Deployment of a Shallow Water Wave Energy Converter at the EMEC Billia Croo Test Site

Device-Specific Addendum to the EMEC Wave Energy Test Site Navigational Risk Assessment

April 2018

Content

1 Introduction

Anatec Ltd. updated the Navigation Risk Assessment (NRA) for the European Marine Energy Centre (EMEC) wave energy test site at Billia Croo in 2014 (*Anatec 2014*). This assessment used a device neutral methodology for the entire wave test site. The intention was that this would be combined with a device-specific annex, which this document provides.

Developing a separate annex for each individual technology deployed at the test site ensures that any variation to the risk posed by new or unique devices is identified and the site-wide NRA will remain current. This enables EMEC to manage the site's safety and ensure that the risk remains as low as reasonably practicable. The purpose of this document is to identify all the relevant device-specific information required to inform the NRA annex for Laminaria's wave energy device. This document provides brief indication of the working principle of the Wave Energy Converter (WEC), the results of the third party verification, the description of the individual phases of the deployment and the identified risks due to the WEC and the potential increased marine vessel traffic on site. The Project-Specific NRA was developed to support the Marine Licence application for the Laminaria WEC for the first full-scale deployment at EMEC.

Laminaria NV is planning to install a 200 kilowatt (kW) WEC at the wave energy test site Billia Croo at EMEC. The deployment period will start in August 2018 and will end with the decommissioning of the WEC in September 2019. A marine licence for 18 months will be applied for to allow for contingency in the project schedule.

The Laminaria WEC consists of one main floater which is connected by four individual mooring lines to a single gravity base anchor. The main floater can absorb the energy of incident waves from all wave directions, heights and periods simultaneously. As a result of the horizontal movement in the water, the WEC is subjected to a tilting and translating motion. These motions are transferred through the mooring lines to the PTO chambers located at the bottom of the WEC.

2 Device and project specific information

This section of the Project-Specific NRA will give an overview of the working principle of the Laminaria WEC. Brief information is given on the Laminaria company, the project in general and the deployment location of the WEC at Billia Croo. More detailed information can be found in the *Project Information Summary* of Laminaria.

2.1 Development outline

Laminaria NV is a Belgian wave energy developer and was established in 2011. The main focus of the company is to create innovative solutions that offer a higher return on investment and show increased productivity compared to the leading technologies in the sector. The first sea trial of the Laminaria WEC has been conducted in 2015 around 1 km off the costs of Belgium with a 1:5 scale model. The main aim of the testing was the validation of the load management strategy which was highly effective and the WEC survived a storm with significant wave heights (Hs) of up to 2.7 m (corresponding wave heights in full-scale conditions: 13.5 m Hs)

The Laminaria WEC to be installed at EMEC during this project is a surge and pitch operating point absorber. Incident waves provide a tilting and translation motion which will be transferred by the four mooring lines to the PTO chambers located at the bottom of the WEC. Each PTO chamber consists of two drums which move back and forth and transferring the movement of the WEC to convert wave energy into electricity.

The project will be the first full-scale Laminaria WEC deployment and will be conducted in berth two of the wave energy test site, Billia Croo.

The deployment period at EMEC is planned to start in August 2018 with the installation of the WEC and the gravity base anchor. The installation will take roughly one day to be fulfilled. The decommissioning of the WEC will be the reverse order of the installation and therefore, the WEC will be also recovered during one day in September 2019.

Laminaria developed a system in which the WEC is able to increase and decrease the submergence level of the main floater to ensure nominal loads at all times. This strategy also provides continuous nominal electricity production.

2.2 Developer Details

During the deployment period of the Laminaria WEC, the CEO of Laminaria, Steven Nauwelaerts, will be present at the test site at EMEC. This enables a fast decision-making process in case of unplanned activities in relation to the WEC and ensures the accurate configurations at all times. Anything related to the WEC during the deployment period can be addressed to Laminaria NV. Steven Nauwelaerts will be the 24 hour duty manager (whom operates as the emergency contact person):

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2.3 Device details

The Laminaria WEC consists of one main floater which is connected by four individual mooring lines to the gravity base anchor. The main floater can absorb energy of incident waves from all wave directions, heights and periods simultaneously. As a result of the horizontal movement in the water, the WEC is subjected to a tilting and translating motion. These motions are transferred through the mooring lines to the Power Take Off (PTO) chambers located at the bottom of the WEC. Each PTO chamber consists of a drum-system, a gearbox, an electrical motor and an asynchronous generator mounted on a main shaft.

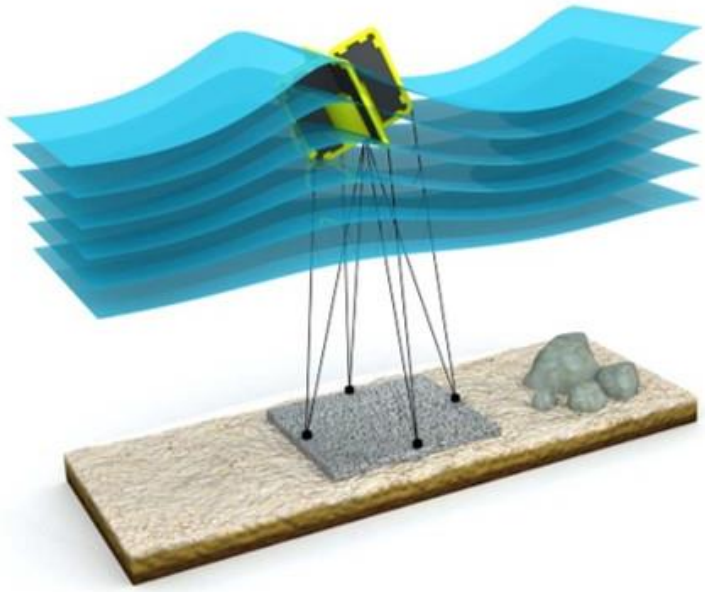

Figure 1: Artistical illustration of the Laminaria WEC

The unique concept of the Laminaria WEC is the storm protection system which enables the WEC to produce continuous electricity even during severe environmental conditions. Loads acting on the Laminaria WEC and the mooring lines will be measured by load cells.

In case of an exceeding of the pre-defined load threshold, the WEC will activate the storm protection system and increases the submergence of the WEC to lower energy parts of the water until the nominal load threshold is reached again. This feature enables the Laminaria WEC to produce a continuous and steady electricity production. With an identification of an undercut of the load threshold, the submergence of the WEC will decrease step by step into higher energy parts of the water.

There is one storm protection system installed in each PTO chamber of the WEC to ensure the functionality of the system at all times. The storm protection system consists of the gearbox and the electric motor. In normal operating conditions, the two drums per shaft are fixed relative to each other. In storm protection mode, one of the drums is rotated relative to the other and decreases the total length of the mooring lines and thereby altering the position of the WEC in the water column. Therefore, the impact of extreme wave energy loads is reduced. The Laminaria WEC remains operational during storm conditions in storm survival mode and can maintain electrical generation. During small sea states with typical waves of 3 m Hs, the WEC can protrude the sea surface by up to 1 m.

The mooring lines are configured in a W-shaped layout (consisting of two V-shaped layouts) as indicated in Figure 2. The motion of the WEC gives a reeling out of the mooring lines of one V-shaped part of the mooring line layout. This leads to an increase of the same V-shaped part and a compensatory reeling in and shortening of the other V-shaped part of the mooring line layout.

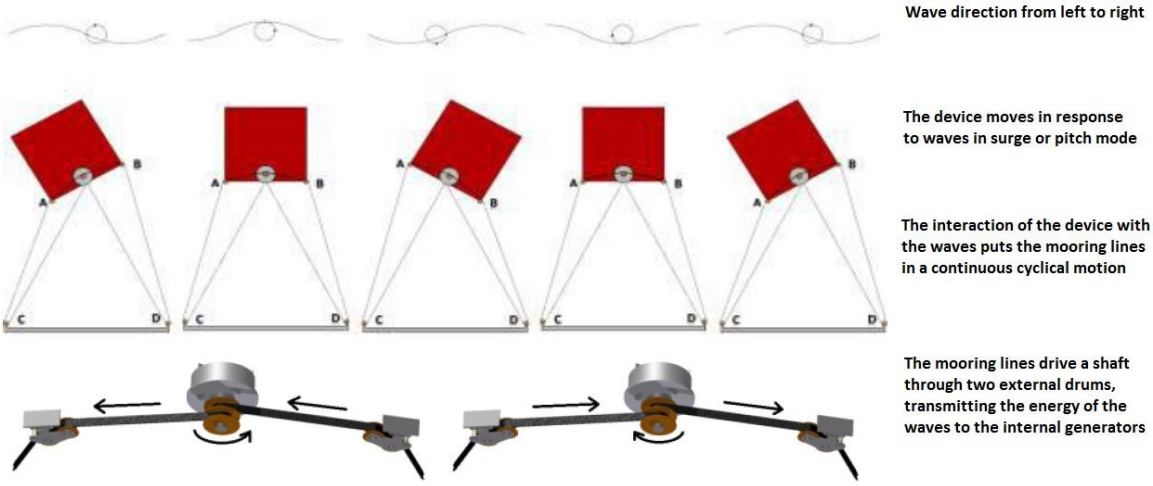

Figure 2: Schematic sketch of the WEC movement (pitch), the changing mooring line layout and the movement of the mooring lines on the drum-system

The following figures will give a better understanding of the WEC design and the corresponding dimensions:

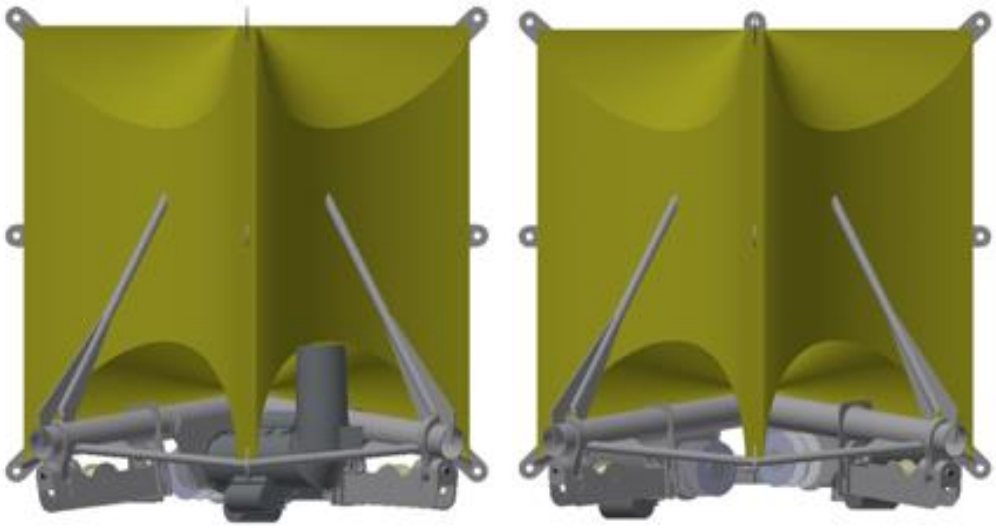

Figure 3: Drawing of the main floater with attached PTO chambers

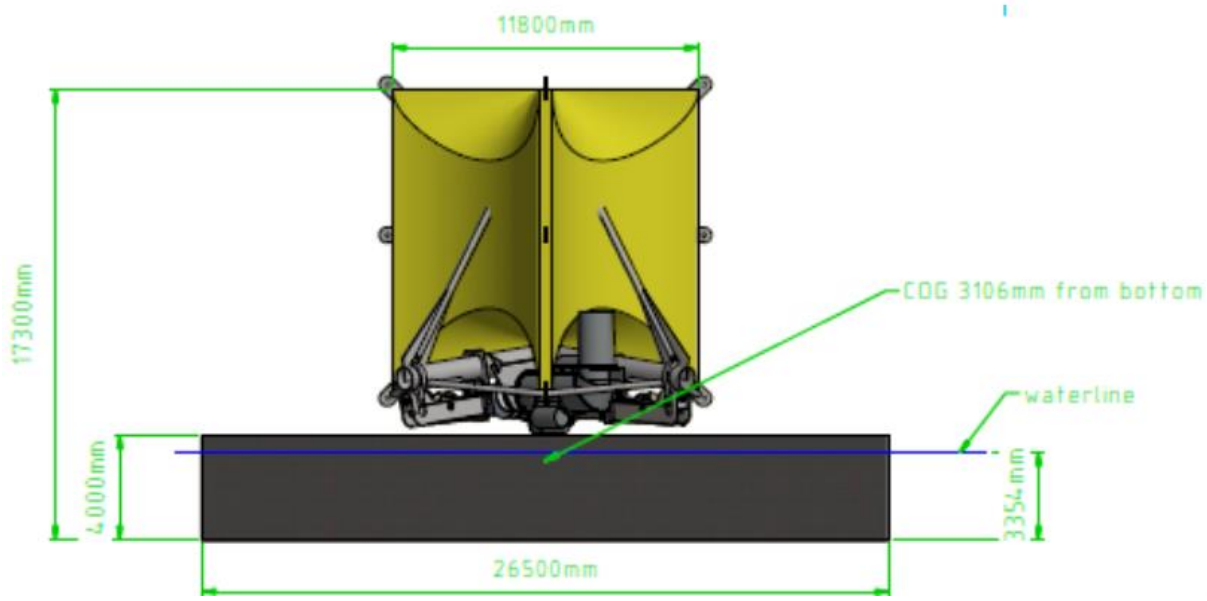

Figure 4: Drawing of the WEC assembly during the towing

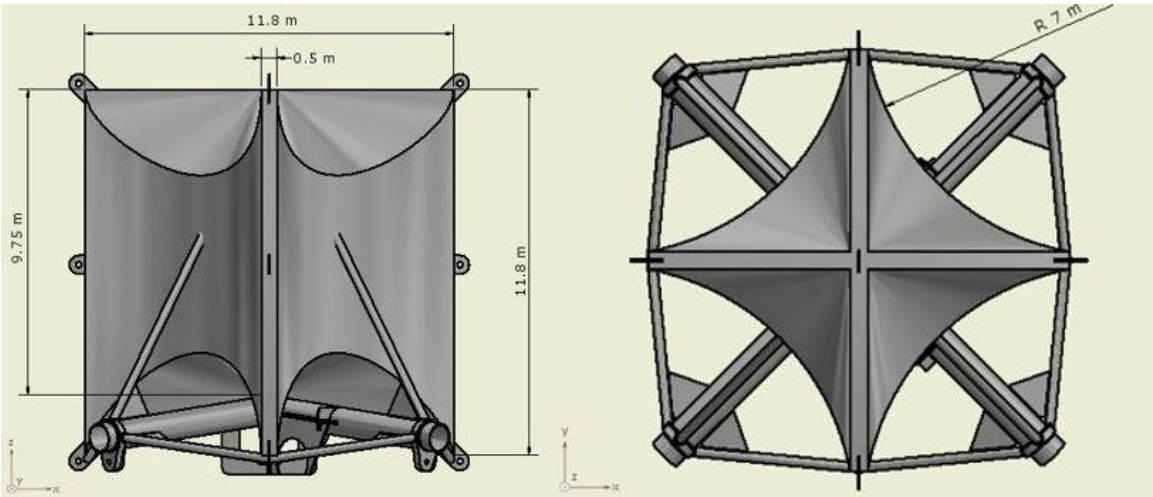

Figure 5: Laminaria WEC design with dimensions

Figure 6: Front and site view of the WEC

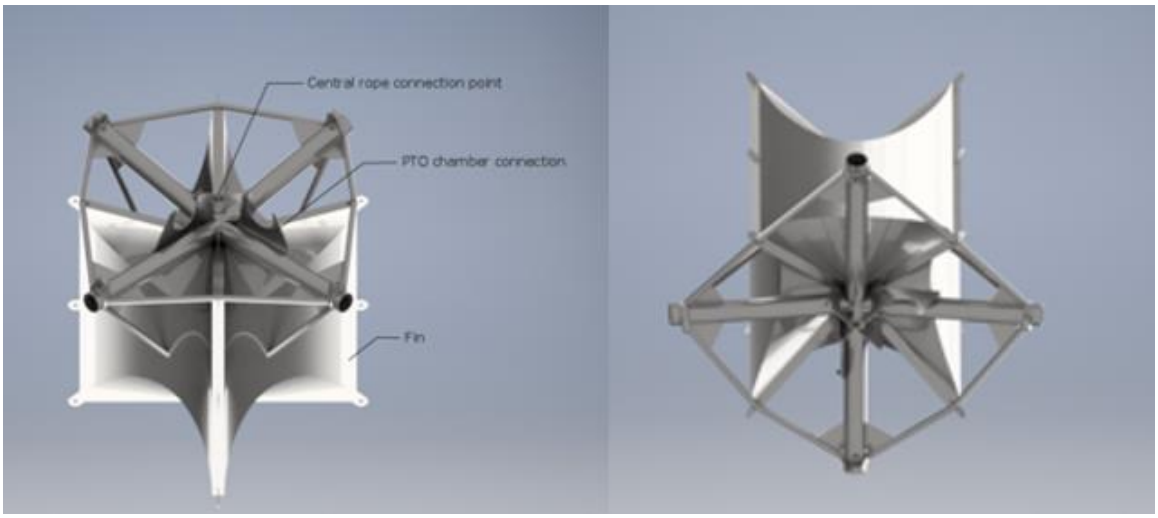

Figure 7: Bottom view of the WEC

Table 1 gives an overview on the dimensions of the Laminaria WEC:

Table 1: Main Dimensions of the Laminaria WEC

Part of the WEC	Dimensions
Overall height of the WEC	13.30 m
Overall width of the WEC	11.80 m
Height of the fins	11.80 m
Width of the fins	0.5 m
External radius of the hull	7 m
Centre of Gravity	6.35 m
Estimated mass	250 t
Anchor footprint	26.5 m x 26.5 m
Anchor height	3 m
Anchor mass	2,200 t

Due to the design of the active mooring lines, the Laminaria WEC will only move inside the anchor footprint (702.25 m^2). The storm protection system of the WEC will decrease and increase the submergence of the main floater and therefore, the whole water column above the anchor footprint may be used by the movement of the floater depending on the actual sea states at Billia Croo.

To decrease the potential environmental impacts of the WEC as much as possible, Laminaria developed a gravity base anchor design. The anchor will be similar to a concrete pontoon to allow towing of the whole structure to the deployment location. Figure 8, Figure 9 and Figure 10 show the design of the gravity base anchor used for the deployment of the Laminaria WEC at EMEC. The anchor will include chambers which will be filled with air during the towing of the WEC but can be flooded with sea water to decrease the buoyancy of the anchor. With the decreasing buoyancy and the un-spooling of the mooring lines, the anchor will be submerged to the seabed. The buoyancy level will be regulated by the number of chambers filled with water and air to avoid the increase anchor speed with increasing submergence. With this set up, the buoyancy can be regulated, and the same negative buoyancy can be kept until the anchor is installed. Gravity base anchors do not require drilling or dredging of the seabed. The mooring lines of the main floater will be attached to the anchor and therefore, no interactions are required regarding the installation after the submergence of the anchor.

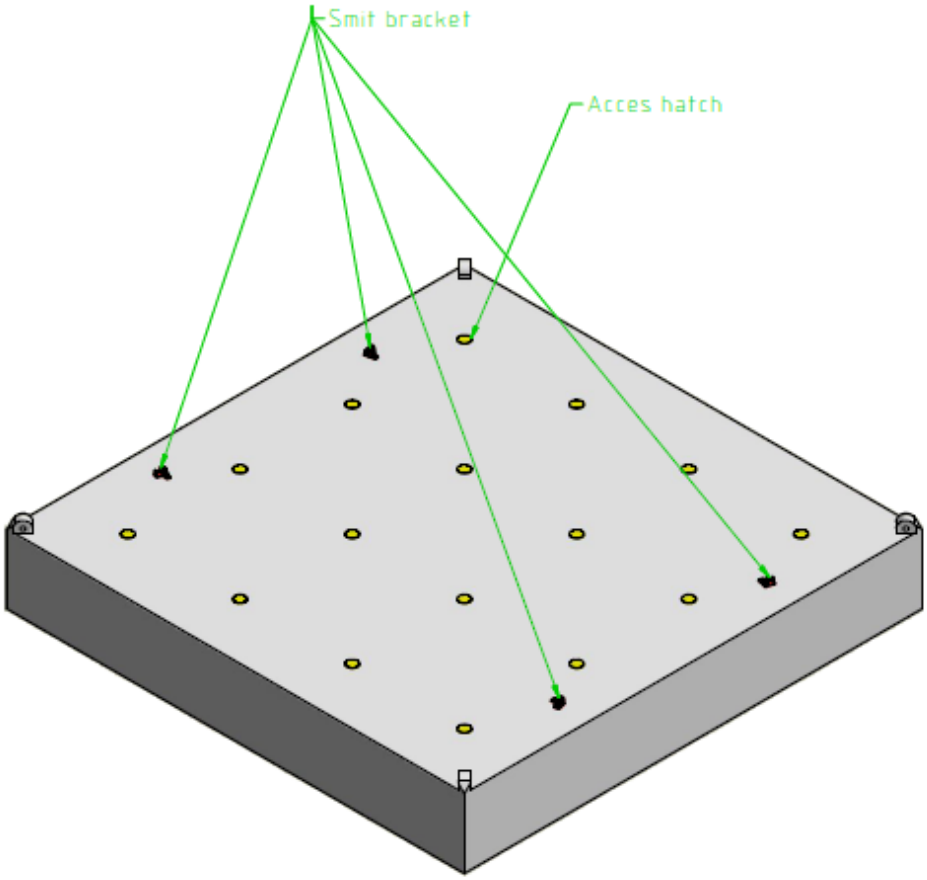

Figure 8: Drawing of the gravity base anchor

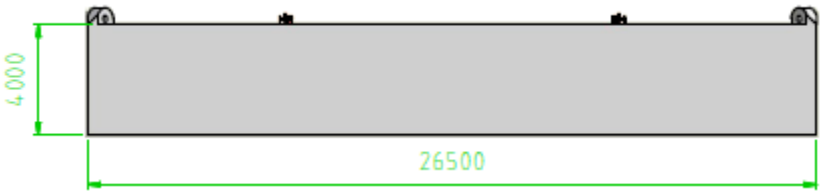

Figure 9: Drawing of the gravity base anchor (front view)

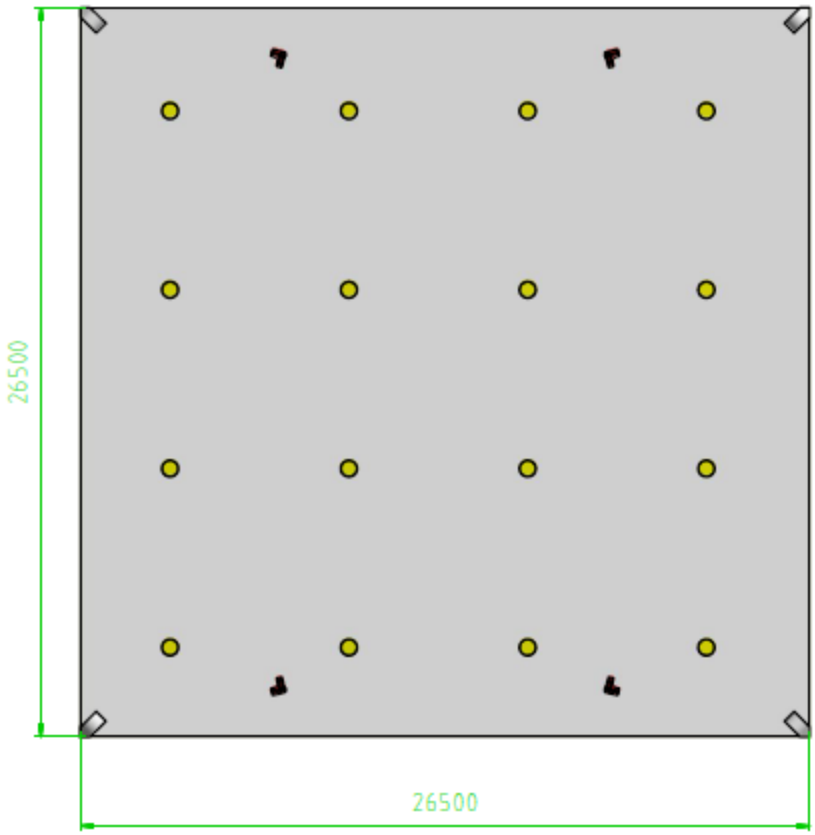

Figure 10: Drawing of the gravity base anchor (top view)

The Laminaria WEC will re-use the umbilical connected to the subsea cable of berth two for the electric connection of the WEC to the local grid. The connection between the umbilical and the WEC is made by a cable terminator.

2.4 Design Certification / Third Party Verification

The Third Party Verification (TPV) of the WEC is currently under development and being conducted by Orcades Marine. The TPV is being completed for the WEC's deployment at the Billia Croo wave energy test site.

For the structural analysis of the steel structure for the Laminaria wave energy converter, the guidance DNVGL – OS – C101 was followed during the process. The standard includes the following limit states:

- Fatigue limit states (FLS)
- Accidental limit states (ALS)
- Ultimate limit states (ULS)
- Serviceability limit states (SLS)

Additionally, to the DNVGL standard, the Load and Resistance Factor Design (LRFD) method was used to identify the safety level by applying loads and resistance factors for a characterisation of reference values of the basic variables such as loads acting on the structure and resistance of the materials in the device. On all 3D drawings of the components of the Laminaria device, a Finite Element Analysis was performed. The feasibility study of the mooring loads and the foundation was obtained by INNOSEA and the reference standard of the analysis DNVGL – ST0164 and the DNVGL – OS – E301 was used for the analysis regarding the mooring lines. For the geotechnical design of the gravity-base anchors the DNVGL – OS – C101 and the DNVGL – ST – 0126 were followed.

2.5 Device Location

The Laminaria WEC will be deployed at test berth two of the EMEC Billia Croo wave energy test site located off the west coast of Orkney Mainland. Table 2 below states the area of the Billia Croo test site marked with cardinal buoys and the test berth two.

Table 2: Billia Croo navigational cardinal buoys and berth two coordinates

	Coordinates (WGS84)	
Location	Latitude	Longitude
North cardinal buoy	59° 00.000'N	003° 24.330'W
West cardinal buoy (1)	58° 58.529'N	003° 24.638'W
West cardinal buoy (2)	58° 59.500'N	003° 25.330'W
South cardinal buoy	58° 57.431'N	003° 23.028'W
East cardinal buoy	58° 58.386'N	003° 22.399'W
Berth two	58° 58.586'N	003° 23.335'W

Table 3 shows the proposed licence boundary coordinates of the Laminaria WEC. The area allows for micro-siting to keep the environmental impact on the seabed to a minimum.

Table 3: Laminaria proposed licence boundary coordinates

	Coordinated (WGS84)	
Location	Latitude	Longitude
North west corner	58° 58.753'N	003° 23.354'W
North east corner	58° 58.592'N	003° 22.928'W
South west corner	58° 58.444'N	003° 23.358'W
South east corner	58° 58.598'N	003° 23.768'W

Figure 11: Indication of the Billia Croo wave energy test siteFigure 11 shows the location of the Billia Croo test area and the location of test berth two is indicated in Figure 12. Figure 13 indicates roughly the deployment area of the Laminaria WEC.

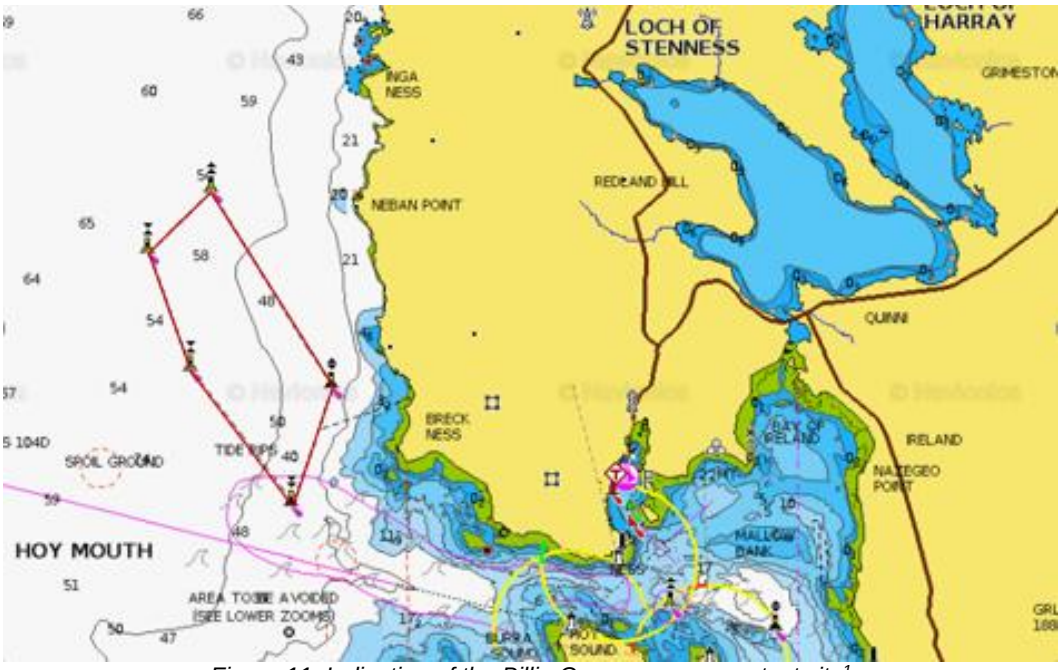

Figure 11: Indication of the Billia Croo wave energy test site[1]

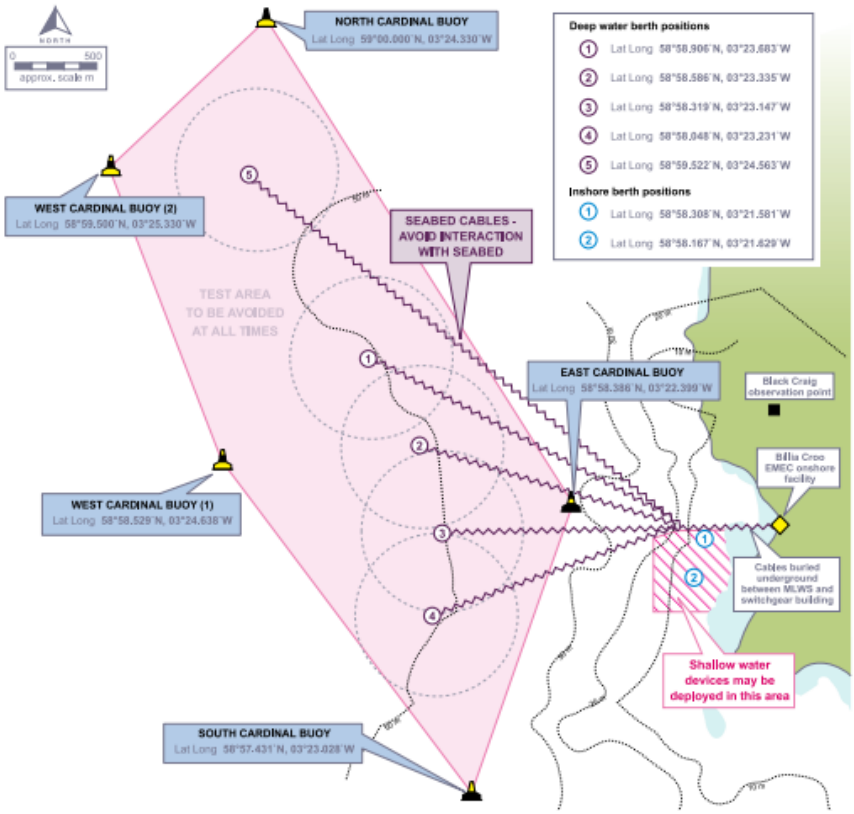

Figure 12: Berth two location at the Billia Croo test site[2]

[1] Chart from Navionics: https://webapp.navionics.com/?lang=en#boating@9&key=%7Df%7DfJb_%60S [09.03.2018]
[2] Abbott Risk Consulting Ltd, "Navigational Safety Risk Assessment for the Wave Test Site at the European Marine Energy Centre", EMEC website, [02.11.2017]

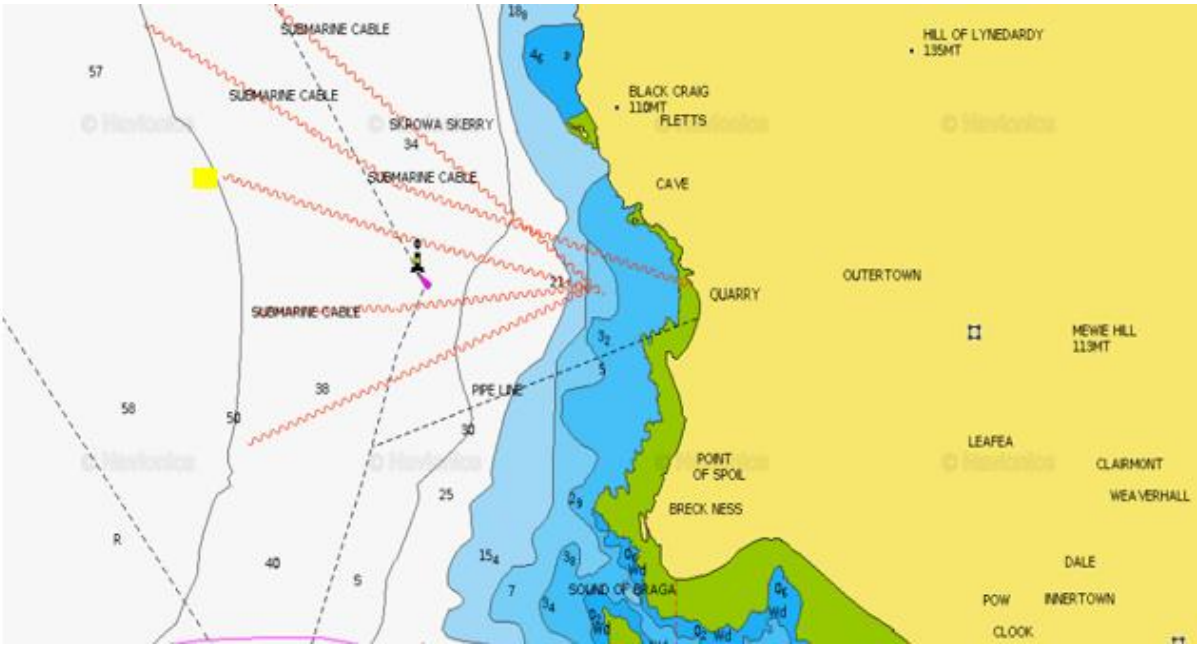

Figure 13: Indication of the deployment area of the Laminaria WEC (marked in yellow)[3]

The Laminaria WEC will only move within the footprint area of the gravity base anchor but will occupy the whole water column above the footprint (as mentioned in 2.3). There are no operational conditions in which the WEC will move outside of the anchor footprint. In accidental conditions like only one mooring line is left to connect the WEC with the anchor, the main floater will exceed the anchor footprint. This situation implements that the height adaptation with all redundancies failed and three mooring lines broke simultaneously.

The Billia Croo wave energy test site marked on navigational charts and devices within the test site should be charted. Few other sea users utilise the test site with the exception of maintenance vessels for developers and/or EMEC. Potential interactions of the Laminaria WEC with other wave energy devices is highly unlikely due to the distance between test berths. The closest navigational feature will be the east cardinal buoy marking the inner perimeter of the Billia Croo test site. The potential risks for navigational features and marine vessels will be evaluated in section 5 and identified mitigation measures will be stated.

3 Phase Specific Information

This part will give an overview of the installation, operation and decommissioning phases of the Laminaria WEC during the deployment period at EMEC. Details about marine vessels required will be given and maintenance procedures are stated. Annex one will

[3] Map from: https://webapp.navionics.com/?lang=en#boating@11&key=cf%7DfJ~bvS

give an overview on the potential marine vessels of Laminaria during the deployment period at EMEC.

3.1 Construction / Installation

The Laminaria WEC consists of two main parts: the main floater and the gravity base anchor. Both parts will be constructed in Belgium and will be assembled in the port of Zeebrugge. The main floater will be connected by the four individual mooring lines to the anchor. The anchor design will be similar to a concrete pontoon, which will consist of several chambers. To enable the WEC to be towed by a multi-cat vessel from the harbour of Zeebrugge to Scotland, the chambers of the anchor will be filled with air to keep it afloat. To be able to tow the WEC through Scottish waters, Laminaria will obtain the following three licences: marine warranty, tow warranty and the load line exemption. The duration of the tow will be dependent on the weather occurring during the action and the corresponding speed the vessel is able to travel with. The time required for the transport of the WEC is estimated with five to ten days.

For the installation of the WEC, only one multi-cat vessel is required. The Multi-Cat vessel will tow the WEC from the port of Lyness to the deployment location. More detailed information about the vessel fleet and the tow plan can be found in the *Vessel Management Plan (VMP)* of Laminaria. The chambers of the anchor will be slowly flooded with sea water and will slightly submerge the anchor below the water surface. The lowering of the anchor will continue until the main floater is slightly submerged. The positive buoyance of the main floater is able to stabilise the whole WEC structure. The chambers of the anchor will be fully filled with air or water to allow a controlled submergence of the structure. The mooring lines will be un-spooled and the installation is fulfilled when the anchor reaches the seabed. The mooring lines of the WEC will be spooled on to submerge the main floater as far as possible. From the deepest submergence, the commissioning process will be achieved. A marine air hose is connected to the anchor for the recovery and decommissioning of the anchor structure and is marked slightly above the seabed with a marker buoy.

During the commissioning process the monitoring of the PTO behaviour in mechanical, electrical and thermic properties is conducted and the results are compared with the design threshold. The mooring line and main floater loads will be measured while increasing the device gradually to more energy exposure by decreasing the device's submergence. The failure algorithms will be tested to ensure that the device is able to activate the safety features by itself and to ensure a correct behaviour.

The installation process of the Laminaria WEC will be fulfilled during one day and can take place in sea sates with wave heights of up to 2 m Hs. The marine vessel required will be mobilised from the harbour in Kirkwall.

The main navigational risk regarding the WEC installation is the collision with other marine vessels during the towing of the WEC. To decrease the risks as much as possible, mitigation measures have been identified in section 5.2.

In addition to heightened risk of collision of the WEC with marine vessels, detachment of the WEC from the multi-cat vessel during the towing to or from the harbour could occur. The WEC will be connected with a tug line to the multi-cat vessel. To ensure a safe transportation, a second tug line is connected to the WEC to provide safety in case of a damage or failure of the first tug line.

3.2 Operation

During the operational phase, the Laminaria WEC will only move inside the anchor footprint and the submergence will correspond to the sea states at Billia Croo. During more severe environmental condition like storms, the WEC will be further submerged whereas with more calm conditions, it is more likely that the WEC will be closer to the water surface. The operational phase of the Laminaria WEC will start directly after the installation of the WEC in August 2018 and will end with the decommissioning in September 2019. It is planned to retrieve the WEC during the deployment period several times to advance the installation method. Additional to these retrievals, it can be expected that further retrievals can occur due to the first full-scale deployment of the Laminaria WEC.

Similar to the installation phase of the Laminaria WEC, the main navigational risk is the collision of the WEC with marine vessels. From reviewing vessel activity in the area, it is estimated that the majority of marine vessels within the confines of the Billia Croo test site, will be most likely involved in operations associated with the working test site and maintenance of the Laminaria device and other test devices onsite. The Laminaria marine vessels will be more likely in contact with the WEC due to the towing and works on site. The marine operator, Leask Marine, will be responsible for the vessels required and will support Laminaria during the installation, operation and decommissioning phase of the WEC to ensure safe working conditions. Risk of collision with the WEC would be higher when the WEC is submerged to a distance within the under-keel clearance of vessels onsite. The level of submergence is corresponding to the actual sea state but there are two maximum submergence positions: the maximum submergence of the WEC while producing electricity is 17.2 m, but it can be submerged until 22 m in severe environmental conditions (without electricity generation; submergence level indicated from the average water level at site).

The WEC is connected by four mooring lines to the gravity base anchor which result in four times redundancy of device loss. Each intact mooring line of the WEC is designed to be able to hold loads of the WEC with the main floater being on the surface. This set-up

is able to survive wave conditions with wave heights of up to 8 m Hs, which was tested during the tank testing campaign at Plymouth in November 2018.

Loads on the mooring lines and the main floater will be measured constantly via load cells mounted on the mooring lines and the main floater. These load cells are coupled to the electrical connection of the WEC to the grid and in an unlikely event of the disconnection of the electrical connection of the WEC, the load cells are powered by the back-up battery system.

The storm protection system will be activated automatically, if the load cells are measuring loads exceeding a pre-defined threshold. The mooring lines will be spooled on to submerge the WEC further in the water column until nominal loads are achieved again. Additionally, a minimum tension will always be kept on the mooring lines to avoid slack. In case of a severe damage or failure of one mooring line, the WEC will increase the submergence to lower energy regions to avoid the damage of additional mooring lines. During the deployment period at EMEC, the WEC will keep the position until manual recovery to decrease the risk of free floating to a minimum. The Laminaria WEC is designed to continue electricity production even with two mooring line failures.

In the highly unlikely event of free floating of the WEC, two ballast chambers can be flooded to submerge the WEC to the seabed. The recovery of the WEC from the seabed will require a diver who connects the marine air hoses to a small work vessel in order to be able to surface the WEC structure. To be able to track the WEC at all times, a GPS system will be installed which will be powered with a battery back-up in case of a disconnection from the electrical cable.

In case of a severe misalignment or a detected failure of parts of the WEC (for example the mooring lines, electrical motor, water ingress, electrical failure), the WEC will automatically activate the storm protection system to submerge the WEC to a lower energy region of the water column. The Laminaria team will try to solve the misalignment or failure without removal of the WEC from the water. During the deployment period at EMEC, no maintenance is scheduled, but the WEC will be retrieved several times to practice the installation method of the WEC. These retrievals will be used to adjust potential misalignments. The Laminaria WEC is able to float invert for maintenance purposes which eliminates the requirement of lifting the WEC out of the water. The PTO chambers are attached at the bottom of the WEC which enable a removal without dismantlement.

The Laminaria WEC will be connected to the SCADA system of EMEC. In case of damage or failure of parts of the device, the EMEC staff will be informed immediately by a Laminaria representative. Additional, all necessary authorities will be informed to ensure safety for all marine users. Laminaria will keep in line with the Emergency Response Procedures implemented at EMEC and vary these to make them more suitable for the

potential failure modes of the Laminaria. The most severe failure would be a free-floating of the Laminaria WEC due to disconnection of the main floater from the anchor. In this case, the height adaptation cannot provide safety and therefore, there are two ballast chambers included in the design of the main floater, which will be flooded to submerge the WEC towards the seabed. For the recovery of the WEC, a crane vessel is required to ensure a safe up-lifting. The crane will be connected to the WEC and will bring it close to the surface. The water of the ballast chambers can be released to ensure a controlled surfacing of the WEC. With empty ballast chambers, the WEC can be towed to the harbour of Lyness. These ballast chambers can be filled as last resort to prevent the WEC becoming a marine hazard.

3.3 Maintenance

During the deployment at EMEC, no scheduled maintenance is planned, but the WEC will be recovered and re-installed several times during the deployment period. The aim of the re-instalments is to obtain more knowledge of the process itself to improve the procedure as well as the time needed for the instalment and receiving of the device.

Before each recovery, a video survey will be conducted of the whole structure and the gravity base anchor. The device will be recovered from the test berth two and towed back to the harbour in Lyness. The towing time depends on the weather conditions and a conservative view is taken when estimating the towing time to be around 1.5 hours. The WEC can be turned upside down to enable an easier access to the PTO chambers and the electronics inside the main floater. The advantage of this method for maintenance procedures is that there is no need for a crane vessel which removes the WEC from the water. After changes or repairs on the WEC have been conducted, the WEC will be towed back to the test berth 2 and re-installed for testing and electricity generation.

For the towing of the WEC, Laminaria and Leask Marine will develop a tow plan to ensure a safe transportation of the WEC.

Potential risks during maintenance periods are similar to the risks during the installation phase of the WEC. The highest risk of collision is during the period of towing the WEC to the nearest harbour.

There is no scheduled maintenance planned for the deployment period at EMEC, but the WEC will be recovered and re-installed several times. These opportunities will be used for small maintenance processes or re-alignments of parts of the WEC, if necessary. The maintenance would take place in the harbour of Lyness. The gravity base anchor will act as a concrete pontoon which give a platform to work on the WEC. Emergency Response Procedures will be developed for this work environment.

3.4 Removal / Decommissioning

The decommissioning of the main floater and the anchor will be executed in the reverse order than the installation process. The Laminaria device will be decommissioned by one Multi-Cat vessel and one small work vessel.

The small work vessel will recover the marker buoy at the end of the marine air hose and recover the buoy. The end of the air hose will be connected to an air compressor which will fill the chambers of the anchor with air to increase the buoyancy to a level of around zero buoyancy. The chambers will be either filled completely with air or water to ensure a safe and stable surfacing of the gravity base anchor. This process will take between 2.5 to 3 hours. During this process, the main floater of the WEC will be at the water surface not connected to the maintenance vessels. With the slow decrease of submergence of the anchor, the mooring lines will be spooled in to keep the tension and avoid slack. With secured mooring lines and an accurate position of the main floater on the anchor, the WEC will be towed from the deployment site back to the base port of Lyness. The decommissioning can be fulfilled during one day.

Due to the similar process compared to the installation of the WEC, similar potential risks have been identified. During the transport from the deployment site to the base port of Lyness, collision of marine vessels and the WEC could potentially occur. As stated in 3.1, this risk will be mitigated by proper lighting of the marine vessels as well as an operational window during hours of daylight. Retro-reflective tape or panels will be installed at the upper part of the WEC to ensure proper marking and the device will be painted in yellow to decrease risks of collision with other marine users. Two tug lines will connect the WEC to the multi-cat vessel to ensure a safe transport and to reduce the risks to marine users. Detailed information about all potential risks can be found in section 5 and further descriptions of the mitigation measures employed are provided in Section 5.2.

The following Emergency Response Procedures are in place during the decommissioning of the WEC:

Man over board: works person falls over board of the ship

1. Immediately provide afloat assistance (additional to the swimming west) in form of a lifesaver or similar
2. Help the works person to climb out of the water
3. Notification to EMEC and other marine authorities
4. Identify the cause of the situation

Interaction with marine vessel:

1. Immediately provide help for people affected
2. Notification to EMEC (keep up-to-date) (Laminaria employee)
3. Notification to all necessary authorities (keep up-to-date) (Laminaria employee and EMEC staff)

4. Monitoring of damage on the WEC and identification of adaptation measures like activation of the storm protection system to decrease main floater towards lower energy regions of the water (if this did not occur automatically)
5. Identification of the cause of the interaction (Laminaria employee and EMEC staff)
6. Planning for maintenance to recover and repair the WEC (Laminaria employee)

4 Consultation

An initial consultation with the Northern Lighthouse Board has been undertaken to gain an early indication of the marking and lighting requirements. This risk assessment will be consulted upon as part of the marine licence application process.

5 Risk Assessment

This section of the NRA identified the potential risks occurring due to the WEC deployment at EMEC. Mitigation and adaptation measures have been identified to decrease the potential risks to marine stakeholders and navigation to a minimum. In addition, further information is given on structural parts of the WEC which may further decrease navigational risks associated with the testing of the WEC.

5.1 Risk Review

The identification of the navigational risks relating to the deployment of the WEC did not show any additional risks to the identified ones in the Navigational Risk Assessment of the Billia Croo wave energy test site at EMEC. The main risk identified during the evaluation was the risk of collision of the WEC with marine vessels.

Work vessels directly associated with Laminaria's testing, will have higher risks of collision due to the close proximity of work to the WEC.

The Billia Croo wave energy test site is a charted area and typically avoided by other marine users. Therefore, the collision risk potential with other marine users is estimated to be more likely during the towing of the WEC compared to the other deployment phases inside the Billia Croo test site.

During the development of the Laminaria WEC, potential risks due to the presence of WEC have been taken into account and therefore, there are several mitigation measures and adaptation procedures included in the design. These include measures for station keeping of the WEC, the WEC will be connected by four mooring lines to the anchor structure which result in four-times the redundancy in the event of a mooring line damages or destruction, resulting in a WEC loss. Additional to the quantity of mooring lines, the developed storm protection system will submerge the WEC into lower energy regions in case of severe damage, failure or destruction of the mooring lines but also for

misalignment of other WEC parts (like the electrical motors, electrical connection or the drum system, etc.). In case of a failure of the storm protection system, the submergence of the WEC can be increased manually. In the highly unlikely case of the destruction of all four mooring lines at the same time, two ballast chambers can be filled with sea water to decrease the positive buoyancy of the WEC and to submerge it to the seabed. Therefore, the loss of station of the WEC is highly unlikely. The implemented security features are able to be controlled remotely to decrease the risks to other marine users and maintenance vessels. The submergence via height adaptation system is only controllable remotely when the connection between the WEC and the electrical connection is not damaged or did not fail. The ballast chambers can be controlled remotely also in a case of electrical failure. The WEC consists of a back-up battery system which powers the most important features to secure a safe installation of the WEC.

Table 4 shows the identified navigational risks of the deployment of the Laminaria WEC and the corresponding mitigation and adaptation measures.

Table 4: Navigational risks and proposed mitigation measures of the Laminaria WEC

Potential issue	Results / Effects	Deployment phase	Proposed Mitigation Measures	Adaptation of the results / effects
Collision of WEC with other marine vessels or operator vessel	a. Damage to WEC b. Damage to marine vessel (→ possible vessel sinking) c. Water ingress in device (→ possible WEC sinking) d. Man over board e. Mooring line damage/destruction (→ disconnection from the anchor; severe: free floating of WEC, becomes hazard for marine vessels) f. Damage electric cable g. Destruction of electric cable h. Disconnection WEC from electric cable	• Towing of WEC • WEC in harbour • Installation phase • Operational phase • Recovery phase • Decommissioning phase	✓ Updated Notice to Mariners ✓ Expertise of Leask Marine in handling WECs ✓ Ensure the overall understanding of the WEC principal for all people on marine vessels required by Laminaria ✓ Operational time only during hours of daylight (as much as possible) ✓ Appropriate charting of the WEC deployment location at Billia Croo ✓ Appropriate marking of the WEC itself, advised by the Northern Lighthouse Board ✓ Appropriate charting of the WEC deployment location at Billia Croo ✓ Emergency response procedures will be in place to provide a safe work environment ✓ Water ingress monitoring ✓ WEC consists of a battery to activate the storm protection system (submergence of the WEC) in case of a damage/ disconnection of the electric cable ✓ Regular WEC inspections	• TPV of the structure of the main hull identifies damage can appear without further severe results on the WEC • Two layers of seals to protect from water ingress • Identification of maintenance operations after water ingress notification of the WEC • In severe cases: the ballast tanks of the WEC can be flooded to bring the WEC to the seabed and prevent a navigational hazard at sea • Mooring line destruction: the WEC will on-spool the mooring line to prevent a hazard at sea • In the even of an emergency, notice will be given to other marine users in the area, via marine communication channels (keep them up-to-date until the situation is solved) • HIRA and safety toolbox talk before the start of any works
Man over board	a. Life threatening situation	• Towing of WEC • Installation phase • Recovery phase	✓ Expertise of Leask Marine in handling WECs ✓ Ensure the overall understanding of the WEC	• Emergency response procedures will be in place to provide a safe work environment

Potential issue	Results / Effects	Deployment phase	Proposed Mitigation Measures	Adaptation of the results / effects
		• Decommissioning phase	principal for all people on marine vessels required by Laminaria ✓ Ensure that workers on the vessels have the required certificates and qualifications	• Immediately report to EMEC staff and notice on marine communication channels (keep them up-to-date until the situation is solved) • HIRA and safety toolbox talk before the start of any works • Ensure safety equipment is located on board of the vessels
Disconnection of tug line from marine vessel or WEC	a. Free floating of the WEC (WEC becoming hazard) b. Tug line becoming hazard (→ entanglement of tug line with marine vessel)	• Towing	✓ Expertise of Leask Marine in handling WECs ✓ Two tug lines during towing of the WEC to ensure safe transport	• Emergency response procedures will be in place to provide a safe work environment • Immediately report to EMEC staff and notice on marine communication channels (keep them up-to-date until the situation is solved)
Entanglement of marine vessels with tug line	a. Marine vessels becoming hazard at sea (→ no navigational control over the vessel anymore; severe: collision of vessel with other marine users) b. Damage to ships	• Towing	✓ Updated Notice to Mariners ✓ Expertise of Leask Marine in handling WECs	• Emergency response procedures will be in place to provide a safe work environment • Immediately report to EMEC staff and notice on marine communication channels (keep them up-to-date until the situation is solved)
Significant drifting of the anchor	a. Misplacement of the WEC (not align with the coordinated given in Notice to Mariners)	• Operational phase	✓ TPV of the WEC design identified no significant drifting during nominal conditions and usual storms ✓ GPS identification of the position of the WEC	• Alarm system in case of significant movement • Activate storm protection mode to decrease the energy exposure on the main hull • Immediately report to EMEC staff and notice on marine communication channels (keep them up-to-date until the situation is solved)

Potential issue	Results / Effects	Deployment phase	Proposed Mitigation Measures	Adaptation of the results / effects
Uncontrolled surfacing of anchor	a. Main floater damage b. Entanglement of marine vessels in loose mooring lines c. Vessel damage (→ severe: sinking of marine vessel)	• Recovery phase • Decommissioning phase	✓ Anchor will be filled with air until zero buoyancy is reached to decrease the risks for marine vessels and people ✓ Step by step surfacing of the anchor	• Emergency response procedures will be in place to provide a safe work environment • Immediately report to EMEC staff and notice on marine communication channels (keep them up-to-date until the situation is solved)

5.2 Mitigation

During the review of the site-wide NRA, the following mitigation measures (Table 5) were identified as applicable to this project and will be adopted. Additional project-specific mitigation measures have also been outlined in Table 5.

Table 5: Relevant mitigation measures and project commitments

Identified mitigation measures / recommendations	Project commitment
Billia Croo test site has been established since 2003 and therefore, charts and other nautical publications already highlight the Billia Croo site.	All infrastructure associated with the project will be deployed within the boundaries of the test site.
Appropriate charting of the WEC deployment location at Billia Croo	Locational information will be promulgated to the UK Hydrographic Office to ensure appropriate marking of the WEC. UKHO will be included in the final Notice to Mariners distribution list.
The devices at the site should be marked as per the NLB requirements, based on IALA Recommendation 0-131 on the marking of offshore wave and tidal energy devices.	The device will be painted yellow for maximum daytime conspicuity, retro-reflective tape/panels to the upper part of the device will be applied. It will not be necessary to light the device, as advised by the Northern Lighthouse Board.
EMEC's Maritime Safety Information procedure ensures the appropriate authorities are informed of works being carried out in waters within EMEC's test site such that the information is promulgated through appropriate channels to mariners.	Laminaria will issue Notice to Mariners (NtM) prior to operations onsite to ensure other sea users are aware of works. NtM will be released to inform marine stakeholders on the duration, location and works to be fulfilled.
Developers are required by the regulators and their consultees to produce an independent structural verification report for their device. It is a contractual requirement that a report that certifies the integrity of the structural design of the device and its foundation for the conditions expected at the site, e.g. tested to withstand 50-year return period. The report shall be provided by an independent accreditation agency of recognised international standing and reputation.	Laminaria will contract a Third Party Verification of their device and mooring system, the conditions at Billia Croo test site.
Consequences and emergency response procedures should a device (or any part of device) lose station need to be developed on a device-specific basis.	Laminaria will develop their own ERPs for key incident types. This will account for EMEC's ERPs. The ERPs will take account into account alerting

	of the potential hazard via position monitoring systems, e.g. SCADA system, and availability of a 24-hour emergency contact.
During these activities, it is important that vessels working at the site adhere to guidelines and are watchful of the passing traffic in the area. Site vessels should avoid obstructing passing traffic as far as practicable.	Vessels involved in works onsite will be watchful of other sea users in the area, and, as far as practical, not obstruct passing vessel routes. NtM will be issued prior to any works involving vessels with restricted manoeuvrability.
Time of marine works	Works will be restricted to the hours of daylight, where practical, to facilitate visibility of works onsite and vessel movements.
AIS data is continuing to be collected by EMEC, covering the Billia Croo site.	In the event of an incident onsite associated with the Laminaria project, EMEC will provide AIS data collected.
Liaise with the RNLI and the MCA about the devices to be deployed and provide any further information requested to assist SAR response.	Laminaria to provide a device-specific appendix to theEMEC Emergency Response and Co-operation Plan to the MCA.
HIRA and safety toolbox talk before the start of any works	Prior to all marine operations, a HIRA and toolbox talk will be performed. Ensure that workers on the vessels have the required certificates and qualifications (regarding emergency responses)
Ensure the overall understanding of the WEC principal for all people on marine vessels required by Laminaria	All work personnel will be updated on the working principle of the WEC, prior to commencing marine operations.
Electrical back-up system of the WEC to provide communication or safety actions also in case of a disconnection of the electrical cable from the device	The Laminaria WEC includes a battery back-up system which will power the GPS location tracking and the height adaptation.
Ensure the safe transport of the device between the harbour and the deployment site	The WEC will be towed by a multi-cat vessel with two installed towing lines to prevent a free-floating of the WEC.
Ensure a safe working environment for workers of the marine vessels	Laminaria will make sure that only worker with required certificates and qualification will work on the marine vessels.
Controlled and safe decommissioning of the WEC	The Laminaria WEC will be decommissioned as one whole structure. The anchor will consist of several chambers which can be flooded with air or water to ensure a controlled and regulated surfacing of the anchor structure.

Additional to the mitigation measures mentioned in Table 5, the Laminaria WEC consists of several sensors to monitor the operational state of the WEC:

- Noise monitoring: noise of the WEC will be measured with three microphones located in the main floater. The main source of the produced noise is estimated to be waves interacting with the WEC.
- Camera monitoring: a camera attached to the bottom of the WEC will monitor the drum systems, PTO systems and the upper part of the mooring lines to identify possible interactions or potential entanglement of marine species. The video will be a live-feed which enables immediate action in case of unforeseen events.
- Temperature monitoring: the temperature of the individual parts of the main floater will be measured to identify potential misalignments.
- Water ingress monitoring: monitoring of potential water ingress is in place to immediately identify water in the main floater or the PTO chambers.
- Load monitoring: loads cells will monitor the loads on the mooring lines and the main floater which will be used for the activation of the storm protection system. INNOSEA will support Laminaria in load monitoring of the WEC (part of the LAMWEC-project). The load cells will ensure tension on all mooring lines at all times which reduces the risk of entanglement with marine species.
- Torque monitoring of the drum system
- Electrical connection monitoring: the electrical connection will be monitored to identify potential misalignments or damages. INNOSEA will support Laminaria in load monitoring of the WEC (part of the LAMWEC-project).
- GPS monitoring: the WEC will be equipped with a GPS tracker to identify the position. This is an additional safety feature for the unlikely case of drifting or free floating of the WEC and can identify the WECs position after the unlikely occurrence that the ballast tanks have been flooded.

The storm protection of Laminaria is the main design element to decrease risks for the surrounding area of the WEC. In case of misfunctions, damages, failures or destruction of the parts of the WEC, the system will be activated immediately. The design of the WEC and the installation process enables Laminaria to decrease the time required at sea as well as the number of marine vessels needed. This will overall decrease the risks of collision with other marine users. Detailed information about the work principle of the storm protection system can be found in the *Project Information Summary* of Laminaria.

The Notice to Mariners will be issued regularly before the installation, deployment, maintenance and decommissioning periods.

5.3 Third Party Verification results

To follow once TPV has been completed.

6 References

Anatec Ltd., 2014. *A2866-EMEC-NRA-1: Navigation Risk Assessment Update, European Marine Energy Centre, Billia Croo Wave Energy Test Site*.

Maritime and Coastguard Agency, MGN 543 (M+F) Safety of Navigation: Offshore Renewable Energy Installations (OREIs) - UK Navigational Practice, Safety and Emergency Response .

European Marine Energy Centre, Grid-Connected Wave Test Site, European Marine Energy Centre, http://www.emec.org.uk/facilities/wave-test-site/

Annex One: Details of potential marine vessels to be used during the deployment period of the full-scale Laminaria WEC

Leask Marine	
Vessel Name	MV C-Fenna
Type of vessel	Neptune Eurocarrier 2611
Flag state	UK
Port of registration	Kirkwall
Year built	2013
Vessel International Maritime Organisation Number (IMO)	9675963
Official number	922340
Call sign	MBAH3
Vessel Owner	Leask Marine
Operating Company	Leask Marine
Length	26.48 m
Beam	11 m
Depth	3.5 m
Draught	2.61 m

Leask Marine	
Vessel Name	MV C-Odyssey
Type of vessel	Multiworker Twenty6
Flag state	UK
Port of registration	Kirkwall
Year built	2011
Vessel International Maritime Organisation Number (IMO)	9636307
Official number	917987
Call sign	2ETW7
Vessel Owner	Leask Marine
Operating Company	Leask Marine
Length	26 m
Beam	10.5 m
Depth	3.5 m
Draught	2.5 m

Leask Marine	
Vessel Name	MV Uskmoor
Type of vessel	Workboat
Flag state	UK
Port of registration	Kirkwall
Year built	1984
Vessel International Maritime Organisation Number (IMO)	
Official number	
Call sign	
Vessel Owner	Leask Marine
Operating Company	Leask Marine
Length	16 m
Beam	5.5 m
Draught	1.5 m

Leask Marine	
Vessel Name	MV Challenge
Type of vessel	Landing Craft
Flag state	UK
Port of registration	Kirkwall
Year built	1989
Vessel International Maritime Organisation Number (IMO)	
Official number	
Call sign	
Vessel Owner	Leask Marine
Operating Company	Leask Marine
Length	14.4 m
Beam	4.26 m
Draught	1.44 m

Leask Marine	
Vessel Name	MV Prosperous
Type of vessel	Work boat
Flag state	UK
Port of registration	Kirkwall
Year built	1988
Vessel International Maritime Organisation Number (IMO)	
Official number	728642
Call sign	2HHN3
Vessel Owner	Leask Marine
Operating Company	Leask Marine
Length	11.6 m
Beam	4.2 m
Draught	2.0 m

All the details above have been taken from: http://www.leaskmarine.com/index.php [19.03.2018]

Green Marine	
Vessel Name	Green Isle
Type of vessel	DAMEN Multi-Cat vessel
Flag state	UK
Yard number	571674 / A15058
Year built	
Vessel International Maritime Organisation Number (IMO)	
Official number	
Call sign	
Vessel Owner	Green Marine
Operating Company	Green Marine
Length	27.70 m
Beam	12.45 m
Draught	2.89 m

Green Marine	
Vessel Name	Green Chief
Type of vessel	DAMEN Stan Tug
Flag state	UK
Yard number	3113
Year built	1980
Vessel International Maritime Organisation Number (IMO)	
MMSI	235.075.142
Official number	
Call sign	
Vessel Owner	Green Marine
Operating Company	Green Marine
Length	26.0 m
Beam	7.80 m
Draught	3.00 m

All the details above have been taken from: https://view.publitas.com/k4-graphics/green-marine-fleet-spec-sheets/page/16 [19.03.2018]