Westerduinweg 3
1755 LE Petten
P.O. Box 15
1755 ZG Petten
The Netherlands

www.tno.nl

T +31 88 866 50 65

TNO 2022 R10328

The importance and the need for long term wind measurements in the Dutch North Sea

Date	21 February 2022
Author(s)	Bernard H. Bulder Aki Pian Hans Verhoef
Copy no	
No. of copies	
Number of pages	15 (incl. appendices)
Number of appendices	
Sponsor	Ministry of Economic Affairs & Climate Policy
Project name	2021 Wind Conditions @ North Sea
Project number	060.47011

Executive summary

Due to further expansion of the Dutch offshore wind energy after 2030 new (offshore) locations will be selected to build wind farms. To enable the development of the new areas it will be required to have a good insight in the available wind resource is these areas. In this report the need for new locations for long term wind measurements is investigated and the criteria to evaluate potential new locations is presented.

The conclusion is that new measurement locations in or near the search areas are important to uphold the quality of the wind resource assessment. The wind resource assessment in itself is one of the most important information sources for wind farm developers to design the wind farm.

The quality of measurements is improved when there is no need for corrections, e.g. due to wind farms in the proximity or wind farms that will be erected in the proximity in the near future.

The value of measurements and the certainty of measurements is improved when measurements can be performed for a longer period.

Contents

1 Dutch deployment plan of offshore wind energy

1.1 Introduction

In this report it is investigated the need for new long term wind measurement locations at the North Sea looking to the Dutch roadmap wind energy.

1.2 The Dutch wind energy road map

The European offshore wind plans have settled the goal of 75GW of installed capacity in the North sea by 2030, [1]. The Netherlands, with a current combined capacity of 1.7 GW, has a roadmap for the Dutch offshore wind portfolio, in the first phase till 2023, in which the installed capacity will increase to 4.5 GW [2]. In the second phase, till 2030, an additional 7.0 GW of offshore wind will be tendered to reach a total of 11.5 GW (Figure 1). It is expected that offshore wind energy will generate 40% of the total electricity demand in the Netherlands in 2030 [1]. Recently, the Dutch government has announced, on top of the present road map, to look for locations for an additional 10 GW to be realised around 2031 (Figure 2) to generate 45 TWh electricity [2].

The current installed capacity (2021) and the first phase of the offshore wind roadmap in the Dutch North sea are the following wind farms projects:

- Egmond aan Zee (OWEZ):108 MW, commissioned in 2007
- Princess Amalia: 120 MW, commissioned in 2008
- Luchterduinen: 129 MW, commissioned in 2015
- Gemini: 600 MW commissioned by 2017
- Borssele (I-V): 1.4 GW in operation by end of 2020
- Hollandse Kust (I-IV) (zuid): 1.4 GW expected in operation by 2022 and fully commissioned in 2023
- Hollandse Kust (V) (noord) expected in operation by 2024 with a total capacity of 700 MW

Reaching to ~4.5 GW in total.

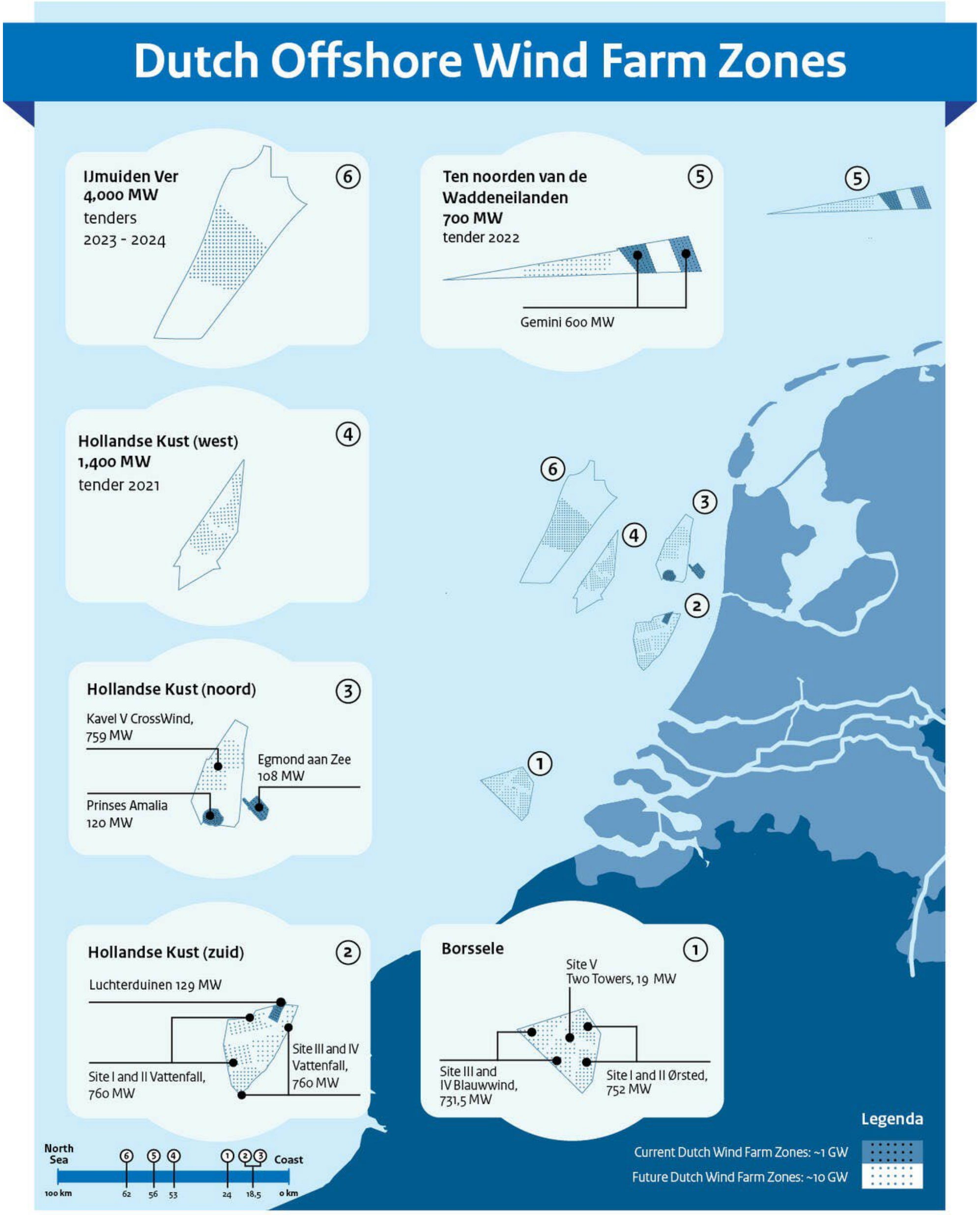


Figure 1 Dutch offshore wind farm designated area for 2030

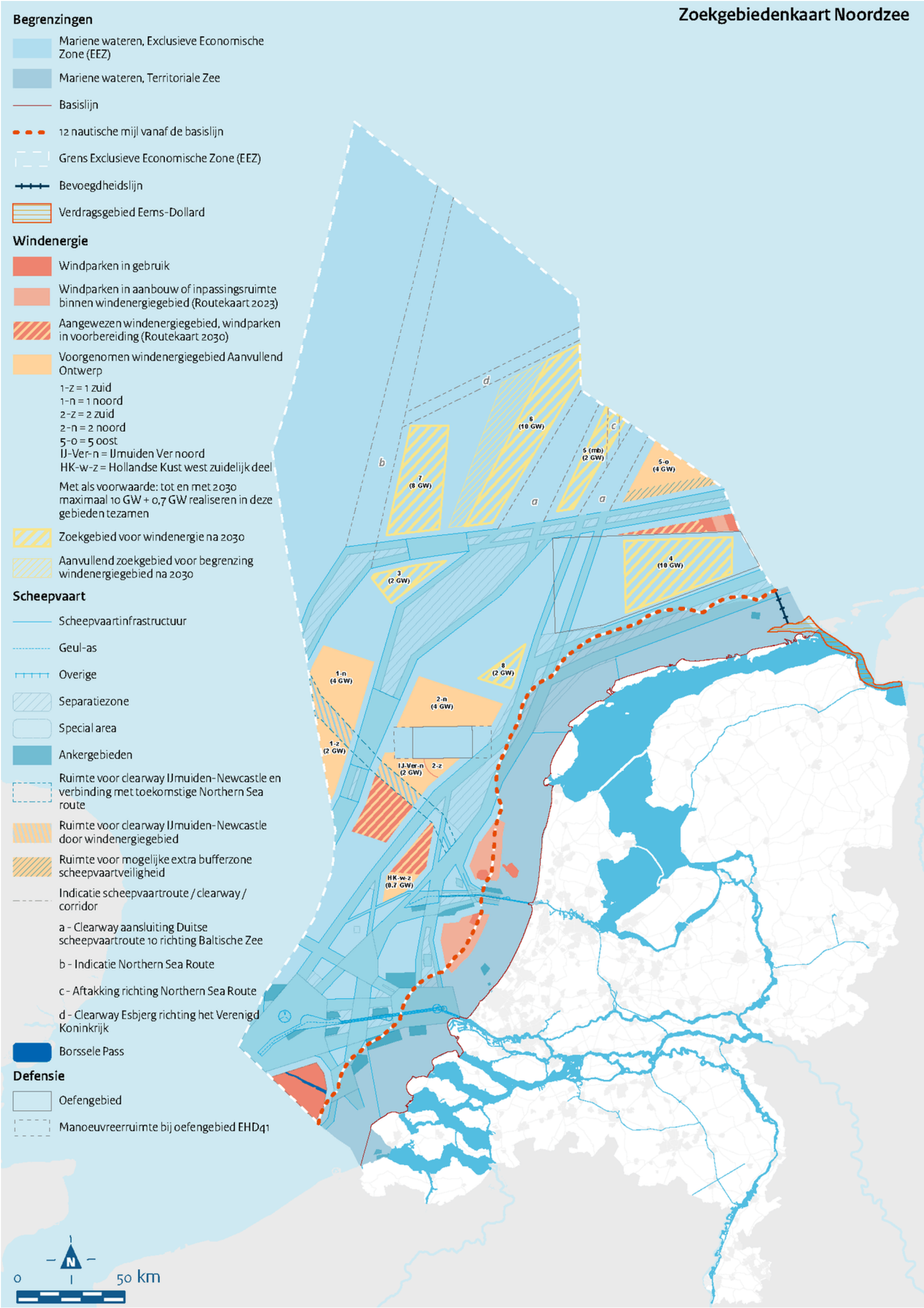


Figure 2 Update Dutch offshore wind farm designated area for 2030 and after 2030

1.3 Scenario 2030

By 2030, the end of the phase 2 of the road map, the Netherlands wants to reach a total installed capacity of 11.5 GW offshore. The selection of the suitable areas for offshore wind farms has already taken place and the RVO's website [1] presents the following areas:

- Hollandse Kust (west) with a foreseen installation of 1.4 GW
- Ten Noorden van de Waddeneilanden with a foreseen installation of 0.7 GW
- IJmuiden Ver with a foreseen installation of 4 GW

With a total capacity of 6.1 GW and taking into account that the AC substations have the transmission capability to be overplanted by 8% the total installed capacity is foreseen to be 11.5 GW.

1.4 Scenario after 2030

In the most recently updated offshore wind farm development plan, the following research areas are identified to install a maximum of 10.7 GW:

- 1 zuid (2 GW)
- 1 noord (4 GW)
- 2 zuid
- 2 noord (4 GW)
- 5 oost (4 GW)
- IJmuiden Ver Noord (2 GW)
- Hollandse Kust west zuidelijk deel (0.7 GW)

For the naming of these locations we refer to Figure 2. By 2050 the expected wind portfolio foresees the addition of well over 27 GW, because in some scenarios the offshore wind portfolio may reach 60-70GW.

2 Importance of long term wind measurements for the development of wind energy

2.1 Introduction

Wind-resource assessments (WRAs) have a direct impact on the financing of projects and therefore crucial for the decision whether or not to develop and construct offshore wind farms. The primary result of the WRA is the Annual Energy Production (AEP) estimate, which in turn is the most important factor to determine the viability of a wind farm project.

A reduction in uncertainty improves the financial terms for wind farm developers. In addition, when wind projects perform closer to expectations, it strengthens the trust between consultants, developers, the financial community, policymakers, and the general public.

The best is of course to erect a long-term measurement mast at the potential construction site, but this is offshore therefore quite expensive and mostly costs too much time. The most commonly used method to determine the WRA at a site, when there are no onsite long term wind measurements available, is to apply a method called Measure – Correlate – Predict, or MCP in short, see e.g [3].

In this MCP method the measurements are split in two different sets: first a short term wind data set measured in the proximity of the location of the wind farm for which the wind resource assessment is determined and the second usually is a long term data set measured at a greater distance of the location of interest (LOI). The short term measurements are correlated with the long term wind measurements (more than 10 years but preferably more than 25 years). There are no “definitive” requirements with respect to the distances of the short and long term measurement as long as there is a good correlation between both datasets. There are also no strict requirements with respect to the duration of the measurements however the shorter the measurement periods the higher the uncertainty of the resulting AEP. The requirement is most often described as to use the best data available.

When there are no reliable long term wind resources available in the wide area around the potential site it is quite common to apply long term hind cast data from numerical meteorological models supplied by the meteorological institutes around the world and correlate those with the short term measurements in the proximity of the location of interest.

When there are no measurements available in the proximity of the potential site the hindcast data is correlated with measurements at several locations and it is investigated whether the correlation factor is uniform or there is a trend in the correlation with respect to location, directional sector and/or e.g. distance to shore.

The advantage of using the modelled data from forecasts made in the past, thus making it hind cast data, is that, that data is often available at a relative high spatial resolution and can be evaluated at several heights and locations based on model based interpolation techniques. While data measured at a meteorological measurement location are often measurements at a relatively low altitude and often on shore, in the coastal region, with varying disturbances over time and in direction.

Wind farm project developers are relying on accurate wind resource analysis for several reasons. An accurate wind resource prediction is required to make an optimal wind farm lay-out to determine the wind farm efficiency, i.e. determine the wake losses of wind turbines in the wind farm as a function of the wind speed and wind direction. Next to that the wind farm production estimate has to be determined where it is of the utmost importance to know the probability distribution of the wind farm yield. This is required to be able to negotiate the financial terms with lenders and financiers. Usually the financial world does not look at the P_{50} (mean expectation: 50% chance the yield is higher, 50% chance the yield is lower) but at the P_{90} (90% chance the yield will be higher) or P_{95} or even P_{99} to determine the willingness and size of their financial involvement. The uncertainty is sometimes also denoted as the ratio of P50 over the P90. The closer that value is to 1 the less uncertain the annual energy production is. Especially the uncertainty in the wind resource determines the ratio of P50 over the P90.

2.2 Requirements of project developers for the wind resource analysis

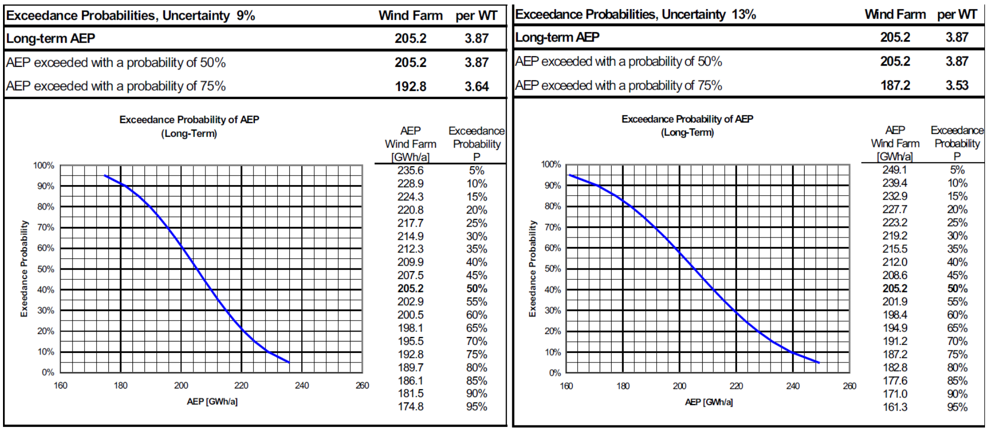
As already mentioned the main objective for project developers with a WRA is to predict the AEP in a reliable way. Due to the fact that the WRA is one of the largest uncertainties in the determination of the AEP[1], see Figure 3, and that the reliability of the AEP prediction is valuable in financial terms, some qualitatively requirements are described below.

It is required that the wind resource analysis is based on local measurements, preferably for a minimum period of a year in combination with long term wind measurements or hindcast data that is available within a reasonable distance to the LOI, usually where the new wind farm will be developed. The wind resources should be available as a spatial distribution of at least a few locations in the area the wind farm will be developed. The spatial distribution can be based on local measurements that are performed at two or more locations or based on high quality hindcast data of a meteorological model that can provide data at a grid of points in between which the wind resources can be interpolated.

Next to the average wind resource the wind farm developers require to have the uncertainty in the wind resources as part of the uncertainty in the energy yield estimate. In most situations the uncertainty of the wind distribution is the largest factor in the formulation of the distribution of energy yield in time.

Wind farm developers usually require to have the following statistical distribution figures of the yield P_{75}, P_{90}, P_{95} and sometimes the P_{99} for several duration periods e.g. for 1, 10, 15 and 20 yrs.

[1] Other uncertainties to be mentioned are the uncertainties in the wake loss predictions, which in turn are also dependent on the wind resource assessment.



Exceedance Probabilities, Uncertainty 9%	Wind Farm	per WT
Long-term AEP	205.2	3.87
AEP exceeded with a probability of 50%	205.2	3.87
AEP exceeded with a probability of 75%	192.8	3.64

AEP Wind Farm [GWh/a]	Exceedance Probability P
235.6	5%
228.9	10%
224.3	15%
220.8	20%
217.7	25%
214.9	30%
212.3	35%
209.9	40%
207.5	45%
205.2	50%
202.9	55%
200.5	60%
198.1	65%
195.5	70%
192.8	75%
189.7	80%
186.1	85%
181.5	90%
174.8	95%

Exceedance Probabilities, Uncertainty 13%	Wind Farm	per WT
Long-term AEP	205.2	3.87
AEP exceeded with a probability of 50%	205.2	3.87
AEP exceeded with a probability of 75%	187.2	3.53

AEP Wind Farm [GWh/a]	Exceedance Probability P
249.1	5%
239.4	10%
232.9	15%
227.7	20%
223.2	25%
219.2	30%
215.5	35%
212.0	40%
208.6	45%
205.2	50%
201.9	55%
198.4	60%
194.9	65%
191.2	70%
187.2	75%
182.8	80%
177.6	85%
171.0	90%
161.3	95%

Figure 3 an example of a wind farm with equal P50 but with different uncertainties and consequently different P70, P90 etc. due to Wind Resources and other reasons. (Copied from [4])

In the (recent) past it was quite common to determine a wind index for each year and the distribution of the wind index. Figure 4 below shows the variation in the wind over the period 1990 – 2008 in standard deviations. As can be seen the wind index fluctuates quit strong on year to year basis and the profitability of a wind farm project is strongly influenced by the yield of the first years of operation.

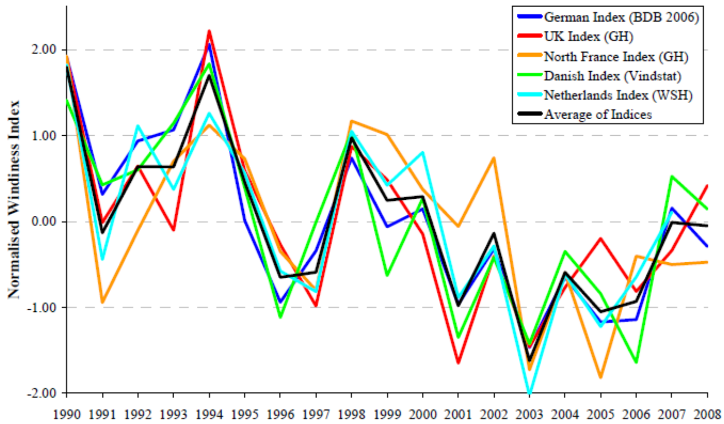


Figure 4 The normalized wind index of several north European countries 1990 – 2008, copied from [5]

Next to the long term average wind data it will be required to determine

- year to year variations of the average wind speed and,
- seasonal or monthly variations and
- diurnal or daily variations of the wind speed.

2.3 The MCP method

The MCP method can be divided in several different correlation methods and different sources of long term wind resources. In [6] a description is given of 4 methods ranging from correlating the annual average wind speed to correlating the energy content to correlating the wind speed and direction distributions. Several other descriptions can be found how the MCP method can be applied.

The two most often used methods are correlating short term wind measurement on site with long term measurements at a meteorological station at a greater distance, see Figure 5 and the other is correlating hindcast data as the source of the long-term data with short-term measurements on site. The short-term measurements are either performed with a met mast with measurements of wind speed, direction, temperature and air pressure and humidity at several heights or performed with a floating LiDAR which measures the wind speed and direction at several altitudes. The hindcast data is available on a grid, e.g. see Figure 6 where the model is capable to interpolate between grid points.

In both cases the period of overlap in the short-term measurements at the location of interest and long term measurements, whether on shore or the hind cast data, is correlated. Correlation is performed on the average wind speed per wind direction sector, usually per sector of 30º. The correlation that is found for the short-term period that both measurements or measurements and hindcast data are available and assume that this is valid for the entire period the long term measurements / hindcast data is available.

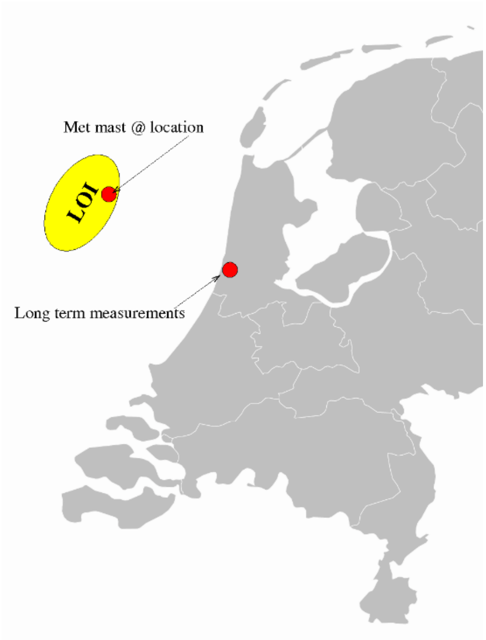


Figure 5 Correlation between short term measurements on site and long term measurements on shore

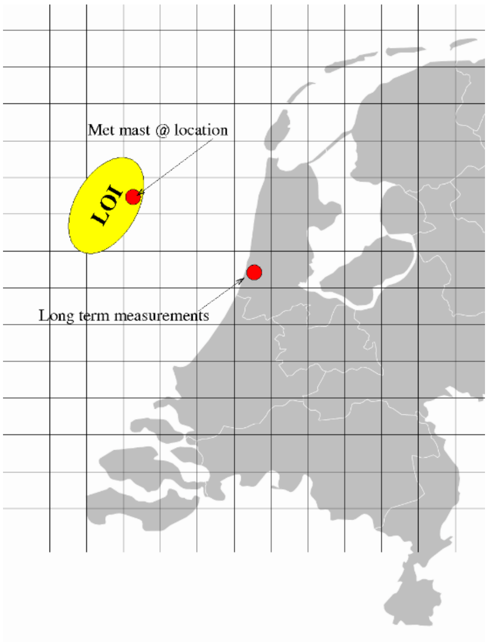


Figure 6, Correlation between hind cast data and short term measurements on site and long term measurements on shore.

2.4 Specifications of the requirements for the new measurement location(s)

When new wind farms are planned in areas that are not in the proximity of existing measurement locations the uncertainties increase to unacceptable high values. Therefore, it is important to develop new measurement locations in the proximity of the new wind farm locations. These new long-term measurement locations should not be disturbed by wind farms in the foreseeable future. A met mast or LiDAR location that will be in the influence sphere of a wind farm will lose its value, at least for the wind directions that are influenced by the wind farm. Depending on the size of the wind farm the influence sphere of a wind farm can easily stretch out 30 or 40 km around the wind farm.
With the large number of wind farms to be developed until 2030 and even more after that, as well in the Dutch part of the North Sea as in international zones, it is a challenge to find locations that will not be disturbed by any wind farm in the near future, , but some suggestions are presented in this report.

3 Current TNO long term measurement locations

Wind resource assessments and energy yield assessments are fundamental for the planning and the development of offshore wind farm farms since that determines for a large extend the business case. Therefore, accurate wind measurements play an essential role, which assists the unhindered implementation of offshore wind farms in the North Sea. In this regards, from 2014, TNO is performing for the Dutch Ministry of Economic Affairs and Climate Policy a long term measurements campaign applying LiDARs on platforms in different locations in the North Sea. The measurements are performed in three strategically locations: on platforms Lichteiland Goeree (LEG), Europlatform (EPL) and K13A until 2030. The validated measurements are published by TNO on the website and are used by the various developers and operators of offshore wind farms. Every year TNO reviews the measurements, the value of the measurement locations and provides an overview of the wind conditions for each location and provides an overview of the wind conditions for each location. The existing three long-term measurement locations are in the southern part of the Dutch North Sea, with K13A being the one that is most northernly and westerly. The roadmap for the development of the Dutch offshore wind farms shows that significant amount of wind power will be developed in the Northern part of the Dutch North Sea. It is evident that for the business case of these northern wind farms it is recommended to add new locations in that area.

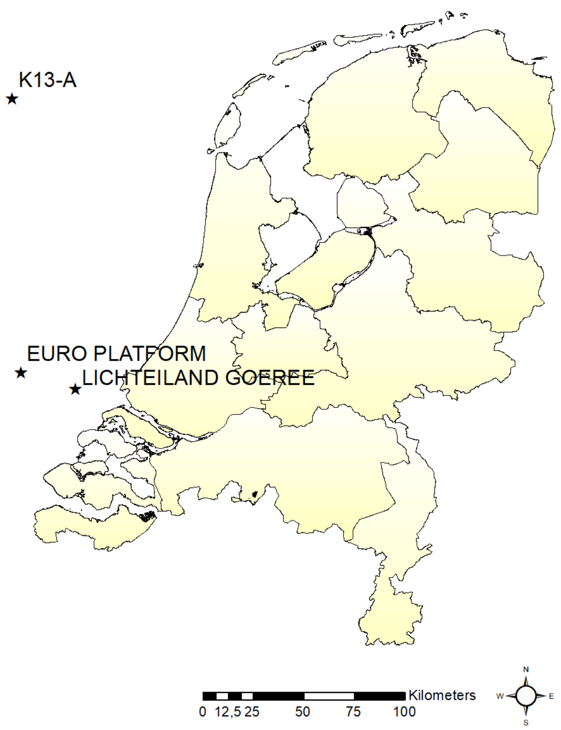


Figure 7 Present TNO offshore long term measurement locations

4 TNO's long term wind measurements supporting Dutch offshore wind development

The present three measurement locations, EPL, LEG and K13A should be maintained. Although EPL and LEG are relatively closely positioned to each other, these two platforms are valuable because these platforms are disturbed by surrounding wind farms. Since the disturbance occurs in different sectors, it means the combination gives the complete wind field. LEG is disturbed by the Borssele wind farms in different wind sectors than the EPL meteorological station. Having both measurements, from LiDAR measurements, available will measurements can be correlated with the wind atlas in all sectors. This makes it possible to determine the entire "undisturbed" wind resource.

It is certain that new wind farms will be planned in more northernly locations. In that area there are no wind energy met masts, leading to higher uncertainties in the wind resource. The platforms that are used by KNMI to measure the hourly meteo data are performed at a height that is too low for the present large wind turbines.

Additional measurements with LiDAR system must be added to the existing platforms in order to cover the area above the Wadden Islands, where in the near future large amounts of wind farms will be planned and installed.

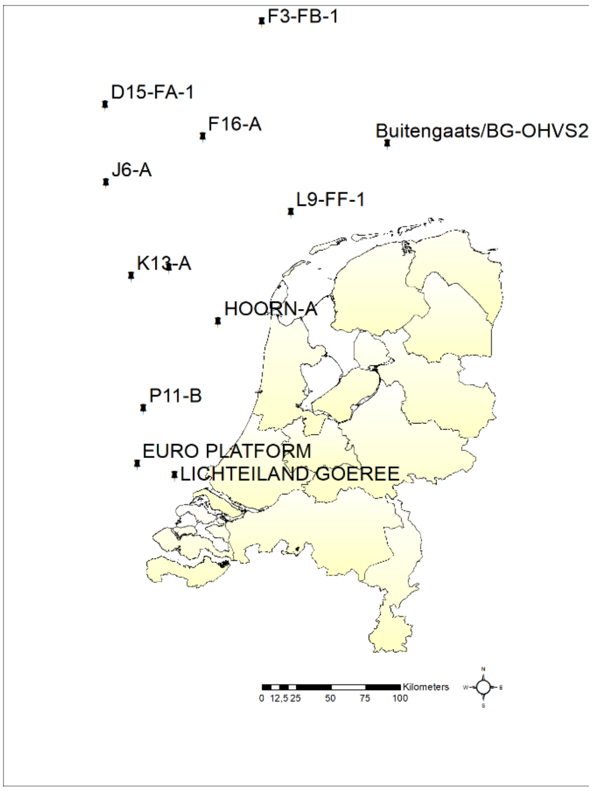


Figure 8 KNMI Offshore meteo measurement locations

5 Bibliography

[1] "Ministry of Economic Affairs & Climate Policy", “Wind op Zee,” Rijksoverheid, [Online]. Available: https://windopzee.nl/. [Accessed 24 11 2021].

[2] "Ministry of Economic Affairs & Climate Policy", “Wind op zee tot en met 2030,” Rijksoverheid, [Online]. Available: https://windopzee.nl/onderwerpen/wind-zee/wanneer-hoeveel/wind-zee-2030/. [Accessed 24 11 2021].

[3] Measnet , “Evaluation of site specific wind conditons,” MEASNET, 2016, version2.

[4] H. Klug and D. Wilhelmshaven, “What does Exceedance Probabilities P90-P75-P50 Means?,” *Environmental Science,* 2006.

[5] P. Thomas, S. Cox and A. Tindal, “Long term wind speeds trends in Europe,” in *EWEC*, Marseille, 2009.

[6] A. L. Rogers, J. W. Rogers and J. F. Manwell, “Comparison of the performance of four measure correlate predict algorithms,” *Journal of Wind Engineering and industrial aerodynamics,* vol. 93, no. 3, pp. 243-264, 2005.