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ENFAIT
ENABLING FUTURE ARRAYS IN TIDAL

Data Requirements Definition & Collection Plan

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Contents

1 Summary

A Funding Grant was awarded from the European Union's Horizon 2020 research and innovation programme in January 2017 to demonstrate a grid-connected tidal energy array at a real-world tidal energy site, propelling tidal energy towards competing on a commercial basis with alternative renewable sources of energy generation – Enabling Future Arrays in Tidal (EnFAIT). This was in response to the call LCE-15-2016: Scaling up in the ocean energy sector to arrays to generate significant learning through demonstration of cost-effective tidal arrays.

This document is produced as a summary of information regarding the modelling tools to be used in the EnFAIT Work Package 10 (Validation of Array Modelling Tools) and their inputs. It contains summary information about the currently existing data sets for the site and array and outlines a plan for closing the gap between these two lists. It is also to be submitted to satisfy deliverable D10.1 of the EnFAIT project and to be made available for public dissemination.

The goal of this document is to share knowledge amongst project partners about the tools to be used and define all inputs required to make best use of these. For this purpose, the best use of existing industry standards and guidelines, such as IEC/TS 62600-201:2015 Part 201: Tidal energy resource assessment and characterization, is presented here.

2 Introduction

This deliverable is the first of EnFAIT Work Package 10: Validate Array Modelling Tools. The aim of this deliverable is to present the required data for the DTOcean and the array interaction modelling tools. Existing data is summarised in EnFAIT deliverable D9.1 "Reliability and maintenance data from existing Nova M100 deployment for tidal array baseline", which is not available for public dissemination.

The DTOcean tool (Optimal Design Tools for Ocean Energy Arrays), [1], provides design tools for deploying wave and tidal energy converters arrays. It is modularised into five stages: hydrodynamics (designs the layout of converters in a chosen region and calculates their power output), electrical sub-systems (designs an electrical layout for the given converter locations and calculates the electrical energy exported to shore), moorings and foundations (designs the foundations and moorings required to secure the converters at their given locations), installation (designs the installation plan for the energy converters and the array components), and operations and maintenance (calculates the required maintenance actions and power losses resulting from the operation of the converters over the lifetime of the array).

The five stages can be analysed from three thematic assessments: economics, reliability and environmental, see Figure 1. The economic assessment tool produces economic indicators for the design, in particular the Levelised Cost of Energy (LCOE). The reliability assessments give indicators for each sub-component of the overall system: system, sub-system, and component mean time to failure, risk priority number and percentage of reliability. Finally, the environmental impact assessment identifies the most sensitive receptors/stressors, which are combined into different environmental functions.

DTOcean will be used in the first instance for array layout validation of the actual set of turbines. The data collected in EnFAIT work packages WP4 and WP6 will then be used to improve and validate the tool. Later, DTOcean will be used to support the extended array design, and finally numerical predictions will be compared with results obtained from the actual array.

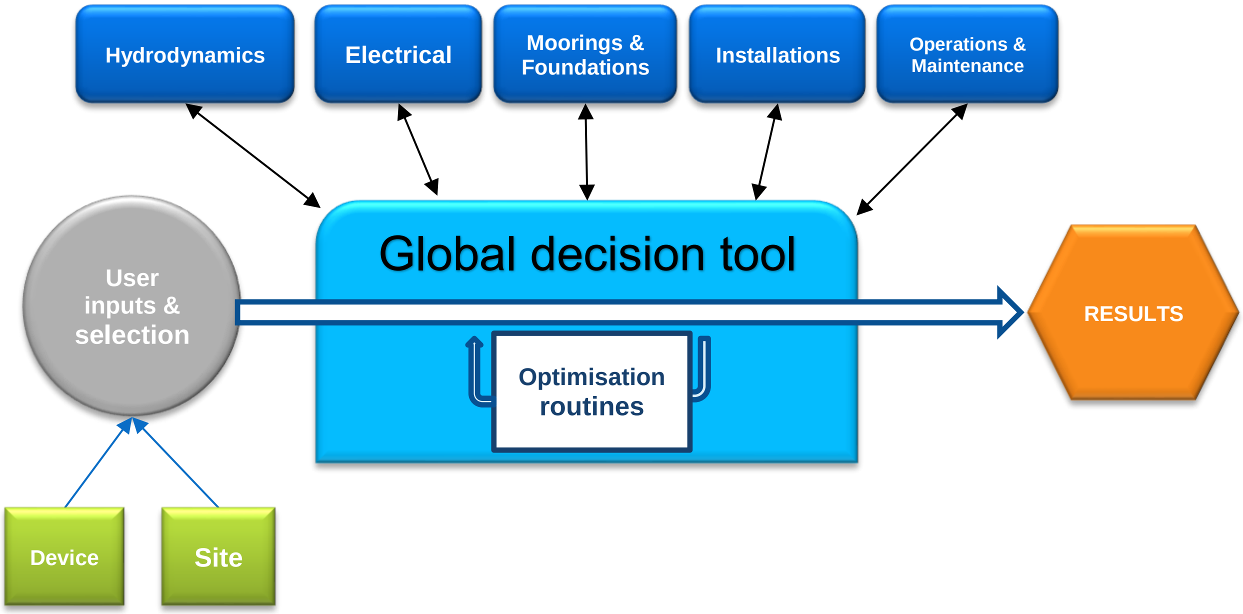

Figure 1: DTOcean working scheme.

The Array Interaction Modelling tool will be used to analyse loads in turbine blades, as well as wakes resulting from the flow interactions between turbines. The goal is to analyse the effects on the performance of the overall array. For that purpose, different software packages are analysed in this deliverable to check their suitability.

The deliverable is structured as follows: first, the applicability of technical specifications in tidal energy converters is analysed. Then, the data requirements for DTOcean and the array interaction modelling are presented, followed by a data collection plan. Finally, two appendices summarise the compulsory and optional data required for DTOcean.

3 Use of IEC/TS 62600-201:2015

The International Electrotechnical Commission's (IEC) Technical Specification for wave, tidal and other water current converters is used now in order to make the best use of the available data. Particularly, Part 201 of this document, related to tidal energy resource assessment and characterisation, is taken into account, [2]. It should be noted that this Technical Specification describes only the aspects of the resource required to calculate Annual Energy Production (AEP); e.g., it does not describe aspects of the resource required to evaluate design loads or to satisfy environmental regulations. Therefore, it is used to build a solid data bin around the study zone, which will be useful for future analyses in the area within this project.

The information in this section has been obtained from [2].This part of IEC 62600 establishes a system for analysing and reporting, through estimation or direct measurement, the theoretical tidal current energy resource in oceanic areas that may be suitable for the installation of arrays of Tidal Energy Converters (TECs). It is intended to be applied at various stages of project lifecycle to provide suitably accurate estimates of the tidal resource to enable the arrays' projected annual energy production to be calculated at each TEC location in conjunction with IEC 62600-200, [2].

Aspects of the methodology to be followed when undertaking a tidal resource assessment depend on the scope of the analysis and its objectives. Two distinct types of studies, feasibility and layout design, are defined as indicated in Table 1.

Table 1: Resource assessment stages. [Source: [2]]

Stage	*Aim*	*Area*	*Level of uncertainty*
Stage 1	Feasibility	Whole estuary, channel, etc.	Medium
Stage 2	Layout design	Development site	Low

For the EnFAIT project, Stage 2 is considered for the analysis done in WP10, as the development site is well-known and the study done is related to the layout design. The level of uncertainty is low, as most of the data should be available through direct on-site measurement, or accurate models.

A Stage 2 study is focused on generating detailed information on the tidal energy resource in a specific area, through supporting the layout design of a tidal array, and may incorporate energy extraction impacts depending upon the project scale, [2]. Particularly for this stage, the recommended quality in data is given in Table 2.

Table 2: Model and field survey recommendations (overview). [Source: [2]]

		Stage 2
Modelling	Minimum number of harmonic constituents for modelling driving boundary (tidal amplitude)	8 – 12
	Grid resolution at the area of interest	< 50m
	Period of run	>35 days
Physical data requirements	Bathymetry	see a
	Tidal height	see b
	Wave characteristics	see c
	Meteorological data	see d
	Flow structure / Eddies / Turbulence	see e
	Stratification, seawater density and sediment measurement	see f
Data analysis	Harmonic analysis on available current data (Minimum number of constituents)	20

a. Bathymetry

The quality and resolution of available bathymetric data directly influences the ability of a numerical model to replicate the flow dynamics. Accordingly, best practice in terms of sourcing and quality checking bathymetry data needs to be followed. Processes to ensure that the numerical domains appropriately replicate the actual bathymetry should be adopted and justified.

b. Tidal height

The data at the location shall include:

- Location.
- Start date and duration of measurement period.
- Measurement methods.
- Calibration reports / calibrations applied to the data.
- Tidal range and vertical datum.
- Analysed tidal constituent data, including the amplitude and phase of all constituents identified as important such that at least 95% of the total variance is captured by the constituents.
- An assessment of the overall quality of data collected should be conducted. This could be performed with goodness of fit tests and statistical hypothesis testing to check the validity of collected data. The percentage of data that has been found to be good quality should be calculated. Data that is believed to be erroneous shall be highlighted, and for purposes of further data manipulation, can be removed from the record.

c. Wave characteristics

Existing wave data at the location of interest shall be reviewed. If sufficient information is already available at a specific location, there may not be a need for further measurements. If the area of interest is not exposed to swell waves, or if it is considered that the wave climate can be modelled using appropriate long-term wind datasets, there might be no requirement for a wave monitoring survey, but the decision shall be explained and an assessment of the wave characteristics detailed, including current conditions and local sea water level. For the purpose of resource assessment, the potential for substantial wave-current interaction to have a significant impact on the development of flow conditions shall be considered.

d. Meteorological data

Meteorological phenomena such as wind, still water level, and atmospheric pressure can impact coastal flow development.

i. Wind data

The details of measured wind data across the model simulation domain shall be listed with reference to the location of the monitoring station and the period of measurements, and the quality of the data available shall be assessed following the IEC standards for wind resource characterisation [3]. In the absence of measured wind data, a combination of numerical model wind simulation outputs and processed satellite derived wind data (re-analysis data) may be used. If this approach is used, details of the simulated wind data, its characteristics, and an assessment of accuracy of the predictions shall be reported.

ii. Atmospheric pressure

Atmospheric pressure data coincident with the field data period shall be obtained from an appropriate source (e.g. a national weather forecasting service).

e. Turbulence, eddies and flow structure

The scale, frequency, and magnitude of turbulent current eddies is not currently known. Therefore there are likely to be significant uncertainties in the modelling. In the first instance, the effect of turbulent eddies is not taken into account, following the recommendations of the IEC technical specification.

Related to flow around structures, tidal flows past obstructions (e.g., headlands, islands, and in-stream structures) can result in separation, vortex (eddy) formation and shedding that may significantly alter inflow characteristics to TECs positioned leeward of these bathymetric anomalies. Navigation charts should be consulted to identify obstructions that may lead to significant vortex formation and shedding. For the Stage 2 resource assessments, detailed hydrodynamic modelling should be validated with remote sensing techniques, or stationary/mobile current profiler data collected leeward of the obstruction to verify estimates of the shedding frequency and eddy sizes.

f. Stratification, seawater density and sediment measurement

CTD (Conductivity, Temperature, Density) data near the project site, which can assist with determining the relative importance of stratification and horizontal density driven currents, shall be identified and reviewed. The location, period of record and an assessment of the quality of the data shall be reported.

4 Data needed for DTOcean

For DTOcean to work, a series of data are required. Some of this data is compulsory, e.g. without them the program cannot compile. Many others are optional data, which can be added to the modules to obtain better quality results.

a. MAIN COMPULSORY DATA

i. Lease area

This describes the area in which devices may be placed and the "cable corridor" is the search area in which the export cable should be laid. Each is described on a regular grid, the lease area having approximately 10m resolution and the cable corridor potentially having lower resolution in order to reduce computational cost. Note the cable corridor bathymetry should overlap the lease area bathymetry, at least partially. In the following sections, parameters marked "LA" are required for the lease area, and those marked "CC" are required for the cable corridor.

ii. Bathymetry

The bathymetry(s) must be provided in a conformal 2-dimensional Cartesian coordinate system projection with units of metres, such as UTM. Each grid must be regularly spaced and oriented as east-west / north-south, but it does not necessarily need to be a square domain.

A minimum of one sediment layer must be provided. The last layer given in the format below is also assumed to have infinite depth. The format for providing the bathymetry and layer information is as shown in Table 3.

Table 3: Bathymetry format for DTOcean.

Point	*Seafloor Depth*	*Layer 1 Distance Below Floor*	*Layer 1 Sediment Type*	*Layer 2 Distance Below Floor*	*Layer 2 Sediment Type*	*etc.*
…	…	…	…	…	…	…

Available sediment types are: loose sand, medium sand, dense sand, very soft clay, soft clay, firm clay, stiff clay, hard glacial till, cemented, soft rock coral, hard rock and gravel cobble.

- At least one sediment layer is required, with its starting depth and thickness. The start depth of the first layer describes the bathymetry (LA, CC).
- Manning numbers over the entire area are required (LA).
- Average soil characteristics at a single point: maximum temperature (LA, CC) and soil resistivity (LA, CC).
- Definition of any "no go" areas (e.g. due to environmental concerns, other installations, etc.) (LA, CC).

iii. Tidal data

For the hydrodynamics module of DTOcean, at least one week of hourly time series data is needed at each grid point for:

- U (Current velocity, main horizontal direction) (LA)
- V (Current velocity, secondary horizontal direction) (LA)
- Turbulence intensity (LA)
- Sea surface height (ssh) (LA)

Please note that if a month or more is provided, results are significantly better. Moreover, for the O&M module of DTOcean to properly work, one year of hourly-data in a single-point of the array for the tidal resource are needed. However, this information can be obtained by extrapolating data from a minimum of 1-month resource data. The process is described in [3], where it is possible to obtain the main tidal components and constructing a whole year series from this. This fits with the IEC TS, which specifies a minimum of 35 days for resource modelling purposes.

Same is applicable to wave data (Hs and Tp), and to wind speed magnitude (at least 1 year, hourly data at a single point):

- Tidal velocity magnitude (LA)
- Hs, Tp (LA)
- Wind speed magnitude (LA)

Also, long term tidal characteristics (10-year return period) are needed:

- Max current (LA, CC)
- Predominant direction (LA, CC)

iv. Wave data

As described in previous paragraphs, at least 1-year hourly data for Hs, Tp (LA) in a single point is needed. Also, long term wave characteristics (50 years return period) is necessary: Hs & Tp (LA), Direction (LA, CC) and representative gamma for JONSWAP spectrum (LA). The IEC TS for wave resource characterisation establishes that the time stories should be recorded at the maximum available resolution for a single representative year, [4].

v. Wind data

As described before, at least 1-year hourly data for wind speed magnitude (LA) in a single point is needed. Moreover, long term wind characteristics (100-year return period) is needed: speed, direction, gust speed and gust direction (LA).

vi. Other required data

- Long term water level characteristics (50-year return period), maximum and minimum (LA)
- Shipping probability histogram for dead weights (LA, CC)
- Shoreline landing point (must be within the cable corridor region) (LA)

All this information is summarised in *Appendix I*, together with an extended list of required data needed for DTOcean to run.

b. OPTIONAL DATA

On top of the required data, the more information is given to DTOcean, the better results will be obtained. A list with examples of the optional data to include is given in Appendix II.

5 Data needed for the Array Interaction Modelling

A set of different software packages are under consideration for the array modelling. These are summarised below:

a. MIKE21

Mike21 is a coastal modelling tool. It is capable of simulating physical, chemical or biological processes in coastal and marine areas. Mike21 enables the following modelling:

- Assessment of hydrographic conditions for design, construction and operation of structures in stratified and non-stratified waters
- Environmental impact assessments
- Coastal and oceanographic circulation
- Optimisation of ports and coastal protection infrastructures
- Lake and reservoir hydrodynamics

- Cooling water, recirculation and desalination
- Coastal flooding and storm surge
- Inland flooding and overland flow
- Forecast and warning systems

The key inputs required into a model in Mike21 are:

- Bathymetry
- Tidal forcing conditions
- Wind conditions
- Wave conditions
- Water properties
- Sea bed friction

b. ANSYS CFD

ANSYS Computational Fluid Dynamics (CFD) is a tool to model and solve complex fluid problems. ANSYS Fluent software contains the broad physical modelling capabilities needed to model flow, turbulence, heat transfer, and reactions for industrial applications. These range from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing, and from clean room design to wastewater treatment plants.

The key modelling inputs required are:

- Turbine and structure geometry
- Water flow conditions (boundary conditions)
- Bathymetry

c. Tidal Bladed

Tidal Bladed, developed by DNV-GL, is the industry-standard tidal turbine modelling tool. It provides with accurate numerical load and performance estimates. Tidal bladed has been validated in a series of unique projects, including the ReDAPT (Reliable Data Acquisition Platform for Tidal) project, [5]. Tidal Bladed utilises common functionality with the industry leading wind turbine design tool Bladed, whilst introducing essential subsea science.

Tidal Bladed currently features:

- Time-domain simulation of combined current, wave and wind loading with full hydroelasticity modelling and seismic excitation, plus a range of supporting steady state calculations.
- A range of wave and current models to define the hydrodynamic forces acting on the device.
- Models to describe 'added mass' effects on both the rotor and support structure.
- An accurate representation of buoyancy forces acting on the device.

Key modelling inputs required are:

- Turbine and structure geometry
- Blade geometry and physical properties

- Water flow conditions
- Bathymetry

Data for validation purposes, such as blade bending, shaft torque, or foundations loads, should be measured. Also, turbulence related to wakes around turbines should be characterised.

6 Collection plan

The following information has been collected up to date for the possible sources of information in different fields. Please note that these sources are external to the project, and could be used for validation purposes. However, as mentioned before, a specific data summary for the EnFAIT project is developed in the EnFAIT deliverable D9.1 "*Reliability and maintenance data from existing Nova M100 deployment for tidal array baseline*", which is not available for public dissemination.

a. Bathymetry

The EMODnet Digital Terrain Model (DTM) (http://www.emodnet-bathymetry.eu/data-products). It is generated for European sea regions from selected bathymetric survey data sets and composite DTMs, while gaps with no data coverage are completed by integrating the GEBCO Digital Bathymetry.

The DTM with its information layers is made freely available for browsing and downloading through the Bathymetry Viewing and Download service.

Another option is the EDINA gridded bathymetry (http://digimap.edina.ac.uk/). It is part of the Hydro Spatial One data. Gridded bathymetry data is available as a 1 arc-second grid which has cell size of approximately 30m. The data can be used to create 3D surface models of the ocean floor.

b. Tidal series

The UK National Tide Gauge Network (http://www.ntslf.org/data/uk-network-real-time) records tidal elevations at 44 locations around the UK coast, [6]. However, the closest of these locations to the Bluemull Sound is Lerwick, which is considerably far away, and then of limited use for the purpose of this project.

The British Oceanographic Data Centre (https://www.bodc.ac.uk) has data for a numerical model for the site of interest. In particular, the numerical model presents values for the Bluemull Sound for current velocity (depth averaged north and east velocity components), and surface elevation relative to mean tidal level.

c. Wave and wind series

As commented before, water surface elevation can be obtained from the British Oceanographic Centre numerical model (station 64046 of UK Met Office (www.metoffice.gov.uk) or WMO ID: 64041 at http://wavenet.cefas.co.uk/Map).

Moreover, the ERA-Interim (https://www.ecmwf.int/en/research/climate-reanalysis/era-interim) is a global atmospheric re-analysis data-set continuously updated in real time from 1979. Daily data in 12 hours intervals for wave (significant wave height, mean wave period, and mean wave direction) and wind (10 metre U wind component, and V component) parameters can be downloaded, among many others.

d. Existing data from Nova

EnFAIT deliverable *D9.1 "Reliability and maintenance data from existing Nova M100 deployment for tidal array baseline"* has more details on existing data prior to the start of the project, but this is not available for public dissemination.

Appendix I Summary of compulsory data for DTOcean

A. PROJECT DATA

- Condition Based Maintenance Health Threshold
- Operation Type Weighting for Electrical Substations
- Installation Rates: Fuel Cost
- Installation Equipment Safety Factors: Divers
- Monitoring Costs for Device and Array Sub-Systems
- Number of Crews per Shift
- Operation Type Weighting for Device Umbilical Cable
- Operation Type Weighting for the Export Cable
- Wage for Specialist Crew at Daytime e.g. Diver
- Working Days per Week during Winter
- Wage for Technicians at Daytime
- Grout Cost per kg
- Operation Type Weighting for Inter-Array Cables
- Calendar Based Maintenance Interval
- Operation Type Weighting for Device Foundations
- Installation Equipment Safety Factors: Cable Burial
- Installation Port Safety Factors
- Port Cost Percentage
- Foundation Safety Factor
- Array Rated Power
- Electrical Sub-Systems On-Site Maintenance Requirements
- Installation Costs Contingency Factor
- Installation Equipment Safety Factors: ROV
- Grout Strength Safety Factor
- Installation Commissioning Duration
- Network Configuration
- Concrete Cost per kg
- Lease Area Installation Entry Point
- Project Start Date
- Installation Equipment Safety Factors: Vibro-Driver
- Moorings and Foundations On-Site Maintenance Parts Data

- Steel Cost per kg
- Installation Equipment Safety Factors: Hammer
- Duration of a Shift
- Minimum Q-Factor
- Electrical Sub-Systems On-Site Maintenance Parts Data
- Annual End Month for Maintenance
- Energy Selling Price
- Installation Rates: Grout
- Operation Type Weighting for Device Mooring Lines
- Wage for Specialist Crew at Night Time e.g. Diver
- Moorings and Foundations On-Site Maintenance Requirements
- Number of Shifts per Day
- Moorings and Foundations Subsystems Annual Failure Rates
- Electrical Network sub-system Annual Failure Rates
- Installation Rates: Surface Laying Rate
- Annual Start Month for Maintenance
- Project Lifetime
- Installation Rates: Loading
- Maximum Seabed Gradient
- Wage for technicians at night time
- Tidal Probability Bins
- Working Days per Week during Summer
- Sub-System On-Site Maintenance Operations
- Vessel Safety Factors
- Installation Rates: Split Pipe Laying Rate
- Installation Equipment Safety Factors: Split Pipe
- Number of Available Crews
- Sub-System Replacement Operations

B. SITE DATA

- Site Blockage Ratio.
- Maximum Surface Current Direction.
- Maximum JONSWAP gamma

- Maximum gust wind velocity
- Predominant direction of maximum gust
- Mean wind velocity
- Predominant mean wind direction
- Maximum significant wave height
- Maximum peak wave period
- Predominant wave direction
- Vertical current profile
- Maximum tidal stream current velocity in lease area
- Maximum water level
- Minimum water level
- Tidal occurrence extraction point
- Presence of a helideck
- Tidal current stream series
- Wave time series (installation)
- Wind speed time series
- Bathymetry (coordinates, layer type, depth, sediment)
- Manning numbers
- Cable landing point
- Cable corridor bathymetry (coordinates, layer type, depth, sediment)
- Tidal time series (X, Y (UTM coordinates), t, U (east-west horizontal flow speed), V (north-south horizontal flow speed), sea surface height (ssh))
- Lease boundary
- Projection string

C. DEVICE DATA

- Assembly duration
- Centre of gravity
- Connect duration
- Connector type
- Position of device in local coordinate system
- Device disconnect duration
- System submerged volume

- System dry beam area
- System dry frontal area
- Device foundations location
- System height
- Maximum installation water depth
- Minimum installation water depth
- System length
- Device load out method
- System mass
- Minimum distance between devices in X and Y direction
- System profile
- Device rated power
- Device rated voltage
- System surface roughness
- Device transportation method
- System wet beam and frontal area
- System width
- Device heading angle span
- Tidal turbine cut-in/ cut-out velocity
- Turbine rotor diameter
- Turbine performance curves (coefficients of power, thrust and velocity)
- Device access requirements (maximum current velocity, Hs, Tp, wind velocity. Operation duration)
- Device subsystem costs and annual failure rates
- Device inspection requirements (crew preparation delay, maximum current velocity, Hs, Tp, wind velocity. Operation duration. Specialists and technicians required)
- Device on-site maintenance requirements (spare parts preparation and crew delay, plus same requirements as previous requirements, spare parts dimensions, operation duration)
- Device technology type

Appendix 2 Summary of optional data for DTOcean

A. PROJECT DATA

- Weight for the turbidity risk
- Weight for the underwater noise risk
- Annual repair cost estimate
- Installation cost estimate per MW
- Weight for the chemical pollution risk
- Power histogram bin width
- Measured electrical field
- Lease area boundary padding
- Weight for the footprint weight
- User defined array layout
- Weight for the temperature modification
- Moorings and foundations inspections requirements (sub-system, inspection and access duration, crew preparation delay, technicians and specialists required, maximum wave height and period for access, maximum wind speed and current for access, maximum wave height and period, and wind and current velocity for inspections)
- Measured noise
- Weight for the collision risk
- Use of curtail devices
- Electrical sub-system cost estimate per MW
- Export cable landfall construction technique
- Moorings and foundations cost estimate
- Measured magnetic field
- User selected installation tool

B. SITE DATA

- Monthly observation of receptors
- Initial temperature
- Initial noise
- Presence of protected species
- Weight for the reserve effect
- Initial turbidity

- Initial electrical field
- Soil sensitivity
- Initial magnetic field
- Weight for the reserve effect
- Weight for the energy modification
- Protected areas

C. DEVICE DATA

- Floating device draft
- Device towing bollard pull
- Device footprint coordinates
- Device power factor
- Foundation type
- Inter-distance between turbines
- Device access requirements
- Device sub-system costs
- Device sub-system annual failure rates
- Device inspection requirements
- Device control system installation specification
- Device on-site maintenance requirements
- Device on-site maintenance parts data
- Device operation weightings
- Device replacement requirements
- Weight for the reef effect
- Weight for the resting place
- Device cost

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