DNV·GL

THOR OFFSHORE WIND FARM

Certification Report Concept

Energinet Eltransmission A/S

Report No.: CR-C-DNVGL-SE-0190-07164-0
Date: 2021-02-26

Project name:	Thor Offshore Wind Farm	DNV GL Energy
Report title:	Certification Report Concept	Renewables Certification Det Norske Veritas, Danmark A/S
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Date of issue:	2021-02-26	
Project No.:	10273553 / 644363	
Report No.:	CR-C-DNVGL-SE-0190-07164-0	
Applicable contract(s) governing the provision of this Report:		
	209648-SFA-20201210, PO nb. 4500048702	

Objective:

To confirm the successful evaluation of the conceptual metocean site conditions for the Thor Offshore Wind Farm according to DNVGL-SE-0190.

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Keywords:

Concept, Thor Offshore Wind Farm

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2021-02-26	Issue of Feasibility Statement	IPL	JSIMON	PR

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1 EXECUTIVE SUMMARY

This report confirms that DNV GL, as accredited Certification Body, has verified the conceptual meteorological and marine (metocean) site conditions documentation for the Thor Offshore Wind Farm (OWF) according to the service description in DNVGL-SE-0190:2020-09 for Project Certification Phase 0: Concept, for Energinet Eltransmission A/S (Energinet), the Danish national transmission system operator for electricity and natural gas. The conceptual metocean site conditions evaluation can be taken as background for subsequent DNVGL-SE-0190 and IECRE OD-502:2018 certification phases.

The aim of the Concept phase according to the service description in DNVGL-SE-0190 is to provide an overview of design parameters and design methods intended for the project, for an early identification of critical items, if any. The conceptual metocean site conditions assessment for Thor OWF is part of the Concept certification phase and produces preliminary metocean design parameters to be applied for preparing a tender for the Thor OWF concession.

The 440 km^2 Thor OWF will be established in the North Sea, west of Nissum Fjord, minimum 20 km from shore and is planned to have a capacity of minimum 800 MW and maximum 1000 MW and to be in full operation no later than ultimo 2027. The gross area, wherein the Thor OWF will take up part of the area, is shown in Figure 1 below.

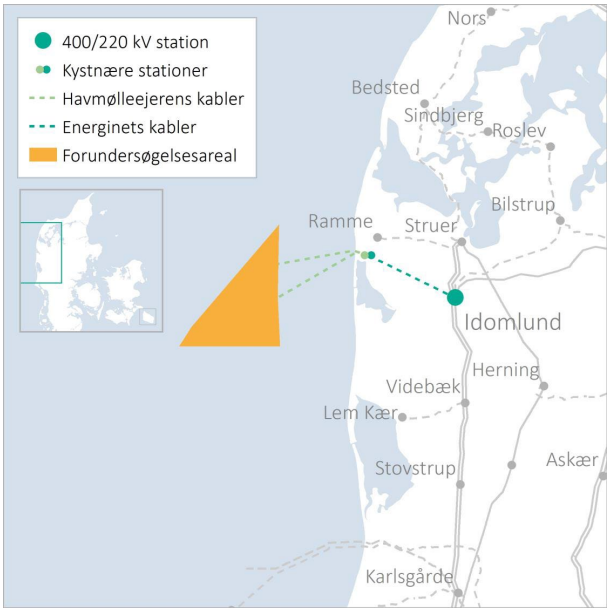

Figure 1: Map showing the gross area (orange polygon), whereof the Thor OWF will take up part [From /3/ figure 1.1]

As expected for a tender phase, the data is not as complete as for a design basis phase, and the DNV GL evaluation does not provide a general approval of metocean design parameters or methods for the subsequent Design Basis certification phase according to DNVGL-SE-0190, for which more detailed documentation and review is required.

DNV GL's verification of plausibility for the conceptual metocean design parameters is based on document review and described in the appendices to this report, see section 3. A summary of conditions and outstanding issues, if any, is listed in section 5 and section 6.

The technical plausibility check performed by DNV GL confirms that the documentation from Energinet related to the Thor OWF tender process as listed in appendix A section A4 fulfils the relevant demands set up in the applied Certification scheme.

2 CERTIFICATION SCHEME

The applied Certification Scheme is listed below:

Document No.	Title
DNVGL-SE-0190:2020-09	Project certification of wind power plants

3 LIST OF REPORTS

The appendices to this report comprise the detailed DNV GL certification reports which normally include reference standards/documents, list of design documentation as well as summary and conclusion of the DNV GL evaluation.

APPENDIX	Revision	Subject
A	0	Conceptual metocean site conditions
B	0	Summary of key approved conceptual metocean site conditions

4 CONDITIONS

The conditions identified during the technical evaluation are listed in the following. The conditions are assigned to the certification phases in which they need to be considered and evaluated:

For the Design Basis and Design certification phases, the following shall be determined:

- DNV GL has evaluated the documentation /1/ - /3/, defined in section A4, for conceptual design data and the design parameters presented are suitable for conceptual design only. For the design basis certification phase the metocean parameters shall be further analysed, e.g.
    - the meteorological conditions shall be further justified, if possible with observations close to the site
    - the current speed and direction shall be validated
    - consistency between wind forcing of the models and design wind shall be analysed
    - more refined hindcast model set-ups are recommended
    - the wave crest levels shall be further justified
    - more detailed wave breaking assessment shall be included.

5 OUTSTANDING ISSUES

There are no outstanding issues for the conceptual metocean site conditions part of the Concept Certification Phase.

6 CONCLUSION

Under consideration of the conditions listed in Section 4, the technical plausibility check performed by DNV GL confirms that the documentation from Energinet related to the Thor OWF tender process as listed in appendix A section A4 fulfils the relevant demands set up in the Certification scheme specified in Section 2.

Summary of key approved conceptual metocean data is given in Appendix B.

APPENDIX A
Conceptual metocean site conditions

Evaluation of Conceptual metocean site conditions for Thor Offshore Wind Farm

A1 Description of verified component, system or item

This appendix describes the DNV GL evaluation of the conceptual meteorological and marine (metocean) site conditions for the Thor Offshore Wind Farm (OWF) according to DNVGL-SE-0190:2020-09.

The conceptual metocean site conditions assessment (SCA) produces preliminary metocean design parameters to be applied for preparing a tender for the Thor OWF concession.

As expected for a tender phase, the data is not complete as for a design basis phase, and the DNV GL evaluation does not provide a general approval of design parameters or methods for the subsequent Design Basis certification phase according to DNVGL-SE-0190, for which more detailed documentation and review is required.

The conceptual metocean SCA for Thor OWF is developed by the project organization Energinet Eltransmission A/S (Energinet) with contributions from C2Wind and DHI; the conceptual metocean SCA documentation is defined in section A4 below.

A2 Interface to other components/systems

The conceptual metocean SCA evaluation is part of the Concept certification phase of the Project Certification Scheme specified in DNVGL-SE-0190:2020-09 and can be taken as background for subsequent DNVGL-SE-0190 and IECRE OD-502:2018 certification phases.

A3 Basis for the evaluation

The Applied codes and standards used in combination with the Certification Scheme DNVGL-SE-0190:2020-09 are listed below:

Doc. No.	Rev.	Title
DNVGL-ST-0126	2016-04	Support structures for wind turbines
DNVGL-ST-0437	2016-11	Loads and site conditions for wind turbines
IEC 61400-1	2019-02	Wind energy generation systems – Part 1: Design requirements
IEC 61400-3-1	2019-04	Wind energy generation systems – Part 3-1: Design requirements for fixed offshore wind turbines
DNVGL-RP-C205	2019-09	Environmental conditions and environmental loads

The evaluation has been based on the following loads, design basis as well as other specific criteria:

Ref.	Doc. No.	Rev.	Title
[UKHSE]	-	2002	Offshore Technology Report, Environmental considerations. Doc 2001/010. Health & Safety Executive (2002).
[HANNESDOTTIR19]	-	2019	Hannesdóttir Á., Kelly M., Dimitrov N. Extreme wind fluctuations: joint statistics, extreme turbulence, and impact on wind turbine loads. Wind Energ. Sci., 4, 325–342 (2019). Link: https://doi.org/10.5194/wes-4-325-2019
[POLLAK]	-	2014	Pollak D. A. Characterization of Ambient Offshore Turbulence Intensity from Analysis of Nine Offshore Meteorological Masts in Northern Europe. DTU Wind Energy Master Thesis M-0056. EWEM/DTU/UO (2014-08-03). http://www.pcwg.org/proceedings/2014-10-06/06-Turbulence-Intensity-measmnts-offshore-4-PC-verification-wind-res-assmt-R-RiveraLamatA-D-Pollack-Dong.pptx.

A4 Documentation from customer

The conceptual metocean SCA documents for the Thor OWF are defined as the following documents:

Ref.	Doc. No.	Rev.	Title
/1/	19009-4	2 / 2021-01-29	C2Wind for Energinet Eltransmission A/S: Thor Offshore Wind Farm - Wind Conditions for a Light Site Conditions Assessment
/2/	19009-3	1 / 2020-12-26	C2Wind for Energinet Eltransmission A/S: Thor Offshore Wind Farm - Description of measurement datasets
/3/	proj. no. 11824164	Final 2.0 / 19-11-2020	DHI: Thor Offshore Wind Farm - Metocean Hindcast Data and Validation Report

List of documents taken for information only:

Ref.	Doc. No.	Rev.	Title
/A/	-	2021-02-01	E-mail from Rémi Gandoin to [Iris Pernille Lohmann, Gema Parro]. Dated: ma 01-02-2021 14:21. Subject: "RE: Thor Havmøllepark: VCS replies & sending updated Doc. No. 19009-4"
/B/	ECN-E--14-058	February-2015	Wind measurements at Meteorological Mast Ijmuiden (J.P. Maureira Poveda, D.A.J. Wouters), (https://publicaties.ecn.nl/PdfFetch.aspx?nr=ECN-E--14-058)

A5 Evaluation work

The DNV GL evaluation activities are outlined in this section. To facilitate the overview of the approved conceptual metocean site specific conditions the key data are presented in tabular form in Appendix B.

The DNV GL verification of the conceptual metocean site conditions is primarily based on document review assisted by minor independent calculations, with focus on the technical plausibility of the conceptual metocean design parameters specified in the metocean site conditions documents (Section A4). DNV GL's communication with the customer during the verification process has been through Verification Comment Sheets (VCS) where Technical Queries, Non-Conformances and Advices to the documents that constitute the verified conceptual metocean SCA may be raised.

A5.1 Meteorological Site Conditions

The meteorological conditions for conceptual design for this project encompass the site conditions related to mainly wind, where a distinction is made between normal and extreme conditions.

The meteorological parameters for conceptual design are developed by C2Wind as described in /1/ based on, for example, wind resource assessments from Høvsøre and Horns Rev M2 meteorological masts, New European Wind Atlas (NEWA) and ERA5: Copernicus Climate Change Service (operational wind speed), IJmuiden meteorological mast and LiDAR data set (operational wind shear, wind profile for load calculations, ambient and characteristic turbulence), Offshore technology report, Health & Safety Executive [UKHSE] (extreme wind speed), research article [HANNESDOTTIR19] (extreme turbulence model), New European Wind Atlas (mean air temperature) and Horns Rev M2 and FINO3 meteorological masts (air density). The wind shear and turbulence intensity, both for EWM, have been decided according to IEC 61400-1.

DNV GL finds that the methodologies applied in /1/ and /2/ for deriving the conceptual meteorological design parameters are according to best engineering practice. DNV GL has evaluated the conceptual site conditions presented in /1/ for plausibility, and found them suitable for conceptual design, though considered to be on the low side as per DNV GL's expectations in the area.

A5.2 Marine Site Conditions and wind-wave correlation

The marine conditions for conceptual design for this project encompass the site conditions related to mainly water levels, waves and currents, where a distinction is made between normal and extreme conditions.

The main part of the marine parameters for conceptual design for Thor OWF are developed by DHI and given in the DHI marine hindcast report /3/, which presents results and analyses from the hydrodynamic hindcast model MIKE21 HD (water levels and currents) and spectral wave hindcast model MIKE21 SW. Further to /3/, a data package including hindcast data associated with /3/ is part of the DHI delivery for the conceptual design.

The DNV GL plausibility review is only including parameters presented in the DHI report /3/. Other required metocean parameters, such as e.g. water density, water temperature, marine growth, as well as some parameters where further analyses of the data in the DHI delivery are required, are left open to the designers for conceptual design and possible subsequent 3rd party review.

All hindcast models described in /3/ are forced with the high-resolution reanalysis COSMO-REA6 (CREA6) dataset developed by the Hans-Ertel-Centre of the Deutscher Wetterdienst and the University of Bonn in Germany. The wind and wave correlations are thus obtained from the CREA6 wind, which may be different from the conceptual wind /2/. Consistency between the CREA6 wind and the conceptual design wind /2/ has not been investigated for conceptual design, however, the verification of CREA6 wind with local wind measurements gives confidence that the wind used for wind-and-wave correlations is acceptable for conceptual design.

In the data package associated with /3/, the waves are divided into wind-sea and swell-wave components, so that the designers may choose to apply these in the design, or to apply the total wave component. Further, data are extracted at 3 locations covering the site, so that the designers may choose a design based on the most conservative marine conditions of the three locations, i.e. covering the whole site, or alternatively a design based on the marine parameters at specific locations within the site. Finally, a timeseries of directional spectra is provided at another geographical point on the site, almost coinciding with one of the 3 geographical points mentioned above. This timeseries of directional spectra can be used by designers to analyse wave components (e.g. using some separation criterion for wind-sea and swell) that suit the specific needs of the designer.

The extreme values are based on extreme value analysis of the background data as described in /3/. Detailed wave breaking analysis is not performed for conceptual design, and the choice of how wave breaking is included in the conceptual design is left with the designers.

Relating to the extreme crest elevation with various return periods, these are given based on two methods:

- Stream function theory
- Statistical convolution of the long-term probability distribution of the most probable waves with the short-term probability distribution (represented by the Forristall distribution) of the individual crest elevations given the most probable wave heights

The stream function wave crest elevations include high order non-linearity and thus represent the maximum wave crest elevation which is possible for a given maximum individual wave H_{max}. However, the wave crest elevations are stochastic and may therefore be over-estimated by the maximum possible wave crest elevation found by the stream function theory.

Conversely, the Forristall distribution does not take into consideration higher order non-linearity as the stream function theory, and therefore the statistical convolution, though including the stochastic process, may yield under-estimated wave crest levels.

This is addressed in DNVGL-RP-C205:2019 section 3.5.10.4:

It should be noted that the Forristall distribution is based on second order simulations. Higher order terms may result in slightly higher crest heights. Hence extremes predicted by this distribution are likely to be slightly on the low side. To account for higher order non-linearities, it is recommended to increase the maximum crest height with a factor 1.05.

For the conceptual marine parameters presented in /3/, the crest elevations obtained with the stream function theory are around 9 % larger, in m MSL, than the crest elevations obtained with the statistical convolution based on the Forristall distribution. DNV GL has accepted the crest elevations from both methods for conceptual design. In the design basis phase one set of crest levels should be given, for example by adhering to the above cited recommendation in DNVGL-RP-C205.

DNV GL finds that the applied hindcast models are state of the art, and the methodologies applied in the extreme value analysis and for deriving the conceptual marine design parameters in /3/ are according to best engineering practice. DNV GL has evaluated the conceptual marine design parameters presented in /3/ for plausibility and found them to agree with DNV GL's expectations in the area. Though e.g. local and more refined hindcast setups should be used for detailed design parameters (please refer to section A6), DNV GL finds the parameters given in /3/ suitable for conceptual design.

A6 Conditions to be considered in other certification phases/modules

The conditions identified during the technical evaluation are listed in the following. The conditions are assigned to the certification modules in which they need to be considered and evaluated:

In the Design Basis certification phase, the following shall be determined:

- DNV GL has evaluated the documentation /1/ - /3/, defined in section A4, for conceptual design data and the design parameters presented are suitable for conceptual design only. For the design basis certification phase the metocean parameters shall be further analysed, e.g.
    - the meteorological conditions shall be further justified, if possible with observations close to the site
    - the current speed and direction shall be validated
    - consistency between wind forcing of the models and design wind shall be analysed
    - more refined hindcast model set-ups are recommended
    - the wave crest levels shall be further justified
    - more detailed wave breaking assessment shall be included.

A7 Outstanding issues

There are no outstanding issues for the conceptual metocean site conditions part of the Concept Certification Phase.

A8 Conclusion

Under consideration of the conditions listed in Section A6, the technical plausibility check performed by DNV GL confirms that the documentation from Energinet related to the Thor OWF tender process as listed in Section A4 fulfils the relevant demands set up in the Section A3 Basis for the evaluation and Certification scheme specified in Section 2 of the main report.

Summary of key approved conceptual metocean data is given in Appendix B.

APPENDIX B
Summary of key approved conceptual metocean site conditions

Wind conditions – Normal	
Annual average wind speed (at proposed hub height 140.0 m MSL)	10.50 m/s
Weibull A-parameter	11.85 m/s
Weibull k-parameter	2.3
Wind shear for extrapolation in the interval [114;164] m MSL	0.06
Wind shear for load calculation	0.09
Ambient turbulence / characteristic turbulence at 15 m/s (NTM)	5.0% / 6.9%
Air density	1.23 kg/m^3
Wind conditions – Extreme	
Wind speed 50-year recurrence, 10 min. (at proposed hub height)	47.0 m/s
Wind shear for EWM	0.11
Turbulence intensity for use with EWM	11%
Air density	1.21 kg/m^3
Most conservative marine conditions (at the location P1, P2 or P3 as indicated)	
Highest astronomical tide (HAT) (P3)	+0.6 m MSL
Lowest astronomical tide (LAT) (P2 and P3)	-0.6 m MSL
Significant wave height for 50-year recurrence period, $H_{m0,50\text{-}yr}$ (P1)	9.7 m
Significant wave height for 1-year recurrence period, $H_{m0,1\text{-}yr}$ (P1)	7.1 m
Peak wave period $T_{p,50\%}$ for extreme for 50-year recurrence wave $H_{m0,50\text{-}yr}$ (P1)	14.9 s
Peak wave period $T_{p,50\%}$ for extreme for 1-year recurrence wave $H_{m0,1\text{-}yr}$ (P1)	12.8 s
Extreme deterministic wave height for 50-year recurrence period, $H_{max,50\text{-}yr}$ (P1)	18.3 m
Extreme deterministic wave height for 1-year recurrence period, $H_{max,1\text{-}yr}$ (P1)	12.8 m
Extreme wave crest elevation* (Forristall) for 50-year recurrence period (P1)	13.8 m MSL
Extreme wave crest elevation* (Forristall) for 1-year recurrence period (P1)	9.2 m MSL
Extreme high-water level* for 50-year recurrence period (P3)	2.2 m MSL
Extreme high-water level* for 1-year recurrence period (P3)	1.6 m MSL
Extreme depth averaged current speed for 50-year recurrence period (P1, P2, and P3)	0.9 m/s
Extreme depth averaged current speed for 1-year recurrence period (P1, P2, and P3)	0.7 m/s

* excluding sea level rise and vertical land movement

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