FOWPI

FIRST OFFSHORE WIND PROJECT OF INDIA

Metocean Data Requirements

EUROPEAN UNION

This Project is funded by The European Union

1 About FOWPI

The First Offshore Wind Project of India (FOWPI) is part of the “Clean Energy Cooperation with India" (CECI) programme, funded by the European Union (EU). The programme aims at enhancing India's capacity to deploy low carbon energy production and improve energy efficiency, thereby contributing to the mitigation of global climate change. Project activities will support India's efforts to secure the energy supply security, within a well-established framework for strategic energy cooperation between the EU and India.

FOWPI is defined as a conceptual offshore wind farm near the coast of Gujarat, 25 km off Jafarabad. The project scope focus is on preliminary investigations and advisory for the wind farm including wind turbine foundation, electrical network, metocean modelling, wind resource, environmental scoping, financial modelling and others. FOWPI uses the outputs from Facilitating Offshore Wind in India (FOWIND) project (2013-2018) also supported by the European Union. FOWIND and FOWPI bring the vast experience of European countries in offshore wind, to support India with the creation of a national knowledge centre and with technical support for setting up the first offshore wind-farms in the country.

FOWPI is led by COWI A/S (Denmark) with support from COWI Pvt Ltd India and WindDForce Management Ltd. (India). The project is implemented in close collaboration with the European Union, the Ministry of New and Renewable Energy- India (MNRE) and National Institute of Wind Energy- India (NIWE).

Contract: No 2015/368469 Start 01-2016 Duration: 42 months

2 Disclaimer

This publication was produced with the financial support of the European Union for illustrative purposes only. Contents do not necessarily reflect the views of the European Union, or endorsements towards any particular project, product or service provider. The EU and authors provide no warranties or undertakings and are not liable for any type of loss of loss or damage, direct or indirect, resulting from the use of the information contained in the report.

3 Copyright statements

4 About the European Union

The Member States of the European Union have decided to link together their know-how, resources and destinies. Together, they have built a zone of stability, democracy and sustainable development whilst maintaining cultural diversity, tolerance and individual freedoms. The European Union is committed to sharing its achievements and its values with countries and peoples beyond its borders.

The 14th annual Summit between India and the European Union (EU) was held in New Delhi on 6 October 2017. Both sides adopted a Joint Statement on Clean Energy and Climate Change, reaffirmed their commitments under the 2015 Paris Agreement, and agreed to co-operate further to enhance its implementation. India and the EU noted that addressing climate change and promoting secure, affordable and sustainable supplies of energy are key shared priorities and welcomed the progress on the Clean Energy and Climate Partnership, adopted at the 2016 EU-India Summit, and reiterated their commitment to its implementation and further development. In particular the EU is committed to continue cooperation in view of the cost-effective development of offshore wind in India.

5 Acknowledgements

FOWPI is grateful for the support provided by European Union (EU), Ministry of New and Renewable Energy-India (MNRE), National Institute of Wind Energy- India (NIWE), and the Wind Industry.

6 Contact information

FOWPI Project Management

C/o Gabriel Zeitouni, COWI A/S
Parallelvej 2, 2800 Kongens Lyngby
Denmark

FOWPI Project Secretariat

C/o Nikhilesh Singh, WinDForce Management Services Pvt. Ltd.
Unit No: 408- 4th Floor Tower B,
Unitech Business Zone, Sector-50,
Golf Course Extension Road, Gurugram, Haryana – 122008
India

www.fowpi.in
info@fowpi.in

Metocean Data Requirements

Version No.	Document Released Date	Edited By	Modified Sections	Reason for Changes
Version 0	31/01/2017	JESP/SADA/KPMA		
Version 1.0	07/09/2017	JESP	None	From Draft to Version 1.0
Version 1.1	28/08/2019	GAZE	Front Pages	Layout/Format

COWI

METOCEAN DATA REQUIREMENTS

OFFSHORE WIND FOUNDATIONS

ADDRESS COWI A/S
Parallelvej 2
2800 Kongens Lyngby
Denmark

TEL +45 56 40 00 00
FAX +45 56 40 99 99
WWW cowi.com

PROJECT NO.	DOCUMENT NO.
A073635	A073635-014-003

VERSION	DATE OF ISSUE	DESCRIPTION	PREPARED	CHECKED	APPROVED
1.0	07/09/2017	First Issue	JESP	JSTE	PEVL

CONTENTS

1 Introduction

The present technical note describes the requirements for metocean data when being used by COWI for calculations of hydrodynamic interaction with Offshore Wind Turbine (OWT) foundations.

The note mainly serves as an internal COWI guideline to be used in projects related to OWT design. However, the note may also be distributed to clients as a guidance and specification of metocean data to be provided for COWI to make a robust and cost-efficient OWT foundation design.

The requirements are aligned with the specifications given in [1] and [2]. The present note gives details of these specifications as well as provides detailed requirements given by COWI. The present note is not considered as a stand-alone specification of needed metocean data, but shall be used in conjunction with project governing standards (e.g. [1] and [2]).

The background time series data for the metocean analysis can be site-specific measurements or from a calibrated hindcast model. For an Offshore Wind Farm (OWF) site with large horizontal extent or with large variations of seabed bathymetry, it will also be necessary to have information of the variation of the governing metocean parameters across the site.

2 General requirements

The general requirements to the basic background data for a metocean analysis is establishment of a site-specific database (e.g. by measured or hindcast time series data) containing information about the following:

- wind speeds and directions
- wave heights (significant and maximum), wave periods (spectral and individual) and wave directions
- information of partition into wind sea and swell components (if relevant)
- correlation of wind and wave statistics
- current speeds and directions (tidal and residual)
- water levels (tidal and residual)
- occurrence and properties of sea ice (if relevant)
- occurrence of icing (if relevant)
- other relevant metocean parameters such as air and water temperatures and densities, water salinity, site bathymetry, marine growth, etc.

The duration of the time series (hindcast and/or measured) shall cover a sufficiently long period. The period shall be at least 10 years (cf. [2]).

It is important that the data accuracy is assessed in the metocean report – e.g. by validation of hindcast data against site-specific measurements. If non-accredited oceanographic measurements are used (e.g. in case of historical measurements) the quality of data shall be state-of-the-art. Safety margins shall be given or added if the data accuracy is reduced when compared with site-specific measurements.

As the OWF may cover a large area, it is important that the metocean report includes information of the bathymetry variation over the entire area and preferably is including information of water depth for all positions. The vertical reference level (datum) shall be defined.

The metocean report shall include a discussion of probable sea level rise during the lifetime of OWF. The recommendations in [4] can be used.

For assessment of extreme conditions, the following average return periods shall be considered for OWT foundations: 1 year, 5 year and 50 year. For extreme conditions related to design of Offshore Sub Stations (OSS) the following average return periods shall be considered. 10 year and 100 year.

3 Wind Data

3.1 General

It is emphasized that an OWF metocean report does not constitute a full wind study, which would be required for wind turbine design or wind resource assessment. The analysis of the wind data carried out in an OWF metocean report is solely intended for foundation design. If the data and results of the separate wind resource assessment report are available, it will be beneficial for the overall reliability of the metocean study to make a comparative study.

The wind data shall be given as 10-minute average values at a height corresponding to 10m above Mean Sea Level (MSL). The wind speeds may also be given relative to the hub-height of the wind turbine (if this is known). A conversion formula relating various average periods and vertical levels shall also be specified (the relation given in [3], section 2.3.2.11 may be used).

3.2 Operational wind data

The operational wind data shall be described by a wind rose (graphical plot and in tabular form). The directional sectors shall be 30° or less.

Statistics (maximum, minimum, mean and standard deviation) of wind speeds on a monthly as well as annual basis shall be given. Directional statistics (in sectors of 30º or less) shall also be given.

Scatter plots and scatter tables of wind speed versus wind directions shall be provided. The interval of any wind speed bin used in the above shall be 2 m/s or less (bins of 1 m/s is preferred), and the wind direction sectors shall be 30° or less.

3.3 Design wind data

The metocean report related to foundation design does not replace a full wind study for turbine design or wind resource assessment. The extreme wind speeds given in a metocean report for foundation design are listed for reference and are often based on the wind conditions used in a hindcast modelling.

It is recommended to assess the extreme wind speeds against site-specific measurements or towards detailed results from a wind resource assessment report.

The extreme wind speeds shall as a minimum be given for omni-directional conditions for average return periods of 1 year, 5 year, 10 year, 50 year and 100 year. Presentation of directional extreme wind speeds in sectional intervals of 30º are recommended.

4 Wave Data

4.1 General

Even though there is some correlation between wind and wave conditions (both for magnitude and direction), it is not certain that they are fully aligned. Misaligned wind and wave conditions may lead be more onerous design conditions than fully aligned wind and wave. Requirements for coupled wind and wave analyses are presented in section 4.4.

Operational and design wave data shall as a minimum be described by the following set of integral parameters:

- Significant wave height, H_s [m]
- Spectral peak wave period, T_p [s]
- Zero-crossing wave period, T_{02} [s]
- Mean wave direction, *MWD* [deg]

Optionally, additional wave parameters may also be provided:

- Maximum wave height, H_{max} [m]
- Wave period, T_{01} [s]
- Peak wave direction, *PWD* [deg]
- Directional Standard deviation, *DSD* [deg]

Separation of all the above parameters into wind-sea and swell components may optionally also be made.

An assessment of governing wave spectrum and associated parameters is required.

4.2 Operational wave data

4.2.1 Statistics

The operational wave data (H_s, T_p and T_{02}) shall be described by standard statistical parameters (mean, maximum, minimum and standard deviation). At least the standard statistical parameters shall represent omni-directional wave data, but preferably also for directional data (e.g. in 12 directional intervals of 30°). Seasonal (monthly or quarterly) statistics may also be given.

In scatter tables the recommended bin size for wave heights is 0.5m or less and 0.5s or less for wave periods (cf. [1], section 12.4). If directional data is available, the widths of wind and wave direction sectors shall be 30° or less.

4.2.2 Rose data

Wave roses of H_s versus *MWD* shall also be given – both in tabular format as well as graphically (at least 12 directional intervals and 0.5m resolution of H_s).

4.2.3 Scatter tables

Scatter tables and plots shall be given for the following combinations of wave parameters:

- H_s vs. T_p
- H_s vs. T_{02}
- H_s vs. *MWD*

Scatter tables based on omni-directional data are required while scatter tables based on directional data (e.g. 12 directional intervals of 30 degrees) are optional.

Optionally, these tables may be given for wind sea and swell individually.

4.3 Reference Sea States

4.3.1 Normal Sea State (NSS)

According to [2] the Normal Sea State (NSS) is characterised by a significant wave height, a peak period and a wave direction. It is associated with a concurrent mean wind speed. The significant wave height $H_{s,NSS}$ of the normal sea state is defined as the expected value of the significant wave height conditioned on the concurrent 10-minute mean wind speed. The normal sea state is used for calculation of ultimate loads and fatigue loads.

For fatigue load calculations a series of normal sea states shall be considered, associated with different mean wind speeds. It shall be ensured that the number and resolution of these normal sea states are sufficient to predict the fatigue damage associated with the full long-term distribution of metocean parameters. The range of peak periods T_p appropriate to each significant wave height shall be considered.

The NSS can be described through a number of (H_s, T_p) scatter tables governed by wind speed intervals and wind directions.

4.3.2 Severe Sea State (SSS)

According to [2] the Severe Sea State (SSS) is characterised by a significant wave height, a peak period and a wave direction. It is associated with a concurrent mean wind speed. The significant wave height of the severe sea state $H_{s,SSS}$ is defined by extrapolation of appropriate site-specific metocean data such that the load effect from the combination of the significant wave height $H_{s,SSS}$

and the 10-minute mean wind speed at hub-height has a return period of 50-years.

To calculate SSS on basis of time series data the formulation from [1], Annex G, can be used. Here it is assumed that H_s can be described by a normal distribution in each wind speed interval. The unconditional extreme significant wave height with a return period of 50-years may be used as a conservative estimate for $H_{s,SSS}$ for a given wind speed. The range of peak periods T_p appropriate to each significant wave height shall be considered.

4.3.3 Extreme Sea State (ESS)

According to [2] the Extreme Sea State (ESS) is characterised by a significant wave height, a peak period and a wave direction. The significant wave height $H_{s,ESS}$ is the unconditional significant wave height with a specified return period.

Design data for the significant wave height, H_s, shall be estimated for average recurrence periods of 1 year, 5 year, 10 year, 50 year and 100 year. The influence of the water level on the extreme significant wave heights shall be included.

The design significant wave height shall be given corresponding to a 3-hour reference period. The range of associated wave peak spectral periods shall be given. The range of peak spectral periods shall be assessed on basis of analyses of hindcast or measured data (e.g. from a scatter plot of H_s and T_p).

The design individual wave heights, H_D, corresponding to the design significant wave heights shall be given - either based on analyses of measured data or by applying a probability distribution like e.g. the Rayleigh distribution as described in [3], section 3.5.9. As described in [1], section 12.4, the extreme individual wave heights may also be established by convolution of the long term distribution of the significant wave height H_s and peak spectral period T_p, with the conditional short term distribution of individual wave height H given the significant wave height H_s as described. The extreme wave heights may, however, be limited by water depth. The associated range of design wave periods, T_D, shall also be determined (cf. [1], section 6.4.1.6).

The associated design wave crest height, η_D, may be required for estimation of e.g. splash zone or air-gap estimations. The method described in [3], section 3.5.10 can be used for calculation of design crest height.

An overview of required design wave data to be supplied is given in Table 4-1.

Table 4-1 Required omni-directional design wave data

Return Period [Years]	H_s [m]	H_D [s]	T_p range [s]	T_D range [s]	η_D [m]
1	$H_{s,1}$	$H_{D,1}$	$T_{p,low,1}$-$T_{p,high,1}$	$T_{D,low,1}$-$T_{D,high,1}$	$\eta_{D,1}$
5	$H_{s,5}$	$H_{D,5}$	$T_{p,low,5}$-$T_{p,high,5}$	$T_{D,low,5}$-$T_{D,high,5}$	$\eta_{D,5}$
10	$H_{s,10}$	$H_{D,10}$	$T_{p,low,10}$-$T_{p,high,10}$	$T_{D,low,10}$-$T_{D,high,10}$	$\eta_{D,10}$
50	$H_{s,50}$	$H_{D,50}$	$T_{p,low,50}$-$T_{p,high,50}$	$T_{D,low,50}$-$T_{D,high,50}$	$\eta_{D,50}$
100	$H_{s,100}$	$H_{D,100}$	$T_{p,low,100}$-$T_{p,high,100}$	$T_{D,low,100}$-$T_{D,high,100}$	$\eta_{D,100}$

4.4 Joint wind and wave data

The site-specific metocean database shall be analysed in order to establish the long-term joint probability distribution of the following parameters:

- mean wind speed at hub height, V_{hub}, and corresponding direction, *WD*
- significant wave height, H_s, and Mean Wave Direction, *MWD*

The following types of analyses are needed:

- Wind and wave joint distribution (H_s, V_{hub}): Scatter tables, environmental contour lines (IFORM) – omni-directional and directional
- Wind and wave misalignment: Omni-directional and directional. Example given in Table 4-2
- Weibull fit parameters for both V_{hub} and H_s may be determined for the data belonging to each cell of the Table 4-2 (if sufficient data are available)

Table 4-2 Sketch of wind and wave misalignment table determined for either Hub Wind Speed (V_{hub}) or Significant Wave Height (H_s). Wind Direction is abbreviated WD while Mean Wave Direction is abbreviated MWD. Probabilities are given for N directional intervals as well as for ALL intervals.

V_{hub} or H_s	WD_1	WD_2	...	WD_N	WD_{ALL}
MWD_1	Prob(1,1)	Prob(1,2)	...	Prob(1,N)	Prob(1,ALL)
MWD_2	Prob(2,1)	Prob(2,2)	...	Prob(2,N)	Prob(2,ALL)
...	...	...	...	...	...
MWD_N	Prob(N,1)	Prob(N,2)	...	Prob(N,N)	Prob(N,ALL)
MWD_{ALL}	Prob(ALL,1)	Prob(ALL,2)	...	Prob(ALL,N)	100%

4.5 Breaking waves assessment

Breaking waves may occur at the site of an offshore wind turbine depending on the water depth, sea floor slope, wave height, period and wave steepness. Based on an assessment of these parameters, the guidance provided in Annex C of [1] may be followed to determine the nature and dimensions of breaking waves based on site conditions.

5 Water Level Data

5.1 General

The water level at a given time consists of a tidal component and a storm surge residual component induced by wind and pressure. Time series of separated tidal and residual components can be derived by a tidal analysis of the time series of total water level.

The above time series shall be determined from the site-specific metocean database. Accurate estimates of storm surge require a long-duration data set. Long duration measurements or hindcast available from a nearby location may be used together with correlation techniques to derive the site-specific storm surge characteristics.

5.2 Tidal datums and statistics

Definition of the various tidal datums are given in Table 5-1 and depicted in the sketch in Figure 5-1. The tidal datums shall be given with respect to Chart Datum (CD).

Table 5-1: Tidal datums. Required data are given with red colour while the remaining data are optional.

Tidal datum	Abbreviation
Highest Astronomical Tide	**HAT**
Mean High Water Springs	MHWS
Mean High Water Neaps	MHWN
Mean Sea Level	**MSL**
Mean Low Water Neaps	MLWN
Mean Low Water Springs	MLWS
Mean Lower Low Water Springs	MLLWS
Lowest Astronomical Tide	**LAT**

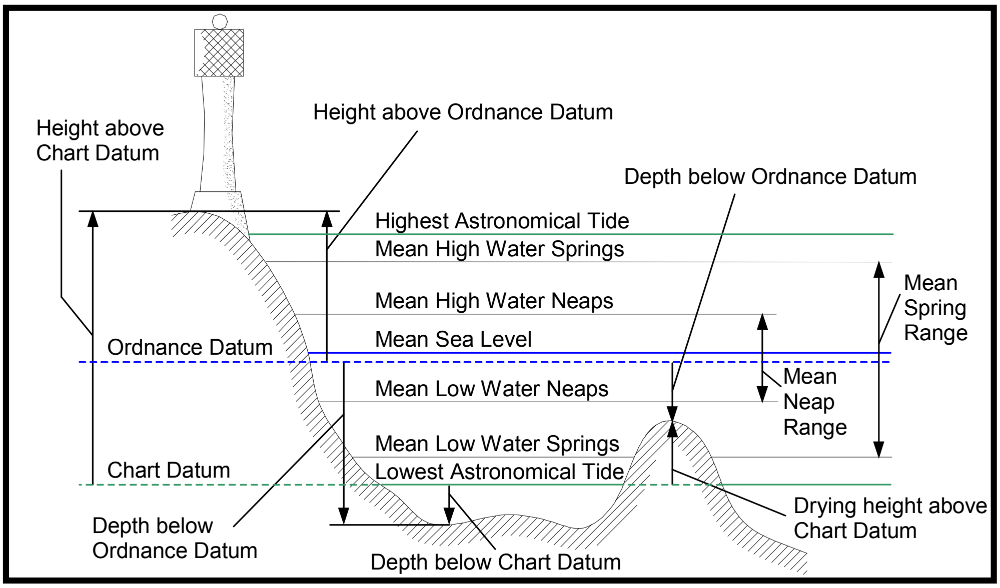

Figure 5-1: Illustration sketch of various tidal datums.

The values of ***HAT*** (Highest Astronomical Tide), ***LAT*** (Lowest Astronomical Tide) and ***MSL*** (Mean Sea Level) are required data and are determined on basis of statistical values (maximum, minimum and mean) from the entire tidal water level time series. The remaining tidal levels (which are optional) are determined based on peak values during spring and neap periods during the entire tidal level time series.

The operational high and low water level data (total and residual) shall be described by standard statistical parameters (mean, maximum, minimum and standard deviation).

5.3 Design water levels

For design purposes either a high water level or a low water level will be governing. The highest water level ***HSWL*** (Highest Still Water Level) consists of an astronomical tide above MSL plus a positive storm surge component. The lowest water level ***LSWL*** (Lowest Still Water Level) consists of an astronomical tide below MSL plus a negative storm surge component. The design water levels shall be given for average return periods of 1 year, 5 year, 10 year, 50 year and 100 year.

6 Current Data

6.1 General

Sea currents consist of tidal currents and wind generated currents (also termed residual currents) and are given by speed and direction. The residual currents may also be generated by density differences in the water column, as wave-induced surf currents or due to storm surge or pressure differences.

It shall be clearly specified whether the reported current speed is a depth averaged value or given as the value at still water level (i.e. a surface value).

Time series of separated tidal and residual current components can be derived by a tidal analysis of the time series of total current. The velocity and directional characteristics of each significant current component at the site shall be separately assessed.

The current variation over depth shall be specified – either based on measurements or based on application of a standard profile as given in [2], section 2.4.8.3.

6.2 Operational current data

The operational current data (total, tidal and residual) shall be described by standard statistical parameters (mean, maximum, minimum and standard deviation). At least the standard statistical parameters shall be given for omni-directional current speeds, but preferably also as directional data (e.g. in 12 directional intervals of 30 degrees).

Current roses (total, tidal and residual) shall also be given – both in tabular format as well as graphically.

6.3 Design current data

For design purposes, the depth-averaged (or still water level) current speed shall be given for average return periods of 1 year, 5 year, 10 year, 50 year and 100 year.

It is required to provide the omni-directional design current speeds. Directional design current speeds may optionally also be provided. It is suggested to apply a 30 degrees resolution of the directional design current data (i.e. providing the design current speed in 12 directional sectors).

7 Additional Data

7.1 Sea Ice

According to [1] the possible influence of sea ice shall be assessed during the design of the support structure of an offshore wind turbine that will be installed at a site where sea ice is expected to occur.

An assessment of sea ice will require detailed information concerning the properties of the sea ice at the offshore wind turbine site. The manufacturer shall describe in the design documentation the sea ice properties assumed. The following parameters shall be determined from statistical data from an ice atlas or a similar document:

- ice thickness with a 50-year recurrence period
- ice crushing strength
- risk of current or wind induced ice floe migration
- risk of forces induced by fluctuating water level
- frequency of ice concentration

7.2 Other environmental conditions

According to [1] the following environmental conditions shall be assessed for comparison with the assumptions made in design of an offshore wind turbine:

- normal and extreme air temperature ranges
- normal and extreme water temperature range
- water density
- salinity

The following data may also be given (if available):

- marine growth (density and thickness as function of depth)
- hail and snow
- humidity
- lightning
- solar radiation
- chemically active substances

7.3 Weather Windows and downtime

Weather windows and weather downtime are of importance for transportation, installation and maintenance of an offshore wind turbine. An assessment of weather windows and weather downtime shall be given for the site of the wind turbine. The assessment can be made on basis of a hindcast time series.

An example is given in Table 7-1 of a weather window table with probability (percentage of total time) for a given month where the conditions for a given weather window are fulfilled.

Table 7-1 Example of weather window table showing probability (percentage of total time) for a given condition (e.g. H_s < 2.0m) on a monthly basis. Duration of weather windows are 3, 6, 12, 18, 24, 36, 48, 72 and 96 hours. The numbers in the table are fictitious.

H_s<2.0m	Weather Window [Hours]								
	3	6	12	18	24	36	48	72	96
January	7.3	7.1	6.2	5.4	4.6	3.2	2.2	0.7	0.2
February	9.3	9.1	8.3	6.8	6.0	4.7	3.4	2.3	1.9
March	10.4	10.0	9.2	8.2	7.1	4.9	3.4	1.9	0.1
April	19.2	18.7	17.3	15.1	13.3	10.3	7.4	3.0	0.7
May	23.4	22.8	20.5	17.9	15.8	13.0	9.9	5.9	2.9
June	20.3	19.6	17.9	15.9	14.4	10.6	7.5	4.6	1.9
July	23.4	22.8	21.1	18.0	16.2	13.9	11.2	6.9	4.0
August	23.4	22.7	21.2	18.7	17.2	14.1	11.9	7.2	5.2
September	16.1	15.4	14.0	12.9	11.5	8.2	6.2	2.6	1.0
October	12.3	11.9	10.7	9.1	7.8	6.1	4.2	2.9	1.3
November	9.0	8.8	8.2	7.3	5.8	4.0	2.6	1.8	1.0
December	8.5	8.3	7.5	6.4	5.4	3.8	2.8	0.5	0.2

8 References

[1] IEC 61400-3. International Standard. Wind turbines – Part 3: Design requirements for offshore wind turbines. Edition 1.0, 2009-02

[2] DNVGL-ST-0437. Loads and site conditions for wind turbines. Edition November 2016

[3] DNV-RP-C205. Recommended Practice. Environmental Conditions and Environmental Loads. Edition April 2014

[4] IPCC (2013). Summary for Policymakers. In: Climate Change 2013:The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

FOWPI

FIRST OFFSHORE WIND
PROJECT OF INDIA