EnFAIT

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ENFAIT
ENABLING FUTURE ARRAYS IN TIDAL

DTOcean: Scenario Definition & Performance Metrics

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Contents

Abbreviation and Definition

ADCP	Acoustic Doppler Current Profilers
AEP	Annual Energy Production
CAPEX	Capital Expenditure
DTOcean	Design Tools for Ocean Energy Arrays
EnFAIT	Enabling Future Arrays in Tidal
LCOE	Levelised Cost of Energy
MWh	Megawatt Hour
O&M	Operation and Maintenance
WP	Work Package

1 The Project

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.

One of the purposes of Work Package (WP) 10 of the EnFAIT project is to validate the DTOcean open source tool. This document is produced to summarise the DTOcean first stage performance metrics for EnFAIT for use in future comparisons, as well as all scenario information. The aim of this deliverable document is to establish a baseline position of the present capabilities of the DTOcean model for the EnFAIT project.

Please note that this document presents the preliminary outputs from the DTOcean suite of tools (for example, regarding array layout). It does not represent the design of the actual deployed array, nor is it proposed to change the existing array design. A comparison of DTOcean outputs with the existing array design choices made by Nova Innovation is provided in this document and summarised in section 4.5. The aim of this comparison is to provide a baseline validation of DTOcean: insights gained from the design decisions made by Nova Innovation in deploying an existing array will then be incorporated in the DTOcean tool design.

This report is submitted to satisfy deliverable D10.3 of the EnFAIT project and will also be made available for public dissemination.

The document is structured as follows:

- Section 1 describes the EnFAIT project's motivation and the objective of the present work.
- Section 2 introduces DTOcean, an open source tool used for the optimisation of array design.
- Section 3 defines the scenarios used in the analysis of the EnFAIT array. The data used for the simulations, regarding bathymetry, tidal series, turbine and other relevant information are presented.
- Section 4 presents a validation study for DTOcean, comparing the outputs provided by the tool against the existing array.
- Section 5 shows the conclusions of this baseline comparison, summarising the differences observed between the numerical model outputs and the existing array. A set of guidelines for future areas of development is also provided in this section.

2 DTOcean

DTOcean is a European collaborative project, which resulted in an open source numerical tool for array optimisation of wave and tidal energy converters. This section explains the main DTOcean structure regarding its modules, assessments and purpose. For further explanation of the design tool, the DTOcean Project can be referenced (DTOcean Project).

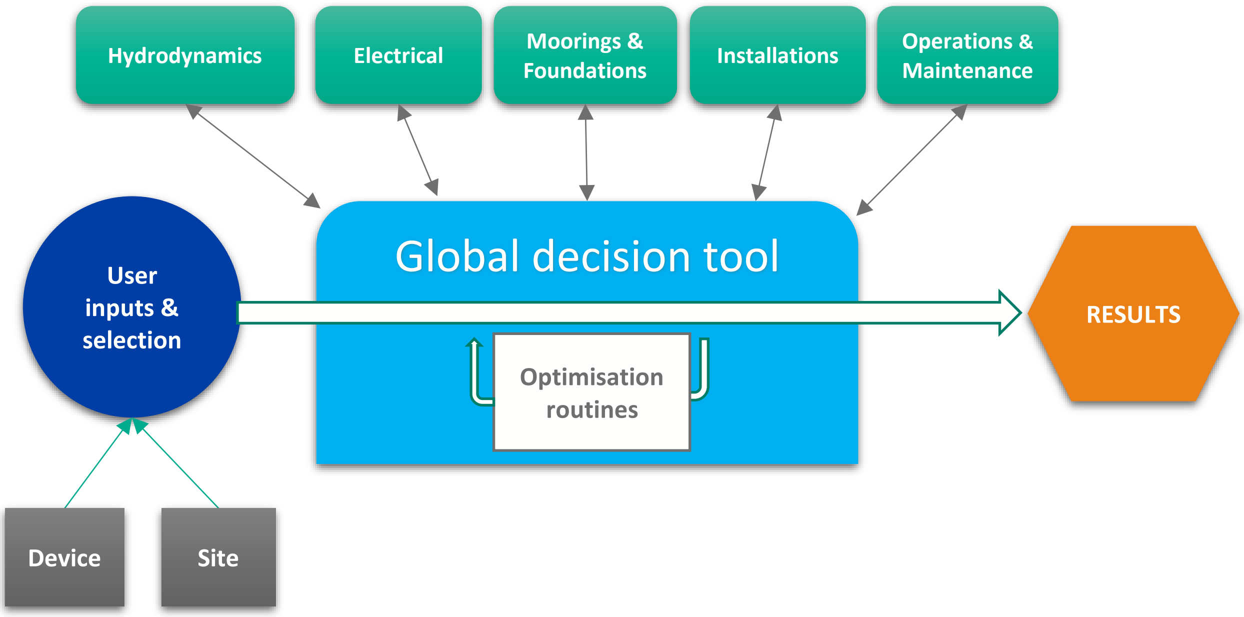

Figure 1: DTOcean structure. [Source: (DTOcean Project)]

DTOcean stands for Optimal Design Tools for Ocean Energy Arrays, (DTOcean Project). DTOcean is modularised into five stages: hydrodynamics; electrical; moorings and foundations; installations; and operations and maintenance. The hydrodynamics module designs the layout of marine energy converters in a chosen region and calculates their power output. The electrical sub-systems module designs an electrical layout for the given converter locations and calculates the electrical energy exported to shore. The moorings and foundations module designs the foundations and moorings required to secure the converters at their given locations. The installation module designs the installation plan for the marine energy converters and the array components. Finally, the operations and maintenance module calculates the required maintenance actions and energy 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. The economic assessment tool produces economic indicators for the design, in particular the Levelised Cost of Energy (LCOE). The reliability assessments evaluate the reliability of the foundation and electrical components during the array lifetime (DTOcean, 2016). Finally, the environmental impact assessment identifies the most sensitive receptors/stressors, which are combined into different environmental functions.

DTOcean is used in the first instance for array layout validation of the existing array of turbines in the EnFAIT project. The data collected during the EnFAIT project will be used to validate and improve the DTOcean tool. Later on in EnFAIT, DTOcean will be used to support the extended array design, and numerical predictions will again be compared with results obtained from the extended array.

3 DTOcean scenario definition

3.1 Bathymetry

The EnFAIT array is located in the Bluemull Sound, in the Shetland Islands between Yell and Unst in the north of Scotland, see Figure 2.

Figure 2: Location of the Bluemull Sound. Array lease area depicted in a white square. [Source: (Google, 2018)]

3.1.1 Bluemull Sound

The bathymetry of the Bluemull Sound can be seen in Figure 3; the lease area is also shown.

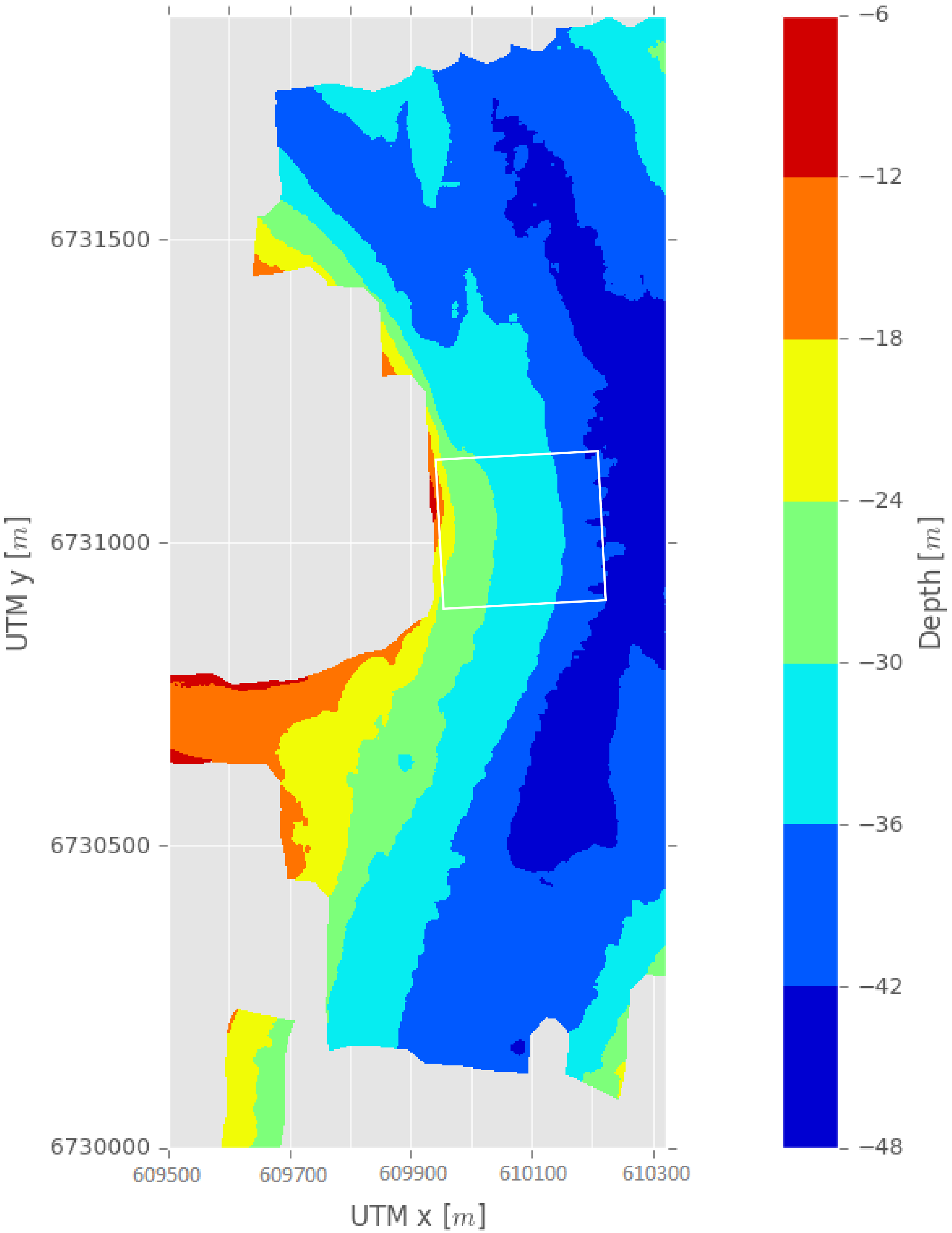

Figure 3: Bluemull Sound bathymetry. Lease area depicted in a white square.

3.1.2 Lease area

The bathymetry of the lease area is plotted in Figure 4. The resolution of the bathymetry is given in cells of 5m x 5m area.

The bathymetry of the lease area also showing the location of the three turbines already deployed, can be seen in Figure 9.

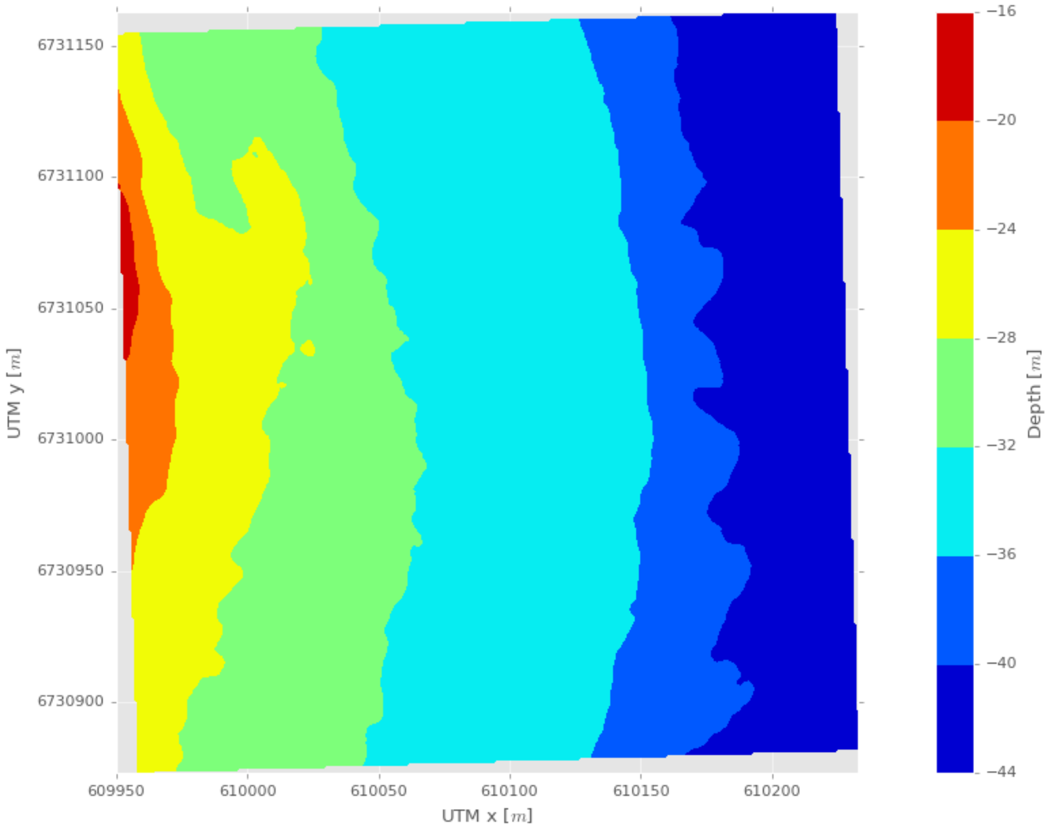

Figure 4: Bathymetry of the lease area. 5m x 5m resolution.

3.1.3 Cable corridor bathymetry

The cable corridor bathymetry is also necessary for the cable export routes calculation in the Electrical module of DTOcean. The cable corridor is the area within which the exporting cables are deployed to transfer the power from tidal site to shore. This is shown in Figure 5, using the same resolution as in the Figure 4.

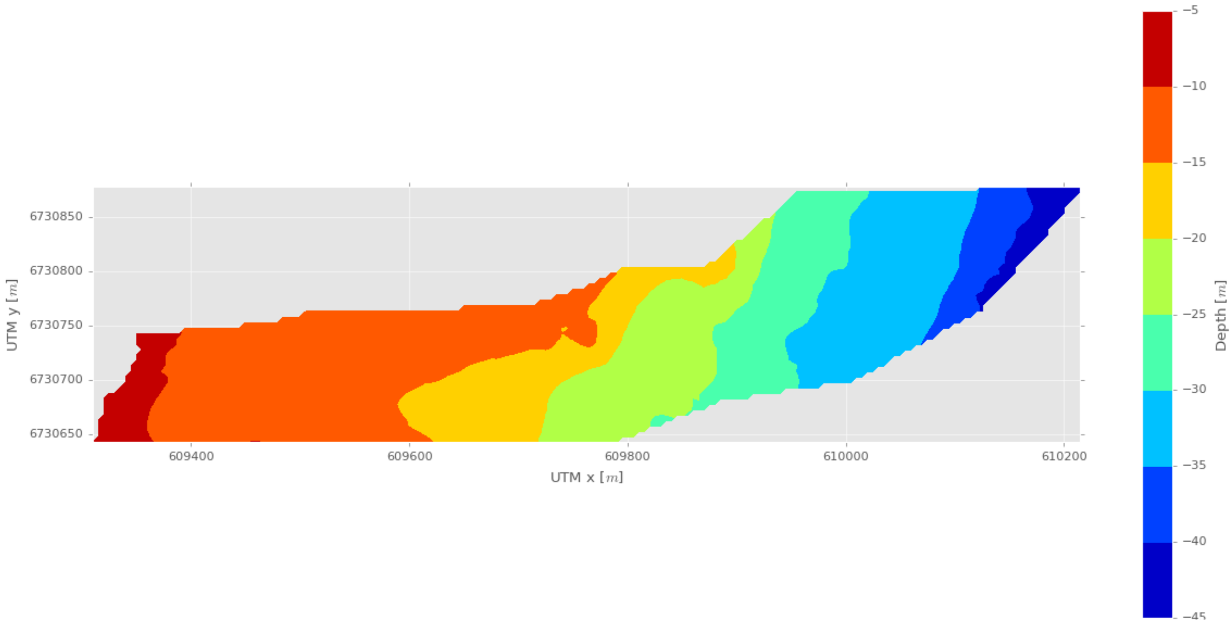

Figure 5: Cable corridor bathymetry. 5m x 5m resolution.

3.1.4 Project boundaries

Taking into account the information provided in previous sections, the project boundaries considered are shown in Figure 6. The lease area (blue square outline), linked to the cable corridor (green outline), finishing in the export cable landing point (red dot) are plotted. Note that the cable corridor overlaps slightly with the lease area to ensure the tool finds an entire path for the cable.

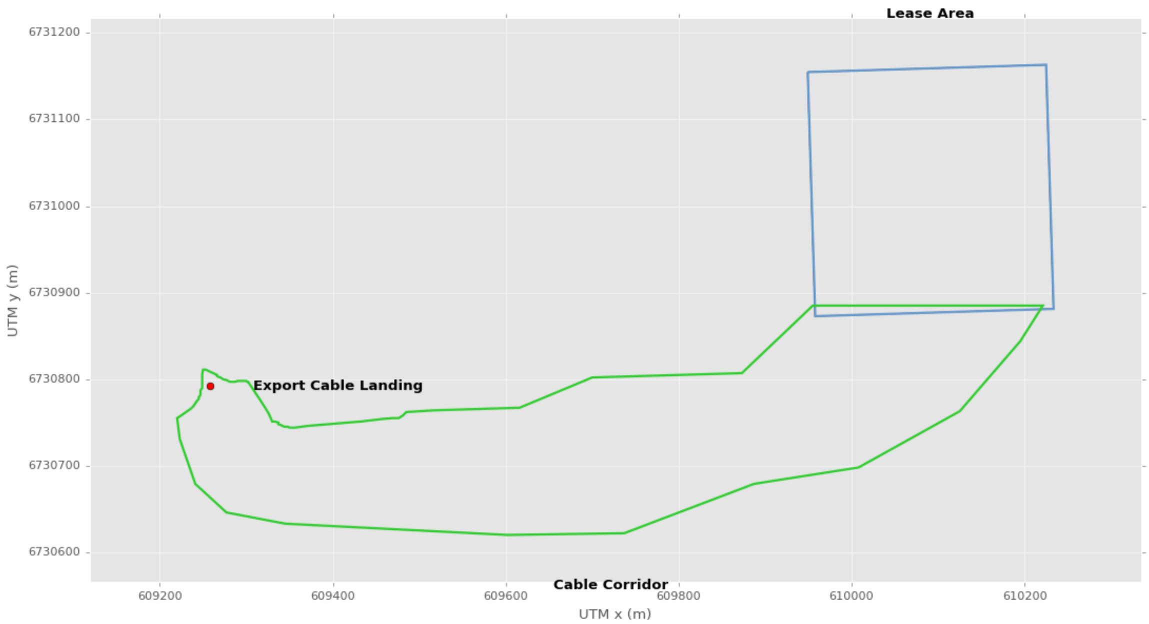

Figure 6: Project boundaries in DTOcean.

3.2 Tidal series

The tidal series data has been obtained from the information provided by EnFAIT project deliverable D10.2: Bluemull Sound Site Resource Map (ref document: EnFAIT-EU-0021). Three Acoustic Doppler Current Profilers (ADCPs) were installed in the Bluemull Sound to monitor flow conditions and help understand the site tidal resource. This data has been used in this analysis as an initial input to DTOcean. The tidal velocities for the array lease area are extrapolated from those 3 points of the ADCPs using a tidal flow model, which returns the hourly average velocity for a period of two weeks in order to match the DTOcean requirements. A general overview of the tidal flow at Bluemull Sound is plotted in Figure 7.

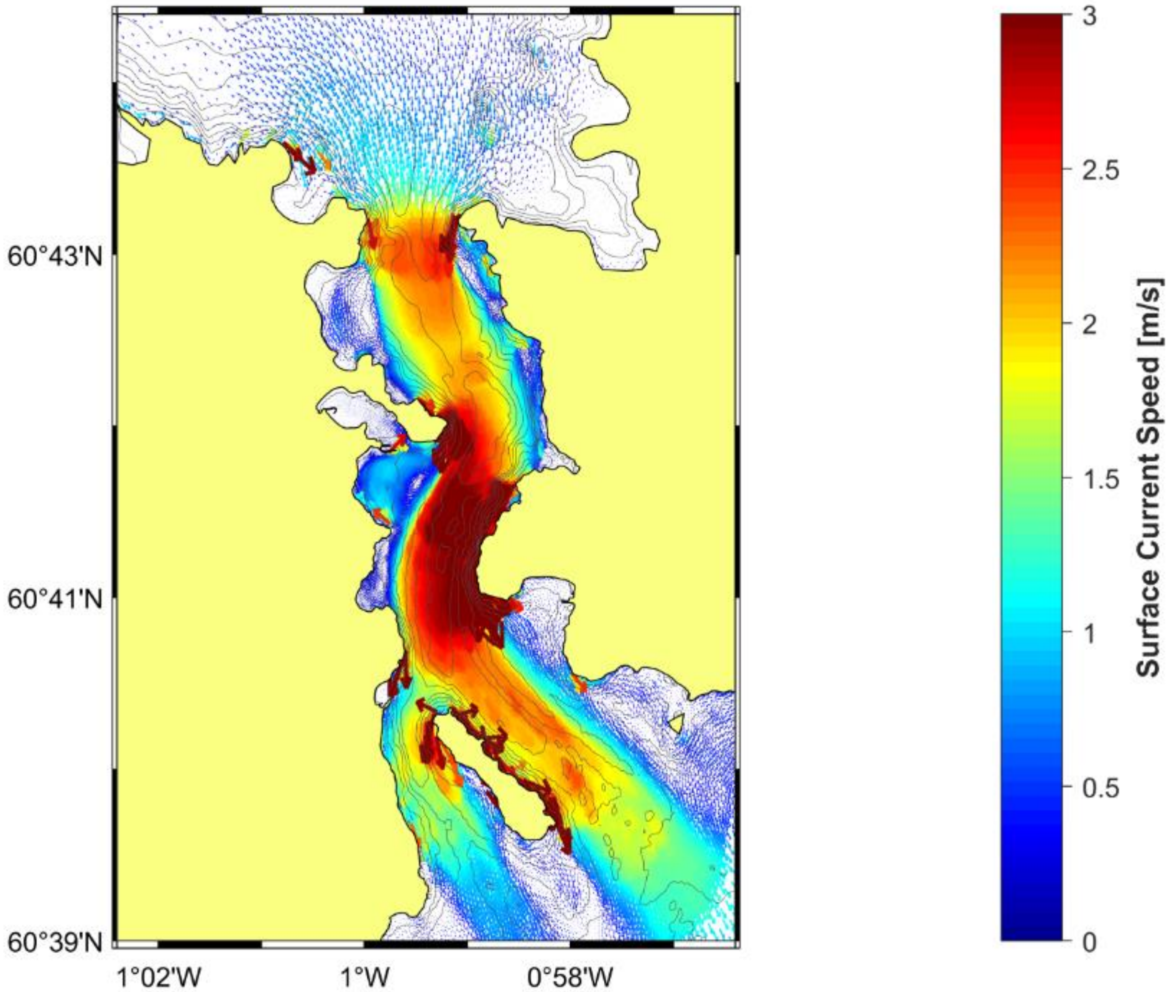

Figure 7: Example of tidal flow at the Bluemull Sound.

3.3 Turbine description

The turbine used for the DTOcean simulations is the Nova M100 100kW tidal turbine. A representation of the turbine is shown in Figure 8.

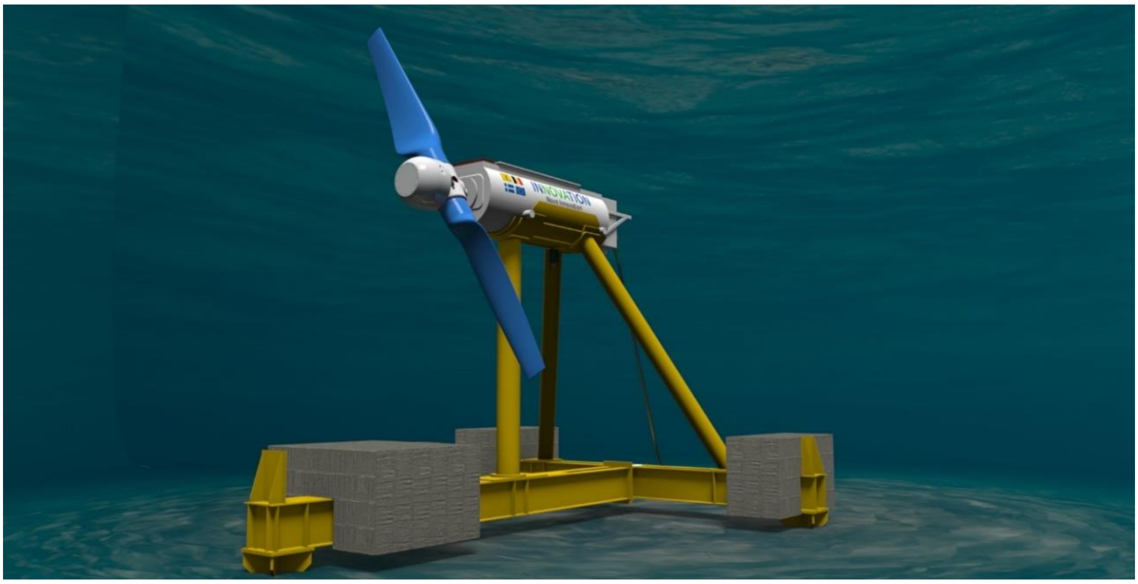

Figure 8: Nova M100 tidal turbine.

A three-turbine array is analysed in this part of the project, representing the existing array in the Bluemull Sound. In follow-on deliverables of the EnFAIT project, comparisons will be made with the full-sized six-turbine array.

3.4 Other data relevant to DTOcean

Other aspects of the array are relevant for the DTOcean outputs to be accurate. These are summarised in the following list:

- Datum: 1.37m below Ordnance Datum at Newlyn (UK).
- Turbulence intensity: 15%
- Manning number: 0.03523
- Device rated power: 100 kW, bi-directional
- Network configuration: radial
- Cables burial depth: 0m
- Project lifetime: 20 years
- Discount rate: 10%
- Minimum draft clearance: 15m (license condition)

4 Comparison of DTOcean metrics with existing tidal array

In order to provide an overview of the array performance, establish the initial metrics for future comparisons, and validate the DTOcean tool, a real case study has been analysed with DTOcean, where three turbines of the EnFAIT array in the Bluemull Sound have been considered.

Each module of DTOcean is evaluated in this section to understand the tool and establish confidence levels with its choices. For each choice made by DTOcean, a comparison with the three turbines deployed by Nova Innovation in the Bluemull Sound is carried out. At the end of this deliverable document, a full comparison table is provided showing how the DTOcean suggestions align with the existing array. The classifications used for this comparison exercise is shown in Table 1. A colour code and a corresponding letter define the classification, which is divided into three categories, as follows:

- High similarity (**H**) **Green** : DTOcean outputs are similar to those of the existing array;
- Medium similarity (**M**) **Yellow** : some similarity between DTOcean outputs and existing array;
- Low similarity (**L**) **Red** : different results between DTOcean and existing array.

Table 1 – Classification criteria.

Comparison between DTOcean and existing array	Classification
High similarity	H
Medium similarity	M
Low similarity	L

4.1 Hydrodynamic Metrics

The Hydrodynamics module of the DTOcean tool aims to identify an array configuration that maximises the Annual Energy Production (AEP) of the array (DTOcean, 2016). Further to the array design and AEP definition, the Hydrodynamics module can also provide other outputs, such as array capacity factor, power production per device, and resource reduction.

In order to compare the numerical model in DTOcean with the existing array, some metrics are initially assessed: AEP, array design, and array orientation, as a comparison of the outputs obtained by DTOcean and the choices made for the existing array.

4.1.1 AEP comparison

The AEP estimated with the DTOcean Hydrodynamic module considers array interaction effects. Electrical losses and downtime service influence the final AEP calculation and related cost of energy - these are estimated in later modules of DTOcean: Electrical and Operation & Maintenance (O&M), respectively. In this baseline case, the electrical module will be considered, while the O&M module is not used - so availability is assumed as 100%. Outputs of the O&M module will be considered in future deliverables from the EnFAIT project.

Therefore, the comparison of the AEP given by DTOcean shown in Table 2 considers the array interaction solely. For comparison purposes, the existing array theoretical AEP is taken as a reference (100%), and the numerical model is expressed relative to that.

Table 2: AEP comparison.

AEP	Numerical Model (DTOcean)	Theoretical existing array	Classification
Array	102%	100%	H

As can be seen in Table 2, the difference between DTOcean and the theoretical array AEP is minimal. Therefore, this comparison is classified with a high level of similarity. The theoretical AEP represents the maximum energy production for given tidal conditions in the Bluemull Sound. Thus, the value provided by DTOcean after the optimal location of devices within the lease area is expected to be close to the theoretical value.

4.1.2 Turbines location comparison

The existing M100 turbines are located near to the south of the licenced array area in the Bluemull Sound. This general location was selected to minimise the length of the subsea export cables required. This improves both cost and reliability, whilst minimising environmental impact.

The preferred arrangement for the three turbines in the existing array was selected as a single row, oriented approximately perpendicular to the direction of tidal flow, to avoid any flow interactions between turbines. Micro-siting of each individual turbine was then carried out to ensure that all technical and environmental depth requirements were met, whilst selecting areas of seabed that were relatively level and free of any obstructions.

Sufficient lateral (*i.e.* cross-flow) space was left between turbines to enable marine operations to be conducted without risk of encroaching on neighbouring turbines. However, the turbines are located close enough together to allow servicing to be carried out on more than one turbine using the same mooring spread, reducing the number of offshore operations required. These operational constraints resulted in the locations shown in Figure 9 for the three turbines in the existing array.

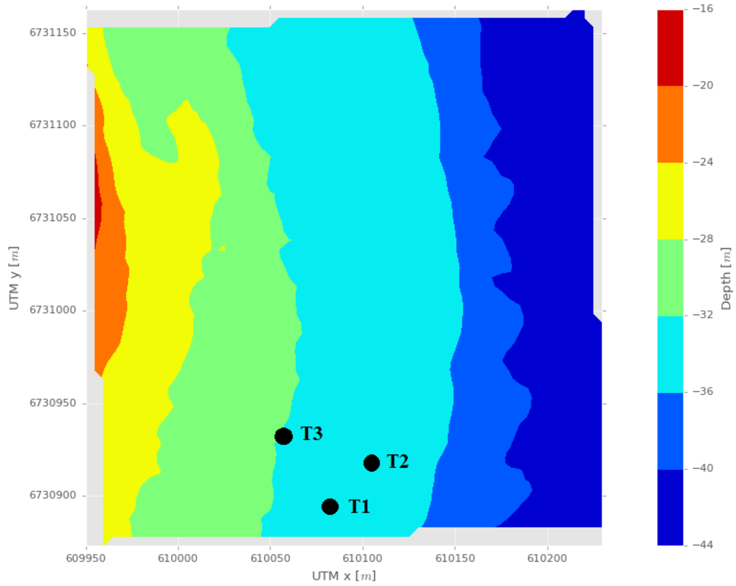

Figure 9: Actual location of turbines in existing array.

DTOcean, however, defined the optimal location for the devices by considering only one constraint: the maximisation of the AEP. This is due to the application of the Hydrodynamics module only in the first instance. Please note that the modules are run independently in this analysis. A combined strategy will be considered in future deliverables of this project and will be investigated in detail then. Taking that into account, the optimal location of turbines using DTOcean is as shown in Figure 10.

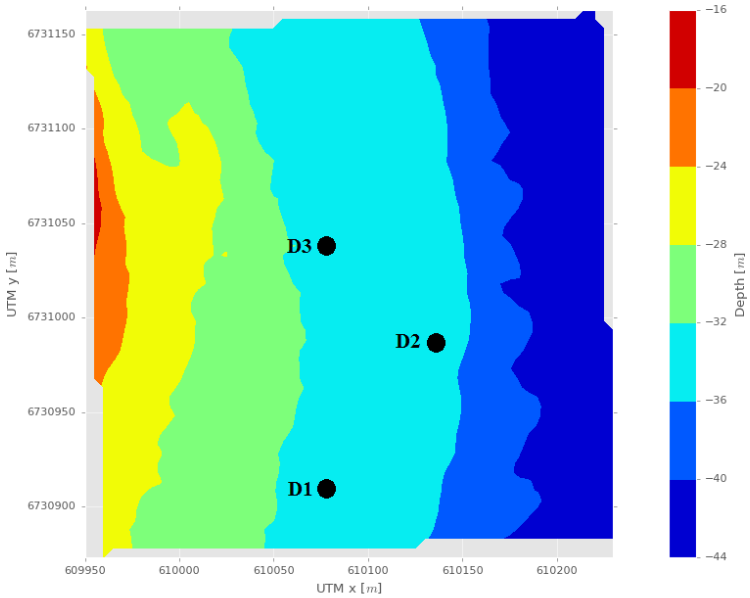

Figure 10: Optimal location of turbines suggested by DTOcean.

Figure 10 shows the optimal distribution of turbines suggested by DTOcean to maximise the energy production of the array. In this case, the turbines are distributed across the lease area. Turbine device D1 is placed in the same area where the existing turbines are located, but the other two devices are placed further north. DTOcean chose these locations to reduce the interaction between devices to a minimum. The comparison between locations given by the numerical model and the existing array is presented in Table 3.

Table 3: Turbines location comparison.

Item	Numerical Model (DTOcean)	Existing array	Classification
Turbines location	Distributed across lease area	South of lease area	M

The turbine location choice is classified as medium similarity (M). The difference between choices is due to the application of different constraints. DTOcean is automatically set to choose locations for turbines to maximise AEP, while the existing array design choice was also based on considerations such as the minimisation of subsea export cable length and the minimisation of the number of offshore operations.

4.1.3 Array orientation comparison

The M100 tidal turbine does not have any yaw mechanism, and so to capture the maximum energy from the flow each individual turbine is optimally oriented by aligning its gravity base foundation appropriately. As reported in EnFAIT document EnFAIT-EU-0021 (deliverable D10.2), there is a slight misalignment between ebb and flood tides at the site of the Bluemull Sound tidal array, though both tides are of similar maximum strength and energy content. The M100 turbine operates with similar efficiency in both tidal directions and so the orientation of each turbine was therefore selected to closely align each turbine's axis of rotation with the overall mean flow direction.

The final factor influencing turbine orientation was a desire to simplify the export cable runs back to shore. The preferred initial direction of cable lay was to the south due to the relative position of the cable corridor, as shown in Figure 6. The M100 export cables exit the turbines from the opposite end of the nacelle to their rotors, as shown in Figure 8. This sets the overall orientation of the turbines on the existing array design.

DTOcean provides two options for the array orientation value. It can be previously defined as an input; or the optimum orientation can also be estimated for maximisation of AEP, and therefore be treated as an output. For the case study, the second option was adopted and the array orientation was optimised on DTOcean. In both cases, DTOcean considers a single orientation for the entire array, so all devices are therefore aligned with each other.

The orientation provided by DTOcean is in the same range as those of the existing turbines, however for the existing array, an orientation for each individual device is defined. For this reason, the classification of the array orientation is defined with a medium level of similarity, see Table 4.

Table 4: Relative Array Orientation.

Item	Numerical Model (DTOcean)	Existing array	Classification
Array orientation	General array orientation	Different for each turbine	M

4.2 Electrical Metrics

The Electrical Sub-Systems module on DTOcean has the aim to identify different electrical network configurations, for a certain site, device, and array layout. In order to find the optimum configuration, efficiency and component costs of different feasible network solutions are evaluated (DTOcean, 2016). The following sections present a comparison of the outputs obtained by DTOcean and the choices made for the existing array.

4.2.1 Cable route comparison

Each of the three M100 turbines installed at Bluemull Sound has a subsea export cable connecting it directly to its onshore electrical infrastructure. Each cable transmits both power and communications for a single turbine. The cables transit through the licenced cable corridor and are brought ashore at the Cullivoe Pier. The cable routes can be seen in Figure 11.

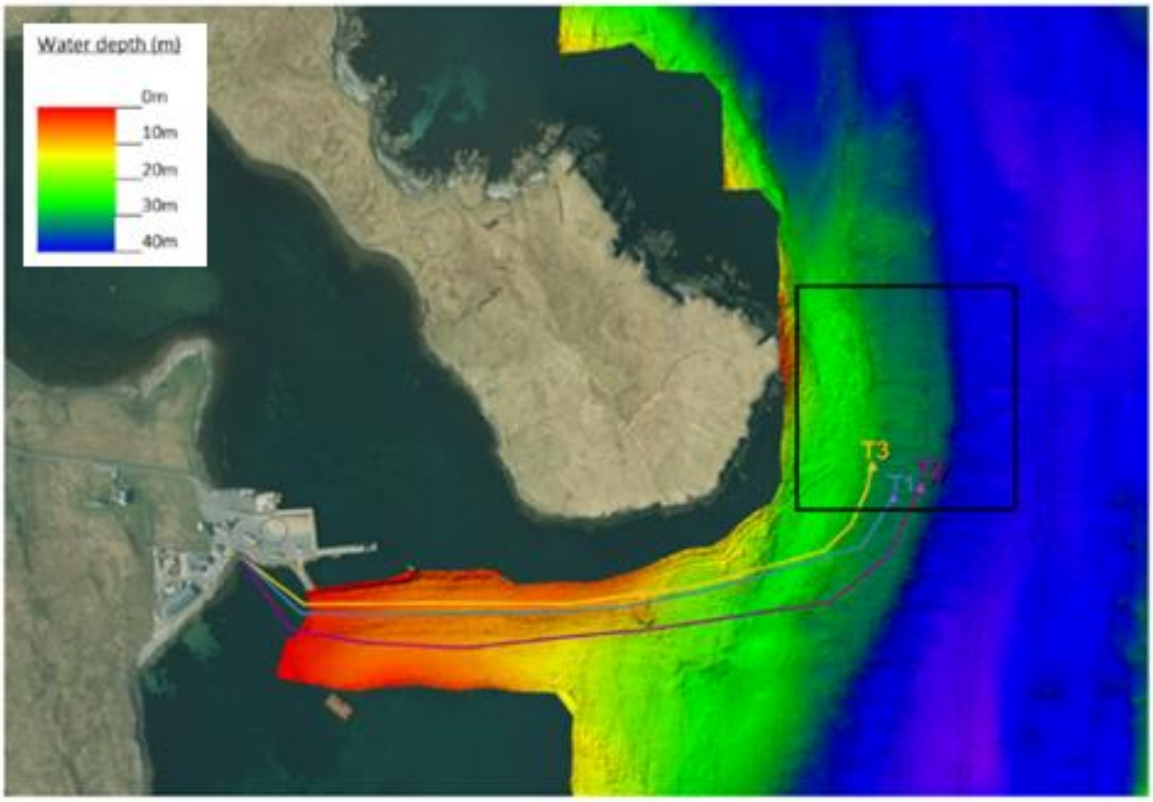

Figure 11: Actual location of turbines at Bluemull Sound and cable route.

In order to define the cable route for the array system, DTOcean assumes a methodology to optimise electrical costs and electrical losses, both parameters influencing the techno-economic evaluation. Therefore, shorter lengths are normally chosen. This causes some differences with the cable routes of the existing array. The DTOcean electrical layout for the current EnFAIT case study is presented in Figure 12. The collection point (substation) is placed offshore, which leads to a reduction on cable length as there is only one cable to connect the devices to shore. However, the costs related to operate and maintain a substation offshore and the risks associated with this placement are not taken into account in the DTOcean numerical model. This leads to a different solution between DTOcean and the existing array.

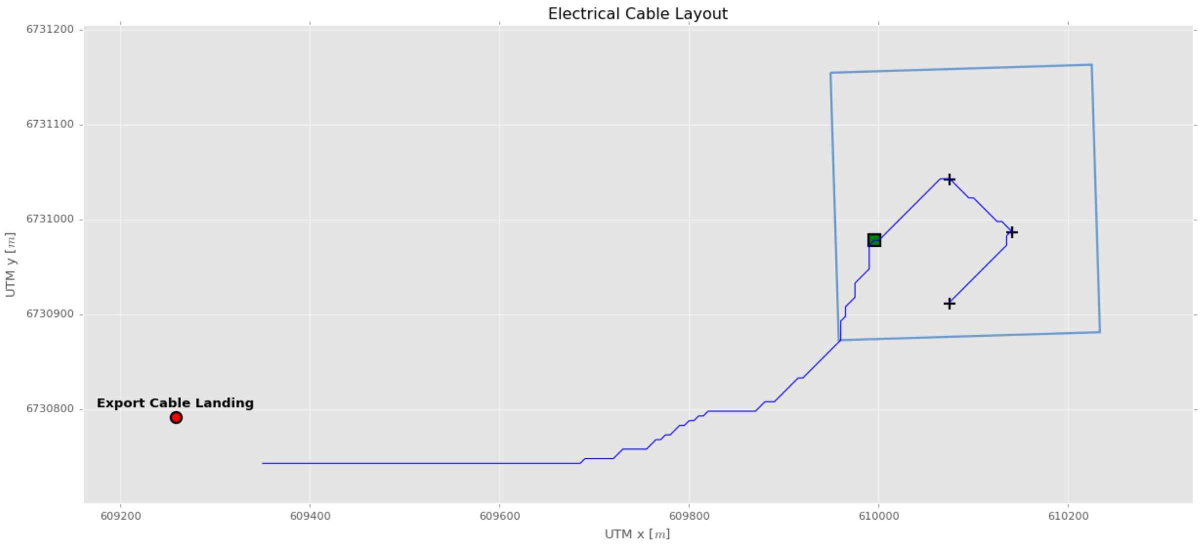

Figure 12: DTOcean cable route.

Please note there is a missing section of cable route near the coast due to the lack of available bathymetry in that area. Table 5 shows the comparison between route choices.

Table 5: Cable route comparison.

Item	Numerical Model (DTOcean)	Existing array	Classification
Cable route	One collector cable	One cable per turbine	L

The option proposed by DTOcean focuses on the use of a single cable from the offshore substation to shore. While this choice is sensible for large arrays, it is not so straightforward for smaller arrays. The reduction in reliability by the insertion of a collection cable, plus the introduction of an offshore substation would increase the costs of energy extraction. Therefore, the choice provided by DTOcean would be valid for fully-sized commercial arrays.

Figure 12, also shows that DTOcean choice regarding the intra-array cabling was based on the radial connection. For bigger arrays, a star connection might be a better approach due to costs of connectors.

4.2.1.1 Existence of a substation or collection point

For small arrays of turbines located close to a suitable cable landing point, connecting each turbine via its own export cable offers an attractive option in terms of cost, simplicity of operations and reliability, and so this was the solution selected for the existing array in Bluemull Sound. There was therefore no need for an offshore substation (or 'hub').

The array extension being designed as part of the EnFAIT project will include an offshore substation. One reason for this is because, for larger arrays located further from shore, both the cost and the environmental impact associated with individual export cables is expected to become unacceptably large.

DTOcean provides a substation by default, and then the choices of the numerical model and existing array design are different in this case. The classification is showed in Table 6.

Table 6: Offshore substation comparison.

Item	Numerical Model (DTOcean)	Existing array	Classification
Offshore substation	Substation	No substation	L

4.2.2 Cable installation comparison

The seabed in the Bluemull Sound is relatively flat, consisting of weathered bedrock and cobbles in the main tidal channel. This rock becomes overlaid with sand and sediment closer to the shore, away from the influence of the strongest tidal flows. The M100 cables were designed to be stable on the seabed under their own weight under all predicted environmental conditions at the site. Therefore, there was no need for additional cable protection or burial along any of the cable route.

This cable laying method minimises the cost of cable installation as well as reducing the environmental impact compared with other methods (such as trenching or burying the cables). Similarly, by bringing the cable onshore at the existing Cullivoe Pier breakwater, there was no requirement to trench or drill at the cables' landfall, reducing environmental impacts and costs yet further.

DTOcean uses a library that considers costs related to different cable installation processes. The installation processes provided by DTOcean are *jetting*, *ploughing*, *cutting*, and *dredging*. The *laying* method however is not an available option in the existing numerical model; therefore, the model defaults to another technique, which obviously differs from the existing array design, see Table 7. The installation method chosen by DTOcean is *Cutting*, due to the stiffness of the seabed material (hard rock). However, the cable burial depth is specified as an input to be on the seabed surface (0m depth), so the selected method is just a combination of the limited available options. For that reason the comparison between the existing array and DTOcean is classified as low similarity (L), see Table 7.

Table 7: Cable installation comparison.

Item	Numerical Model (DTOcean)	Existing array	Classification
Cable installation	Cutting	Surface laying	L

4.3 Moorings & Foundations Metrics

DTOcean has a Mooring & Foundations module, which performs different analyses (static and quasi-static) to provide an optimum solution with low capital cost. The solution evaluates the suitability for a site, device and loading conditions and assesses the compatibility with the array layout. If not previously defined by the user, DTOcean is able to identify the optimum foundation type and location points (DTOcean, 2016).

This module presents four sub-modules: load class; foundation class; mooring class; and substation class. There is also an additional sub-module, the umbilical, which communicates with the mooring class sub-module. The choice between mooring or foundation sub-module depends on whether the tidal turbine device is fixed or floating, which is defined by the user.

The inputs for the Mooring & Foundations module are defined by the user, by previous modules (hydrodynamic and electrical system), and also taken from the DTOcean global database (DTOcean, 2016).

4.3.1 Type of foundation - Devices

The foundations for the existing M100 turbines are gravity bases. At the scale of these turbines, this concept offers a very reliable and cost-effective method of installation, as well as enabling straight-forward decommissioning at end of life without leaving any residual environmental impacts.

DTOcean has a database with different type of foundation components. Together with site information, the modelling tool provides the most suitable type of foundation for the project (DTOcean, 2016). For the EnFAIT case study considered in this deliverable, the foundation type provided by DTOcean was the same as used in the existing array. The classification of this choice is provided in Table 8, with a high similarity (H) in choice.

Table 8: Devices foundations.

Item	Numerical Model (DTOcean)	Existing array	Classification
Devices foundations	Gravity	Gravity	H

4.3.2 Mass of the foundation

DTOcean also estimates the bill of materials regarding the foundation type chosen. A relative comparison with the existing array is presented on Table 9. It is considered that the existing array provides a normalised value (100%) and that the Numerical Model from DTOcean is a proportional percentage of that.

Table 9: Foundation mass.

Item	Numerical Model (DTOcean)	Existing array	Classification
Foundation mass	71%	100%	H

The mass of foundation is classified as a high similarity. DTOcean outputs from future analysis later in the EnFAIT project are expected to be more accurate when other modules are included, due to O&M contributions to the foundation calculation.

4.3.3 Type of foundation - Substation

The foundations of the offshore substation being designed for installation as part of EnFAIT will also be a subsea gravity base solution for the same reasons as those presented previously for the turbine device foundations.

In DTOcean, the Substation class operates similarly to the Foundation class of the devices. However, contrasting from the many types of foundation that DTOcean provides for devices, there is only one type of foundation provided for the substation. For that reason, the solution obtained on DTOcean for the foundation of the substation (i.e. piling) is different from the choice made for the existing array design. The classification of this choice is provided in Table 10, showing a low similarity (L) on the substation foundation.

Note that the substation for the existing array here refers to the planned substation for the next phase of turbine deployment within EnFAIT: there is not currently a substation deployed at the site in Bluemull Sound.

Table 10: Substation foundation.

Item	Numerical Model (DTOcean)	Existing array	Classification
Substation foundation	Pile	Gravity	L

4.4 Economic Metrics

4.4.1 CAPEX comparison

Capital expenditure is calculated from the values given in the modules of DTOcean described earlier: Hydrodynamic, Electrical Infrastructure and Mooring & Foundation Systems. Table 11 shows the relationship of the CAPEX of each module in relation to the CAPEX of the existing array.

Table 11: CAPEX comparison.

Scenario	CAPEX **(DTOcean / Existing array)**	Classification
Substructure	63%	M
Electrical System	102%	H
Total CAPEX	90%	H

Total CAPEX cost includes device, substructure and electrical costs and it is classified as a high similarity (H) in choice. Electrical system cost is also classified with high similarity, while the substructure cost is classified with medium similarity.

The difference between foundations costs is mainly due to the foundation of substation, and to the difference in mass of device foundations between DTOcean and the existing array. As previously mentioned, DTOcean only allows one choice for the substation foundation: piling, which is likely to be more expensive in reality to deploy than a gravity base for a project of this scale. However, DTOcean disregards installations costs associated with piling/drilling. Therefore, the CAPEX associated with substructures is lower on the numerical model when compared to the existing array.

It is interesting to note that the number of similarities does not necessarily lead to a convergence in costs. Taking the Electrical System Module as an example, the choices were often classified with a low similarity; however, the resultant costs were similar. Although in the electrical module the length of cable is reduced for the optimised case, the cost of the collecting cable is higher than the cost of individual smaller cables for each turbine, as used in the existing array. In this particular case, that fact balances the final CAPEX of the electrical system.

It is also important to highlight that DTOcean has a database for prices of components. The database should be reviewed regularly, together with the exchange rates. Note that DTOcean gives results in €, while the Nova Innovation array data is provided in £. 2018 exchange rates have been used for comparison purposes, but the variability of that specific rate in the past 3 years makes this a point for future consideration.

DTOcean Installation and O&M modules were not considered at this time. This means that the impact of downtime was disregarded in the AEP calculation (100% availability is assumed); O&M and Installation costs were also not considered. However, as the comparisons are being made section by section, these omissions do not influence the model outputs. These modules will be explored in future deliverables of EnFAIT. For this reason, the final metric assessed on this deliverable is CAPEX per MWh instead of LCOE. Further modelling later in EnFAIT will also consider the LCOE metric comparison between DTOcean and the existing array.

4.4.2 CAPEX per MWh comparison

Table 12 presents the difference in CAPEX per MWh between the results given by DTOcean and the existing array values.

Table 12: Cost of Energy comparison.

Item	Ratio **(DTOcean / Theoretical existing array)**	Classification
CAPEX/MWh	88%	H

The classification shows that there is high similarity (H) between results. It deals with the 10% difference in Total CAPEX (see Table 11) and also the 2% difference in AEP (see Table 2), resulting in 88% of similarity as presented on Table 12.

4.5 Assessment of DTOcean Capabilities

This section assesses the current DTOcean capabilities, summarising and qualitatively comparing the outputs of DTOcean with the existing EnFAIT array design, see Table 14. Table 13 is a reminder of the classification criteria, as presented earlier in Table 1. The code is divided into three categories, high similarity (H) – Green; medium similarity (M) – Yellow; and low similarity (L) – Red.

Table 13 – Classification criteria.

Comparison between DTOcean and existing array	Classification
High similarity	H
Medium similarity	M
Low similarity	L

Table 14 – Summary of qualitative comparison between DTOcean and existing array.

Modules	Subcategories	Classification	Module Classification
Hydrodynamic Metrics	AEP	H	M
	Turbines location	M	
	Array orientation	M	
Electrical Metrics	Cable route	L	L
	Existence of a substation	L	
	Cable installation	L	
Mooring and Foundation Metrics	Foundation type – Devices	H	M
	Foundation mass – Devices	H	
	Foundation type – Substation	L	
Economic Metrics	Substructure costs	M	H
	Electrical costs	H	
	Total CAPEX	H	
	CAPEX per MWh	H	

The results summarised in Table 14 show that the metrics and module where the biggest differences are observed between DTOcean and the existing array, belong to the electrical module. These discrepancies focus on the cable routing, substation and installation of cables. DTOcean only provides the option of having a substation with a collector cable to shore. While this choice might be useful for large arrays with many turbine devices, its advantages are not so obvious when there are fewer devices, as in the EnFAIT case.

The rest of the modules present reasonable resemblance to the design choices taken in the Bluemull Sound array. There are, however, some cases where DTOcean shows some limitations in terms of available options, such as the case of the array orientation, where multiple orientations should be available for different devices. As in previous comments, this would make sense for fully commercial arrays, while for early stage arrays like EnFAIT the choices proposed by DTOcean would introduce a lack of reliability, increasing the operational costs.

4.5.1 Areas for further investigation

After comparing DTOcean with an existing array design, some areas for further investigation and improvement for the DTOcean numerical model are listed below:

* Turbine location: DTOcean considers only one boundary for the turbine location definition, the maximisation of AEP. The effect of other boundaries affecting the cost of energy calculation should be included, since turbine placement influences capital, installation and O&M costs.

* Array orientation: DTOcean only allows one general direction for the array, where all devices are similarly aligned with each other. The AEP results should be further investigated when considering different directions for each device.

* Cable route: DTOcean considers an offshore substation, which results in different cable configurations. The costs should also be assessed when disregarding the offshore substation.

* Existence of a substation: this is a DTOcean requirement. It could be treated as an option to place a substation offshore to assess different results.

* Cable installation technique: DTOcean does not include the *laying* cable installation technique as an option. This should be included in later improvements of the tool.

* Substation foundation type: DTOcean only provides the pile choice for the substation. More options should be provided.

5 Conclusions and future work

The objective of the EnFAIT project is to enable future tidal arrays by demonstrating a grid-connected tidal energy array at a real-world energy site. In Work Package 10 of the project, the DTOcean tool is used to inform the extended array design as well as to validate and refine the DTOcean model based on the experience gained during the EnFAIT project. This deliverable document summarises the initial performance metrics of the DTOcean suite of tools, and a comparison is made with the results provided by the existing array. The aim of this comparison is to provide a baseline to understand the level of validation of DTOcean, and this deliverable also suggests areas of further investigation for future improvements of the numerical tool.

The EnFAIT array is located in the Bluemull Sound in Shetland, Scotland. Currently, three tidal turbines are deployed. For this first run of DTOcean, the bathymetry has been cropped to the lease area of the array. Site information related to the tidal series is also included. Currently, the Hydrodynamics, Electrical systems and Moorings & Foundation modules are being used. The Installation and O&M modules will be assessed in detail during the next stages of the project and then the reduction of LCOE by the assessment of availability, reliability and operation costs will be carried out. Moreover, this report evaluates Economic metrics. Future analysis will include reliability and environmental assessments.

These initial capabilities and outputs of DTOcean are compared with the existing array, and the classification of choices is summarised in Table 14. The quantitative analysis presented here highlights differences in the outputs provided by DTOcean and the existing array. In general, the hydrodynamic module presents a medium level of similarity between numerical outputs and existing array, showing better results for AEP calculations. The moorings and foundations module also presents a medium level of accuracy when compared to the existing array. The weakest module is the electrical one, as the results do not match the choices taken in the existing array. Finally, the economic assessment presents a good level of accuracy in general terms. In most of the cases, the divergence of results between DTOcean and the existing array are due to DTOcean focusing on fully commercial arrays, which differs from early stage arrays like EnFAIT. Follow-on deliverables from the EnFAIT project will use this qualitative assessment method of the capabilities of DTOcean to further analyse their progress to a greater level of validation.

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