Netherlands Enterprise Agency

Assessment Wind Measurement Program North Sea

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ASSESSMENT WIND MEASUREMENT PROGRAM

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Netherlands’ Enterprise Agency

Report No.: 14-2781, Rev. 1
Document No.:
Date: 20141205

Project name:	Assessment Wind Measurement Program	DNV GL Energy
Report title:	Assessment Wind Measurement Program North Sea	Renewables Advisory, the Netherlands
Customer:	Netherlands' Enterprise Agency	P.O. Box 9035
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Date of issue:	20141205	
Project No.:	74106430	
Report No.:	14-2781, Rev. 1	Tel: +31 26 356 9111
Document No.:		

Task and objective:

Prepared by:	Verified by:	Approved by:
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[Name] [title]	[Name] [title]	
[Name] [title]	[Name] [title]	

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☒ Client's Discretion
☐ Published

Keywords:
Offshore, Energy Assessment, Measurement Strategy, LiDAR

Reference to part of this report which may lead to misinterpretation is not permissible.

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2014-10-06	First issue	Hans Cleijne	Peter Frohböse	
1	2014-12-05	Revised version including client comments	Hans Cleijne	Detlef Stein	Peter Frohböse

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0 EXECUTIVE SUMMARY

0.1 English summary

RvO has requested DNV GL to investigate the possibilities to improve wind resource data in the Netherlands' part of the North Sea with the purpose to use it during project development and FEED studies for the five wind farm zones under development. The objective of the assessment was to give insight in the added value of a wind measurement campaign compared to the existing information of the North Sea wind climate.

To this end DNV GL has described available wind data sets for the North Sea and their usefulness for producing bankable energy assessments. The reported datasets include the offshore metrological masts at IJmuiden Ver, OWEZ, Fino 1 and Fino 3 and the KNMI measuring platforms Goeree Lichteiland and Europlatform.

Met masts have historically been employed to provide meteorological data for assessments of wind resource and energy production of offshore wind farms. In the recent past, ground based LiDAR devices have gained industry acceptance for onshore wind resource assessments. As a result of this development, floating LiDAR systems have been developed and are aimed at complementing or replacing offshore met mast due to their lower cost.

An inventory of measuring devices and their main characteristics was made in order to assess the possibilities to deploy these devices in wind farm zone measuring campaigns. The inventory included fixed metrological masts for onsite deployment, fixed mounted LiDAR's on existing platforms and LiDAR equipped metrological buoys.

Six measuring strategies were designed in order to assess the level of uncertainty as well as the potential economic benefit resulting from these strategies. For four wind farm zones (Borssele 1, Borssele 2, Hollandse Kust Zuid and Hollandse Kust Noord) a detailed uncertainty analysis was made resulting in an estimated final uncertainty represented by a P90/P50 value. This value was then used to estimate the differences in the Cost of Energy resulting from the uncertainty of the particular measurement campaign strategy. Using Net Present Value the economic benefit of each strategy was determined for each of the wind farm zones.

Table 0-1 gives a high level overview of the results of this analysis.

Table 0-1 Assessment of measurement strategies for wind farm zones

	Wind zone	Borssele 1	Borssele 2	Hollandse Kust Zuid	Hollandse Kust Noord
Baseline	Existing met data (LEG, EPF ,OWEZ, IJmuiden) Mesoscale models (MERRA, ERA, Harmonie) Fixed LiDAR LEG, EPF	+	+	++	++
1	Floating LiDAR on location	O	++	-	-
2	Fixed mast on location	--	--	+	--

On the basis of this analysis DNV GL comes to the following conclusions:

1. Traditional fixed measuring offshore metrological masts are still the reference for offshore wind measurement. However, they suffer from long deployment times due to long permitting processes, design and tendering process;

2. Fixed LiDARs mounted on existing platforms are an attractive option to obtain reliable and accurate wind resource data. Deployment time is mainly dependent on obtaining permission from the platform owner. Since October 2014 ECN has installed a LiDAR on Goeree LE platform;

3. Europlatform is another option for installation of a fixed LiDAR. For this option permission has to be granted by the platform owner (Rijkswaterstaat). This option is attractive because (i) it can serve as a backup for the measurements at Goeree LE, and (ii) it provides insight in the wind speed gradient near the Dutch coast;

4. Floating LiDAR equipment is on the path to commercial application. It is expected that several floating LiDARs will enter the pre-commercial stage making them suitable to be used in bankable wind assessment reports;

5. Refurbishment of OWEZ offshore metrological mast is not beneficial from an energy assessment point of view. Already one year of reliable, undisturbed measurements is available. Disturbanceof the wind speed measurements by OWEZ windfarm is the cause for the fact that this mast is no longer of use for energy assessments;

6. Extension of IJmuiden Ver met mast beyond 2015 is not necessary from an energy assessment perspective. IJmuiden Ver met mast is the only mast in the Dutch North Sea area that is exposed to all wind directions; it has high accuracy wind measurements, according to IEC standards; measurements can be used for pre- and post-verification of floating LiDAR equipment; it has the potential to become a long, stationary historical record for offshore energy assessment and be a reference point for offshore wind atlases to be developed;

7. Borssele 1, Borssele 2 and Hollandse Kust Zuid wind farm zone benefit considerably from fixed LiDAR measurements at Goeree LE that started in October 2014;

8. For Hollandse Kust Noord OWEZ met mast serves de facto as an onsite mast, therefore this zone does not benefit from the additional fixed LiDAR measurements;

9. Borssele 2 can benefit considerably from a 12 month onsite floating LiDAR-campaign. It is expected that for Borssele 1 a floating LiDAR can be used for a period of 6 months as a consequence of the required tendering process and measurement preparations. Therefore the value of floating LiDAR measurements for Borssele 1 is limited;

10. Deployment of a floating LiDAR at Hollandse Kust Zuid or Noord does not improve the energy assessment uncertainty, because of the availability of highly reliable measurements from the fixed LiDAR at Goeree LE, or data from OWEZ metrological mast;

11. There is potential benefit to install a fixed metrological mast at Hollandse Kust Zuid as it is the option with the lowest uncertainty levels compared to the alternative measuring strategies.

DNV GL has the following recommendations:

1. Because the OWEZ metrological offshore mast has already one year of high quality undisturbed data available, it is DNV GL's opinion that a restart of this mast should not be advised, as this would not yield additional data that adds value to a bankable wind assessment report;

2. DNV GL advises not to extend the operation of IJmuiden Ver offshore metrological mast beyond the end of 2015 for energy assessment purposes. DNV GL remarks that the existing data set is already more than sufficient as a basis for bankable reports. However, in the interviews conducted by DNV GL there was consensus that the IJmuiden Met mast is a valuable data source also for other purposes than energy yield assessments, and it should be seriously considered to continue the measurements beyond the present campaign end;

3. DNV GL proposes to investigate further the possibilities to install a fixed LiDAR at Europlatform as soon as possible. In this way it will be possible to establish redundancy for other measurement campaigns and to gain more insight in the wind speed and direction gradient near the shore. Issues to be solved are (i) agreement with the platform owner, (ii) power supply, (iii) operation of the LiDAR;

4. Given the fact that there is a considerable economic benefit in early installation of a floating LiDAR in the Borssele wind farm zone, DNV GL recommends to start the procurement for data collection using an onsite floating LiDAR as soon as possible in order to obtain the longest possible wind data record for Borssele 1 and Borssele 2. DNV GL recommends focusing the procurements process on data availability and data quality. As a minimum the floating LiDAR to be used should be at least in the pre-commercial stage in order to provide bankable data.

0.2 Nederlandse samenvatting

RvO heeft DNV GL gevraagd om te onderzoeken wat de mogelijkheden zijn om de winddata in het Nederlandse deel van de Noordzee te verbeteren met het doel om deze te kunnen gebruiken voor projectontwikkeling en het uitvoeren van FEED-studies voor de vijf windparkgebieden die door de overheid zijn gedefinieerd. Het doel van de studie was om inzicht te geven in de toegevoegde waarde van verschillende windmeetcampagnes in vergelijking tot bestaande Noordzee windklimaatgegevens.

Toegespitst op dit doek heeft DNV GL een overzicht gemaakt van beschikbare windgegevens op de Noordzee en in kaart gebracht in hoeverre deze te gebruiken zijn voor het maken van *bankable* energieopbrengstrapporten. Dit overzicht bevat een beschrijving van de offshore meetmasten IJmuiden Ver, OWEZ, Fino 1 en Fino 3, en de KNMI platforms Lichteiland Goeree en Europlatform.

Meetmasten zijn historisch gezien toegepast om meteorologische data te verzamelen voor de bepaling van windenergieopbrengsten van offshore windparken. In het recente verleden zijn grondgebonden LiDAR-meetinstrumenten door de windindustrie geaccepteerd voor het bepalen van het onshore windklimaat. Als een logische vervolgstap in deze ontwikkeling zijn drijvende LiDAR-systemen ontwikkeld die bedoeld zijn om de metingen op vaste meetmasten aan te vullen of te vervangen tegen de laagst mogelijke kosten.

Om vast te stellen wat de toepassingsmogelijkheden zijn van de beschikbare meetinstrumenten tijdens de meetcampagnes is er een inventarisatie gemaakt van beschikbare instrumenten en hun karakteristieken. Deze inventarisatie omvat vaste meteorologische meetmasten voor installatie in de windgebieden, vaste LiDAR’s voor installatie op bestaande platforms en meteorologische boeien voorzien van LiDAR’s.

Zes verschillende meetcampagnes zijn ontwikkeld om te bepalen wat de resulterende onzekerheid is in de bepaling van de energieopbrengst. Dit is gebruikt om het economisch voordeel te bepalen van deze strategieën. Voor de 4 windgebieden (Borssele 1, Borssele 2, Hollandse Kust Zuid en Hollandse Kust Noord) is er een gedetailleerde onzekerheidsanalyse die resulteerde in een schatting van de P90/P50-waarde. Deze waarde werd vervolgens gebruikt om de verschillen in de Cost of Energy te bepalen als gevolg van de gehanteerde meetcampagnestrategie. Op basis van netto-contante-waarde werd tenslotte bereken wat de economische voordelen waren van de verschillende meetcampagnes.

Tabel 0-2 Analyse van de waarde van meetcampagnestrategieën voor 4 windgebieden

	Windgebied	Borssele 1	Borssele 2	Hollandse Kust Zuid	Hollandse Kust Noord
Baseline	Bestaande meteodata (LEG, EPF ,OWEZ, IJmuiden) Mesoscale modellen (MERRA, ERA, Harmonie) Vaste LiDAR LEG, EPF	+	+	++	++
1	Drijvende LiDAR op locatie	O	++	-	-
2	Vaste meetmast op locatie	--	--	+	--

Op basis van deze analyses trekt DNV GL de volgende conclusies:

1. Traditionele windmetingen op vaste offshore meteorologische masten zijn nog steeds de referentie voor offshore windmetingen. De installatietijd van vaste masten is echter lang als gevolg van lange vergunningsprocedures, ontwerpactiviteiten en aanbestedingsprocedures;
2. Vaste LiDAR's die kunnen worden bevestigd op bestaande platforms zijn een aantrekkelijk optie om betrouwbare en nauwkeurige winddata te verzamelen. De doorlooptijd voor het installeren van dergelijke apparatuur wordt vooral bepaald door de tijd die nodig is voor het verkrijgen van toestemming van de platformeigenaar. In oktober 2014 heeft ECN een LiDAR geïnstalleerd op Lichteiland Goeree;
3. Europlatform is een tweede optie voor installatie van een drijvende LiDAR. Ook voor dit platform is toestemming nodig van de eigenaar (Rijkswaterstaat). Deze optie is aantrekkelijk omdat (i) metingen van dit platform kunnen dienen als back-up voor de metingen op Lichteiland Goeree, en (ii) de metingen inzicht geven in de oost-west windsnelheidsgradiënt dicht bij de Nederlandse kust;
4. Drijvende LiDAR-installaties zijn op weg naar commerciële toepassing. Men verwacht dat binnenkort verschillende drijvende LiDAR's de zogenaamde *pre-commercial stage* zullen bereiken wat het mogelijk maakt om ze te gebruiken voor *bankable* windopbrengstrapporten;
5. Uit het oogpunt van energieopbrengstbepaling heeft het weinig zin om de OWEZ-windmeetmast op te knappen en weer in gebruik te nemen. Er is reeds 1 jaar betrouwbare, ongestoorde data beschikbaar. De huidige verstoring van de windsnelheid door OWEZ windpark maakt de metingen aan OWEZ windmeetmast grotendeels ongeschikt voor windenergieopbrengstbepalingen;
6. Verlenging van de meetcampagne van de IJmuiden Ver mast na 2014 is niet nodig uit oogpunt van energieopbrengstbepaling. IJmuiden Ver met mast is echter de enige meetmast in dit deel van de Noordzee die in alle windrichtingen ongestoord is; de metingen zijn van hoge kwaliteit (IEC-standaard); en de metingen zijn geschikt voor pre- en post verificatie van drijvende LiDAR apparatuur. IJmuiden Ver heeft de potentie om een referentiepunt te worden voor het bepalen van offshore windenergieopbrengsten en windatlassen door een lange reeks op te bouwen van hoogwaardige en stationaire windreeksen;
7. De windgebieden Borssele 1, Borssele 2 en Hollandse Kust Zuid profiteren aanzienlijk van de installatie van een vaste LiDAR op Lichteiland Goeree die data produceert sinds oktober 2014 doordat deze de nauwkeurigheid van de energiebepaling verhoogd.
8. Voor Hollandse Kust Zuid dient de OWEZ windmeetmast de facto als een mast in het windgebied. Als gevolg daarvan voegen de LE Goeree LiDAR metingen geen waarde toe aan deze reeds nauwkeurige metingen;
9. Voor Borssele 2 is er een aanzienlijk financieel voordeel te behalen door het uitvoeren van een meetcampagne van 12 maanden met een drijvende LiDAR-metingen in het windgebied. Voor Borssele 1 is de verwachting als gevolg van de lengte van het aanbestedingsproces en de voorbereidingen voor de campagne in de orde van 6 maanden aan metingen kan worden verzameld voor de start van de tender eind 2015. Als gevolg van deze kortere periode is de waarde van de metingen voor Borssele 1 lager;

10. Toepassing van een drijvende LiDAR in Hollandse Kust Zuid of –Noord levert geen toegevoegde waarde ten opzichte van de dan beschikbare hoogwaardige data van de vaste LiDAR op LE Goeree of de OWEZ windmeetmast;
11. Het installeren van een vaste meetmast in Hollandse Kust Zuid heeft potentiele voordelen, aangezien het daar de laagste onzekerheid heeft vergeleken met de andere meetcampagnestrategieën.

DNV GL heeft de volgende aanbevelingen:

1. Aangezien de OWEZ meetmast al de beschikking heeft over één jaar van hoogwaardige ongestoorde data, adviseert DNV GL om de metingen van OWEZ niet te hervatten, omdat dit geen toegevoegde waarde heeft voor het bepalen van windenergieopbrengsten;
2. DNV GL adviseert om de meetcampagne aan de IJmuiden Ver windmeetmast niet te verlengen na eind 2015 met het doel om windenergieopbrengstbepalingen te verbeteren. DNV GL merkt op dat de beschikbare dataset al meer dan voldoende is om *bankable* windrapporten te produceren. Tijdens de interviews die DNV GL heeft uitgevoerd was er desalniettemin brede consensus dat IJmuiden Ver is een waardevolle bron van data ook voor andere doelen dan windopbrengstbepaling. Het verdient daarom serieuze aandacht te onderzoeken wat de mogelijkheden zijn om de meetcampagne voort te zetten na het einde van de huidige meetcampagne;
3. DNV GL stelt voor om zo snel mogelijk te onderzoeken wat de mogelijkheden zijn om een vaste LiDAR te installeren op Europlatform. Dit biedt de mogelijkheid om redundantie in te bouwen voor de huidige meetcampagnes en om meer inzicht te krijgen in de oost-west gradiënt van windsnelheid en –richting nabij de kust. Daarbij moeten een aantal knelpunten worden opgelost (i) overeenstemming met de platformeigenaar, (ii) energievoorziening, (iii) beheer van de LiDAR;
4. Gezien de conclusie dat er een aanzienlijk economisch voordeel te behalen valt bij het zo vroeg mogelijk installeren van een drijvende LiDAR in windgebied Borssele, beveelt DNV GL aan om zo snel mogelijk met een aanbestedingsprocedure te starten om een zo lang mogelijke windreeks te verzamelen voor Borssele 1 en 2. DNV GL beveelt daarbij verder aan om bij het aanbestedingstraject vooral aandacht te besteden aan de kwaliteit en de beschikbaarheid van de te leveren windgegevens. Als een minimumeis zou de geselecteerde drijvende LiDAR moeten voldoen die gesteld zijn om toegelaten te worden tot de "*pre-commercial stage*".

1 INTRODUCTION

1.1 Background

RvO has invited DNV GL to provide a proposal for the project “Assessment wind measurement program”, reference is made to SDE149059C7VU/ml.

The Dutch Government has defined three offshore Wind Zones where 3,500 MW offshore wind power will be deployed:

- The Borssele Wind Farm Zone: 1,400 MW;
- The South Holland coast Wind Farm Zone: 1,400 MW;
- The North Holland coast Wind Farm Zone: 700 MW.

In each zone wind farm sites will be defined. Third parties can tender for building and exploiting a wind farm in each site. The Dutch government will provide tenderers a site data set, with soil- water- and wind data, to stimulate competitive bids. /1/

This assessment concerns the possibilities to improve wind resource data in the Netherlands’ part of the North Sea with the purpose to use it during project development and FEED studies (hence not for research or for climatological studies). Improving the data should result into more accurate calculations of the annual energy production, hence lower risk surplus and therefore lower cost of capital. It is assumed this reduces the project costs and will result in a lower SDE-grant.

The objective of the assessment is to give insight in the added value of a wind measurement campaign compared to the existing information of the North Sea wind climate.

There are different possibilities to assess the wind resource at a certain location

- The use of existing information by using models and interpretations of historical data;
- Extra measurements with (new) stationary met masts;
- Use of LiDAR or Floating LiDAR.

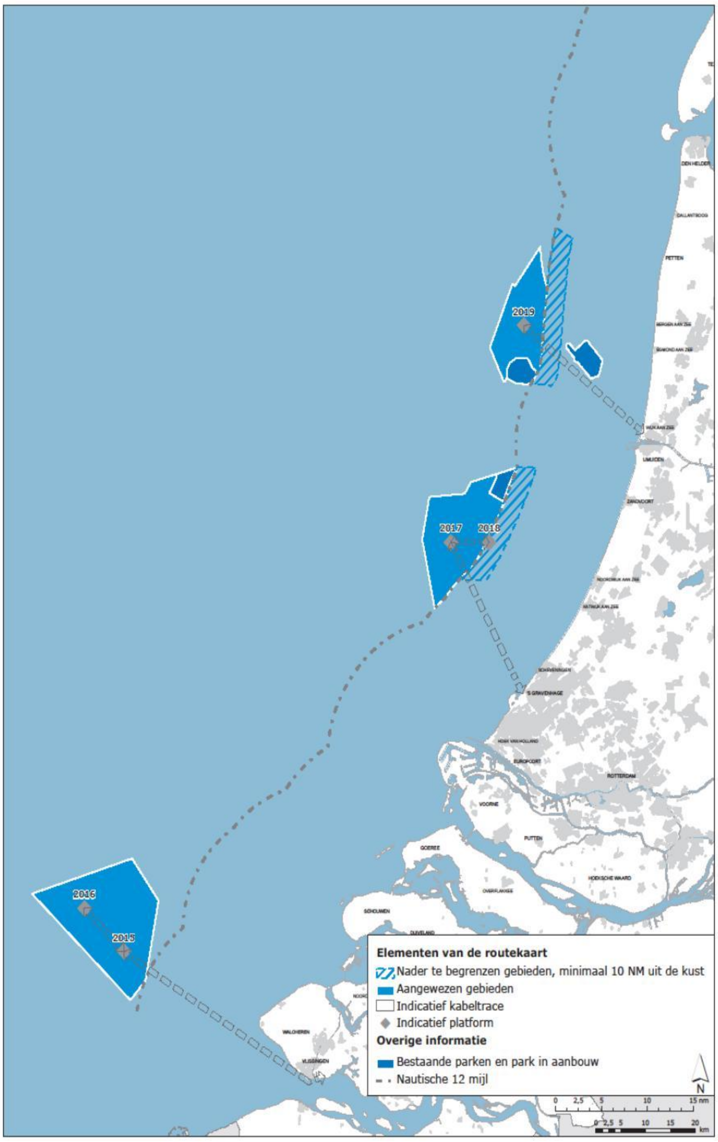


Figure 1-1 Wind farm zones to be developed until 2023

1.2 Objective

The objective of this assessment is to identify the possible wind measurement campaigns on the North Sea and insight in the added value of each possibility.

The following questions will be addressed:

1. What are the costs, mobilization time, reduction of uncertainty (in wind resource assessment) and thus contribution to a lower risk surplus of all possible wind measurement campaigns;
2. Which wind data and data quality are essential for calculating a reasonable business case for a wind project in the areas?
3. What is the relation between wind climate and an offshore wind farm business case?

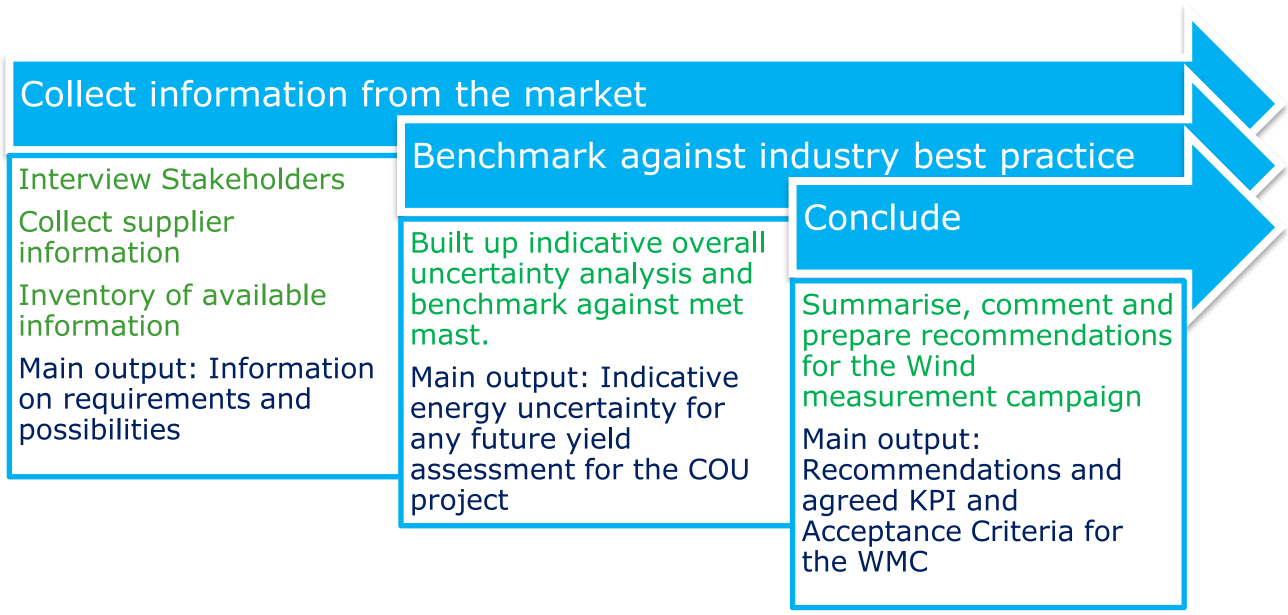
4. Which wind data are available to date, how accurate are these data sources and what do they contribute to lower the risk surplus?

5. Which wind measurement techniques are available to obtain wind data to evaluate business cases? What are the characteristics of these measurement techniques?

6. To what extent do nearby located wind farms influence measurements and thus influence determination of the wind regime? How can these uncertainties be reduced?

1.3 Approach

Met masts have historically been employed to provide meteorological data for assessments of wind resource and energy production of offshore wind farms. In the recent past, ground based LiDAR devices have gained industry acceptance for onshore wind resource assessments. As a result of this development, floating LiDAR systems have been developed and are aimed at complementing or replacing offshore met mast due to their lower cost.



In order to meet the objectives of the assignment DNV GL has adopted the following approach:

- Interview relevant stakeholders for the Dutch offshore wind energy market;
- Collect information from wind measurement equipment suppliers;
- Make an inventory of available data;
- Develop wind assessment scenarios for the acquisition of wind climate data;
- Analyse the impact of these scenarios on the uncertainty of the energy yield on the financial performance of 2 reference wind farms;
- Draw conclusions and make recommendations on wind measurement strategy.

1.4 Report structure

Chapter 3 contains a description of existing wind measurements in the North Sea and their relevance for energy assessments for the offshore wind zones under consideration.

Chapter 4 gives a description of available measurement techniques and their characteristics.

Chapter 5 describes possible wind measurement strategies for the Borssele 1 and 2, Hollandse Kust – Zuid en Hollandse Kust Noord. The costs and benefits of these measurement strategies have been evaluated. Finally recommendations are given for a measurement strategy for each of the offshore wind farm zones.

2 INVENTORY OF EXISTING MEASUREMENTS

2.1 Available measurements for the North Sea

In the Dutch part of the North Sea a number of meteorological data points are available (Figure 2-1). The characteristics of these data points are collected in Table 2-1.

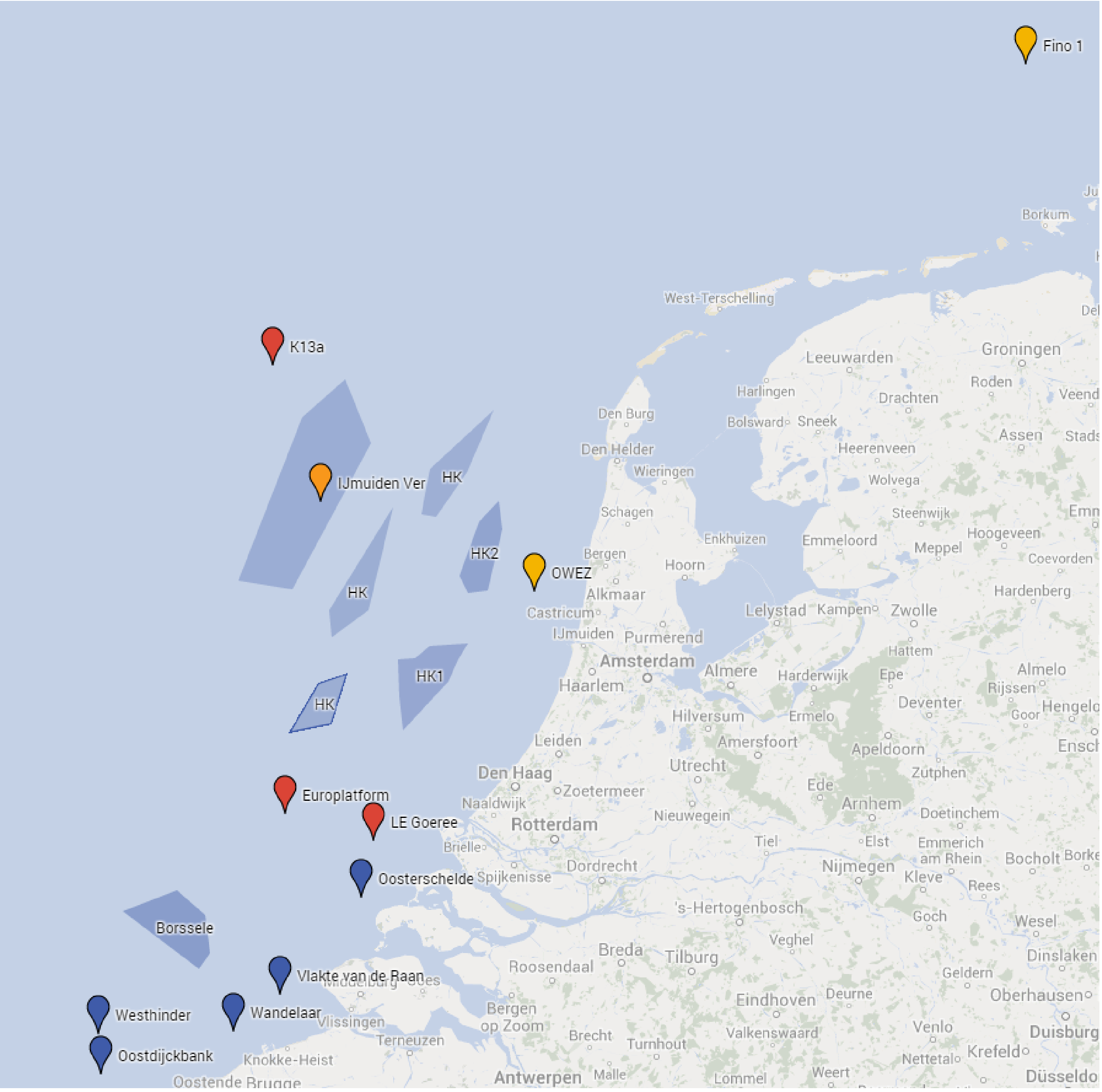


Figure 2-1 **Wind speed measurements in the North Sea in relation to wind zones (red: KNMI station, orange: offshore met mast, blue: additional measurement).**

Table 2-1 Overview of available measurement points in the North Sea

Name	Data since	Measuring height	Type of data
Meteomast IJmuiden	2012	100 m	Offshore met mast
Fino 1	2004	103 m	Offshore met mast
OWEZ met mast	2005	116 m	Offshore met mast
LE Goeree	1981	38 m	KNMI offshore
Oosterschelde	1982	16.5 m	Precipitation
Vlakte van de Raan	1981	16.5 m	
K13a	1980	73.8m	KNMI offshore
Europlatform	1983	29 m	KNMI offshore
Wandelaar			Low measuring mast
Oostdijckbanck			Low measuring mast Radar platform - heli platform
West-Hinder	1977		Measuring mast

At present a number of data sources are available:

1. Publicly available data including results of NORSEWInD EU project /2/ to provide a dependable offshore wind atlas of the North Sea and weather model data including European Reanalysis (ERA) /3/ and Modern-Era Retrospective Analysis for Research and Applications (MERRA) /4/ and Harmonie (KNMI) /5/;
2. Publicly available data from Europlatform, Goeree LE and Vlakte vd Raan and K13a offshore from KNMI national weather service. Measurements are also available from Meetnet Vlaamse Banken /6/[1];
3. Publicly available high quality tall offshore metrological mast data from the existing IJmuiden Ver /7/and OWEZ masts /8/.

In addition other sources exist (Westhinder, Oosterschelde, etc.) that are considered less useful for energy assessments as these are mainly routine weather stations having lower altitude measuring instruments. The accuracy of the data is not considered to be sufficient for a bankable wind report

[1] Since 1 March there is a data portal for retrieval of historical data (www.kustdata.be)

2.2 Met Mast IJmuiden

Figure 2-2 Met Mast IJmuiden

In the framework of the FLOW research program RWE has erected a fixed offshore met mast in 2011. The mast is located approximately 75 km west of IJmuiden. At several heights (between 25 m and 100 meter) sensors have been mounted that measure wind speed, wind direction, temperature and pressure.

ECN rents the Met mast since 2012 and is responsible for the measurement campaign, including data storage, analysis and publishing. The measurement data are public.

A fixed LiDAR system has been installed capable of measuring wind speed and direction up to 300 m.

The mast is used as reference measurement and to verify for floating LiDAR sensors, as part of the Carbon Trust Offshore Accelerator roadmap for the commercial acceptance of floating LiDAR technology. /9/

In the interviews conducted by DNV GL there was consensus that the IJmuiden Met mast is a valuable data source, and it should be seriously considered to continue measurements beyond the present campaign which ends in 2015. IJmuiden met mast is the only mast in the Dutch North Sea area that is exposed to all wind directions; it has high accuracy wind measurements, according to IEC standards; measurements can be used for pre- and post-verification of floating LiDAR equipment; it has the potential to become a long, stationary historical record for offshore energy assessment and be a reference point for offshore wind atlases to be developed. /7/ /10/

However, DNV GL remarks that the existing data set is already more than sufficient as a basis for bankable reports and that from an energy yield assessment perspective there is no need to extend the measuring period beyond the end of 2015.

2.3 Offshore Wind Farm Egmond aan Zee (OWEZ)

As part of the measurement and evaluation program for OWEZ a fixed met mast has been erected. The mast has started operation in 2005. The first year of operation the met mast was undisturbed by obstacles. Since the construction of the OWEZ wind farm the measurements are affected by wake effects in a number of wind directions. A number of wind directions are still undisturbed and could be used for reference measurements closer to shore.

Wind speeds and wind directions (horizontal and vertical) are measured at 21, 70 and 116 m.

According to ECN, the mast needs some refurbishment to become fully operational again. However again according to ECN the mast has been maintained on an annual basis and there are no HSE issues that prevent operation again.

Given the fact that already one year of high quality undisturbed data is available and that an extension would yield significantly disturbed (by the OWF) data, it is DNV GL's opinion that such a restart should not be advised, as this would not yield additional data that could be used for a bankable report.

2.4 Lichteiland Goeree and Europlatform

Lichteiland Goeree (LEG) and Europlatform (EPD) are so-called essential WMO meteorological stations. On a routine basis wind speed and wind direction measurements are made and recorded automatically since the 1980's. LE Goeree has is at 19 km distance to the coast and has a met mast height of 38 m, while EPF is at 45 km distance to the coast and has a met mast height of 29 m.

Figure 2-3 Europlatform (left) and Goeree LE(right).

The wind measurements are quality controlled by KNMI and published in the public domain. As such the measurements provide very valuable long term records that can be used to correlate with shorter term offshore wind speed measurements. Especially, Europlatform is used for this purpose on a regular basis.

Since wind speed measurements are made at low altitude and the platforms are bulky, the measurements can be assessed as highly disturbed and thus are not useful for improving "bankability" of the wind assessments.

In the framework of a FLOW research project, ECN has installed a fixed LiDAR at LE Goeree in October 2014. The platform is essential for Rotterdam harbour, taking away the risk that the platform would be removed soon (as happened to meetpost Noordwijk before).

ECN has also plans to install a fixed LiDAR at Europlatform. A fixed LiDAR at Europlatform has a number of advantages: Europlatform is closer to the Borssele wind zone; together with the measurement at LE Goeree it offers excellent insight into the East West wind speed and wind direction gradient; and finally the measurement at EPF can serve as backup in case there is a measurement failure at LE Goeree. Since the power supply and other facilities are less advanced than at LEG, further development of this possibility has temporarily been suspended. However, it should definitely be possible to install a LiDAR at EPF.

As will be shown in the next chapters installation of fixed LiDAR's at EPF and LEG is a relatively low cost solution that provides reliable wind data in an area centrally located with respect to Borssele and Hollandse Kust.

2.5 FINO 1 and FINO 3

In January 2002, the Federal Government of Germany decided the construction of three research platforms (FINO1, FINO2 and FINO3) in the North Sea and the Baltic Sea, on three potentially suitable sites in the immediate vicinity of major offshore wind farms which are at the planning and application stage. /11/

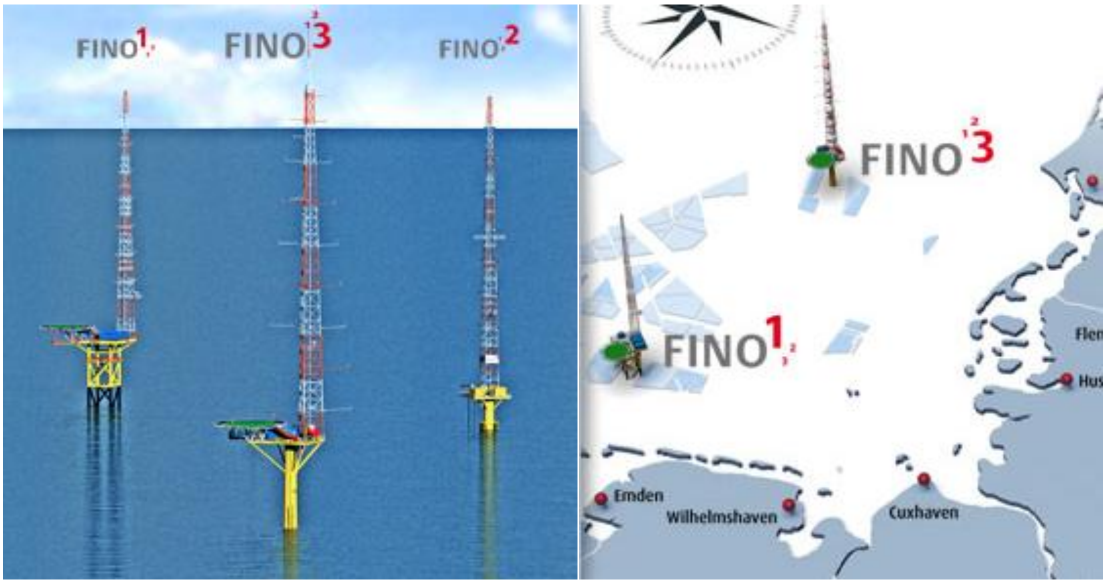


Figure 2-4 FINO masts in Germany

Scientific studies conducted on these platforms include the following:

- Measurement of wind speed, wind direction and turbulence in relation to height;
- Measurement of wave height and wave propagation;
- Measurement of the strength of sea currents;
- Seabed subsurface conditions;
- Lightning measurements.

Each of the three research platforms has its own structural form and independent internal communication systems:

FINO1, which is most relevant for this study is located ~45 kilometres to the north of the island Borkum in the North Sea, was brought into service in summer 2003, and is still operational.

Wind data are publicly available and are used on a regular basis for commercial energy assessments or research activities. For the Netherlands Fino1 is especially important for the area “Boven de Wadden”. For the locations under investigation in this report Fino1 is mainly used as a reference point for meso-scale wind modelling.

3 MEASUREMENT DEVICES

This section provides an overview of available measurement devices that will be included in the monitoring assessment strategies below.

3.1 Meteorological masts

Measurements from cup anemometers mounted on mast structures are the long-established industry standard for the measurement of wind speeds in the wind energy industry. The development of wind turbine power characteristics are based to some extent inherently on cup anemometer technology and therefore at this time, from the perspective of industry convention, cup anemometers should be considered the most preferable option.

A key risk associated with a measurement campaign based on an offshore meteorological mast is that associated with the design. Failure to meet 'industry best practice' may lead to increased levels of uncertainty and in some cases problems with basic traceability and provenance of the measured data. DNV GL is familiar with several examples of offshore wind monitoring campaigns which have fallen well-short of such standards and hence this ‘design risk’ should not be underestimated. The following non-exhaustive, basic guidance is provided for information in order to illustrate some of the key requirements that should be considered.

In order that the primary (top-most) anemometer is subject to the lowest possible flow distortion, a vertical mounting arrangement is recommended. Guidance on this arrangement is provided in the IEC 61400-12-1.

Wind speed measurements at multiple heights on the mast are desirable in order to characterise the vertical variation of wind speed (wind shear), which is important for design purposes as well as if any vertical adjustment to the wind data are required as part of a wind resource assessment. In addition, multiple instruments add redundancy to the system such that should an individual anemometer or wind vane fail, missing data may be ‘reconstructed’ through correlation analysis to other data channels.

If mounted correctly mounting arrangements for the anemometers should yield an overall bias in wind speed measurements of no more than 0.5 %..

All anemometry should be calibrated at a fully approved MEASNET facility prior to installation. Further calibrations should be conducted post removal, to assess any potential instrument drift across the measurement period. No ultra-sonic anemometry is recommended. Whilst such instruments are of value in assessing the vertical components of wind flow, in offshore application this is of marginal relevance.

In general, cup anemometry (as opposed to ultra-sonic anemometry) has proven to be a relatively robust technology from a reliability perspective and the risk of occasional instrument failures due to wear or lightning strikes is substantially mitigated through the inherent level of redundancy offered by the presence of several instruments on the mast.

Traceability is considered crucial to the value and 'bankability' of the gathered data and should be achieved through appropriate documentation and quality systems in order to allow a clear 'data-path' to be established from the anemometer cups through to the final wind data.

Deployment of a fixed met mast requires considerable lead time:

- Permit application and subsequent legal periods for appeal (> 6 months);
- Specification, tendering, construction and installation (> 1 year).

Investment costs for a fixed mast are in the order of 10 million Euros, while operational costs are in the order of 250 kEUR per annum.

3.2 Platform-mounted LiDAR

Widespread validation work carried out by LiDAR device manufacturers and the academic community onshore as well as offshore, to date, indicate that leading LiDAR technologies offer high levels of accuracy comparable to conventional mast measurements.

This has led to the current position of DNV GL with respect to the use of fixed based, vertically looking LiDAR technology offshore on stationary platforms for the purpose of formal wind resource and energy yield assessment. The following position is based on the review of an extensive body of onshore and offshore evidence, as reported in formal Position Statements on both the WINDCUBE and ZephIR LiDAR, previously issued [/12/, /13/]:

DNV GL generally considers a WINDCUBE or ZephIR operated on an offshore stationary platform as a benign scenario provided that enough evidence is provided to ensure no significant flow distortion from the platform or its components might affect the measurements.

Offshore wind farms have high capital costs and therefore, when employing relatively new technology for a purpose as vital as predicting the future energy output of a large wind farm, particular care should be exercised in the design of the measurement campaign. Thus, in addition to the statements mentioned above, the following comments provide an outline of best practices for the use of LiDAR's for offshore wind resource assessment.

Given the importance of measurements, it is considered appropriate to validate the specific device used at an appropriate onshore flat terrain test site before and – should inconsistent behaviour be observed during the measurement campaign – after the offshore measurement campaign. Comparison with a met mast provides traceability back to classical anemometry; therefore, the validation of the remote sensing device should be made against a tall conventional meteorological mast (although other verification configurations may prove to be sufficient).

The length of the data set and data coverage rates achieved are key considerations in measurement campaigns and remote sensing campaigns should span a similar period as those undertaken with conventional masts. Also, it is important to deploy a device with a sufficient power supply and an appropriate O&M program such that it can be expected that data coverage rates up to hub height will be close to 100 %.

Finally, a concern with the installation of any measurement equipment is ensuring that the equipment is working correctly when it is deployed. DNV GL considers that measures to increase confidence that the equipment is working correctly before, during and, after the required deployment may be considered to be good practice.

In conclusion, under the above-mentioned conditions, it is anticipated that similar uncertainty results would be obtained from an energy prediction based on data from a WINDCUBE or ZephIR LiDAR mounted on a stationary platform as the uncertainty results from an energy prediction based on data from a conventional offshore met mast employing classical anemometry.

Nevertheless, DNV GL is aware of a number of issues in LiDAR technology that, although in some cases device specific, could lead to inaccuracies in the measurements. These include, but may not be limited to, corrections for certain meteorological conditions such as cloud cover, measurement height errors due to focusing errors, reduced data availability due to low aerosol concentrations in the atmosphere (though of lesser importance, offshore), and uncertainties in the open field nature of any LiDAR measurement verifications. It should also be noted that although remote sensing devices do record turbulence intensity quantities, the implication of volume averaging effects on these quantities and the relation to classical anemometry are not fully understood.

Currently there are a few standards or best practice guidelines available (like IEA RP 15 and currently revised IEC 161400-12-1) for measurements conducted using remote sensing technologies such as LiDAR, which should be followed. Furthermore, a joint DNV GL internal best practise guidelines are currently being drafted. However, DNV GL recommends that the following procedure be followed for pre/post calibration of LiDAR devices to be deployed offshore on fixed platforms.

Initial factory calibrations should be conducted, allowing calibration of the LiDAR device in a controlled environment. Once these tests are passed, an open atmosphere validation against a second reference LiDAR is undertaken. The reference LiDAR will itself have undergone an independent calibration, within the last year, against a conventional tall meteorological mast. DNV GL also recommends that the LiDAR device be itself verified against a conventional meteorological mast by an independent and well established testing organisation and this should be carried out both prior to and following the site measurement campaign. Such verification is considered to be a "best practice" procedure.

Installation of the LiDAR device should be such that no overhead obstructions interfere with the laser or cause flow distortion in the measurement cone. This can easily be achieved for devices installed on a tailored platform. However, it becomes more difficult if a device is to be installed on a pre-existing structure.

As with all wind measurements, it is important that high quality documentation is maintained regarding the calibration, installation and maintenance of the LiDAR device, throughout the measurement campaign.

The associated power systems for LiDAR technologies are a significant consideration, especially when deployed offshore. LiDAR devices typically consume several times the power requirement of conventional anemometry-based systems. This means that significant autonomous power generation must be deployed alongside these systems, with remote platforms likely to require multiple power generating units (photovoltaic panels, wind props, etc.) and a large indigenous battery storage. Although this power requirement can be meteorological with such power sources, it is recommended that reserves, such as back-up diesel generators, are installed to provide extra power during times of low reserve. This has the obvious knock-on impacts for O&M and reliability. It is understood that the power supply at Europlatform could be rather limited.

Preliminary validation studies and DNV GL experience have shown that LiDAR devices are capable of exhibiting good reliability, often equalling or exceeding that for conventional meteorological mast measurement systems. However, unlike meteorological mast measurements, LiDAR units typically utilise a single sensor to measure wind speeds at a site and therefore these devices do not have the benefit of inherent redundancy provided by several independent sensors. This, combined with the likelihood of access to offshore platforms being restricted by adverse weather conditions, is likely to delay remedial works should a system experience failure. For that reason a 2nd LiDAR deployment on the same fixed platform is recommended to mitigate such a risk of failure.

Deployment of a platform mounted LiDAR does not require a permitting process, but should of course be negotiated with the platform owners. The installation of a fixed LiDAR on LE Goeree shows that it is possible to come to an agreement with RWS. According to ECN, negotiations to install a fix LiDAR at Europlatform could probably be concluded rather fast. Some arrangements would have to be made to provide power to the LiDAR, but that could be done rather quickly, so that a measurement campaign of 6 months for Borssele is considered feasible.

The option of using a fixed LiDAR is only realistic when an existing platform is already available. In case a dedicated platform needs to build it is likely that a floating LiDAR is more feasible due to the high cost of the platform.

3.3 LiDAR meteorological buoy

The majority of technical risks associated with LiDAR buoys are not unique, but common with platform-mounted LiDAR, namely those regarding measurement accuracy, power supply, operability, reliability, data storage and communications. However, there are some risks and technical concerns specific to LiDAR buoy measurement campaigns, and these are detailed below.

Validation work carried out by LiDAR device manufacturers and the academic community, to date, indicate that leading LiDAR technologies offer comparable levels of accuracy to conventional mast measurements. However, LiDAR wind measurements are still a relatively new field within the wind industry, with *floating* LiDAR wind measurements an even more immature field.

There is an uncertainty associated with the measurement accuracy of any LiDAR device. As with conventional anemometry, this uncertainty can be reduced through the selection of a well-established unit with a proven track-record, along with the specification of suitable calibration and mounting arrangements.

There currently exist no definitive standards for measurements conducted using remote sensing technologies on floating platforms such as LiDAR. DNV GL is aware that IEA best practise guidelines are currently being drafted and it is likely that these will be formalised in the coming years. In the meantime, DNV GL recommends that a pre/post calibration procedure of the floating LiDAR device be carried out.

Installation of the LiDAR device should be such that no overhead obstructions interfere with the laser or cause flow distortion in the measurement cone. This can easily be achieved for floating LiDAR devices which require no supporting structure or lightning finials at or near the measurement heights.

As with all wind measurements, it is important that high quality documentation is maintained regarding the verification, installation and maintenance of the LiDAR device, throughout the measurement campaign.

Prior to the commencement of a monitoring campaign in one of the wind zones, initial factory calibrations of the LiDAR device should be conducted in a controlled environment. Once these tests are passed, an open atmosphere validation against a second reference LiDAR (ideally land-based or platform-based) is undertaken. Then, the following 'best practice' procedure is recommended at for instance IJmuiden-Ver:

- Pre-campaign calibration for 3 months to a high quality nearby offshore meteorological mast;
- Onsite measurement period of at least 1 year (part of which should overlap with the subsequent onsite mast campaign, if there is one);
- Post-campaign calibration for 3 months to the same offshore meteorological mast.

The verification period only needs to be long enough to gather a statistically significant amount of data from each direction sector and wind speed bin. Three months is recommended as a suitable period for such verification.

The post-campaign calibration is recommended primarily because LiDAR remote sensing is a new technology, and its characteristics over long deployment periods (e.g. calibration drift) are relatively unknown. A post-campaign verification will help to quantify and if necessary adjust for any drift in measurements that occurs.

Preliminary validation studies and DNV GL experience have shown that LiDAR devices are capable of exhibiting good reliability, often equalling or exceeding that for conventional meteorological mast measurement systems. However, this level of validation is limited to onshore/platform mounted LiDAR devices and does not take into consideration the more onerous conditions in which any floating unit would have to operate. This is compounded by the fact that unlike meteorological mast measurements, LiDAR units typically utilise a single sensor to measure wind speeds at a site and therefore these devices do not have the benefit of inherent redundancy provided by several independent sensors. This, combined with the likelihood of access to any offshore buoy being restricted due to adverse weather conditions, is likely to delay remedial works should a system experience failure.

One option to mitigate this risk would be to deploy some additional conventional anemometry on the LiDAR buoy. This would provide some level of redundancy, should the LiDAR device itself fail. This will allow any missing data to be ‘patched’ from data recorded from the conventional anemometry (suitably adjusted via correlation analyses). Although this will provide some level of redundancy, the greater the level of ‘patching’ required, the greater the measurement uncertainty. This would also be compounded by the lack of wind speed measurements at multiple heights, which would lead to further uncertainties in characterising the vertical variation of wind speed (wind shear).

For a conventional buoy with LiDAR a permit application needs to be submitted to Rijkswaterstaat – either online or on paper. The application needs to be submitted no later than four weeks ahead of the deployment. Even though not strictly required, it is very important to obtain the informal approval of the Dutch Coastguard beforehand because RWS normally follows the recommendation of the Dutch Coastguard. A lead time of at least 8 weeks should be incorporated in the planning schedule.

3.4 Overview table

Table 3-1 Overview of wind measurement or wind data provision strategies

	Fixed met mast	Fixed LiDAR	Floating LiDAR	Reanalysis date MERRA/ERA/ Harmony
Measurement principle	Traditional cup anemometers	LiDAR anemometry	LiDAR anemometry with or without motion compensation	Virtual weather model data
Reliability	Baseline	Baseline	Under investigation	Standard product
Maturity	Baseline	Baseline	Pre-commercial	Standard product, but under continuous development
Accuracy	2%	2-4%	4-7% (pre-commercial) 2-4% commercial	10%
Implementation requirements	Permit to build and operate (RWS)	Available platform Power supply Agreement with platform operator	Permit to build and operate (RWS)	None
Mobilization time[2]	>1 year	Dependent on agreement with platform operator Limited construction period	2 months for permit Dependent on availability of equipment at manufacturer	None
Costs	10 million EUR	200 kEUR	1 million EUR	10,000 EUR

[2] For RVO.nl all procurements > 134 EUR including VAT will be done by a Public Tender, lead time at least 2-3 months. Any consenting procedures can be done in parallel.

4 MEASUREMENT STRATEGIES FOR WIND ZONES

4.1 Introduction

4.1.1 Measurement strategy

Meteorological measurement campaigns are required to provide quality wind data, so as to minimise uncertainties associated with the prediction of the long-term wind resource, thereby improving confidence in the long-term energy production forecast of a wind farm which is under development.

In order to provide high quality wind data for the wind zones under consideration (Borssele, Hollandse Kust and IJmuiden Ver), DNV GL has undertaken a review of available metrological data in the region. The review has resulted in three potential categories of metrological data which could be used to predict the long-term wind resource;

1. Use of publicly available data including results of NORSEWInD EU project to provide a dependable offshore wind atlas of the North Sea and weather model data including European Reanalysis (ERA) and Modern-Era Retrospective Analysis for Research and Applications (MERRA);
2. Use of publically available metrological data including high quality tall offshore wind measurements in the North Sea and offshore national weather service measurements;
3. Commissioning of new high quality metrological measurements in the Borssele zone, Hollandse Kust Zuid or Hollandse Kust Noord.

For the three potential categories of metrological data which have been identified to predict the long-term wind resource of the wind zones a number of detailed measurement scenarios have been developed for each of the zones. For the scenarios which include the commissioning of new high quality metrological measurements a range of offshore measurement technologies has been proposed by DNV GL including current best practice measurements and new technology which is being brought to market and that is expected to reach maturity over the next 1-3 years.

The measurement technologies considered by DNV GL are summarised below:

- Offshore metrological mast;
- Fix platform mounted LiDAR;
- Floating LiDAR.

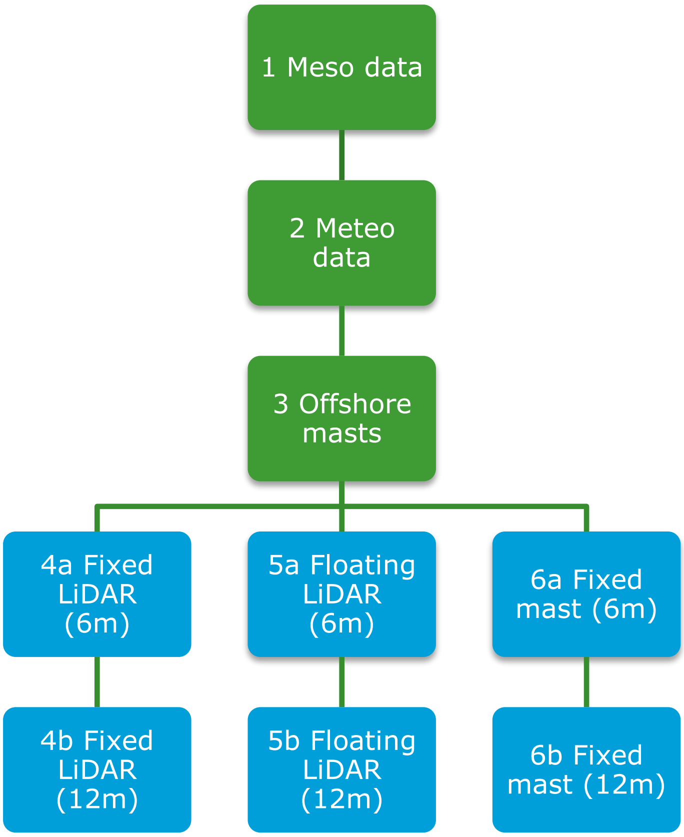


Figure 4-1 Data source and measurement scenarios for uncertainty comparison

Based on the review of available metrological data and the proposed measurement technologies DNV GL proposes the following scenario options (see Figure 4-1) to provide the data required for the prediction of the long-term wind resource and energy production for the Borssele zone:

1. Publicly available data including results of NORSEWInD EU project to provide a dependable offshore wind atlas of the North Sea and weather model data including European Reanalysis (ERA) and Modern-Era Retrospective Analysis for Research and Applications (MERRA);
2. Publicly available data form Europlatform, Goeree LE and Vlakte van de Raan offshore national weather service stations which are located between 30 and 50 km from the Borssele zone. With the additional data detailed in strategy 1;
3. Publicly available high quality tall offshore metrological mast data from the existing IJmuiden and OWEZ masts, which are located between 130 and 140 km from the Borssele zone. With the additional data detailed in strategy 2. This is the first bankable strategy and will be used as a reference when assessing the uncertainties of strategies 4 to 6.
4. New high quality metrological measurements located at Europlatform or Goeree LE offshore platforms utilising a fix platform mounted LiDAR for a period of six months (a) and for a period of 12 months (b), with the additional data detailed in strategy 3. Because ECN has started measurements at Goeree LE in October 2014, one year of data will be available for each of the wind farm zones in time. Therefore this strategy is used as the baseline in all economic analyses.

5. New high quality metrological measurements located at the zone of interest (Borssele, Hollandse Kust Zuid, Hollandse Kust Noord) utilising a floating LiDAR for a period of six months (a) or for a period of 12 months (b) with the additional data detailed in strategy 3;
6. New high quality metrological measurements located at the zone of interest utilising tall offshore metrological mast for a period of six months (a) or for a period of 12 months (b) with the additional data detailed in strategy 3;

DNV GL has assessed these six measurement campaign strategies from the perspective of a future Energy Production Assessment for a project in the wind zones with the aim of providing high quality wind data and to minimise uncertainties associated with the prediction of the long-term wind resource, thereby improving confidence in the long-term energy production of a project in the Borssele zone, or Hollandse Kust zones resulting in a 'Bankable project'. For each of the zones the appropriate wind measurement strategies have been selected and analysed.

As part of the assessment DNV GL has also looked into the value of a restart or refurbishment of the Egmond aan Zee metrological mast. Due to the disturbed wind flow by the existence of OWEZ wind farm, DNV GL believes there is little value in the restart of this mast and it has therefore not been considered this scenario further. In addition, the impact of extension of the measurement period for IJmuiden Ver on the uncertainty was addressed. Because already 3 years of measurement data will be available at the moment of tender the impact is very low and therefore this option has not been included in the financial assessments.

The notion of "bankability" with respect to gathered site wind data may be considered in two ways:

- As a **binary** parameter determining whether a particular dataset and associated analysis is deemed suitable to be considered by lenders in the context of non-recourse project finance in the definition of central and stress case financial modelling. In this instance DNV GL takes the view that a formal, quantitative uncertainty analysis is a pre-requisite for this process with the definition of a distribution of predicted net energy production (P75, P90 etc.) in addition to the central estimate (P50). If in general qualified Technical Advisers have sufficient confidence in the provenance of the source data and understanding of the sources of uncertainty within the analysis, then a formal uncertainty analysis should usually be possible.
- As a **measure** of the quality or perceived accuracy of the energy production assumptions for the project in question. In this instance it is assumed that pre-requisite conditions for a formal uncertainty analysis as described above have been met. Stress case financial modelling using downside estimates (typically P90 energy output) will be one of the ways in which the lender determines the conditions of their offer (most notably loan size and interest rates). Therefore it can be seen that some projects are more "bankable" than others on the basis of such financial modelling. It is within the project developer's power to improve the conditions for financing (or make their project more "bankable") by maximising the P90 prediction via investment in a carefully designed and executed wind monitoring campaign (amongst other measures such as strong warranties etc.).

The potential levels of uncertainty have been quantified in terms of the P90 to P50 ratios of long-term energy production for a 10 year future averaging period. It should be noted that for the purposes of the work reported here, DNV GL has assessed the future uncertainties on a hypothetical basis using the best available site information and nominal assumptions informed by our extensive experience in the field of offshore wind resource and energy production assessment. As such, the values for energy yield and uncertainty thereof provided in this report should be treated as indicative. If engaged to carry out an energy production assessment for the wind farm zones in the future, DNV GL reserves the right to deviate from the values presented in this report, should this be necessary for technical reasons at the time of the assessment. However there is a high certainty in the relative behaviour of the uncertainties against each other.

While DNV GL has strived to estimate uncertainties that reflect engineering best-practice, based on our experience of measurements throughout northern Europe, these values may not necessarily represent the view taken by potential future investors, or their advisers. Furthermore, the intangible perceived risk-profile associated with projects that rely on "remote" measurements can have a significant bearing on investor confidence, over and above the pure analytical results presented in this report.

DNV GL considers it necessary for mast measured wind data to be available for the assessment of meteorological wind turbine design conditions at a wind farm site. The following parameters are of importance when checking site suitability of a wind turbine and informing the design basis for a wind turbine support structure:

a) Mean wind climate;

b) wind speed, frequency distribution & vertical wind shear;

c) Extreme wind climate –wind speed & vertical wind shear;

d) Mean ambient turbulence (further informing design turbulence).

Further objectives of the metrological measurements include the definition of design conditions for wind turbine site-suitability checks, balance of plant design and certification. Therefore, any measurement campaign must meet the data requirements for the above analyses.

4.1.2 Indicative uncertainty assessment

The strategies defined above have been analysed here to assess the potential level of uncertainty associated with a future Energy Production Assessment along with the assumed wind farm information detailed in Section 4.1.3

The uncertainties that have been considered can be categorised as affecting the prediction of either wind speed or energy production. The uncertainties considered have been summed as independent errors, on a root-sum-square basis, to give the total uncertainty in the projected net energy yield. Wind speed dependent uncertainties have been incorporated using a factor of 1.3 for the sensitivity of the annual energy output to changes in annual mean wind speed. This is a nominal assumption based on DNV GL experience on sites with similar wind conditions. The resulting combined uncertainty in net energy production for the project is considered to represent the standard deviation of what is assumed to be a Gaussian process. Based on this assumed distribution, the 90 % probability of exceedance level (P90) is calculated for each discrete candidate option (Figure 4-2).

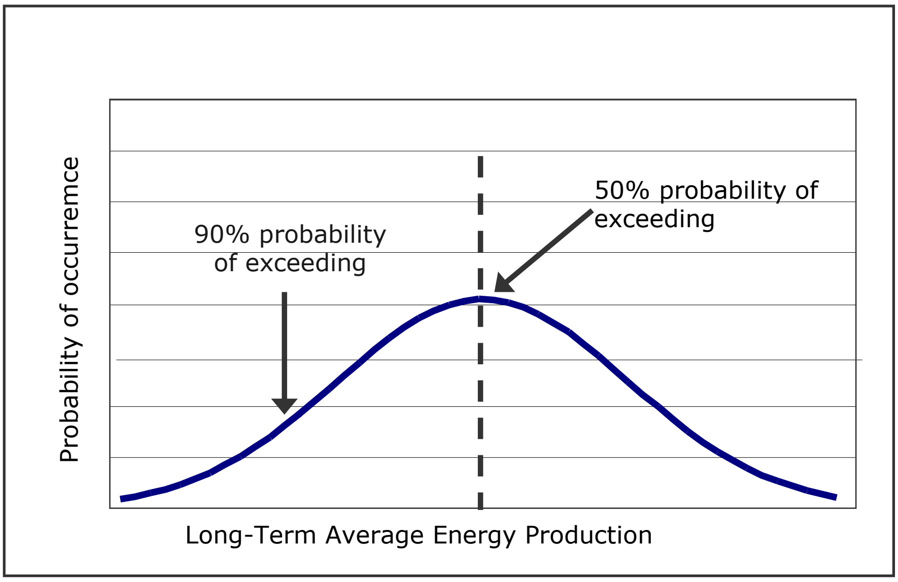


Figure 4-2 Definition of project uncertainty

DNV GL considers four of the six campaign options to be capable of providing favourable and thus "bankable" wind data if executed in accordance with relevant standards and best industry practice - hence fulfilling the binary condition outlined above. The relative merits of these strategies in delivering an assessment with the lowest levels of uncertainty, for improved project financing are discussed below. Based on this assessment, DNV GL has the following conclusions and recommendations (Figure 4-1):

1. DNV GL considers that, of all the strategies assessed, Strategy 1 and 2 are not capable of providing high quality wind data to minimise uncertainties associated with the prediction of the long-term wind resource and energy production. Therefore these two strategies are not capable of providing "bankable" wind data and result in the highest uncertainty as no high quality offshore wind measurements are available in these two strategies;
2. Using available data only (i.e. a combination of strategy 1-3) it is possible to carry out an energy assessment that provides "bankable" wind data for wind farms in the Dutch North Sea area and is considered state-of-the-art for a bankable wind energy assessment.

Strategies 4 to 6 will be investigated in more detail when considering the three wind farm zones.

4.1.3 Impact on project economics

The impact on project economics of the variation in P90/P50 ratios between each of the candidate strategies has been examined through preliminary modelling. The model is subject to the following preliminary assumptions, which are based on the SDE+ -values for 2014. /14/

Table 4-1 Overview of financial parameters used for the baseline calculation

Parameter	Value
Wind farm site capacity	350 MW
Wind turbine technology	6 MW
Total CAPEX	3500 EUR / MW
Total OPEX	100,000 EUR / MW / annum
Total reference energy value	157 EUR / MWh
Net average energy yield (as capacity factor)	4000 MWh / MW
Discount Rate	7.7%
Gearing	65% Equity
Stress parameters	
Average Debt Service Coverage Ratio	1.3 at P90 value
Minimum equity level	30%

In this project DNV GL has used a modified SDE-model that characterises a hypothetical stress-case used by lenders to assess the lender's risk of the expected energy output of the project. Other factors that are influenced by better wind measurements have not been taken into account, such as better input data for design calculations for wind turbines, foundations and wake effects. These data include turbulence, vertical profiles and extreme wind conditions. Quantification of these effects is beyond the scope of this project.

For this, the P90 energy yield assumption is used to drive the gearing (debt/equity ratio) of the project. The gearing of the project is selected in such a way that the average Debt Service Coverage Ratio (DSCR) over the project lifetime is equal to 1.3 at an energy yield that corresponds with the P90 exceedance level.[3] The mentioned value has been estimated from current market practice seen in past projects. However this factor may vary also with other parameters and depend on the lenders appetite on offshore risk or risk understanding.

With the selected gearing ratio the Cost of Energy (or Basisbedrag) was calculated for each measurement strategy. Since strategies 1 and 2 were qualified as non-bankable, they are not included in the table. It shows that the influence of the measurement strategies is approximately 0.1 Eurocent/kWh.

The change in Net Present Value (Delta NPV) has been estimated for each measurement relative to the Baseline (defined below), for a 15 year operational lifetime. For a given candidate strategy, the Cost of Energy is calculated using the SDE-model under the conditions for DSCR=1.3, as mentioned above.

The NPV of the revenues is calculated according to

$$NPV = \sum_{n=1}^{15} \frac{AER}{(1+DR)^{(n+1)}}$$

3 DSCR is a parameter that is used by lenders to calculate the ability of the project to fulfil its repayment duties to the banks. DSCR is the ratio between free cashflows and the total of interest and the loan term (the debt service).

Where

$$AER\ (Annual\ Equity\ Return) = \left(Energy\ \ Revenue - OpEx\right) \times (1 + ER)^{(n-1)} \times (1 - TR)$$

The cost-benefit value of the measurement strategies was derived by using the abovementioned NPV and subtracting the cost of the measurement campaign.

It should be noted that the choice of a discount ratio is not trivial. The government uses a net cash flow system and looks at total expenditures without discounting, while companies will use a commercial discount ratio. Therefore in this report two different values are used, i.e. zero for government cash flows and 7.7% as the value that is commonly used in the SDE offshore calculations.

The **baseline** for the economic calculations includes all publicly available data, i.e. measurements from offshore met masts, meso-scale weather data and 1 year of fixed LiDAR data from LE Goeree.

Early October 2014, ECN installed a LiDAR at LE Goeree. This data will be publicly available and can therefore be used by future bidders as input.

Note: The quality of the Energy Assessment is one factor out of several to assess the "financial risk" connected to an offshore project. The assessment undertaken in this report only considers this risk, neglecting the variation of other influencing factors. In a "real project" the influence of other risks could overrule the risk connected to the energy assessment. Thus all evaluations are best seen relatively to each other, where the absolute values have been derived assuming standard project setup.

4.2 Borssele wind zone monitoring strategy

4.2.1 Introduction

The Borssele wind farm zone has a total planned capacity of 1,400 MW. It will be tendered in 2 parcels of 700 MW each. The first parcel (Borssele 1) will be tendered starting December 2015. The second parcel (Borssele 2) is planned to be tendered starting December 2016.

Given the limited time until the start of the first tender round and the lead times involved in deploying new measurements, the analysis has been split in 2 parts, i.e. Borssele 1 and Borssele 2. This analysis will be presented below.

4.2.2 Proposed meteorological monitoring strategies

Based on the review of available metrological data and the proposed measurement technologies DNV GL proposed options to provide the data required for the prediction of the long-term wind resource and energy production for the Borssele 1 zone and for the Borssele 2 zone.

For Borssele 1 and 2 the following measurement strategies were considered for the economic analysis:

A. The uncertainty reference is a combination of measurement strategies 1, 2, and 3, i.e. mesoscale modelling data (1), existing meteo data from existing offshore weather service stations (2), high quality measurements from tall offshore metrological masts OWEZ and IJmuiden Ver (3);

B. 12 months of fix LiDAR data from Goeree LE (4b);

C. New high quality metrological measurements located at the Borssele zone utilising a floating LiDAR for a period of six months (a) and for a period of 12 months (b) combined with the additional data already available for the baseline. For Borssele 1, option (a) is considered feasible, while for Borssele 2 option (b) it is assumed that the measurements with the floating LiDAR will be continued to complete a full year. This has been considered in this assessment;

D. New high quality metrological measurements located at the Borssele zone utilising a tall offshore metrological mast for a period of 1 year with the additional data detailed in the baseline.

Because the data from strategy B will be made available as public data, a combination of strategies A and B defines the baseline for the economic analysis.

Strategy D has been included for reference only. It shows the energy assessment uncertainty that could be achieved ideally. However, given the short lead time to the tenders for the Borssele zones and the mobilization time of at least 1.5 years, deployment of a fixed mast is not feasible. Therefore there was no need for a further financial assessment of strategy C.

The Borssele area is located close to the Belgian border. On the Belgian side offshore wind farms are operational already, while more wind farms are planned for the future. DNV GL have assumed that wind measurements are planned sufficiently downstream of these wind farms that wind farm wakes will have a negligible effect on the measurements. Therefore it is not considered necessary to perform additional measurements to the West of the Borssele zone in order to make wake free measurements.

4.2.3 Assessment of Borssele wind farm zone campaigns

Figure 4-3shows the overall indicative uncertainty for each of the measurement campaign strategies A to D. Detailed results of the analysis can be found in Appendix B.

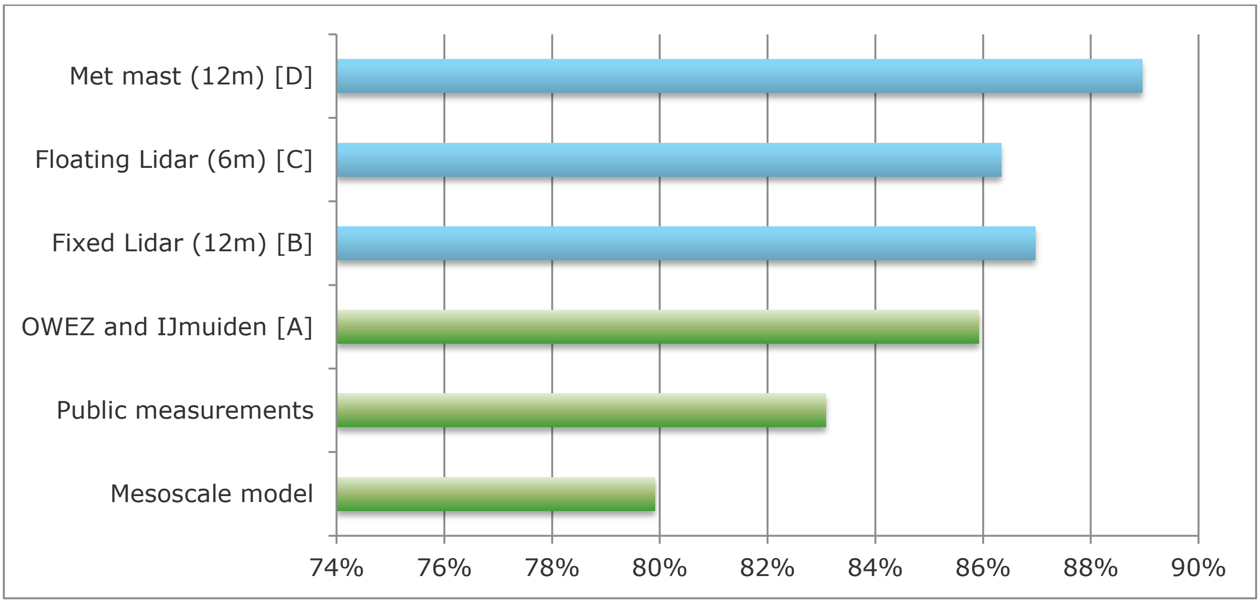


Figure 4-3 P90/P50 values for Borssele 1 location. Blue indicates new measurement campaigns.

For the new measurement campaigns in comparison with reference scenario A, Figure 4-3 clearly shows that

- Mesoscale models and use of public measurements are not capable of providing results with sufficient uncertainty. Therefore they are only used in conjunction with the other measurement campaigns;
- As mentioned before using publicly available data from OWEZ and IJmuiden in combination with public metrological station data and mesoscale modelling provides results that have an uncertainly level sufficiently to be acceptable for bankable report;
- Borssele 1 wind farm zone benefits considerably from 12 months of fixed LiDAR measurements on Goeree LE by decreasing the uncertainty in the energy yield assessments (P90/P50=87.0%);
- A floating LiDAR campaign of 6 months decreases the uncertainty compared to reference scenario A (P90/P50=86.3%), but this improvement is less than the fixed LiDAR campaign. The improvement in the spatial correlation is outweighed by the uncertainty due to the shorter measuring period;
- A fixed mast on site offers the most accurate level of energy yield assessment, but this is option is not available due to long deployment times. Therefore, this option will not be considered in the economic assessment.

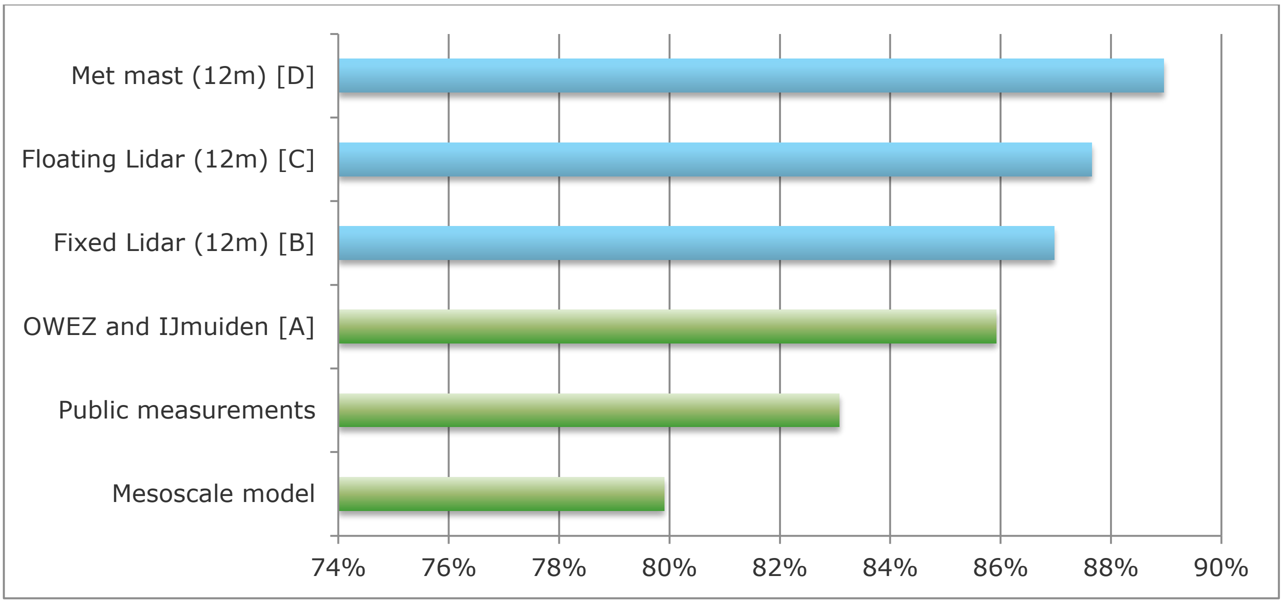


Figure 4-4 P90/P50 values for Borssele location. Blue indicates new data.

Figure 4-4 shows the result for Borssele 2 wind farm zone. As mentioned the difference with Borssele 1 is given by the fact that the floating LiDAR campaign has been continued to complete a full year of measurements.

In addition to the remarks made above the following remarks can be made regarding Borssele 2 wind farm zone:

- Borssele 2 wind farm zone benefits considerably from 12 months of fixed LiDAR measurements on Goeree LE by decreasing the uncertainty in the energy yield assessments (P90/P50=87.0%);

- Borssele 2 benefits considerably from a 12 months floating LiDAR measurement campaign on site (P90/P50=87.7%). This value is higher than that of the fixed LiDAR on Goeree LE;
- Although the available deployment time for a fixed mast is one year longer, deployment of a fixed metrological mast is still not considered feasible and is not further taken into account for the financial analysis.

4.2.4 Predicted impact on project economics for the Borssele zone

Table 4-2 Cost – benefit analysis of measurement strategies for Borssele wind farm zones.

Strategy (additional to baseline)	Baseline [B]	Floating LiDAR (6m) [C]	Floating LiDAR (12m) [C]
P90/P50	87.0%	87.0%	87.7%
CoE (€ct/kWh)	15.89	15.89	15.84
Cost-benefit (k€, 0% discount)			
Benefit relative to baseline		0	18.7
Cost of measurement strategy		0.8	1.4
Cost Benefit		-0.8	17.3
Cost-benefit (k€, 7.7% discount)			
Benefit relative to Base Line		0	10.9
Cost of measurement strategy		0.8	1.4
Cost Benefit		-0.8	9.5

Table 4-2 presents indicative uncertainties for each of the relevant candidate strategies under review. Full results of the assessment can be found in Annex B.

- **Baseline strategy (A+B)**
  Campaign costs include installation and operation of a fixed LiDAR at Goeree LE of 12 months. Since this budget has already been allocated, cost have been considered zero;
- **Floating LiDAR (C)**
  It is assumed that a floating LiDAR will be rented for a period of the period of the measuring campaign (6 months for Borssele 1 and 12 months for Borssele 2). This includes also the cost for installation, marine operation and data handling;
- **Fixed Met Mast (D)**
  Installation of a fixed mast is not possible due to long lead times. No financial cost-benefit calculation has been made.

It should be noted that it is still difficult to accurately predict campaign costs for floating LiDAR devices, as their costs are not currently well understood and are likely to change rapidly over the coming years, as the technology matures. For this study we have assumed costs of devices which have just entered the market, being in the pre-commercial stage. However, it is possible that suppliers are keen to demonstrate their devices at favourable conditions, as it offers an opportunity to demonstrate robustness and accuracy after the initial test period.

Meteorological monitoring campaign costs have historically been driven by fluctuating market forces, most notably by installation vessel supply. Consequently the costs provided as part of this study should be viewed primarily in the context of differentiating between candidate strategies, rather than as absolute values.

The model calculations show that more accurate measurements result in a reduction of the cost of capital due to a higher debt/equity gearing. This is reflected in Table 4-2 where a higher P90/P50 value results in a lower Cost of Energy.

4.2.5 Conclusion and recommendations for Borssele wind farm zone

For Borssele 1 DNV GL concludes the following:

- The expected financial benefit of a one year fixed LiDAR measuring campaign compared to the reference situation ([A]) is estimated at 17 million EUR. In hindsight therefore it can be considered a good decision to implement these measurements and make them available for public use;
- A floating LiDAR measurement campaign of 6 months [C] does not reduce the energy yield uncertainty compared to the baseline situation. Hence, no financial benefit is expected from this measurement strategy for Borssele 1.

For Borssele 2 DNV GL concludes:

- Installation of a floating LiDAR is possible for a period of at least 12 months;
- A measuring strategy using a floating LiDAR in the Borssele wind farm zone reduces the energy yield uncertainty compared to the baseline situation, resulting in a lower expected Cost of Energy (0.05 €/kWh);
- The Net Value of this investment amounts to 17 million Euro (at 0% discount rate).

DNV GL therefore recommends implementing a measurement campaign using a floating LiDAR in Borssele wind farm zone in order to obtain at least 12 months of wind speed data for the Borssele 2 tender.

4.3 Hollandse Kust Zuid

4.3.1 Introduction

The wind farm zone Hollandse Kust Zuid has a total planned capacity of 1,400 MW. Parcels of 700 MW each are expected to be tendered in 2017 and 2018. Because there is sufficient time to prepare for onshore measurements, DNV GL has not made a distinction between the parcels and considered Hollandse Kust Zuid as one wind farm zone. The financial analysis has been made for a total of 1400 MW installed power.

4.3.2 Proposed meteorological monitoring strategies

For Hollandse Kust Zuid, it is considered appropriate to adopt the same strategies as for Borssele and Hollandse Kust Noord. In this way it is possible to allow the benefits to each zone to be reviewed and the total benefit of each strategy across all the three zones to be considered.

For Hollandse Kust Zuid it was assumed that campaigns have a minimum length of 12 months. The tendering scheme allows for sufficient time to prepare and execute the measurements. Since it is not recommended to undertake a bankable energy assessment of less than 12 months of data, shorter measuring periods have not been considered.

Therefore the analysis includes the following strategies for Hollandse Kust Zuid:

A. The uncertainty reference is a combination of measurement strategies 1, 2 and 3 i.e. mesoscale modelling data (1), existing meteo data from existing offshore weather service stations (2), high quality measurements from tall offshore metrological masts OWEZ and IJmuiden Ver (3);

B. 12 months of fix LiDAR data from Goeree LE (4b);

C. New high quality metrological measurements located at the Hollandse Kust Zuid zone utilising a floating LiDAR for a period of 12 months combined with the additional data already available the baseline;

D. New high quality metrological measurements located at the Hollandse Kust Zuid zone utilising a tall offshore metrological mast for a period of 12 year with the additional data detailed in the baseline.

Because the data from strategy B will be made available as public data, a combination of strategies A and B defines the baseline for the economic analysis.

4.3.3 Assessment of Hollandse Kust Zuid wind farm zone campaign

Figure 4-5 shows the overall indicative uncertainty for each of the measurement campaign strategies A to D. Detailed results of the analysis can be found in Appendix B.

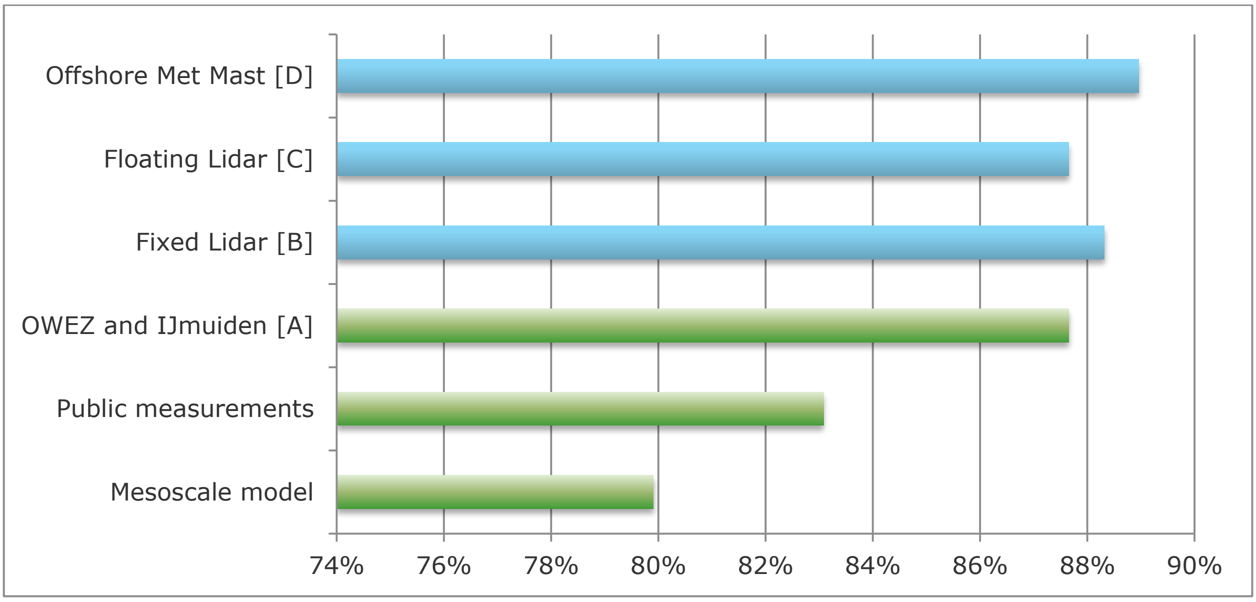


Figure 4-5 P90/P50 values for Hollandse Kust Zuid. Blue indicates new data.

When comparing the new measurement campaigns with the existing data from scenario A, Figure 4-5 clearly shows that:

- Mesoscale models and use of public measurements are not capable of providing results with sufficient uncertainty. Therefore they are only used in conjunction with the other measurement campaigns;

- Publicly available data from OWEZ and IJmuiden Ver in combination with public metrological station data and mesoscale modelling (strategy A) provides an energy assessment that is considered bankable. Due to the vicinity of OWEZ met mast to the wind farm zone the uncertainty level is low at a P90/P50-value of 87.7%;
- Hollandse Kust Zuid wind farm zone benefits from 12 months of fixed LiDAR measurements on Goeree LE [B] and shows a higher value of P90/P50 (88.3%) than reference strategy A;
- A floating LiDAR campaign of 12 months [C] does not improve the uncertainty level (P90/P50=87.7%). Although the floating LiDAR is located on site, a floating LiDAR still being in pre-commercial stage causes a higher uncertainty level compared to strategies A and B, hence there is no additional value to apply this strategy;
- A fixed mast on site [D] offers the most accurate level of energy yield assessment (P90/P50=89.0%). As mentioned above, there is still sufficient time to develop this option and in contrast to the situation in Borssele wind farm zone this option is considered for economic impact.

4.3.4 Predicted impact on project economics for Hollandse Kust Zuid wind farm zone

Table 4-3 Cost – benefit analysis of measurement strategies for Hollandse Kust Zuid

Strategy (additional to baseline)	Baseline	Floating LiDAR (12m)	Met mast on site (12m)
P90/P50 ratio	88.3%	88.3%	89.0%
CoE (€ct/kWh)	15.84	15.84	15.76
Cost-benefit (k€, 0% discount)			
Benefit relative to Base Line		0	35.2
Cost of measurement strategy		1.4	10.0
Cost Benefit		-1.4	25.2
Cost-benefit (k€, 7.7% discount)			
Benefit relative to Base Line		0	20.5
Cost of measurement strategy		1.4	10.0
Cost Benefit		-1.4	10.5

Table 4-3 presents the cost benefit analysis for each of the relevant candidate strategies for Hollandse Kust Zuid. Full results of the assessment can be found in Annex B.

For the cost of the measuring campaigns we have made the following assumptions:

- **Baseline strategy (A+B)**
  At the time of the Hollandse Kust Zuid tender data from Goeree LE is already available in the public domain from previous measurements. Cost for this strategy have been considered zero;
- **Floating LiDAR (C)**
  It is assumed that a floating LiDAR will be rented for a period of 12 months. This includes also the cost for installation, marine operations and data handling;
- **Fixed Met Mast (D)**
  In this case it is assumed that a fixed met mast will operate for a period 12 months at Hollandse Kust Zuid wind farm zone. The full CAPEX (10 MEUR) of the mast has been used as investment in year 0.

The financial analysis underlines the conclusion in the uncertainty analysis. Option 4 using a fixed LiDAR on EPF or LEG provides the highest financial value. The vicinity of the platforms causes that use of floating LiDAR doesn’t give additional value for the Hollandse Kust Zuid locations. A fixed Met Mast on site represents high investment costs and requires a considerable amount of preparation. Nevertheless, this strategy (D) provides the highest economic value in the cost benefit analysis.

4.3.5 Conclusions and recommendations for Hollandse Kust Zuid wind farm zone

For Hollandse Kust Zuid DNV GL concludes the following:

- Hollandse Kust Zuid benefits from the same fixed platform mounted LiDAR installed Goeree LE. The expected financial benefit of a one year fixed LiDAR measuring campaign compared to the reference situation ([A]) is estimated at 21 million EUR. In hindsight it can be considered a good decision to implement these measurements and make them available for public use;
- A floating LiDAR measurement campaign of 12 months [C] does not reduce the energy yield uncertainty compared to the baseline situation. Hence, no financial benefit is expected from this measurement strategy for Hollandse Kust Zuid. Moreover the cost of the floating LiDAR campaign cannot be shared over Hollandse Kust Zuid and Hollandse Kust Noord, which means that 2 devices need to be installed, or the same device needs to be moved;
- Installation of a fixed mast at Hollandse Kust Zuid wind farm zone further decreases the uncertainty compared to the other wind farm strategies. The Net Value of this investment amounts to 17 million Euro (at 0% discount rate).

DNV GL therefore recommends implementing the following measurement campaign strategy

- Use publicly available fixed LiDAR data from Goeree LE in combination with wind mapping and publicly available historical data;
- Not to install a floating LiDAR in Hollandse Kust Zuid wind farm zone;
- To consider installation of a fixed Met Mast on site taking into account the additional economic value on the one hand and the extensive preparations needed on the other hand.

4.4 Hollandse Kust Noord

4.4.1 Introduction

The wind farm zone Hollandse Kust Noord has a total planned capacity of 700 MW. It is assumed that this parcel will be tendered in 2019. Hollandse Kust Noord is located very close to the existing wind farms Prinses Amalia and wind farm Egmond aan Zee (OWEZ).

The analysis for the Hollandse Kust Noord is presented below.

4.4.2 Proposed meteorological monitoring strategies

For Hollandse Kust Zuid, it is considered appropriate to adopt the same strategies as for Borssele and Hollandse Kust Noord. In this way it is possible to allow the benefits to each zone to be reviewed and the total benefit of each strategy across all the three zones to be considered.

For Hollandse Kust Noord it was assumed that campaigns have a minimum length of 12 months. The tendering scheme (2019) allows for sufficient time to prepare and execute the measurements. Since it is not recommended to undertake a bankable energy assessment of less than 12 months of data, shorter measuring periods have not been considered.

Therefore the analysis includes the following strategies for Hollandse Kust Noord:

A. The uncertainty reference is a combination of measurement strategies 1, 2 and 3 i.e. mesoscale modelling data (1), existing meteo data from existing offshore weather service stations (2), high quality measurements from tall offshore metrological masts OWEZ and IJmuiden Ver (3);

B. 12 months of fix LiDAR data from Goeree LE (4b);

C. New high quality metrological measurements located at the Hollandse Kust Noord zone utilising a floating LiDAR for a period of 12 months combined with the additional data already available the baseline;

D. New high quality metrological measurements located at the Hollandse Kust Noord zone utilising a tall offshore metrological mast for a period of 12 year with the additional data detailed in the baseline.

Because the data from strategy B will be made available as public data, a combination of strategies A and B defines the baseline for the economic analysis.

It should be noted that OWEZ metrological mast is very near the projected wind farm zone Hollandse Kust Noord and will be considered an onsite measurement.

4.4.3 Assessment of Hollandse Kust Noord wind farm zone campaign

Figure 4-6 shows the overall indicative uncertainty for each of the measurement campaign strategies A to D. Detailed results of the analysis can be found in Appendix B.

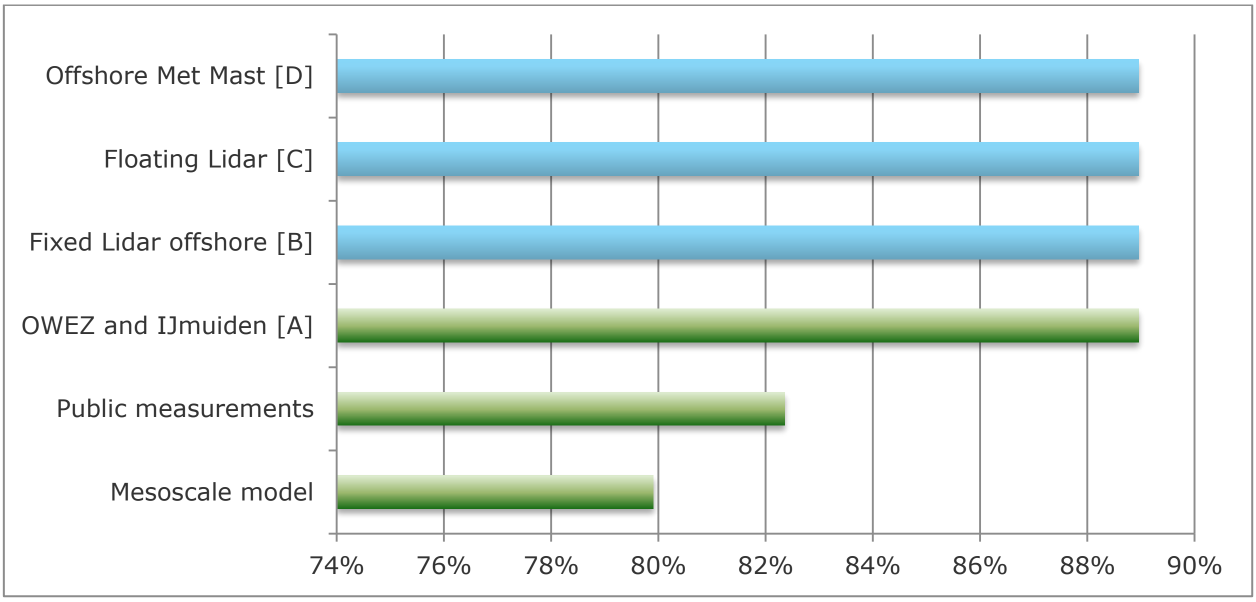


Figure 4-6 P90/P50 values for Hollandse Kust Noord. Blue indicate new data.

When comparing the new measurement campaigns with the existing data from scenario A. Figure 4-6 clearly shows that:

- Mesoscale models and use of public measurements are not capable of providing results with sufficient uncertainty. Therefore they are only used in conjunction with the other measurement campaigns;

- Publicly available data from OWEZ and IJmuiden Ver in combination with public metrological station data and mesoscale modelling (strategy A) is considered a 12 months fixed mast measuring campaign with a value of P90/P50=89.0%. This is the same value that is found for a dedicated metrological mast on site (strategy D);
- Measurements from the fixed LiDAR at Goeree LE (B), a floating LiDAR at Hollandse Kust Noord site (C) or an onsite metrological met mast (D) do not improve the uncertainty already obtained using OWEZ and IJmuiden Ver data (A). Therefore there is no additional benefit in adopting these measurement campaign strategies.

4.4.4 Predicted impact on project economics for Hollandse Kust Noord wind farm zone

Table 4-4 Cost – benefit analysis of measurement strategies for Hollandse Kust Noord

Strategy (additional to baseline)	Baseline	Floating LiDAR (12m)	Fixed Met mast (12m)
P90/P50 ratio	89.0%	89.0%	89.0%
CoE (€ct/kWh)	15.76	15.76	15.76
Cost-benefit (k€, 0% discount rate)			
Benefit relative to Base Line	0	0	0
Cost of measurement strategy		1.4	10.0
Cost Benefit		-1.4	-10.0
Cost-benefit (k€, 7.7% discount)	0		
Benefit relative to Base Line		0	0
Cost of measurement strategy		1.4	10.0
Cost Benefit		-1.4	-10.0

Table 4-4 presents the cost benefit analysis for each of the relevant candidate strategies for Hollandse Kust Noord. Full results of the assessment can be found in Annex B.

For the cost of the measuring campaigns we have made the following assumptions:

- **Baseline strategy (A+B)**
  At the time of the Hollandse Kust Noord tender data from Goeree LE is already available in the public domain from previous measurements. Cost for this strategy have been considered zero;
- **Floating LiDAR (C)**
  It is assumed that a floating LiDAR will be rented for a period of 12 months. This includes also the cost for installation, marine operations and data handling;
- **Fixed Met Mast (D)**
  In this case it is assumed that a fixed met mast will operate for a period 12 months at Hollandse Kust Zuid wind farm zone. The full CAPEX (10 MEUR) of the mast has been used as investment in year 0.

The financial analysis underlines the conclusion in the uncertainty analysis. The uncertainty level (reflected in the P90/P50 values) is already at the reference level of 89.0%. The other measurement campaign strategies (B, C and D) all have a higher uncertainty level and therefore Hollandse Kust Noord does not benefit from them. However, they require investment and operational costs. Therefore the Net Present Value of these campaigns is negative. Therefore, DNV GL would recommend not deploying such campaigns for Hollandse Kust Noord.

4.4.5 Conclusions and recommendations for Hollandse Kust Noord wind farm zone

For Hollandse Kust Noord DNV GL concludes the following:

- For Hollandse Kust Noord the existing measurements from the OWEZ metrological mast can be considered as onsite measurements. Therefore, the uncertainty level for this wind farm zone is considered already low and equals the level when deploying a new fixed metrological mast onsite;
- As the reference value is already obtained in the baseline, it is not expected that Hollandse Kust Noord wind farm zone will benefit from the fixed LiDAR measurements at Goeree LE in terms of improved uncertainty or economic benefits with respect to a lower Cost of Energy;
- For the same reason it is not beneficial to install a floating LiDAR onsite. The uncertainty found for a floating LiDAR campaign of 12 months is not expected to be lower than the value found in the baseline;
- Installation of a fixed mast at Hollandse Kust Noord is not considered to lower the uncertainty compared to the baseline.

DNV GL therefore recommends implementing the following measurement campaign strategy to obtain data for wind resource assessments:

- Rely on publicly available data to estimate the available wind resource, i.e. historical data from weather stations, metrological mast at IJmuiden-Ver and OWEZ, fixed LiDAR data from Goeree LE and wind mapping;
- Not execute a floating LiDAR measuring campaign in Hollandse Kust Noord wind farm zone;
- Not install a fixed metrological mast in the wind farm zone.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Table 5-1 Assessment of measurement strategies for wind farm zones

	Wind zone	Borssele 1	Borssele 2	Hollandse Kust Zuid	Hollandse Kust Noord
Baseline	Existing met data (LEG, EPF ,OWEZ, IJmuiden) Mesoscale models (MERRA, ERA, Harmonie) Fixed LiDAR LEG, EPF	+	+	++	++
1	Floating LiDAR on location	O	++	-	-
2	Fixed mast on location	--	--	+	--

1. Traditional fixed measuring offshore metrological masts are still the reference for offshore wind measurement. However, they suffer from long deployment times due to long permitting processes, design and tendering process;

2. Fixed LiDARs mounted on existing platforms are an attractive option to obtain reliable and accurate wind resource data. Deployment time is mainly dependent on obtaining permission from the platform owner. Since October 2014 ECN has installed a LiDAR on Goeree LE platform;

3. Europlatform is another option for installation of a fixed LiDAR. For this option permission has to be granted by the platform owner (Rijkswaterstaat). This option is attractive because (i) it can serve as a backup for the measurements at Goeree LE, and (ii) it provides insight in the wind speed gradient near the Dutch coast;

4. Floating LiDAR equipment is on the path to commercial application. It is expected that several floating LiDARs will enter the pre-commercial stage making them suitable to be used in bankable wind assessment reports;

5. Refurbishment of OWEZ offshore metrological mast is not beneficial from an energy assessment point of view. Already one year of reliable, undisturbed measurements is available. Disturbanceof the wind speed measurements by OWEZ windfarm is the cause for the fact that this mast is no longer of use for energy assessments.

6. Extension of IJmuiden Ver met mast beyond 2015 is not necessary from an energy assessment perspective. IJmuiden met mast is the only mast in the Dutch North Sea area that is exposed to all wind directions; it has high accuracy wind measurements, according to IEC standards; measurements can be used for pre- and post-verification of floating LiDAR equipment; it has the potential to become a long, stationary historical record for offshore energy assessment and be a reference point for offshore wind atlases to be developed;

7. Borssele 1, Borssele 2 and Hollandse Kust Zuid wind farm zone benefit considerably from fixed LiDAR measurements at Goeree LE that started in October 2014;

8. For Hollandse Kust Noord OWEZ met mast serves de facto as an onsite mast, therefore this zone does not from the fixed LiDAR measurements;

9. Borssele 2 can benefit considerably from a 12 month onsite floating LiDAR-campaign. It is expected that for Borssele 1 a floating LiDAR can be used for a period of 6 months as a consequence of the required tendering process and measurement preparations. Therefore the value of floating LiDAR measurements for Borssele 1 is limited;

10. Deployment of a floating LiDAR at Hollandse Kust or Noord does not improve the energy assessment uncertainty, because of the availability of highly reliable measurements from the fixed LiDAR at Goeree LE, or data from OWEZ metrological mast;

11. There is potential benefit to install a fixed metrological mast at Hollandse Kust Zuid as it is the option with the lowest uncertainty levels compared to the alternative measuring strategies.

5.2 Recommendations

1. Because the OWEZ metrological offshore mast has already one year of high quality undisturbed data available, it is DNV GL's opinion that such a restart of this mast should not be advised, as this would not yield additional data that adds value to a bankable wind assessment report;

2. DNV GL advises not to extend the operation of IJmuiden Ver offshore metrological mast beyond the end of 2015 for energy assessment purposes. DNV GL remarks that the existing data set is already more than sufficient as a basis for bankable reports and that from an energy yield assessment perspective there is no need to extend the measuring period beyond the end of 2015. However, in the interviews conducted by DNV GL there was consensus that the IJmuiden Met mast is a valuable data source also for other purposes than energy yield assessments, and it should be seriously considered to continue the measurements beyond the present campaign end;

3. DNV GL proposes to investigate further the possibilities to install a fixed LiDAR at Europlatform as soon as possible. In this way it will be possible to establish redundancy for other measurement campaigns and to gain more insight in the wind speed and direction gradient near the shore. Issues to be solved are (i) agreement with the platform owner, (ii) power supply, (iii) operation of the LiDAR;

4. Given the fact that there is a considerable economic benefit in early installation of a floating LiDAR in the Borssele wind farm zone, DNV GL recommends to start the procurement for data collection using an onsite floating LiDAR as soon as possible in order to obtain the longest possible wind data record for Borssele 1 and Borssele 2. DNV GL recommends focusing the procurements process on data availability and data quality. As a minimum the floating LiDAR to be used should be at least in the pre-commercial stage in order to provide bankable data.

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APPENDIX A: AVAILABLE MET MASTS

#	KNMI nr	Location	Data since	Lat/Lon	Type of station	Information available at	Notes		
1	252	K-13-A	1980	53°13'01.00"N 3°13'12.00"E	KNMI offshore unmanned automatic meteostation	geoservices rijkswaterstaat	Mast is 40 m above platform, disturbance <2-8%, measurements since 1976	Regional Basic Synoptic Station	
2	254	Meetpost Noordwijk	1990-2006	52°16'00.00"N 4°18'00.00"E	KNMI offshore unmanned automatic meteostation	geoservices rijkswaterstaat	Wind sensor 9 m above deck of platform, on edge (25m diameter platform, measurements since 1990, disturbance 0-10%. Removed in 2006?	Regional Basic Synoptic Station	52°16'26"N
3	312	Oosterschelde	1982	51°46'00.00"N 3°37'00.00"E	Precipitation station	geoservices rijkswaterstaat	Data is a bit odd (small z0), measurements since 1982		
4	313	Vlakte vd Raan	1991	51°30'00.00"N 3°15'00.00"E	KNMI offshore unmanned automatic meteostation	geoservices rijkswaterstaat			
5	320	Goeree LE	1981	51°56'00.00"N 3°40'00.00"E	KNMI offshore unmanned automatic meteostation	geoservices rijkswaterstaat	Sensors around 15m above deck, but relatively close to the tower. Measurements since 1981	Regional Basic Synoptic Station	51°55'33"N
6		**Goeree LE (fixed LiDAR)**	planned Oct 2014	51°56'00.00"N 3°40'00.00"E	ECN realized				
7	321	Europlatform	1983	51°59'55.00"N 3°16'35.00"E	KNMI offshore unmanned automatic meteostation	geoservices rijkswaterstaat	Sensors 10 m above platform, measurements since 1983	Regional Basic Synoptic Station	
8		Europlatform (fixed LiDAR)	recommended	51°59'55.00"N 3°16'35.00"E					
9		OWEZ	2005	52°36'22.90"N 4°23'22.70"E	Offshore wind mast	www.noordzeewind.nl, eg http://www.noordzeewind.nl/wp-content/uploads/2012/02/OWEZ_R_121_20080701_20081231_wind_resource_2008_2.pdf			
10		IJmuiden Mast	2011	52°50'53.512"N 3°26'08.317"E					
11	*nr 06239*	*F/03*	*1994*	*54°51'00"N 4°44'00"E*			*Large station: must give large disturbance, maesurements in 1994*		
12	*285*	*Huibertgat*	*1981*						
13		*FINO-1*	*2004*	*54°01' N 06°35' E*	*Offshore wind mast*	*FINO website*			
14		Center Borrsele		51°41'60.00"N 2°59'42.00"E					

APPENDIX B: RESULTS OF UNCERTAINTY ASSESSMENT

Table 6-1 Results for Borssele wind zone

Monitoring Strategy	Strategy 1	Strategy 2	Strategy 3	Strategy 4a	Strategy 4b	Strategy 5a	Strategy 5b	Strategy 6a	Strategy 6b
Description	Public wind maps and virtual weather model data	Public measurements	OWEZ and IJmuiden	Fixed LiDAR offshore platform	Fixed LiDAR offshore platform	Floating LiDAR centre of site for stage 2 device with pre-deployment validation against offshore met mast	Floating LiDAR centre of site for stage 2 device with pre-deployment validation against offshore met mast	Offshore Met Mast	Offshore Met Mast
Notes	Assume some basic high level validation of weather model data	Assumes wind mapping	Assumes wind mapping and 24 months of data	Assumes wind mapping and 6 months data	Assumes wind mapping and 12 months data	Assume 6 months	Assume 12 months	Assume 6 months	Assume 12 months
Improvements to reduce uncertainty	Jump straight to Strategy 2 or 3	Jump straight to Strategy 3 using tall mast data	None	6 months of LiDAR data or two LiDARs on both Goeree LE and Europlatform	12 months of LiDAR data or two LiDARs on both Goeree LE and Europlatform	6 months of LiDAR data	12 months of LiDAR data	None	None
WMC Start Date	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Years of Wind Data	n/a	n/a	2,0	0,5	1,0	0,5	1,0	1,0	1,0
Assumed Mast Height [m MSL]	n/a	n/a	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Uncertainty Assessment Data									
Years of Primary Data	0,0	0,0	2,0	0,5	1,0	0,5	1,0	0,5	1,0
Years of Reference Data	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0	10,0
Energy Sensitivity Ratio	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3	1,3
Assumed Hub-Height [m]	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
Data sources used									
Primary Data Source	virtual weather model data	Europlatform	OWEZ and Ijmiden	Fixed LiDAR	Fixed LiDAR	Floating LiDAR	Floating LiDAR	Offshore Met Mast	Offshore Met Mast
Secondary Data Source	Public wind map	Goeree LE / virtual weather model data	See Strategy 2	See Strategy 3	See Strategy 3	See Strategy 3	See Strategy 3	See Strategy 3	See Strategy 3

Uncertainties									
Wind Speed	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**
Anemometer Accuracy	10,0	4,0	2,0	0,0	0,0	0,0	0,0	2,0	2,0
LiDAR Accuracy	0,0	0,0	0,0	2,5	2,5	4,0	4,0	0,0	0,0
Flow Distortion	0,0	4,0	2,0	1,0	1,0	0,0	0,0	1,0	1,0
Period Representing Long-Term	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9
Wind Flow Modelling – Vertical	0,0	4,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Wind Flow Modelling – Horizontal	1,0	4,0	**5,0**	**4,0**	**4,0**	**1,0**	**1,0**	**1,0**	**1,0**
Correlation to Reference	0,0	0,0	2,0	4,0	2,5	4,0	2,5	4,0	2,5
Correlation to Reference (Weighted)	0,0	0,0	1,6	3,8	2,3	3,8	2,3	3,8	2,3
Consistency of Reference Source	**0,0**	**0,0**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**	**0,9**
Energy									
Wake Calculation (Internal + External)	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0
Frequency Distribution	5,0	4,0	3,0	3,0	2,0	3,0	2,0	3,0	2,0
Power Curve	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0
Project Availability	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0	3,0
Future Wind Variability (10year)	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9	1,9
P50	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
P90	**0,80**	**0,83**	**0,86**	**0,86**	**0,87**	**0,86**	**0,88**	**0,88**	**0,89**
P90/P50	**79,9%**	**83,1%**	**85,9%**	**85,7%**	**87,0%**	**86,3%**	**87,7%**	**87,5%**	**89,0%**
Delta P90/P50 [%]	**1,00**	**1,04**	**1,08**	**1,07**	**1,09**	**1,08**	**1,10**	**1,10**	**1,11**

Table 6-2 Indicative uncertainty analysis for Hollandse Kust Zuid

Monitoring Strategy	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 6
Description	Public wind maps and virtual weather model data	Public measurements	OWEZ and IJmuiden Baseline	Fixed LiDAR offshore platform	Floating LiDAR centre of site for stage 2 device with pre-deployment validation against offshore met mast	Offshore Met Mast
Notes	Assume some basic high level validation of weather model data	Assumes wind mapping	Assumes wind mapping and data from 2005/2006 at OWEZ mast	Assumes wind mapping and 12 months data from Goeree LE or Europlatform	Assume 12 months	Assume 12 months
Improvements to reduce uncertainty	Jump straight to Strategy 2 or 3	Jump straight to Strategy 3 using tall mast data	None	Note	None	None
WMC Start Date	n/a	n/a	n/a	n/a	n/a	n/a
Years of Wind Data	n/a	n/a	2.0	1.0	0.5	1.0
Assumed Mast Height [m MSL]	n/a	n/a	100.0	100.0	100.0	100.0
Uncertainty Assessment Data						
Years of Primary Data	0.0	0.0	1.0	1.0	1.0	1.0
Years of Reference Data	10.0	10.0	10.0	10.0	10.0	10.0
Energy Sensitivity Ratio	1.3	1.3	1.3	1.3	1.3	1.3
Assumed Hub-Height [m]	100.0	100.0	100.0	100.0	100.0	100.0
Data sources used						
Primary Data Source	virtual weather model data	K13	OWEZ and Ijmiden	Fixed LiDAR	Floating LiDAR	On site offshore Met Mast
Secondary Data Source	Public wind map	Europlatform	See Strategy 2	See Strategy 3	See Strategy 3	See Strategy 3
Uncertainties						
Wind Speed	[%]	[%]	[%]	[%]	[%]	[%]
Anemometer Accuracy	10.0	4.0	2.0	0.0	0.0	2.0
LiDAR Accuracy	0.0	0.0	0.0	2.5	4.0	0.0
Flow Distortion	0.0	4.0	2.0	1.0	0.0	1.0
Period Representing Long-Term	1.9	1.9	1.9	1.9	1.9	1.9
Wind Flow Modelling - Vertical	0.0	4.0	0.0	0.0	0.0	0.0

Wind Flow Modelling - Horizontal	1.0	4.0	3.0	2.0	1.0	1.0
Correlation to Reference	0.0	0.0	2.5	2.5	2.5	2.5
Correlation to Reference (Weighted)	0.0	0.0	2.3	2.3	2.3	2.3
Consistency of Reference Source	0.0	0.0	0.9	0.9	0.9	0.9
Energy						
Wake Calculation (Internal + External)	5.0	5.0	5.0	5.0	5.0	5.0
Frequency Distribution	5.0	4.0	2.0	2.0	2.0	2.0
Power Curve	2.0	2.0	2.0	2.0	2.0	2.0
Project Availability	3.0	3.0	3.0	3.0	3.0	3.0
Future Wind Variability (10year)	1.9	1.9	1.9	1.9	1.9	1.9
P50	1	1	1	1	1	1
P90	0.80	0.83	0.88	0.88	0.88	0.89
P90/P50	79.9%	83.1%	87.7%	88.3%	87.7%	89.0%
Delta P90/P50 [%]	1.00	1.04	1.10	1.11	1.10	1.11

Table 6-3 Indicative uncertainty analysis for Hollandse Kust Noord

Monitoring Strategy	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Strategy 6
Description	Public wind maps and virtual weather model data	Public measurements	OWEZ and IJmuiden Baseline	Fixed LiDAR offshore platform	Floating LiDAR centre of site for stage 2 device with pre-deployment validation against offshore met mast	Offshore Met Mast
Notes	Assume some basic high level validation of weather model data	Assumes wind mapping	Assumes wind mapping and data from 2005/2006 at OWEZ mast	Assumes wind mapping and 12 months data from Goeree LE or Europlatform	Assume 12 months	Assume 12 months
Improvements to reduce uncertainty	Jump straight to Strategy 2 or 3	Jump straight to Strategy 3 using tall mast data	None	Note	None	None
WMC Start Date	n/a	n/a	n/a	n/a	n/a	n/a
Years of Wind Data	n/a	n/a	2.0	1.0	0.5	1.0
Assumed Mast Height [m MSL]	n/a	n/a	100.0	100.0	100.0	100.0
Uncertainty Assessment Data						
Years of Primary Data	0.0	0.0	1.0	1.0	1.0	1.0
Years of Reference Data	10.0	10.0	10.0	10.0	10.0	10.0
Energy Sensitivity Ratio	1.3	1.3	1.3	1.3	1.3	1.3
Assumed Hub-Height [m]	100.0	100.0	100.0	100.0	100.0	100.0
Data sources used						
Primary Data Source	virtual weather model data	K13	OWEZ and Ijmiden	Fixed LiDAR	Floating LiDAR	On site offshore Met Mast
Secondary Data Source	Public wind map	Europlatform	See Strategy 2	See Strategy 3	See Strategy 3	See Strategy 3
Uncertainties						
Wind Speed	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**
Anemometer Accuracy	10.0	4.0	2.0	0.0	0.0	2.0
LiDAR Accuracy	0.0	0.0	0.0	2.5	4.0	0.0
Flow Distortion	0.0	4.0	2.0	1.0	0.0	1.0
Period Representing Long-Term	1.9	1.9	1.9	1.9	1.9	1.9

Wind Flow Modelling - Vertical	0.0	4.0	0.0	0.0	0.0	0.0
Wind Flow Modelling - Horizontal	1.0	5.0	1.0	1.0	1.0	1.0
Correlation to Reference	0.0	0.0	2.5	2.5	2.5	2.5
Correlation to Reference (Weighted)	0.0	0.0	2.3	2.3	2.3	2.3
Consistency of Reference Source	0.0	0.0	0.9	0.9	0.9	0.9
Energy						
Wake Calculation (Internal + External)	5.0	5.0	5.0	5.0	5.0	5.0
Frequency Distribution	5.0	4.0	2.0	2.0	2.0	2.0
Power Curve	2.0	2.0	2.0	2.0	2.0	2.0
Project Availability	3.0	3.0	3.0	3.0	3.0	3.0
Future Wind Variability (10year)	1.9	1.9	1.9	1.9	1.9	1.9
P50	**1**	**1**	**1**	**1**	**1**	**1**
P90	**0.80**	**0.82**	**0.89**	**0.89**	**0.88**	**0.89**
P90/P50	**79.9%**	**82.4%**	**88.6%**	**88.7%**	**87.7%**	**89.0%**
Delta P90/P50 [%]	1.00	1.03	1.11	1.11	1.10	1.11

APPENDIX C: UNCERTAINTY CATEGORIES

Table 2. Recommended Uncertainty Sub-categories, Definitions, and Comments

Uncertainty Category	Description	#	Example Subcategories	Sub-category Definition/Comments
1. Site measurement	Includes sensor uncertainty and quality of project data	1a	Instrument accuracy	Variability in measurement of wind speed by individual instruments. Includes calibration uncertainty.
		1b	Measurement interference	Uncertainty due to effects of masts on measurements or other types of interference. For masts, includes tilted anemometers, separation concerns or any other mounting issues. For remote sensing, includes physical or atmospheric interference on the measurement.
		1c	Data quality and metadata	Uncertainty regarding possible bias due to any removed or missing data or lack of quality metadata. Includes uncertainty due to non-encrypted data or non-traceable data sources, or for inconsistencies/ contradictory metadata.
2. Historic wind resource	Includes MCP uncertainty of local and reference data, historic variability and reliability of long term reference	2a	Period of data representative (of long term)	Representativeness of period of data relative to project period of interest.
		2b	Reference site	Correlation uncertainty and uncertainty associated with consistency and quality of long-term references, measured or modelled.
		2c	Wind speed frequency distribution – past	For a given mean wind speed, the distribution can have variability. Uncertainty regarding measured distribution relative to true long-term distribution.
		2d	On-site data synthesis	Uncertainty associated with "filling in" data.

Uncertainty Category	Description	#	Example Subcategories	Sub-category Definition/Comments
3. Vertical extrapolation	Includes uncertainty related to the estimate of wind speeds at elevations above ground level for which there are no direct measurements. This includes uncertainty associated with estimating the true vertical profile of horizontal wind speed across the height range of interest.	3a	Extrapolation to hub height	Uncertainty of representativeness of shear or other extrapolation model up to hub height. Also could include the extent to which the hub-height wind speed is not representative of the rotor plane average wind speed.
4. Future wind variability	Includes future variability of resource. Considers both the variability of the wind climate.	4a	Interannual variability	Uncertainty regarding whether the true long-term mean wind speed will occur over the project life.
		4b	Climate change	Local and global climate patterns (long- and medium-term phenomena).
		4c	Wind frequency distribution – future	Uncertainty/variability in year-to-year distribution in future.
5. Spatial variation	Includes the uncertainty of extrapolating from met tower locations to individual turbine locations.	5a	Model inputs	Quality of terrain data, roughness maps. Includes degree of site uniformity with respect to terrain and vegetation.
		5b	Horizontal extrapolation	Representativeness of masts relative to turbine locations (exposure, terrain, vegetation, elevation, etc.).
		5c	Other uncertainty	Includes model bias, model quality and error, complexity of terrain, quality of Weibull fit used in model.
6. Plant performance and losses	Includes the uncertainty of estimating turbine production, efficiencies with respect to atmospheric conditions, and all plant losses including wake losses.	6a	Availability	Turbine and balance of plant over project lifetime.
		6b	Wake effects	Includes uncertainty in the model inputs (including wind direction), and that associated with model performance and appropriateness for site. Also includes uncertainty related to any proposed neighbouring sites (construction timing, layout, turbine type).

Uncertainty Category	Description	#	Example Subcategories	Sub-category Definition/Comments
		6c	Turbine performance	Includes power curve uncertainty, uncertainty on performance under site conditions for which power curve is not valid. Includes impact of atmospheric stability.
		6d	Electrical losses	Line loss, metering.
		6e	Environmental	Blade soiling, blade degradation, weather effects.
		6f	Curtailment	Includes uncertainty with respect to wind sector management, grid and ramp-rate, offtaker, and/or environmental curtailment.
		6g	Other losses	Includes uncertainties associated with other project specific losses.
7. Other		7		Includes other uncertainties that do not fit into the above six uncertainty categories.

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Netherlands Enterprise Agency (RVO.nl) | December 2014