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Recommendation for additional locations on the North Sea for long term wind resource measurement for wind energy application

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Summary

Europe aims to become the first carbon-neutral continent by 2050 and has constantly expanded its targets to realize such a goal. Most notably is the newest “Fit for 55” framework, in which the 27 member-countries have agreed on reducing their national greenhouse gas emissions by 55% by 2030 compared to 1990 levels. This has demanded further revision of national climate targets and considerations towards increased deployment of renewable energy sources in all countries.

In this regard, the roll-out of renewable energy strongly relies on the deployment of offshore wind farms, in which the European offshore wind plans have settled on a target of 75GW of installed capacity in the North Sea by 2050. The Netherlands has clear ambitions to develop its own offshore wind industry in the North Sea. It has recently made considerable steps to further deploy this technology with the announcement of 10 GW of additional wind energy capacity to be installed by 2030, added to the already 11.5 GW originally planned under previous national climate plans.

Furthermore , the search areas dedicated for this expanded development of offshore wind farms have already been selected. The areas of consideration show that wind energy will be further deployed in locations to the north, far from the coast, and where currently no accurate data on wind conditions are available. Due to this, there is a need to properly characterize the wind resource of these new regions to improve the quality of the future wind farms that will be developed and constructed there.

Therefore, this report aims to assess the North Sea infrastructure to investigate potential sites for the installation of a new wind condition monitoring campaign. This assessment has been made considering the following factors:

- The locations of existing and future wind farms (Dutch and international environment),
- The locations of oil and gas platforms and their decommissioning plans,
- The location of KNMI sites for meteorological measurements,
- The location of TNO’s existing long-term wind condition monitoring campaign along the Dutch North Sea.

This assessment has resulted in identifying four zones of clustered platforms. These zones were then further shortened to three platforms that were more preferable locations to address the wind conditions for the ‘Ten Noorden van de Waddeneilanden’ site, and four platforms preferable to monitor the wind conditions in the northern sector of the Dutch North Sea. After a discussion with RVO, the first platform suggested in this study has been agreed for further investigation. Nevertheless, it is recommended to contact the direct operator of the selected platforms to verify their decommissioning dates.

Finally, a recommendation on the instrumentation is provided, it is based on the instrumentation information from the TNO’s current measurement campaigns and with further recommendations for the installation of new monitoring sensors.

Contents

1 Dutch deployment plan of offshore wind energy

1.1 Introduction

Europe aims to become the first carbon-neutral continent by 2050 (European Green Deal [1]). Most notably is the newest “Fit for 55” framework, in which the 27 member-countries have agreed on reducing their national greenhouse gas emissions by 55% by 2030 compared to 1990 levels. This has demanded further revision of national climate targets and considerations towards further deployment of renewable energy sources in all countries [2]. In this regard, the roll-out of renewable energy strongly relies on the deployment of offshore wind farms in the upcoming decades, in which the European offshore wind plans have settled to a goal of 75GW of installed capacity in the North Sea by 2030.

The Netherlands has set a high target for the expected capacity installed of wind energy by 2030 [3] and beyond [4]. Wind farms are being planned further from the coast where information on the wind conditions is often limited. The importance of wind condition monitoring is addressed in [5]. TNO has investigated the current infrastructure in the North Sea to select new promising locations for a long-term wind condition measurement and assessment program that can better serve the development of the new Dutch tendering areas for future offshore wind farms. In the selection process for new measurement campaign locations, existing oil and gas platforms along with their decommissioning plans, and (future) wind farm locations of the Netherlands, the UK, Germany, Belgium, and Denmark are taken into consideration.

1.2 Offshore wind energy deployment scenarios in the Netherlands

The Netherlands has a cumulatively installed 2.9 GW of offshore wind energy as of 2021 [6]. This rapid development in recent years has been part of a roadmap for the Dutch offshore wind portfolio, which initially consisted of two phases. The first phase comprises of having an additional 4.5 GW operational by 2023 , followed by achieving a total installed capacity of 11.5 GW by 2030 in the second phase. The latter phase was recently expanded to now target a total installed capacity of 21.5 GW of offshore wind tenders by 2030 [7]. These developments have brought with it the selection of 5 new lease areas to the northern sector of the Dutch North Sea as presented in Figure 1.

Figure 1 Locations of existing Dutch offshore wind farms and updated (in March 2022 [8]) designated area.

2 North Sea infrastructure

In the selection process for a new location for a long-term measurement campaign for wind conditions, TNO has analysed the currently available infrastructure and the future deployment plans in the North Sea. In this section, an overview of the main infrastructure available is presented. This allows for a better understanding of which conditions have been considered in the analysis.

2.1 Current TNO long term measurement locations

Wind resource and energy yield assessments are fundamental for the planning, feasibility, and the overall development of offshore wind farms, see [5]. Therefore, accurate wind measurements and site conditions are needed to ensure that risks are properly mitigated, that uncertainties are better assessed, and that the measurements themselves are of good quality and representative of the location of the site. Since 2014, TNO has been performing long-term measurement campaigns for the Dutch Ministry of Economic Affairs and Climate Policy at three strategic offshore platforms in the North Sea: Lichteiland Goeree (LEG), Europlatform (EPL) and K13A, as shown in Figure 2. The data measured in the "Wind Conditions @ North Sea" project are retrieved and post-processed monthly for verification purposes, and then the information is made publicly accessible through the web-service https://www.windopzee.net/en/. In addition, since 2020 TNO has published annual reports that characterize and asses the wind conditions for each existing measurement campaign location, and are available at https://www.windopzee.net/en/. These reports are used by many developers and operators of offshore wind farms.

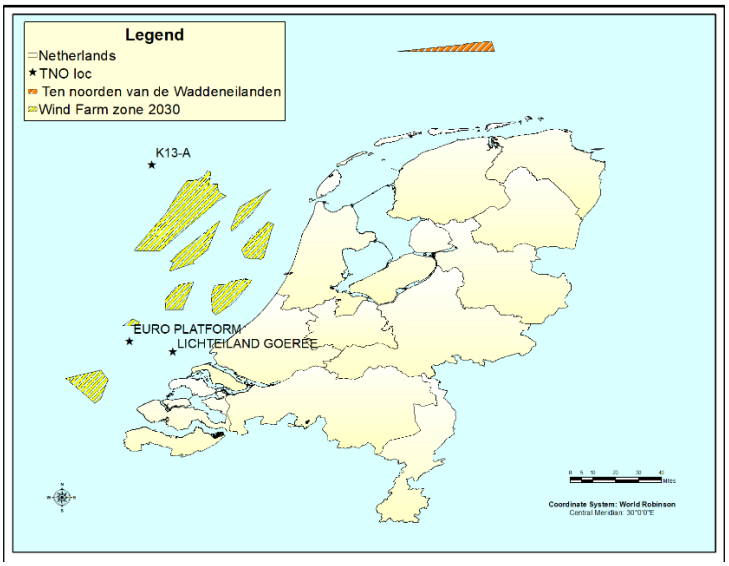

Figure 2 Long term measurement locations on the North Sea operated by TNO

2.2 KNMI offshore locations

KNMI performs meteorological observations by automated systems measuring certain variables in several locations, both on the coast and on offshore installations,

a list of measurements location can be founded here [9]. The offshore locations are illustrated in Figure 3. However, due to the low-level height of the instruments, the resulting wind measurements provide a large degree of uncertainty for the wind resource estimation required for wind energy application, which typically requires measurements and long-term predictions to be made at over 100m in height.

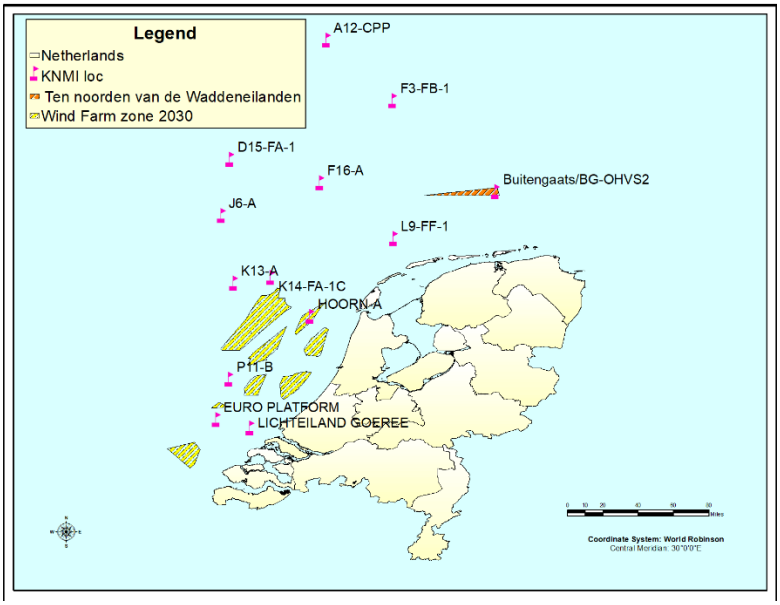

Figure 3 KNMIs meteorological stations on offshore infrastructure in the North Sea

2.3 Oil and gas platforms

As mentioned in Section 1, large scale deployment of offshore wind energy is needed to fulfil the requirements of the ambitious climate plans of the Netherlands. The Dutch offshore wind energy road map foresees a roll-out of 21.5 GW until 2030. At the same time, a *Masterplan for Decommissioning and Re-use of oil and gas infrastructure* [10] has been developed. For many of these oil and gas platforms, a decommissioning date is already planned, and by 2050 it is foreseen that most platforms will be decommissioned. For the selection of a new measurement campaign location, the oil and gas platforms that have a later decommissioning date provide an unique opportunity to be further utilised for the new long-term wind measurement campaign.

An inventory of existing oil and gas production platforms has been made in this section, and the locations of the current production platforms are shown in Figure 4. Each platforms' decommissioning date is subject to different circumstances, and it can vary from one year to the other depending on several criteria, such as the costs calculated to continue operating these platforms. In this report, three timeline of expected dates for decommissioning are described in three scenarios provided by *"The North Sea Energy Atlas"* [11] named in this study:

- "Short scenario": this scenario provides the shortest timeline for the expected decommissioning dates of all the platforms;
- "Most-likely scenario": this scenario provides the expected decommissioning dates that are most-likely to occur of all the platforms;

- "Long scenario": this scenario provides the latest timeline for the expected decommissioning dates of all the platforms.

It is important to underline that these dates were extrapolated at the end of 2021 and therefore might have changed since the writing of this report. Therefore, for the selected locations it is recommended to contact the platforms' operators to verify the current expected decommissioning date.

The following tables present the list of expected dates for each platform for the *Short scenario*, the *Most-likely scenario* and the *Long scenario*, with additional information on whether the platforms are also KNMI measurement site locations described in the previous section. The first table, Table 1, presents the platforms which are expected to be dismantled after 2027 in all the scenarios. These platforms are preferred as they have a higher probability to remain after 2027 as all the three scenarios predict. Table 2 presents the list of platforms expected to be dismantled after 2027 only in the *Most-likely scenario* and in the *Long scenario*. These platforms have a lower probability to remain after 2027, and as in the *Short scenario* they are planned to be dismantled before 2027. Finally, Table 3 presents the list of platforms expected to be dismantled after 2027 only in the *Long scenario*. These platforms are least likely to remain after 2027 as only in the long-term scenario their dismantling is expected after 2027.

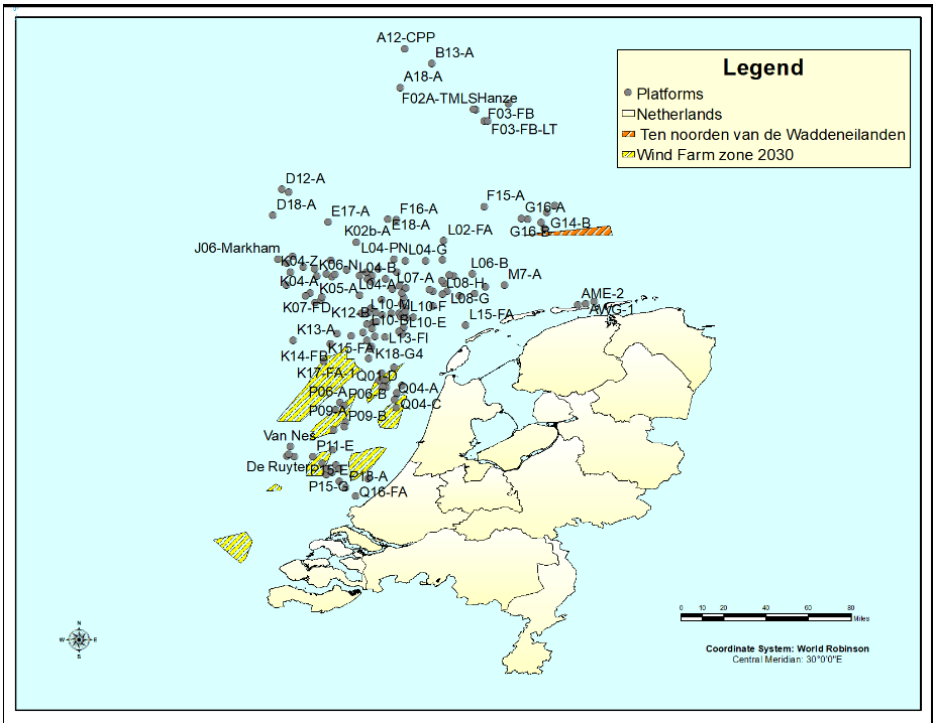

Figure 4 The existing oil and gas platforms on the north Sea

Table 1 Platforms expected to be dismantled after 2027 between the three scenarios and KNMI stations [11]

Name	Short scenario	Most-likely scenario	Long scenario	KNMI station
A12-CPP	x	x	x	x
AME-2	x	x	x	
AWG-1	x	x	x	
F03-FB	x	x	x	x
F03-FB-LT	x	x	x	
Hanze	x	x	x	
J06-Markham	x	x	x	x
K04-A	x	x	x	
K05-A	x	x	x	
K05-B	x	x	x	
K05-CU	x	x	x	
K05-EN/C	x	x	x	
K07-FA	x	x	x	
K07-FB	x	x	x	
K07-FD	x	x	x	
K08-FA-1	x	x	x	
K08-FA-2	x	x	x	
K08-FA-3	x	x	x	
K09ab-B	x	x	x	
K13-A	x	x	x	x
K14-FA	x	x	x	
K14-FB	x	x	x	
K15-FA	x	x	x	x
K15-FB	x	x	x	
K15-FC	x	x	x	
K15-FG-103	x	x	x	
K15-FK	x	x	x	
K17-FA-1	x	x	x	
L02-FA	x	x	x	
L05-D	x	x	x	
L05-FA	x	x	x	
L13-FC	x	x	x	
L13-FD	x	x	x	
L13-FE	x	x	x	
L13-FI	x	x	x	
L15-FA	x	x	x	
Q13a-A	x	x	x	

Table 2 Platforms expected to be dismantled after 2027 in the *Most-likely scenario* and a *Long scenario* [11]

Name	Short scenario	Most-likely scenario	Long scenario	KNMI station
K01-A		x	x	
K04-BE		x	x	
L06-B		x	x	
L08-P4		x	x	
Q01-D		x	x	
Q04-C		x	x	

Table 3 Platforms expected to be dismantled after 2027 only in the *Long scenario* and KNMI stations [11]

Name	Short scenario	Most-likely scenario	Long scenario	KNMI station
L05-C			x	
L11-B			x	
De Ruyter			x	
G17d-A			x	
K12-G			x	
L05-B			x	
L08-P			x	
L09-FA			x	
L09-FB			x	
L09-FF-1			x	x
M7-A			x	
N07-FA-1			x	
P15-E			x	
P15-F			x	

3 Selection of new locations proposed in the TNW proximity

Considering the Dutch roadmap for the development of the future offshore wind farms, new wind projects will be planned in more northernly locations, further from the coast. In these remote areas there are no available meteorological masts (met masts) and no LiDAR measurement campaigns running. This leads to higher uncertainties in regard to establishing a long-term assessment of the wind resource, as developers will need to rely on measurement locations farther from site, on re-analysis data, or other models. As described in the previous section, there are KNMI stations currently measuring meteorological wind conditions, however, these measurements are performed at a low height that is not applicable for the predicting the wind speeds at hub heights of present and future large wind turbines. Therefore, it is recommended to implement additional measurement locations installed with LiDAR systems to cover the area above the Waddeneilanden, where large amounts of wind farms are expected to be deployed in the near future. For the installation of a LiDAR system, existing infrastructure can be considered.

For the selection of a new location, it is important that the platform will be in operation for several years to allow the measurement campaign to run for at least 5 years, and preferably longer. Longer data sets provide a better understanding of annual wind variability, help reduce uncertainty, and reduce seasonal biases. Therefore, a selection of promising locations has been made considering the existing platforms in the North Sea and their expected dismantling date after 2027, see Figure 5.

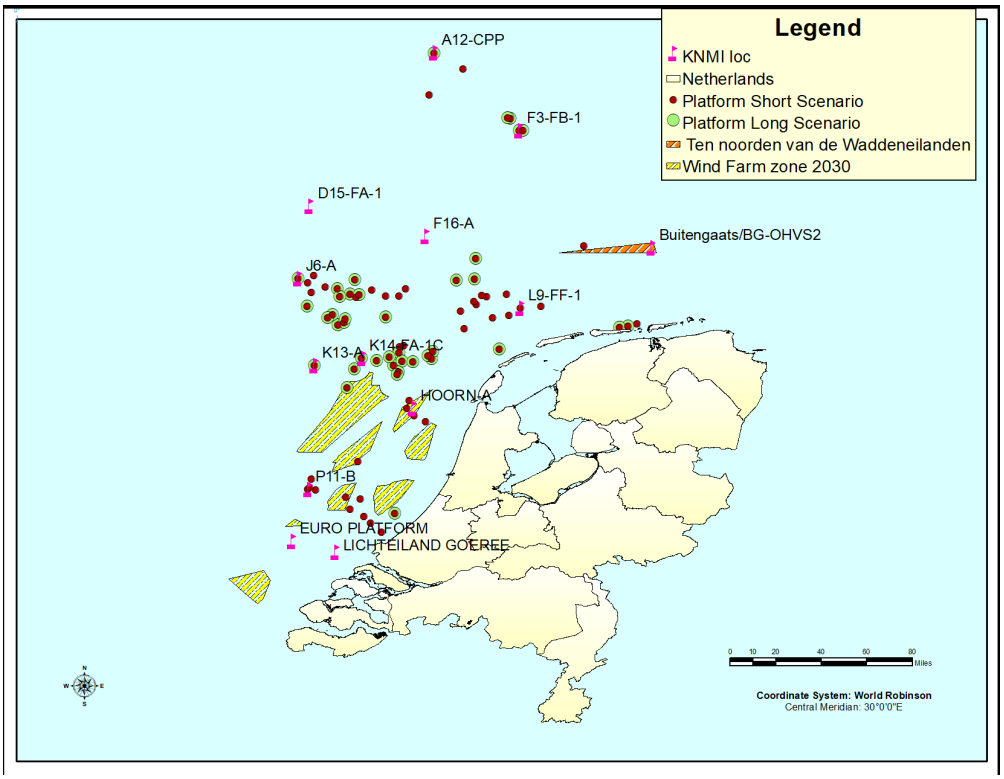

Figure 5 Platform expected to be dismantled after 2027, in the short scenario (red circle) and long term scenario (green circle) term scenario; and KNMI meteorological stations (pink flag)

It is also preferable that the locations are in proximity of future wind energy development areas but not too close for the reason that the wind measurements are heavily influenced by the wind farms themselves. Wind farms notably influence the wind conditions over a very long distances downstream, causing wakes that lead to reduced wind speeds overall. Therefore, to keep the distances practical, all platforms situated in an area within 30 km distance from existing and planned wind farms are excluded. In this regard, Figure 6 shows a buffer distance around the wind farm zones of 30km (light orange) and 40km (dark orange) to highlight the proximity of the available platforms to either existing or planned wind farms by 2030.

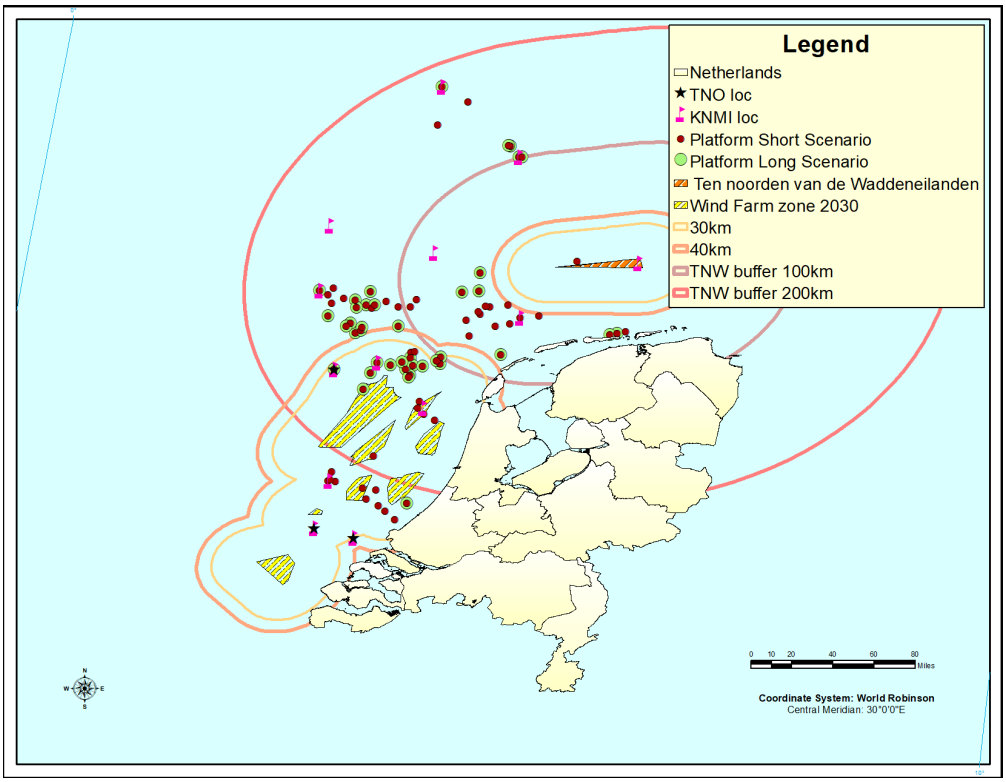

Figure 6 Platform expected to be dismantled after 2027 in the short scenario (red circle) and long term scenario (green circle) term scenario; and KNMI meteorological stations (pink flag). Radius distances from wind farm zones are illustrated: 30km and 40km from the existing wind farms zones, 30km, 40km, 100km and 200km from TNW wind farm area

The remaining platforms are investigated considering the location of KNMI site measurements and TNO's long-term measurement campaigns. The region was divided into four cluster zones for the possible deployment of an additional LiDAR long term measurement campaign. These locations are illustrated in Figure 7. A description of each cluster and the list of platforms in each zone is provided in the following list:

- **Zone 1** – North (purple pin). This cluster contains one platform, the G17-dA, expected to be dismantled after 2027 only in the long scenario. It is located in the boundary of the Ten Noorden van de Waddeneilanden (TNW) wind farm planned zone; with a foreseen installation of 0.7 GW by 2030. This platform represents an excellent location for addressing the wind condition at TNW site. Nevertheless, once the wind farm construction stage will start, this site will be strongly influenced by all the installation activities required and once operational, by the wake effects generated by wind farm itself. Therefore, this location represents a short-term measurement location, as after 2030 it is expected that the measured wind resource will be strongly affected by the presence of the neighbouring wind farm. Furthermore, as already mentioned, G17-dA platform is expected to be dismantled after 2017 only in the Long scenario, meaning that there are higher probability for this platform to be dismantled before.

- **Zone 2** – West (green pins). This cluster is located around 50km West from the TNW site. This zone contains three platforms, L02-FA, L05-FA and L05-D, all of

which are expected to be dismantled after 2027 in all the scenarios. This zone is situated in the free space between the areas of TNW and the areas selected for the Hollandse Kust wind farms and IJmuiden Ver. Therefore, this location represents a promising area, which will be less affected by the existing and future wind farms operations. At the same time, it is located fairly close to the TNW site which will provide a good measurement of the wind resource for the wind farm.

- **Zone 3** – North (red pins). This cluster is located in the North part of the Dutch sea, between 100 and 200km distance from the TNW site, comprising of: F03-FB, F03-FB-LT and A12-CP, the latter also KNMI platforms. As previously mentioned, the new wind farm zones selected for the scenario after 2030 are located in the northern part of the Dutch sea. Therefore, this location can be considered strategically important for monitoring the wind resource where currently there are not any high-quality measurement devices, except for the one at low height of KNMI.

- **Zone 4** – West (blue pins). Finally, the last cluster is located further west from Zone 2. This location is closer to the Hollandse Kust and IJmuiden Ver areas, around of 50km, and about 100km distance from TNW site. It contains 6 platform (K-04, K-05,K-06,K-07,K-08 and J-06) of which only one, J-06-Markham is also a KNMI measurement location. Nevertheless, these platforms are also close to the location of K13-A, platform on which TNO is already conducting a long-term measurement campaign.

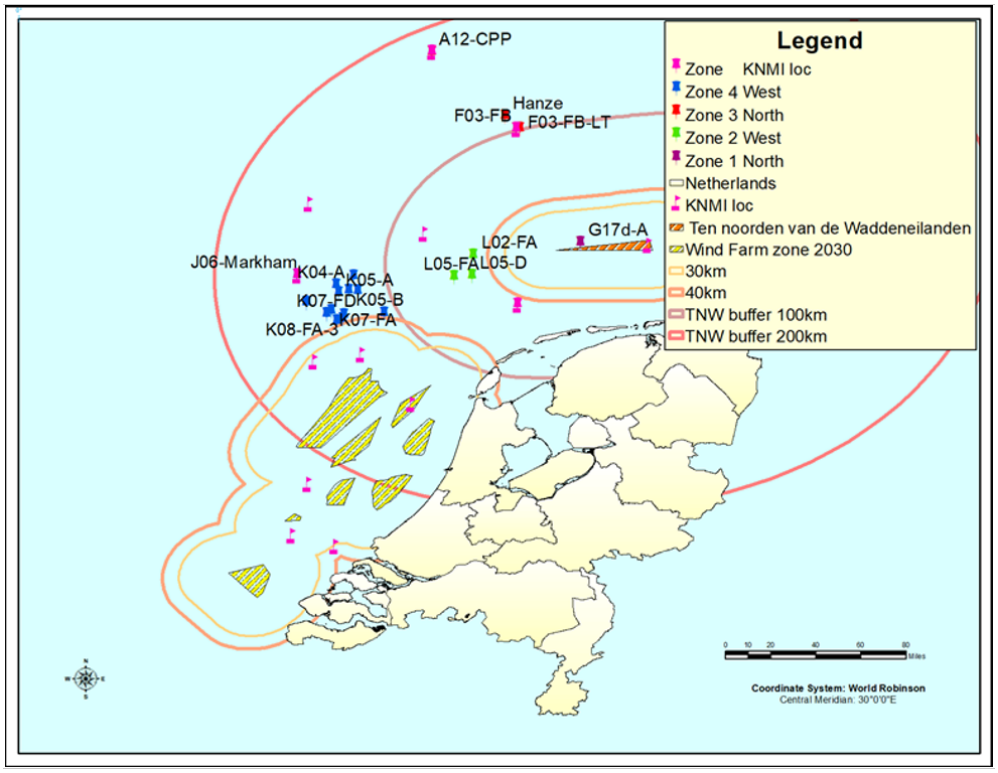

Figure 7 Selected platforms zone for further investigation based on the location

3.1 International wind energy deployment plan of the North Sea

As mentioned in the previous section, the location of neighbouring wind farms is relevant for the selection of a new site for a LiDAR measurement campaign. The North Sea expects a large-scale deployment of wind farms not only from the Netherlands but also from all the neighbouring countries who have direct national waters of their own. Therefore, international plans are hereafter addressed. In particular, the neighbouring countries who's national water's border that of the Netherlands offshore area, and also aiming to deploy wind farms in the North Sea are: United Kingdom, Belgium and Germany. In this analysis, two scenarios are considered: wind farms that are planned to be operational before 2030 and search areas for wind farm deployment after 2030.

The following maps illustrate these two scenarios in combination with the available platform locations. Wind farms zones operational by 2030 are illustrated in Figure 8 and Figure 9 highlights the four cluster of selected platforms. It can be seen that Zone 1, Zone 2 and Zone 3 will not be affected by the operational wind farms from the neighboring countries. However, the conclusion is different for Zone 4, which is expected to be in the nearby vicinity of both Dutch and UK wind farms. When addressing the scenarios after 2030, a more crowded North Sea is illustrated in Figure 10, with additional search areas from the Netherlands, Belgium and Germany. Observing Figure 11 apart from the Dutch areas which will be located in the surrounding of Zone 1, Zone 2 and Zone 4, the expected search areas considered for the German offshore deployment will be in the direct vicinity of Zone 3.

In conclusion, it is important to consider in the analysis the potential wake effects of expected international offshore wind farms. It is recommended to select a platform among Zone 2 and Zone 3. Zone 2 will provide relevant information on the wind resource for the wind farm planned by 2030, whereas Zone 3 will be more relevant for the long-term scenarios, after 2030.

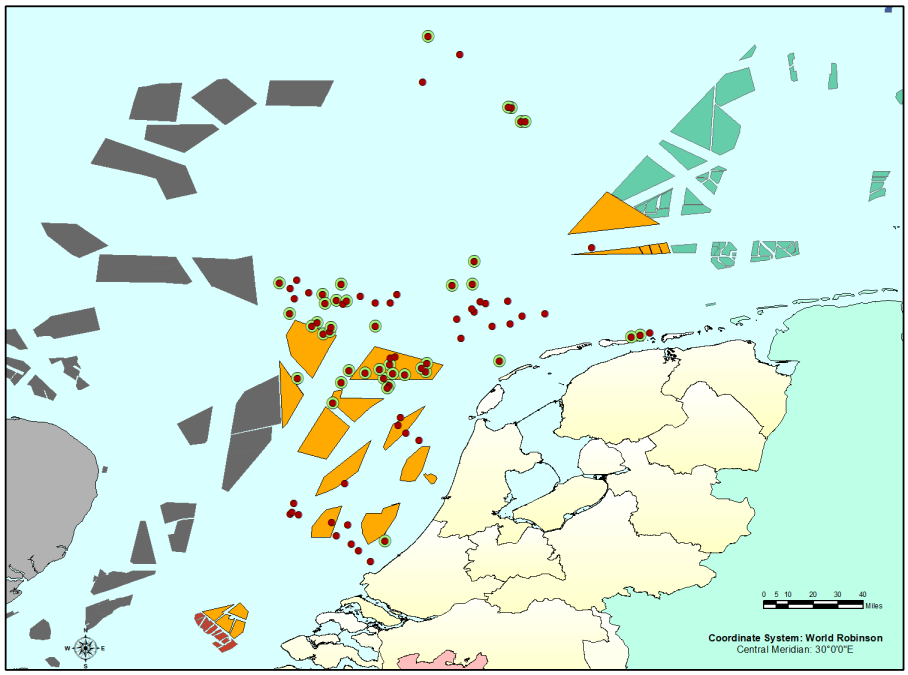

Figure 8 Wind farms zone planned to be operational before 2030 for UK (grey), BE (red), GE (green), NL (orange), oil and gas platforms

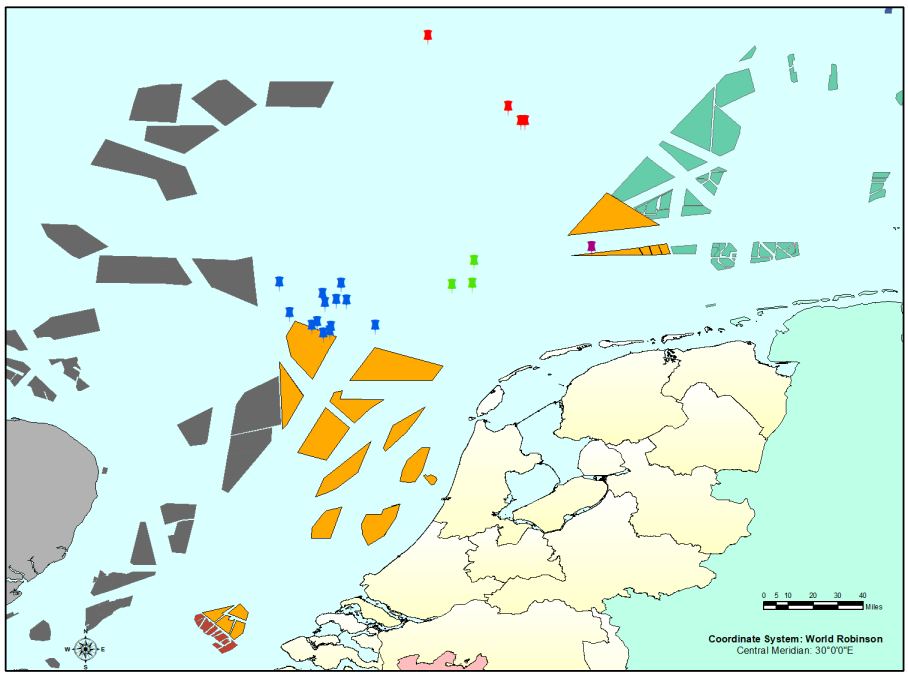

Figure 9 Wind farms zone planned to be operational before 2030 for UK (grey), BE (red), GE (green), NL (orange) and the 4 selected zones of oil and gas platforms for wind measurement siting

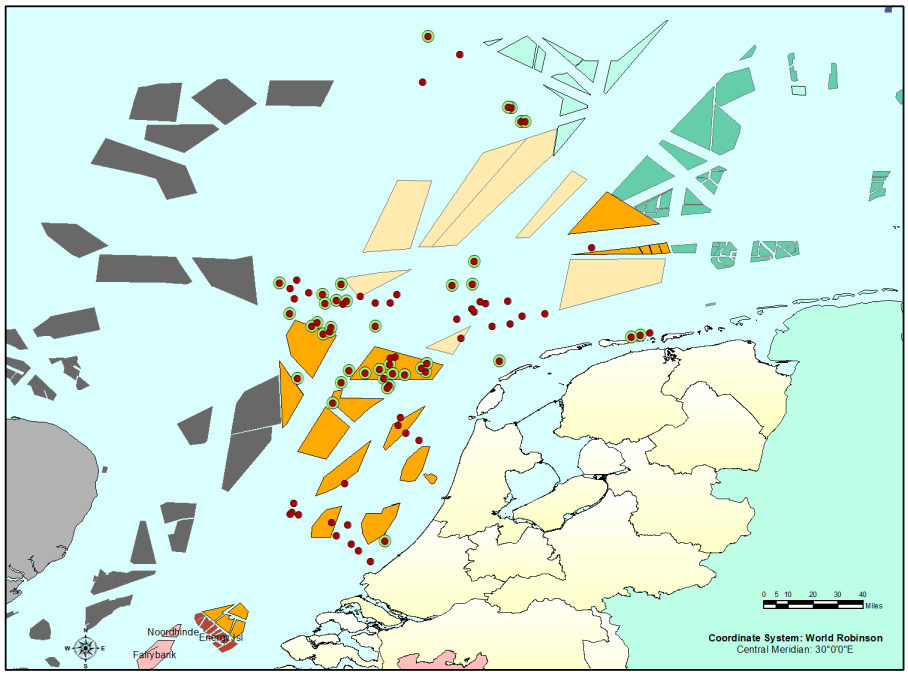

Figure 10 Wind farms zone planned to be operational before 2030 for UK (grey), BE (red), GE (green), NL (orange), search areas for wind farm after 2030 for GE (light green), NL (light orange) and oil and gas platforms

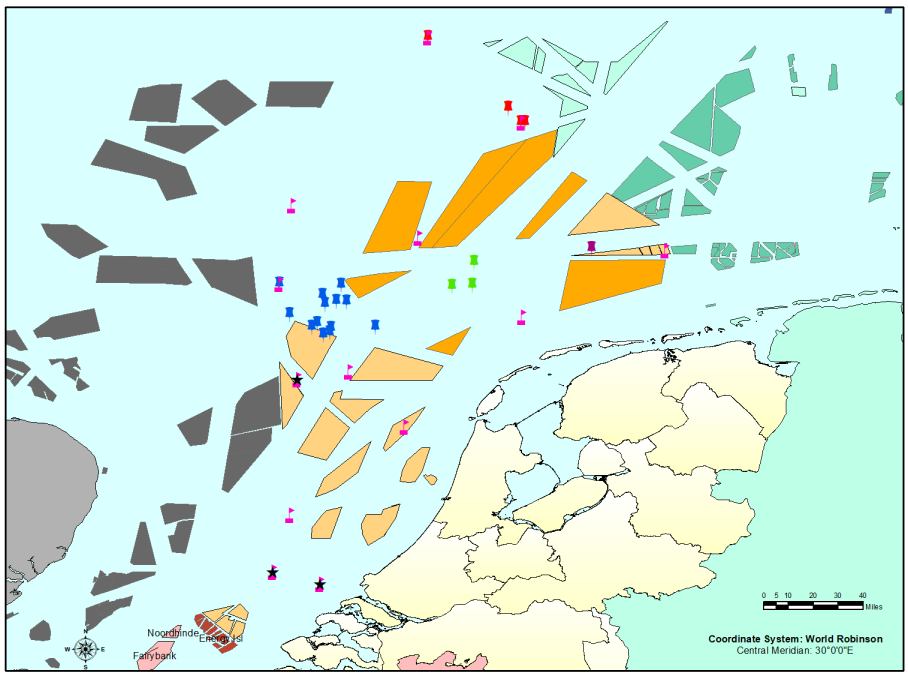

Figure 11 Wind farms zone planned to be operational before 2030 for UK (grey), BE (red), GE (green), NL (orange), search areas for wind farm after 2030 for GE (light green), NL

(light orange) and the 4 selected zones of oil and gas platforms for wind measurement siting

As final remark on the effect of current operational and future wind farms on the measurements location, in the following Figure 12 [12], the prevailing wind direction are shown for the three locations, where TNO is performing long term measurements campaigns. These three locations are the aforementioned EPL, LEG and K13a platforms. The Figure shows the wind roses for the wind resources over the period 2016-2021. The North Sea is influenced by a wide range of oceanic effects including the large-scale atmospheric circulation North Atlantic Oscillation (NAO), North Atlantic low pressure systems and tides and continental effects (freshwater discharge, heat flow, input of pollutants) [12]. The prevailing wind direction from the monitored locations is the South-West direction.

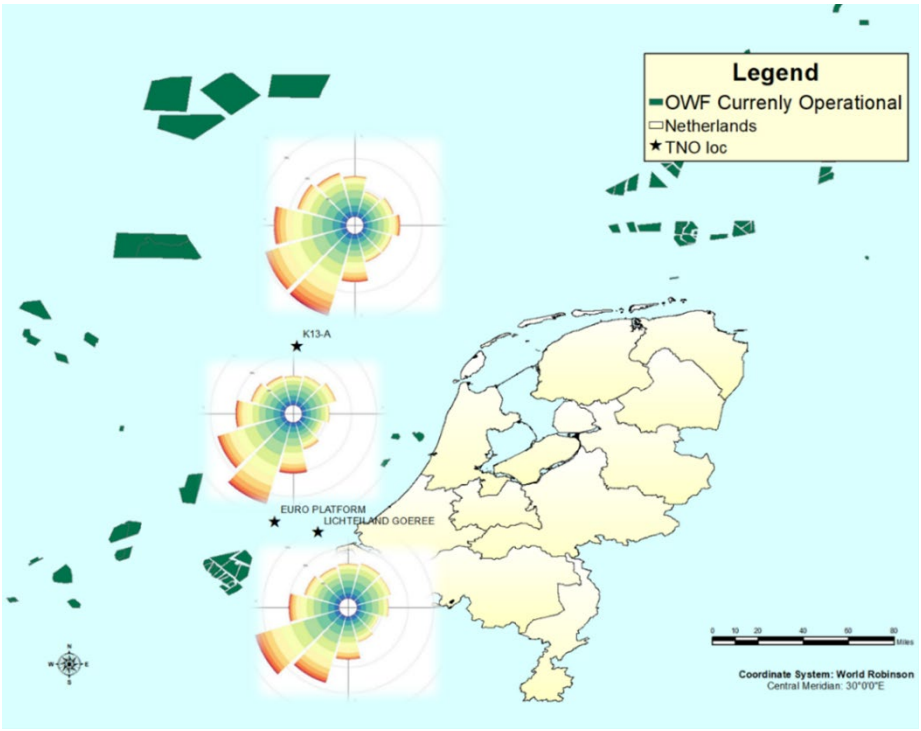

Figure 12 International and Dutch offshore wind farms currently operational and TNO measurement locations with wind roses at 141m for the 2016-2021 period [12]

3.2 Final platform suggestion

Finally, a list of selected platforms is hereby presented. All the platforms selected are expected to be decommissioned after 2027 in all the three addressed scenarios. For the measurement of wind condition to address wind resource for the planned wind farms by 2030, the most suitable location are the platforms in Zone 2. This cluster contains three locations:

- L02-FA,
- L05-FA and
- L05-D.

For the measurement of the wind conditions for the wind farm planned after 2030, a platform from Zone 3 is a more suitable candidate as they are located further North,

where there are currently no measurement campaign running. The platforms in Zone 3 are:

- F03-FB,
- F03-FB-LT and
- A12-CP;

of which the last two are recommended as they are also KNMI measurement locations. As already mentioned, the expected date for decommissioning can vary year by year. For this analysis, only data from 2021 are used, thus it is recommended to contact the platform operator to confirm the decommissioning data before concluding with the selection.

3.3 Instrumentation and measurement campaign

As mentioned in Section 2, TNO is performing LiDAR long-term measurement campaigns at three platforms in the North Sea. For these campaigns two types of LiDAR are used: a LEOSPHERE WINDCUBE V2 LiDAR for the Lichteiland Goeree (LEG), and a Zephir ZX300 LiDAR at the Europlatform (EPL) and at K13a platforms. For each location an instrumentation report is available [13], [14], [15], which contains valuable information regarding suggestions of the instrumentations to be applied in the new location. The reports provide detailed information on the instrumentation used, its mechanical and electrical installation and the setting of the measurements, such as measurement heights, orientation and data format. Furthermore, these reports present results following the data handling, quality control and exporting of the generated data. Finally, they describe the operation and maintenance (O&M) aspects of the measurement campaign.

In addition to monitoring wind conditions on site, TNO also recommends the deployment of additional data monitoring systems. Several metocean conditions such as wave, current and other meteorological data, are fundamental inputs for other design, and assessment activities of wind farms.

Waves information can be used to estimate the spatial variation of the extreme wave conditions required for design calculations of a wind farm project. Currently available wave measurement data provide low spatial and temporal resolution and are limited in the measurement length period. Accurate high resolutions waves measurements will support the roll-out of the planned wind farms in the upcoming years. Therefore, a buoy installation is recommended for wave monitoring.

4 Conclusion

Considering the different scenarios of wind energy deployment in the Dutch and international North Sea, the need for new, accurate, high-resolution wind condition measurements is paramount for the future success, and feasibility of new wind farms. The importance for new locations is described in [5]. In this report, potential new sites are addressed. When selecting a new location, several parameters are considered, including the location of existing and future wind farms, the location of KNMI site measurements, the location of TNO's current long-term measurement campaigns and finally the oil and gas platforms available in the North Sea along with their decommissioning plans. From this analysis, four strategically positioned zones were selected which contain a cluster of platforms. In addition, international developments were also considered to address wind flow effects due to potential neighbouring wind farms.

The conclusions from this analysis is a list of 6 platforms, 3 located in the surrounding of the expected wind farm zones in the scenario by 2030, and which are relevant for TNW site. These were found to be: L02-FA, L05-FA and L05-D. The other three platforms are located in northern sector of the Dutch North Sea and represent a strategical location for monitoring the wind conditions of future wind farms for the scenario after 2030. The recommended platforms are: F03-FB, F03-FB-LT and A12-CP.

After a discussion with RVO it has been agreed to further investigate the L02-FA platform.

Nevertheless, it is recommended to contact the direct oil and gas platform operators to verify the exact decommission date, as it is subject to changes in time due to different parameters and restrictions.

Finally, a brief instrumentation description has been provided, referring to the instrumentation reports of the current TNO long-term wind condition measurement campaigns running since 2014 at ELP, LEG and K13-a. New metocean monitoring sensors are also recommended to provide better insight into the environmental conditions in the North Sea. One of these systems is a wave monitoring radar, which can provide valuable information on the wave conditions necessary for the wind farm design-related activities.

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