the Norwegian Coastal Administration (Kystverket) and the Norwegian Hydrographic Service (Statens Kartverk Sjø). Since national ports are not necessarily the closest port to the zones, we have also included the nearest ISPS terminal. The appearance of other terminals within a distance of approximately 100 km from the zones has been described qualitatively.

The site assessment carried out is not a detailed evaluation of the technical attractiveness of the zones, but illustrates the technical conditions and allows us to draw some overall conclusions. However there are some gaps and limitations in the technical assessment. First, the location of the site(s) within the 15 different zones is not based on a thorough evaluation of the bathymetry and distance to grid connection point, but those factors have been considered to the greatest extent possible in order to illustrate the technical attractiveness of the zone. Information on sea bed condition has not been available and therefore not included in the assessment. Optimization of the location of the site(s) due to wind conditions within the zone have not been carried out. The technical feasibility of the different cable routes has not been scrutinized, but we have tried to avoid very shallow water. In addition environmental aspects like restricted areas have been taken into account in the sketching of the cable routes. Furthermore this assessment does not identify if the ports and harbors are suitable for offshore wind farms operations. Neither does it identify the optimal O&M port for each of the zones and does not assume new built ports, but gives an estimate of distance to the nearby harbors. Further analyses at a later stage must be carried out in order to fill the gaps and limitations in this assessment.

Remaining parameters that have major impact on the CAPEX and OPEX are site accessibility and **weather window**; and the **conditions of seabed**. Of these two, only weather window was considered at general level (an average of three zones with extremes is applied to all 15 zones), thorough assessment is required in the future.

5 Technical review

A review of the characteristics of the zones and its sites is provided in Appendix 1. Table 7 below lists a summary of the site characteristics for each zone.

connection to the national road network and the national sea lane network. The government is responsible for the transport infrastructure of both the national sea lane – and national road network connecting any National Port.

¹⁵ISPS Port Terminals are terminals complying with the standards of the International Ship and Port Facility Security (ISPS) Code. The requirements of the ISPS Code in terms are related to certain security standards of port facilities and port equipment.

Table 7. Outputs from the technical review / site assessment. Source: Multiconsult, 2012

Zone	Zone cat.	Capacity (MW)	Number of sites within zone	Net capacity factor [1] (%)	Distance site to closest harbor [2] [km]	Onshore export cable length [km]	Offshore export cable length [km]	Total cable length [km]	Area of Site (km ²)	Average site depth (m)	Site water depth spread [3]
1 SANDSKALLEN SØRØYA NORD	NS	200	1	39 %	50	2	53	55	19	48	low
2 VANNØYA NORDØST	NS	200	1	37 %	22	3	27	30	19	42	high
3 AUVÆR	NS	200	1	38 %	32	0-11	33-54	33-65	19	26	med
4 NORDMELA	NS	200	1	43 %	10	1-9	4-36	5-45	19	31	low
5 GIMSØY NORD	NS	200	1	41 %	16	0	21	21	19	20	low
6A TRÆNAFJORDEN SELVÆR N [4]	NS	200	1	42 %	12	1	64	65	19	23	high
6B TRÆNAFJORDEN SELVÆR S	NS	200	1	45 %	6	1	68	69	19	41	high
7 TRÆNA VEST	OD	1000	3	44 %	30	2-34	104-133	106-167	109	243	NA
8 NORDØYAN VIKNA	YTRE NS	200	1	43 %	56	0-20	18-64	18-84	19	28	low
9 FRØYABANKEN	OD	1000	3	42 %	58	0-4	78-112	78-116	107	175	NA
10 STADTHAVET	OD	1000	3	48 %	71	5-14	88-116	93-130	107	203	NA
11 OLDERVEGGEN	NS	200	1	47 %	19	0-6	26-52	26-58	19	38	low
12 FRØYAGRUNNENE	NS	200	1	48 %	9	0-23	16-37	16-60	19	32	med
13 UTSIRA NORD	OD	1000	3	47 %	28	5-6	29-57	34-63	107	272	NA
14 SØRLIGE NORDSJØ I	OS	1000	3	49 %	150	2	200	202	109	63	low
15 SØRLIGE NORDSJØ II	OS	1000	3	50 %	160	2	171	173	109	57	low
[1] corresponds to net production estimate published by StormGeo in "Fagutredning 1", table 12 on page 42 [2] quality of harbor not assessed [3] reflects the degree of variation of water depths over a given site. 'NA' stands for floating structures which are less sensitive to water depth variation [4] Træna fjorden – Selvær can be split into North and South. Especially the Northern site is located in very complex setting, which makes it difficult to assess technical and economic viability on par with the remaining zones. In assessment, the Southern site is used. See Appendix 1 for more info.											

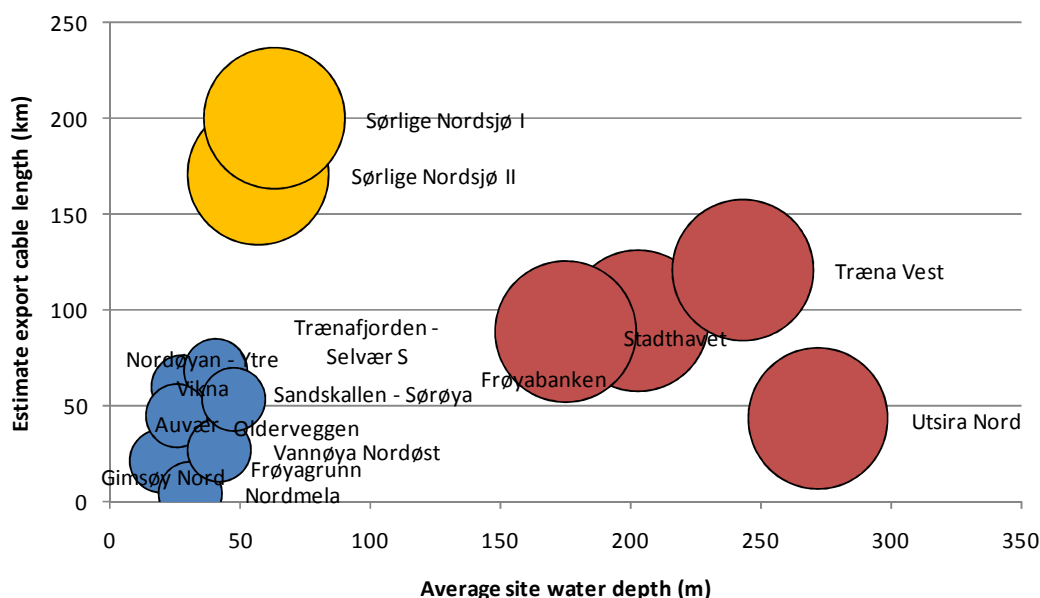


Figure 18. Estimated export cable length (km) versus average site water depth (m).
 NS (in blue), OS (in yellow), OD (in red). Source: Multiconsult

5.1.1 Technical attractiveness

Table 8 below provides a qualitative overview of the technical attractiveness of the different zones. As described in chapter 4.3.1, Technical attractiveness is determined using three key factors: Basis of Design / Site conditions; technology maturity and supply chain readiness, deliverability.

The colour code used to rank the **technical attractiveness** of the 15 offshore wind zones has the following meaning:

	High attractiveness, maturity and readiness, Low risks and uncertainties
	Medium attractiveness
	Low attractiveness, maturity and readiness, High risks and uncertainties

The technical scoring indicator is based on the weighted average of the following parameters and sub parameters. All parameters have been evaluated in a 2020 perspective. Relative weights (%) are applied on a [-1;1] normalized range for each parameter.

Site complexity & Risk - 40%

- Average water depth (m) – 40%
- Water depth variation [1=low; 2= med; 3= high], floaters are scored low by default (not sensitive to water dept variation) – 30%
- Offshore cable length (m) – 10%
- Distance to main harbor (km) – 10%
- Met ocean complexity [1=low; 3= high] – 10%

Technology immaturity – 35%

- likely foundation complexity [1=low bottom fixed; 3= high floater] – 90%

- distance to shore (km) [1=low < 50; 3= high > 100] - 10%

Supply chain un-readiness/deliverability – 25%

- likely foundation complexity [1=low bottom fixed;2=mixed; 3= high floater] – 50%
- capacity (MW) – 50%

Table 8. Technical attractiveness. Source: Multiconsult

Zone	Segment	MW	TECHNICAL ATTRACTIVENESS	Basis of Design / Site conditions	Technology maturity ¹⁶	Supply chain readiness, deliverability
1 SANDSKALLEN SØRØYA NORD	NS	200			mixed	
2 VANNØYA NORDØST	NS	200			mixed	
3 AUVÆR	NS	200			Bottom fixed	
4 NORDMELA	NS	200			Bottom fixed	
5 GIMSØY NORD	NS	200			Bottom fixed	
6 TRÆNAFJORDEN SELVÆR	NS	200			Bottom fixed	
7 TRÆNA VEST	OD	1000			floating	
8 NORDØYAN YTRE VIKNA	NS	200			mixed	
9 FRØYABANKEN	OD	1000			floating	
10 STADTHAVET	OD	1000			floating	
11 OLDERVEGGEN	NS	200			mixed	
12 FRØYAGRUNN	NS	200			mixed	
13 UTSIRA NORD	OD	1000			floating	
14 SØRLIGE NORDSJØ I	OS	1000			mixed	
15 SØRLIGE NORDSJØ II	OS	1000			mixed	

Nearshore shallow areas clearly appear as more attractive technically due to their smaller size which enables use of relatively shallow waters for which technical and supply chain solutions are more mature than deep

¹⁶ The table above also provide a pre screening of possible support structure solutions for the base case scenario of 2020: Floating, Bottom fixed or mixed. The “mixed” category indicates that some sites may have a non negligible share of water depth beyond 35m from which some floating solutions are applicable. It is important to note that this impacts earlier indication from the Havvind, 2010 report that all sites with water depth under 70m would be by default bottom fixed.

floating areas. The limited distance to shore and possible placement of substation onshore also contribute to reduce technical uncertainties and risks during construction and O&M phases.

Offshore shallow are to become more attractive over time as technology maturity and supply chain readiness gets in place thanks to foreign developments in UK and Germany. The zones are particularly challenging due to the distance from shore which may require innovative O&M configuration and technology to mature.

Offshore deep will remain challenging in 2020 as full maturity for floating offshore wind solutions may not be tested enough to support large scale commercial scale. Each of the zones needs to be seen in its own context, as particularly weather and access to land plays a large role in their attractiveness and feasibility.

6 Economic assessment of the 15 zones

6.1 Methodology

The cost model used to estimate total costs of developing the designated 15 offshore wind zones has been specifically tailor made to meet the requirements of the assignment. The model is based on Microsoft Excel and uses site-specific variable parameters as input to calculate costs that are comparable across zones. The model's methodology is built on simplified levelised cost of energy principles and cost breakdown specific to the offshore wind farms. The complete lifecycle perspective is taken into account from development phase to decommissioning (ref. Figure 19).

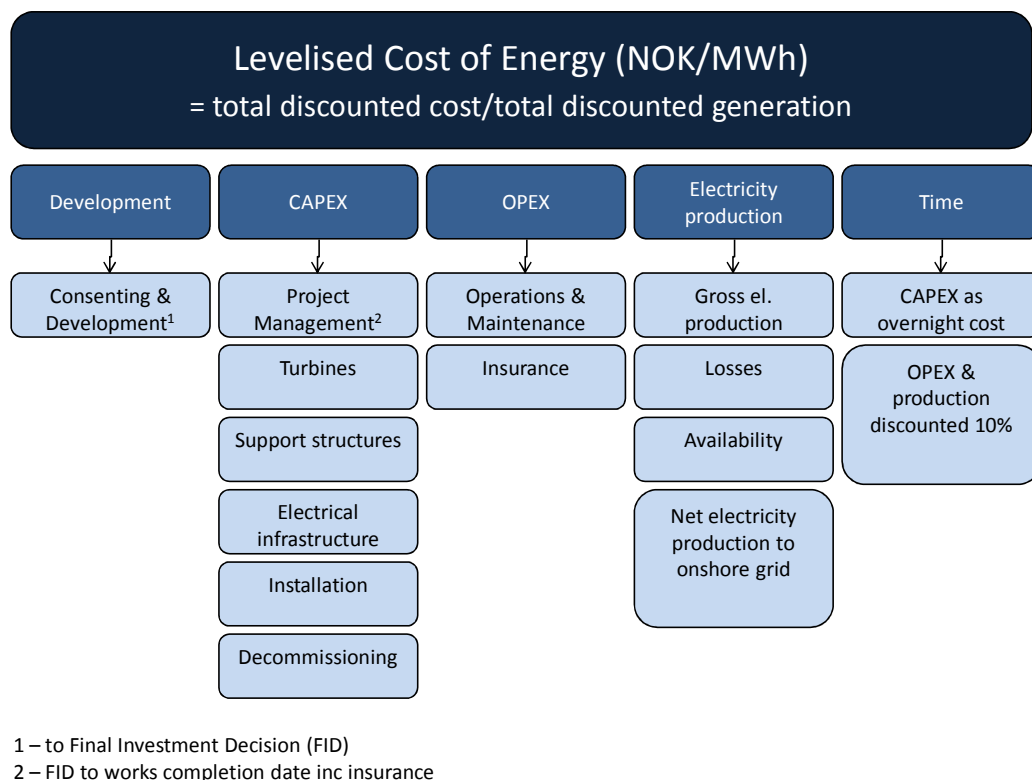


Figure 19. Drivers of the cost model used for ranking

The model has been expanded as a result of pre-screening of Norwegian conditions (covering large span of water depths for instance), review with other relevant reports as well as consultation with partners (such as

SINTEF and K2 Management) and key technology stakeholders in the Norwegian market (refer to Chapter 4). It is built as a generic technology-neutral model. The model covers:

- Full project consenting, development and management costs
- All procurement and construction costs
- Water depth's impact on cost of support structures and installation
- Full electrical equipment from inter-array cables to onshore substation upgrade
- Full-scope analysis of O&M costs, modeled on three categories and three different locations with weather data including wind speed and wave height
- A discount rate of 10%

The model does not cover:

- Re-financing possibilities
- Transmission charges
- Split of CAPEX into several years (e.g. several years for construction and consequent discounting need)
- Choice of different turbines with different load curves – only a fictional 10MW turbine is used with given net capacity factor from each zone as described in Fagutrending 1 by StormGeo.

The model's ability to produce true results has been tested by using the Crown Estate's figures on current project trends (The Crown Estate, 2012) as input and comparing the levelised cost of energy as output to that calculated by the Crown Estate. Total variance of the results was 6% for a 1000MW zone using same MW costs and cost categories as input and same net production per MW as output. The variance is primarily owing to differences in used discounting methodology.

The model uses a number of variable (zone-specific) parameters as input. Input is based on four different sources:

- Net capacity factor calculated by StormGeo in Fagutredning 1¹⁷ (not part of this report).
- Public GIS data, which provides the geographical context and bathymetry conditions over the site and eventual cable routes
- Calculations performed in Technical Assessment (refer to Chapter 4)
- Public sources and best guess estimates (refer to Appendix 1)

The input parameters are expressed as cost per MW or unit costs – depending on the cost item to be evaluated (e.g. a substation has a unit cost; whereas procurement of a wind turbine generator is usually calculated per MW). Adding up relevant cost items will allow for calculation of total cost per category (total development cost; total procurement cost; total installation & logistics cost; total O&M cost; total decommissioning cost). It is also shown how large share of total cost each such cost element makes up.

The O&M costs are also known as **OPEX** of a wind farm and can be calculated either for an average year or as a discounted cash flow from the entire operating period of 20 years. The remaining costs (including a discounted decommissioning cost) are identified as **CAPEX**. CAPEX and discounted OPEX divided by discounted production return a **total lifetime levelised cost** (LCOE) of the zone:

¹⁷ Net capacity factor is published in table 12 on page 42 ("stor utbygging") in the report "Fagutredning 1". Since size of wind farms used by StormGeo in Fagutredning 1 differs significantly from the 200MW/1000MW size used by Multiconsult in this report, then StormGeo's calculated net capacity factor has been applied to 200MW/1000MW to arrive at a proximate net production estimate (MWh) in line with StormGeo's work.

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

Where:

LEC = Average lifetime levelised electricity generation cost

I_t = Investment expenditures in the year *t*

M_t = Operations and maintenance expenditures in the year *t*

F_t = Fuel expenditures in the year *t*

E_t = Electricity generation in the year *t*

r = Discount rate

n = Life of the system

CAPEX (per MW), OPEX (per MW per year) and levelised cost (per MWh) are compared for each of the 15 zones to identify which zone is likely to have the lowest cost of energy. Levelised cost will be the determinant for end-ranking of the 15 zones.

6.2 Assumptions for the cost model

6.2.1 Technical assumptions

Table 9 below summarizes assumptions that have been used (see also Figure 20 and Figure 21):

Table 9. Used criteria for calculations. Source: SINTEF and Multiconsult

Design Element	Assumptions (2020)	Notes
Turbine size	10 MW	Current state of the art is 5-6MW. Research projects target up to 20MW. Increased turbine size will reduce the required number of foundations and, hence, installation operations.
Size and number of wind farm	200MW (1 farm) for small zones 1000MW (3 farms) for large zones	To reach economies of scale, make the project attractive to investors, attract the interest from technology and supply chain players, 200MW is chosen as the smallest preferred zone size. Large zones are assumed to constitute 3 wind farms with total capacity of 1000MW.
Foundation/Anchoring	The cost model does not assess different foundation/anchoring solutions. The price is included as part of the support structure.	Different foundations and anchoring solutions are required dependent on the support structure and the soil conditions. Water depth is today a key critical cost driver which may become moderate over time if floating solutions become cost competitive.
Substations	1 per wind farm, i.e. 200MW requires 1 substation and 1000MW needs 3	Separate costs are assumed for the substations, as 200MW zone needs a 1200t 132/33kV and 1000MW zone needs a 1500t

	substations.	220/33kV substation
Inner array cables	25km for small zones. 126km for large zones.	Half of the inner array cables are assumed to be 240mm ² , the remainder 640mm ²
Export cable	We assume that each zone will be connected with only one export cable to shore. Export cable includes subsea cable and land cable to nearest transformer. Distance is estimated based on routing in GIS-maps.	Planning, financing and deploying the grid connection and transmission in time for the project commissioning are major issues in key offshore wind markets in UK and Germany. Export cable length is also impacting capital expenditure and potential power losses and is therefore a key attractiveness factor. Grid connection to shore should be governed on zone, regional or even national level to optimize cost. Various ownership structures for grid connection are available. 200MW zones comprise a 1000mm ² 132kV cable; 1000MW zones would have a 1400mm ² 320kV cable.
Met mast	At least 1 met mast for small zones. At least 3 met masts for large zones.	Depending on zone depth, bottom fixed or floating met.masts are used
Living platform	Living platforms are assumed to be used for sites with greater than 20km distance to nearest harbor.	Only one living platform will be used per zone; there are no synergies assumed from several nearby zones.
Weather window considerations	Included in O&M costs.	High level analysis of wind speeds and wave height based on actual data has been used to calculate O&M costs. Further estimation of weather impacts is part of a separate "Fagutredning".

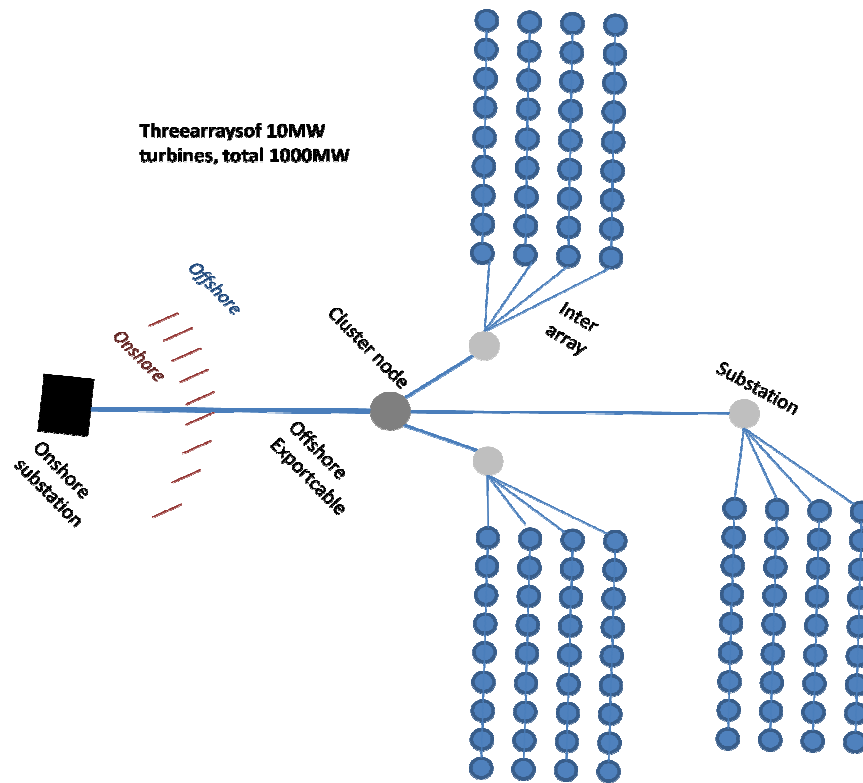


Figure 20. Assumed design of a 1000MW site – large zone. Source: SINTEF for Multiconsult

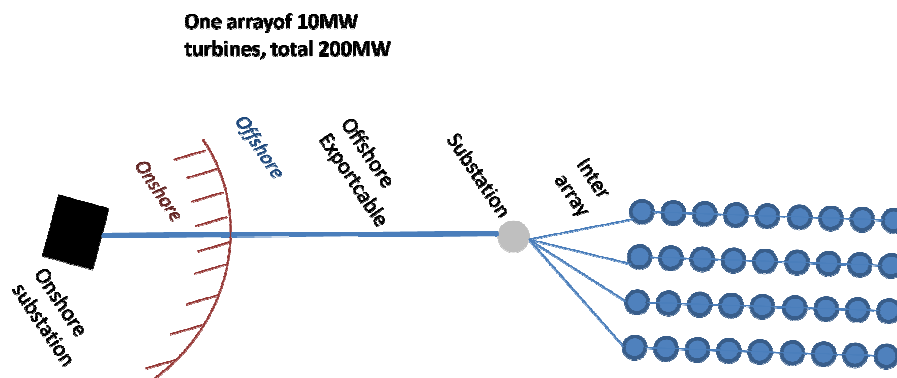


Figure 21. Assumed design of a 200MW site – small zone. Source: SINTEF for Multiconsult

6.2.2 Cost assumptions

- All input parameters are pre-determined for economic evaluation by third parties and/or as shown in Chapter 4.
- All costs are calculated in real 2012 values but correspond to a project built in 2020, assuming a configuration and design of offshore wind farm for a 10MW wind turbine.
- A discount rate of 10% is used for all calculations.
- A lifetime of 20 years is assumed (today the standard lifetime is 20 years but an extension to 25 to 30 years is considered possible in a 2020 perspective – see sensitivity subchapter).
- Net production estimate uses net capacity factor developed by StormGeo in Fagutredning 1 (table 12, page 42) and applies this to 200/1000MW sites.

Development Costs

Most existing reports bundle all development costs together to include application fees, legal fees, wind measurements, salaries, administrative expenses etc. This figure can vary significantly but since it only makes up 1-2% of overall project lifetime costs, the variance is not important for indication of LCOE.

Procurement Costs

The procurement costs relate to one-time purchasing of equipment and materials. There are three major cost categories: turbine; support structure/foundations; and electrical infrastructure.

Cost of a wind turbine generator has been frequently discussed openly and a relatively uniform agreement exists on such costs amounting to ca 10,4 million NOK per MW for an installation in year 2020 - see for example The Crown Estate (2012) and Energy Technologies Institute (2012).

Cost of foundations is easier to predict for jacket technology and much harder for floating support structure, as the latter is an emerging technology. This has already been discussed in Chapter 3 above. For cost analysis a representative sample of cost figures from past and current projects for different bottom-fixed support structure types (monopile, GBS and Jacket) has been compiled to arrive at most realistic cost figures. For floating structures, assumptions have been consolidated with the two most mature technologies available to date: Hywind (SPAR) and Windfloat (semi-submersible).

Substation and cabling costs are defined by two basic offshore wind farm configurations. These are a 200 MW configuration with AC collection and transmission and a 1000 MW system with AC collection and HVDC transmission. The design used for cost modeling is thought to represent the main elements as a basis for preliminary cost estimation. Actual design must be based on detailed site assessment.

The 200 MW configuration is assumed with an AC collection and transmission system. A straight forward layout of the wind farm is assumed with 20 turbines a 10 MW connected by five feeders operated at 33 kV. The feeders are assumed by three core XLPE subsea cables with copper conductors, at the far end by 240 mm² conductors and closer to the substation with 640 mm² conductors.

The distance between the turbines is assumed to be 7 rotor diameters giving total cable lengths of 12.6 km of 240 mm² and 12.6 km of 640 mm². The substation is assumed to host a 132/33 kV transformer, switchgear and ancillaries with a total weight for the topside around 1200 tons installed at a jacket or similar substructure.

The connection to shore is by 132 kV HVAC assuming a three core XLPE subsea cable with 1000 mm² copper conductors. Some de-rating of the cable must be assumed for transition through the J-tube bringing cable capacity possibly somewhat below 200 MW, but for cost estimation the selected cable is still considered a fair assumption. Compensation of reactive losses is assumed by reactors at onshore connection point and if required, also offshore at the offshore sub-station. The amount and split of reactive compensation on- and offshore would be part of a more detailed design.

In the 1000 MW configuration the collection system is as for the 200 MW wind farm, but with three 220/33 kV offshore substations each connecting a 330 – 340 MW wind farm. These substations are assumed about 10 km apart and connected by separate three core XLPE subsea cable with 1000 mm² copper conductors to a 1000 MW HVDC VSC platform. Transmission to shore is by 320 kV HVDC 1400 mm² sub-sea cable, through a landfall transition and connecting to 1000 MW onshore HVDC VSC station.

Installation and Logistical Costs

Installation costs can be grouped into six major categories: installation cost of foundations; installation of substation; installation of cables; installation of the wind turbine generator; construction project management; and insurance and financing costs.

Foundation installation costs vary depending on depth of site: for depths up to 70m this report uses jacket foundations; in deeper waters floating foundations are chosen. Due to expected maturity of floating technology a significant cost reduction is expected for installation of such foundations by year 2020 (refer to

Appendix 3). The values used in cost calculations are based on experience and publicly available reports; and have been further cross-checked during interviews with industry representatives.

Wind turbine installation costs are largely made up of two components – the preparatory work carried out at harbor (assuming complete pre-assembly of turbines) and the on-site assembly of a pre-assembled wind turbine to a pre-installed foundation.

A landfall transition is assumed for bringing the cable from subsea to land. A general water depth of 50m is assumed to calculate average cable costs per km for bottom fixed turbines, whereas for floaters 200 m is assumed. The cost of the electrical system is sensitive towards water depth, but not significant compared to the general uncertainty in cost of components.

Project management and financing costs are tied to the size of the project and hence vary significantly depending on size of the zone. As multiple wind farms can be developed and owned by separate parties within the same 1000MW zone, no cost synergies are assumed for such costs in 1000MW vs 200MW.

A flat 10% contingency is applied to cover uncertainty related to all procurement and installation related costs. This is a commonly used percent share¹⁸. The contingency is not calculated on insurance and financing fees.

Operation and Maintenance Costs

The O&M costs can be divided into six categories, all calculated per installed MW. However the actual costs per MW for the same category (e.g. transportation costs) vary depending on the size of the zone (200 vs 1000 MW) and location (near shore / far offshore). Operation costs cover general surveillance of the wind farm in an onshore control centre. This means that operation costs cover all normal, daily work done off- or onshore to enable the turbines to produce electricity is regarded as operation. Insurance cost is calculated separately to allow for compensation of lost production or claims related to power plant failure.

The rest of daily O&M costs cover repairing faults (minor and major) and carrying out preventive maintenance on the equipment to improve its condition. Depending on the number of failures, maintenance on a turbine should normally be done only a few times each year. In the system level there will always be a mix of component maintenance strategies, simply because the components that form the system have different failure types and consequences, thus have different criticality, and should therefore be maintained differently. In principle, the O&M plan should consider the risk of failures, taking into account both the probabilities and consequences of failures.

In addition, the weather (particularly the wave conditions on the site) plays a significant role when designing the maintenance plan for an offshore wind farm. Normally, the weather conditions at sea are better during summer than in the winter, thus most of the preventive maintenance activities are done during the summertime. Along the coast of Norway the weather conditions vary substantially, generally being rougher than in most other countries (e.g. Denmark, Germany, UK). At the same time the Norwegian service providers have long experience with the weather conditions from the marine and oil and gas industries, which is something the offshore wind industry will benefit from. Another aspect that differentiates Norway from many other countries is the deep waters close to shore. From an O&M point of view this will not have much negative implications. On the positive side, this implies that there are many deepwater ports along the coast of Norway making it possible to carry out rehabilitations etc.

Going further offshore have some implications that will effect also the operation and maintenance. When it comes to planning and design it will be profitable to invest in more redundancy in some of the less costly but still critical components (e.g. sensors, instrumentation and communication). Generally, more robust components (even if more expensive) should be considered for improving the reliability, and also more use of condition monitoring and remote presence. Investment and operation costs of the offshore wind farm vessel

¹⁸See for example The Crown Estate (2012)

fleet can therefore be expected to constitute up to over 30% of the total cost of energy for a far offshore wind farm. This means that large savings can be obtained if the vessel fleet is optimised with respect to size and vessel characteristics, and the fleet is operated efficiently. Going more than about 20 km from shore, a living platform may be a relevant solution. Sea-sickness may be a problem if people need to be transported more than 30 minutes in significant wave heights above 1 m (Cockburn, 2010). The implication of this "trivial" phenomenon may be that the mobilisation time will be increased by the personnel recovery time before they can start working.

For calculations used in this report, costs were calculated separately for monitoring, maintenance staff salaries, transportation, electrical infrastructure maintenance, consumables, storage and insurance. The costs vary depending on size of the zone (200 vs 1000 MW – the larger zone has some synergies from e.g. electrical infrastructure maintenance) as well as their location (<20 km from shore, 20-100 km from shore, >100 km from shore) and whether an on-site accommodation platform exists or not. An average wave height from three different measurement spots – Utsitra nord, Frøyabanken and Stadthavet – was used to accurately calculate transportation costs. The calculations assume a breakdown of a major component in year 13, but all costs are calculated as an average annual value over 20 year lifetime.

Historically, there are little cost data available for offshore wind power in general and particularly when it comes to O&M costs. This is of course due to the fact that there is relatively few offshore wind farms built as yet, and most of the existing farms are from the last five years. Thus, there is little experience to support sound O&M cost estimates. *The Economics of Wind Energy* (EWEA, 2009) suggests annual O&M costs to be NOK 128/MWh, except for Middelgrunden where the O&M costs are assumed to be €12/MWh (= NOK 96/MWh). *Douglas-Westwood* (Douglas-Westwood, 2010) suggested the O&M costs in 2010 to be NOK 710 000/MW, with an expected decrease to NOK 570 000/MW in 2030. The corresponding figures used in this report suggest average O&M costs to be in the range of 600 000 – 700 000 NOK/MW for a 200 MW farm, and 500 000 – 600 000 NOK/MW for a 1000 MW farm by 2020.

Decommissioning Costs

A great uncertainty exists in terms of decommissioning costs of wind turbines. No numbers have been agreed on for even onshore wind turbines, as too few of them have approached end of useful lifetime. Whereas for onshore turbines the business case usually assumes a zero decommissioning cost owing to return value from scrap metal; the costs of dismantling offshore wind farms are much greater. The Crown Estate report elaborates that "reverse assembly process to installation takes 1 year. Piles and cables cut off at a depth below seabed which is unlikely to lead to uncovering. Environmental monitoring conducted at end. Residual value and cost of scrapping ignored" (The Crown Estate, 2012). Hence similar cost per MW to that proposed by the Crown Estate are used in this report (3-3,5 mNOK/MW).

6.3 Results of the cost model

This chapter presents all figures relative to each other; full figures are available in Appendix 2.

6.3.1 CAPEX

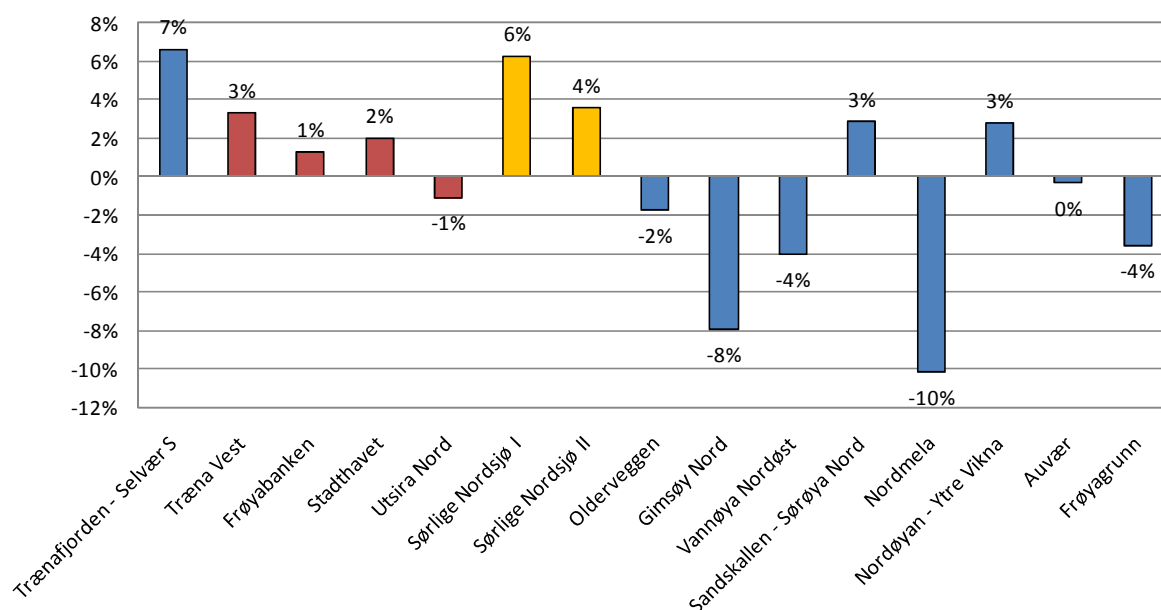


Figure 22. Overview of calculated CAPEX per MW (0% = 15 zone average). Yellow indicates far offshore shallow water zones; red is for far offshore deep waters; blue is near shore shallow waters.

Performed calculations indicate a CAPEX range of 26-31 million NOK per MW, with higher CAPEX in far offshore sites. Depth of the zone does not seem to be a major driver of CAPEX in such offshore locations: comparison of shallow water vs deep water offshore locations (accordingly shown as yellow and red on figure 23) shows that procurement and installation would in fact be higher in the former category as opposed to the deep-water latter. Lowest development costs per MW would be in a zone closest to shore, and here depth makes a difference: turbines in relatively shallow waters cost less. At the same time it is visible that three of the near-shore zones also have above-average capital investment costs per MW. Closer observation confirms that these zones are located at a greater distance from harbors and connection points than the remainder of the near-shore grouped zones. Hence, more cable and more time is needed to install wind turbines in such locations. It is logical that nearby shallow locations reduce both procurement and installation costs significantly. On the other extreme highest CAPEX per MW owes much to great distance from shore, hence constituting an investment for living platform and HVDC conversion station for 1000MW zones (note: all far offshore zones are 1000MW).

6.3.2 OPEX

Actual distance to shore has not been considered in detail, rather the O&M costs are grouped based on category (<20km from shore, 20-100km from shore, >100km from shore). Figure 23 lists the different costs per MW – ranging from as low as 507 000 NOK/MW to 564 000 NOK/MW. As visible from the figure, all zones except Utsira Nord are at the higher end, with insignificant variance. It would be expected that far offshore installations are much more exposed to intensive weather conditions and suffer from higher O&M costs per MW. The results prove the opposite for a number of reasons: (1) all far offshore zones are 1000MW, which allows for economies of scale compared to a 200MW zone – despite increased investments in HVDC conversion station, thicker export cable etc; (2) O&M costs for all far offshore zones are calculated with an on-site living and maintenance platform. Although this platform comes at an extra investment cost, this is outweighed by the added benefits of lower transportation costs and faster responsiveness to breakdown on site. Large deviation from average in case of Utsira Nord owes to the fact that the zone has both an on-site platform (like all 1000MW zones) as well as is up to 50% closer to shore and harbors compared to the rest of

the 1000MW zones. In fact some of the 200MW zones are even further offshore than Utsira Nord but have not been allocated a living platform due to their small size.

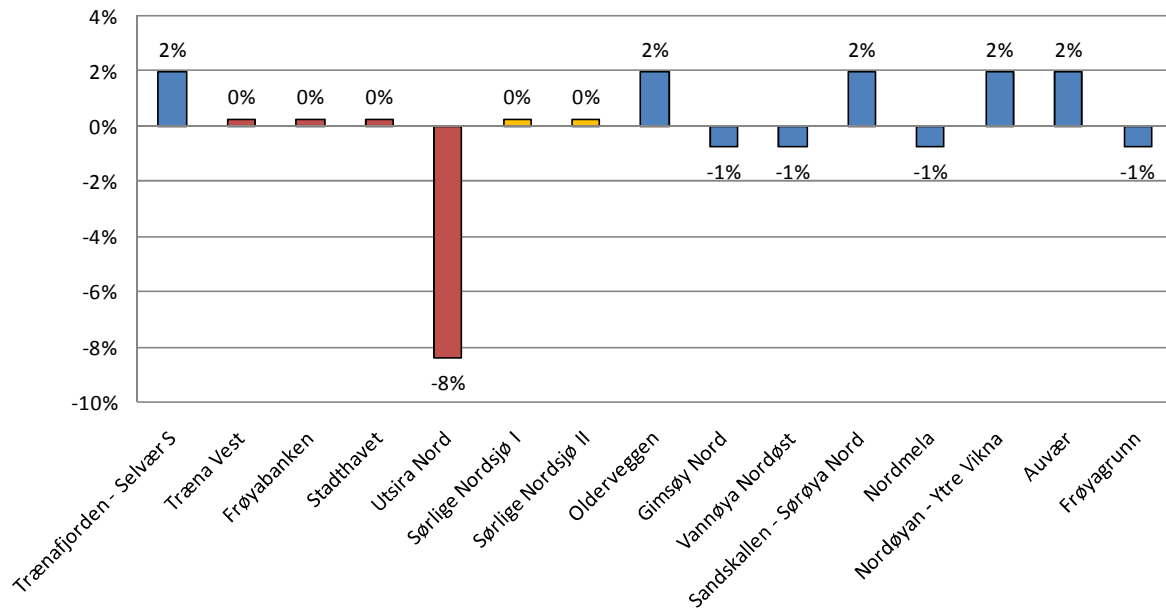


Figure 23. Overview of calculated OPEX per MW (0% = 15 zone average). Yellow indicates far offshore shallow water zones; red is for far offshore deep waters; blue is near shore shallow waters.

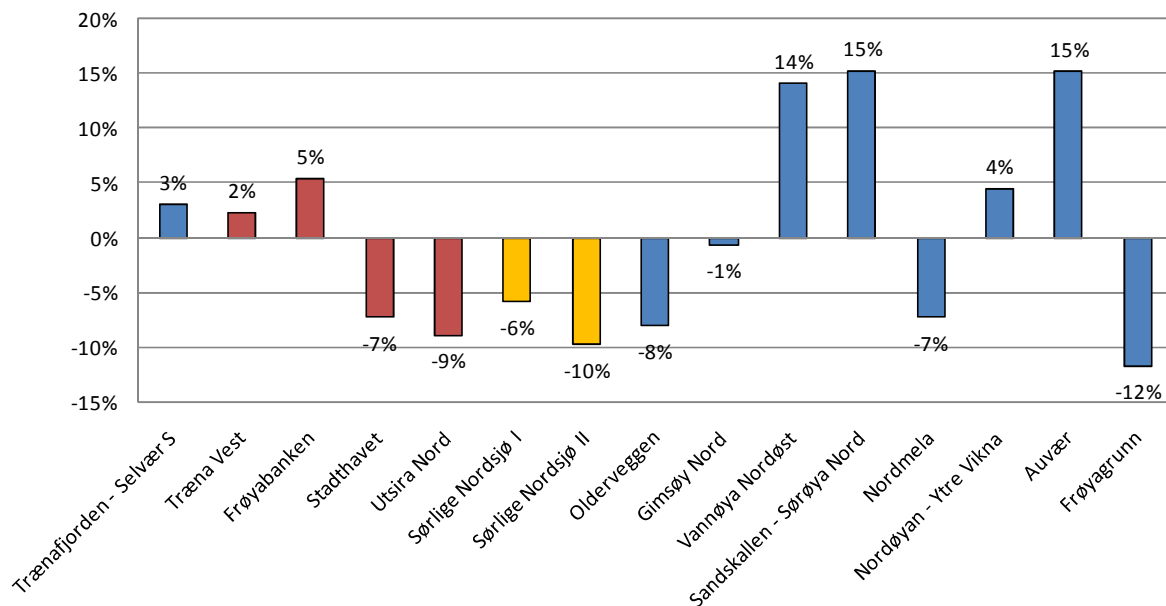


Figure 24. Overview of calculated levelised cost in 15 zones (0% = 15 zone average). Yellow indicates far offshore shallow water zones; red is for far offshore deep waters; blue is near shore shallow waters.

As economic ranking of the zones needs to highlight the most economically feasible areas, it is logical to use levelised cost of energy for guidance. As explained earlier, levelised cost of energy considers both lifetime project costs (CAPEX and OPEX) as well as lifetime production. The calculated levelised cost of the 15 zones ranges between 907-1183 NOK/MWh, generally being higher in smaller near-shore zones (although Frøyagrund, Nordmela and Olderveggen from the same category also have one of the lowest LCOE). This is a result from mix of economies of scale, distance to shore (far offshore zones have on-site living and maintenance platforms) as well as the production factor (ref. Figure 24). Figure 25 proves that distance to

shore plays a big role in determination of total investment costs, however the spread is not linear for levelised costs. Figure 26 proves that depth is not a direct determinant.

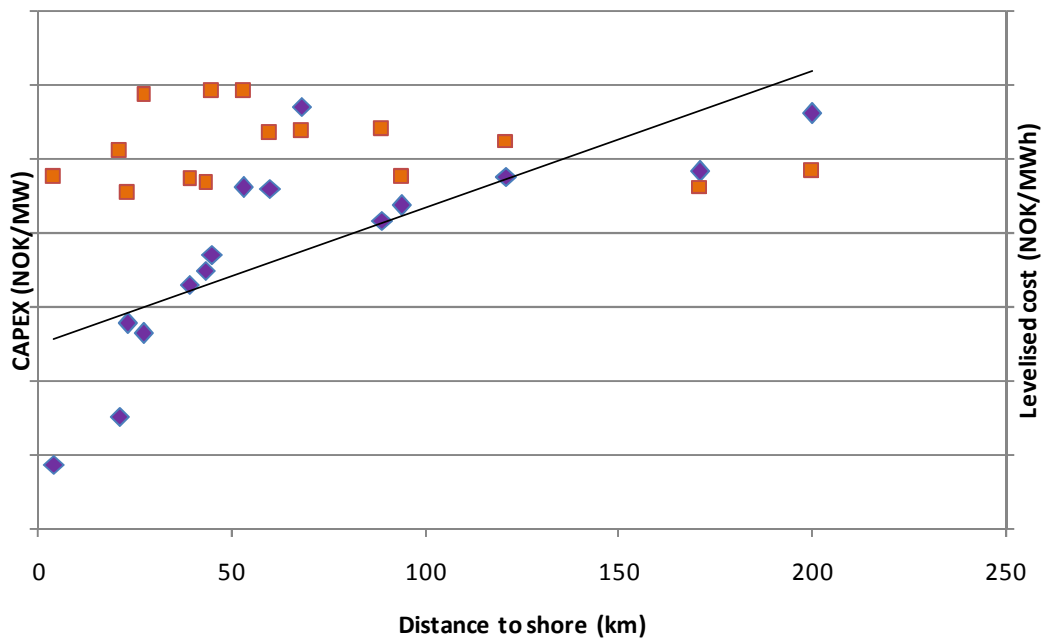


Figure 25. Comparative ranking of the zones relative to distance. Purple marks show CAPEX with a black linear trendline, orange marks show LCOE, without trendline. Note two different vertical axes (with different scale)!

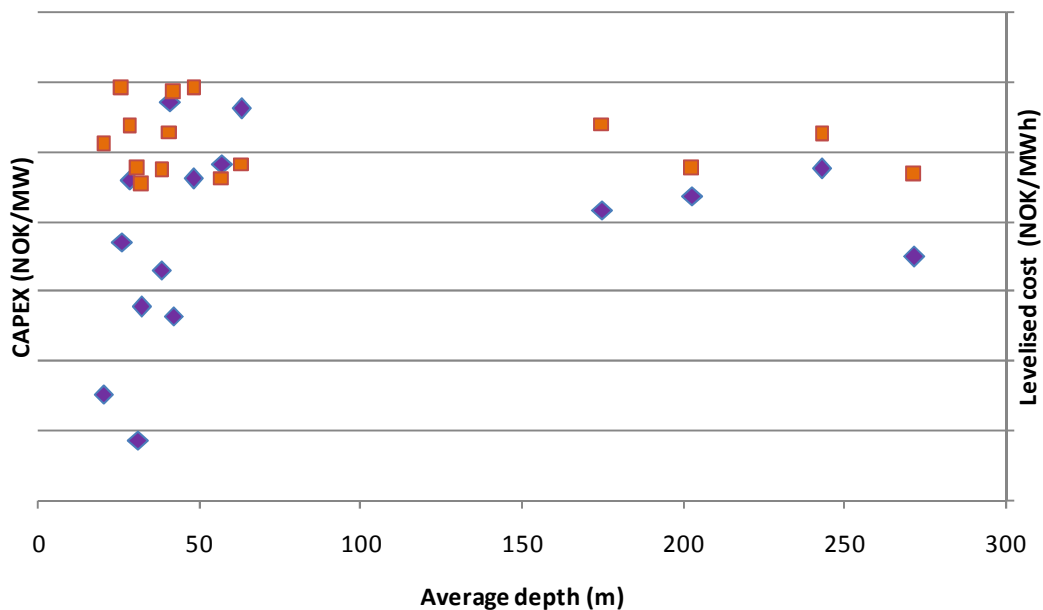


Figure 26. Comparative ranking of the sites' relative to depth: purple marks show CAPEX, orange marks show LCOE. Note two different vertical axes (with different scale)!

Calculated levelised costs are indeed on the lower side of other internationally published figures (see e.g. (The Crown Estate, 2012)). Figure 27 demonstrates that size of the capacity factor might be part of the reasoning why Norwegian values are higher: much of the existing literature uses 37-40% capacity utilization factor, whereas the values used in the 15 Norwegian zones range from 37-50%. As validation of accurate capacity factor was not part of this report's deliverables sensitivity testing has been performed to also allow for lower

factor values. However using base case values it can be concluded that Norway has the potential to become one of most attractive offshore wind zones in Europe.

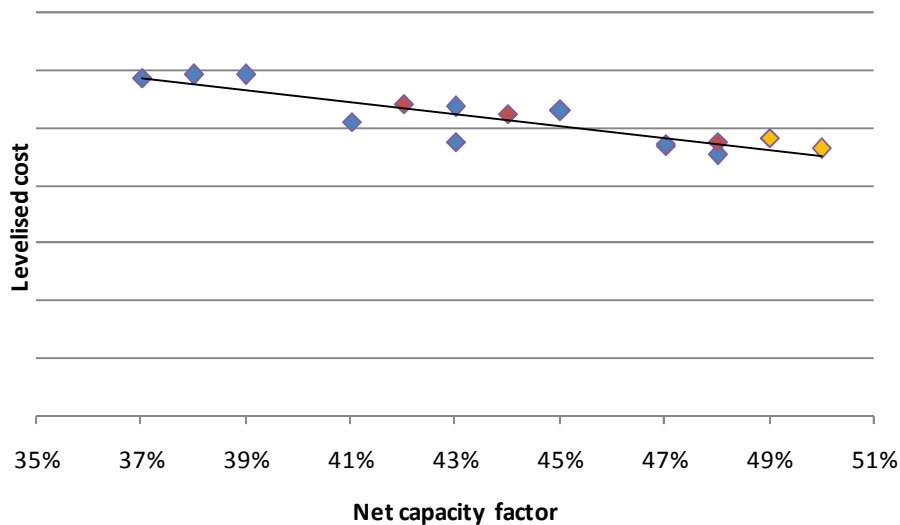


Figure 27. Relationship between productivity and end-cost. Yellow indicates far Offshore Shallow water zones; red is for far Offshore Deep waters; blue is Near-shore Shallow waters.

The levelised cost of energy is lowest in three zones in near shore shallow waters. As most of the 15 zones are located in that category, the same zone also has a lot of variance. Shallow waters also contribute to low LCOE even if the distance increases. As zones with mid-distance from shore also exhibit a large LCOE variance similarly to near-shore zones, the far-offshore shallow water zones seem to be a much safer choice for the investor. This is partly explained by the fact that only 2 zones fitted into this category, hence greatly limiting possible variance. Several faraway deepwater zones of 1000MW make up the last category, hence also explaining the larger variance between minimum and maximum LCOE.

The preliminary analysis conducted under the mandate of this report shows that judging by groups of zones, near shore zones available for development would be less preferred by the investor in year 2020 as far offshore zones have more benefits which outweigh the higher upfront investment costs. Namely, higher production factor is a direct determinant of lower LCOE, whereas depth and distance to shore have no direct correlation to end-costs. Such a conclusion must be made with high caution, as far offshore zones are also larger at 1000MW and none of the near shore zones are bigger than 200MW. Results have shown that most attractive LCOE is in fact available at some closer, less-costly zones so site-specific differences need to be acknowledged within each zone.

6.4 Sensitivity

Great uncertainty exists for predicting accurate cost levels 20 years ahead. Future costs will be impacted by several key factors, such as raw material prices, level of competition, commercialization of innovative technologies, etc. All such cost drivers have an influence partly independently of each other, partly as a reaction to each other – and this makes it especially hard to come up with accurate predictions for cost progression over years while at the same time introducing ever larger wind turbines. As much of cost trend elaboration was covered Chapter 3 and is available in Appendix 3; the sensitivity testing here has been carried out for more imminent potential changes:

- 10% devaluation of euro against Norwegian krone (calculated as 10% lower procurement costs)

- Lower R&D results not leading to expected cost reductions (calculated as 10% higher procurement costs)
- Useful lifetime of the wind farm extended from 20 to 25 and 30 years
- 5% more yield from greater understanding and optimization of the wind farm
- 5% less yield due to lower net capacity factor
- 8% and 12% discount factors as opposed to the default 10%
- Greater uncertainty and possible cost overruns due to immature technology (calculated as 15% contingency instead of default 10%)

The results are shown in Figure 28. Clearly the biggest impact factor comes from use of discounting methodology. The 10% used in this report is a commonly accepted value throughout the industry, but investors might want to use different discounting depending on their cost of capital. It is also evident that prolonging lifetime of the wind farm has a favourable effect on the levelised cost of energy. Interpretation of such result however needs caution – O&M costs were calculated for 20 years lifetime, assuming a major breakdown in year 13. The sensitivity testing applies the same annual average O&M cost throughout 25 and 30 years, which is however unrealistic as aging turbines have more wear and tear, produce less and need more maintenance. Hence such illustration is purely descriptive. As levelised cost of energy is directly dependent on the production, it also comes as no surprise that maximizing yield has a favourable effect. Similarly, failure to reap planned yield results in higher overall lifetime costs by the same factor (5% lower yield translates to 5% higher LCOE). Project contingency seems to be having less impact on the LCOE, but possible depreciation of the euro against the Norwegian krone (NOK) poses a threat – hence investors might want to consider currency hedging in case of large-scale offshore wind farm developments.

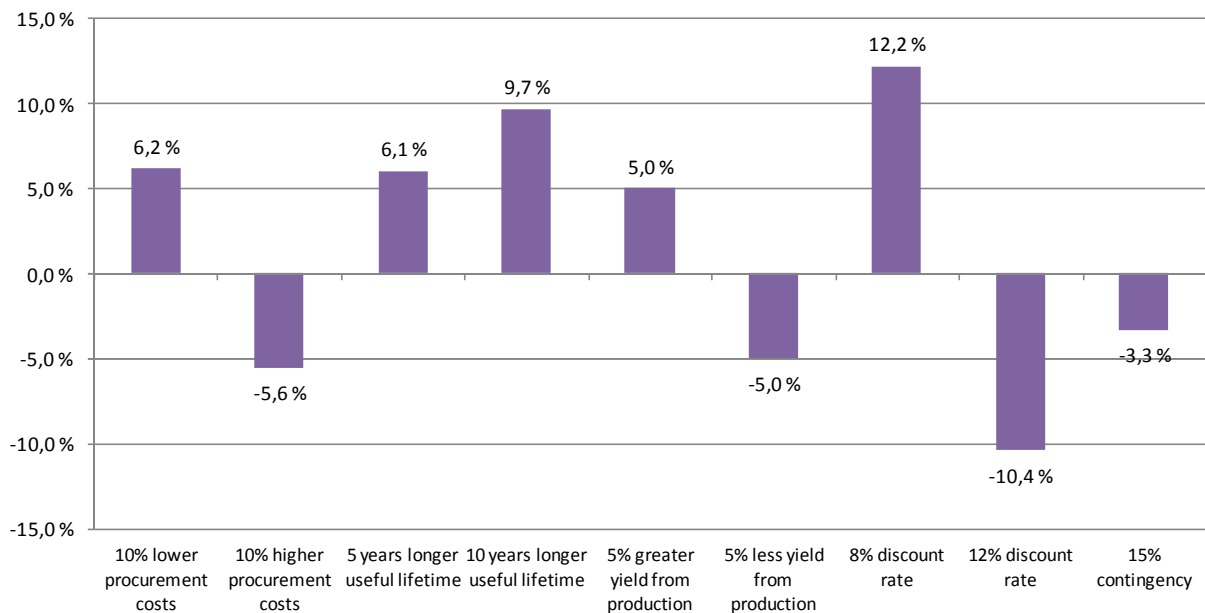


Figure 28. Sensitivity of LCOE

There are also several key uncertainties specifically for the annual O&M costs. In the figures below the sensitivities in the annual O&M costs per MW due to variation of some vital parameters are shown, and the lessons learned from this can be summarized as follows:

- The *number of operations* have significant impact on the costs (linear relation), and an increase from 10 (base case) to 30 operations per year leads to nearly a doubling of the costs (ref. Figure 30).

- The *share of failures for heavy components* is difficult to estimate, and at the same time it has big impact on the costs. An increase from 1 % (base case) to 2 % of the failures results in close to 25 % higher costs (ref. Figure 30).
- The O&M costs per MW decrease with the *wind farm size*, as should be expected, but when it reaches a certain point the reduction levels out. In our case the reduction is considerable up to about 500 MW, while above 1000 MW the decrease in the costs is small (ref. Figure 31).

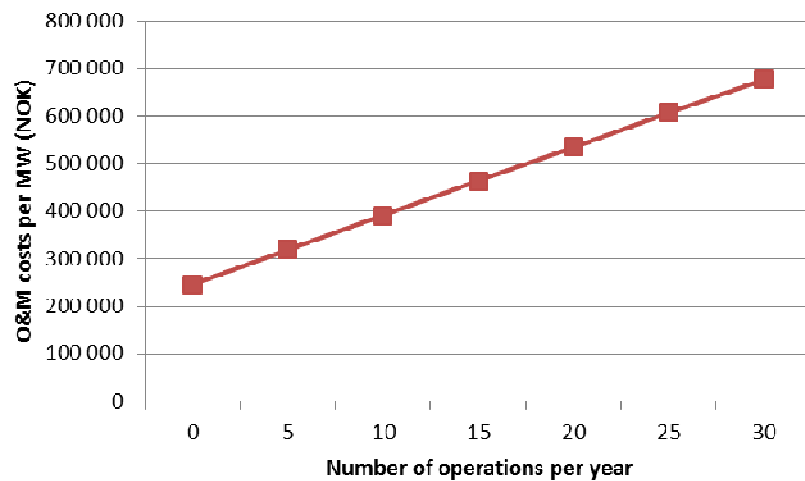


Figure 29. Annual O&M costs as function of the number of operations

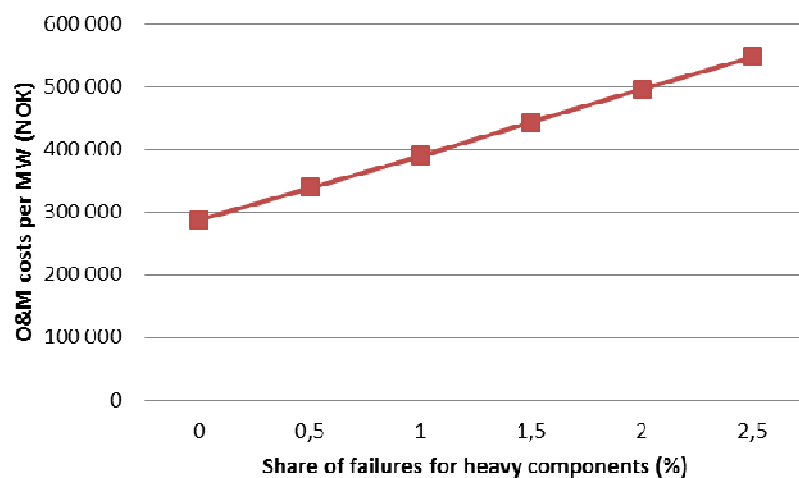


Figure 30. Annual O&M costs as a function of share of failures for heavy components

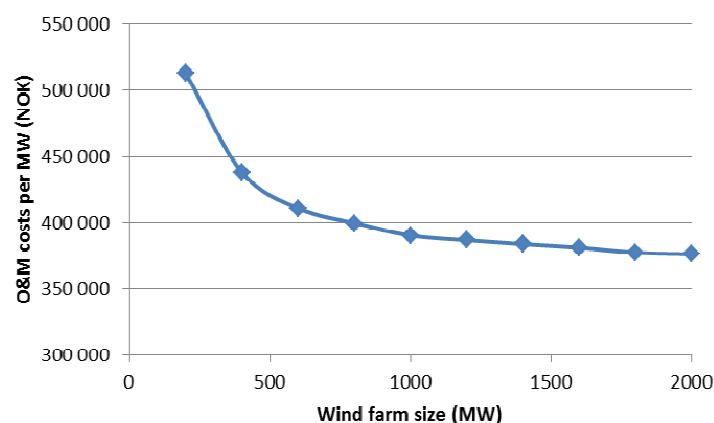


Figure 31. Annual O&M costs as a function of the wind farm size

6.5 Economic attractiveness of the 15 zones

Considering the level of uncertainties regarding timeframe, site conditions and technology maturity, the economic assessment does not aim at estimating accurately the costs of each of the 15 offshore wind areas. Thanks to realistic assumptions, the bottom up cost model provides nevertheless a sufficient basis for comparing and ranking the attractiveness of different areas through the analysis of relative normalized cost (ref. Table 10).

The colour code used to rank the **economic attractiveness** of the 15 offshore wind zones has the following meaning:

	Low levelised cost of energy per MW relative to the other zones
	Average levelised cost of energy per MW relative to the other zones
	High levelised cost of energy per MW relative to the other zones

The economic scoring indicator is based on the estimation of the levelised cost of energy per MW in the 2020 base case.

Three key cost drivers (weighted average of the net capacity factor, average site depth and total cable length) are provided in the table for information in order for the reader to understand the main drivers behind the relative economic attractiveness. The reading of the table clearly indicates that in the context of the 15 zones in a 2020 perspective the net capacity factor is the most influencing cost factor.

Table 10. Economic attractiveness of the 15 zones

Zone	Segment	MW	ECONOMIC ATTRACTIVENESS	Net capacity factor (%)	Average site depth (m)	Total cable length [km]
1 SANDSKALLEN SØRØYA NORD	NS	200				
2 VANNØYA NORDØST	NS	200				
3 AUVÆR	NS	200				
4 NORDMELA	NS	200				
5 GIMSØY NORD	NS	200				

6	TRÆNAFJORDEN SELVÆR	NS	200				
7	TRÆNA VEST	OD	1000				
8	NORDØYAN YTRE VIKNA	NS	200				
9	FRØYABANKEN	OD	1000				
10	STADTHAVET	OD	1000				
11	OLDERVEGGEN	NS	200				
12	FRØYAGRUNN	NS	200				
13	UTSIRA NORD	OD	1000				
14	SØRLIGE NORDSJØ I	OS	1000				
15	SØRLIGE NORDSJØ II	OS	1000				

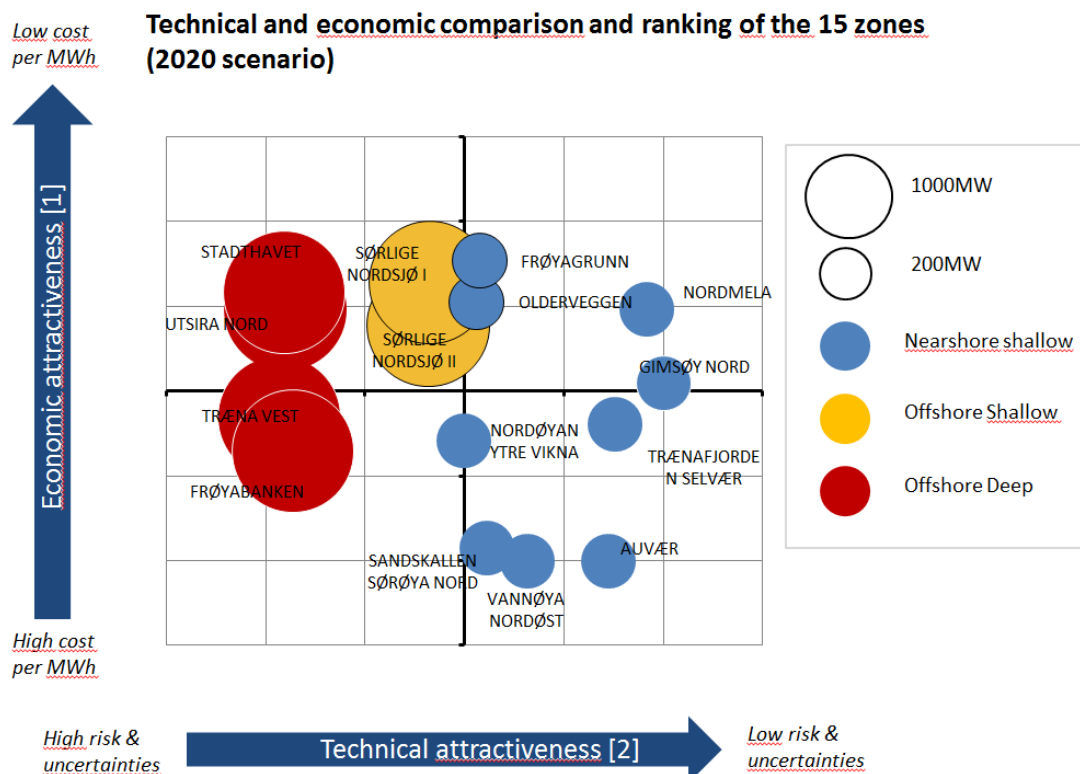
7 Technical and economic assessment - summary

Table 11 below presents the high level results of the overall attractiveness assessment using a color code.

Table 11. Zone comparison and ranking

Zone		Segment	MW	ECONOMIC	TECHNICAL
1	SANDSKALLEN SØRØYA NORD	NS	200		
2	VANNØYA NORDØST	NS	200		
3	AUVÆR	NS	200		
4	NORDMELA	NS	200		
5	GIMSØY NORD	NS	200		
6	TRÆNAFJORDEN SELVÆR	NS	200		
7	TRÆNA VEST	OD	1000		
8	NORDØYAN YTRE VIKNA	NS	200		
9	FRØYABANKEN	OD	1000		
10	STADTHAVET	OD	1000		
11	OLDERVEGGEN	NS	200		
12	FRØYAGRUNN	NS	200		
13	UTSIRA NORD	OD	1000		
14	SØRLIGE NORDSJØ I	OS	1000		
15	SØRLIGE NORDSJØ II	OS	1000		

The results of the assessment are plotted into Figure 32 to indicate the relative technical and economic attractiveness of the different zones.



[1] Based on levelised cost of energy calculation

[2] Technical risk & uncertainties based on a) Site conditions complexity; b) Technology maturity and c) supply chain readiness

Figure 32. Attractiveness of the 15 offshore wind zones. Source: Multiconsult

We introduce 5 new zone categories (A-E) corresponding to the attractiveness level in a 2020 perspective. Category A is the most attractive in terms of economics and technical aspects (Table 12).

Table 12. Final scoring of the zones – 2020 perspective

Categories of zones	Zone	Segment	MW	Average water depth on site (m)	Offshore cable length (km)	Net capacity factor (%)
A	4	NORDMELA	NS	200	31	43 %
	5	GIMSØY NORD	NS	200	20	41%
	11	OLDERVEGGEN	NS	200	38	47 %
	12	FRØYAGRUNN	NS	200	32	48 %
B	14	SØRLIGE NORDSJØ I	OS	1000	63	49 %
	15	SØRLIGE NORDSJØ II	OS	1000	57	50 %
C	1	SANDSKALLEN SØRØYA NORD	NS	200	48	39 %
	2	VANNOYA NORDØST	NS	200	42	37 %
	3	AUVÆR	NS	200	26	38 %

	6	TRÆNAFJORDEN SELVÆR S	NS	200	41	68	45 %
	8	NORDØYAN YTRE VIKNA	NS	200	28	60	43 %
D	10	STADTHAVET	OD	1000	203	94	48 %
	13	UTSIRA NORD	OD	1000	272	43	47 %
E	7	TRÆNA VEST	OD	1000	243	121	44 %
	9	FRØYABANKEN	OD	1000	175	89	42 %

Category A - Shallow waters (average in the 30-40m range) and limited water depths variation allows technology being developed for UK and Germany projects ahead of 2020 to be used. Supply chain constraints should be limited due to the small size total generation capacity in each zone (200MW) and foreign capabilities ready by then to complement Norwegian industry if necessary. The distance to shore and offshore cable length is limited, which reduces cost and risks of marine operations. Water depth variability is high on all these zones which could bring more construction and supply chain challenges. Unfavorable wave conditions bring also challenges to the zones. The wind conditions are very good, which allows for relatively low levelised cost of energy especially in international context.

Technical attractiveness could improve over time as innovative structure design and installation methods mitigate risks associated with high seas and mature support structure concepts well suited for sites with high variable depths.

Category B - Deeper zones in the 60-70m range for which technology and supply chain are not in place in 2012. Both bottom fixed and floaters could be envisaged over the zones. Long distance to shore and expensive grid transmission costs are counter-balanced by excellent wind conditions which overall could bring levelised costs at attractive levels. In addition, the large size of the site may enable economies of scale. Synergies with the UK round 3 Dogger Bank area could also be investigated.

Technical attractiveness will improve over time as innovative solutions for deep bottom fixed and floating structures (such as semi submersibles and TLP for water depth suited for 35-70m water depths) are brought to maturity. These large zones will allow mass serial productions in due time and could employ the same supply chain as deepest areas of UK round 3 zones.

Category C - These four near shore zones are of limited capacity (200MW). This enables deployment with moderate supply bottlenecks exposure. Wind conditions are relatively lower than in category A and B although still high in comparison to European offshore wind standards.

Technical attractiveness may not evolve over time as wind conditions should remain lower than in other categories.

Category D - Large scale deep water projects of 1GW or more will be challenging to deliver within 2020. An emerging supply chain may have developed by 2020 but it is likely that cost reduction through economies of scale and supply competition will not be triggered by then. Distance to shore will be an additional issue for which innovation O&M solutions may be required.

Over time, increased technology maturity and supply chain readiness on floating structures will make these zones more attractive.

Category E - These 2 floating areas represent relatively similar technical design characteristics to category D but relatively lower wind conditions combined with increased distance to shore make them less attractive.

These zones are likely to remain relatively less attractive due to unfavorable wind conditions.

8 Conclusions and recommendations

8.1 Summary of findings

Technical analysis

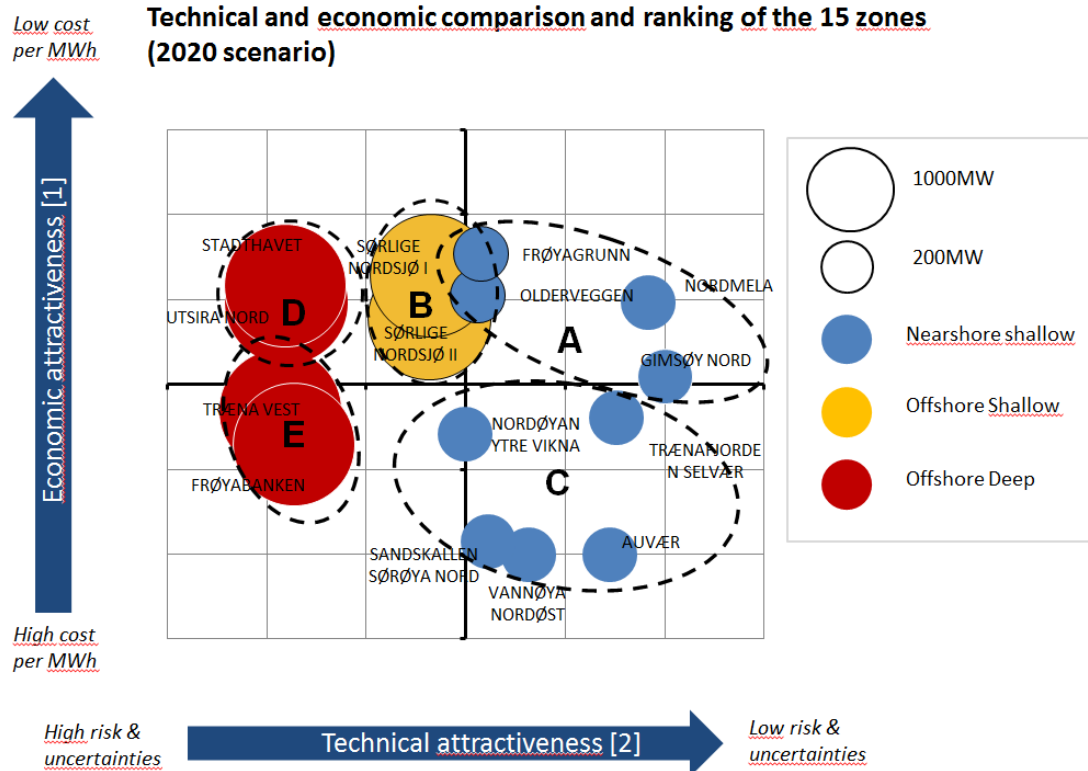
- Norway has relatively deep waters in comparison to projects under construction in Europe. Several of the 15 zones will require floating structures as turbines will be placed in deeper than 70 meters. A finding of the study is that some of the sites considered earlier for bottom fixed could be suitable either for floating and/or bottom fixed. This is due to the recent acceleration in the development of semi submersible and TLP solutions, applicable from 35m, and expected to be cost competitive with bottom fixed in 50m during the 2020-2025 period.
- Some zones have the characteristics of high water depth variation which will present technical challenges translating to possible supply chain issues and impacts on cost.
- Export cable length varies from 10 to 200km and requires innovative solutions to overcome cost reduction, risk and safety issues of operating far offshore. As some zones are located near archipelagos, some substations could be placed on shore although current study has not looked at this possibility.

Economic analysis

- Performed calculations indicate a CAPEX range of 26-31 million NOK per installed MW, with higher CAPEX in far offshore sites.
- OPEX ranges from 510 to 570 thousand NOK per installed MW. In most zones, the OPEX would be at the higher end of the range.
- The calculated levelised cost of the 15 zones ranges between 907-1183 NOK/MWh, generally being higher in smaller near-shore zones. The levelised cost of energy for Norway in 2020 corresponds to the cost reduction expectation expressed in UK of 1kNOK/MWh by 2020. However this is firstly due to very good Norwegian wind conditions (as per calculated net production estimate in Fagutredning 1).
- Highest impact on levelised cost would come from expansion of useful lifetime of the wind farm and choice of discounting methodology. All base case values used in this report are those believed to be most realistic. The sensitivity analysis of levelised cost performed as part of this report shows that the 900-1200 NOK/MWh range is realistic, although subject to limitations.

Comparison and ranking

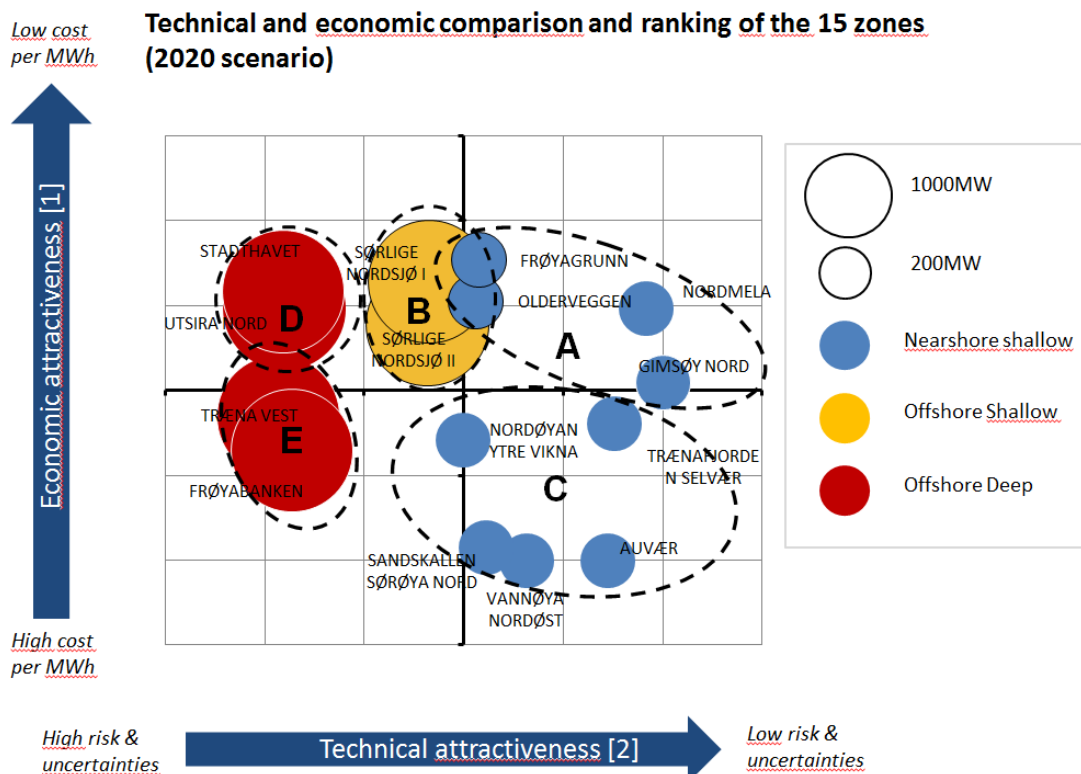
The final attractiveness results are summarized in



[1] Based on levelised cost of energy calculation

[2] Technical risk & uncertainties based on a) Site conditions complexity; b) Technology maturity and c) supply chain readiness

Figure 33 below. Category A is the most attractive while E less attractive.



[1] Based on levelised cost of energy calculation

[2] Technical risk & uncertainties based on a) Site conditions complexity; b) Technology maturity and c) supply chain readiness

Figure 33. Attractiveness categories. Source: Multiconsult

It is important to note that additional attractiveness criteria may be considered by developers and financial sponsors. In particular the size of the project may impact the level of interest. In foreign markets, the current average size of project under construction is around 210MW, however future projects under planning with financial backing have capacities of minimum 300MW per site. Accordingly, the smaller zones of 200MW may not be as attractive to key financial players as a 1000MW zone.

8.2 Takeaways for the Spatial planning and SEA

8.2.1 Scope and selection / attractiveness criteria of an offshore wind site

Relevant attractiveness indicators for the selection of a site are suggested below:

- **Wind conditions** – The ability to produce at low cost energy depends on wind conditions
- **Minimal capacity of 200MW (typical)** - to reach economies of scale, the project must be attractive to investors and attract the interest from technology and supply chain players in developing innovative solutions.
- **Grid access and integration** – Planning, financing and deploying the grid connection and transmission in time for the project commissioning are major issues in key offshore wind markets in UK and Germany. Export cable length is also impacting capital expenditure and potential power losses and is therefore a key attractiveness factor.
- **Maturity and cost competitiveness of support structure eligible for the site** – Water depth is today a key critical cost driver which may become moderate over time if floating solutions become cost competitive.
- Suitability and availability of the supply chain for the construction phase in time for the project delivery is likely to increase over time.

- Level of potential conflicts and risk related to environmental and social impacts might increase as turbines get larger.
- As per the initial mandate of the study, our primary focus in the study is on commercial scale projects. Nevertheless some of the offshore zones could serve the purpose of demonstration plant or medium scale pilot plant. Particularly Northern part of Trænafjorden –Selvær offers a wide range of varying depths as well as islands with onshore/offshore positioning possibilities. This should be further assessed.

8.2.2 Implications for environmental impact assessments

- The choice of turbine technology impacts potential visual impact. This will particularly influence the visibility, size, the number and spacing of turbines. The development of innovative non conventional turbines such as vertical axis turbines could have an important influence on visual impact, bird impact, radar/aviation for which little experience and knowledge is been gathered.
- The choice of support structure / foundation design affects the scoping of possible environmental impacts. As shown in the study, the choice of support structure design dictates the offshore installation methods to be utilized for which environmental impact varies (ex: impact on piling of jackets). The dimensions and anchoring of each foundation which varies with site conditions impacts the scale of possible environmental disturbance and damage (ex: footprint of a gravity base structure).
- The materials (concrete or steel in most cases) have consequences on the potential impacts of the marine environment during the O&M and decommissioning phase.
- The list of eligible support structure / foundation design impacts possible direct and indirect benefits to society. The fabrication and installation methods will also dictate the choice for suitable construction facilities in Norway or abroad. Value creation for industry and employment will depend directly on the choice of technology.

8.3 Recommendations to NVE

Norway offshore wind rationale, vision and road map

- Consolidate rationale and vision for developing offshore wind in Norway in parallel to deploying an offshore wind export industry.
- A long term horizon of 2030-2050 must be taken into account to integrate into a single strategy a) the exploitation of Norway's offshore wind resources together with b) the realization of the export market potential for the Norwegian industry (already relevant today)
- Define and commit to road map, including eventually offshore wind specific targets to be defined realistically together with the industry and politicians

Development of a Norwegian technology platform and industry

- Map Norwegian capabilities and competitiveness in the international offshore wind market and map out value creation from export and domestic market potential
- Investigate further the potential/opportunities and barriers/risks/challenges in the transfer and coexistence of offshore wind industry and offshore Oil & Gas.
- Link R&D to short and medium term market reality, through involvement in demonstration and commercial projects
- Strengthen research focus on economics, cost reduction and technology/supply chain interrelations.

Technology selection

- Monitor technology development and competitive arena in the global market
- Develop international collaboration through R&D, demonstration as well as supply chain partnerships

Economics

- Conduct technical-economic studies on specific case to better understand levelised cost of energy. Special attention to be paid on technology risk and uncertainties, dependence on external cost factors such as commodity prices.
- Build cost forecasting intelligence to monitor future cost competitiveness of offshore wind from Norway versus alternatives in domestic and international markets.
- Translated economic reality and national political targets with appropriate support schemes

Zone qualification and selection

- Define the purpose¹⁹ of deployment and success factors of the project:
 - Demonstration
 - Pilot
 - Large scale commercial
- Build zone selection criteria in line with the above.
- Improve integrated planning and decision making tools taking into account relevant parameters, including wind resources, grid connection, installation or service harbor, wind farm access, sea depths, design wind conditions, wave heights and seabed conditions.
- Schedule in a timely manner the necessary studies and surveys to support the zone qualification ahead of the selection
- Engage with foreign authorities to exchange views and retrieve lessons learnt to support the above.
- Engage with potential industry players, developers and operators in the assessment and prioritization of the zones in order to a) allow lessons learned to be taken into account and b) secure their interest in participating in the development of the zones.

Environmental impact assessment

- New innovative technologies, especially related turbines and support structures, will impact supply chain, economics and most probably the scope of environment impact assessment. Future planning and EIA requirements must be designed to allow the emergence of new technologies.
- Demonstration and pilot projects can provide key platforms for monitoring environmental issues in parallel to the technical qualification of new technologies.

Pilot plant

- Consider the implementation of a pilot plant program ahead of defining strict planning framework in order to allow lessons learnt for all stakeholders

¹⁹ See definition of demonstration, pilot and commercial projects in Appendix Technology and cost development trends

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10 List of Figures

Figure 1. Current European offshore wind project in operation and pipeline. Source: EWEA, 2011.....	11
Figure 2. Overview of a typical offshore wind farm cluster (1-1,5GW) in 2012-2015. Source: Multiconsult.....	12
Figure 3. Overview of the key offshore wind obstacles ahead of 2020 ambitions. Source: Multiconsult	13
Figure 4. Future project trends: Water depth (m) deployment in 2015, 2020 and 2030. Source: Multiconsult .	13
Figure 5. Evolution in conventional turbine dimensioning. Source: Multiconsult.....	14
Figure 6. Innovation and maturity for the leading concepts under development. Source: Multiconsult	17
Figure 7. Norway's unique energy, offshore and maritime heritage. Source: Multiconsult	19
Figure 8. CAPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate (2012)	20
Figure 9. OPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate (2012).....	20
Figure 10. Levelised cost of offshore wind energy (NOK / kWh). Source: Data from BCG 2010, graph by Multiconsult.....	21
Figure 11. Fabrication and installation of support structure/foundation + installation of turbine. Source: Multiconsult.....	23
Figure 12. Bottom fixed costs – Foundation fabrication/installation and 10MW turbine installation. Source: Multiconsult.....	24
Figure 13. Foundation supply/installation and 10MW turbine installation cost comparison over the 2012-2030 period (optimistic scenario regarding cost reduction for floating) Source: Multiconsult	24
Figure 14. The 15 offshore wind zones: near shore and further offshore; in shallow and deep waters.....	25
Figure 15. Zone assessment methodology used for this report	26
Figure 16. Plotting of the 15 zones based on zone water depth and distance to onshore grid connection: NS (in blue), OS (in yellow), OD (in red). Size of the bubble relates to size of zone (200/1000MW). Source: Multiconsult.....	27
Figure 17. Methodology for determining onshore and offshore cable lengths and relevant water depth on a given zone. Source: Multiconsult	31
Figure 18. Estimated export cable length (km) versus average site water depth (m). NS (in blue), OS (in yellow), OD (in red). Source: Multiconsult	33
Figure 19. Drivers of the cost model used for ranking	35
Figure 20. Assumed design of a 1000MW site – large zone. Source: SINTEF for Multiconsult	39
Figure 21. Assumed design of a 200MW site – small zone. Source: SINTEF for Multiconsult.....	39
Figure 22. Overview of calculated CAPEX per MW (0% = 15 zone average). Yellow indicates far offshore shallow water zones; red is for far offshore deep waters; blue is near shore shallow waters.....	43
Figure 23. Overview of calculated OPEX per MW (0% = 15 zone average). Yellow indicates far offshore shallow water zones; red is for far offshore deep waters; blue is near shore shallow waters.....	44
Figure 24. Overview of calculated levelised cost in 15 zones (0% = 15 zone average). Yellow indicates far offshore shallow water zones; red is for far offshore deep waters; blue is near shore shallow waters.	44
Figure 25. Comparative ranking of the zones relative to distance. Purple marks show CAPEX with a black linear trendline, orange marks show LCOE, without trendline. Note two different vertical axes (with different scale)!	45
Figure 26. Comparative ranking of the sites' relative to depth: purple marks show CAPEX, orange marks show LCOE. Note two different vertical axes (with different scale)!	45
Figure 27. Relationship between productivity and end-cost. Yellow indicates far Offshore Shallow water zones; red is for far Offshore Deep waters; blue is Near-shore Shallow waters.	46

Figure 28. Sensitivity of LCOE	47
Figure 29. Annual O&M costs as function of the number of operations.....	48
Figure 30. Annual O&M costs as a function of share of failures for heavy components	48
Figure 31. Annual O&M costs as a function of the wind farm size.....	49
Figure 32. Attractiveness of the 15 offshore wind zones. Source: Multiconsult.....	51
Figure 33. Attractiveness categories. Source: Multiconsult	55

11 List of Tables

Table 1. Assumptions used in this report	15
Table 2. Support structure technical feasibility and maturity according to water depth. Source: Multiconsult .	16
Table 3. Internal cost reduction factors directly addressable by various market participants (Source: Multiconsult)	22
Table 4. Zone segmentation	26
Table 5. Three key drivers of technical attractiveness	28
Table 6. Key site condition factors influencing LCOE.....	28
Table 7. Outputs from the technical review / site assessment. Source: Multiconsult, 2012	32
Table 8. Technical attractiveness. Source: Multiconsult	34
Table 9. Used criteria for calculations. Source: SINTEF and Multiconsult	37
Table 10. Economic attractiveness of the 15 zones	49
Table 11. Zone comparison and ranking.....	50
Table 12. Final scoring of the zones – 2020 perspective	51

APPENDICES

Appendix 1: Comparative overview of the 15 zones

Appendix 2: Detailed results of the economic assessment

Appendix 3: More Descriptive Overview of Technology and cost development trends in Offshore Wind

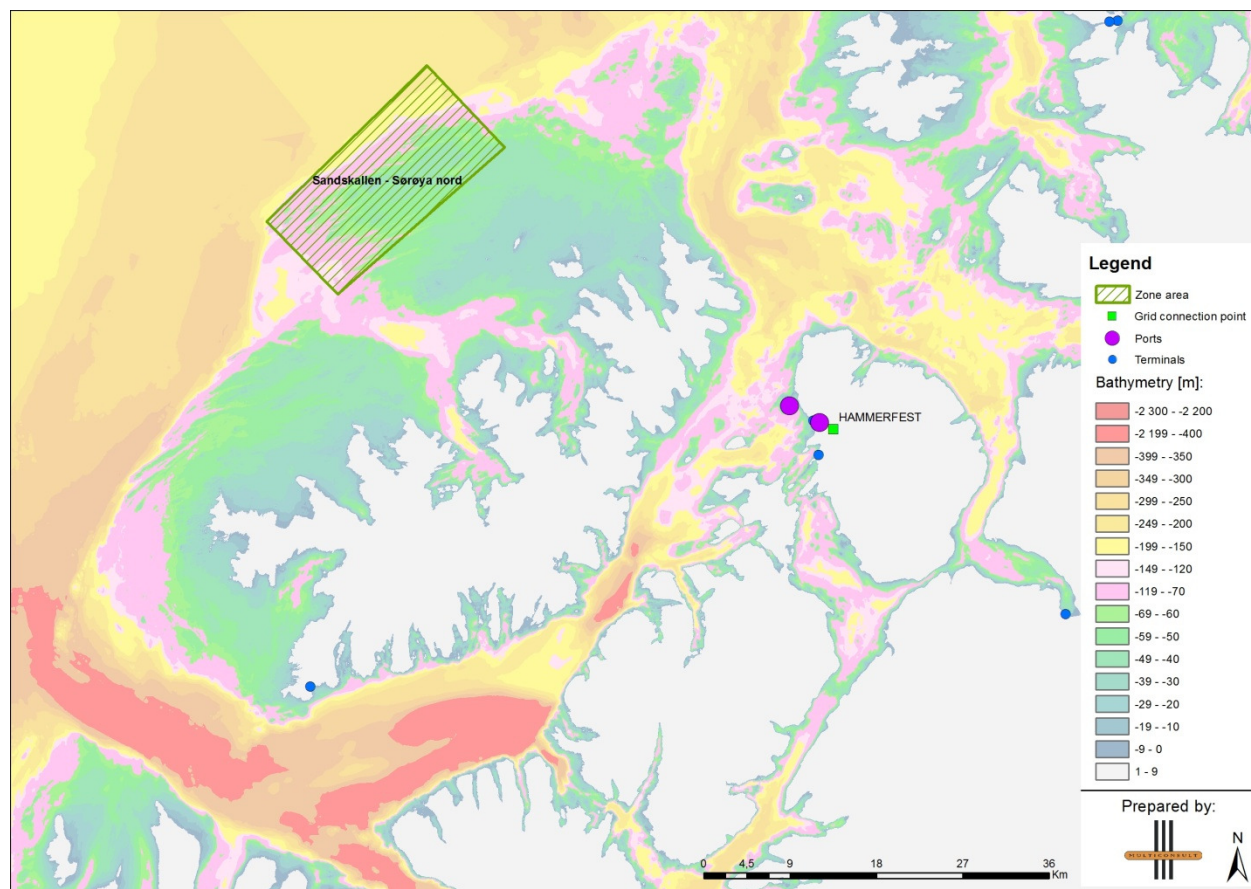
Appendix 4: Detailed overview of used assumptions

Appendix 5: Source of GIS data

Appendix 6: About the authors & contact information

Appendix 1: Comparative overview of the 15 zones

Sandskallen – Sørøya Nord



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3300 hours	
Grid connection point		Hammerfest	
Total zone area		260 km ²	
Distance from zone to shore		14 km	
Average zone depth		54 m	
Calculated bathymetry within the zone:			
0-20 m	0 %	80-100m	13 %
20-40 m	1 %	100-120m	9 %
40-60 m	35 %	120-140m	4 %
60-80m	22 %	>140m	16 %

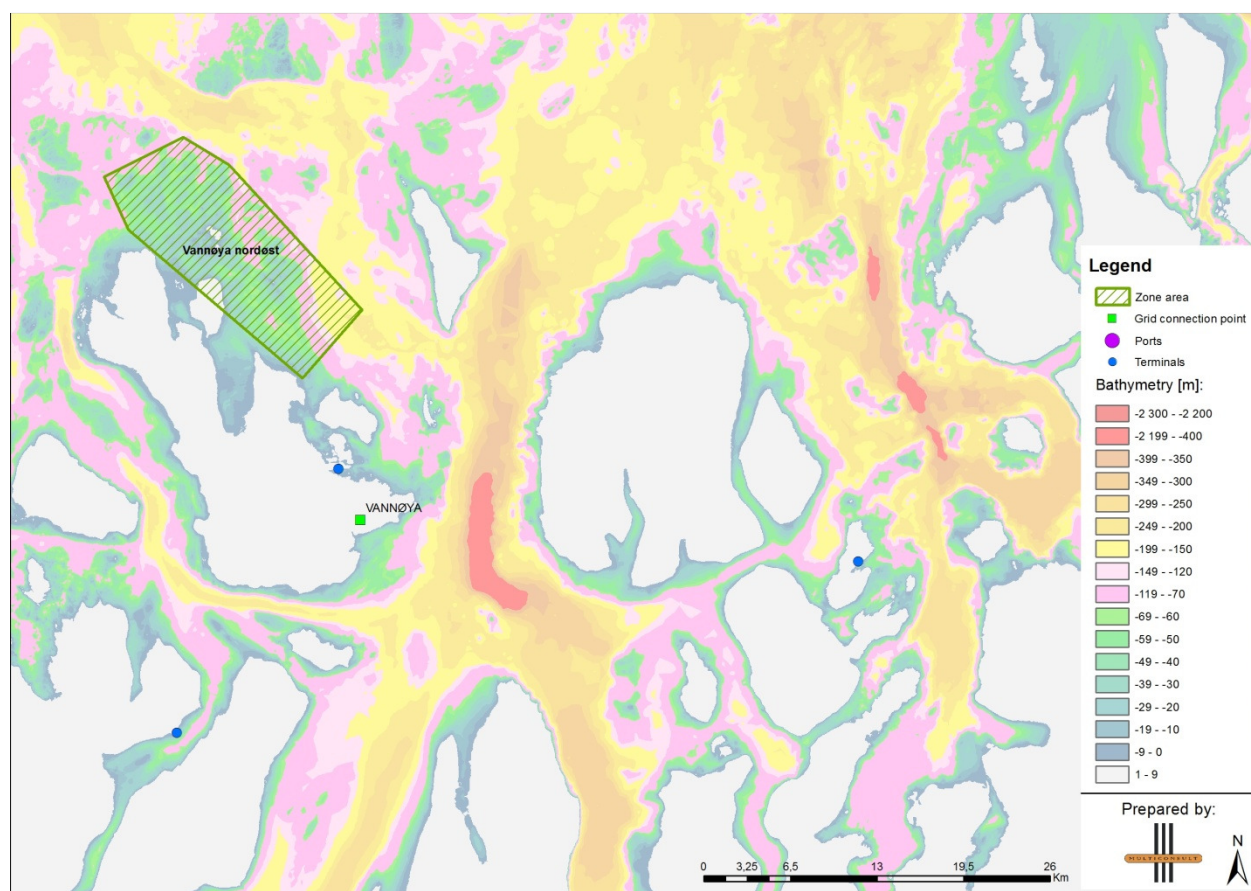
New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	39% / 683 280 MWh		
Site area	19 km ²		
Distance from zone to closest national port or ISPS terminal	50 km / 50 km		
Export cable length (subsea cable from zone to shore)	53 km	Total length to grid connection: 55 km	
Onshore cable length (from shore to connection point)	2 km		
Average site depth	48 m	Min: 35m / Max: 68m	

Calculated bathymetry within the site:			
0-10m	0%	40-50m	73%
10-20m	0%	50-60m	20%
20-30m	0%	60-70m	4%
30-40m	3%	>70m	0%

The wind farm within the zone "Sandskallen – Sørøya Nord" is located about 50 km from the grid connection point and main port facilities. The export cable route to Hammerfest substation seems quite clear and is assumed to be feasible due to lack of too shallow water or narrow straits. The calculated average water depth for a wind farm site located close to the northeastern corner of the zone is 47 meters, and the bulk of the site is located between 40 and 50 meters water depth. Micro-siting should enable homogenization of water depths and improve cost reduction / production to grid.

Vannøya Nordøst



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3000 hours	
Grid connection point		Fakken	
Total zone area		154 km ²	
Distance from zone to shore		<1 km	
Average zone depth		43 m	
Calculated bathymetry within the zone:			
0-20 m	5 %	80-100m	9 %
20-40 m	25 %	100-120m	4 %
40-60 m	32 %	120-140m	2 %
60-80m	14 %	>140m	8 %

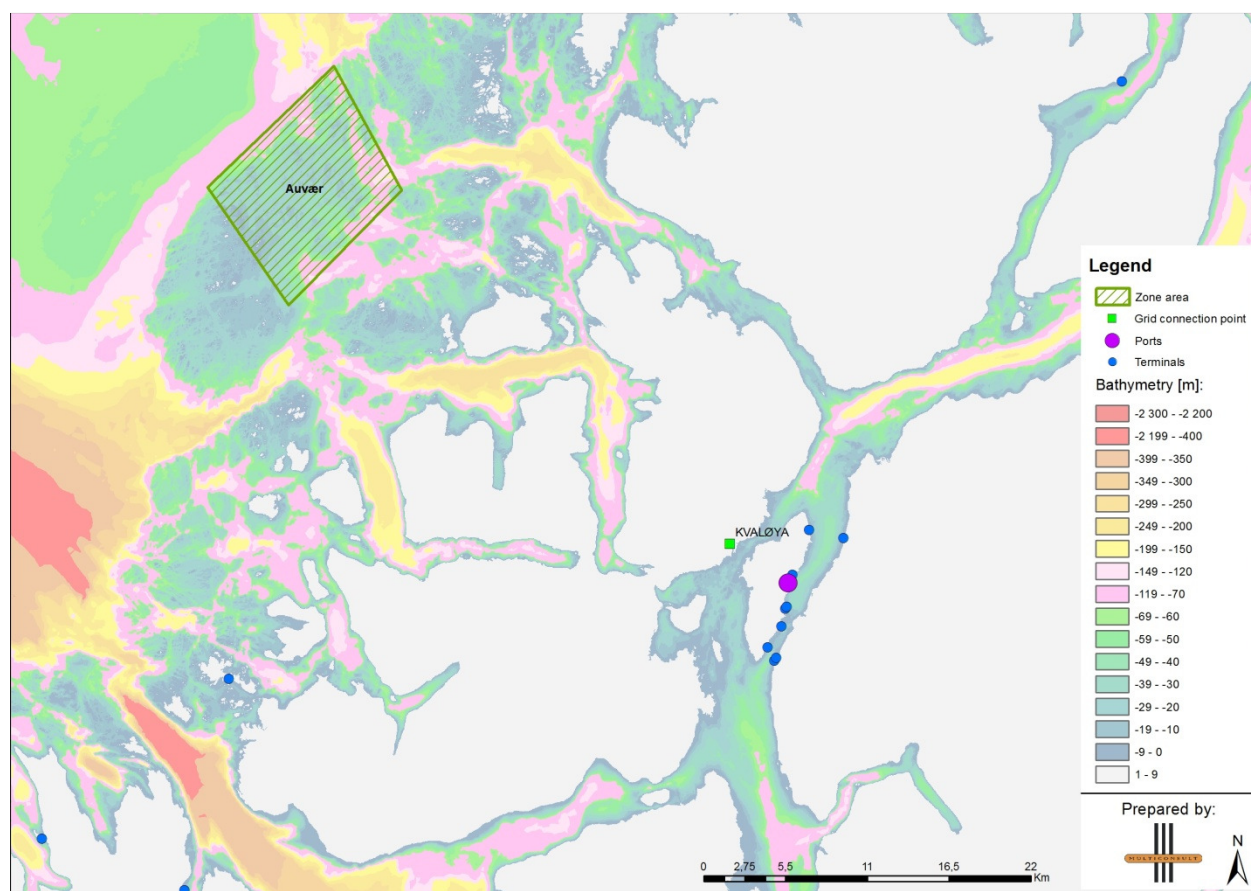
New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	37% / 648 240 MWh		
Site area	19 km ²		
Distance from zone to closest national port / ISPS terminal	91 km / 18 km		
Export cable length (subsea cable from zone to shore)	27 km	Total length to grid connection: 30 km	
Onshore cable length (from shore to connection point)	3 km		
Average site depth	42 m	Min: 17m / Max: 69m	

Calculated bathymetry within the site:			
0-10m	0%	40-50m	34%
10-20m	0%	50-60m	18%
20-30m	11%	60-70m	3%
30-40m	33%	>70m	0%

The wind farm within the zone "Vannøya nordøst" is located about 30 km from the grid connection point and 22 km from the closest ISPS terminal. The closest national port is located about 90 km from the wind farm site. It might pose a challenge placing the export cable between the main island (Vannøya) and the archipelago outside of the eastern part of Vannøya due to shallow water, but a cable route on the Northern side of the islands seems feasible. The wind farm enjoys the possibility to position its substation on shore (on one of the nearby islands). This has not been considered in economic calculations, but could allow for cost reduction as well as better accessibility and safety. The calculated average water depth for the site is 51 meters, and the bulk of the site is located between 50 and 70 meters water depth.

Auvær



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3000 hours	
Grid connection point		Kvaløya	
Total zone area		105 km ²	
Distance from zone to shore		11 km	
Average zone depth		33 m	
Calculated bathymetry within the zone:			
0-20 m	15 %	80-100m	7 %
20-40 m	44 %	100-120m	5 %
40-60 m	16 %	120-140m	1 %
60-80m	12 %	>140m	0 %

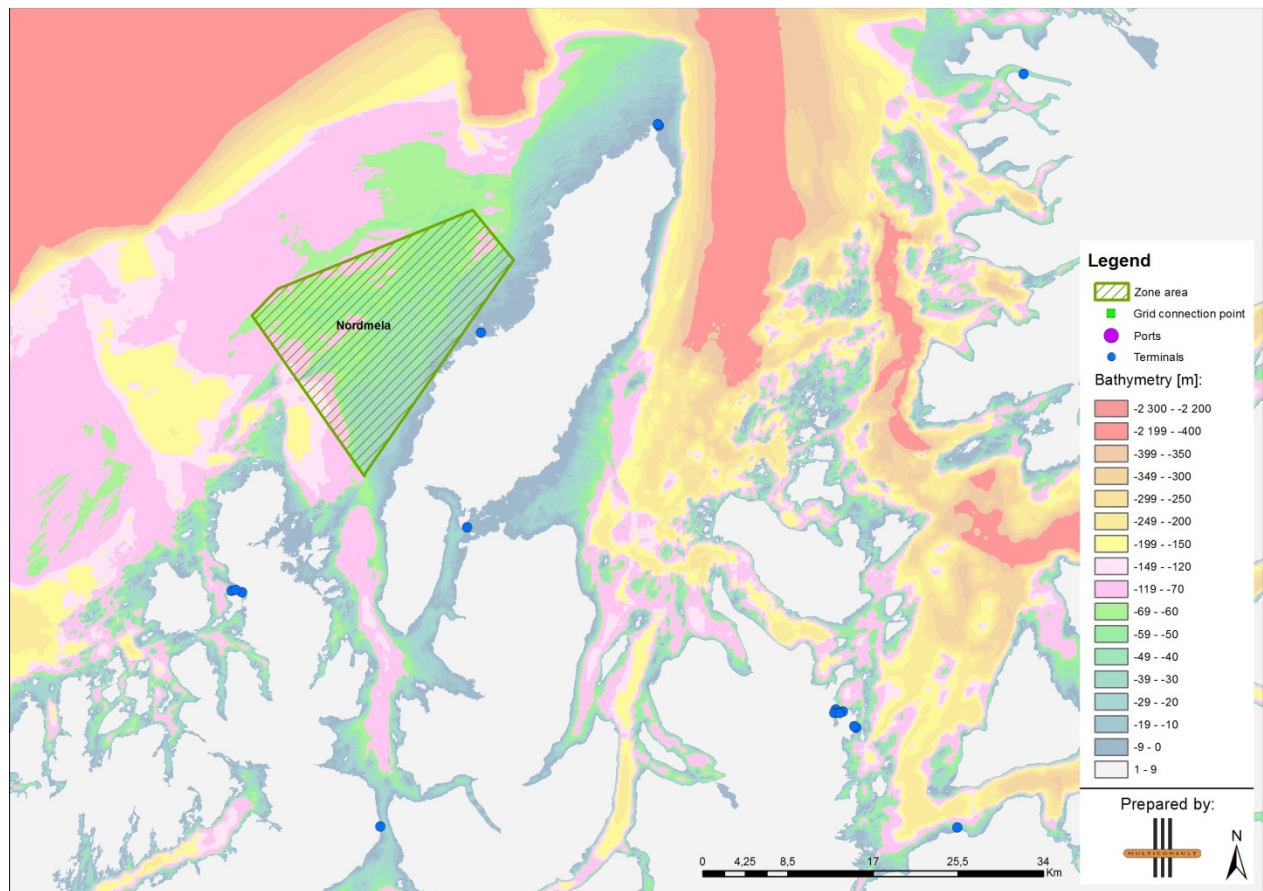
New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	38% / 665 760 MWh		
Site area	19 km ²		
Distance from zone to closest national port / ISPS terminal	54 km / 32 km		
Export cable length (subsea cable from zone to shore)	33-54 km	Total length to grid connection: 33-65km	
Onshore cable length (from shore to connection point)	0-11 km		
Average site depth	26 m	Min: 4m / Max: 45m	

Calculated bathymetry within the site:			
0-10m	0%	40-50m	4%
10-20m	21%	50-60m	0%
20-30m	51%	60-70m	0%
30-40m	24%	>70m	0%

The wind farm within the zone "Auvær" is located about 50 km from the grid connection point and closest national port. In addition there is an ISPS terminal approximately 30 km south of the area. The shortest export cable routes include crossing the island Kvaløya by an onshore cable. It seems possible to connect the wind farm to the substation by a continuous offshore cable, resulting in an approximately 7 km longer cable. Shallow waters and steep slopes may cause some challenges and require further screening. In placing wind turbines, shallow water depths below 10m should be avoided due to difficult serviceability. Micro-siting should enable homogenization of water depths and improve cost reduction. Auvær also has the possibility to place its substation on shore to allow cost savings, better accessibility and safety. Calculations used in this report place substation in marine environment. The calculated average water depth for the site within the zone is 27 meters, and the bulk of the site is located in shallow water between 20 and 40 meters depth.

Nordmela



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3050 hours	
Grid connection point		Risøyhamn/Andenes	
Total zone area		332 km ²	
Distance from zone to shore		2 km	
Average zone depth		49 m	
Calculated bathymetry within the zone:			
0-20 m	2 %	80-100m	3 %
20-40 m	21 %	100-120m	2 %
40-60 m	40 %	120-140m	2 %
60-80m	30 %	>140m	0 %

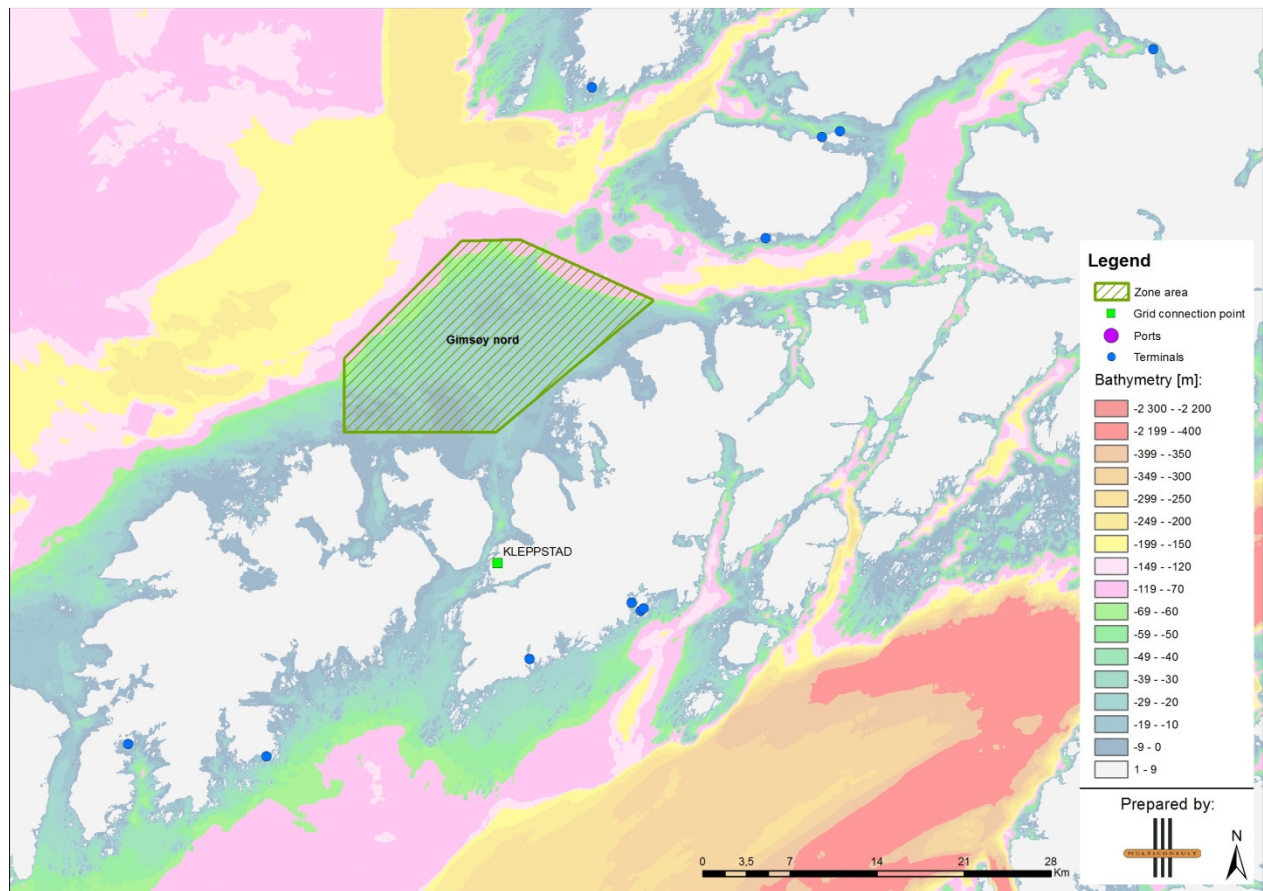
New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	43% / 753 360 MWh		
Site area	19 km ²		
Distance from zone to closest national port / ISPS terminal	160 km / 10 km		
Export cable length (subsea cable from zone to shore)	4-36 km	Total length to grid connection: 5-45km	
Onshore cable length (from shore to connection point)	1-9 km		
Average site depth	31 m	Min: 22m / Max: 42m	

Calculated bathymetry within the site:			
0-10m	0%	40-50m	1%
10-20m	0%	50-60m	0%
20-30m	33%	60-70m	0%
30-40m	66%	>70m	0%

Based on bathymetry conditions the wind farm within the zone “Nordmela” is located in shallower waters while better wind conditions may be found in the Northwestern part of the zone with deeper waters. This puts the farm closer to the potential substation “Risøyhamn” than “Andenes”. The shortest export cable route is about 13 km long. A continuous offshore cable to the substation will increase the total length by approximately 20 km. The distance to “Andenes” substation is almost 40 km. If the site was to be located further north, the substation “Andenes” might be more suitable. Wind farm’s own substation could be located on shore, which would allow for cost reduction, increased accessibility and safety. Current calculations place substation in the marine environment. The calculated average water depth for the site within the zone is 32 meters, and the bulk of the site is located in shallow water between 20 and 40 meters depth. There are several ISPS terminals in a distance from 10 to 40 km from the site, and the closest national port is located approximately 160 km away.

Gimsøy Nord



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		2950 hours	
Grid connection point		Kleppstad	
Total zone area		245 km ²	
Distance from zone to shore		1 km	
Average zone depth		29 m	
Calculated bathymetry within the zone:			
0-20 m	22 %	80-100m	4 %
20-40 m	53 %	100-120m	1 %
40-60 m	11 %	120-140m	0 %
60-80m	9 %	>140m	0 %

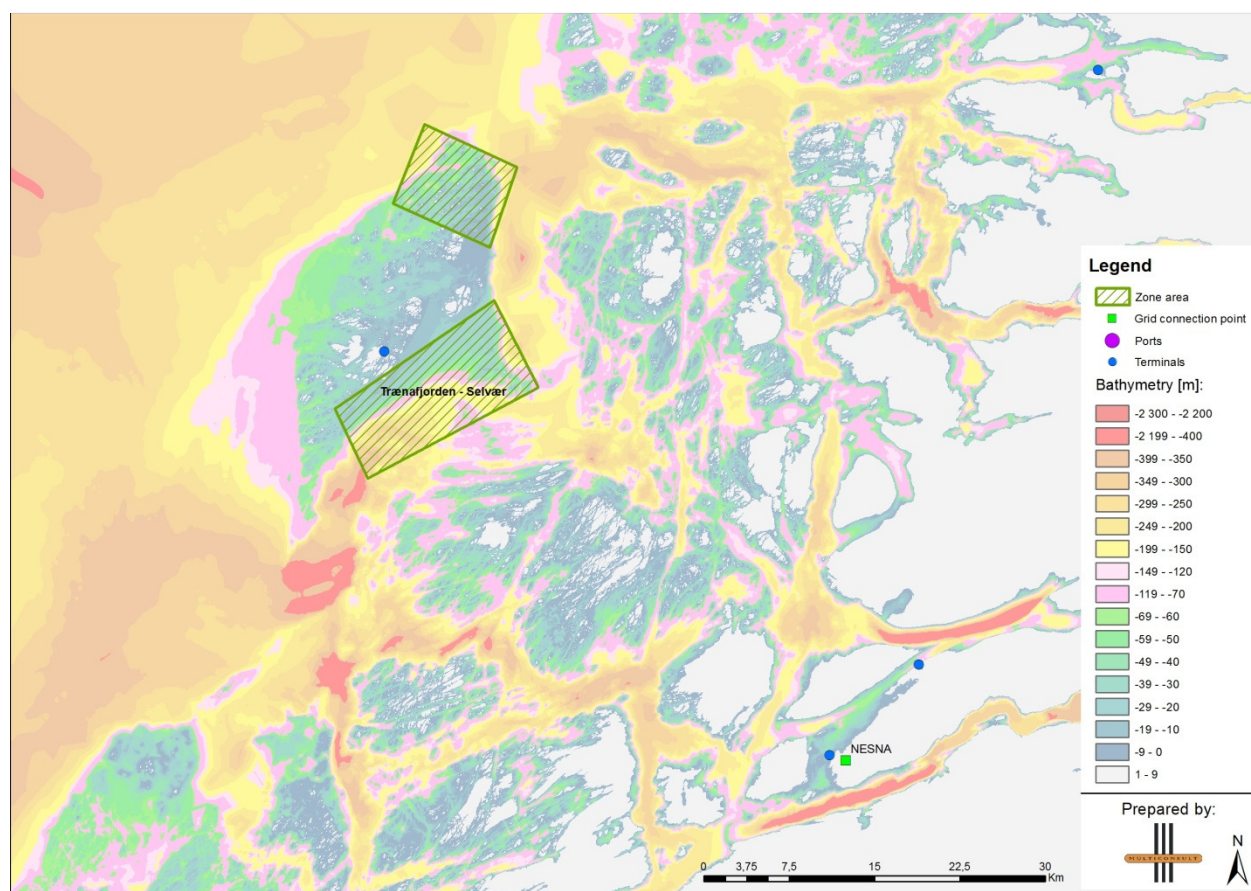
New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	41% / 718 320 MWh		
Site area	19 km ²		
Distance from zone to closest national port / ISPS terminal	270 km / 27 km		
Export cable length (subsea cable from zone to shore)	21 km	Total length to grid connection: 21km	
Onshore cable length (from shore to connection point)	<1 km		
Average site depth	20 m	Min: 13m / Max: 35m	

Calculated bathymetry within the site:			
0-10m	0%	40-50m	0%
10-20m	49%	50-60m	0%
20-30m	50%	60-70m	0%
30-40m	1%	>70m	0%

The wind farm site within the zone “Gimsøy nord” is located about 21 km from the grid connection point and approximately 27 km from the closest ISPS terminal. The distance to the closest national port is more than 250 km. The location of the site has been driven by distance to grid connection point, resulting in almost 90 % of the site being located in very shallow water. The area between 0 and 10 meters will cause challenges for marine operations and is hence avoided. It is possible to move the wind farm site further from shore to deeper waters. This might benefit the wind conditions as well. Locating the wind farm in the northern part of the zone will increase the offshore cable by approximately 8 km.

Trænafjorden – Selvær



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3400 hours	
Grid connection point		Nesna	
Total zone area		197 km ²	
Distance from zone to shore		26 km	
Average zone depth		32 m	
Calculated bathymetry within the zone:			
0-20 m	12 %	80-100m	4 %
20-40 m	26 %	100-120m	3 %
40-60 m	11 %	120-140m	3 %
60-80m	6 %	>140m	33 %

New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	42%-45% / ca 788 400 MWh in Selvær S		
Site area	19 km ²		
Distance from zone to closest national port and ISPS terminal	120 km / 6 km		
Export cable length (subsea cable from zone to shore)	64 km / 68 km	Total length to grid connection: 65-69km	
Onshore cable length (from shore to connection point)	1 km		
Average site depth	41 m	Min: 2m / Max: 134m	

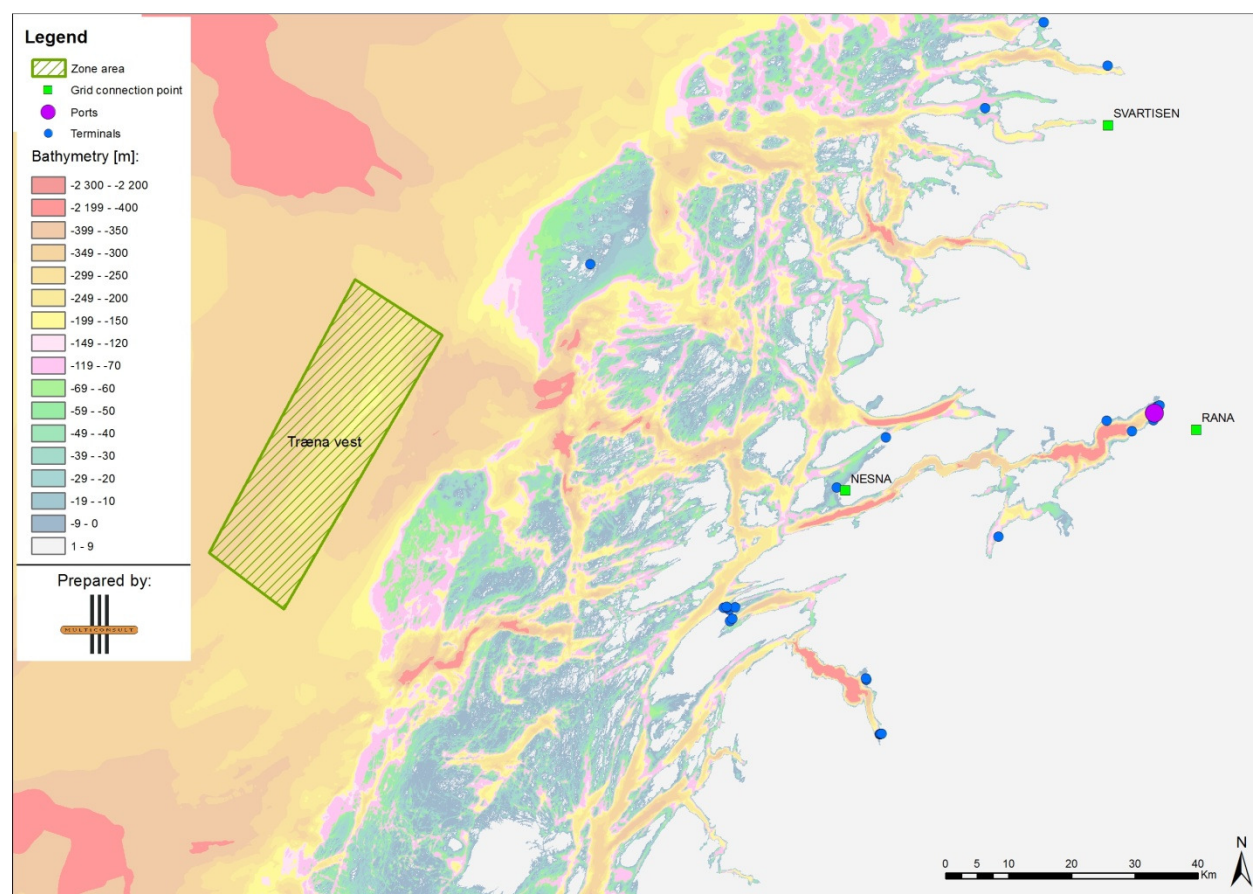
Calculated bathymetry within the site:			
0-10m	0%	40-50m	14%
10-20m	3%	50-60m	8%
20-30m	25%	60-70m	5%
30-40m	37%	>70m	8%

The unique shape of the two zones requires a customized site layout. Especially the Northern zone is a very special area with multiple small islands. Technical feasibility depends on micro-siting of each turbine = this is not a conventional offshore wind farm site. On the positive side, there are opportunities to place substation on shore, which allows for some cost savings as well as increased accessibility and safety. In the Southern zone, likely site configuration will follow the North shallow waters in a rectangular or arched shape. Due to the zone's bathymetry no turbines should be placed below 50m water depth. Similarly to the Northern zone, substation could be located on shore on one of the islands. Træna fjorden – Selvær contains nearly all ranges of water depths for bottom fixed and floating technology and could hence be a good candidate for demonstration zone.

Utilizing both areas for wind power development requires an additional offshore cable length of approximately 10 km in order to link them together. The distance from the site to the grid connection point "Nesna" is a bit less than 70 km. The calculated average water depth for the site within the zone is 24 meters, and the bulk of the site is located in shallow water between 10 and 30 meters depth.

The closest ISPS terminal is located about 6 km from the site on an island called "Træna". If the terminal appears not to be suitable for offshore wind operations, the second closest is located approximately 44 km from the site.

Træna vest



Data based on the preliminary study in 2010

Zone category		OD	
Allowed capacity range		500 – 1500 MW	
Expected full load hours		3500 hours	
Grid connection point		Rana/Svartisen	
Total zone area		773 km ²	
Distance from zone to shore		45 km	
Average zone depth		271 m	
Calculated bathymetry within the zone:			
<180 m	0 %	260-280 m	17 %
180-200 m	2 %	280-300 m	17 %
200-220 m	7 %	300-320 m	27 %
220-240 m	10 %	320-340 m	2 %
240-260 m	19 %	>340m	0 %

New calculated data based on assumptions described in chapter 5

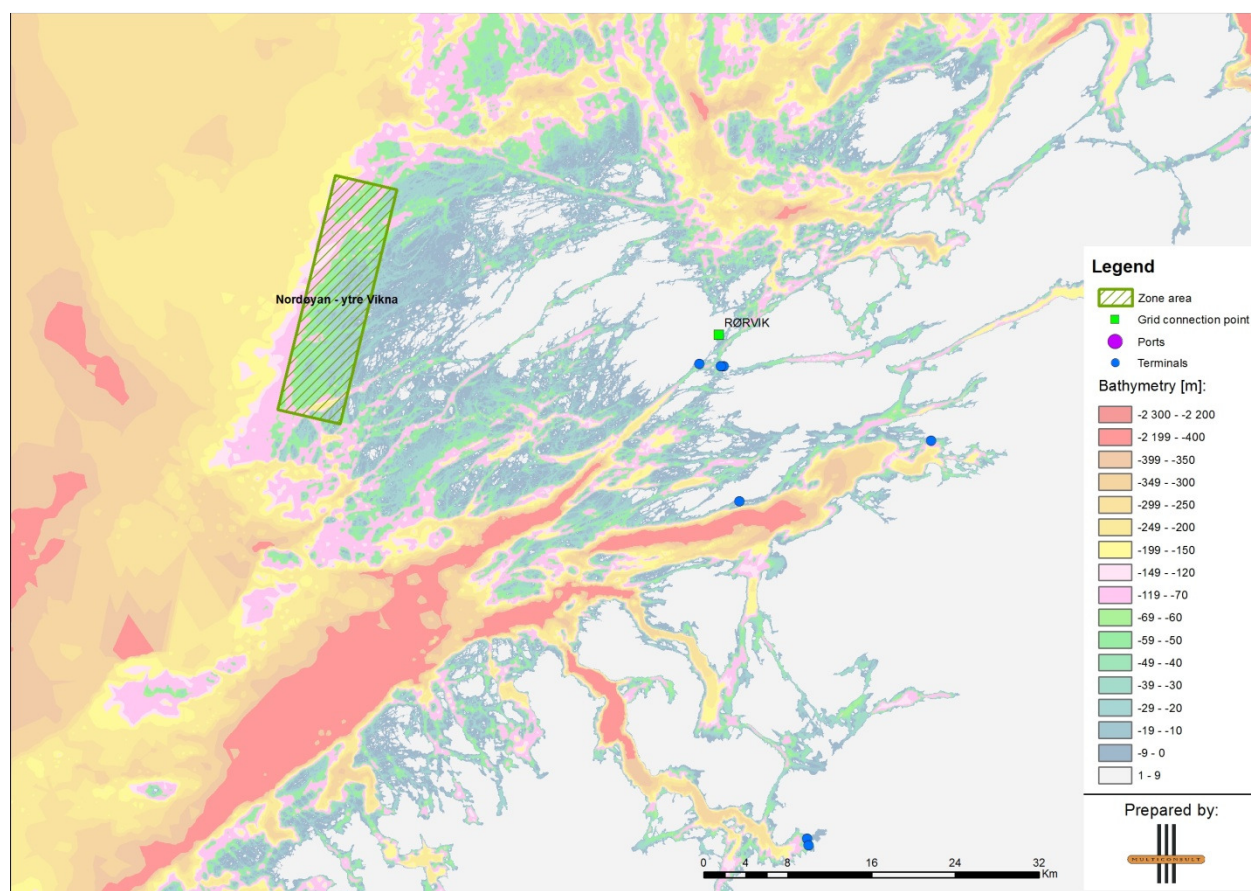
Total assumed capacity of wind farm(s) in this particular zone	1000 MW		
Sites within zone	3 (i.e. two 300 and one 400 MW offshore wind farms)		
Net capacity factor / expected annual net production	44% / 3 854 400 MWh		
Site area	109 km ²		
Distance from zone to closest national port and ISPS terminal	130 km / 30 km		
Export cable length (subsea cable from zone to shore)	104-133 km	Total length to grid connection: 105-167km	
Onshore cable length (from shore to connection point)	2-34 km		

Average site depth		243 m	Min: 187m / Max: 307m
Calculated bathymetry within the site:			
<180 m	0 %	260-280 m	13 %
180-200 m	6 %	280-300 m	17 %
200-220 m	12 %	300-320 m	1 %
220-240 m	30 %	320-340 m	0 %
240-260 m	21 %	>340m	0 %

Site position and configuration depends on water depth versus wind direction benefits as prevailing winds are in the North-South direction as well as the shallower water trench. The wind farm sites has two viable grid connection points "Svartisen" and "Rana" (both hydro power plants with reservoir) with no apparent differences. Both connection points are located in the range of 130 -140 km from the wind farm sites. The calculated average water depth for the sites within the zone is 224 meters, and the bulk of the area is located between 200 and 240 meters depth.

The closest ISPS terminal is located about 30 km from the sites on an island called "Træna". If the terminal appears not to be suitable for offshore wind operations, the second closest is located approximately 75 km from the sites.

Nordøyen – Ytre Vikna



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3350 hours	
Grid connection point		Rørvik	
Total zone area		140 km ²	
Distance from zone to shore		12 km	
Average zone depth		37 m	
Calculated bathymetry within the zone:			
0-20 m	16 %	80-100m	9 %
20-40 m	20 %	100-120m	10 %
40-60 m	31 %	120-140m	4 %
60-80m	9 %	>140m	1 %

New calculated data based on assumptions described in chapter 5

Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	43% / 753 360 MWh		
Site area	19 km ²		
Distance from zone to closest national port and ISPS terminal	210 km / 56 km		
Export cable length (subsea cable from zone to shore)	18-64 km	Total length to grid connection: 18-84km	
Onshore cable length (from shore to connection point)	0-20 km		
Average site depth	28 m	Min: 1m / Max: 108m	

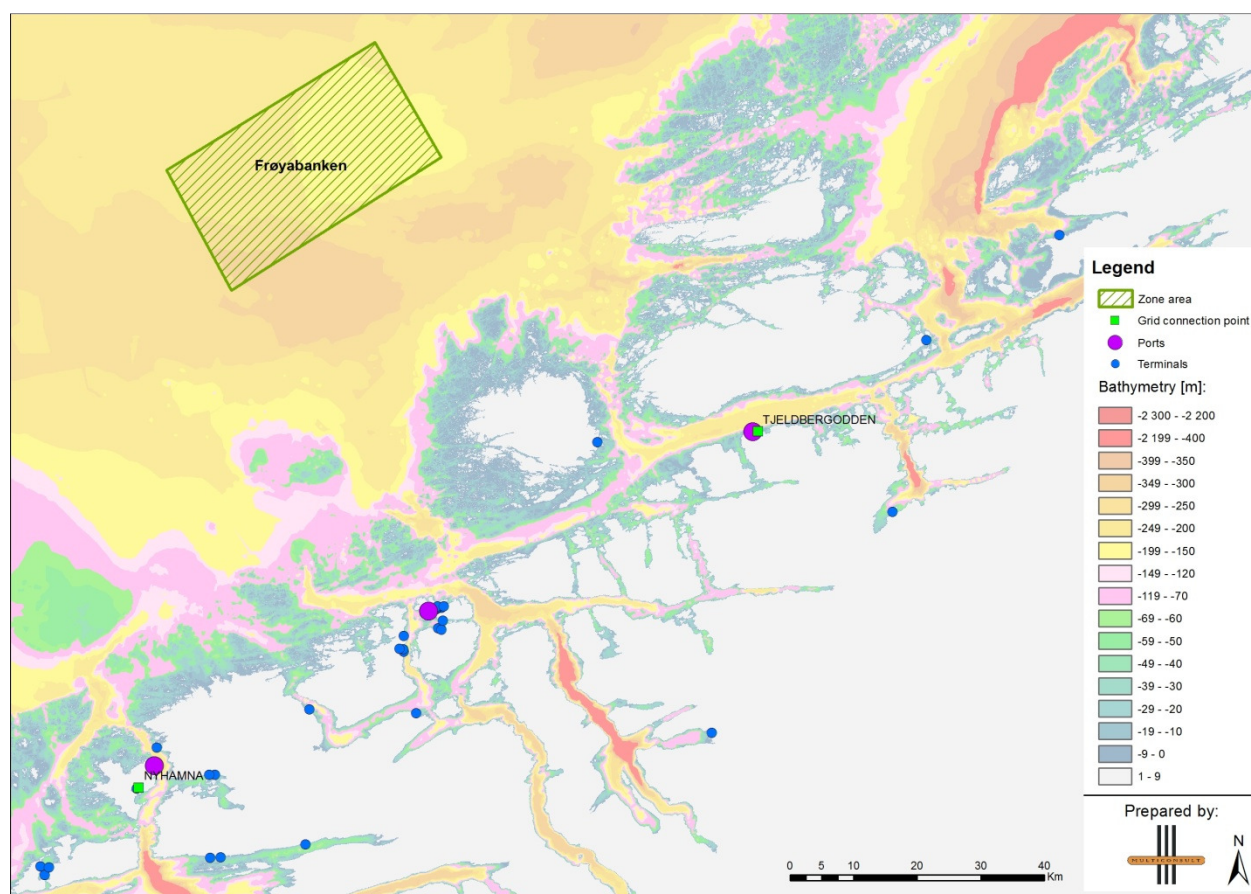
Calculated bathymetry within the site:			
0-10m	8%	40-50m	13%
10-20m	34%	50-60m	14%
20-30m	23%	60-70m	1%
30-40m	6%	>70m	<1%

Water depth spread is wide on the zone and may impact cost efficiency unless micro siting succeeds to harmonize water depths (within the 20-40m range in any case). Shallow waters below 10m should be avoided. Micro siting should enable homogenisation of water depths and improve cost reduction.

The grid connection point “Rørvik” is located a bit less than 40 km from the site within the zone “Nordøyan – ytre Vikna”. The shortest cable route involves challenging waters comprising small islands and water depths within the range of 0 and 10 meters. A continuously offshore cable located either north or south of “Vikna” will increase the length of the offshore cable by 15-28 km. The calculated average water depth for the site is 33 meters, and 50 % of the site is located between 10 and 30 meters depth.

The closest ISPS terminal is located about 56 km from the site, and the distance to the closest national main port is approximately 210 km.

Frøyabanken



Data based on the preliminary study in 2010

Zone category		OD	
Allowed capacity range		500 – 1500 MW	
Expected full load hours		3300 hours	
Grid connection point		Tjeldbergodden/Nyhamna	
Total zone area		819 km ²	
Distance from zone to shore		34 km	
Average zone depth		210 m	
Calculated bathymetry within the zone:			
<160 m	0 %	240-260 m	3 %
160-180 m	30 %	260-280 m	3 %
180-200	13 %	280-300 m	5 %
200-220 m	29 %	300-320 m	6 %
220-240 m	11 %	>320m	0 %

New calculated data based on assumptions described in chapter 5

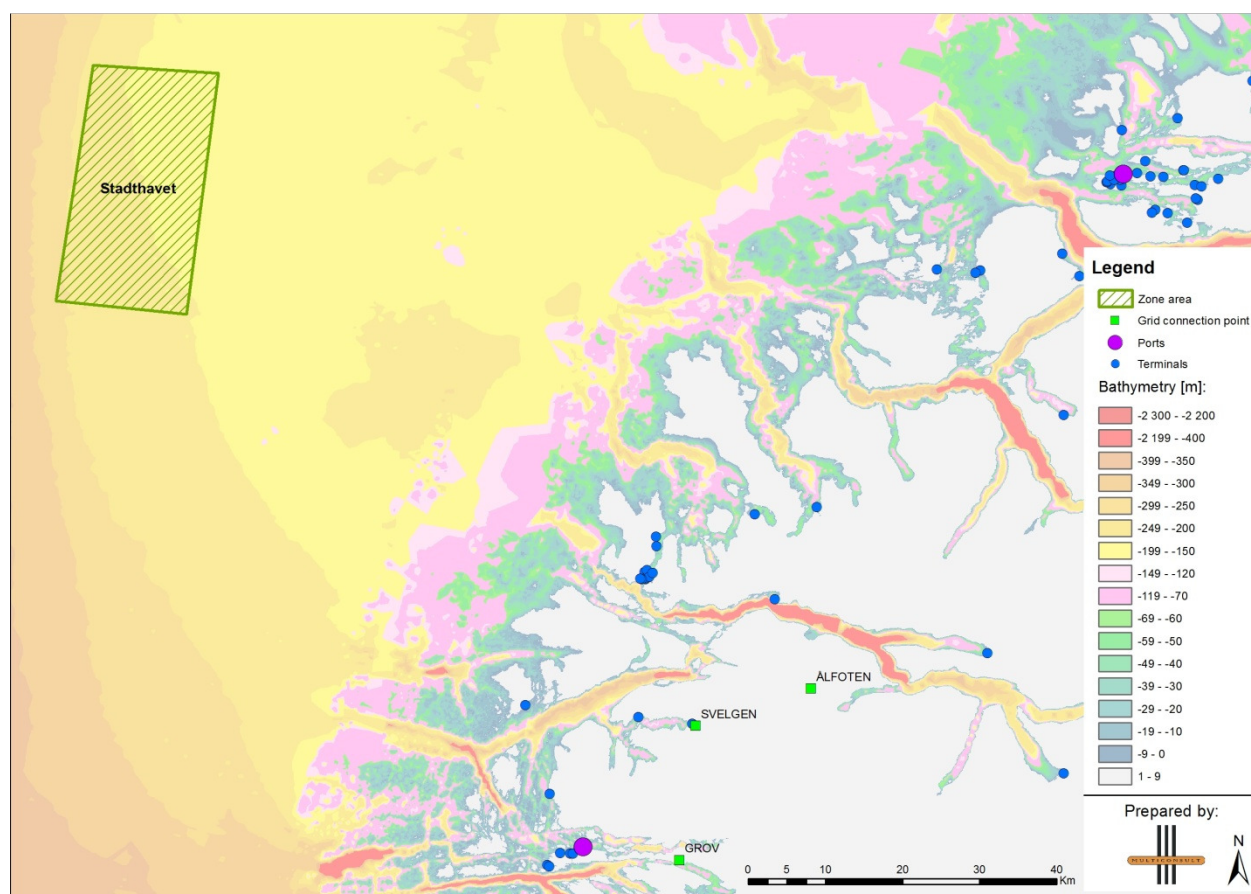
Total assumed capacity of wind farm(s) in this particular zone	1000 MW		
Sites within zone	3 (i.e. two 300 and one 400 MW offshore wind farms)		
Net capacity factor / expected annual net production	42% / 3 679 200 MWh		
Site area	107 km ²		
Distance from zone to closest national port and ISPS terminal	64 km / 58 km		
Export cable length (subsea cable from zone to shore)	78-112 km	Total length to grid connection: 78-116 km	
Onshore cable length (from shore to connection point)	0-4 km		

Average site depth		175 m	Min: 160m / Max: 205m
Calculated bathymetry within the site:			
<160 m	0 %	240-260 m	0 %
160-180 m	72 %	260-280 m	0 %
180-200 m	27 %	280-300 m	0 %
200-220 m	1 %	300-320 m	0 %
220-240 m	0 %	>320m	0 %

The main driver for the location of the wind farm sites within the zone “Frøyabanken” has been water depths, but distance to the two potential grid connection points “Tjeldbergodden” and “Nyhamna” has also been taken into account. Both grid connection points are located within a distance of approximately 90 km from the sites. The calculated average water depth for the sites is 185 meters, and the bulk of the area is located between 160 and 200 meters depth.

There are three national ports in a distance of 64-88 km from the sites. In addition several ISPS terminals are located on the mainland and some of the islands outside the mainland.

Stadthavet



Data based on the preliminary study in 2010

Zone category		OD	
Allowed capacity range		500 – 1500 MW	
Expected full load hours		4000 hours	
Grid connection point		Ålfoten	
Total zone area		520 km ²	
Distance from zone to shore		58 km	
Average zone depth		208 m	
Calculated bathymetry within the zone:			
<160 m	0 %	240-260 m	7 %
160-180 m	3 %	260-280 m	0 %
180-200	38 %	280-300 m	0 %
200-220 m	31 %	300-320 m	0 %
220-240 m	20 %	>320m	0 %

New calculated data based on assumptions described in chapter 5

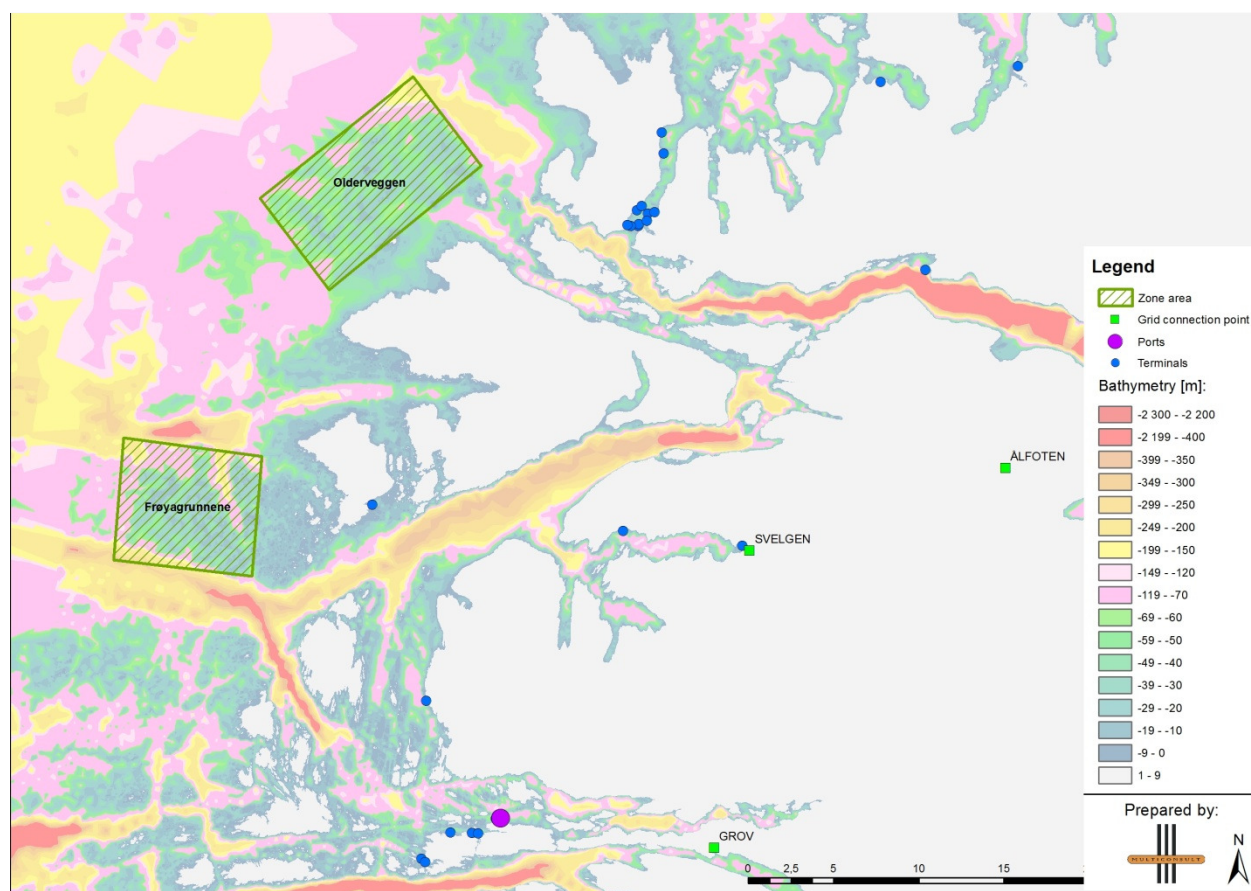
Total assumed capacity of wind farm(s) in this particular zone	1000 MW		
Sites within zone	3 (i.e. two 300 and one 400 MW offshore wind farms)		
Net capacity factor / expected annual net production	48% / 4 204 800 MWh		
Site area	107 km ²		
Distance from zone to closest national port and ISPS terminal	94 km / 71 km		
Export cable length (subsea cable from zone to shore)	88-116 km	Total length to grid connection: 93-130 km	
Onshore cable length (from shore to connection point)	5-14 km		

Average site depth		203 m	Min: 185m / Max: 236m
Calculated bathymetry within the site:			
<160 m	0 %	240-260 m	0 %
160-180 m	0 %	260-280 m	0 %
180-200 m	44 %	280-300 m	0 %
200-220 m	44 %	300-320 m	0 %
220-240 m	11 %	>320m	0 %

The main driver for the location of the wind farm sites within the zone “Stadhavet” has been distance to the potential grid connection point “Ålfoten”, but the bathymetry conditions has also been taken into account. The calculated average water depth for the sites within the zone is 206 meters, and the bulk of the sites are located between 180 and 220 meters depth.

There are several ISPS terminals located in a distance of 71-90 km from the sites. The location of the closest national port is approximately 94 km away from the wind farm area.

Olderveggen



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3650 hours	
Grid connection point		Svelgen	
Total zone area		76 km ²	
Distance from zone to shore		2 km	
Average zone depth		43 m	
Calculated bathymetry within the zone:			
0-20 m	4 %	80-100m	6 %
20-40 m	30 %	100-120m	2 %
40-60 m	38 %	120-140m	1 %
60-80m	16 %	>140m	4 %

New calculated data based on assumptions described in chapter 5

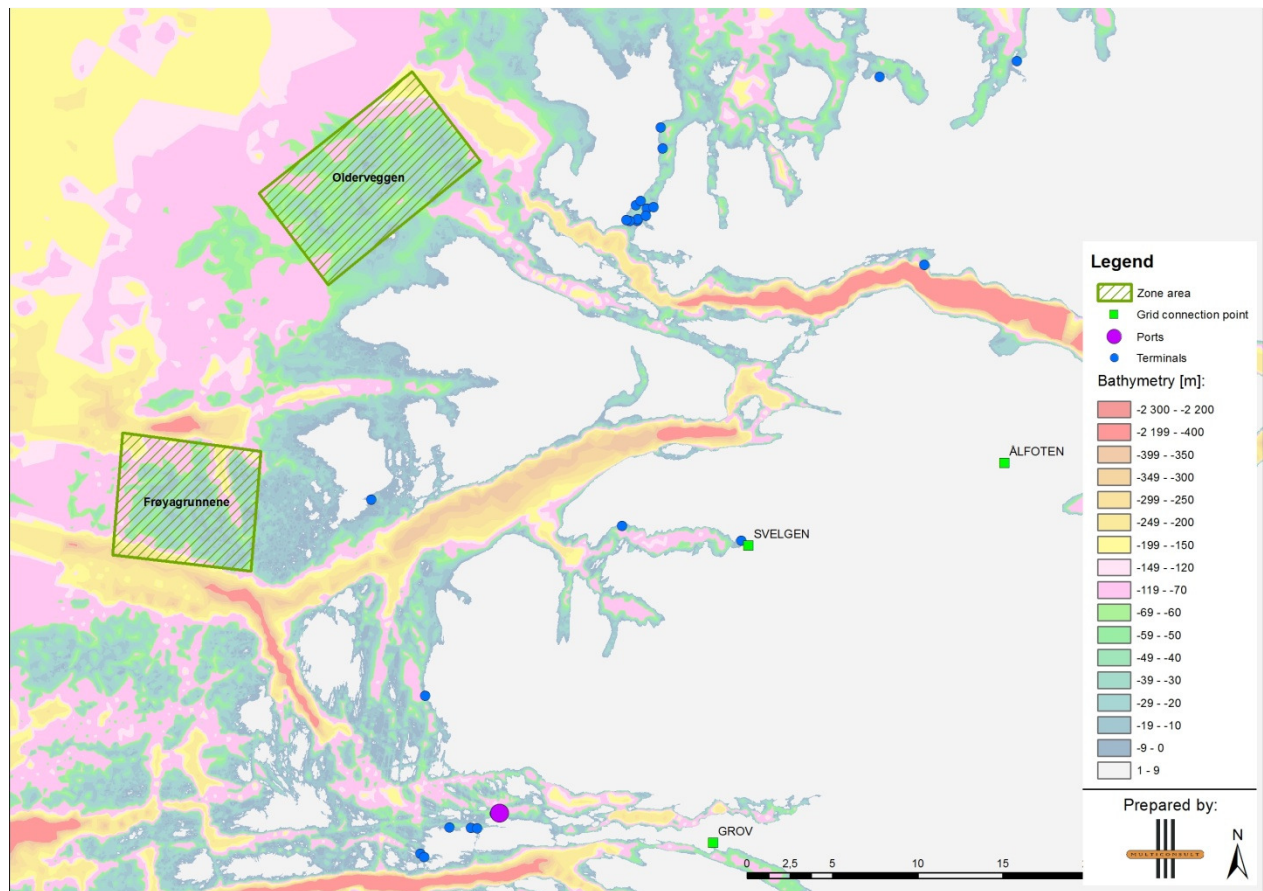
Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	47% / 823 440 MWh		
Site area	19 km ²		
Distance from zone to closest national port and ISPS terminal	45 km / 19 km		
Export cable length (subsea cable from zone to shore)	26-52 km	Total length to grid connection: 26-58 km	
Onshore cable length (from shore to connection point)	0-6 km		
Average site depth	38 m	Min: 2m / Max: 67m	

Calculated bathymetry within the site:			
0-10m	<1%	40-50m	29%
10-20m	4%	50-60m	13%
20-30m	25%	60-70m	1%
30-40m	28%	>70m	0%

The main drivers for the location of the wind farm site within the zone “Olderveggen” have been water depths and distance to grid connection point. It is possible to move some wind turbines further into shallower water depths than have been considered for calculations in this report. The potential connection point “Svelgen” is located approximately 45 km from the site. The calculated average water depth for the site is 37 meters, and the bulk of the site is located between 20 and 50 meters.

There is a hub of ISPS terminals located approximately 12 km from the wind farm site, and the distance to the closest national main port is approximately 45 km.

Frøyagrunn



Data based on the preliminary study in 2010

Zone category		NS	
Allowed capacity range		100 – 300 MW	
Expected full load hours		3750 hours	
Grid connection point		Svelgen/Grov	
Total zone area		58 km ²	
Distance from zone to shore		9 km	
Average zone depth		33 m	
Calculated bathymetry within the zone:			
0-20 m	13 %	80-100m	9 %
20-40 m	30 %	100-120m	10 %
40-60 m	15 %	120-140m	2 %
60-80m	8 %	>140m	13 %

New calculated data based on assumptions described in chapter 5

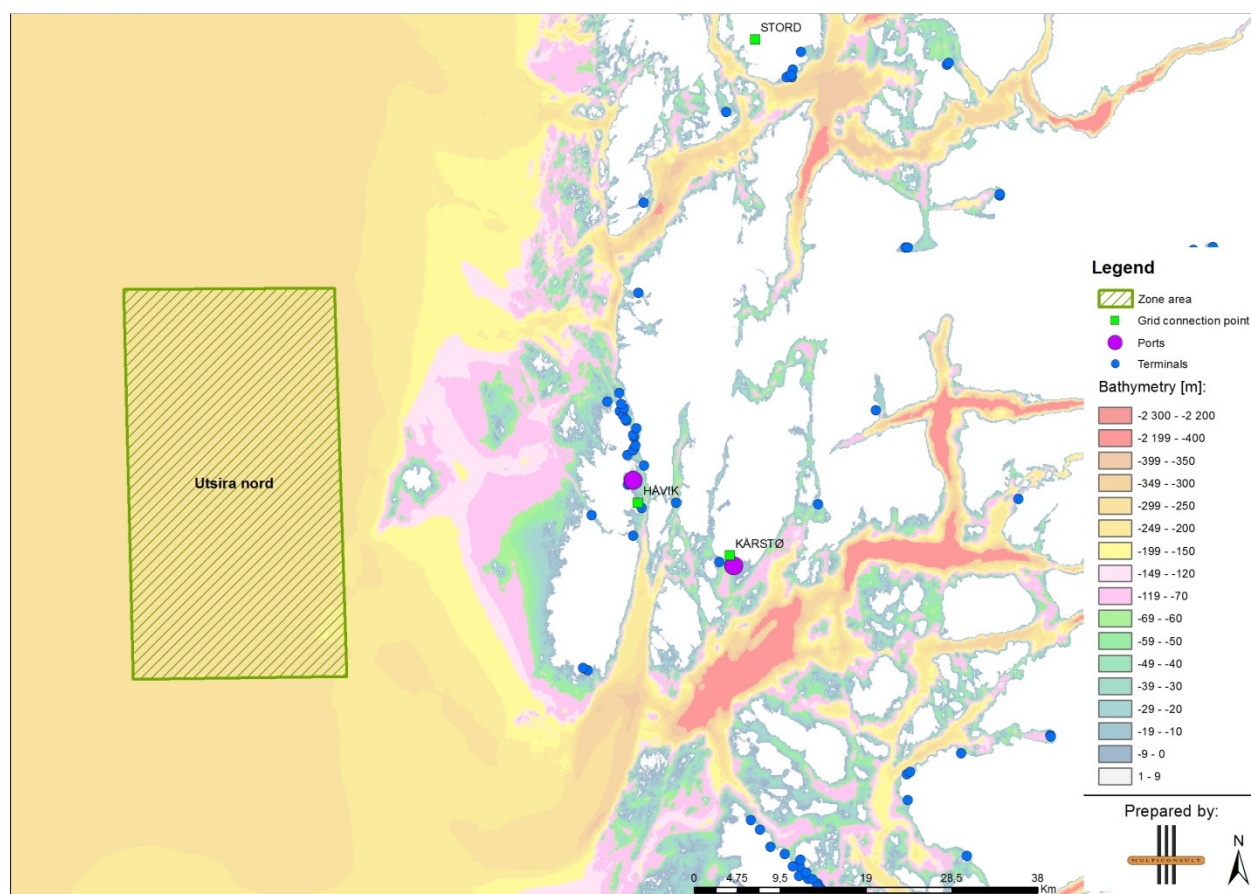
Total assumed capacity of wind farm(s) in this particular zone	200 MW		
Sites within zone	1 (i.e. one 200 MW offshore wind farm)		
Net capacity factor / expected annual net production	48% / 840 960 MWh		
Site area	19 km ²		
Distance from zone to closest national port and ISPS terminal	23 km / 9 km		
Export cable length (subsea cable from zone to shore)	16-37 km	Total length to grid connection: 16-60 km	
Onshore cable length (from shore to connection point)	0-23 km		
Average site depth	32 m	Min: 10m / Max: 110m	

Calculated bathymetry within the site:			
0-10m	0%	40-50m	14%
10-20m	24%	50-60m	5%
20-30m	31%	60-70m	2%
30-40m	19%	>70m	4%

Frøyagrunnene has an unnatural fit between water depth and prevailing wind direction. The main drivers for the location of the wind farm site within the zone “Frøyagrunnene” have been water depths and distance to the potential grid connection points “Svelgen” and “Grov”. Calculations made in this report use “Grov”. Both substations are located in a distance from the site implying the length of the export cable being approximately 41 km. The calculated average water depth for the site within the zone is 37 meters, and the bulk of the site is located between 20 and 50 meters.

The distance to the closest ISPS terminal is 9 km. In addition several terminals are located approximately 21 km from the wind farm site. The distance to the closest national main port is approximately 23 km.

Utsira Nord



Data based on the preliminary study in 2010

Zone category		OD	
Allowed capacity range		500 – 1500 MW	
Expected full load hours		3750 hours	
Grid connection point		Håvik/Kårstø or Stord/Husnes	
Total zone area		1 010 km ²	
Distance from zone to shore		58 km	
Average zone depth		267 m	
Calculated bathymetry within the zone:			
<160 m	0 %	240-260 m	16 %
160-180 m	0 %	260-280 m	77 %
180-200	0 %	280-300 m	6 %
200-220 m	0 %	300-320 m	0 %
220-240 m	1 %	>320m	0 %

New calculated data based on assumptions described in chapter 5

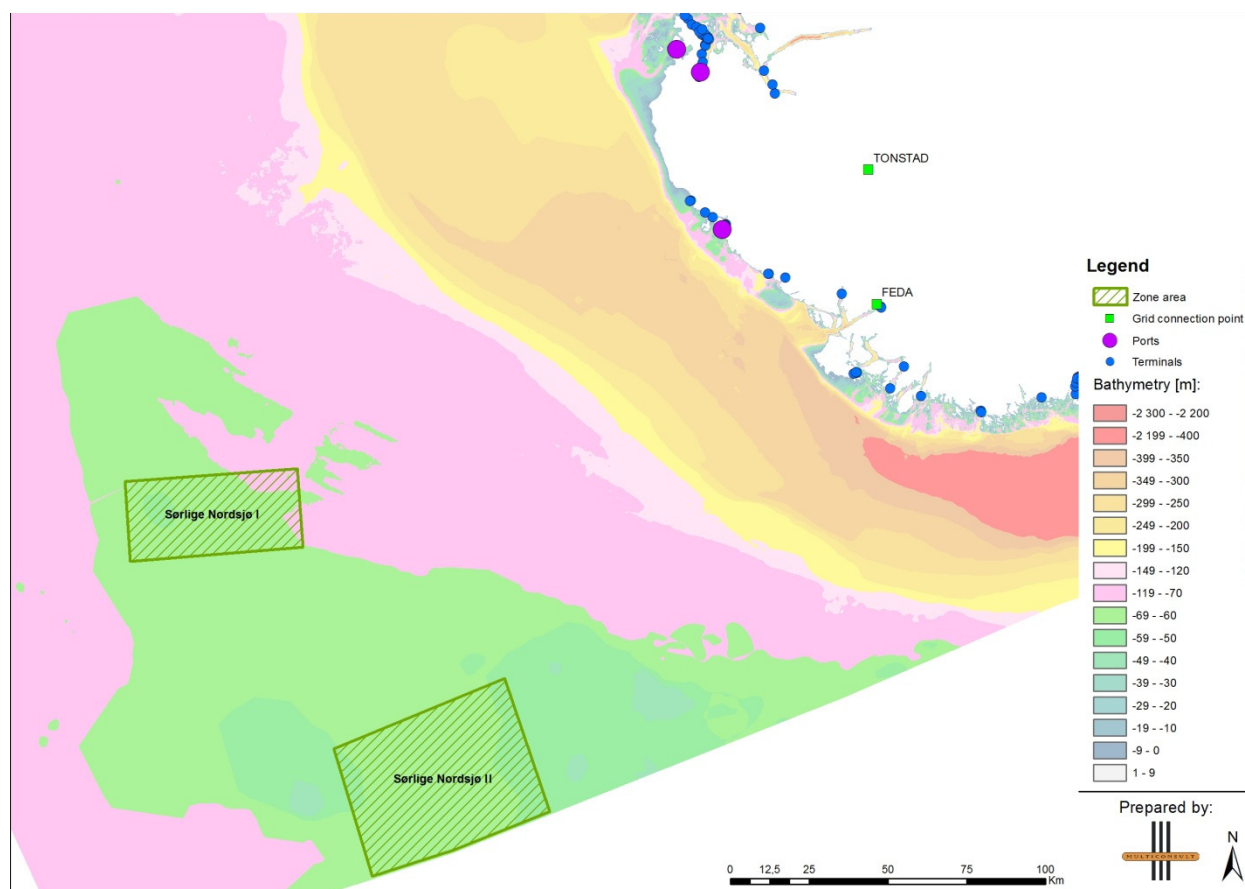
Total assumed capacity of wind farm(s) in this particular zone	1000 MW		
Sites within zone	3 (i.e. two 300 and one 400 MW offshore wind farms)		
Net capacity factor / expected annual net production	47% / 4 117 200 MWh		
Site area	107 km ²		
Distance from zone to closest national port and ISPS terminal	55 km / 28 km		
Export cable length (subsea cable from zone to shore)	29-57 km	Total length to grid connection: 34-63 km	
Onshore cable length (from shore to connection point)	5-6 km		
Average site depth	272 m	Min: 185m / Max: 270m	

Calculated bathymetry within the site:			
<160 m	0 %	240-260 m	4 %
160-180 m	0 %	260-280 m	66 %
180-200 m	0 %	280-300 m	26 %
200-220 m	1 %	300-320 m	0 %
220-240 m	3 %	>320m	0 %

Driven by distance to grid connection point, the wind farm sites can be located either northernmost or southernmost within the zone "Utsira nord", dependent on which grid connection point to be chosen. The two southernmost, "Håvik" and "Kårstø", have been favored in this assessment. The calculated average water depth for the sites within the zone is 273meters and almost all of the site areas are located between 260 and 300 meters depth.

The closest ISPS terminal is located approximately 28 km from the wind farm sites. In addition there is a hub of terminals about 40 km away from the area. The distance to the closest national port is approximately 55 km.

Sørlige Nordsjø I



Data based on the preliminary study in 2010

Data based on the preliminary study in 2016			
Zone category		OS	
Allowed capacity range		1000 – 1500 MW	
Expected full load hours		4050 hours	
Grid connection point		Feda/Tonstad	
Total zone area		1 375 km ²	
Distance from zone to shore		149 km	
Average zone depth		64 m	
Calculated bathymetry within the zone:			
0-20 m	0 %	80-100m	0 %
20-40 m	0 %	100-120m	0 %
40-60 m	18 %	120-140m	0 %
60-80m	82 %	>140m	0 %

New calculated data based on assumptions described in chapter 5

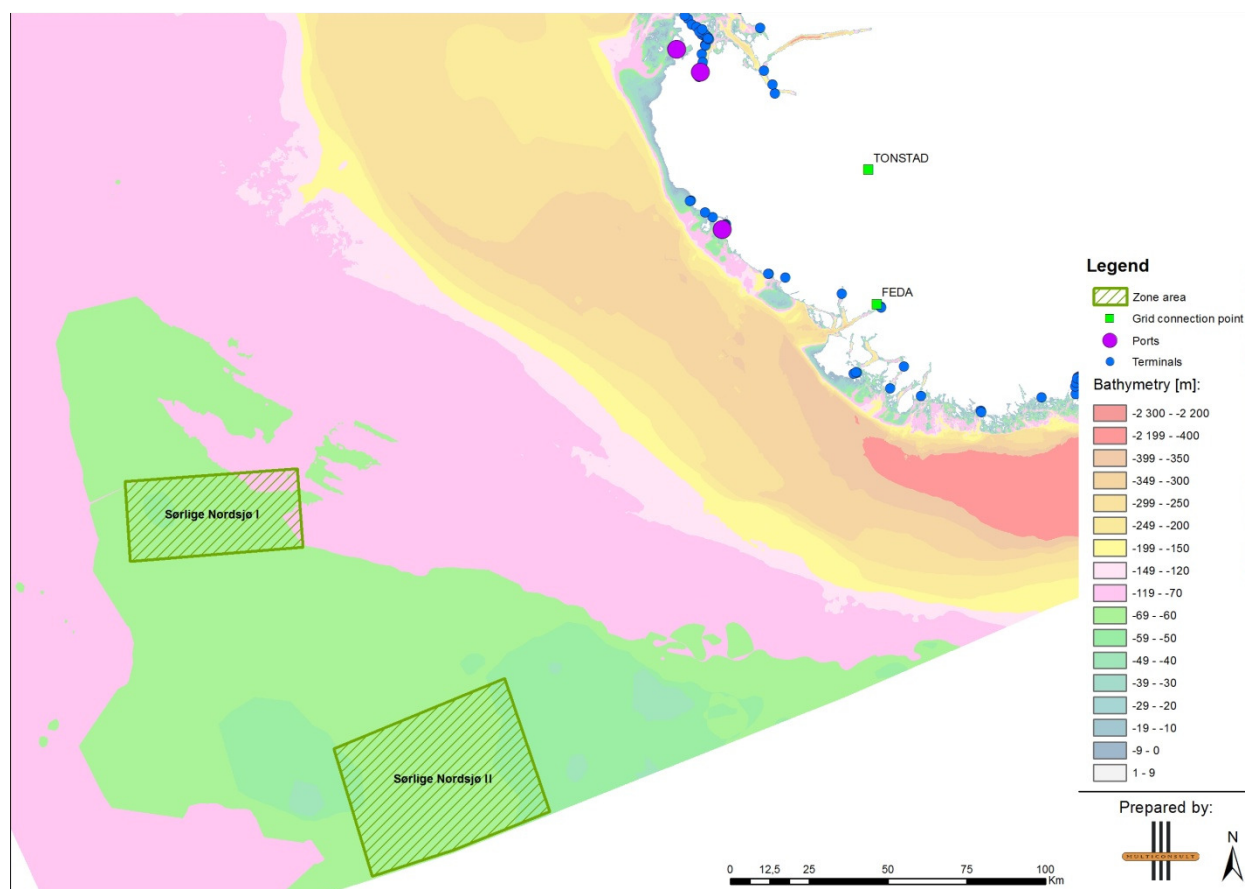
Total assumed capacity of wind farm(s) in this particular zone	1000 MW		
Sites within zone	3 (i.e. two 300 and one 400 MW offshore wind farms)		
Net capacity factor / expected annual net production	49% / 4 292 400 MWh		
Site area	109 km ²		
Distance from zone to closest national port and ISPS terminal	164 km / 160 km		
Export cable length (subsea cable from zone to shore)	200 km	Total length to grid connection: 202 km	
Onshore cable length (from shore to connection point)	2 km		

Average site depth		63 m	Min: 50m / Max: 70m
Calculated bathymetry within the site:			
0-10m	0%	40-50m	0%
10-20m	0%	50-60m	41%
20-30m	0%	60-70m	59%
30-40m	0%	>70m	0%

The main driver behind the location of the wind farm sites within the zone “Sørlige Nordsjø I” has been distance to shore. This needs to be compared to somewhat varying water depths to arrive at best possible micro-siting. In the preliminary study in 2010, potential grid connection points have been identified as “Feda” or “Tonstad”. In this assessment, “Feda” is chosen due to this connection point being the one closest to the sites. Choosing the other alternative “Tonstad” represents an increase of the onshore cable length by approximately 43 km. The calculated average water depth for the sites within the zone is 63 meters and all the site areas are located between 50 and 70 meters depth.

The closest ISPS terminal national main port is located about 160 km from the wind farm site.

Sørlige Nordsjø II



Data based on the preliminary study in 2010

Data based on the preliminary study in 2016			
Zone category		OS	
Allowed capacity range		1000 – 1500 MW	
Expected full load hours		4050 hours	
Grid connection point		Feda/Tonstad	
Total zone area		2 591 km ²	
Distance from zone to shore		140 km	
Average zone depth		60 m	
Calculated bathymetry within the zone:			
0-20 m	0 %	80-100m	0 %
20-40 m	0 %	100-120m	0 %
40-60 m	6 %	120-140m	0 %
60-80m	93 %	>140m	0 %

New calculated data based on assumptions described above

Total assumed capacity of wind farm(s) in this particular zone	1000 MW		
Sites within zone	3 (i.e. two 300 and one 400 MW offshore wind farms)		
Net capacity factor / expected annual net production	50% / 4 380 000 MWh		
Site area	109 km ²		
Distance from zone to closest national port and ISPS terminal	164 km / 150 km		
Export cable length (subsea cable from zone to shore)	171 km	Total length to grid connection: 173 km	
Onshore cable length (from shore to connection point)	2 km		

Average site depth		57 m	Min: 53m / Max: 60m
Calculated bathymetry within the site:			
0-10m	0%	40-50m	0%
10-20m	0%	50-60m	100%
20-30m	0%	60-70m	0%
30-40m	0%	>70m	0%

The main driver behind the location of the wind farm sites within the zone “Sørlige Nordsjø II” has been distance to shore. This needs to be compared to somewhat varying water depths to arrive at best possible micro-siting. In the preliminary study in 2010, potential grid connection points have been identified as “Feda” or “Tonstad”. In this assessment, “Feda” is chosen due to this connection point being the one closest to the sites. Choosing the other alternative “Tonstad” represents an increase of the onshore cable length by approximately 43 km. The calculated average water depth for the sites within the zone is 65 meters and all the site areas are located between 60 and 70 meters depth.

The closest ISPS terminal is located about 150 km from the site, and the distance to the closest national main port is approximately 164 km.

Appendix 2: Detailed results of the economic assessment

Published as a separate report.

Appendix 3: More Descriptive Overview of Technology and cost development trends in Offshore Wind

Published as a separate report.

Appendix 4: Detailed overview of used assumptions

Published as a separate report.

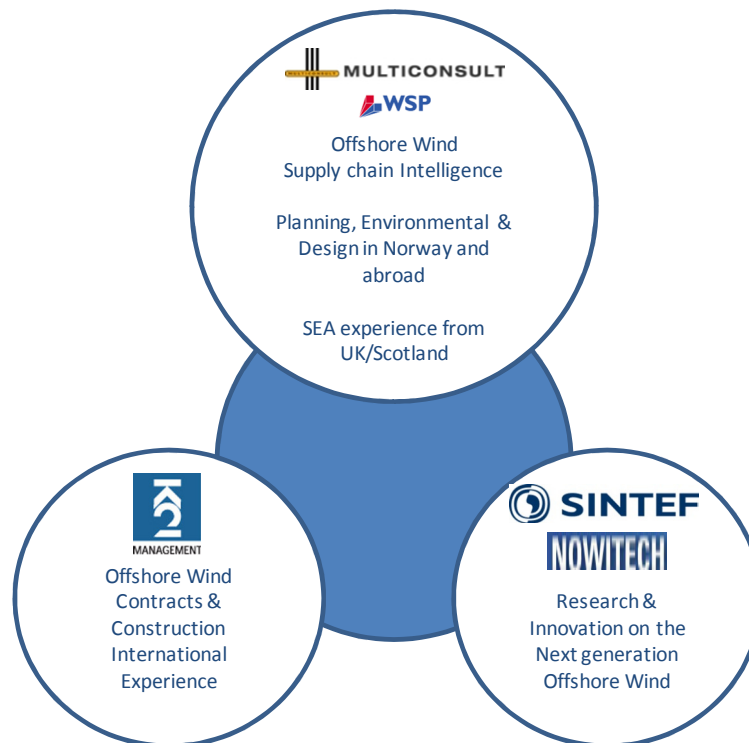
Appendix 5: Source of GIS data

Source	Data	Format	Resolution	Coverage	Source date
The Norwegian Mapping Authority	Background map Norway	Raster			
	Background map Europe	Raster			
The Norwegian Water Resources and Energy Directorate	Transformer stations	Vector, point			2010
	Offshore wind development zones	Vector, polygon			2010
IBCAO	Digital depth model	Raster	1500×1500 m	The Norwegian Sea and the Barents Sea	
Asplan Viak	Digital depth model	Raster	25×25 m	National data set	
The Norwegian Coastal Administration	National ports and ISPS terminals	Vector, point		National data set	
The Norwegian Directorate for Nature Management	Particularly valuable and vulnerable areas (SVO)	Vector, area		National data set, including Svalbard and Jan Mayen	2010

Appendix 6: About the authors& contact information

The project partner team is comprised of:

- **Multiconsult-WSP** (lead), one of Norway's leading multi-disciplinary consulting, engineering and project management firm in a strategic alliance with WSP, a global consultancy group of 10 000 staff with presence in key offshore wind market including UK and Germany. Its staff has been involved offshore wind market advisory, SEAs, Zone attractiveness assessment and technical economic work. Its advisors bring Norwegian track record as well as strong references in UK, France, Germany or Sweden.
- **SINTEF**, a leading R&D institute in Northern Europe with worldwide leadership on the theme of deep water next generation offshore wind through leading role in NOWITECH research center and involvement in Windspeed project focusing on offshore wind spatial planning and levelised cost in North Sea area.
- **K2 Management**, a leading onshore and offshore wind consultancy based in UK, Denmark, Germany and the USA involved in the planning and execution of offshore wind farm construction globally and currently involved in UK's most significant project for the Crown Estate on cost reduction, technology, supply chain development.



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Calculation of location-specific Levelised Cost of Energy

Project:	Technical and economic evaluation of 15 offshore wind zones					
Subject:	Fagutredning 2					
Title:	Additional commentary to complement the public report					
Client:	NVE					
Date:	15.08.2012					
Distributions:	Open					

Prepared:	Marko Viiding	Discipline:	Offshore wind		
Checked:	Wilfried Pimenta	Department:	New Energy		
Approved:	Jan-Olav Øderud	Index Terms:			

Summary:

In order to better understand the relative attractiveness of the 15 zones vis-à-vis each other, an additional assessment was carried out to plot the indicative levelised cost of energy at each wind turbine's position in the zones.

Rev.No.	Date	Description	Tot.pages	Prepared	Checked	Approved
0	15.08.2012		20	markov	wpdm	jaoe

Introduction

After having published the *Fagutredning 2* report in April 2012, NVE contracted Multiconsult to come up with visual illustration of the levelised cost of energy (LCOE) within each turbine's position in the 15 offshore wind zones. The idea was to show how different positions of wind turbines might affect the levelised cost of energy, as each position exploits a unique wind resource and comes with unique cost base owing to depth and distance to shore. Using input from StormGeo Multiconsult performed a high-level assessment and published results as LCOE-layered maps of the 15 zones.

The study had the following objectives:

- Identify cost-attractive areas within each zone
- Understand possible impact of site location on zone selection , ranking or exclusion
- Evaluate how capacity change can impact the LCOE

Methodology

Calculation of Levelised Cost of Energy at each wind turbine's position is a somewhat theoretical task, as true costs of the wind farm depend on positioning of the turbines as well as positioning of supporting equipment and facilities, such as cabling, substation(s) and offshore servicing platform(s). Therefore, the task comprises both turbine-location-specific calculations as well as calculation of approximate shares of other costs split per turbine. As defined in *Fagutredning 2*, a wind turbine was defined as a 10MW unit, which requires 1250x1250m space around it. Hence the 15 zones were split into a grid of 1250x1250m squares, each with a theoretical possibility to place a wind turbine in the middle of the square.

Data used as input for calculations in this note:

- Average depth of water (m) at each 1250x1250m square
- Average annual gross production (P90MWh) at each 1250x1250m square
- Actual distance to onshore grid connection point (km) from each 1250x1250m square
- Actual distance to closest harbour (km) from each 1250x1250m square

Location-specific calculation output:

- Depth-dependant procurement and installation cost of foundation at each 1250x1250m square
- Present value of net production (P90) at each 1250x1250m square, which is calculated by first applying 95% wind farm availability, 6% aerodynamic losses, 1% electrical array losses and 4% other losses(same as methodology applied by the Crown Estate in their LCOE estimation for year 2020 as further described in report *Fagutredning 2*) to the gross production estimate specifically calculated by StormGeo for each of the same 1250x1250m squares – and then calculating a 20-year present value at 10% discount factor.

Approximate share of total costs per turbine:

- 1/20 or 1/100 (depending on 200MW or 1000MW zone) of internal array cabling costs and export cable costs (both procurement and installation), depending on distance to grid connection point onshore
- 1/100 of procurement and installation costs for connection cable to HVDC node (only in 1000MW zone)
- 1/20 or 1/100 of substation procurement and installation cost
- 1/100 of HVDC conversion station procurement and installation cost (only in 1000MW zone)
- 1/20 or 1/100 offshore maintenance platform procurement cost
- Cost per 10MW (i.e. one wind turbine) for O&M: staffing costs, consumables, storage, infrastructure fee, insurance. Present value of 20 years is used with 10% discount rate.

- Distance-based O&M cost for transport, depending on distance from each 1250x1250m square to closest harbour. Present value of 20 years is used with 10% discount rate.

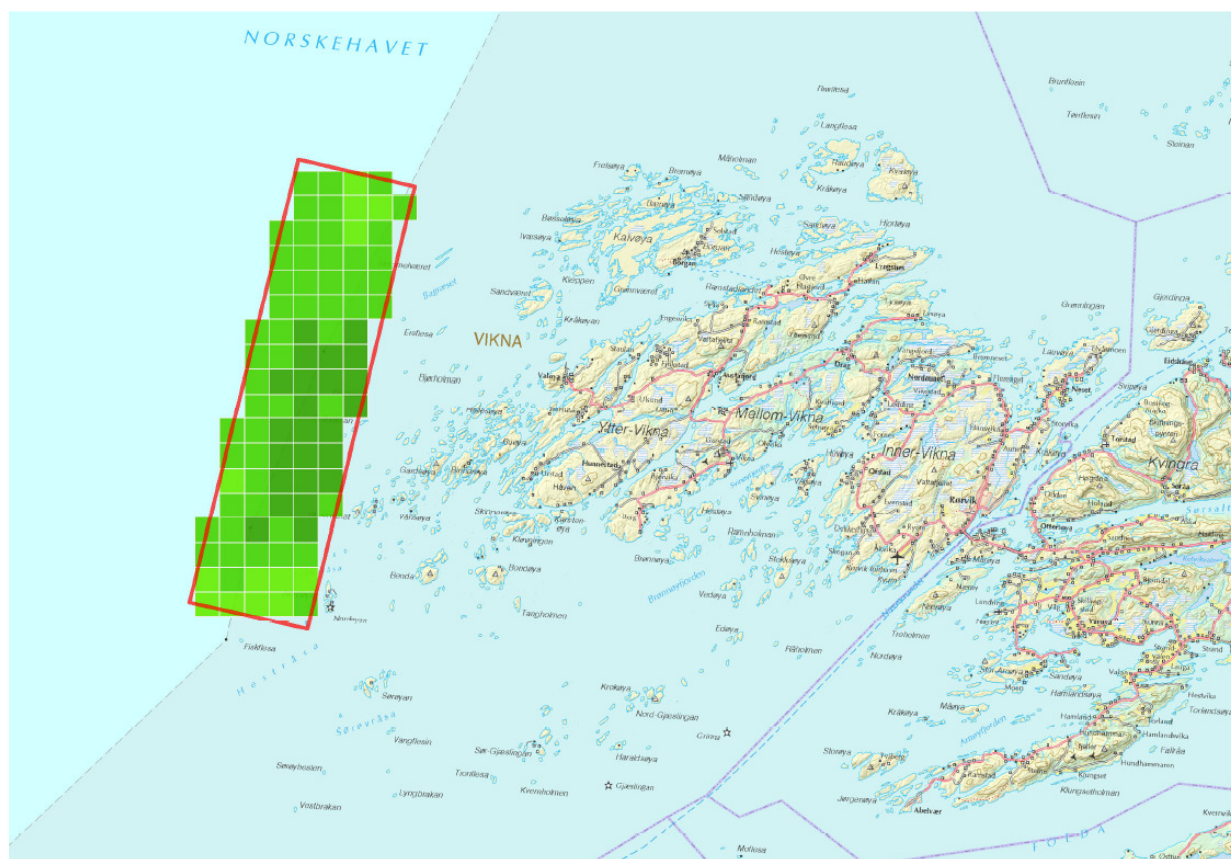
Adding all above costs together returns an approximate total cost per turbine. Dividing this total cost by present value of net production (P90) returns an indicative Levelised Cost of Energy for each 1250x1250m square in each zone. These values of LCOE (in NOK/MWh) are then plotted to the grids of 15 zones in common scale from dark green being lowest LCOE to bright red being highest LCOE. Using a common scale makes it easier to distinguish less costly turbine positions in each zone but also compare the zones to each other.

Limitations of used methodology:

- Calculations in *Fagutredning 2* were based on a subjective assessment for most logical position of a wind farm in each of the 15 zones. In hindsight this does not always match the locations of lowest LCOE as calculated in this study.
- LCOE calculations in this study are a combination of location-specific data and a fraction (i.e. 1/20 or 1/100) of non-turbine-specific costs such as substation or cabling – as explained above. Using such cost fractions is only theoretical and does not allow for consideration of real challenges as was done in holistic assessment of wind park costs in *Fagutredning 2*. Therefore one should not expect that LCOE calculated in this assignment matches LCOE calculations in *Fagutredning 2*.

Results

Figure 1 below provides an indication of the results of calculations for Nordøyen ytre Vikna – as an example. Dark green spots mark positions where placement of turbines would result in LCOE that is lower than the total average calculated for all positions in 15 zones. Presence of lighter green spots means that some positions of turbines would be more costly: up to 10% above the average LCOE of all 15 zones. Therefore in this example wind turbines should first be placed in dark green spots where LCOE is lower.



Levelised cost of energy - Deviation from average (%) -10,0 - -5,0 -4,9 - 0,0 0,1 - 5,0 5,1 - 10,0 10,1 - 15,0 15,1 - 20,0 20,1 - 25,0 25,1 - 30,0 30,1 - 35,0 35,1 - 40,0 40,1 - 45,0 45,1 - 50,0 50,1 - 55,0	Offshore Wind Power		Client:
	Nordøyan - Ytre Vikna		NVE
	Scale: 1:300 000		 Multiconsult AS PO Box 265 Skøyen 0213 Oslo
	Project: 116 371	Date: 10.08.2012	
	Created by: KMO	Revised by:	
	Base map: N250		
	File name: LCOE.mxd		

Figure 1. Example of calculated result for LCOE in one of the zones - Nordøyan ytre Vikna

Owing to the limitations described on the previous page, it is appealing to compare the results of this study with the results of ranking of zones as done in *Fagutredning 2*. This is shown in Table 1.

Table 1. Ranking of the 15 zones vis-à-vis each other

Zone	Rank in this study *	Rank in <i>Fagutredning 2</i> *
Træna fjorden - Selvær S	10	10
Træna Vest	6	9
Frøyabanken	8	12
Stadthavet	1	6
Utsira Nord	3	3
SørligeNordsjø I	2	7
SørligeNordsjø II	5	2
Olderveggen	9	4
Gimsøy Nord	12	8
VannøyaNordøst	13	13
Sandskallen - Sørøya Nord	11	15
Nordmela	15	5
Nordøyan - YtreVikna	7	11
Auvær	14	14
Frøyagrunnene	4	1

* Ranking is on a scale of 1 to 15 with 1 having lowest LCOE and 15 having highest LCOE

As it appears, several zones have the same rank in both cases; whereas ranking of some zones has large differences. This calls for caution when using results of this study to compare zones vis-à-vis each other. Instead, the results are easier to interpret for assessment of optimal turbine placement within the zones. Table 2 lists the variation between minimal and maximal values of LCOE within each zone both in NOK/MWh as well as ranking. In this case, ranking can be used as guidance for sensitivity of turbine placement within each zone. As can be seen, highest rank is earned by the zones where floating foundations are needed (this eliminates depth-determined cost variation for bottom-fixed foundations).

Table 2. Variance between minimal and maximal values of LCOE in each 1250x1250m square in each zone

Zone	Variance between MIN-MAX LCOE (NOK/MWh)	Rank *
Træna fjorden - Selvær S	149	9

Træna Vest	26	2
Frøyabanken	41	4
Stadthavet	22	1
Utsira Nord	39	3
SørligeNordsjø I	92	6
SørligeNordsjø II	66	5
Olderveggen	184	10
Gimsøy Nord	277	14
VannøyaNordøst	394	15
Sandskallen - Sørøya Nord	214	12
Nordmela	236	13
Nordøyan - YtreVikna	130	8
Auvær	200	11
Frøyagrunnene	109	7

* Ranking is on a scale of 1 to 15 with 1 having lowest variance between minimum and maximum LCOE within a given zone

Sensitivity

The idea to use 200MW and 1000MW wind farms in the 15 zones was agreed at the start-up of *Fagutredning 2* for simplification of calculations – it is easier to compare similar zones if they have similar-sized wind farms. Some zones are in fact big enough for somewhat larger wind farms to be built. However as the purpose of *Fagutredning 2* is to compare the zones in the year 2020 perspective, calculating costs for many different-sized wind farms creates too much uncertainty as each size would come with different underlying assumptions. Hence using different-sized wind farms might reduce transparency in assessing the cost of energy on equal terms.

We have therefore only carried out a theoretical sensitivity analysis to indicate how the LCOE changes when upscaling the wind farms from 200MW and 1000MW to 300MW and 2000MW respectively. Based on cost trends indicated in *Fagutredning 2*, we have used the following assumptions:

- Keep the same costs per MW for development fees, procurement and installation of foundations and wind turbine sets, construction management, insurance, contingency and de-commissioning. This means that such costs would increase proportionally.
- Linearly extrapolate the need for electrical equipment (substations, cabling, converters) by a factor of 1,5 (from 200MW to 300MW) or 2,0 (from 1000MW to 2000MW) as suggested by SINTEF, a sub-supplier in *Fagutredning 2*. This is a somewhat simplified yet relatively realistic assumption. However it creates a situation where e.g. 1,5 substations are required for 300MW wind parks (up from 1 substation in 200MW wind park). In this case quantities are ignored and only proportionally increased total costs are considered for calculation of LCOE.
- Use 9,1% lower O&M costs per MW for 300MW zones and 3,6% lower O&M costs per MW for 2000MW zones (as suggested by SINTEF in Figure 31 in *Fagutredning 2*).
- Increase net production from wind farms by a factor of 1,5 for 300MW and a factor of 2,0 for 2000MW (corresponding to linear increase in size of wind parks). StormGeo's net production estimates are used from *Fagutredning 1*. We acknowledge that this is somewhat oversimplistic approach and should be used with caution.

Results have been calculated based on three 200MW sites and two 1000MW sites as shown in Table 3. It appears that above used assumptions increase LCOE for smaller (200MW) zones whereas the effect is

opposite for larger (1000MW) zones. As the LCOE increase is between 4%-7%, i.e. smaller than the 8-10% decrease in larger zones, one could argue that LCOE could in fact decrease if some changes are made to assumptions – e.g. a larger and less costly substation; more optimal arrangements in the O&M phase, more accurate projection of production etc. A more straightforward conclusion seems to be the fact that wind resources are much better at larger (1000MW) zones, which makes it more worthwhile to add additional electricity infrastructure.

Table 3. Results from theoretical upgrade of 200MW to 300MW sites and 1000MW to 2000MW sites

Zone	Capacity change (MW)	LCOE change from upgrade
Trænafjorden - Selvær S	200 → 300	4%
VannøyaNordøst	200 → 300	7%
Auvær	200 → 300	5%
SøriligeNordsjø I	1000 → 2000	-10%
Frøyabanken	1000 → 2000	-8%

Concluding Remarks

Some conclusions can be derived from above exercise.

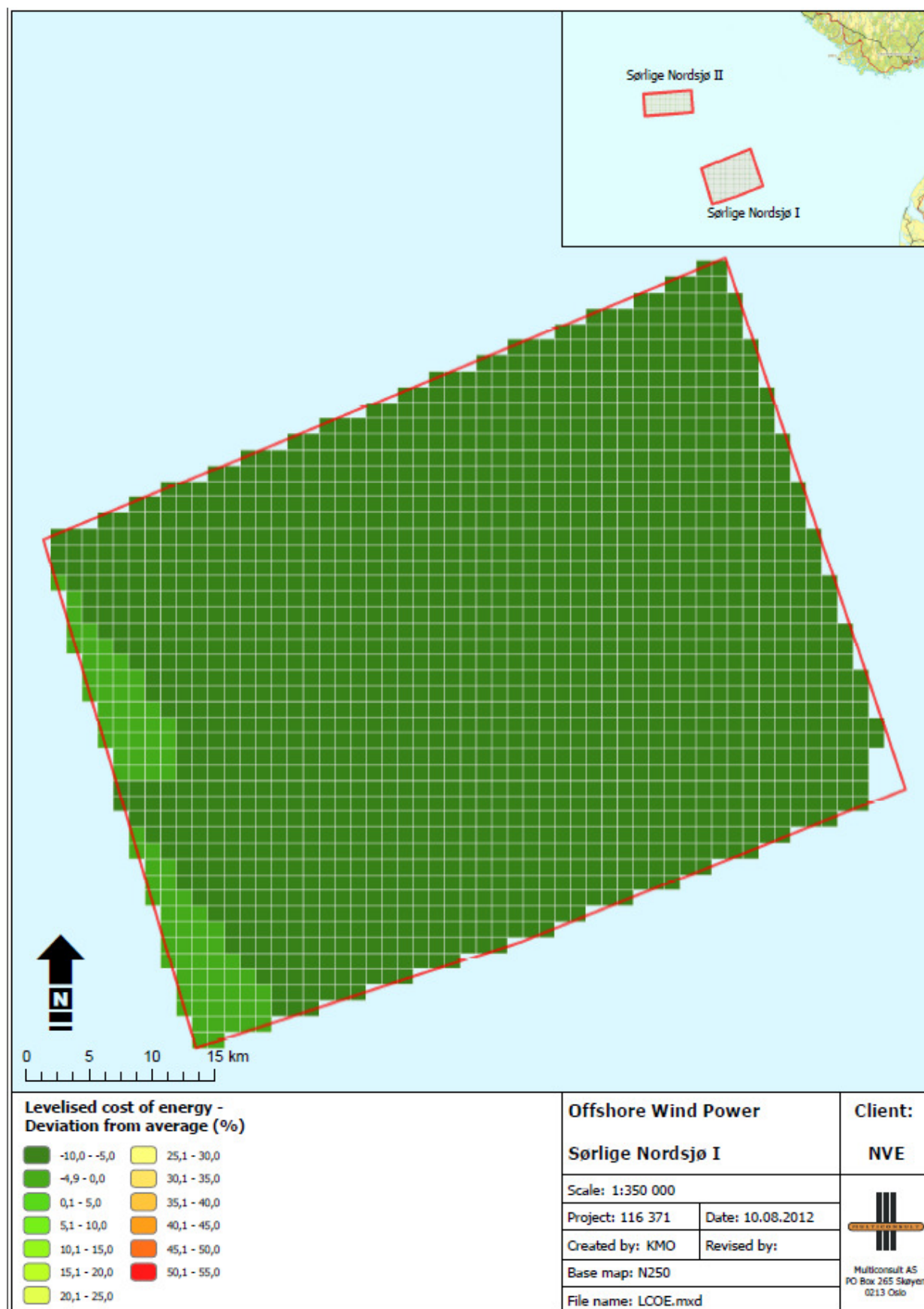
Firstly, the calculations performed for this task show that optimal turbine placement must take into consideration a combination of factors like best wind resource, site depth, and distance to shore – no factor should be seen in isolation. This study includes maps of all 15 zones with location-specific LCOE, which helps to point to areas where turbines should be considered to be placed first. It is therefore recommended that both developers as well as authorities jointly evaluate greener spots on the maps and use them as a starting point for possible siting of offshore wind turbines and determination of forbidden areas.

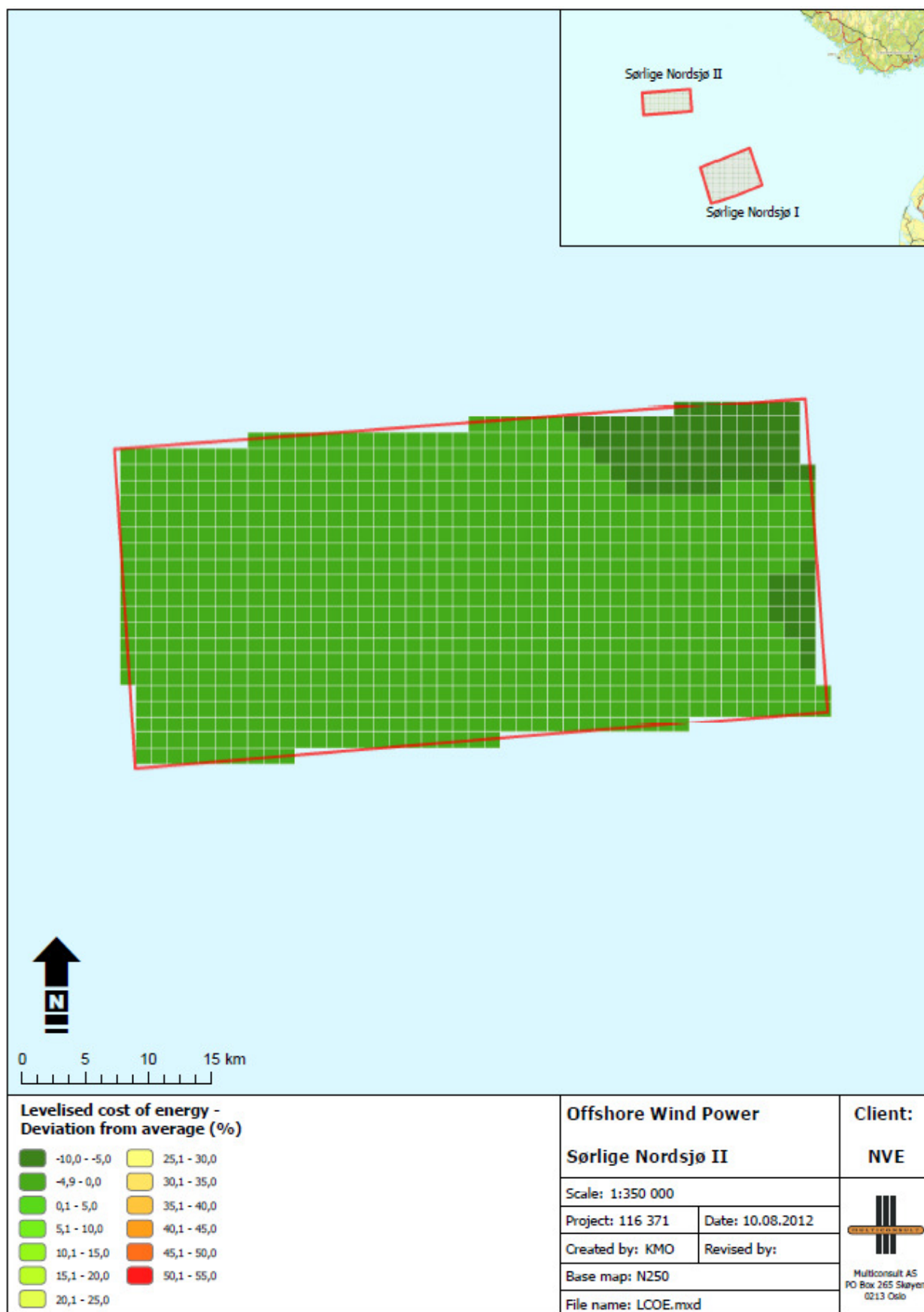
Comparison of the results of this study to the results in *Fagutredning 2* has shown that rankings of the 15 zones do not overlap. This points to the need to evaluate wind farms as a whole, i.e. keep in mind the entire wind farm with its specific location-dependent properties both in terms of production as well as installation and operating costs. Therefore, calculated LCOE in this study is not particularly useful in ranking the zones vis-à-vis each other. For that purpose it is recommended to use the economic and technical ranking of the 15 zones as presented in *Fagutredning 2*.

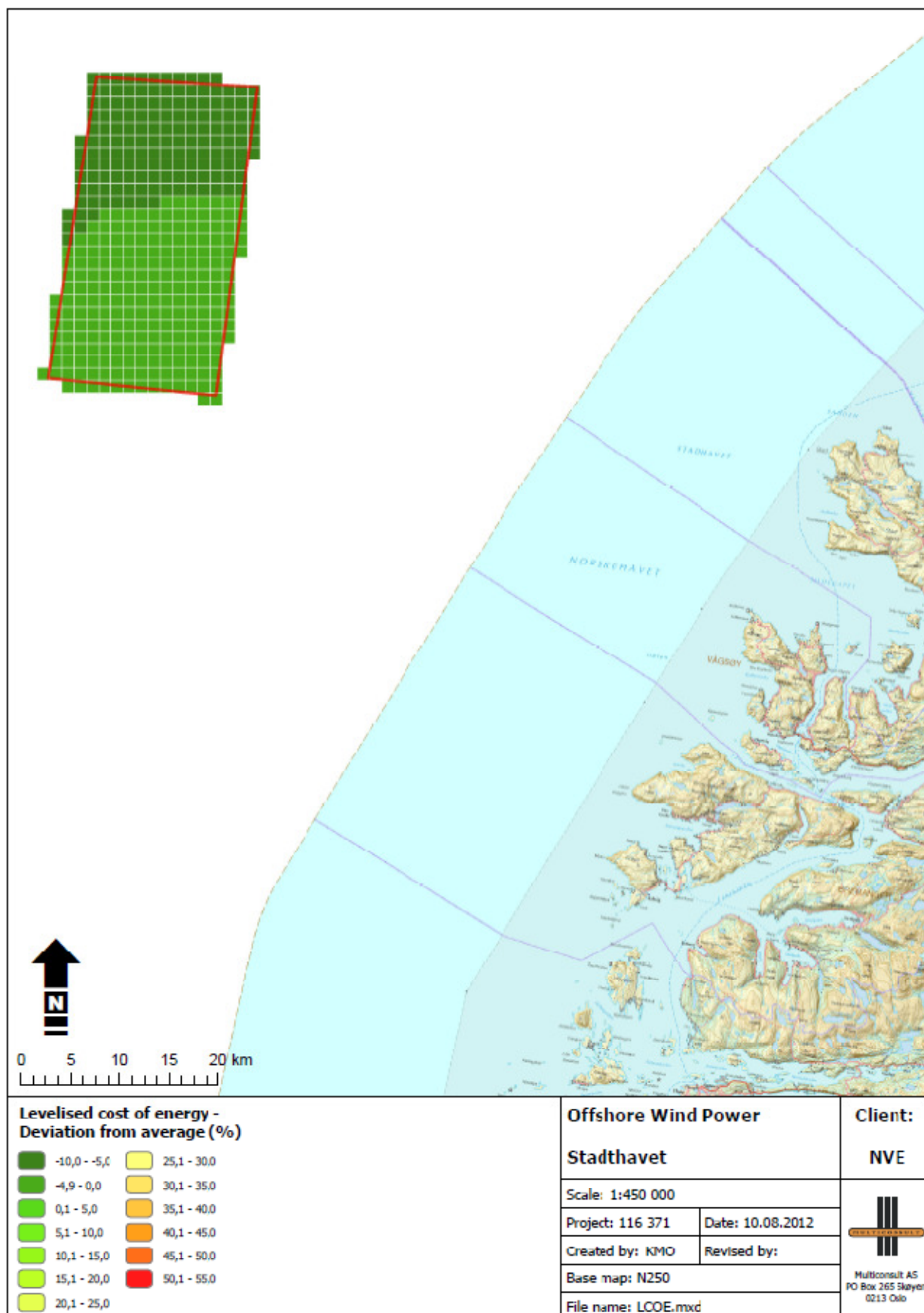
Evaluation of the capacity change shows that LCOE has the potential to decrease if 1000MW wind farms are built bigger. One would expect the same from increasing 200MW wind parks to 300MW, but this was not supported under the assumptions used in current study. As noted above, this points to the need to more thoroughly evaluate necessary equipment for 300MW wind farms as well as pay attention to distance-based cost, which varies much more among the 200MW zones. For greater transparency and comparability it is recommended to keep the 200MW / 1000MW configurations as used in *Fagutredning 2* when assessing the zones' attractiveness.

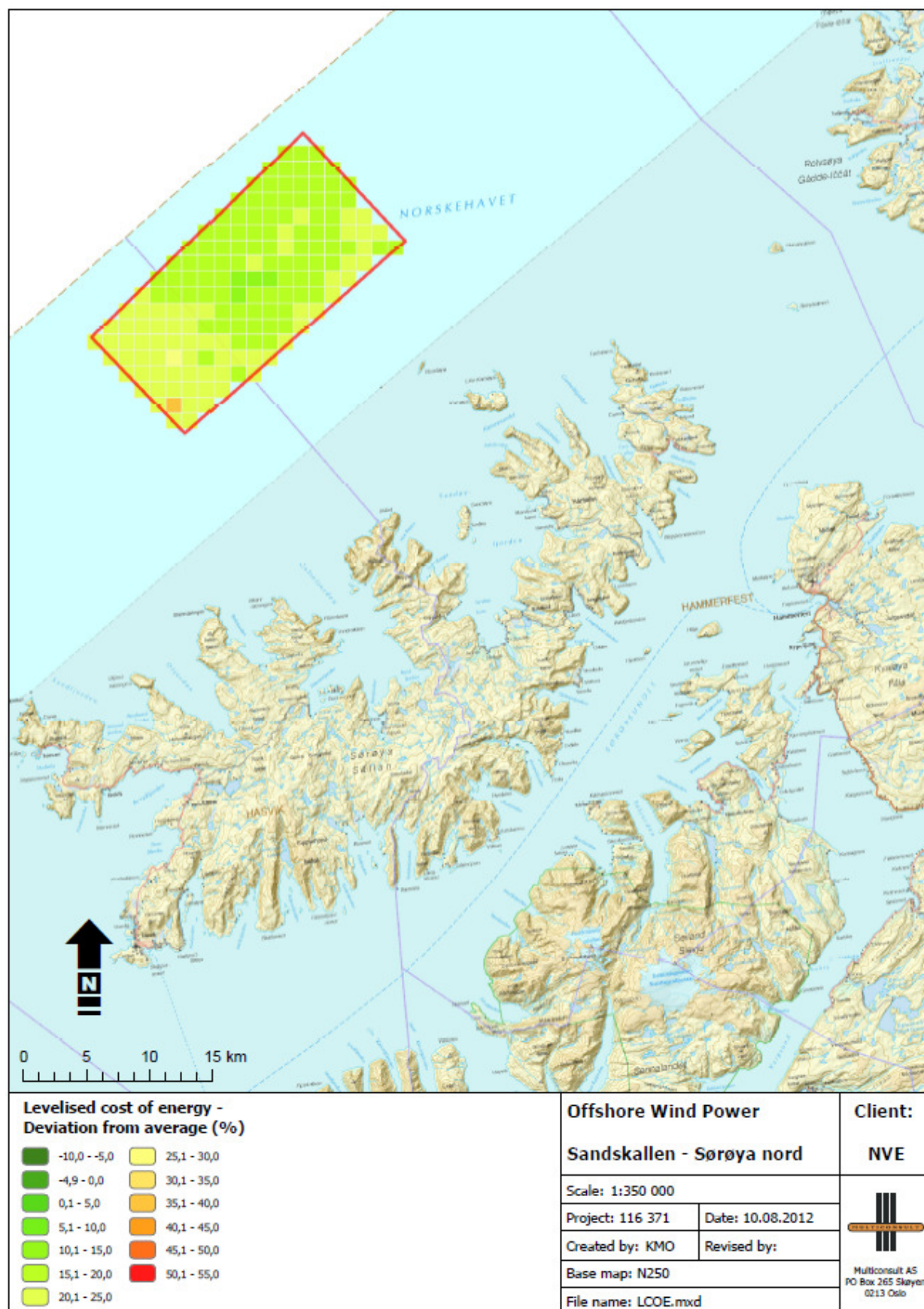
Lastly one has to keep in mind the need to treat the calculations as indicative only. Multiconsult has decided to share actual calculations only with the customer (NVE) and not make them publicly available for avoidance of possible misinterpretation (given the limitations in methodology as discussed above). Publicly all zones can be viewed in relative ranking to the 15 zone average – which however offers somewhat lower level of detail for variance within each zone.

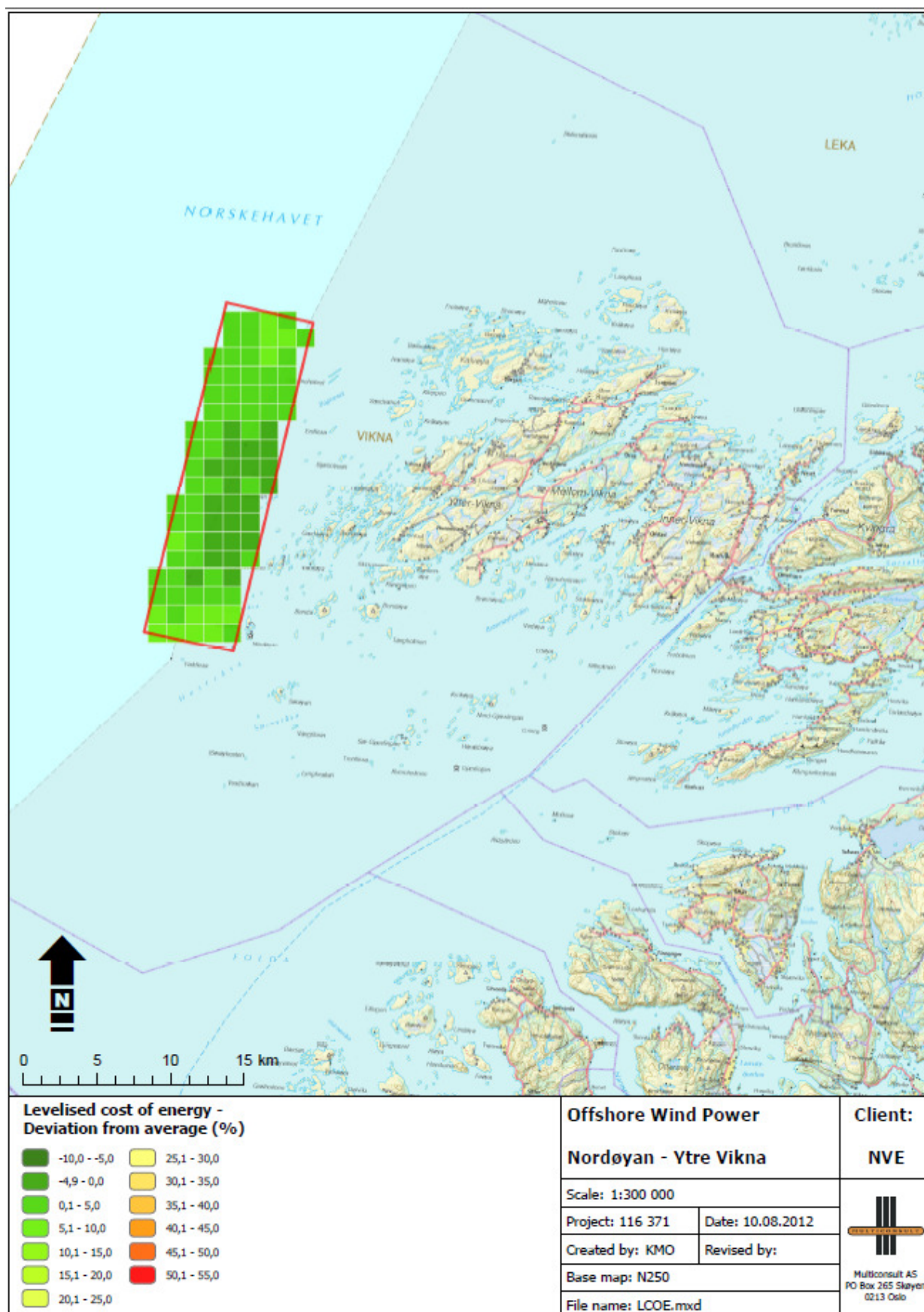
Appendix: illustrative maps of the 15 zones

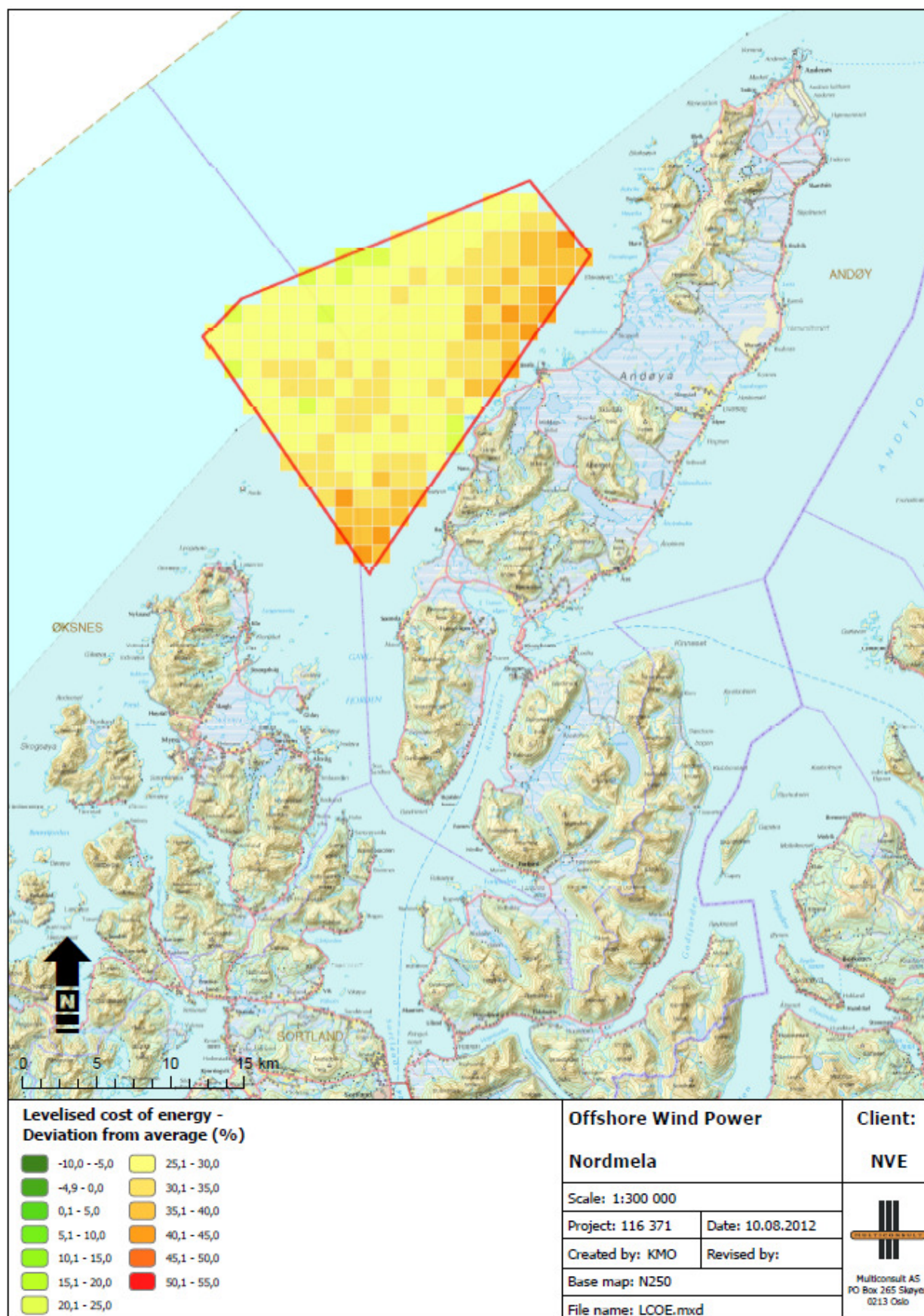


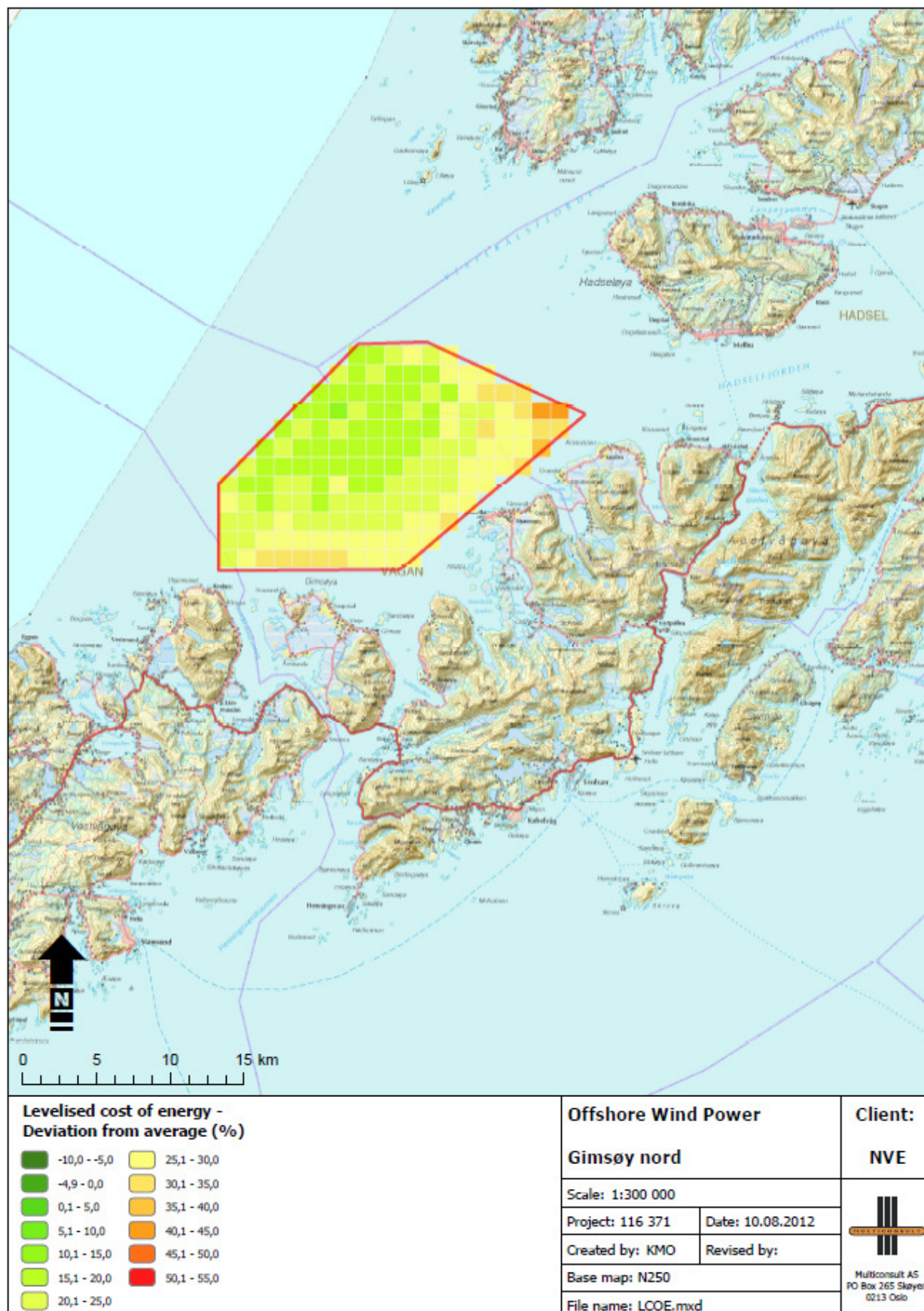


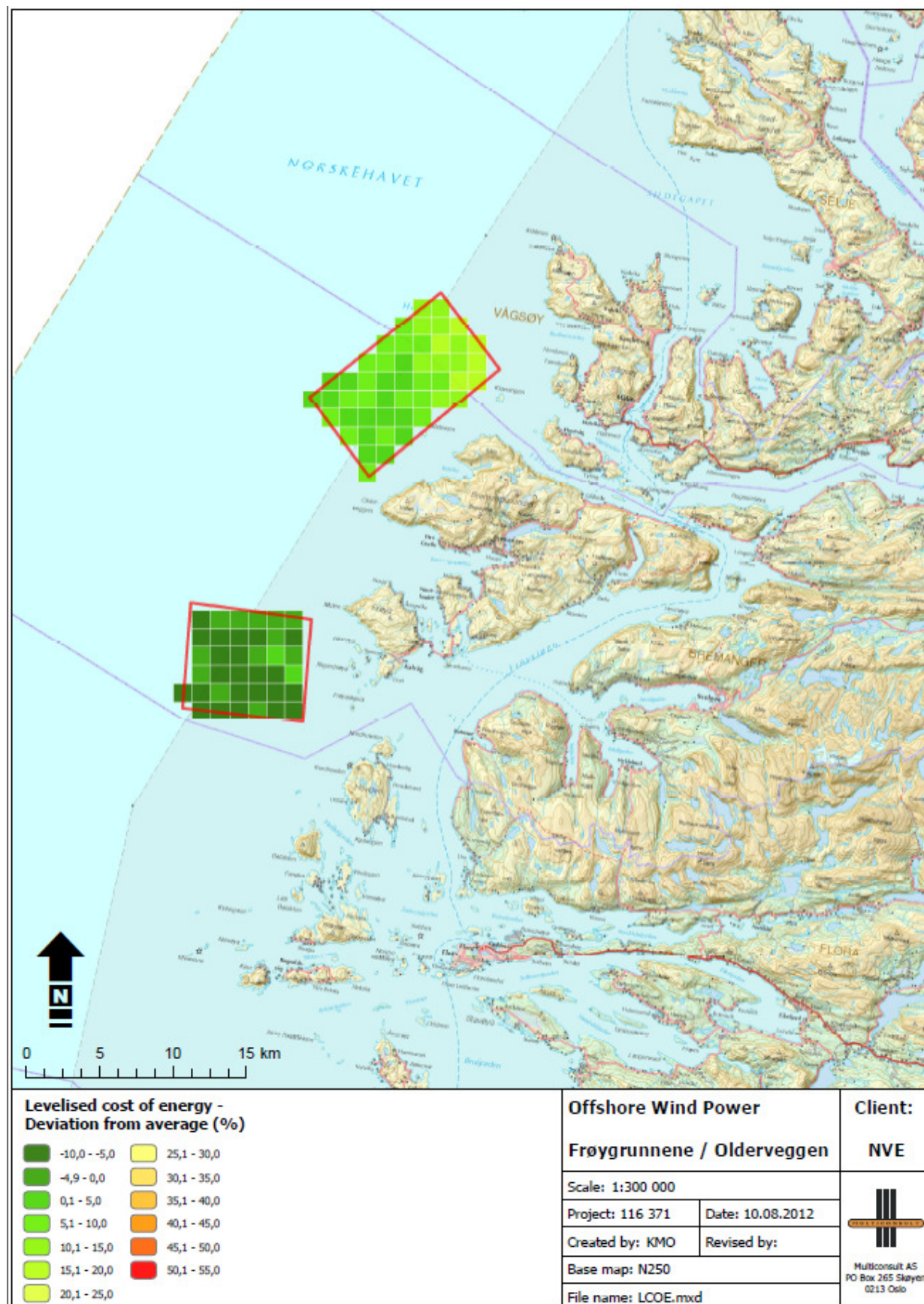


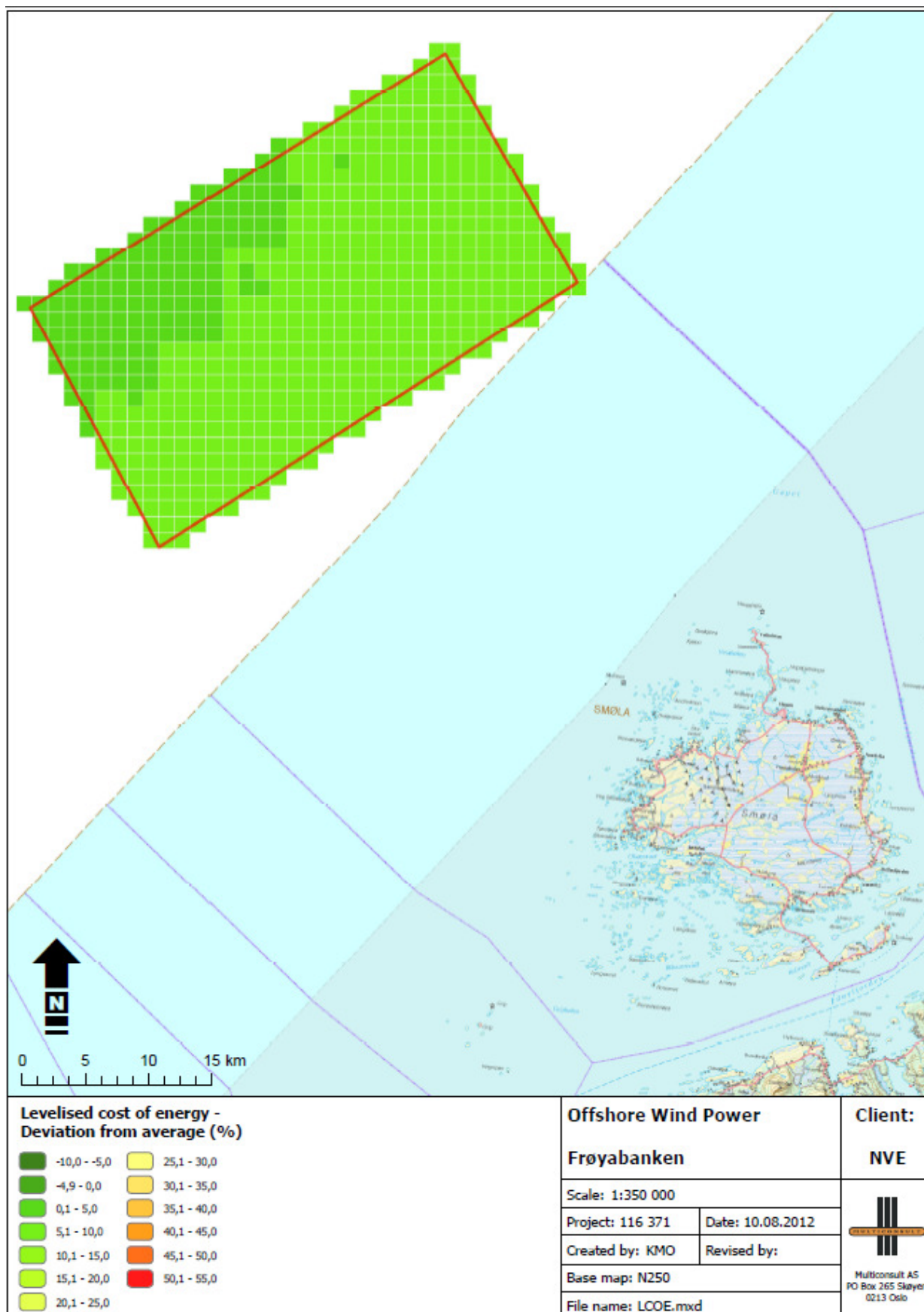


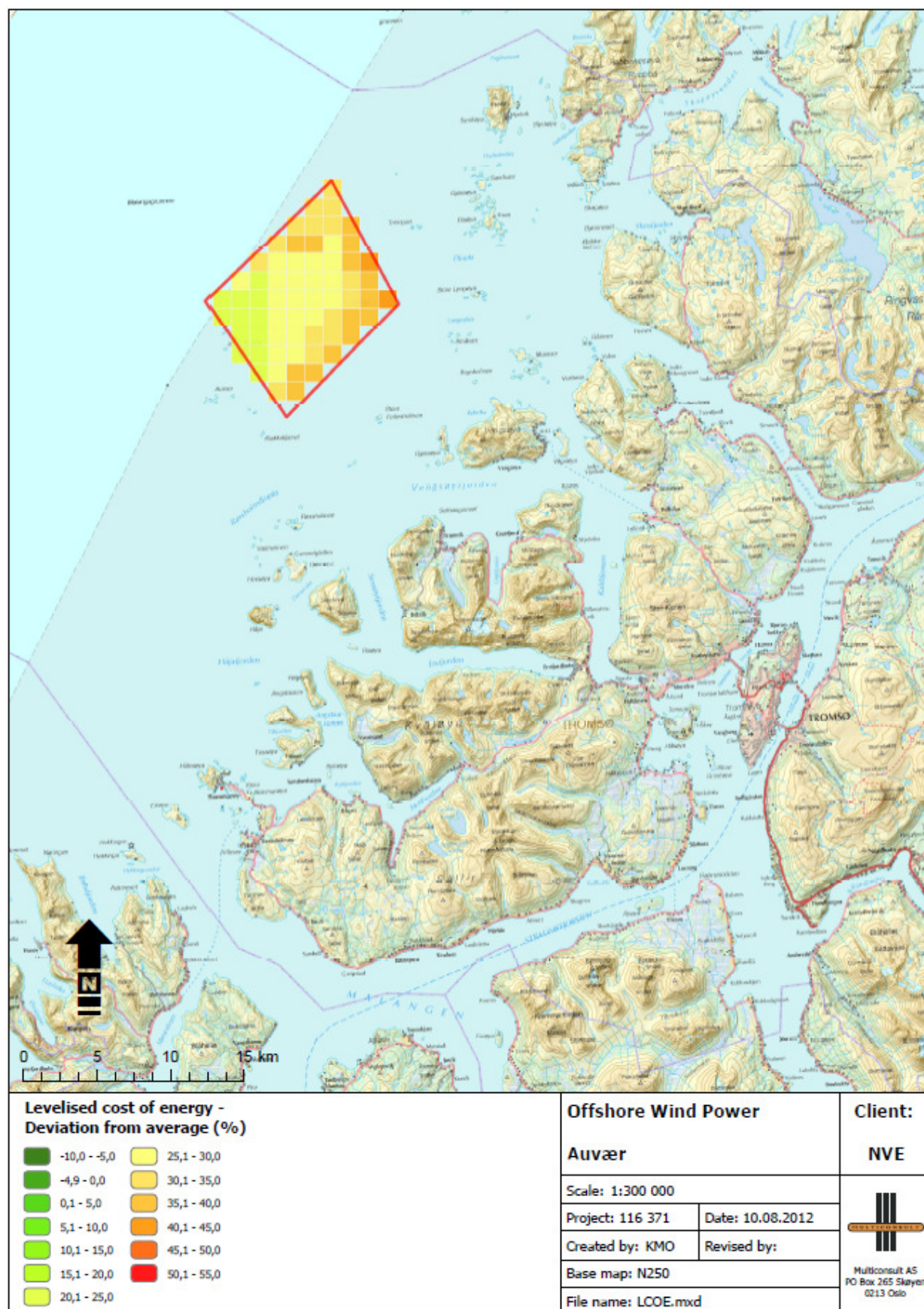


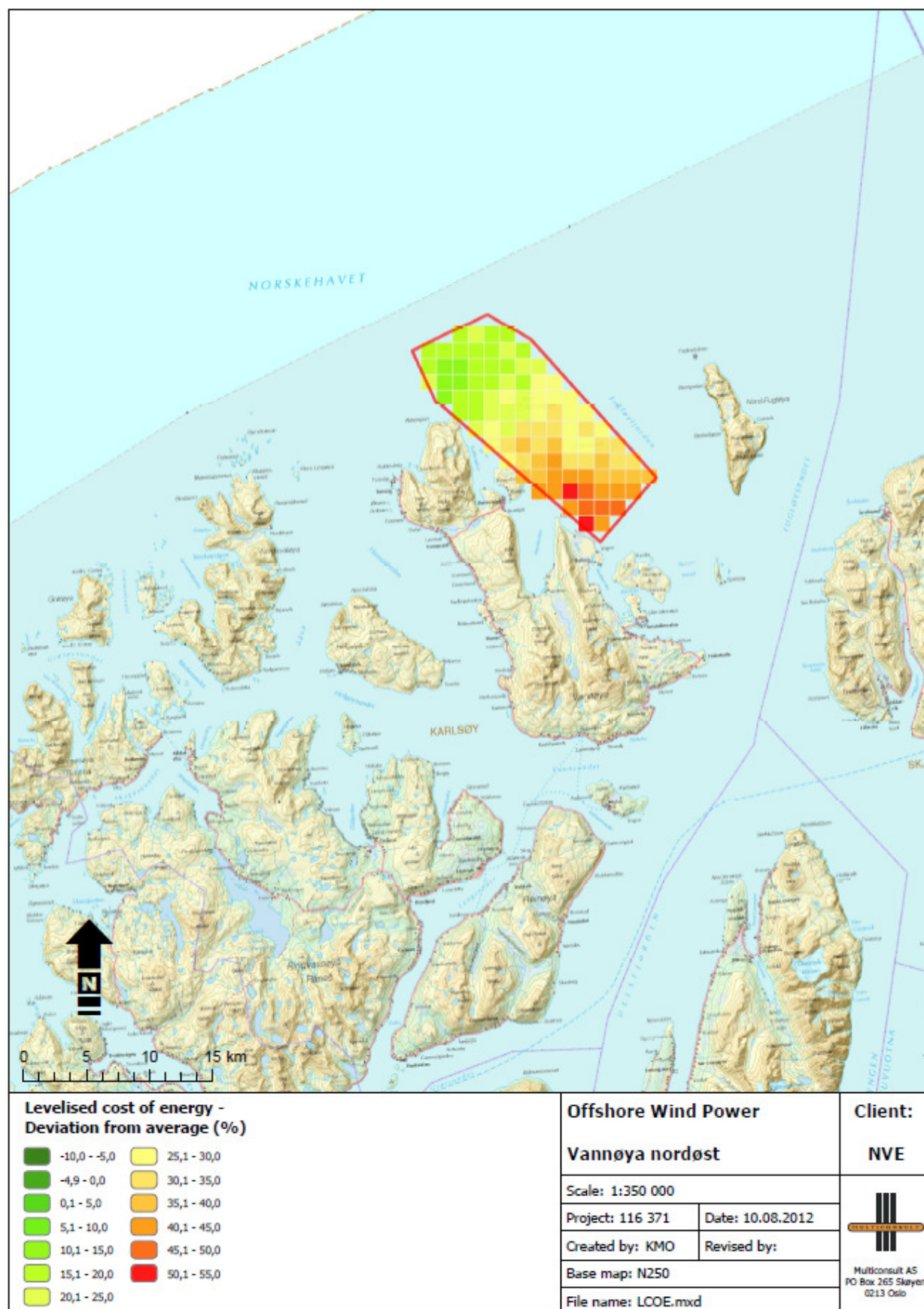


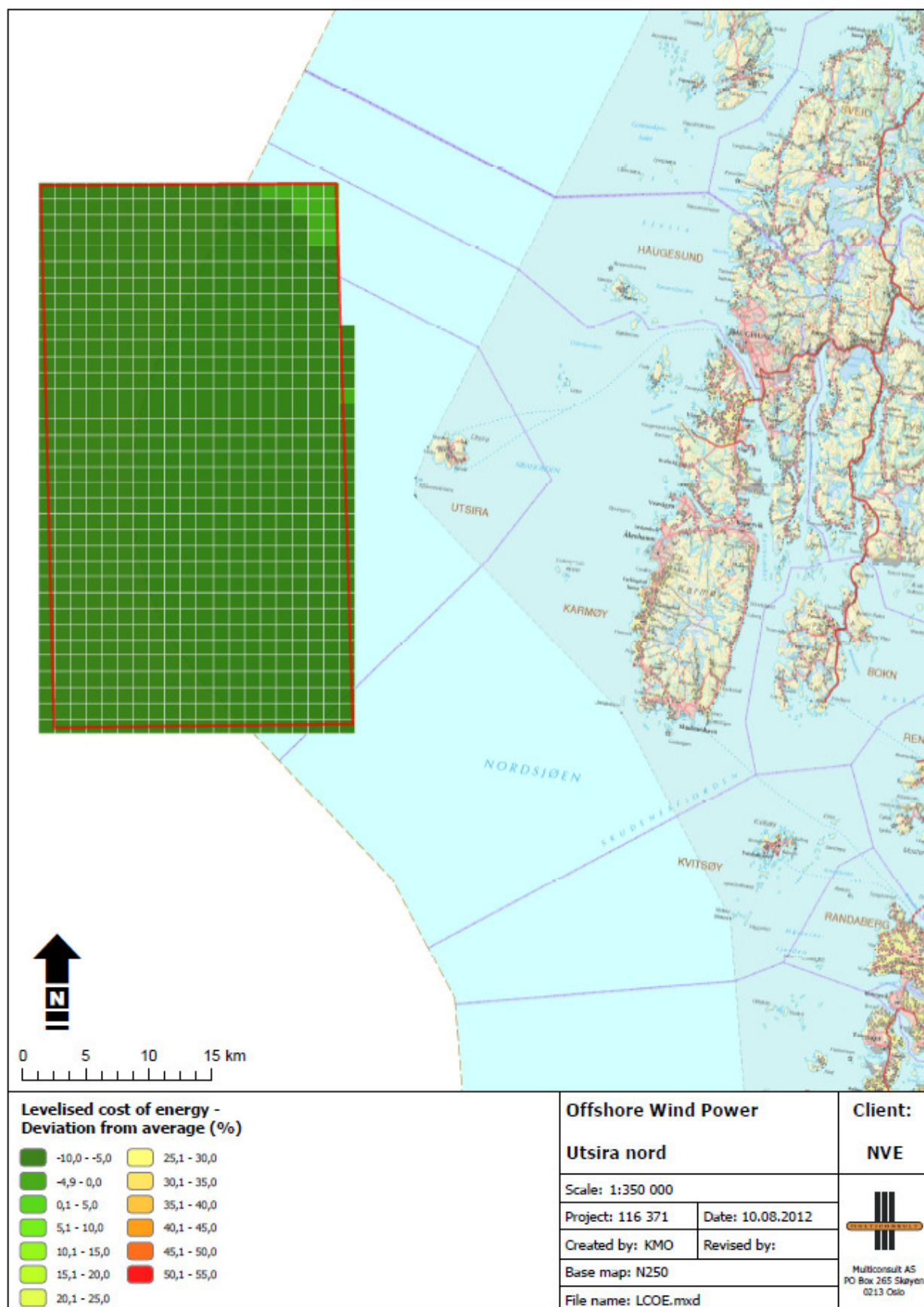


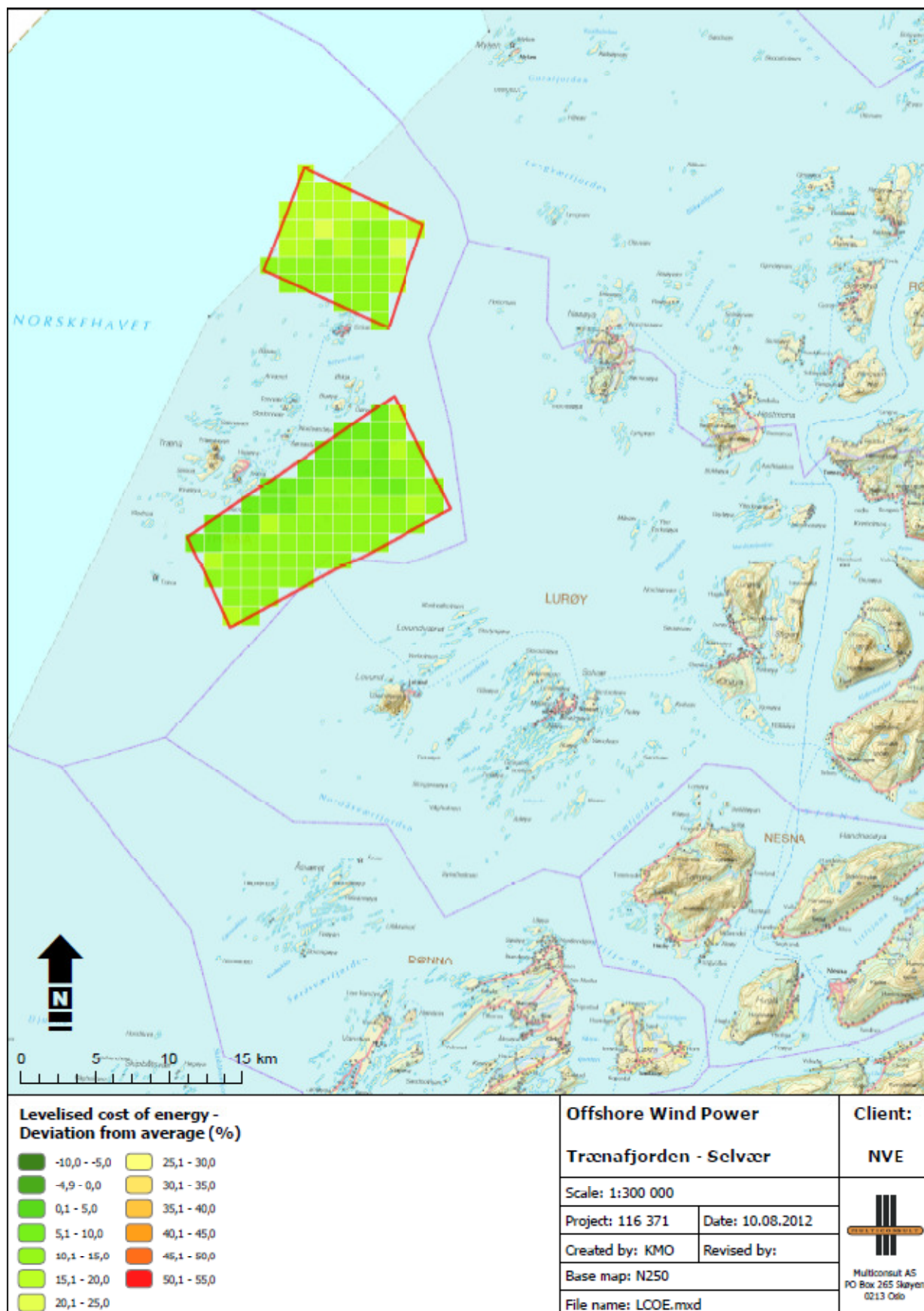


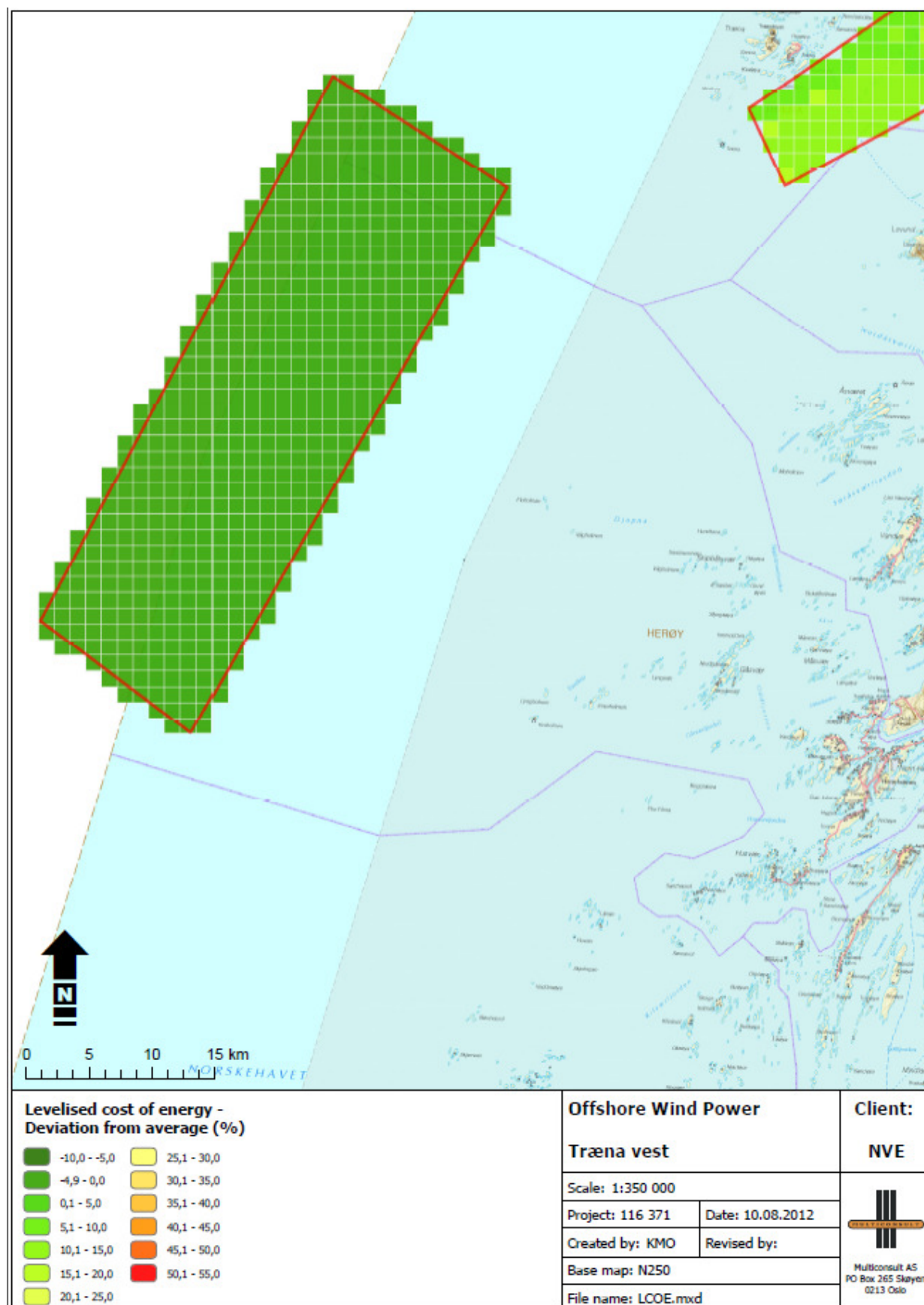














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Fagutredning 2

Teknologi- og kostnadsutvikling

Work Package 2

Technological and Cost Development Trends

APPENDIX 3

Technological and Cost Development Trends

Date: 26.06.2012

A report prepared by Multiconsult for NVE/OED

About Multiconsult: Multiconsult is one of Norway's leading consulting companies with more than 1400 employees spread in 20 offices in Norway and abroad. The company is involved in a broad range of business areas including: Energy, Oil & Gas, Industry, Buildings & Properties, Environment & Natural Resources, Transportation and Infrastructure. Multiconsult has taken a lead role in supporting offshore wind developments in Norway and has expanded its offshore wind advisory and engineering overseas. The company has built its know how through 100 years of engineering in the power sector combined with 40 years of offshore oil and gas track record.

Contents

Glossary of used terms	5
1 Executive summary	6
2 Study objectives and methodology.....	7
2.1 Methodology.....	7
2.2 Exclusions and limitations	7
3 Overview of Market Trends and Technology Outlook.....	8
3.1 Offshore wind development trends.....	8
3.2 Current project trends	9
3.3 Offshore wind challenges.....	9
3.4 The need for innovation and demonstration sites.....	10
4 Introduction to offshore wind technology.....	11
4.1 Definition.....	11
4.1.1 Offshore wind components	11
4.1.2 Offshore wind farm design	12
4.1.3 Offshore wind farm processes	13
4.2 Offshore wind turbine technology trends.....	14
4.3 Innovations and possible step changers	15
4.3.1 Larger turbines.....	15
4.3.2 More reliable and higher yield.....	15
4.3.3 Lighter turbines.....	16
4.3.4 Innovative concepts.....	16
4.3.5 Status and trends.....	17
4.3.6 Bottom-fixed	19
4.3.7 Floating	20
4.3.8 Innovations and possible step changers	20
4.3.9 Bottom fixed	21
4.3.10 Floaters.....	22
5 Assembly and installation	22
5.1 Status and trends	22
5.2 Innovations and possible step changers	24
5.2.1 Pre-assembly of turbine.....	24
5.2.2 Self installing pre-assembled solutions.....	25
5.2.3 Floating dynamic positioning (DP) vessels.....	25
5.2.4 Dedicated support structure installation vessels.....	26

6	Electrical infrastructure	26
6.1	Technology Status and trends.....	26
6.1.1	AC collection and transmission.....	26
6.2	Innovations and possible step changers	30
6.2.1	Offshore grid	30
7	Operation and maintenance	31
7.1	Technology status and trends	31
7.1.1	Introduction to offshore wind operation and maintenance.....	31
7.2	Innovations and possible step changers	33
8	The cost of offshore wind technology	37
8.1.1	Case of a typical 500MW offshore wind farm in UK	37
8.1.2	Future cost trends.....	38
8.1.3	Development	41
8.1.4	CAPEX - Procurement	41
8.1.5	CAPEX - Installation & Logistics.....	42
8.1.6	OPEX	42
8.1.7	Yield – Production of the wind farm	42
9	Offshore wind supply chain	43
9.1	A high demand for specialized supply chain & skills	43
9.2	Towards a global competitive arena	43
9.3	Norway's position in the industry	45
10	APPENDICES	47

Glossary of used terms

Capacity factor - The net capacity factor (expressed in %) of a power plant is the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full nameplate capacity the entire time. To calculate the capacity factor, take the total amount of energy the plant produced during a period of time and divide by the amount of energy the plant would have produced at full capacity.

CAPEX – Capital expenditure, also equivalent to the initial investment cost.

LCOE – Levelised Cost of Energy in NOK/kWh corresponds to the average lifetime levelised electricity generation cost

Lifetime – Number of years of operations of the offshore wind farm. Typically of 20 years for current project, it could be extended to 25 to 30 years in the years to come.

Load factor – see Capacity factor

MW – Megawatt

MWh - Megawatthour

OPEX – Operational expenditure include operational and maintenance costs.

SEA – Strategy Environmental Assessment

Spatial planning – In the context of this report, spatial planning is a tool that brings together multiple users of the ocean – including energy, industry, government, conservation and recreation – to make informed and coordinated decisions about how to use marine resources sustainably.

1 Executive summary

The offshore wind market is accelerating beyond Europe but its industry remains at early stage of development. The technologies and supply chain are evolving rapidly to follow changing projects trends, integrated lessons learned and reach delivery capacity required to meet the growing global demand. While governmental and developers remain focused on the development of bottom fixed projects towards the 2020 horizon, the recognition of the deep water floating market potential is triggering the worldwide development of innovative floating solutions which could lead to market take off earlier than envisaged by the industry.

Achieving significant cost reduction by 2020 is decisive to ensure the sustainable growth of the sector. bottom fixed offshore wind capital expenditure have been growing over the past years due to project trends (deeper, farther offshore), supply bottlenecks combined with volatile commodity prices. Cost reduction may be achieved through technological innovation and supply chain development in particular.

The leading innovation activities aim at lowering costs, ensuring future supply capacity, and minimize risks. Some of the key technological innovations include:

Table 1. Key technological innovation areas and activities

Area	Activities
Planning	• Spatial and physical planning methodologies • Models for site assessment and planning • Cost integration and site assessment tools • Accurate wind resource assessment and design models and tools
Wind farms	• Tools for wind farm layout and wind farm control • Offshore wind power plant capabilities • Ancillary services from wind farms • Short term wind prediction
Wind turbines	• Accelerated full scale test of turbine and components • Design conditions for reliable and multifunctional turbines in farms • Design basis for large offshore turbines in integrated farms • New rotor and generators (larger, lighter, more reliable, longer lifetime)
Support structure & Foundations	• Optimised manufacturing processes • Optimised, cost efficient foundations (gravity based structure, monopile) • New, cost-competitive foundations (jacket, tripod, suction bucket) • Design methods and tools for ground and seabed conditions
Electrical infrastructure	• Voltage level and turbine rated capacity • Combining grid connection with interconnections between power systems areas • Power system compliance for wind farms
Assembly and installation	• Pre-assembly of standardised, stackable components at harbour • Modularisation and standardisation of substations and connection • Cable installation on seabed, quality and protection of cables in farms • Optimised installation methods and planning
Operation and maintenance	• Risk-based cost-optimal O&M planning • Cost-optimal and weather robust, safe, mobile access
Decommissioning	• Not prioritized for the moment but considered as part of the support structure and foundation developments

2 Study objectives and methodology

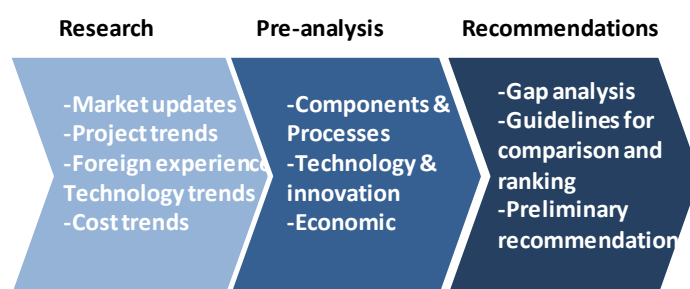
Considering the timeframe uncertainties of a possible offshore wind deployment in Norway, special attention must be given to the description of the outlook for technology that will apply to Norway. Understanding the implications for spatial planning as well as overall strategic deployment of offshore wind in Norway is the focus of the study.

This report presents the status and trends of the offshore wind industry in terms of technology and cost development in a short and long term perspectives.

The report is independent from the assessment of the 15 areas but provides the background information necessary for the analysis (presented in another separate report Fagutredning 2 – teknologi of kostnadsutvikling).

2.1 Methodology

The illustration below presents the overall methodology of the assessment. The present report corresponds to the deliverable attached to the first Research work package presented below.



An initial research work was performed in February and March 2012 based on:

- Review of recent publications
- Attendance to latest international offshore wind conference in Europe
- Market intelligence through in-house knowhow and external sources through the 10 years of monitoring of the offshore wind sector
- Exchanges and interviews with key technology providers including:
 - Turbine manufacturers such as SWAY turbine
 - Bottom fixed structure support: OWEC Tower, Seatower, Windsea jacket (Straum)
 - Floating structure support: Hywind (Statoil), Windfloat (Principle Power), Blue H, Windsea floater (Straum)
- Contractors/Installers such as NorWind Installer
- Developers and investors such as Statkraft, Statoil, Vestavind offshore, Lyse
- Financial entities such as Scatec, Export Finance, DNB

The **preliminary analysis** and **Recommendations** are further discussed in a separate report Fagutredning 2 – teknologi of kostnadsutvikling.

2.2 Exclusions and limitations

In absence of clear guidelines on the timeline for an offshore wind deployment in Norwegian waters, the report is not aimed at providing accurate cost forecasts and restrictive technical recommendations but to

provide comprehensive background facts and trends to understand the key factors and drivers influencing the definition of a national strategic plan.

The report does not aim at giving an exhaustive and detailed state of the art of all different technologies and innovations involved in offshore wind. It rather focuses on the key trends and their implications on Norway's offshore wind spatial planning and deployment strategy.

Future cost projections contained in this report should not be utilized as forecasts. They are mainly provided for illustrative purpose and are built on the basis of a high level interpretation of current market and technology trends.

3 Overview of Market Trends and Technology Outlook

3.1 Offshore wind development trends

After 20 years of relatively slow development, the offshore wind market is finally taking off. As of March 2012, the European Union leads the world with about 4 GW of offshore wind installed. This is only the beginning of a major industrial development. In 2011, a total of 140 GW of projects at various stages of development have been identified throughout Europe as presented in Figure 1 below.

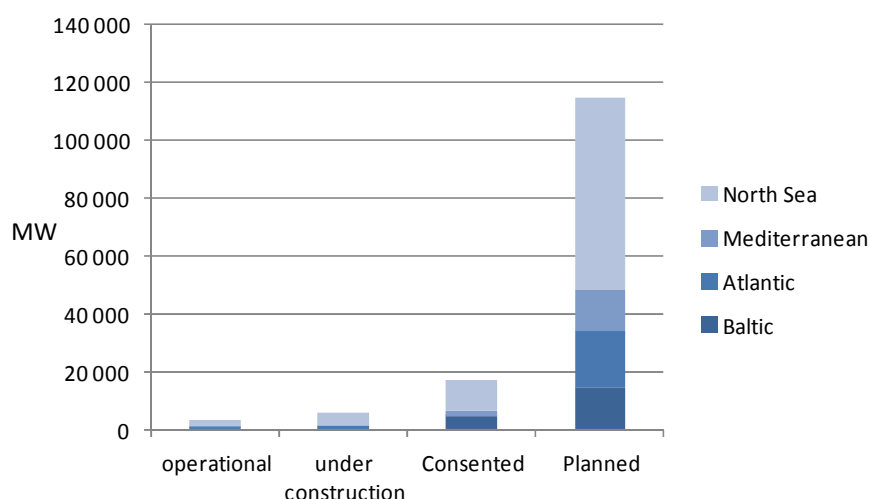


Figure 1. Current European offshore wind project in operation and pipeline. Source: EWEA, 2011

A review of the European National Renewable Energy Action Plans (ECN, 2011) indicates that offshore wind is to play a significant role in Europe's sustainable energy future: by 2020, 12% of the 1217 TWh EU27 renewable energy production is expected to come from about 44 GW of offshore wind. Furthermore EU's "Energy Roadmap 2050" (European Commission, 2011) published late 2011 sets out pathways for an energy sector that is 85% carbon-free by 2050 including a wind power contribution ranging between 32% and 49% of the EU power production. In a recently published plan, Denmark announced the ambitions to build two new offshore wind parks with a total capacity of 1,000 MW by 2020.

Ahead of 2020 targets, a massive wave of construction is expected to take place over the 2015-2020 period thanks to simultaneous market take-offs across Europe (UK round 3, Germany EEZ developments in North and Baltic Seas, France, Netherlands, Denmark among others).

Outside Europe, new markets will take off in Asia and North America. China alone aims at a cumulated offshore wind installed capacity of 5 GW by 2015 and 30 GW by 2020. Furthermore, a scenario study (Carbon Trust, 2011) forecasts a global cumulated installed capacity ranging between 440 and 1150 GW by 2050.

3.2 Current project trends

After a decade of exploiting easily accessible sites in shallow water and close to shore, the average project size has been lifted from 60 MW up to typically 300-400 MW today. In 2010, Thanet (300 MW), the world largest offshore wind farm to date, was commissioned in UK but larger projects such as London array (630 MW) and Greater Gabbard (504 MW) are already under construction. The Dogger Bank UK round 3 zone¹ developed by the Forewind consortium is expected to reach a total capacity of 9-13GW within 2020 through phased deployment of several wind farms.

Most installed offshore wind farms have been installed in waters below 25m (see Figure 2) but future projects are located further offshore, in deeper water depths. This implies new design and construction solutions in support structures, installation methods, HVDC transmission technology and remote manned platforms.

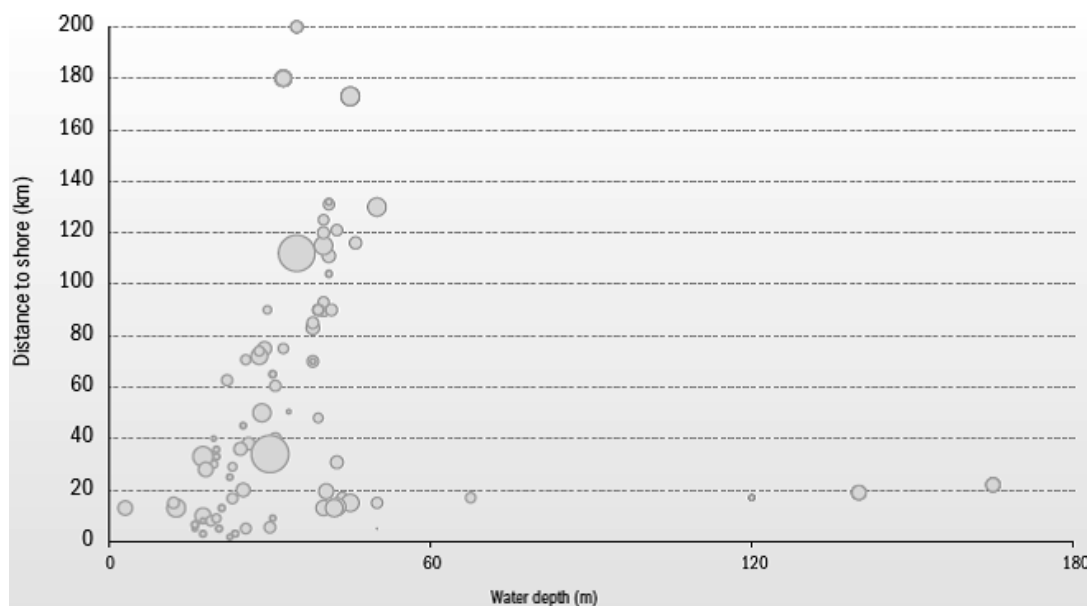


Figure 2. Distance to shore (km) and average water depth (m) of planned projects. Source: EWEA, 2011

3.3 Offshore wind challenges

Various obstacles need to be overcome in the next five years if Europe is to meet its offshore wind targets (see Figure 3):

- **Cost reduction** is most critical, being tackled by all stakeholders. The offshore wind industry is reaching a critical transition point where significant investments must be triggered while cost must be decreased. In UK, for example, the levelised cost of offshore wind energy is currently up to 1,6 NOK/kWh and is expected to decrease down to 1 NOK/kWh by 2020 (The Crown Estate, 2011-2012). Increased industry competition, mass production and innovation are expected to contribute significantly to lowering cost of energy.
- **Technical maturity and reliability.** Innovative solutions must be rapidly developed and demonstrated ahead of commercial deployment. Increased risks and uncertainties due to unproven solutions will require robust risk management.

¹ UK round 3 zones are to be divided in several offshore wind farms



Figure 3. Overview of the key offshore wind obstacles ahead of 2020 ambitions. Source: Multiconsult, 2012

- **Supply and skills bottlenecks.** As the offshore wind market brings large volume of activity and gradually moves in deeper waters, the demand for suitable supply chain, skills and staff capacity is increasing rapidly. Since the financial crisis of 2008-2009, these challenges have turned into opportunities as employment and export potential became major drivers alongside climate change and security of energy supply. It is foreseen that the offshore wind sector will employ 300 000 staff out of 480 000 working for the broader wind power sector.
- **Securing grid connection in a timely manner.** The development of grid connection and transmission is time consuming, especially onshore. Unclear planning process, unclear development and financing responsibilities have postponed offshore wind deployments in Germany and UK.
- **An uncertain policy environment.** The role of governments is decisive in setting and sustaining attractive and predictable policies (offshore wind specific targets, support schemes etc.) with the aim to provide financial players the long term confidence to invest.
- **Securing necessary planning permission and consents in a timely manner.** As presented in a previous report prepared for the Nordic Council of Ministers (Multiconsult, 2010), many planning and consenting framework are not fit for the purpose of offshore wind and are currently under reform.
- **Securing project equity and debt financing is likely to remain difficult** until the European Union finally recovers from the current economic crisis. According to Bloomberg New Energy Finance's Central scenario, a cumulated investment of NOK 1015 billion of capital in offshore wind and associated grid connections could be required to build capacity before 2020.

3.4 The need for innovation and demonstration sites

The demand for innovation is essentially driven by the **need for cost reduction and rapid deployment of new solutions by 2020**. Several new concepts are getting attention, including: lighter and more reliable turbines; cost efficient foundation design and installation methods; onshore pre-assembly of offshore turbines and units (as a means to remove costly offshore operations); mass serial fabrication and installation to trigger economies of scale.

Despite the recent arrival of several new entrants amongst suppliers, **the timeframe allowed to bring cost reduction solutions to maturity is short**: key procurement orders for the first wave of UK round 3 projects are

already expected to take place in the 2014-2016 period. However, for most new technologies, reaching commercial deployment requires the fulfillment of key development milestones including small scale model testing, large scale pilot demonstration and monitoring, detail engineering, certification. Qualifying a new technology such as offshore foundation typically requires 2 years of monitoring of a prototype in operation.

Several test and demonstration projects are needed on the short term: The Crown Estate in UK published a report in august 2011 (The Crown Estate, 2011), indicating the critical need for demonstration sites in order to test necessary technologies particularly in the turbine segment before the commercial deployment of UK round 3.

Table 2 below introduces the different types of project (demonstration, small scale pilot and commercial), their primary purpose and benefits.

Table 2. Introduction to demonstration, small scale pilot and commercial projects

Project category	Scope	Primary purpose	Other benefits
Demonstration	Typically 3 to 10 units	Demonstration and testing of innovative technology and methods Learning for all stakeholders	- Tests and qualifies technology ahead of commercialization - Gives show case and track record to suppliers - Possible platform for international partnerships - Learning for all stakeholders
Small/medium scale pilot	50-200 MW	Procure power and bring value to project owners Learning for all stakeholders	-Triggers upfront investment in the supply chain to serve foreign and domestic markets - Gives show case and track record to suppliers - Possible platform for international partnerships - Learning for all stakeholders
Commercial scale	>200 MW	Procure power and bring value to project owners	Short and long term value creation benefits

Note that small and large scale commercial projects can be phased to include a demonstration element into its development.

4 Introduction to offshore wind technology

4.1 Definition

4.1.1 Offshore wind components

The main recognizable component of an offshore wind farm is the **turbine unit** composed of the wind turbine rotor and nacelle, the tower, the support structure and its foundation. All together this represents by itself about 35 % of an offshore wind farm CAPEX.

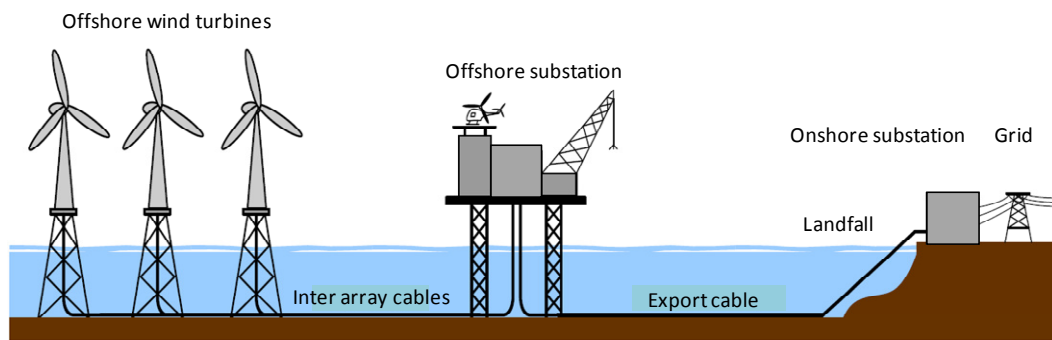


Figure 4. Key components of an offshore wind farm. Source: Multiconsult, illustration by Goodtech 2012

Other offshore items of an offshore wind farm includes inter array cables, exports cables, offshore substation topside and their support structure and foundations. An offshore wind farm also includes onshore items such as the landfall, onshore cable and onshore substation.

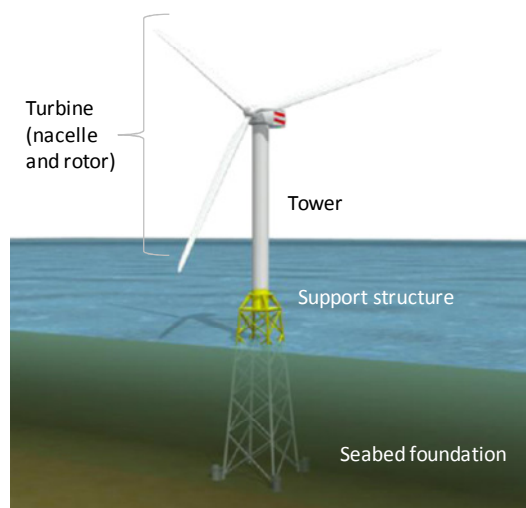


Figure 5. Offshore wind unit – key components. Source: Multiconsult, Illustration by OWEC Tower 2012

4.1.2 Offshore wind farm design

The size of single offshore wind projects is increasing. Their overall design and configuration is also evolving in order to take into account optimal layouts of turbines and likely phasing of the construction into several deployments. As a consequence typical 1000-1500 MW offshore wind projects are divided into several offshore wind farms connected to a similar electrical infrastructure.

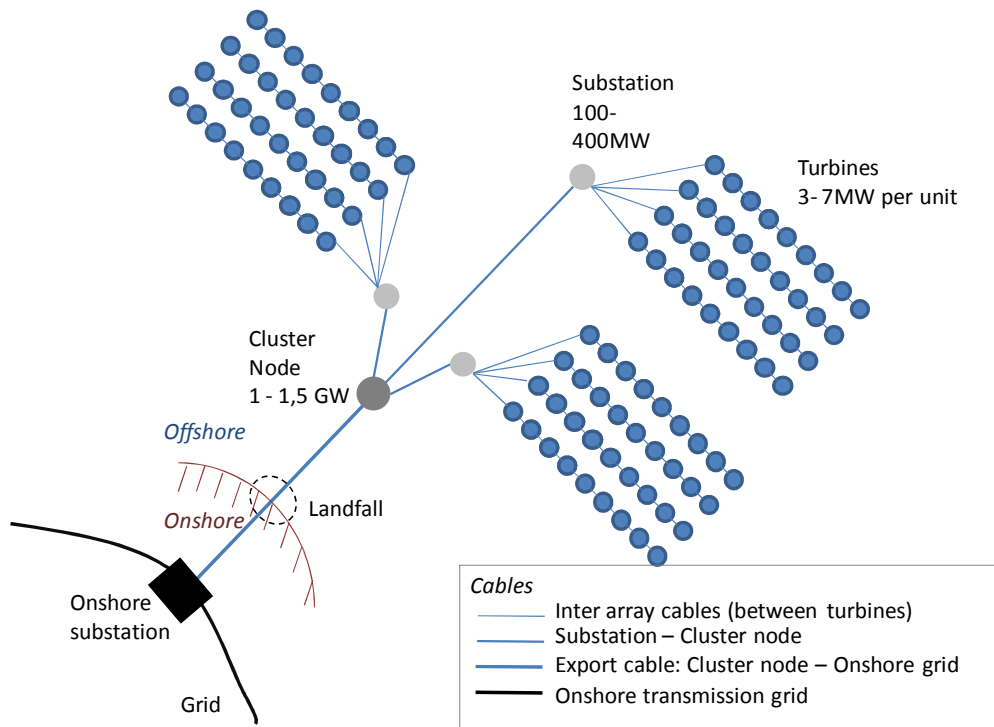


Figure 6. Overview of a typical offshore wind farm cluster (1-1,5GW) in 2012-2015. Source: Multiconsult, 2012

4.1.3 Offshore wind farm processes

The illustration below further describes some of the key components and processes



Figure 7. The main offshore operations and the equipment involved. Source: The Crown Estate, 2009²

From an economic view point it is essential to assess offshore wind from a complete lifecycle perspective. The life of a typical offshore wind farm can be divided in 5 distinct phases: Development & Consenting, procurement and fabrication, installation and commissioning, O&M, decommissioning and repowering.

² A larger illustration is available in appendix

Development	Procurement	Assembly & Installation	Operations & Maintenance	Decommissioning
Development services (e.g. feasibility, licensing, planning, radar).	Turbine - Rotor - Nacelle - Tower	- Seabed preparation/foundation installation - Pre-assembly at construction port - Support structure installation - Turbine installation - Inter array cable-laying - Export cable-laying - Offshore substation installation - Commissioning - Sea-based support	Operations Maintenance - Scheduled - Unscheduled	Dismantling Eventual replacement of turbines
Human impact studies	Support structure and foundation			
Site investigation - Environmental surveys - Coastal process surveys (land-fall sites for power cable route selections) - Met station surveys - Sea bed surveys	Electrical infrastructure - Inter array cables - Export cables - Offshore substation topside - Onshore substation			
Front-end engineering and design				

Figure 8. Breakdown of key activities and supply components of an offshore wind farm. Source: Multiconsult, 2012

4.2 Offshore wind turbine technology trends

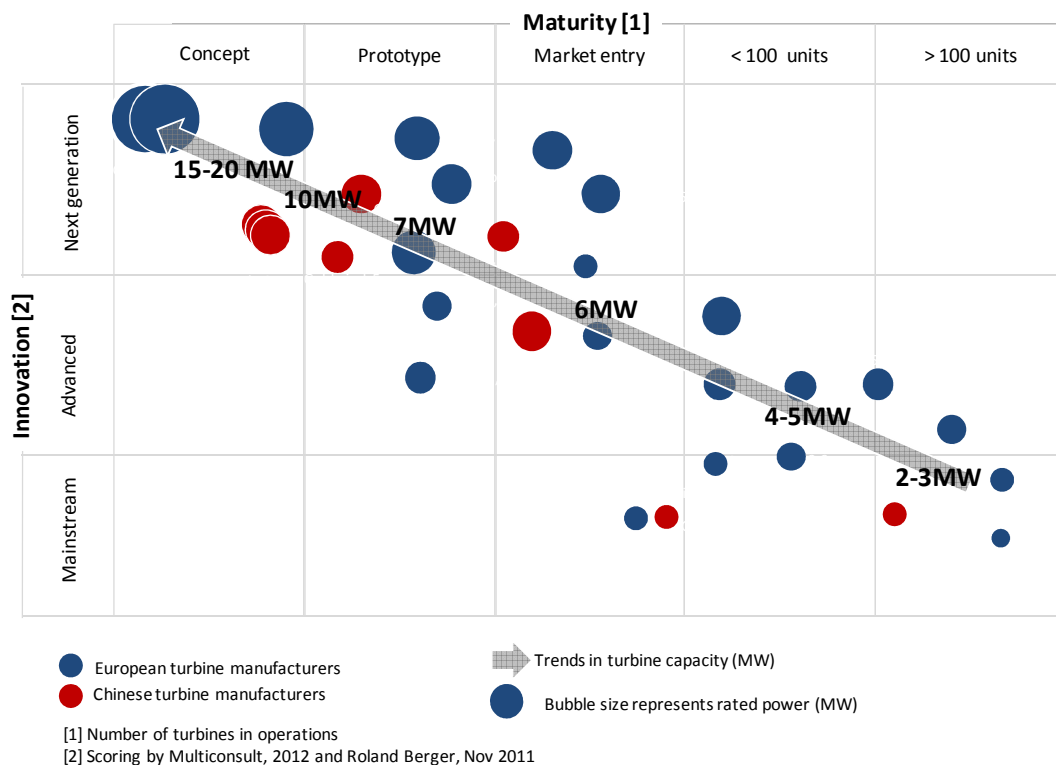


Figure 9. Innovation and maturity in the conventional offshore wind turbine market (non exhaustive). Source: Multiconsult 2012, Roland Berger, 2011

The conventional offshore wind turbine models, based on the 3 bladed, upwind, horizontal axis rotor design were initially developed for onshore purposes. In the latest years, turbines became specifically adapted to the offshore environment keeping nevertheless the overall design principle of onshore wind turbines.

While the maximum onshore turbine capacity now seems to stagnate around 3MW, the capacity of offshore models is increased rapidly. 3-6MW turbine units are being currently deployed while 7MW are now being commercialized for projects to be built in 2015. Turbine manufacturers from Asia have now entered the market on multi-megawatt turbines. See below.

4.3 Innovations and possible step changers

4.3.1 Larger turbines

The industry' general assumption so far is that developing large units leads to cost reductions and lower Levelised Cost of Energy (LCOE). Accordingly, larger 10-15MW units are already on the drawing board. Norwegian turbine developer SWAY has received grants to demonstrate in the incoming years an innovative 10MW offshore wind unit on the onshore test site in Norway. Research work³ carried out in the past years on turbines up to 20MW with an impressive 252m rotor diameter indicates that technical feasibility is achievable although economics rationale for up scaling to these dimensions is yet to be proven.

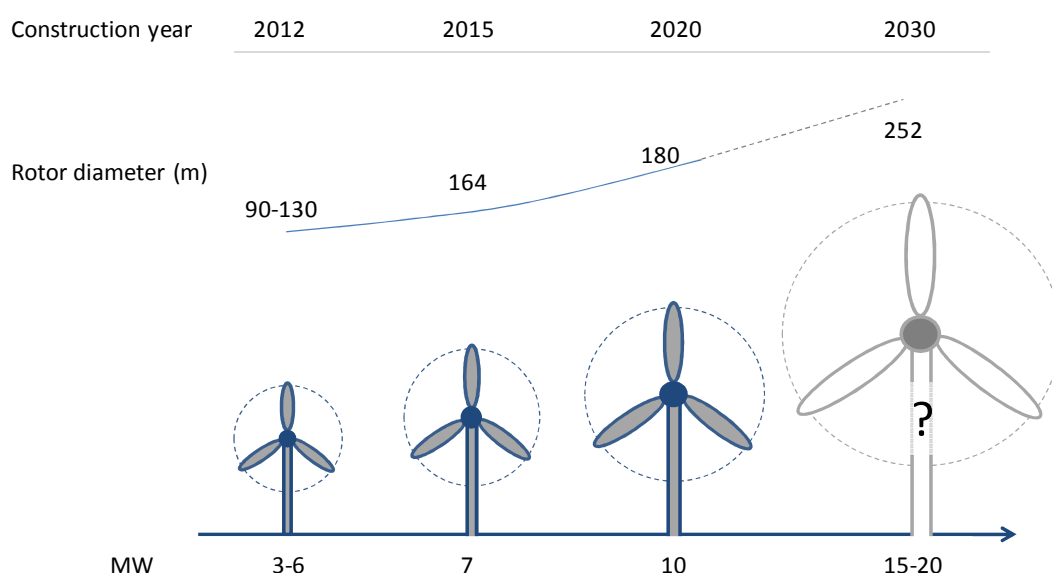


Figure 10. Evolution in conventional turbine dimensioning. Source: Multiconsult, 2012

4.3.2 More reliable and higher yield

Being aware of the increased risk introduced by upscaling turbine technology too rapidly into large commercial projects, some turbine manufacturers prefer to ensure reliability and run robust qualification tests before large scale serial deployment. Technology shifts regarding blades or nacelle components (ex: replacement of gearbox technology with direct drive and or superconductor technology) are expected to bring substantial cost savings through improved yield and reliability.

³ UpWind EU project, 2008

4.3.3 Lighter turbines

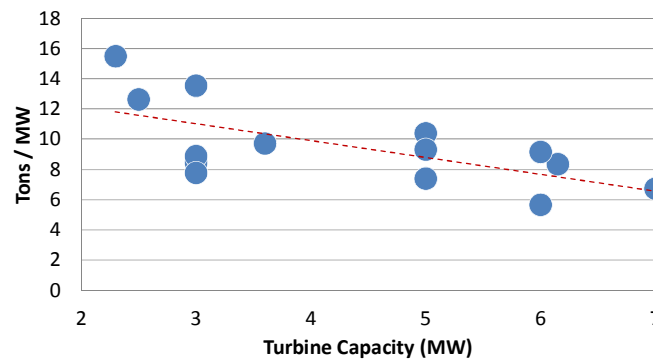


Figure 11. Trend in top head mass per MW for commercial turbines (2-7MW). Source: Multiconsult, 2012

It is observed that top weight of turbines (blades/rotor, nacelle) generally increases as the size of the rotor and rated power increases. Top weight of turbine is a limiting factor impacting severely the cost of support structures (floating in particular) and offshore installation (mobilization of expensive heavy lift vessels). An increasing technology focus is therefore made on developing lighter rotors and nacelles. As a result, the top weight per MW is expected to decrease and stagnate (see Figure 11).

4.3.4 Innovative concepts

It is however commonly accepted in the industry that further scaling up the conventional 3 bladed design may reach its physical and economic limits as other alternative design will compete on cost. The development on innovative concepts is now progressing. With the objective of limiting offshore operations considered as costly and risky, innovation on turbines incorporates design features serving other purpose than the increased energy yield and reliability.

These can be divided in three main technology trends:

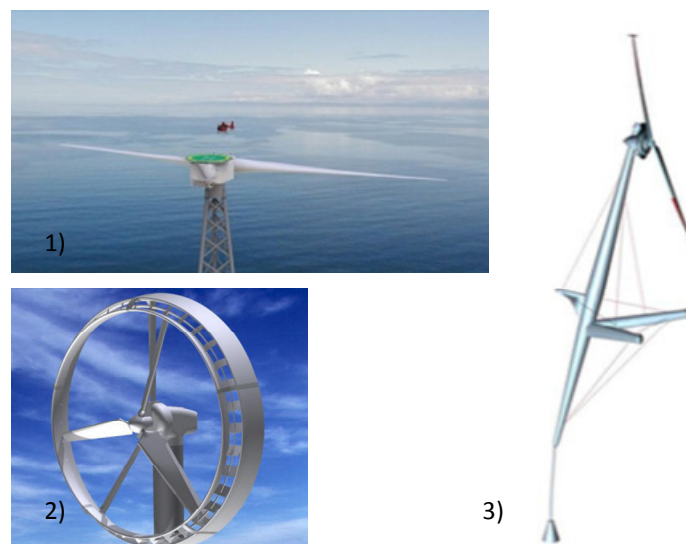


Figure 12. innovative two bladed turbines. Sources: 1) 2B Energy; 2) Innwind; 3) Nautica WindPower

Variants to the conventional turbines

Development of 2 bladed turbines could contribute to the simplification of installation methods and reduce overall cost of each unit (illustration 1 below). According to some players, the development of turbines with more than 3 blades combined with circular lens could improve production performance and ease the

integration with floating support structure (illustration 2). Downwind turbines are also expected to allow better integrated floating designs (illustration 3).

Vertical axis turbines

Inspired by earlier work on onshore vertical axis turbines, various developers are developing large scale vertical axis units for bottom-fixed and or floating support structures with prospects to save costs across the whole lifecycle. Demonstration programs backed by large industry players are underway for some of these concepts such as Vertiwind supported by Technip, a world leading offshore contractor.



Figure 13. Vertical axis turbines. Sources: 1) Vertiax; 2) VertiWind, 3) NOVEL 4) Sea Twirl

Multi-rotor, horizontal axis

The development of the floating market may enable to develop turbine units based on several rotors and generators. Beyond research, several concepts are now developed by Norwegian, European and Asia companies. The Hexicon concept is currently being developed towards a first deployment in Maltese waters and could be ready as early as 2015. Most of these concepts emerge from marine engineering companies rather than turbine industry and therefore still rely on the conventional turbine technologies available to the market. It is however foreseen that optimal and cost efficient solutions will require the development of innovative fit for purpose turbine models.

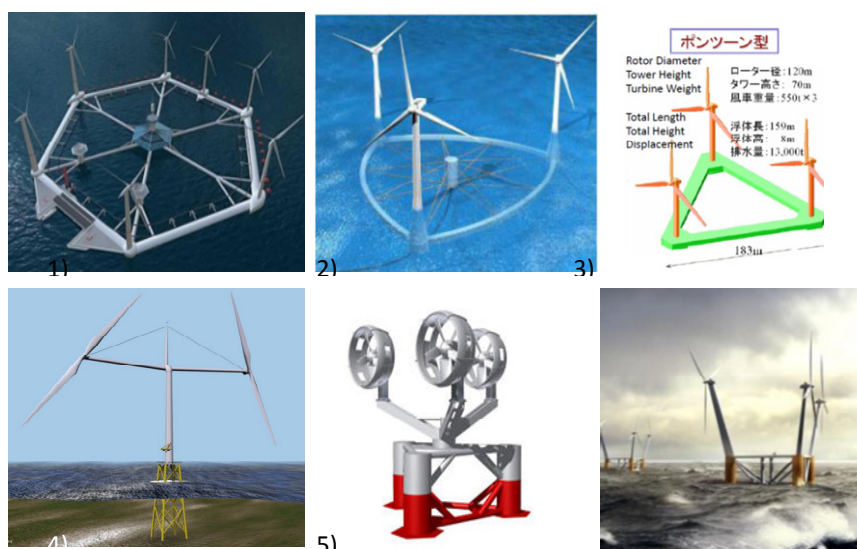


Figure 14. Multi-rotor horizontal axis turbines. Sources: 1) Hexicon;; 2) Pootoon design / Mitsubishi Zosen (Mitsubishi Shipbuilding); 3) Semi submersible / Shimizu Corporation (JP;) 4) Helm Wind; 5) Innwind; 6) Windsea Support structures

4.3.5 Status and trends

There is no universal standard support structure solution for offshore wind. Technology choice is site specific and driven by least cost approach which varies from project to project.

Until recently, solutions for shallow waters such as piled steel monopiles were thought to have reached a certain degree of maturity and reliability. In 2011, a design fault in grouting used to fix wind turbines to their monopiles or towers was discovered⁴. Alternative design and standards have been developed and a large number of monopile based projects are being fixed with costly solutions. This single event demonstrates that the overall offshore wind industry remains immature and based on relatively unproven technology. The lifetime of a complete offshore wind farms being of 20 to 25 years, the industry will not be able to claimed a truly A to Z experience before several years.

To date, technology selection is essentially driven by water depths and soil conditions. The applicability and cost competitiveness of different support structure type depends on a number of site conditions factors. Water depths and seabed conditions are by far the most critical drivers. We can divide the market in two main segments: Bottom fixed and Floating.

Future support structure technology will be increasingly based on the overall cost performance of the supply and installation of the foundation and installation of the turbines. The possible emergence of floating technologies and pre-assembled self installing solutions will be a driving force towards this trend.

Table 3 below presents used assumptions for foundation type; applicability to different water depths and maturity:

Table 3. Support structure technical feasibility and maturity according to water depth. Source: Multiconsult, 2012

Support structure	Foundation/Anchoring	key material	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	> 100
BOTTOM FIXED													
Monopile	Driven/drilled pile(s)	steel											
Monopile	Drilled pile(s)	steel/concrete											
Supported monopiles and guyed towers	Driven/drilled pile(s)	steel											
Gravity Base Structure - concrete	Skirts / Suction	concrete											
Gravity Base Structure - concrete	Seabed preparation for GBS	concrete											
Gravity Base Structure - concrete	Cemented base GBS	concrete											
Lattice towers - Quadripod (jacket)	Driven/drilled pile(s)	steel											
Twisted jacket	Driven/drilled pile(s)	steel											
Tripod	Driven/drilled pile(s)	steel											
Tripile	Driven/drilled pile(s)	steel											
Suction bucket - steel	Suction bucket	steel											
Suction bucket - concrete	Suction bucket	concrete											
FLOATING													
Semi submersible	Depends on soil conditions	steel/concrete											
SPAR	Depends on soil conditions	steel/concrete											
Tension Leg Platform (TLP)	Depends on soil conditions	steel											
Other (Floating barge etc.)	Depends on soil conditions	steel											

color code reflects maturity/exclusion from offshore wind sector.

extensive track record, conventional

limited track record

feasible but not mature

unclear, not investigation for the purpose of offshore wind

not feasible, bottom fixed are excluded from 100 m water depth due to economic reasons

nb: some concepts have been deployed in the offshore oil & gas sector which is not reflected here

4.3.6 Bottom-fixed

The vast majority of offshore wind support structures deployed to date are bottom fixed or monopiles. Gravity based structure (GBS) have also been deployed on a large number of earlier sites. Other designs adapted by the offshore Oil&Gas sector such as jacket and tripods have now been demonstrated and are now being deployed on commercial scale projects in UK and Germany. These designs are now being optimized to the offshore wind purpose to allow cost savings through serial production and installation.

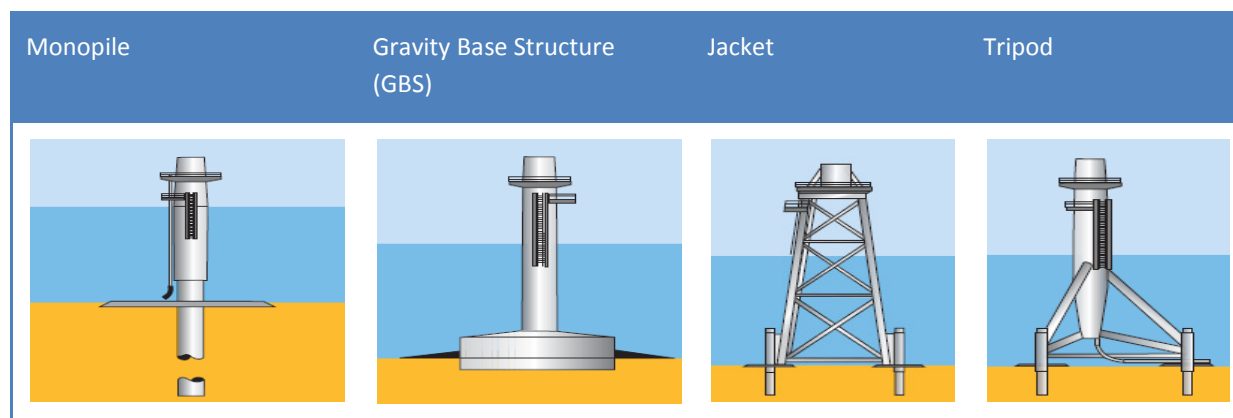


Figure 15. Conventional support structure inspired from the Offshore Oil&Gas sector. Source: Garrad Hassan, 2012

Monopiles will remain the leading type of support structure installed over the next five years, accounting for 36%⁵. Installations of jacket and tripod support structures are forecasted to increase over the next five years. This is to be expected as more German projects enter construction and UK projects move into deeper waters.

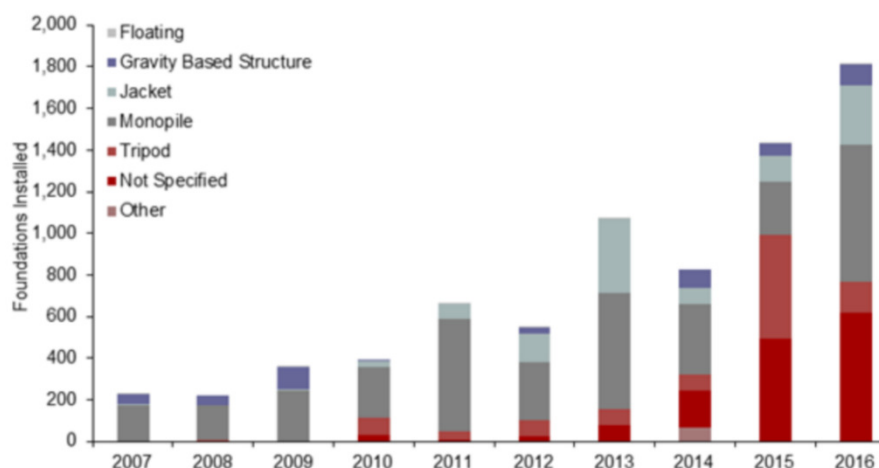


Figure 16. Past and future support structure type 2007-2016. Source: Douglas Westwood, Feb 2012

A number of innovative bottom fixed offshore wind specific concepts have now been engineered. Many of them are specific to particular seabed conditions. Some are already deployed large scale while others remain at early stage of development despite having been conceptualized many years ago. Introducing technology shift solutions often requires upgrades or new built vessels/processes which implies significant upfront investment ahead of the first demonstration project.

⁵ Douglas Westwood, Feb 2012, http://www.intpow.no/ext/ver2/downloads/Dougla_PDF_Frank%20Wright.pdf

4.3.7 Floating

The floating support structure design falls into 3 main categories: Tension leg platform (TLP); Semi submersible; SPAR. Other innovative multi turbine/rotor concepts are also under development.

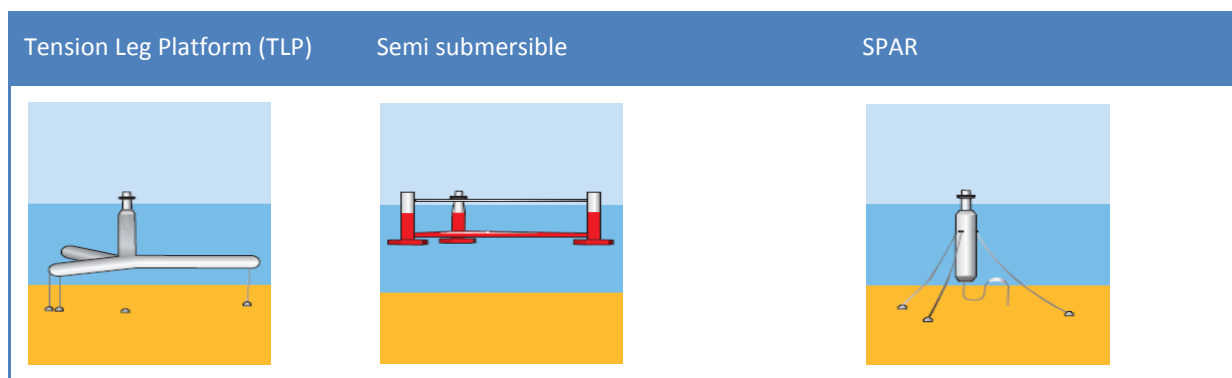


Figure 17. Main floating concept categories. Source: EWEA, 2011

As of today there are no commercial scale offshore wind farms based on floating support structures. In the past years, a few floating structure models have been demonstrated with small and large scale turbines. The floating market is increasingly getting more attention and the technology race has started.



Figure 18. About 8 floating concepts have already been demonstrated in small –medium scale. From left to right: Blue H; Poseidon; Hywind; Sasebo; Windfloat/Principle power; SWAY floater; Wind lens; Sea Twirl

In 2009, the Hywind floating structure developed by Statoil was installed in Norway. It was the first concept to be demonstrated in real offshore conditions using a multi-megawatt turbine.

In 2011, a semi submersible concept called Windfloat developed by Principle Power was installed offshore the shore of Portugal. At commercial scale, the technology will be applicable from 40m.

4.3.8 Innovations and possible step changers

There is an increasing number of support structure concepts but only a few solutions have been fully demonstrated. Support structure technologies fall into four main categories:

- Pre-assembled floating applicable down to 25 meters water depths
- Pre-assembled bottom fixed aimed at water depths up to 70 meters⁶
- Deep water bottom fixed transferred from Oil&Gas
- Innovative bottom fixed solutions focused on serial production in deep waters and bedrock installation

⁶ 70m is perceived as an economic boundary for bottom fixed solution in a 2030 perspective.

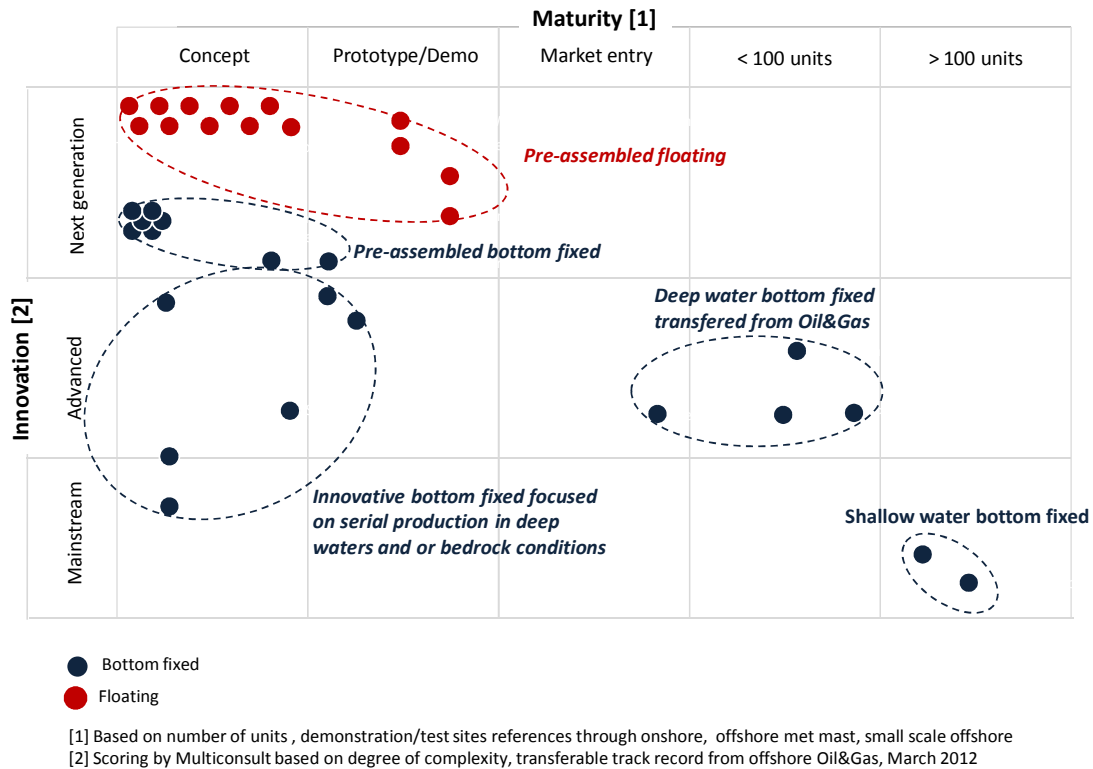


Figure 19. Innovation and maturity for the leading concepts under development. Source: Multiconsult, 2012

4.3.9 Bottom fixed

Multiconsult has referenced more than 80 conventional and innovative bottom fixed designs at different stage of maturity.

Many concepts target the market of meteorological mast which is deployed several years ahead of the construction phase. These smaller projects provide the opportunity to demonstrate the high level feasibility of concepts and economic viability.

Large scale demonstration projects are more costly and financing represent a key barrier for innovative ideas since most of the concepts are still generated by small and medium size companies.

Cost effective standalone support structure solutions for deeper waters (30-70m). The majority of new concepts take into account the ability to mass manufacture and install with ease by removing the use of costly heavy lift vessels and barges.



Figure 20. Self-installing gravity base structure (GBS) during towing to site. Source: Seatower, 2011

Self installing pre-assembled bottom fixed solution – Solutions are being developed with the aim to reduce offshore operations related to the offshore installation of the support structure and turbine. The turbine is first pre-assembled, at quay or within a dry dock, onboard a floated support structure, and then towed to site for onsite installation in one go.

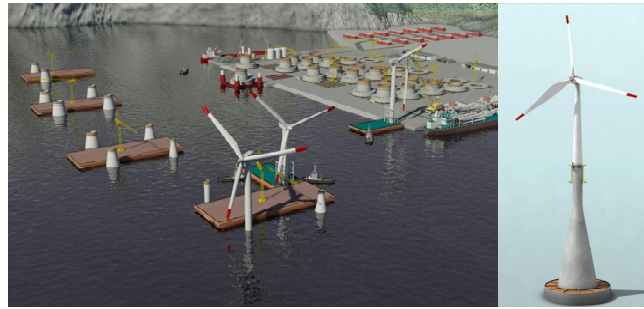


Figure 21. Vici Ventus GBS fabrication and pres assembly site and concepts. Source Vici Ventus, 2011

4.3.10 Floaters

Multiconsult has referenced about 40 to 50 floating concepts.

Most floating demonstration projects have been deployed with smaller turbine than they will utilized at commercial scale. Ahead of commercial deployment a transition phase of improvement and optimisation of the design will be required through small scale projects.

A long list of new concepts floating concepts are emerging indicating the high level of interest for the technology and recognition of potential for the floating sector:

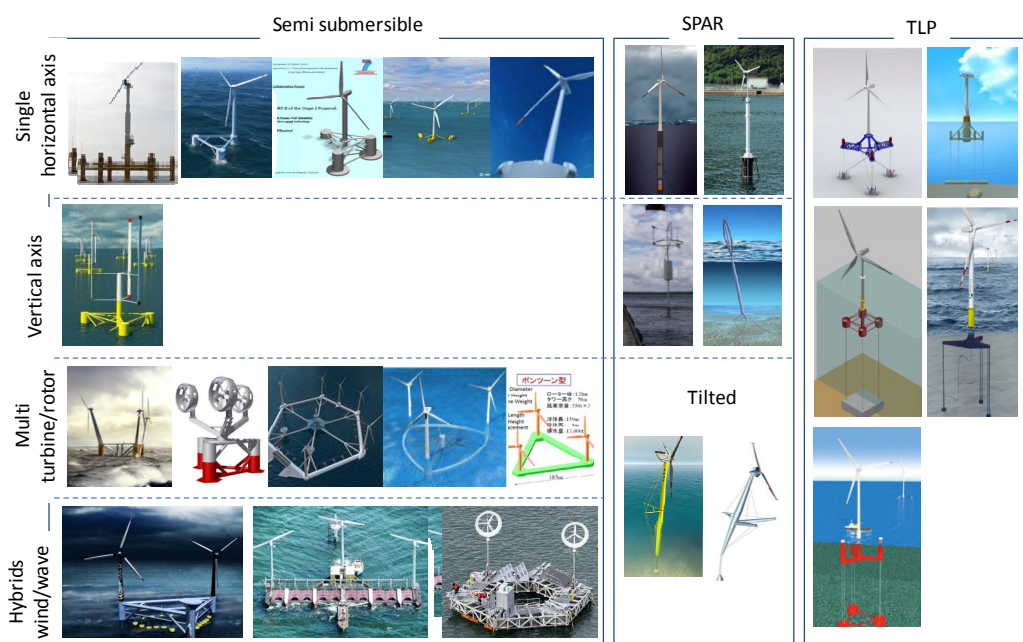


Figure 22. Illustration of some the leading floating concept (non exhaustive)

5 Assembly and installation

5.1 Status and trends

Assembly and installation covers onshore and offshore assembly and marine operation required for the installation of:

- Turbine topside (tower, nacelle and rotor)
- Turbine support structure and foundation

- Substation topside
- Substation support structure and foundation
- Cables

The conventional method of **installing turbine** units consists of installing turbines and support structure/foundations in two separate work packages. For the majority of offshore wind farm deployed today turbine were mounted on top of a monopile or GBS structure installed beforehand.

Important learnings are necessary in the area of support structure installation as past experience shows that several vessels considered to date are inappropriate in dealing with deeper waters, harsh conditions and limited weather windows of distant offshore wind farms. Vessels are available from the offshore Oil&Gas industry but they are usually oversized and too costly for the use of offshore wind where load packages/crane requirements are smaller than in the Oil&Gas business.



Figure 23. Installation of jacket at the Alpha ventus site with the Thiaf installation vessel. Source: NorWind, 2009

Efficient **preparation and pre installation of foundation** is becoming critical in order make cost savings during installation of the support structures. Pre-piling for offshore wind jackets was a method introduced at Alpha Ventus by Norwegian offshore wind companies NorWind and OWEC Tower.

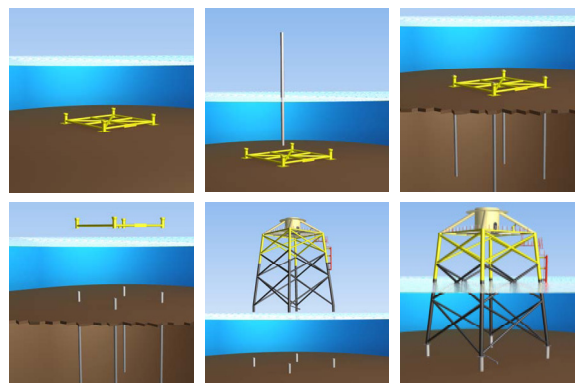


Figure 24. Pre piling methods of offshore jackets using template. Source: NorWind Installer, 2011

The **installation of substation** topside and support structure/foundation has been delivered in two separate packages in most of the projects. More recently, innovative design merges the two scopes through the design of self installable substations which are floated to site before being anchored or jacked up out of the waters. Following this philosophy, Aibel secured in 2011 a contract for such solution in partnership with ABB.

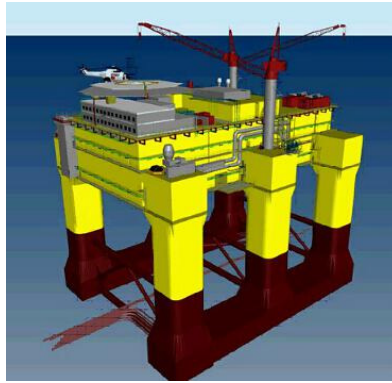


Figure 25. Aibel-ABB substations. Source: Aibel, 2011

To scale up for the incoming construction acceleration, the supply chain is strengthening its capacity and integrating lessons learned into optimal methods and new service equipments suited for the need of deeper projects in harsher conditions.

The demand for heavy lift vessels is increasing rapidly in order to avoid bottlenecks. The minimum installation vessel requirements (full-time working) by 2016⁷:

- 13 turbine installation vessels
- 25 foundation installation vessels
- 14 cable installation vessels (array and export)

To meet this demand, significant investments have been recently made. Norwegian Fred Olsen has invested for instance in two large jack-up vessels built specifically for the offshore wind market:



Figure 26. New built heavy lift vessels. Source: Windcarrier, 2011

5.2 Innovations and possible step changers

5.2.1 Pre-assembly of turbine

Tested once at the Beatrice demonstrator site in Scotland, turbine pre-assembly is still promoted by some technology providers as promising way to reduce cost by minimizing offshore operations related to the offshore installation of the turbine. The turbine is first pre-assembled, at quay or within a dry dock, onboard a vessel or floated support structure, and then towed to site for onsite installation.

⁷ Douglas Westwood, Feb 2012



Figure 27. Turbine pre assembly solutions. Source: Huisman, 2011

5.2.2 Self installing pre-assembled solutions

Various solutions have been designed with the aim to diminish offshore operations and its related risk and costs. In Norway, Vestavind offshore run a design competition in 2011 with the aim to conceptualize suitable foundation for the Havsul offshore wind farm in Norway. Various solutions were developed by leading industry players. Additional work is carried out in the UK through the Carbon trust Offshore Wind accelerator in order to screen, prequalify and rank the attractiveness of different solutions. The illustrations below represents a very few of the concept candidates:

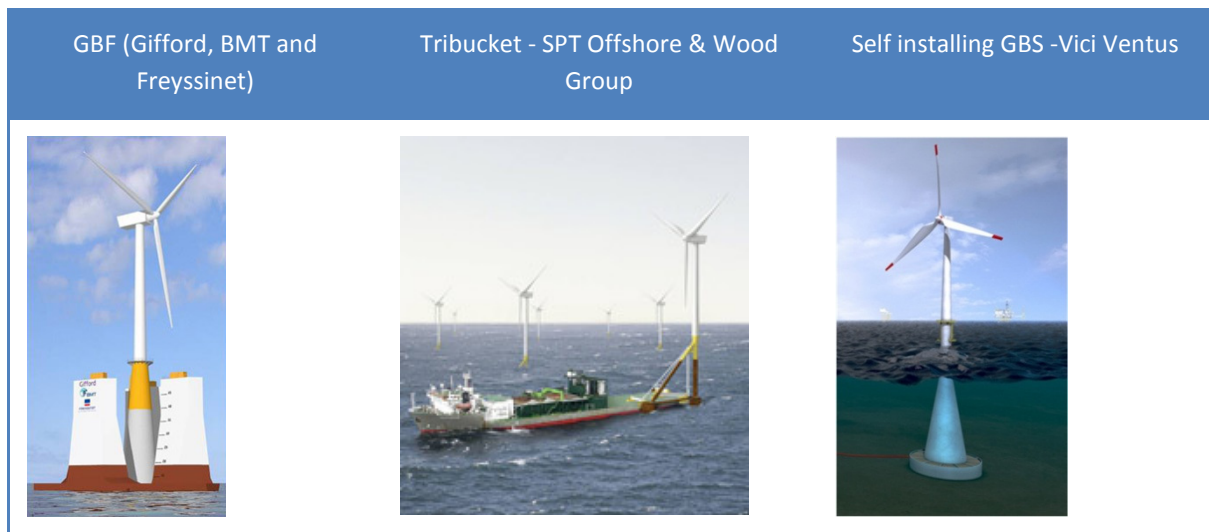


Figure 28. Example of self installing pre assembled solutions. Source: Gifford-BMT-Freyssinet, SPT offshore & Wood group, Vici Ventus

5.2.3 Floating dynamic positioning (DP) vessels

New innovative installation vessels are being developed for harsher environment and deeper waters. Removing the dependence on jack up legs which limits the operational water depth, these vessel uses dynamic positioning (DP) systems to stay in position. These vessels are to be used primarily for the bottom fixed market and could possibly cover some of the needs of the future floating market.



Figure 29. Dynamic positioning (DP) installation vessels dedicated to the installation

5.2.4 Dedicated support structure installation vessels

In an effort to standardize the delivery process for 20-50m water depths range (typically UK round 3) and achieved cost and risk reduction, installation solutions have been developed based on innovative vessels specifically designed for the purpose of offshore wind. These solutions offer high cost reduction prospects but bring a degree of specialization compared to conventional heavy lift vessels. Upfront financing and market introduction is therefore more difficult for these solutions compared to conventional vessels which can cover a broader range of activities (offshore wind turbine installation and other offshore works). Some vessels are also focusing on the floating market such as the Windflip concept suited for SPAR support structure units.

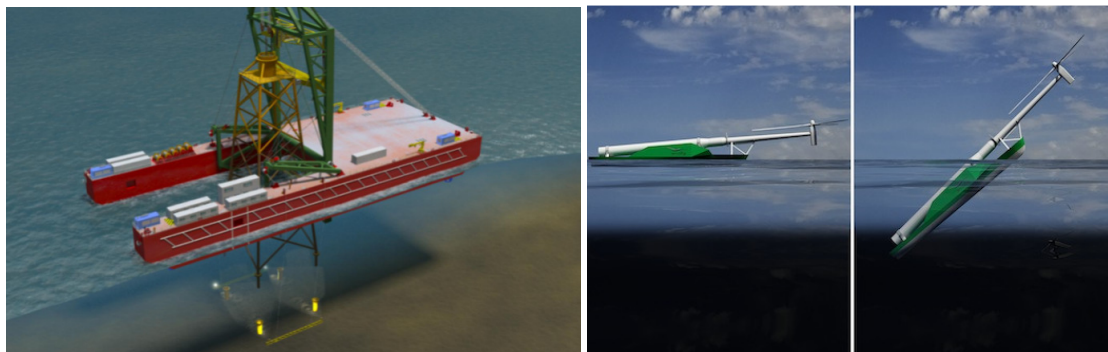


Figure 30. Left: Dedicated vessel to the installation of support structure. Source: Ingenium Ventus, 2012. Right: Dedicated installation vessel for SPAR structure. Source: Windflip, 2011

6 Electrical infrastructure

6.1 Technology Status and trends

This section presents the typical configurations for connecting offshore wind farms. The main elements described are the array cables, the offshore sub-station and the export power cable to shore. All wind farms today employ an AC collection system, and most commonly HVAC for transmission to shore. Larger wind farms further offshore apply HVDC. Future options are also introduced.

6.1.1 AC collection and transmission

This is the typical grid connection solution for offshore wind farms today, consisting of a synchronous AC grid all the way from the wind turbine to mainland AC grid connection point.

All wind farms built to date rely on AC collection grids, with a typical voltage level of around 30 kV. Multiple wind turbines are typically connected in series in a feeder system that minimises the overall cable length. To reduce wake and turbulence, the distance between the turbines must be several rotor diameters, typically 7 rotor diameters are applied; hence the collection cables may stretch several km.

Research and development is on-going to develop larger turbines (10-20 MW). This calls also for higher voltage for the collection system, possibly 66 kV instead of 33 kV being the "standard" today. This could reduce cost of the collection system and lower losses. At the same time this opens for smaller wind farms close to shore to be connected directly to the mainland without further stepping up the voltage. For wind farms ranging above 100MW or so however, the typical configuration will include an offshore substation and high voltage transmission to shore.

The collection cables are connected to an offshore platform containing the step-up transformer(s), necessary protection (switchgear), control and instrumentation, and typically also an emergency diesel generator and fuel, various staff and service facilities, helipad, crane, etc. The platforms may be installed at monopiles, jackets or similar or at gravity-based structures.

From the transformer station, high voltage AC transmission cables transport the power to the mainland AC grid. A typical grid layout is illustrated below.

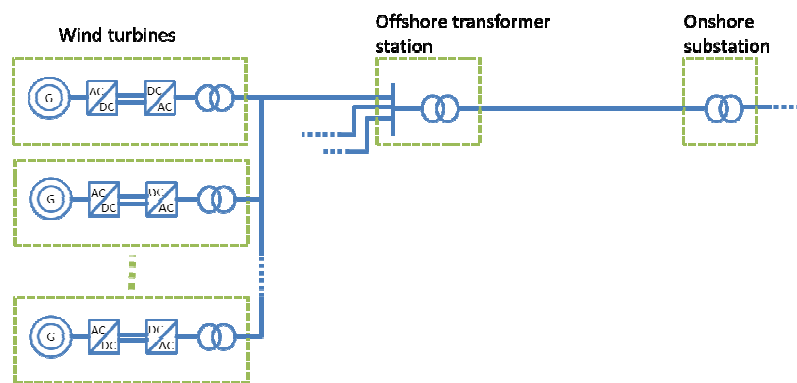


Figure 31. Typical offshore wind farm AC collection and transmission system. Source: SINTEF, 2012

An example offshore wind farm with a configuration is Horns Rev 2. It is a 209 MW offshore wind farm on the western coast of Denmark, consisting of 91 Siemens 2.3 MW turbines. The distance to shore is 27 – 41 km, and water depth is 9 – 17 m. The wind farm inter-array consists of 13 feeders connected to an offshore transformer station, where the voltage is increased from 33 kV to 150 kV. The transmission system consists of a 42 km long submarine cable (170 kV XLPE 3-core power cable including a fibre-optic element), a cable substation connecting submarine and land cables, and a 56 km long land cable (150 kV). The onshore connection point is at 400 kV via another step-up transformer. Further information about the wind farm can be found in Dong (2011).

AC cables have a certain reactance per length unit, and for long distance transmission, the flow of reactive current becomes considerable. This means that there is less capacity available for transmission of active power through the cable. Reactive power compensation devices can be used, but for longer distances with high power HVDC is preferred.

6.1.1.1 AC collection and DC transmission

Larger wind farms further offshore typically apply HVDC transmission. A typical configuration is illustrated below.

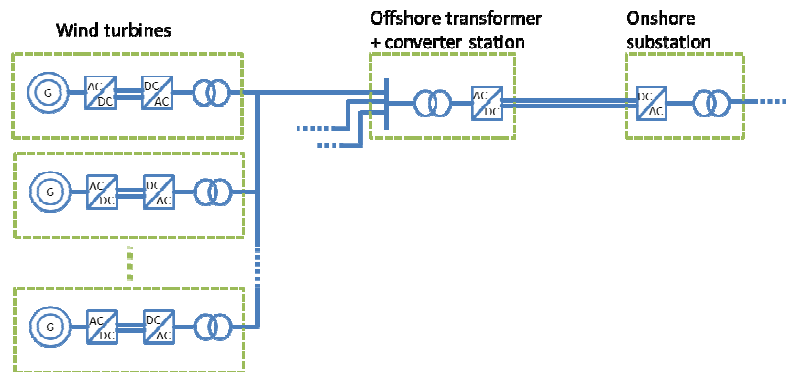


Figure 32. Typical configuration for offshore wind farm with HVDC transmission. Source: SINTEF, 2012

There are two main technologies for HVDC transmission. These are line-commutated converter (LCC) technology, and voltage-sourced converter (VSC) technology.

LCC is well proven for point to point connection between strong grids, e.g. the links between Norway and Denmark and between Norway and Netherlands apply LCC technology. LCC is however less suited for connecting offshore wind farms because of size, controllability and other issues.

VSC is a newer technology being increasingly applied. VSC rely on the integrated gate-commutated thyristor (IGBT), a valve that can be switched both on and off by a control signal. These converters operate by controlling both the amplitude and phase angle of the voltages and thus behaves as voltage sources in the AC grid (hence the name). Due to high switching frequency, the harmonic content is low. Thus the filter requirements are less than for LCC HVDC, which allows for compact converter stations.

Characteristics for VSC HVDC are described in for instance Kling et al (2008) and Asplund (2004). An important feature is that active and reactive power exchange can be controlled independently, and the converter can both produce and consume reactive power. A fast dynamic response can be achieved, to comply with grid code requirements. The ac-voltage can be controlled at both stations, so that the converter can operate in a weak network.

As opposed to LCC HVDC, there is no change of voltage polarity when the direction of power flow is reversed. The fixed polarity of the DC voltage allows for the use of XLPE cables. It also makes it easier to build multi terminal schemes. DC-voltage will be a measure of power balance (corresponding to frequency for AC-system), and voltage droop for the DC-voltage controller can be used to share power between the terminals in a multi-terminal solution.

VSC HVDC has higher switching losses than LCC. The main draw-back is however limited current capability, as over-currents cause thermal stress on the switches, leading to degradation or permanent damage. Due to this, a fault on-shore is critical, as it will reduce the system voltage. Since the current in the converter cannot be increased, the power has to be reduced, i.e. wind power generation has to be reduced quickly as a response to the on-shore fault.

There are currently two technologies available for VSC-based HVDC transmission, marketed by ABB as HVDC Light and by Siemens as HVDC Plus. Both are applied for connecting large offshore wind farms.

Table 4. Examples of projects using VSC HVDC for connection of offshore wind farms

Project name and location	Topology	Commissioned (year)	Rating (MW)	DC voltage (kV)	DC cable (km)
BorWin1 (Germany)	HVDC Light	2012	400	+/-150	125 (submarine) 75 (land)
DolWin1 (Germany)	HVDC Light	2013	800	+/-320	75 (submarine) 90 (land)
DolWin2 (Germany)	HVDC Light	2015	900	+/-320	45 (submarine) 90 (land)
HelWin1 (Germany)	HVDC Plus	2013	576	+/-250	
BorWin2 (Germany)	HVDC Plus	2013	800	+/-300	125 (submarine) 75 (land)
SylWin1 (Germany)	HVDC Plus	2014	864	+/-320	

Bresemi (2007) evaluates the benefits and drawbacks of DC transmission for offshore wind farms. Xu and Andersen (2006) describe HVDC systems for wind farms consisting of doubly fed induction generators.

6.1.1.2 DC collection and transmission

Pure DC grids for offshore wind farms is an active topic for research and development, but no such solutions have yet been implemented in any wind farm that exists or is under construction. The main attraction is potentially reduced costs as the technology may provide for lesser components inside the wind turbines and avoiding the need for large offshore substations. A possible configuration with **DC collection and transmission** is shown in figure 33. Here the standard wind turbines are modified taking out the grid side converter and step-up transformer, and replaced by a DC/DC booster and connected in series to step-up the voltage to transmission level.

Since the turbines are connected in series, the voltage to earth increases for each connected turbine. Although the voltage difference at the DC terminals may be only 3 kV, the voltage to earth will for the last turbine equal the transmission voltage (to earth), e.g. 100 kV. Hence, electrical insulation is a serious challenge for these types of configurations. Insulation has to be incorporated somewhere. One possibility is to use a transformer (as part of the DC/DC booster); other options are to include the insulation in the generator or the entire nacelle. Besides the electrical issues themselves, there is also a question of maintenance at such high voltages. These, and other technical challenges related to DC wind farms are active topics of research.

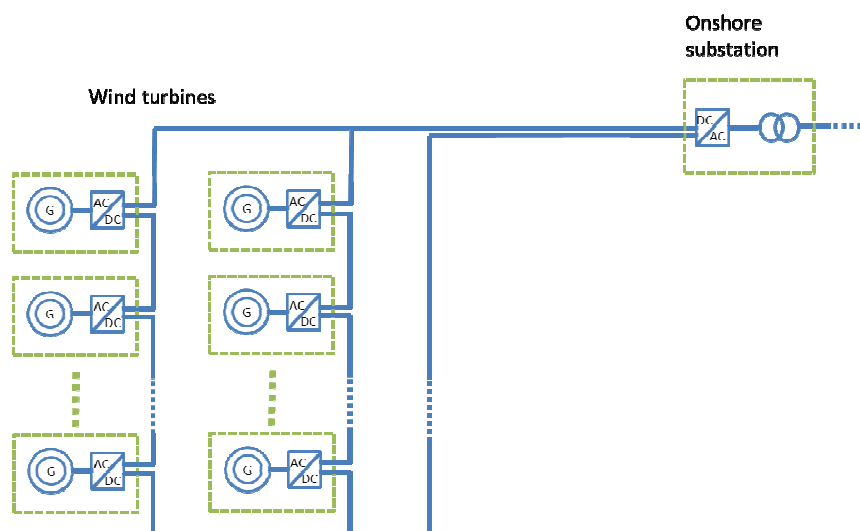


Figure 33. Example configuration of offshore wind farm with DC collection and transmission. Source: SINTEF, 2012

Thorough discussions of DC wind farm options are found e.g. in Lundberg (2006) and Meyer (2007).

6.2 Innovations and possible step changers

6.2.1 Offshore grid

This sub-section discusses some aspects of grid connection of wind farms from a higher level perspective where wind farm connections are coordinated cluster by cluster and with other power exchange cables.

Clustering of wind farms

It is expected that many future offshore wind farms will be in relatively near proximity to each other compared to the distance to shore. In such situations it is likely to be beneficial to have a common grid connection for the wind farms within a cluster. Clustering together with offshore petroleum installations may give additional benefits.

Combined solutions involving offshore wind farms and regional HVDC interconnectors are also an interesting option (De-Decker et al. 2011).

Clustering of offshore wind farms has already been decided in Germany, and offshore cluster substation with transmission cables to land are already built (e.g. HVDC BorWin1). In the German model, these are owned and operated by the Transmission System Operator (TSO), so the wind farm grid connection point is in fact the offshore substation.

Finding the optimal grid layout and control scheme for a wind cluster grid and transmission system is not easy, as wind farms are likely to be developed step-wise and have different owners. For example, the economic considerations should take into account the risk that a planned wind farm may be delayed or not built at all.

Offshore wind farms as part of an offshore power grid

Wind energy is a variable source of electric power and large wind farms and clusters have a significant impact on power prices and power flow in the grid. For this reason they affect the power exchange (both trading and balancing) between different price areas and countries. In areas where offshore wind farms and offshore interconnectors are planned in the proximity of each other, it is therefore highly relevant to consider combined grid solutions. Investigations have shown that solutions where wind farm grid connection is considered in coordination with an offshore grid more generally can give overall cost reductions (De-Decker et al. 2011, Huertas et al. 2011).

To date, grid connection of offshore wind farms has been achieved by dedicated cables, bringing the power directly to shore before transporting it to where the demand is, possibly exporting it via a trade interconnector. Such connections are usually referred to as radial connections. The cost-reducing alternatives mentioned above include some level of meshed grid, where power from wind farms is allowed to flow in more than one direction. An example where such connection options have already been considered is the planned Kriegers Flak wind farms in the German, Swedish and Danish border region of the Baltic Sea.

Multi-terminal DC grid

The term multi-terminal DC grid refers to DC grids with three or more terminals to a common DC bus. For a cluster of wind farms, or in situations where it may be desirable to combine the grid connection of one or more wind farms with an offshore HVDC transmission corridor, multi-terminal HVDC grids are widely thought of as a possible future choice of preference. The main obstacle for the emergence of such solutions today is the lack of proven technology, in particular related to the protection against faults in the DC grid, i.e. DC circuit breakers for high voltages and high power ratings. Current technologies rely on power electronics and are costly. AC protection is inherently easier since the current alternates between a positive and a negative value and is therefore instantaneously zero twice per period. These zero crossings are the points when the circuit breaker breaks the current. More discussion of DC grids and protection is found in Yang et al 2010.

However, it is likely that DC protection equipment will become commercially available in the future.

Different multi-terminal HVDC-VSC topologies for large offshore wind farms are investigated in Gomis-Bellmunt et al (2011), which includes a description of system requirements and a review of control schemes and HVDC circuit topologies. An analysis of DC-side faults, their transients and resulting protection issues is presented in Ref. [17]. The study includes short-circuit faults and cable ground faults, and a protection design and relay coordination method is proposed for a small-scale DC wind farm. Kling et al. (2008) includes a discussion on multi-terminal DC grids and points out that DC-voltage droop characteristics can be used to control the amount of power exchange to the AC-networks.

A good reference that gives a thorough overview of power electronics and grid solutions for offshore wind farms is Nee and Angquist (2011).

Connection to offshore oil and gas installations

Connection of offshore wind farms to offshore oil and gas installations may be a viable option. Typically offshore oil and gas installations are operated with gas turbines for electricity supply. Connecting wind turbines to these will save fuel and emissions as the load of the gas turbines would be reduced, whereas a stable electricity supply is secured by the combination of gas and wind turbines. This can be done for single platforms connecting a few turbines or for a cluster of platforms connecting a medium sized wind farm. Another alternative is to let the wind farm and the oil and gas installation to share the connection to shore. This can be done for small wind farms or large wind farms. In this case the gas turbines on the platforms may not be needed.

7 Operation and maintenance

7.1 Technology status and trends

7.1.1 Introduction to offshore wind operation and maintenance

In the context of offshore wind power all normal, daily work done off- or onshore to enable the turbines to produce electricity is regarded as operation. Included in these activities is surveillance of the wind farm in an onshore control centre. Maintenance, on the other hand, is about repairing faults (minor and major) and

carrying out preventive maintenance on the equipment to improve its condition. Depending on the number of failures, maintenance on a turbine should normally be done only a few times each year.

The maintenance regime applied offshore is in many instances adopted from land-based applications, and the long-term component effects of a saline atmosphere may not be covered by these established maintenance regimes. Historically, most of the maintenance done in the wind power industry has been corrective ("run to failure") (Bratland 2010). For offshore wind farms this is considered too unpredictable because the weather conditions play such a significant role when it comes to possibilities for carry out repair actions. Thus, a shift to more preventive maintenance, and even condition- or opportunity-based, is foreseen.

Current trends in O&M:

- Turbine reliability remains an issue. The early "offshore" turbines were in reality lightly marinized onshore turbines.
- Access systems and strategies have evolved—and will continue to do so. The projects reviewed have varied experience regarding access to the turbines for routine inspections and unplanned repairs. Poor weather conditions, particularly wave conditions, lower accessibility.
- Turbine manufacturers carry burden of early turbine challenges. Five-year operations and maintenance contracts between turbine manufacturers and project owners are the industry norm. The turbine manufacturers are responsible for establishing an operations organization, planned and unplanned maintenance, as well as component replacements.
- O&M crews are based onshore—but that is changing. Commissioned in May 2009, Horns Rev 2 is the first project with on-site living quarters for the operational and maintenance teams. The sailing distance to the nearest port of Esbjerg is 35 nautical miles or approximately 3 hours. The developer has decided that it is more cost-effective to bring the operational team out to the site. With a capacity of 24 persons, the living quarters are located 15 metres from the Offshore
- High Voltage Substation, connected via a bridge. It is expected that projects to be completed farther offshore will rely on similar solutions, including hotel ships and semi-permanent jackups stationed at the site

Operation and maintenance strategies which maximise the energy yield from turbines while minimising O&M costs, are essential for the commercialisation of offshore wind power. The strategies should take advantage of advanced condition-based and risk-based maintenance philosophies in order to improve operational efficiency and reduce costs. They should also address the challenge of access, developing and testing novel systems and vessels to deliver a variety of access options.

Table 5. Strategy elements for offshore wind. Source: Multiconsult, 2012

Strategy Element	Options and Best Practices for Offshore Wind
Maintenance philosophy	•Periodic maintenance (regular preventive + occasional corrective); currently the norm, similar to onshore wind •Predictive maintenance (condition based); becoming the norm
Staffing	•Close to shore: operate from onshore control stations. •Farther from shore: use of offshore accommodation facilities.
Vessel strategies	•Dedicated purpose built lifting vessel (justified for large farms >100 turbines); also use for construction •Mother ship that is permanently offshore to allow smaller service vessels to restock (compliant with

	the Jones Act) •Floating barge to transport a land based crane offshore •Sharing of vessels
Parts and warehousing	•Store critical spares at an onshore O&M center •Shared O&M and spare parts storage facilities
Plant design	•Systems to facilitate component change out, such as crane facilities within the nacelle •Preventive and automatic systems that can carry out oil, brush and filter changes without human presence •Modular drive trains to simplify heavy part replacement •Backup power diesel generator on the substation platform
Access to turbines	•Platforms fixed to towers above the splash zone with fender posts to absorb vessel impact •Flexible gangways extended from the vessel •Winch/netting for personnel and equipment
Safety	•Emphasis on safety during high risk activities such as accessing blades, crane and diving operations •Use of CO2 fire suppression systems in manned areas •Use of elevators in highly corrosive environments
Predictive maintenance	•Install sensors and equipment to monitor the condition of the drive train in real time •Plan ahead for multi-component replacement/repair •Schedule using the equivalent operating hours concept •Optimize gearbox intervention times •Optimize use of vessels •Monitoring of cable temperature, stress, scour, abrasion

7.2 Innovations and possible step changers

Innovative support vessel

We know from the oil and gas sector that offshore supply vessels are one of the most costly resources in the supply chain, and the investment and operation costs of the offshore wind farm vessel fleet can therefore be expected to constitute up to over 30% of the total cost of energy for a far offshore wind farm. This means that large savings can be obtained if the vessel fleet is optimized with respect to size and vessel characteristics, and the fleet is operated efficiently (FAROFF 2010).

The innovation within this area is considerable and the support vessel that is planned by SeaEnergy can serve as an example of this (see Figure 34). The drivers for development and innovation is of course cost reduction and maximising the electricity production, mostly related to the possibility of accessing the turbines in bigger waves heights, to operate in deeper waters and at more distant locations, and the increase in wind farm sizes that is expected (e.g. Doggerbank).



Figure 34. Planned support vessel from SeaEnergy⁸

Mother ship vessel

Going more than about 20 km from shore, a living platform may be a relevant solution. Even a so-called mother/daughter ship may be profitable if the wind farm is large enough. This is shown by the cost estimates done as part of this work. A mother ship serves as living quarter for the maintenance crew, and at the same time it can be used as a crane ship when heavy lifting within the wind farm is required. Even if such a ship is very expensive (≥ 1 billion NOK) it can still be profitable due to the combination of functions it provides. With a living platform or mother ship dedicated to a wind farm, the implications for the daily O&M tasks will be comparable with near shore wind farms since O&M personnel and spare parts are already on site. When it comes to replacement of bigger and heavier components it is always a question of storage space, and with a far offshore wind farm it will of course take more time to get a spare part to the turbine if it is not available on site. Thus, faster and bigger access vessels may be a solution far offshore.

An example of a vessel fleet has been presented by Pieterman et.al., as part of a case study of a 520 MW wind farm consisting of 130 wind turbines of 4 MW rated capacity. The wind farm is located 120 km from the nearest harbour and the water depth is 30 m. The vessels needed for operation and maintenance of this fictitious wind farm are listed below on Figure 35.

The service vessel segment for current wind farms, based on an onshore O&M base is regarded to be covered by the industry and research. However, several aspects are lacking to meet the requirements of the market for far offshore wind farms that require an offshore O&M base / mother ship to drive a cost efficient industry development:

- Detailed functional requirements and capacities (operational range, speed, dynamic positioning, stability, passengers, work shop, storage, crane etc.)
- Health, safety and environment (HSE) accept criteria for all relevant functions and operations
- Safe and robust launch and recovery systems for daughter vessels (of size 24 m / 12 passengers or bigger)

These aspects are being explored in e.g. the FAROFF project in the RENERGI program (FAROFF, 2010)

⁸ <http://www.seaenergy-plc.com>



1 jack-up vessel for transporting and hoisting large components. Jack Up Vessel JU004 ⁹



3 workboat access vessels for transferring technicians and transporting small components. the WindCat MKIII ¹⁰



1 cable laying vessel for replacing power cables¹¹



1 mother ship for accommodation of technicians and storage of small components¹²



2 helicopters for transporting technicians for specific types of maintenance and emergency evacuation¹³



2 diving support vessel for underwater inspections and repair¹⁴

Figure 35. Vessels used in a 520 MW wind farm (the pictures serve only as illustrations)

Manned offshore platforms

Maintenance and service operations involve the transport of crew and equipment to the location. Due to weather window restrictions and the travelling distance from shore, it can be worthwhile for remote wind farms to reduce travelling times by installing an accommodation platform as part of the wind farm. Until now, this concept is only applied at Horns Rev 2, where an accommodation platform was installed alongside the offshore substation.

⁹ <http://www.4coffshore.com>

¹⁰ <http://www.windcatworkboats.nl>

¹¹ <http://www.maritimejournal.com>

¹² <http://www.houlderltd.com>

¹³ Bond Aviation Services <http://www.flightglobal.com/news/articles/winds-of-change-361819/>

¹⁴ OffshoreWind – InWater Service <http://www.nordseetaucher.de>



Figure 36. Offshore substation with accommodation platform alongside. Source: Dong Energy

There are several advantages with coupling an accommodation platform to the sub-station, e.g. utilisation of common infrastructures like power supply and telecommunication. Also sharing of the same helicopter deck and common access facilities for vessels are cost-effective benefits with such a concept. In addition, the maintenance crew will have very easy access for operation and maintenance of the critical components on the sub-station itself.

Access methods

Access to the turbines for maintenance purposes is critical both regarding safety of personnel and unplanned downtime of a turbine. Table 6 gives an overview of the most typical access methods.

Table 6. Characteristics of typical access methods. Source: Access to offshore wind turbines 2004

Type	Signicant wave height in metres	Average wind speed in m/s (1hr at 10 m height)	Example application	Advantages	Disadvantages
Direct boat landing	0.5 - 1.5 (rubber boats) 2.5 (SWATH)	10	Nysted (rubber boats) Bard 1 (SWATH)	Simple	Sensitive to marine growth and icing
Boat landing with motion compensating	2 - 2.5 (OAS) 2 - 3 (Ampelmann)	11.5 (OAS) 14 (Ampelmann)	Tested	Not sensitive to marine growth	Installation of additional equipment on the vessel required
Hoisting by crane	2.5	?	None	Not sensitive to marine growth	Remote control of crane Maintenance offshore required
Helicopter	-	15 - 20	Horns Rev, alpha ventus	Not sensitive to waves Fast transport	Expensive

There is a lot of innovation going on within this area and WindServer by Fjellstrand can stand as an example of one promising concept. WindServer is one of the vessels shortlisted by the Carbon Trust Offshore Wind Accelerator in the UK¹⁵.

¹⁵ <http://www.carbontrust.co.uk/emerging-technologies/current-focus-areas/offshore-wind/Pages/offshore-wind-access-shortlisted.aspx?vessels>



Figure 37. The Fjellstrand WindServer access vessel¹⁶

Floating devices

The turbine and substructure O&M for regular maintenance events follow industry standard intervals. However, in the case of unscheduled turbine maintenance (replacement of a complete turbine nacelle for instance), the floating structures hook-up operation can be reversed so that the system can be towed back to shore to make use of existing shore side infrastructure. This provides the opportunity for significant cost and risk reduction relative to unscheduled maintenance.

8 The cost of offshore wind technology

8.1.1 Case of a typical 500MW offshore wind farm in UK

The average electricity cost of energy (LCOE) for offshore wind has been estimated for a typical project of 500MW in 35 meters water depth to 1370 - 1480 NOK/MWh depending on the wind conditions. The cost estimation assumes a project lifetime of 20 years, a net capacity factor of 43% (taking into account losses) and an applied WACC of 9,5%. Grid connection & transmission cost are not included in the CAPEX but considered as a transmission charge as part of the O&M cost (ref. OFTO regime implemented in UK). The detailed breakdown of typical cost is available in appendix.

Development cost ranges between 450 and 1400 kNOK per MW depending on site specifics (size of the site, distance to shore, degree of possible impacts) and national requirements on impact studies and upfront surveys (pre investment).

Capital expenditure (CAPEX)

As indicated by many reports, CAPEX has increased from 20 to 30 MNOK/MW over the last past 5 years and is expected by the industry to have reached a plateau ahead of incoming cost reductions.

Surveys carried recently through leading institutions active in the sector indicates the five main cost drivers for driving up the cost of offshore wind energy in the past 5 years:

- Unfavorable GBP to EUR exchange rate
- Supply constraints for turbines
- Increased commodity prices (steel¹⁷, copper)
- Supply constraints in installation vessels
- Increased water depth

A typical CAPEX (2012) for a 500MW offshore wind farm is presented below:

¹⁶ Source: <http://www.fjellstrand.no>

¹⁷ A modern offshore wind farm consists typically of up to 72%¹⁷ if the chosen support structure is based on steel such as monopile, tripod or jacket.

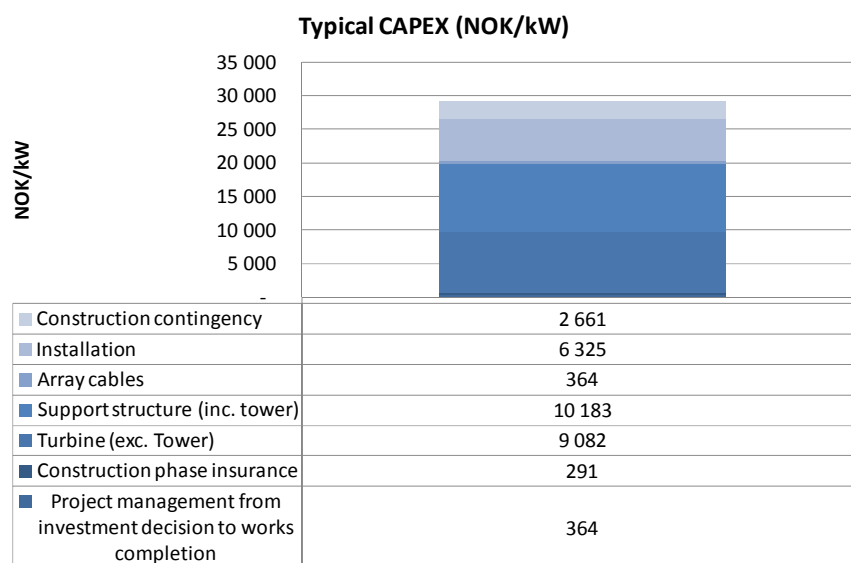


Figure 38. CAPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate 2012

Operational expenditure (OPEX)

O&M cost estimations varies from one study to another. This clearly reflects the lack of operational and maintenance experience from the industry as whole, on large projects in particular.

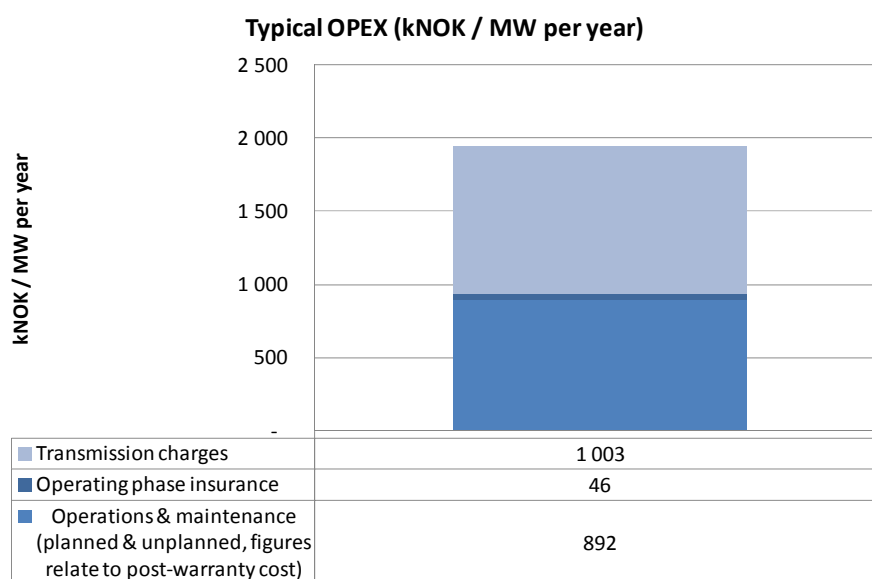


Figure 39. OPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate 2012

Decommissioning cost is estimated by UK and French authorities to be in the range of minimum 400 NOK per MW for bottom fixed sites. High uncertainties stand behind this number which in practice varies with national requirements, water depth, support structure technology, future heavy lift vessels and processes.

8.1.2 Future cost trends

About future cost prognosis

As explained above, offshore wind costs are site specific, subject to various cost drivers and are expected to be reduced through learning, industry competition or innovations. However evaluating long term cost reductions remains a critical exercise to give vision to policy makers regarding the economic potential and cost competitiveness of offshore wind versus other alternative power generation sources.

A study carried out in 2010 presents indications of expected future levelised cost of offshore wind for the purpose of determining the value creation potential for the UK. Considering the amount of uncertainties in addressing the broad national offshore resources in a single assessment, basic assumptions were made to estimate a min-max cost range. Assumptions were consolidated with inputs from the industry and developers sharing their views on how costs are likely to evolve over time in a 2045 perspective. In the graph below, cost projections for floating structures in water depth down to 30 meters have been voluntarily removed.

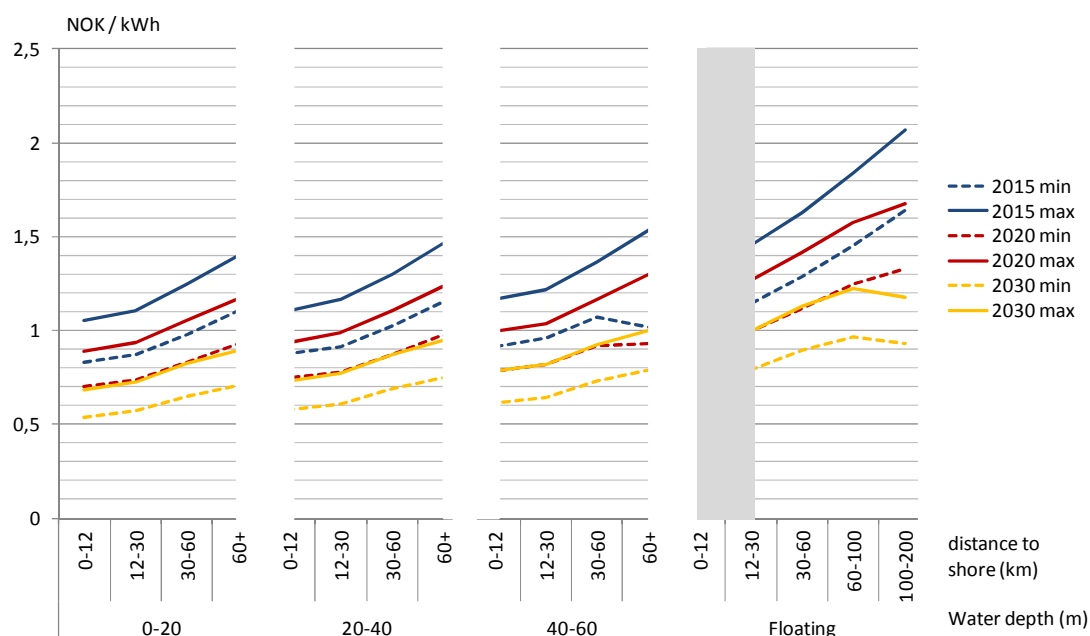


Figure 40. Levelised cost of offshore wind energy (NOK / kWh). Source: Data from offshore valuation report, BCG 2010, graph by Multiconsult 2012

All offshore wind stakeholders recognize that the current high level of offshore wind cost can only last for a temporary phase. The sustainability of the sector relies on its ability to reach grid parity on the long term. Today cost reduction is on the top of the agenda of the offshore wind industry. In a 2020 perspective, the delivery of the UK 2020 ambition in offshore wind requires, according to market players, a decrease of 30% from current cost levels in order to finance the total amount of round 1, 2 and 3 projects. In an effort to accelerate and bring confidence in the market's ability to overcome technical challenges and drive cost down¹⁸ by 2020, several studies are being carried out to identify the cost drivers and project future cost reduction curves, so far with limited success in matching actual data from executed project.

Cost reduction

Aside from the sensitivity to raw materials¹⁹, table 7 below indicates internal cost reduction factors to the industry directly addressable by the market players:

Role of the government - As presented in a recent report²⁰ from the British Wind Energy Association (BWEA), the likelihood of reducing cost substantially over the next 5 years is highly dependent on whether effective

¹⁸ The UK government has recently set the goal of a levelised cost of offshore wind energy of GBP 100/MWh by 2020; corresponding to a 30-40% cost reduction compared to current 2011 levels.

²⁰ BWEA, UK Offshore Wind: Charting the Right Course - Scenarios for offshore capital costs for the next five years, 2009 <http://www.bwea.com/pdf/publications/ChartingtheRightCourse.pdf>

action is taken by Government and industry now. More generally, the national governments' role is key to unleash the potential of cost reduction through giving investors confidence in the market through profitable and stable incentive schemes, implementing reforms towards efficient and stable planning and consenting frameworks, funding RD&D efforts towards cost reduction and stimulating upfront investment in the supply chain through active and sustained regional support. More recently, the UK government has launched a more proactive initiative aimed at challenging the industry through the prospects of reaching specific cost reduction targets as a collaborative effort across all stakeholders²¹.

Table 7. Internal cost reduction factors directly addressable by the market players. Source: Multiconsult, 2012

Technology	Supply Chain	Finance
• Wind farm selection • Wind farm design/layout • Lifetime of the wind farm • Turbine rating and rotor size • Drive train concept • Reliability • Production methods • Support structure type and level of production optimisation • Improved subsea array cable design including robustness • Installation methods for support structures, turbines and subsea cables • O&M strategies and methods of access • Accelerating technology commercialisation	• Risk & contracting approach • Competition • Sourcing – UK v non-UK • Reach (China, mainland Europe, UK) • Supply chain consolidation v. dispersion • Co-operation: co-operative v. hand-off approach to supply chain • Standardisation • Assurance of volume (commitment) • Whole life optimisation approach – trading off CAPEX vs OPEX • Statutory requirements	• Availability of capital and insurance • Perception of and management of risk • Project Sponsors • Participants • Gearing levels • Products (senior debt, senior bonds, subordinated debt / bonds, other risk mitigation instruments such as insurance) • Support (European Investment Bank, Green Investment Bank in UK)

Table 8. Future cost trends per MW in a 2015-2030 perspective. Source: Multiconsult, 2012

Cost items	Typical share of LCOE % in 2012 ²²	2015	2020	2030
Development	1	↗	-	↘
CAPEX - Procurement				
Turbines	29	-	↘	↓
Turbine Jacket foundations	12	↑	↘	↘

²¹ Offshore Wind Cost Reduction Pathway development, The Crown Estate, 2011-2012

²² Some items such as cost of insurance and financing costs are case-specific and excluded in this table

Export cable	5	↑	↗	↗
Inter array cable	1	↑	↗	-
Substation	5	-	↘	↓
CAPEX -Installation & Logistics				
Turbine	2	-	↘	↓
Foundation	4	↗	↘	↘
Export cable	3	↑	↗	↗
Inter array cable	1	-	↗	↗
Substation	5	-	-	↓
OPEX				
O&M	13	↗	-	↘
Electricity production				
Yield, Production from wind farm		-	↗	↗

8.1.3 Development

Cost of development will increase on the short term due to the increase size of projects in unknown conditions. Cost will stabilize as lesson learned are integrated and new purpose made and cost efficient equipment surveys are utilized.

8.1.4 CAPEX - Procurement

Turbine supply - Despite the numerous announcements in the offshore wind turbine supply segment, they are only a few commercial turbine available to the market. Prices are expected to remain stable or increase in the next 3 to 5 years but competitive price pressure should start to take effect from 2015/2016. The cost per MW is expected to fall as larger turbines are introduced into the market. We estimate the current cost for turbine in the range of 72MNOK for 6MW unit. For the purpose of this study we assumed that 12 MNOK/MW will be reduced to 10,4 MNOK/MW in a 2020 perspective where 10MW turbine could be deployed (Base case for the model).

Turbine Jacket foundations supply - Raw material costs will put upward price pressure on jacket manufacturing costs and the lack of industrialization of supply in the next 3 to 5 years means prices are likely to increase in the short term. However, as demand for jackets grows it is expected that new entrants and more automated construction process will emerge. This may result in downward price pressure in the 5 to 15 year time window. If concrete solutions do manage to break into the market then this may also exert downward price pressure in the 5 to 15 year timeframe.

Export cable supply - Prices of export cables are driven by price increases of raw materials and the current supply demand imbalance. As competitive pressure is unlikely to be strong and demand increase, prices are likely to push upwards above inflation over the next decade.

Inter array cable supply- Prices of array cables will be mainly influenced by the price increase of raw materials, however increased competition may offset some of these increases.

8.1.5 CAPEX - Installation & Logistics

Foundation installation - Jacket installation will remain relatively inefficient from 2012 to 2015 but the development of a purpose designed/built fleet should see a downward impact on installation prices per jacket foundation from 2015 onwards for a given turbine and water depth.

Larger turbines should increase the support structure and foundation costs per unit but still lead to a decrease of costs per MW and per MWh.

Turbine installation - WTG installation is already reasonably efficient. Further small price reductions are expected to continue as the capability and number of vessels available to the market increases in the next 5 years. The cost per MW will reduce significantly as the installation costs will not increase in proportion to the increase in MW size of turbines.

Inter array cable installation - It is expected that prices will remain stable or even increase slightly during the next decade.

Export cable installation - It is expected that prices will increase during the next decade unless new vessels are introduced. This is only likely to result in stabilization of prices as new vessels are required just to keep up with demand.

8.1.6 OPEX

When it comes to cost reduction in the O&M area, there are a few major parameters to concentrate on: The number of major failures, i.e. breakdown of heavy components; The number of visits to the turbine; Vessel costs; Size of the wind farm (bigger wind farms have lower costs per MW).

The possible cost reduction measures in each of these areas are of course very different. For increased reliability of heavy components (blades, bearings, gear-box, generator) one should concentrate on the design and installation. Direct-drive wind turbines without the gear-box is one way of "designing away" a problem, but of course that leads to other challenges like the size of the generator.

There are two main solutions for reducing the number of visits to the turbines. One is to utilize more remote presence (surveillance and inspection) and condition monitoring to avoid unnecessary travels, and the other is to develop cost-effective access concepts that make it possible to enter the turbines in bigger wave heights.

The vessel day rates are highly market dependent, and it will in many cases for bigger wind farms be profitable to buy their own vessels. Even a crane ship may be profitable to buy if it can be combined with personnel accommodation (mother ship solution).

One can also expect that the learning curves and economy of scale will bring the costs down, but it is hard to say how much due to the uncertainty of the market element in the calculations.

8.1.7 Yield – Production of the wind farm

Turbine technology and size are expected to improve yields and reduced losses. Better understanding of wake effect within wind farm will contribute to lowering the wake losses. Improved wind modeling and measuring will also contribute to prioritize the best wind producing sites.

9 Offshore wind supply chain

9.1 A high demand for specialized supply chain & skills

The applicability and attractiveness of some innovative support structure technologies may depend on their supply chain requirements. Their deliverability and cost profile depends on the ability to scale up and develop a serial production processes for which specific fabrication and assembly yards may be necessary.

Today the industry is subject to potential supply shortages and increased demand of skills. Table 9 below outlines the current shortages and bottlenecks in the sector.

Table 9. Key shortages & bottlenecks. Source: Multiconsult, 2012

Key supply chain shortages	Key staff & skills bottlenecks
Export HV cables	Offshore engineers
Ports & harbors	O&M technicians
Deep water foundations	Project managers
Turbine supply	Qualification to work offshore
Installation vessels	Offshore wind experience

While the industry has successfully triggered necessary upfront investments in turbine supply and turbine installation vessels, key issues remain on the supply of export cables as well as deep water foundation manufacturing and installation.

Demand for staff capacity and skills will remain tight in the years to come as market size increases gradually and spreads geographically.

9.2 Towards a global competitive arena

To date, all projects have been delivered by an international supply chain. This trend is likely to stay for the years to come: *“The scale of the UK’s offshore wind pipeline means that, even if the domestic supply chain grows rapidly, there will be a need to import a significant proportion of services, vessels and components from established overseas supply chains for some time. Almost £80 billion is predicted to be spent overseas during the capital and operational phases of UK projects built between 2011 and 2022 compared with over £50 billion in the UK”* (RenewableUK, June 2011). In addition, increase of the competition and introduction of innovation will contribute to reducing the overall cost of offshore wind.

Despite the market being at an early stage of development, the potential for value creation is so large that the offshore wind supply chain is quickly growing from a European to a global platform. During the past years, Asian players have moved forward in various part of the supply chain, focusing particularly on turbine and foundation manufacturing. Their advantages include access to raw material such as steel in their domestic market. Quality and reliability has been a challenge for the first supply deliveries from Asia but are expected to improve rapidly.

The market of offshore wind turbine which represents typically 35 % of the CAPEX of an offshore wind farm is a good indicator for understanding the dynamic in the global industry:

The deep water floating technology is also expected to accelerate, thanks to international demonstration initiatives²³ and high ambitions for large scale commercial deployment already expressed by Japan as an answer to the Fukushima nuclear disaster in 2011.

Table 10. Offshore wind turbine market trends. Source: Multiconsult, 2012

Range (MW)	Maturity	Europe	Outside Europe (Asia, North America)
<3	Commercial	Turbines of this size are still being used for demonstrating innovative floating solutions such as Hywind (Norway) and Windfloat (Portugal)	Small scale models of innovative support structures are still utilizing small turbines under 3MW.
3-5	Commercial	The majority of current projects are currently installing commercial turbines from 3,6 to 5MW capacity. Leading providers are Vestas, Siemens, Repower, AREVA and Bard. New entrants include Gamesa, GE (former Scanwind), Mervento.	Sinovel has provided China's first offshore wind farm with 3MW units. AMSC and a large range of Asian companies.
6	Commercial	The largest commercial turbine under deployment is the Repower 6MW to be installed on the Nord See Ost offshore wind farm in Germany in 2012. New entrants include Alstom, Nordex, 2B Energy, Siemens, Schuler.	Sinovel has made its first order of 6MW. And new entrants include Mingyang, Guodian United Power, Goldwind, Doosan, Huayl Electric & MECAL.
7-10	Prototype by 2013	Construction of the first Vestas V164-7.0 MW prototypes is expected in Q4 2012. Serial production is set to begin in Q1 2015 provided a firm order backlog is in place. Gamesa has planned for a 7MW model and Samsung have recently decided to set up a development facility in UK for a 7MW model.	Mitsubishi has announced plans for a 7MW model. NPS is looking at a 8MW model.
10-15	Prototype by 2015	ClipperWind has stopped its 10MW model development while SWAY and Windpowerlimited /Aerogenerator X are both developing 10MW units.	Sinovel, Goldwind (China) and AMSC Sea Titan (US) are developing 10-12MW models.
15	Prototype by 2018	The Azimuth Offshore Wind Energy 2020 project, led by Gamesa, is planning a 15MW offshore wind turbine.	GE (NA) and Guodian United Power (China) are both developing 15MW models.
20	Prototype by 2020	The EU research project UpWind indicated that 20MW units are feasible and could be ready by 2020.	
>20			FUTURAWIND has announced the development of turbine technology suited for turbines up to 25MW.

²³ Such as Hywind in Norway, Windfloat in Portugal, Vertiwind in France or Hiprwind in Spain

9.3 Norway's position in the industry

The Norwegian offshore wind supply chain has gained competitive advantages from its world leading offshore and energy experience, visualized on figure 41 below. Technological and operational expertise from offshore oil and gas is commonly regarded as the main competitive advantage of Norwegian companies in the offshore wind industry. This expertise is, however, not only about supplying components and services but also in the development of technologies and the management of offshore risks.

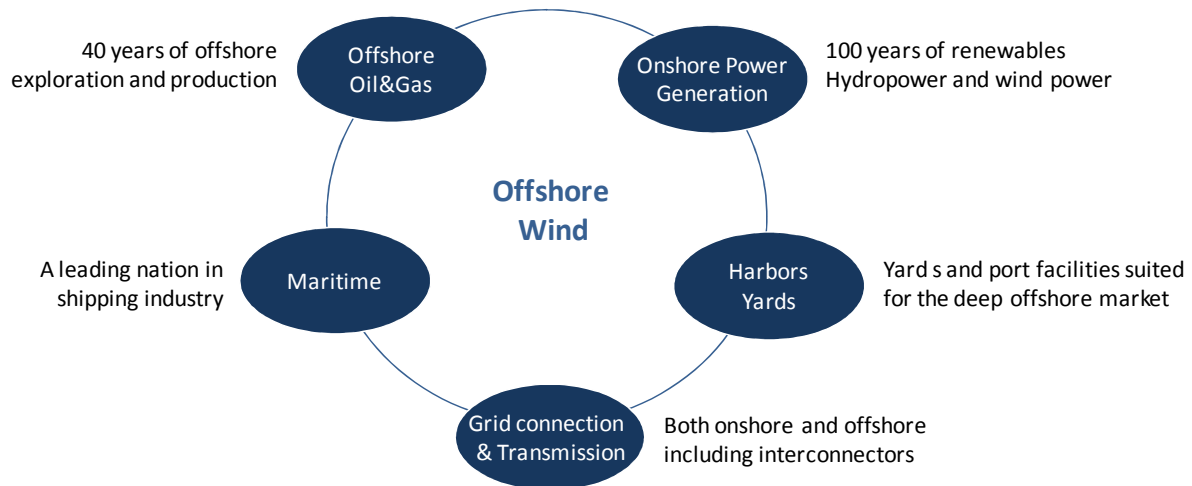


Figure 41. Norway's unique energy, offshore and maritime heritage. Source: Multiconsult 2011

By transferring skills and supply chain assets in the new offshore wind market segment, the potential for diversification and new value creation in the supply chain, services, research and technology is considerable.

As illustrated on figure 42 below, several key contracts have already been secured in the manufacturing and installation of inter array and export cables; design, manufacturing and installation of foundations.

Another public report (Multiconsult for INTPOW and Innovation Norway, 2012) describes the Norwegian offshore wind supply chain and capabilities. The report illustrates the high capabilities and great export potential for the Norwegian industry.

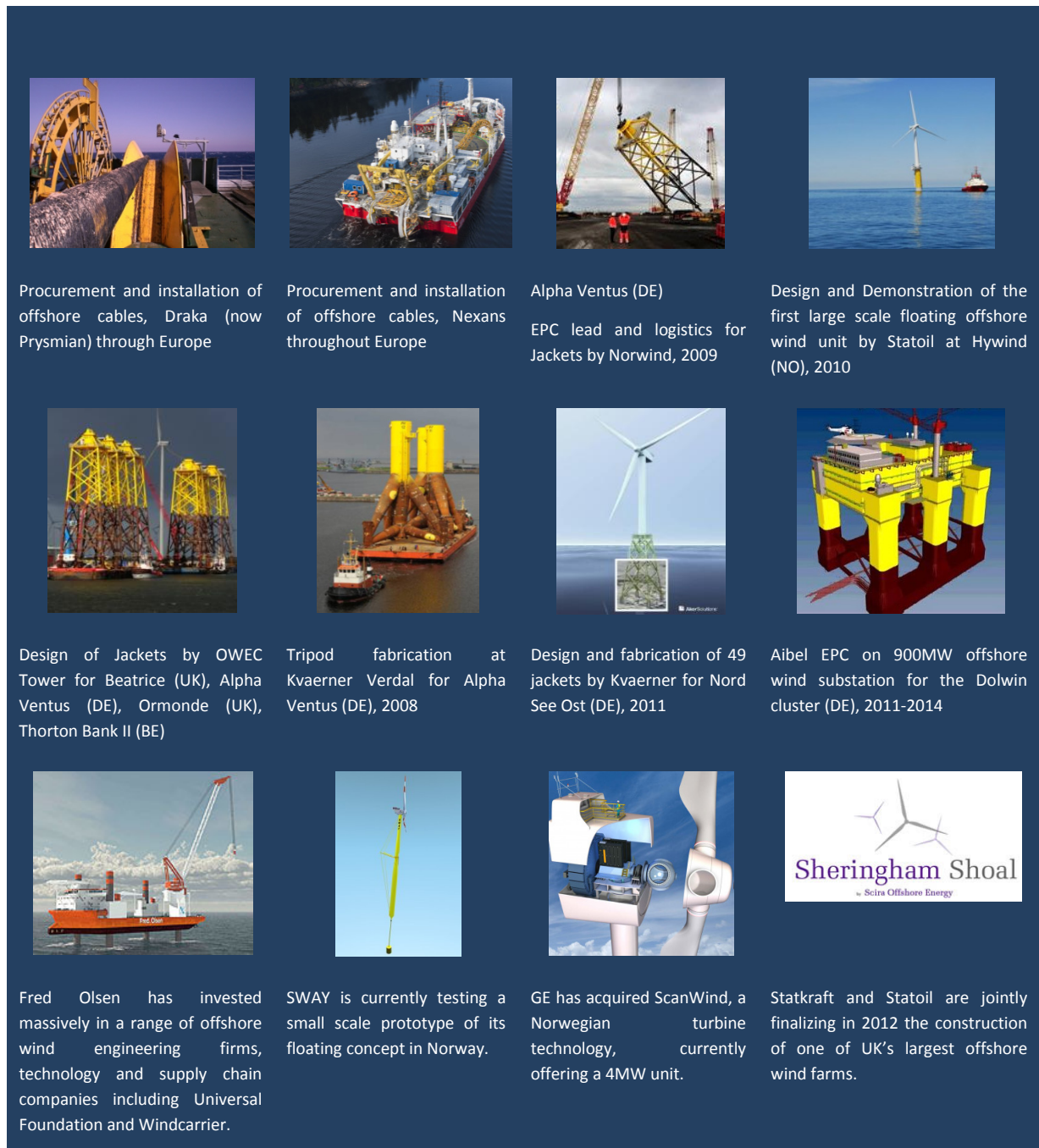


Figure 42. Key references in the Norwegian offshore win track record.

10 APPENDICES

References

Figures

Tables

Cost breakdown of a typical 500MW offshore wind farm

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List of Figures

Figure 1. Current European offshore wind project in operation and pipeline. Source: EWEA, 2011.....	8
Figure 2. Distance to shore (km) and average water depth (m) of planned projects. Source: EWEA, 2011	9
Figure 3. Overview of the key offshore wind obstacles ahead of 2020 ambitions. Source: Multiconsult, 2012	10
Figure 4. Key components of an offshore wind farm. Source: Multiconsult, illustration by Goodtech 2012	12
Figure 5. Offshore wind unit – key components. Source: Multiconsult, Illustration by OWEC Tower 2012.....	12
Figure 6. Overview of a typical offshore wind farm cluster (1-1,5GW) in 2012-2015. Source: Multiconsult, 2012....	13
Figure 7. The main offshore operations and the equipment involved. Source: The Crown Estate, 2009.....	13
Figure 8. Breakdown of key activities and supply components of an offshore wind farm. Source: Multiconsult, 2012	14
Figure 9. Innovation and maturity in the conventional offshore wind turbine market (non exhaustive). Source: Multiconsult 2012, Roland Berger, 2011	14
Figure 10. Evolution in conventional turbine dimensioning. Source: Multiconsult, 2012.....	15
Figure 11. Trend in top head mass per MW for commercial turbines (2-7MW). Source: Multiconsult, 2012	16
Figure 12. innovative two bladed turbines. Sources: 1) 2B Energy; 2) Innwind; 3) Nautica WindPower.....	16
Figure 13. Vertical axis turbines. Sources: 1) Vertiax; 2) VertiWind, 3) NOVEL 4) Sea Twirl	17
Figure 14. Multi-rotor horizontal axis turbines. Sources: 1) Hexicon;; 2) Pootoon design / Mitsubishi Zosen (Mitsubishi Shipbuilding); 3) Semi submersible / Shimizu Corporation (JP;) 4) Helm Wind; 5) Innwind; 6) Windsea Support structures.....	17
Figure 15. Conventional support structure inspired from the Offshore Oil&Gas sector. Source: Garrad Hassan, 2012.....	19
Figure 16. Past and future support structure type 2007-2016. Source: Douglas Westwood, Feb 2012	19
Figure 17. Main floating concept categories. Source: EWEA, 2011.....	20
Figure 18. About 8 floating concepts have already been demonstrated in small –medium scale. From left to right: Blue H; Poseidon; Hywind; Sasebo; Windfloat/Principle power; SWAY floater; Wind lens; Sea Twirl	20
Figure 19. Innovation and maturity for the leading concepts under development. Source: Multiconsult, 2012	21
Figure 20. Self-installing gravity base structure (GBS) during towing to site. Source: Seatower, 2011	21
Figure 21. Vici Ventus GBS fabrication and pres assembly site and concepts. Source Vici Ventus, 2011	22
Figure 22. Illustration of some the leading floating concept (non exhaustive)	22
Figure 23. Installation of jacket at the Alpha ventus site with the Thiaf installation vessel. Source: NorWind, 2009.....	23
Figure 24. Pre piling methods of offshore jackets using template. Source: NorWind Installer, 2011.....	23
Figure 25. Aibel-ABB substation. Source: Aibel, 2011	24
Figure 26. New built heavy lift vessels. Source: Windcarrier, 2011.....	24
Figure 27. Turbine pre assembly solutions. Source: Huisman, 2011	25
Figure 28. Example of self installing pre assembled solutions. Source: Gifford-BMT-Freyssinet, SPT offshore & Wood group, Vici Ventus	25
Figure 29. Dynamic positioning (DP) installation vessels dedicated to the installation	26
Figure 30. Left: Dedicated vessel to the installation of support structure. Source: Ingenium Ventus, 2012. Right: Dedicated installation vessel for SPAR structure. Source: Windflip, 2011	26
Figure 31. Typical offshore wind farm AC collection and transmission system. Source: SINTEF, 2012.....	27

Figure 32. Typical configuration for offshore wind farm with HVDC transmission. Source: SINTEF, 2012	28
Figure 33. Example configuration of offshore wind farm with DC collection and transmission. Source: SINTEF, 2012	30
Figure 34. Planned support vessel from SeaEnergy	34
Figure 35. Vessels used in a 520 MW wind farm (the pictures serve only as illustrations)	35
Figure 36. Offshore substation with accommodation platform alongside. Source: Dong Energy	36
Figure 37. The Fjellstrand WindServer access vessel	37
Figure 38. CAPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate 2012	38
Figure 39. OPEX (NOK/kW; % of total). Source: Multiconsult, The Crown Estate 2012	38
Figure 40. Levelised cost of offshore wind energy (NOK / kWh). Source: Data from offshore valuation report, BCG 2010, graph by Multiconsult 2012	39
Figure 41. Norway's unique energy, offshore and maritime heritage. Source: Multiconsult 2011	45
Figure 42. Key references in the Norwegian offshore win track record	46

List of Tables

Table 1. Key technological innovation areas and activities	6
Table 2. Introduction to demonstration, small scale pilot and commercial projects	11
Table 3. Support structure technical feasibility and maturity according to water depth. Source: Multiconsult, 2012	18
Table 4. Examples of projects using VSC HVDC for connection of offshore wind farms	29
Table 5. Strategy elements for offshore wind. Source: Multiconsult, 2012	32
Table 6. Characteristics of typical access methods. Source: Access to offshore wind turbines 2004	36
Table 7. Internal cost reduction factors directly addressable by the market players. Source: Multiconsult, 2012	39
Table 8. Future cost trends per MW in a 2015-2030 perspective. Source: Multiconsult, 2012	40
Table 9. Key shortages & bottlenecks. Source: Multiconsult, 2012	43
Table 10. Offshore wind turbine market trends. Source: Multiconsult, 2012	44

Cost breakdown of a typical 500MW offshore wind farm in 2012

500MW offshore wind farm, 20 years life time. 35m water depth, 125km distance to O&M port, wind speed of 10 m/s. 9,52 % WACC (Weighted Average Cost of Capital, pre-tax, real).	
CAPEX	NOK/kW
Project Consenting and Development	1 365
Project management from FID to Works Completion	364
Construction phase insurance	291
Turbine (exc. Tower)	9 082
Support structure (inc. tower)	10 183
Array cables	364
Installation	6 325
Construction contingency	2 661
Total CAPEX	30 634
OPEX	kNOK/MW/yr
Operations & maintenance (planned & unplanned, figures relate to post-warranty cost)	892
Operating phase insurance	46
Transmission charges	1 003
Total OPEX	1 940
In-warranty O&M cost as a percentage of po-warranty cost	70 %
Energy Production	
Gross Energy Production (MWh/MW/yr)	4 834
Gross Load Factor	55,20 %
Wind farm availability	91,00 %
Aerodynamic array losses	9,00 %
Electrical array losses	1,00 %
Other losses	4,60 %
Net energy production (MWh/MW/yr)	3 781
Net Load Factor	43,20 %
Decommissioning Total (NOK/kW)	417
Levelised cost of Energy (NOK/MWh) - 2012	1 482,50



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