# ELEMENT: INITIAL ENVIRONMENTAL REPORT

Date of Delivery: 29 November 2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 745862.

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# EXECUTIVE SUMMARY


A Funding Grant was awarded from the European Union's Horizon 2020 research and innovation programme to develop and validate an innovative tidal turbine control system, using the tidal turbine itself as a sensor, to deliver a step change improvement in turbine performance. This will demonstrate Effective Lifetime Extension in the Marine Environment for Tidal Energy (ELEMENT), driving the EU tidal energy sector to commercial reality. This document presents the foreseen environmental monitoring activities planned for the ELEMENT project at two locations representative of the tidal market.

Physical characterisation of conditions at sites is needed to optimise energy conversion and the turbine design. It is also required to inform the environmental impact assessment and relate ecological and biological information to physical conditions in order to understand and predict likely impacts. To date, the characteristics of the mean flow (e.g. speed, direction, current magnitude asymmetry, hydrokinetic resource) can be estimated from existing ADCP measurements. However, a comprehensive assessment of turbulence will require the deployment of a 5-beam ADCP. This will provide the consortium with turbulence dataset which is an essential input to properly conduct fatigue life prediction of the tidal turbine, using a stochastic inflow turbulence simulator. Innovative methodologies will be deployed at one test site to provide characterisations that will be further used in WP6 for the development of the behavioural model of the turbine.

The understanding of the influence of the installation and operation of marine renewable energy devices on marine socio-ecosystems is also key for MRE project consenting. But there are still some knowledge gaps regarding the potential environmental impacts, as they vary along time, across space and depend on the number and size of machines installed and sensitivity of the location. Most notably, there is still a lack of data/knowledge regarding the collision risk of marine megafauna with MRE devices, noise emitted by the devices, and the biocolonisation of devices. This report presents plans to develop ecological characteristics evidence databases and outlines the way gathered data will be used to adapt and feed into models, including the behavioural models developed in WP6 of the ELEMENT project and tools developed in the DTOceanPlus Horizon 2020 project.



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# ABBREVATIONS AND ACRONYMS

ADCP: Acoustic Doppler Current Profiler
ADV: Acoustic Doppler Velocimeter
CRM: Collision Risk Model
ESA: Environmental and Social Acceptance
MRE: Marine Renewable Energy

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# CONTEXT AND OBJECTIVES

## Site Tidal Resource

In order to optimize energy conversion, it is required to properly characterize the physical conditions at sites and thus facilitate the process of selecting tidal power devices appropriate for industrial use. This groundwork also helps in streamlining and standardizing siting and permitting processes which are considered key hurdles for tidal industry development. The European Marine Energy Centre (EMEC) has proposed metrics of the mean flow (e.g. speed, direction, current magnitude asymmetry) which help to evaluate the potential of tidal flow in the most efficient way (Legrand, 2009). Whilst the characteristics of the mean flow are relatively simple to measure (Guerra & Thomson, 2017; Thiébaut & Sentchev, 2016; Thiébaut & Sentchev, 2017), a lack of confidence in the characteristics of the turbulent components of the flow has subsequently resulted in high levels of conservativeness being employed by turbine designers. Turbulent fluctuations in the velocity field may lead to excessive cyclic loading on the turbines which may eventually lead to material fatigue and decreased life expectancy of the machines. Thus, fatigue life prediction is of prime importance when designing and operating a tidal turbine.

The major parameters of tidal flow conventionally used for tidal energy site screening as well as turbulence metrics are presented in this report. All turbulence metrics will be evaluated at both Étel and Bluemull sites and presented in a forthcoming report.

## Site Ecological Characteristics

The presence of marine renewable energy (MRE) devices and possible subsequent changes in physical conditions have the potential to modify the presence of some species at local scales, affect behavioural responses of some organisms and provide new substrates for the development of epibenthic communities (Copping et al., 2016). Considering the deployment of single devices or small arrays, experts are according to say that the environmental impacts are low and highly localized spatially (Copping et al., 2016; e.g. Kregting et al., 2016). However, there are still some knowledge gaps, which might present barriers to consenting even for very small-scale projects, and some potential effects of tidal energy deployments still need to be tested (e.g. Dannheim et al., 2019; Boehlert & Gill, 2019). In addition, in the case of later, larger deployments of devices (tidal energy farms), knowledge gaps may become more problematic unless we gather information to provide an evidence base to de-risk future consenting. Thus, and in order to provide an evidence base to enable the consenting of tidal energy projects, there is a need to better characterize their potential impacts on the environment (Copping et al., 2016; Lejart et al., 2012) through *in situ* monitoring, which in turn will inform the development of more realistic models for predicting impacts. More precisely, site characterization and MRE project data are needed to improve understanding for the sensitivity and vulnerability of environmental receptors to impacts and to improve input parameters for modelling approaches (e.g. food web models, Collision Risk Model (CRM), decision tools including environmental impact assessment). And to better analyse and predict potential impacts to derisk future consenting decisions, the refinement of modelling tools and the development of evidence databases are necessary. Knowledge gaps identified in the context of MRE development include collision risk between tidal energy devices and mobile megafauna (marine mammals, seabirds, fish), biocolonisation of MRE devices leading to technical and environmental issues, and in situ measurements of sound emissions. The priority of these gaps is site specific.

Data needs and experimental designs of field characterization campaigns, as well as modelization needs are presented in this report. The synthesis of existing knowledge and first results of the campaigns and modelling will be presented in the following reports.

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# LOCALIZATION OF THE TEST SITES

The test sites of Bluemull and Étel are both located in western Europe, in the Atlantic Ocean (Figure 1). The Bluemull Sound is located in Shetland, in Northern Scotland, between the islands of Unst and Yell. The Etel test site is located in southern Brittany, Western France. Figure 2 shows the exact location of the Bluemull and the Etel test sites.

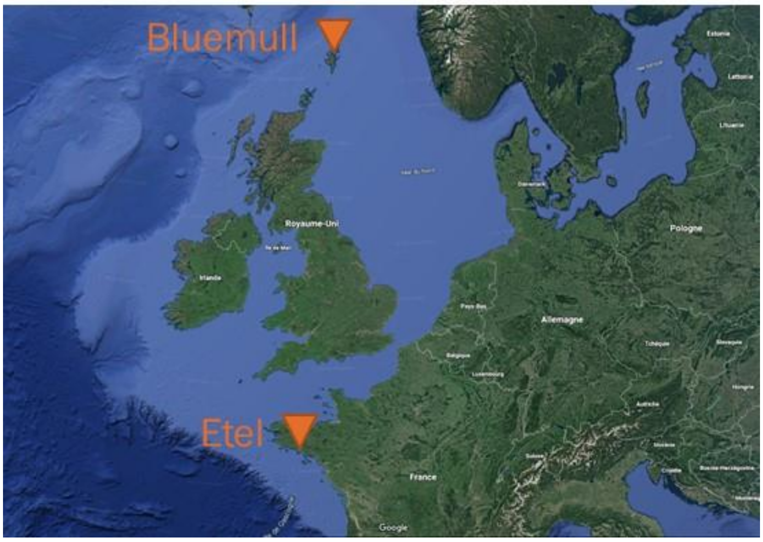


*Figure 1. Location of the two study sites where Nova innovation tidal turbines are currently deployed (Bluemull) and are expected to be deployed (Etel).*


*Figure 2. Precise localization of the Bluemull and the Etel test sites (maps) where the type of device that is currently deployed (M100, 3 turbines, Bluemull) and that is planned to be deployed (Nova RE50, 1 turbine, Etel).*

Both test sites show very different characteristics regarding physical and ecological environment. In particular, Bluemull and Etel show different territory patterns:

- The Shetland Islands are less populated than the Etel area (agglomeration of cities around Etel): 15hab/km² and 100hab/km², respectively;
- Professional fishermen are quite well represented in Shetland;
- Leisure fishermen, recreational boaters, are well represented at Etel;
- Etel is an estuarine system while Bluemull is a sound.

Both sites are located close by or within areas under natural conservation status: there is one Site of Special Scientific Interest and one Special Protection Area close to Bluemull, and the Étel ria is encompassed by Natura 2000 network. Some of the main species that are protected or of interest are the otter (*Lutra lutra*), the european eel (*Anguilla anguilla*), and the red-throted diver (*Gavia stellate*).

The ELEMENT project will allow to provide data analysis and models for these sites, representative of two different tidal energy markets.

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# SITE TIDAL RESOURCES

## Assessment of tidal energy resource

### Current strength, direction and asymmetry

Current strength characterization involves an assessment of the maximum, time averaged velocity, and also asymmetry of the tidal flow. The mean velocity is the average of current velocity magnitudes over a long period including values around slack water or over specific stages of the tidal cycle such as spring and neap tide.

An Acoustic Doppler current profiler (ADCP) is a hydroacoustic current meter similar to a sonar, used to measure water current velocities over a depth range using the Doppler effect of sound waves scattered back from particles within the water column. They are usually the preferred choice for assessing the tidal-stream resource at a site. They provide estimates of flow variability at different depth levels, often sampling the whole water column, and in a large frequency band covering timescales from one second to sub-tidal period. In addition, they can be deployed for long intervals of time (several months), allowing for an assessment of the flow variability over a wide range of timescales.

In order to measure velocities along the three spatial directions, at least three beams are required. In recent years, more functionality has been added to ADCPs (notably wave and turbulence measurements) and systems can be found with 3,4,5 or even 7 beams (Fig. 1).

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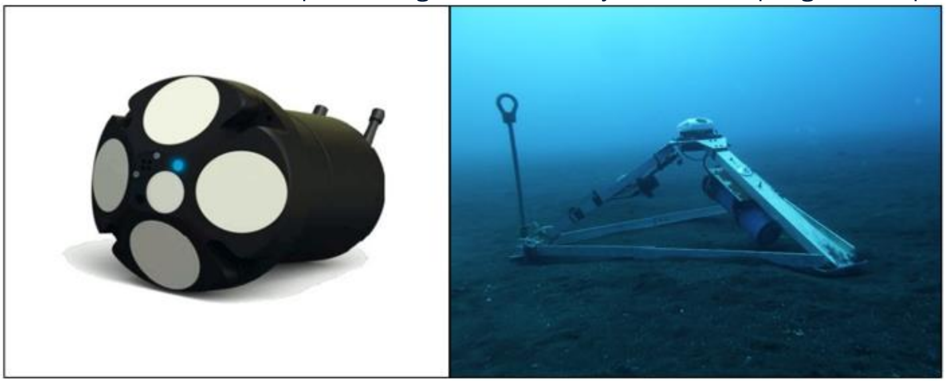

*Fig. 3. Nortek Signature 5-beam ADCP (left-hand panel) deployed in upward-looking configuration (right-hand panel). © Nortek Group.*

The maximum sustained velocity represents the maximum current observed. This parameter establishes peak design loads on device support structures and foundations.

Tidal flow asymmetry concerns, first, the asymmetry of velocity magnitude. An imbalance between the strength of flood and ebb current speeds can exist, generating considerably more power production during one stage of the tide. To determine the asymmetry ($a$), the following expression is used:

$$a = \frac{< U >_{flood}}{< U >_{ebb}}$$

where brackets denote time averaging of velocity values on flood and ebb flow respectively, including slack water periods.

Current direction is the principal (dominant) direction of the flow. This is a relevant metric for tidal stream energy conversion as the predominant design concept for a tidal energy converter is that of a fixed horizontal axis turbine. The principal component analysis (PCA) (Thomson & Emery, 2014) will be applied to ADCP data set in order to determine the principal direction of the flow during the ebb and flood tidal phase. The direction asymmetry $\Delta\theta$ is estimated so as to show a potential deviation of the flow from a straight line (dominant direction). This metric is defined as (Gooch, 2009):

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$$\Delta\theta = |\theta_{flood} - \theta_{ebb} - 180°|$$

The standard deviation of current direction for both ebb and flood flow will be also established.

### Hydrokinetic resource

A simple way to characterize the available resource at a site is to estimate the power within tidal current for different stages of tide and to represent its temporal variation. ADCP measurements allow evaluation of the available theoretical power $P$ from kinetic energy extraction using the conventional relationship:

$$P = \frac{1}{2}\rho A U^3$$

Where $\rho$ is the seawater density, $A$, the swept area of the turbine and $U$, is the mean velocity computed from the three mean velocity components $U_x$, $U_y$, and $U_z$, as: $U = \sqrt{U_x^2 + U_y^2 + U_z^2}$

For tidal power projects it is customary to determine the percentage time that a specified current speed is exceeded during a given period of time. In the same way, available power can be analyzed. Power and velocity occurrence distribution is also a relevant metric for resource characterization at a site. They provide an indication of favourable time for power generation.

## Turbulence metrics

The turbulence intensity (*I*) is a common metric used throughout the wind and tidal industries as well as other engineering fields in order to quantify turbulence. It is defined as:

$$I = \frac{\sigma}{U},$$

where $\sigma \equiv \sqrt{\frac{1}{3}\left(\sigma_x^2 + \sigma_y^2 + \sigma_z^2\right)} \equiv \sqrt{2TKE/3}$, is the standard deviation to the mean velocity $U$ and TKE is the turbulent kinetic energy defined as $TKE = \left(\sigma_x^2 + \sigma_y^2 + \sigma_z^2\right)/2$. This metric has been shown to correlate with the extreme loads exerted on turbine blades and is assumed to be a source of fatigue.

Power spectrum density (PSD) of velocity (hereafter referred to as "spectra") allow determination of the distribution of turbulent energy as a function of frequency, i.e., spectra quantify the amount of energy in the velocity at a range of timescales. For instance, an eddy of size similar to the blade cord is likely to impart larger fatigue loads on the blade than a smaller or larger eddy with the same energy. Likewise, an eddy the same size as the rotor will impart a larger load on the rotor than a much smaller eddy. Quantifying the energy in these eddies is therefore important to accurately estimate the loads they induce.

Spectra, noted $E(k)$, allow for the evaluation of the dissipation rate, $\varepsilon$, of the TKE. Assuming the Kolmogorov relationship of the local isotropic turbulence (Frish, 1995; Pope, 2000), $\varepsilon$ can be given such that:

$$E(k) = C\varepsilon^{2/3}k^{-5/3} \quad ,$$

where $C$ is the Kolmogorov's constant ($C$ = 1.5) and $k$ is the wavenumber. Using Taylor's assumption of frozen turbulence, the frequency $f$ and wavenumber $k$ can be related to the mean velocity $U$ such as: $k = 2\pi f/U$. Thus, the dissipation rate can be estimated from the power spectrum as (Thomson et al., 2012):

$$\varepsilon = \left(\frac{C_0}{C}\right)^{3/2}\left(\frac{2\pi}{U}\right)^{5/2},$$

where $C_0$ accounts for the height of the PSD slope which best fits the spectrum in the inertial subrange.
The value of $\varepsilon$ is used to estimate the integral lengthscale ($L$) such that (Pope, 2000):

$$L = \frac{TKE^{3/2}}{\varepsilon}$$

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These large size turbulent eddies contain the largest proportion of TKE and are therefore likely to contribute significantly to fatigue loads.

Reynolds stresses are other critical turbulence metrics for turbulence characterization at a tidal energy site. They indicate the orientation of the eddies in the flow. Eddies of different orientations may impart forces on distinct components of a tidal turbine. The Reynolds stress tensor $R$ is composed of 3 normal stresses ($\overline{u'^2}, \overline{v'^2}, \overline{w'^2}$) and 3 shear stresses ($\overline{u'v'}, \overline{u'w'}, \overline{v'w'}$):

$$R = \begin{pmatrix} \overline{u'^2} & \overline{u'v'} & \overline{u'w'} \\ \overline{u'v'} & \overline{v'^2} & \overline{v'w'} \\ \overline{u'w'} & \overline{v'w'} & \overline{w'^2} \end{pmatrix}$$

where the prime denotes a fluctuation from the mean and the overbar is used to represent a temporal average.

The most commonly used method to estimate Reynolds stresses with ADCPs is the so-called variance method. With this technique, Reynolds stress profiles are estimated from along-beam velocity measurements, using the difference between the velocity variances along opposing beams, often with an explicit removal of the variance contributed by the Doppler noise.

The use of 4-beam ADCPs for estimating Reynolds stresses has more than 30-year history (e.g., Lohrmann, 1990; Stacey, 1999; Whipple, 2006; Korotenko, 2013). However, such instruments allow quantification of only two components (out of six) of the Reynolds stress tensor. A valuable alternative is the 5-beam ADCPs (Fig. 1). They are similar to the conventional 4-beam Janus configuration, but with the addition of a vertical beam. Such devices have seen occasional use for approximately a decade (Guerra, 2017), but have only recently become widely available as off-the-shelf instruments. With such instruments, 5 components of the Reynolds stress tensor can be computed. However, the horizontal shear stress $\overline{u'v'}$, remained unknown. Recently, brand-new ADCPs with 7 beams have been released. These sensors enable the full estimation of the Reynolds stress tensor. Turbulence metrics that can be quantified with, 4,5 or 7-beam ADCP are summarized in Table 1.

| ADCP | $I$ | $E(k)$ | $\varepsilon$ | $L$ | $\overline{u'^2}$ | $\overline{v'^2}$ | $\overline{w'^2}$ | $\overline{u'v'}$ | $\overline{u'w'}$ | $\overline{v'w'}$ |
|---|---|---|---|---|---|---|---|---|---|---|
|   | ✓ | ✓ | ✓ | ✓ | X | X | X | X | ✓ | ✓ |
|   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | X | ✓ | ✓ |
|   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

*Table 1. Turbulence metrics that can be computed from velocity measurements collected by 4, 5 or 7-beam ADCP.*

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## Étel test site (Brittany, France)

### Available data

The best location suitable for conducting tidal turbine testing will be evaluated based on available data. This task is usually performed through the use of numerical modelling tools since they allow for a large spatial coverage of the investigated area.

To date, works have been carried out numerically by Guinard Ltd prior the deployment of their tidal turbine (P154) at Etel test site. Velocity measurements collected by 4-beam ADCPs were also performed. Available data are the following:

1. 3D bathymetry made by sonar, precision 0.5 meter
2. Numerical model of current made with Seamer95 2D, mesh 20 meters of the entire river and refined mesh of 8 meters between Lorois Bridge and "vieux passage" after CBS shipyard.
3. Three current measurement campaigns 3 weeks each:
    - 4-beam ADCP was deployed prior the P154 tidal turbine. The data were collected in March 2016. Acquisition frequency of 2Hz.
    - Two other campaigns were carried out similarly. Two 4-beam ADCPs were synchronized and spaced together by 20 meters and centralized 10 meters before and 10 meters after the turbine location. Measurements were first collected without the tidal turbine in 2018 and then collected with the operating tidal turbine in April 2019. Acquisition frequency of 2Hz.

The first and second dataset (bathymetry and numerical model) are valuable for the ELEMENT project. However, the third dataset (multiple ADCP measurements) are not needed since they were collected by 4-four beam ADCP which does not allow for an accurate turbulence characterization.

### Characterization campaigns

The turbulence metrics will be characterized through dedicated campaigns planned in April and May 2020. 5-beam ADCP will be deployed for a 2-4 weeks period at tidal turbine testing site, which will be identified through the use of the numerical model Seamer95. The data collected will also enable to characterize the hydrokinetic resource in 3D.

## Bluemull Sound site (Scotland, United Kingdom)

### Available data

To date, three measurement campaigns have been performed at Bluemull Sound site (Table 2). The data were collected in the framework of the EnFait European project. 5-beam ADCPs were deployed in upward and horizontal looking configuration. During the last measurement campaigns, ADVs (acoustic Doppler velocimeters) were installed at hub height (~9 meters above bottom).

During the first measurement campaign, three ADCPs were deployed during the fall of 2017. The instruments collected data for a 3-month period. Velocity measurements were recorded at the sample frequency of 1 Hz. Such frequency is appropriate for general observations and numerical model calibration.

During the second measurement campaign, three ADCPs were deployed in March 2018. ADCPs collected data for periods ranging from 3 weeks to 4 months long at the sample frequency of 4 Hz. The last measurement campaign was performed in May 2019. Two ADCPs and two ADVs were deployed. The instruments collected data for an 18-day period. The first and second ADCP were set to record velocity at the sample frequency of 4 Hz and 8 Hz respectively. Both ADV collected data at the sample frequency of 64 Hz.

The sample frequency used for ADCPs and ADVs during the second and third measurement campaign are appropriate for a detailed site flow characterization including a comprehensive study of turbulence.

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| | Start | End | Sample Frequency |
|---|---|---|---|
| **Measurement campaign 1** | | | |
| ADCP 1 | 02/09/2017 | 30/11/2017 | 1 Hz |
| ADCP 2 | 02/09/2017 | 26/11/2017 | 1 Hz |
| ADCP 3 | 02/09/2017 | 30/11/2017 | 1 Hz |
| **Measurement campaign 2** | | | |
| ADCP 1 | 01/03/2018 | 01/07/2018 | 4 Hz |
| ADCP 2 | 17/03/2018 | 01/04/2018 | 4 Hz |
| ADCP 3 | 01/03/2018 | 25/06/2018 | 4 Hz |
| **Measurement campaign 3** | | | |
| ADCP 1 | 07/05/2019 | 24/05/2019 | 4 Hz |
| ADCP 2 | 07/05/2019 | 24/05/2019 | 8 Hz |
| ADV 1 | 07/05/2019 | 24/05/2019 | 64 Hz |
| ADV 2 | 07/05/2019 | 24/05/2019 | 64 Hz |

*Table 2. Data collected at Bluemull Sound site*

### Characterization campaigns

No additional campaign is planned regarding physical environmental monitoring.

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# SITE ECOLOGICAL CHARACTERISTICS

## Environmental impacts study for consents

The installation of marine renewable energy devices within marine systems can influence marine socio-ecosystems, which is a concept that has been developed by scientists, and most notably Elinor Ostrom (Nobel price of Economy, 2009), in order to analyse the relationships between humans and nature (e.g. Avriel-Avni & Dick, 2019). The potential impacts vary along time (development phase of the project: deployment, operation and decommissioning), across space (MRE site natural and social characteristics) and with the size of the project (single device, small array, commercial array) (Copping et al., 2016). To date, there are still some gaps in the evidence data base regarding the influence of MRE devices on the marine systems, especially while considering arrays of devices. Most notably, there is a lack of *in situ* data to verify the collision risk models considering the interaction of marine megafauna (marine mammals, fish, birds) with MRE devices. Also, there is a need to gain more *in situ* data regarding the noise emitted by tidal energy devices. The biocolonisation of the devices is also a topic that might raise some environmental (as well as engineering) concern depending on the site where tidal energy devices are deployed. However, the composition of fouling communities at MRE sites is still understudied, as studying this process at offshore, highly dynamic and relatively deep sites is challenging (Macleod et al., 2016). The aim of the environmental characterization task in the ELEMENT project is to collect data to improve the knowledge base regarding the environmental impact of marine devices.

### Biocolonisation

A better understanding of the biocolonisation is necessary to answer knowledge gaps at the interface between environmental (e.g. formation of the reef effects, of the stepping stones effect) (Quillien et al. 2018; Want et al. 2017) and technical issues (e.g. influence on mechanical functions, fatigue, biodegradation of MRE components). Some variables related to biocolonisation are critical to measure:

- Biovolume
- Thickness
- Fresh weight
- Species richness
- Presence/absence of non-native species
- Percentage of surface covered
- Abundance

The quantitative data gathered will increase our understanding of the biocolonisation process (which is still limited when considering offshore and highly dynamic sites). *In situ* data is also necessary for testing and developing models aimed at evaluating the fouling of the tidal energy devices in the frame of the control system (which links with the WP6 of the ELEMENT project) and evaluating the environmental impacts of tidal energy projects (which links tools developed in the DTOceanPlus Horizon 2020 project – see below). The objectives relate to the enhancement of the modelization tools as further developed in the following section of this report.

### Underwater noise

Even though noise emitted by operational tidal energy devices is not expected to have a significant negative impact on marine life considering single or a small array of devices (Lossent et al., 2018; Tollit et al., 2019), this issue has regularly arisen at public debates and impacts the consenting of MRE projects. This issue is site specific, and most probably depends on type of stakeholders within the area where MRE projects are planned. *In situ* measurement of noise (background noise before and after device installation at different seasons) can help at derisking this issue.

## Existing data at the two test sites (Étel and Bluemull Sound site)

| Variables | Bluemull | Etel |
|---|---|---|
| **Marine mammals** | Yes, visual countings (11/10 – until now) and videos (08/15 – until now) | No dedicated survey, but opportunistic data available in the area |
| **Diving birds** | Yes, visual countings and videos (08/15 – until now) | - |
| **Fish** | Video recordings (08/15 – until now) | Opportunistic obs by divers |

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| | | |
|---|---|---|
| **Zoobenthic organisms** | - | Yes |
| **Epibenthic communities (biofouling)** | Yes | Yes&No, antifouling tests |
| **Habitats/seafloor characterisation** | Visual obs | Visual obs and sampling |
| **Turbidity** | Visual obs | - |
| **Underwater noise** | - | Background noise |
| **Other physicochemical var.** | - | - |

## Characterization campaigns at Étel test site

### Characterization of the potential of biocolonisation

In order to characterize the biocolonisation at the Étel test site, panels made in a neutral material (PVC) will be deployed *in situ* using an existing buoy and mooring. More specifically, 15 A4 format panels will be set around the buoy keel and surveyed for one year. Some of the panels (3) will last for the duration of the project and will be surveyed by taking pictures, while some other panels will be seasonally retrieved to conduct destructive sampling. The destructive sampling will enable the measurement of several variables (weight/biomass, coverage, thickness, functional groups, and taxonomical characterisation of the fouling organisms). Interpretation of biocolonisation data will be performed considering other available environmental variables (data previously gathered at Etel test site), including current data that will be gathered within the project. The setup of the experiment is planned in Spring 2020.

Existing data at the Shetland site, which has been gathered in the course of a previous project, will be considered to compare the biocolonisation potential at both sites (Etel and Bluemull). Also, opportunistic data collection at Bluemull test site could occur, depending on maintenance timeframe, in the frame of the ELEMENT project.

### Characterization of noise emission

Noise emitted by tidal turbines and background noise can be characterized by setting hydrophones in the environment. In the frame of the ELEMENT project, noise before and after the tidal turbine deployment will be characterised within two areas: the area where the tidal energy device will be deploy and out of the project perimeter. The noise characterization at two contrasted seasons is also important, as the use of the environment varies a lot considering Summer and Winter seasons for example. In particular, maritime traffic (small recreational boats mainly at this site) is much higher in summer than in winter, thus the background noise most probably increase in the area at that time of the year. The setup of the experiment is planned in Summer and Winter 2020.

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# MODELLING THE POTENTIAL ENVIRONMENTAL IMPACTS

## Environmental impacts models improvement

### Collision

Even though the collision risk between tidal turbines and marine organisms is probably limited (Copping et al., 2017, Copping et al., 2013), this potential impact is still a concern that can significantly influence the consenting of MRE projects. First of all, the presence and behaviour of species of concern needs to be assessed around and within the study sites. Then, a collision risk can be estimated. Particularly, near-field behaviour, such as evasion, avoidance and other interactions, is crucial to understand potential consequences. The collision is a potential consequence and can be assessed through collision risk models based on behavioural parameters.

The collision risk is commonly assessed through collision risk models (CRM) (Scottish Natural Heritage, 2016). Collision risk modelling is a growing thematic for different biological models (birds, bats, marine mammals) and are based on species proximity and avoidance rate at different scales around MRE devices, mostly wind turbines (Madsen and Cook, 2016; Cook *et al.*, 2018; Kleyheeg-Hartman *et al.*, 2018). Therefore, a key variable influencing estimation of collision risk is the species avoidance rate. Thus, visual data are needed to enhance estimates of avoidance rate for species of concern (Cook *et al.*, 2018; Kleyheeg-Hartman *et al.*, 2018).

### DTOceanPlus

DTOceanPlus is a suite of second-generation, open source and integrated design tools, applicable to different levels of technology (from subsystems to devices and networks), from concept to development and deployment.

The environmental and social acceptance tool (ESA) aims to assess the environmental impacts generated by the various technological choices and array configurations of wave or tidal devices. This assessment provides a first global evaluation of the potential impacts of a project regarding decisions made on devices, foundations and mooring design, deployment of electrical network and definition of marine operations.

The potential environmental impacts of the Nova innovation tidal energy devices at Étel and Bluemull sites will be assessed in terms of pressures (e.g. chemical pollution or collision risk with marine fauna) and carbon footprint of the projects.

#### *Environmental assessment*

Environmental assessment in DTOceanPlus integrates a collection of specific functions that will be performed to get a basic evaluation of the potential pressures generated by the device array on the marine environment. These functions are, for instance, dedicated to footprint, noise or collision risk. Each environmental function links two entities:

- The ‘stressors’, i.e. the entities that generate a pressure or an environmental effect, stressor is any physical, chemical, or biological entity that can induce a response;

- The ‘receptors’, the entities that are potentially sensitive to stressors;

Stressors may adversely affect specific physical resources of marine ecosystems (the receptors) that interact directly with the biological components of these ecosystems, including plants and animals.

This assessment will provide an opportunity to have basic estimation of the different pressures potentially generated by the device array and to test and improve (based on *in situ* data) the efficiency of DTOceanPlus functionalities of impacts assessment.

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Being identified as a key consenting issue, one of the main concerns of the project is the risk of collision with marine fauna. In DTOceanPlus, the collision risk function estimates the number of intersections, between a large number of parallel lines aligned with the mean current axis. The probability of collision will be: P=nb of lines with at least one intersection/total nb of lines. The expected result is a percentage of risk of collision between a species and the device. The risk is presented by the intersection of a mathematical line with the representation points of location of device. Particular attention will be paid to refining the function to provide a better integration of this key consenting issue into design processes.

In the ELEMENT project context, the DTOceanPlus ESA module will be enhanced by the development and inclusion of new indicators dealing with biofouling and the impact on turbine performance. The biofouling characterization that will be achieved in the project will be an important source of data that will be used to develop some new indicators within the ESA tool. These indicators are intended to inform reef effect as well as the risk of non-invasive species introduction, and to integrate temporal variation of the colonization (e.g. evolution of species diversity).

### *Carbon FootPrint*

Life Cycle Assessment is a method of identifying and assessing the environmental impacts associated with the life cycle of a service or product (from cradle to grave or cradle to cradle for recycling purposes) (Weitz et al., 1999). It is a standardized method whose principles and conceptual framework are presented in "Environmental management, Life cycle assessment: Principles and framework" and "Environmental management, Life cycle assessment: Requirements and guidelines" (ISO, 2006).

For the two sites, the carbon footprint will be estimated regarding five possible phases of the life cycle in DTOceanPlus (Fig.3).

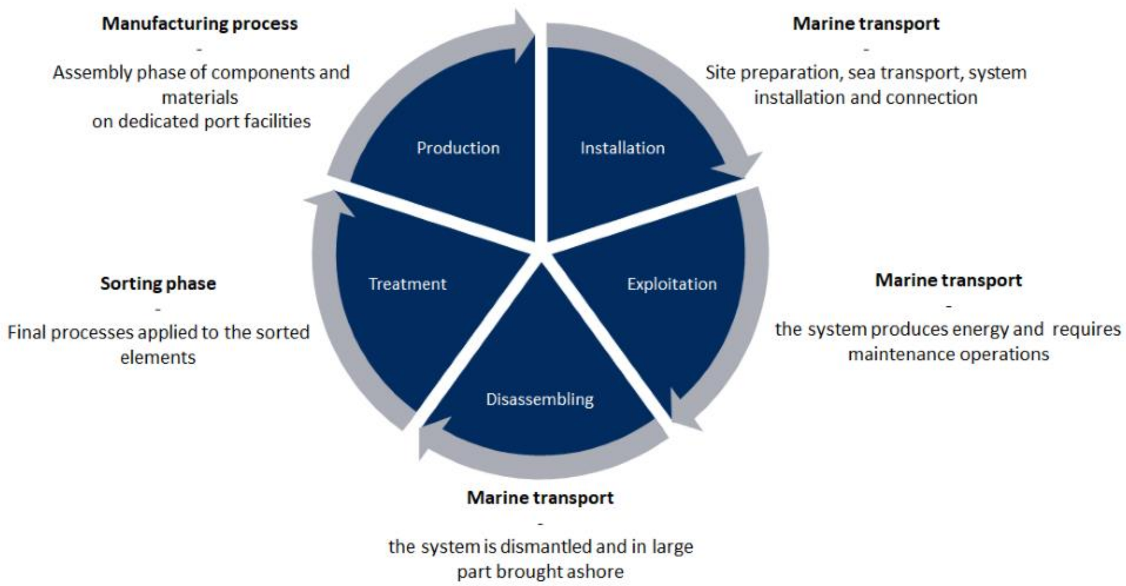


*Figure 3. The five phases considered in the life cycle assessment in DTOceanPlus*

For every phase of the life cycle, there is an inventory of the components and materials weight (e.g. weight of alloyed steel) used for the device, mooring, foundations and electrical components and of the logistic information mobilized from production of materials up to their installation and maintenance (typically, the consumption of fuel, the number of vessels, their power and the duration of intervention).

The purpose of the impact assessment is to translate these flows into potential environmental impacts. In DTOceanPlus, two mid-point indicators are considered:

- The global warming potential (kg CO2/kWh) which is calculated in terms of CO2 greenhouse gas emission per MW produced.

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- The Cumulative Energy Demand (MJ/kWh), calculated in terms of total consumption of primary energy per energy produced.

These two indicators will help understand potential global impact of every phase of the life cycle of the two sites and identify possible axis of design improvements in terms of $CO_2$ emissions and non-renewable energy consumption.

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# CONCLUSION AND NEXT STEPS

Tidal resource data are already available at both test sites and the ELEMENT project will mostly focus on the characterisation of the turbulence metrics through dedicated campaigns planned in Spring 2020 at Etel test site. The measurement campaign will last two to four weeks, using a 5-beam ADCP. The data collected will enable characterisation of flow turbulence as well as the hydrokinetic resource in 3D.

The fouling communities and the acoustic surveys at the Etel test site will start in Spring 2020. The monitoring of the biocolonisation will take place over one year and sampling and photo-survey will take place at different seasons within this year. Acoustic surveys will ideally take place in summer and winter 2020 and encompass a full spring and neap tide cycle. Data gathered will form the basis to refine some of the functions of the control system (WP6) and of the DTOceanPlus ESA tool.

The pelagic megafauna (marine mammals, fish and diving birds) might interact with devices and thus, raise issues for the consenting of tidal energy projects. First, a review will provide an insight of these key issues. Second, these issues will be addressed through a synthesis of studies conducted worldwide. Third, the remaining bottlenecks will be identified and a roadmap for Research and Development will be drafted. In addition, an update of collision risk models reducing uncertainties in the assessment will be proposed.

The environmental assessment using DTOceanPlus and the refinement of some functions will be made possible following the characterization campaigns of the sites and fouling communities and acoustics surveys. This will help provide a better insight on some key consenting issues affecting the conception phase of an offshore renewable energy project.

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