LiftWEC

DEVELOPMENT OF A NEW CLASS OF WAVE ENERGY CONVERTER BASED ON HYDRODYNAMIC LIFT FORCES

Deliverable D7.3

Assessment of Preliminary configurations

Deliverable Lead	University College Cork
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EXECUTIVE SUMMARY

This deliverable describes the results of the assessment of the preliminary configuration designs of the LiftWEC concept. It details the 'Scenario Test Cases' that were run on certain preliminary configuration designs. Due to delays in development of the operations and maintenance software, as well as the large number of preliminary configurations: the assessment approach was to take the broad category of configurations using standard towing vessels and configurations that would require larger vessels. Details are provided on the representative site, met-ocean resource data, vessel parameter data, technician requirements and cost details. A discussion on the results is included and any operational risk areas identified are consolidated into a series of recommendations for consideration for the baseline configuration designs.

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1 INTRODUCTION

Several preliminary configurations have been identified as part of previous work during the LIFTWEC project (see LiftWEC Deliverable LW-D02-03-1x2). Due to the relatively large number of configurations and delays encountered in the development of the Operations and Maintenance model (O&M Expert): the approach taken is to lump several different configurations into broad categories in terms of likely installation and O&M strategies.

For the installation the main categories are;

- Float out installation strategies using conventional vessels
- Fixed structure type foundations that require heavy lift installation vessels

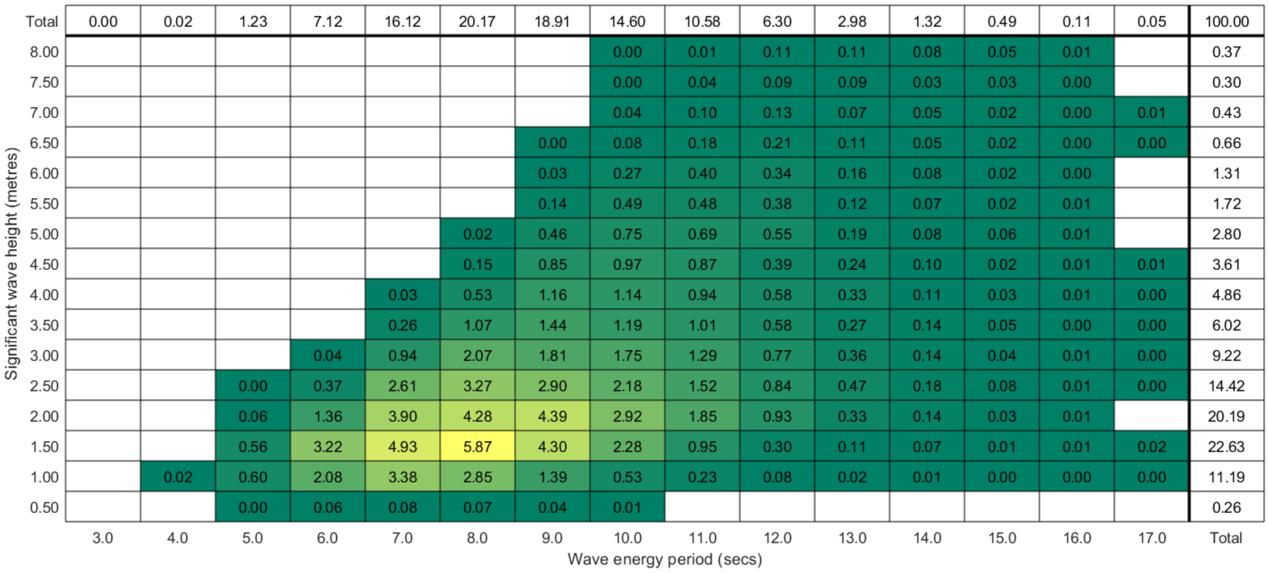
Operations & Maintenance the main categories are similar;

- Tow back, repair and redeploy
- Surface access for minor repairs with tow back for larger repairs
- Surface access for minor repairs with lifting and transport of device for larger repairs

2 SITE CHARACTERISTICS

Mean water level is assumed to be 50m, with a maximum current of 0.1m/s which is assumed can be flowing in 360 degrees relative to a LiftWEC device. A port suitable for service vessels is assumed to be 20km from the site, while a port suitable for installation vessels is assumed to be 50km from the site. The seabed is assumed to be dense sand.

Although the different configurations have several differences between them, the proposed site is a relative constant and therefore makes a logical starting point for investigation. Performing weather window analysis on the site provides very useful information to inform on viable installation and O&M strategies. Previous work for the OPERA project provided a 30 year dataset for the BIMEP site in the Basque region of Spain, while work relating to LEANWIND provided a 16 year dataset for a proposed wind farm location in Bellmullet in the Northwest of Ireland. The Ifremer site (Accensi & Maisondieu, 2015) is proposed for LiftWEC, specifically the HOMERE dataset which provides data from 1994-2020 (scatter diagram shown below), although there are gaps for some years, a 25 year dataset was used for the HOMERE analysis.



	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0	16.0	17.0	Total
Total	0.00	0.02	1.23	7.12	16.12	20.17	18.91	14.60	10.58	6.30	2.98	1.32	0.49	0.11	0.05	100.00
8.00								0.00	0.01	0.11	0.11	0.08	0.05	0.01		0.37
7.50								0.00	0.04	0.09	0.09	0.03	0.03	0.00		0.30
7.00								0.04	0.10	0.13	0.07	0.05	0.02	0.00	0.01	0.43
6.50							0.00	0.08	0.18	0.21	0.11	0.05	0.02	0.00	0.00	0.66
6.00							0.03	0.27	0.40	0.34	0.16	0.08	0.02	0.00		1.31
5.50							0.14	0.49	0.48	0.38	0.12	0.07	0.02	0.01		1.72
5.00						0.02	0.46	0.75	0.69	0.55	0.19	0.08	0.06	0.01		2.80
4.50						0.15	0.85	0.97	0.87	0.39	0.24	0.10	0.02	0.01	0.01	3.61
4.00					0.03	0.53	1.16	1.14	0.94	0.58	0.33	0.11	0.03	0.01	0.00	4.86
3.50					0.26	1.07	1.44	1.19	1.01	0.58	0.27	0.14	0.05	0.00	0.00	6.02
3.00				0.04	0.94	2.07	1.81	1.75	1.29	0.77	0.36	0.14	0.04	0.01	0.00	9.22
2.50			0.00	0.37	2.61	3.27	2.90	2.18	1.52	0.84	0.47	0.18	0.08	0.01	0.00	14.42
2.00			0.06	1.36	3.90	4.28	4.39	2.92	1.85	0.93	0.33	0.14	0.03	0.01		20.19
1.50			0.56	3.22	4.93	5.87	4.30	2.28	0.95	0.30	0.11	0.07	0.01	0.01	0.02	22.63
1.00		0.02	0.60	2.08	3.38	2.85	1.39	0.53	0.23	0.08	0.02	0.01	0.00	0.00	0.00	11.19
0.50			0.00	0.06	0.08	0.07	0.04	0.01								0.26

Figure 2-1; Scatter diagram for the HOMERE Ifremer site (Boudière et al., 2013)

Since significant wave height is the most important/constraining parameter, initial weather window analysis was performed on the three sites: Setting different Hs threshold limits (less than 1m,2m etc) as well as window duration length (e.g. a 12 hour window with Hs<1m) allows for an estimation of site access throughout the year. In the following plots the y-axis represents the percentage wait time i.e. the percentage of the month that can be expected to wait before achieving the desirable weather window.

It can be seen from the Hs<1m plot that both exposed Atlantic sites incur significant wait times for a 12 hour window. Approximately 90% of each month would be spent waiting for such a window. Contrast this with the BIMEP site with wait times of ~50% for the Winter months and excellent wait percentages during the Summer months of ~10%. The 48 hour weather window results are plotted to the right and remain poor for the exposed sites while the BIMEP retains reasonable characteristics. These graphs reveal that the HOMERE site would have significant ramifications for strategies that would require heavy lift installation/O&M strategies. Such strategies require calm sea conditions that are simply not prevalent for the site in question.

The next figure shows the weather windows when the threshold is raised to Hs<2m. It can be seen that this improves the accessibility to the HOMERE site although access during the Winter months would still be scarce. This graph would suggest that preference should be given to installation and O&M strategies where a higher Hs threshold is can be employed. Tow out strategies such as those employed by Pelamis would be more suitable for this type of site. An implication would be that the device would have to utilise similar “plug and play” technologies that Pelamis went to great lengths to achieve: “the machine can be quickly and safely removed in less than an hour with minimal vessel requirements and reinstalled again as easily. The allowable weather windows for such operations mean that they can be conducted with acceptable waiting periods throughout the year, albeit with some inevitable compromise during the winter." (Yemm, Pizer, Retzler, & Henderson, 2012)

Quick release "hands-free" mechanisms were also strongly encouraged by several experts as revealed in D7.1 "Best Practice Guidelines".

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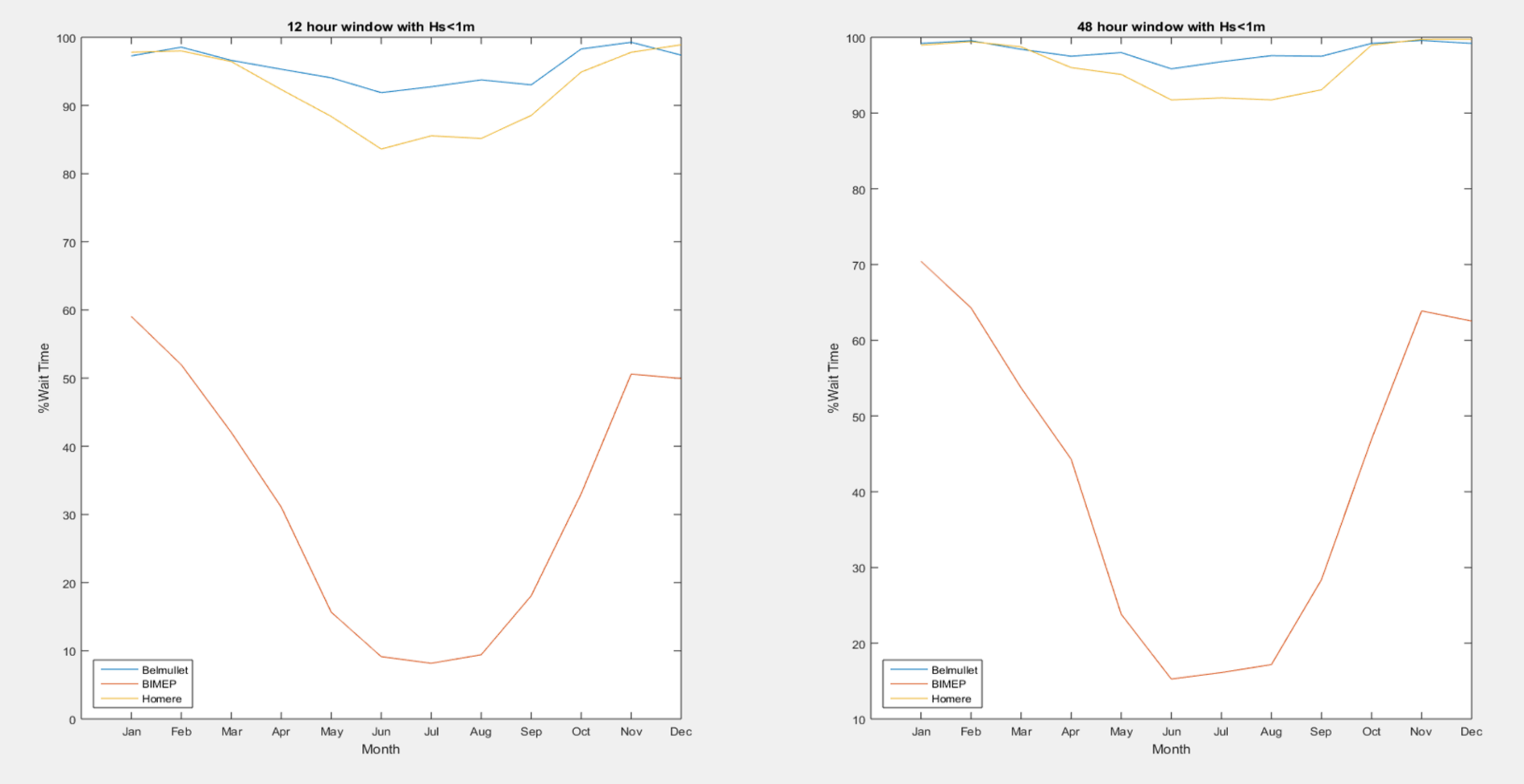

Figure 2-2: Hs<1m weather windows for 12 and 48 hour duration

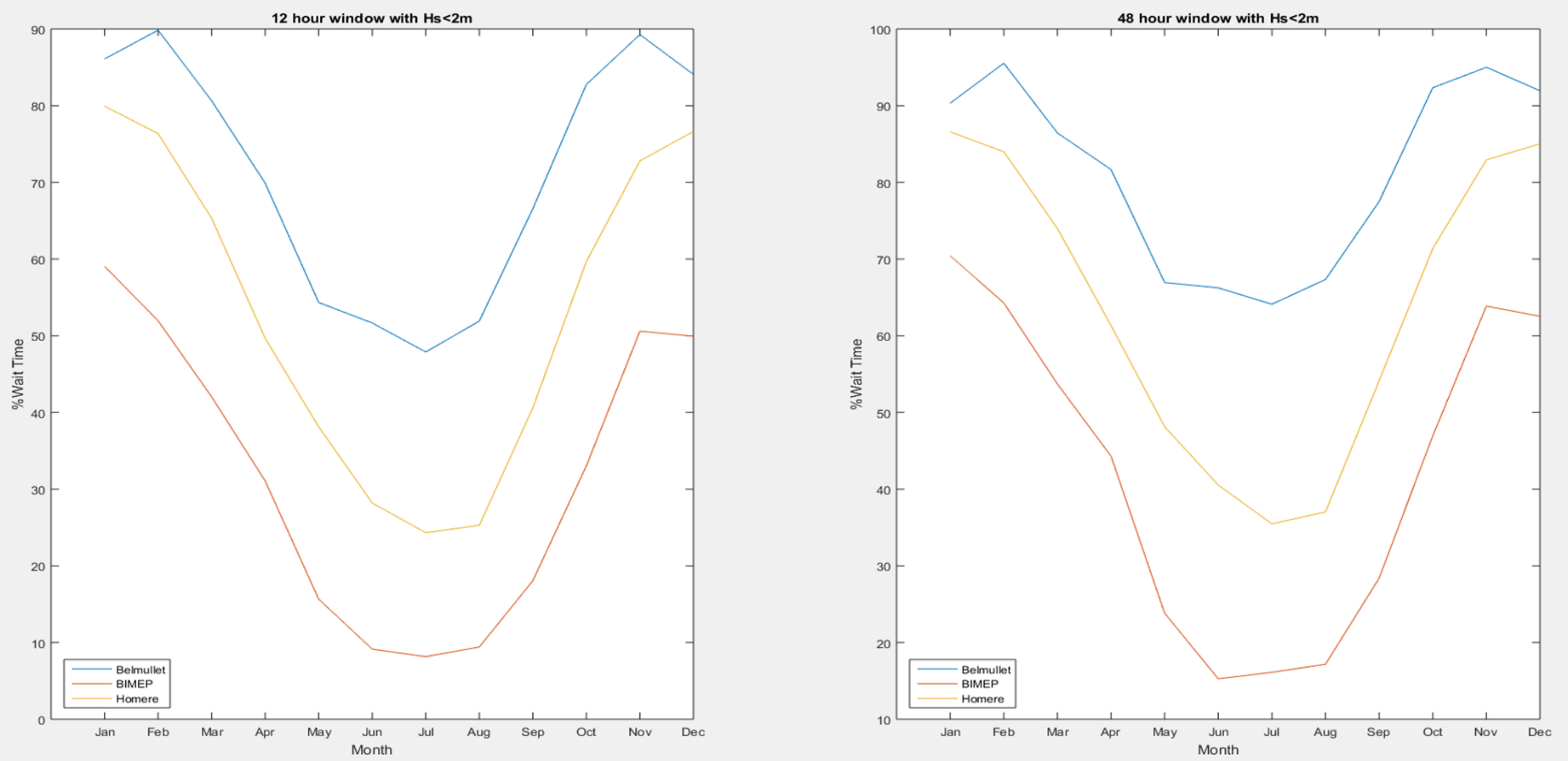

Figure 2-3: Hs<2m weather windows for 12 and 48 hour duration

3 FIXED & FLOATING INSTALLATION CATEGORIES

3.1 FIXED STRUCTURE

A monopile configuration has been chosen as representative of a possible fixed support structure. Monopiles are already used extensively in offshore renewable disciplines. The Figure below displays an early potential CycWEC employing a monopile for fixed support: Some LiftWEC configurations also propose a monopile or several slender piles. As an established technology, there are some benefits to using a monopile (depth dependent). A major benefit often used for Tidal devices, is that it allows for lowering if the device in the water column (for survival) as well as raising the device out of the water, for maintenance.

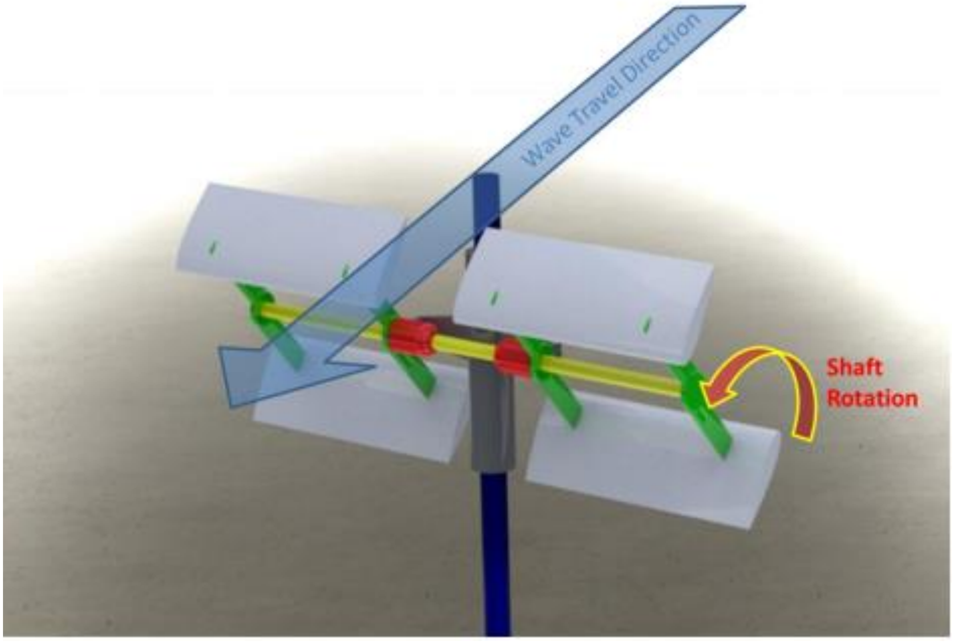

Figure 3-1: Early proposed CycWEC Configuration (S. Siegel, 2010)

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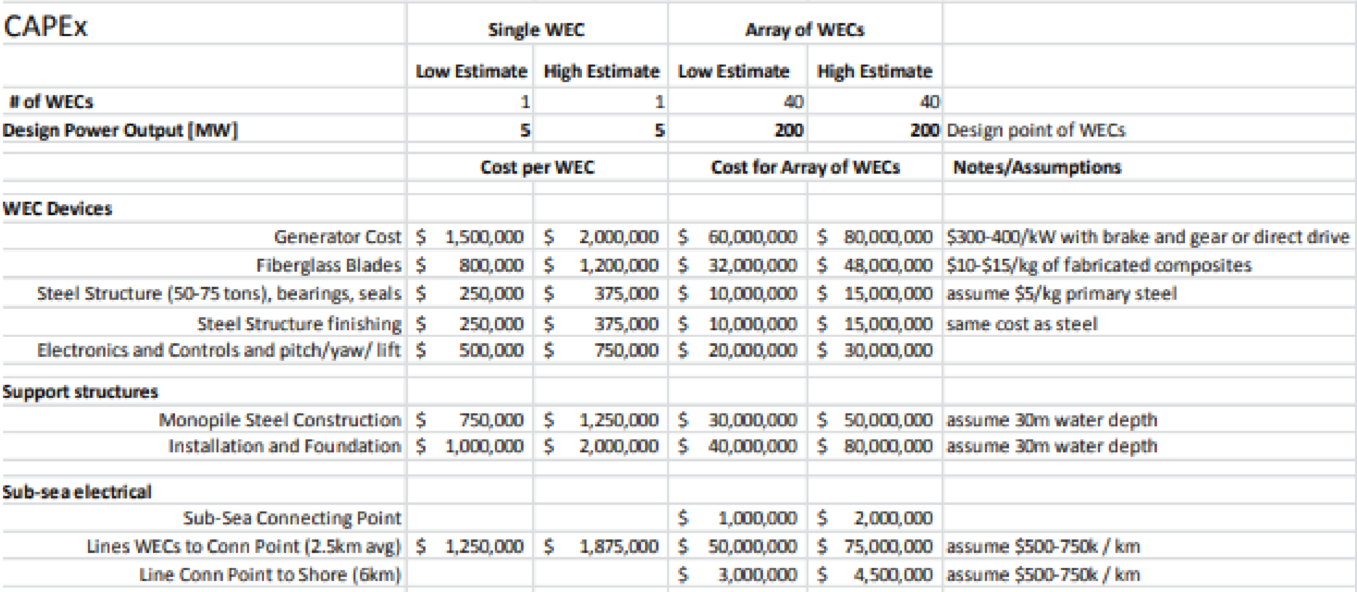
Table 1: Cost estimates for the monopile CycWEC



CAPEx	Single WEC		Array of WECs		
	Low Estimate	High Estimate	Low Estimate	High Estimate	
# of WECs	1	1	40	40	
Design Power Output [MW]	**5**	**5**	**200**	**200**	Design point of WECs
	Cost per WEC		**Cost for Array of WECs**		**Notes/Assumptions**
WEC Devices					
Generator Cost	$ 1,500,000	$ 2,000,000	$ 60,000,000	$ 80,000,000	$300-400/kW with brake and gear or direct drive
Fiberglass Blades	$ 800,000	$ 1,200,000	$ 32,000,000	$ 48,000,000	$10-$15/kg of fabricated composites
Steel Structure (50-75 tons), bearings, seals	$ 250,000	$ 375,000	$ 10,000,000	$ 15,000,000	assume $5/kg primary steel
Steel Structure finishing	$ 250,000	$ 375,000	$ 10,000,000	$ 15,000,000	same cost as steel
Electronics and Controls and pitch/yaw/ lift	$ 500,000	$ 750,000	$ 20,000,000	$ 30,000,000	
Support structures					
Monopile Steel Construction	$ 750,000	$ 1,250,000	$ 30,000,000	$ 50,000,000	assume 30m water depth
Installation and Foundation	$ 1,000,000	$ 2,000,000	$ 40,000,000	$ 80,000,000	assume 30m water depth
Sub-sea electrical					
Sub-Sea Connecting Point			$ 1,000,000	$ 2,000,000	
Lines WECs to Conn Point (2.5km avg)	$ 1,250,000	$ 1,875,000	$ 50,000,000	$ 75,000,000	assume $500-750k / km
Line Conn Point to Shore (6km)			$ 3,000,000	$ 4,500,000	assume $500-750k / km

(S. Siegel, 2010) provides useful details on the expected costs of the various WEC components, blades generator and electronics which will be useful for a spare costs estimates for O&M work. Using supplied estimates of material costs ($10-15/kg for composites and $5/kg for steel will allow for scrappage and resale estimates for the decommissioning work.

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3.2 FLOAT OUT INSTALLATION

A description of the CycWEC components are given in (S. G. Siegel, 2019): The rotor contains the blade pitch control actuators and their associated electromechanical components. The two nacelles attached to the ends of the rotor main shaft are shown in blue (in the figure below). Each nacelle holds the stator component of the generator, as well as the main shaft bearings and the associated power and control system electronics. The nacelles are held in position by two telescoping struts each of which are adjustable in length by means of a telescopic jacking system based on a rack and pinion gear system.

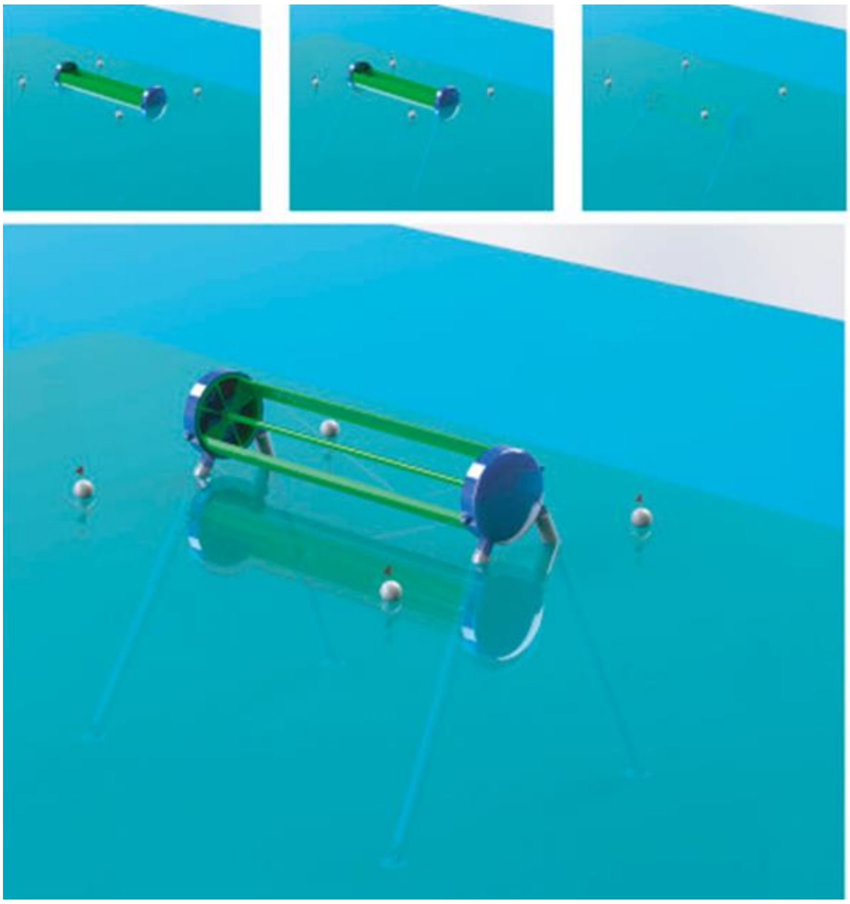

Figure 3-2: CYCWEC device owed out for deployment (top left), with two legs deployed (top center), in the operational position (top right), and maintenance position (bottom). The rotor is shown in green, the nacelles in blue and the strut mooring system in gray [source (S. G. Siegel, 2019)*]*

Seabed preparation involves the four mooring foundation points installed at the ocean floor. The struts (when extended) are attached to the mooring points which can be implemented using suction caissons, driven piles, drilled rock anchors or any other suitable technology depending on ocean floor bathymetry. The device can be towed to site for installation using conventional tug vessels. The

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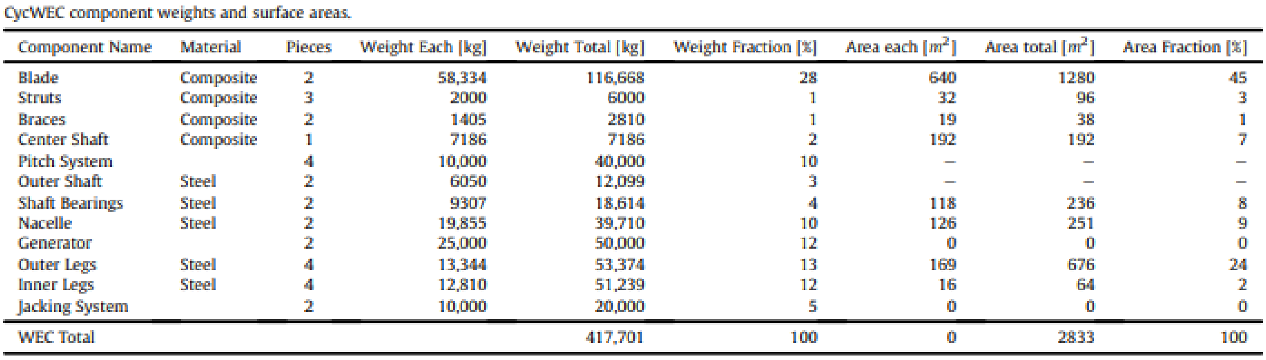
jack up legs would be contracted (via Winches in each opposing nacelle) during transit, and extended/connected to the mooring points upon arrival. At the deployment location the mooring points have been preinstalled and are equipped with marker buoys attached to the mooring points by means of mooring lines. During deployment the mooring lines of the marker buoys engage in a proprietary strut attachment system that allows the struts to connect to the mooring points without any need for diver or Remote Operated Vehicle (ROV) interaction. The cables connecting the struts to the winches stabilize the CycWEC in the axial shaft direction once the CycWEC is deployed. The struts also allow for submergence as a survival strategy and can raised above the water line for operations and maintenance.

The table below provides information relating to the component weights which can be used for the decommissioning model.

Table 2: CycWEC component weights [source (S. G. Siegel, 2019)*]*



CycWEC component weights and surface areas.

Component Name	Material	Pieces	Weight Each [kg]	Weight Total [kg]	Weight Fraction [%]	Area each [m^2]	Area total [m^2]	Area Fraction [%]
Blade	Composite	2	58,334	116,668	28	640	1280	45
Struts	Composite	3	2000	6000	1	32	96	3
Braces	Composite	2	1405	2810	1	19	38	1
Center Shaft	Composite	1	7186	7186	2	192	192	7
Pitch System		4	10,000	40,000	10	–	–	–
Outer Shaft	Steel	2	6050	12,099	3	–	–	–
Shaft Bearings	Steel	2	9307	18,614	4	118	236	8
Nacelle	Steel	2	19,855	39,710	10	126	251	9
Generator		2	25,000	50,000	12	0	0	0
Outer Legs	Steel	4	13,344	53,374	13	169	676	24
Inner Legs	Steel	4	12,810	51,239	12	16	64	2
Jacking System		2	10,000	20,000	5	0	0	0
WEC Total				417,701	100	0	2833	100

Siegel (2010) provides approximate component cost and cost per kilo ($10-15/kg for composites and $5/kg for steel): Using the same figures and used on the weight table above allows a rough estimate of some component costs for the latest proposed CycWEC device

Table 3: Estimation of some CycWEC component costs

WEC		€5,444,190
Generator		€2,000,000
Blades/composite		€1,989,960
Steel Structure		€352,115
Finishing		€352,115
Electronics		€750,000
Support Structure		
Legs (steel only)		€1,047,030

While the figures in Table 2 may suffice for initial investigation, one crucial piece of the puzzle that is missing is the cost of the Jack-up legs system. CycWEC have in essence chosen “solid mooring lines” and the initial CAPEX cost, likely failure rates, and hence likely OPEX costs are required for comparison with conventional mooring options.

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4 INSTALLATION MODEL

4.1 COMMON PROJECT DETAILS

The lifetime of the WEC is set to be 25 years. A total of twenty 5MW WECs were assumed to reach a total farm capacity of 100MW. Average inner array distance is provisionally set to 1.5 km although this figure will need to be revised at a later date, when more information is known about array effects and allowable distances between WECs. At the moment this figure will only influence the amount of inner-array cable needed for the farm. Inner array cable was set to 33 kV with a cost of 204,678 €/km. The export cable was rated at 150 kV at a cost of 492,424 €/km and it was assumed that the export cable would run for 30km before reaching shore. The vessels used and operational duration for cable laying are given in Table 4. Vessel charter costs like any service are subject to supply and demand economics. The figures given in Table 4 were acquired through industry consultation for previous installation and O&M projects.

4.2 INSTALLATION MODEL MONOPILE

A monopile at 50m water depth will have to be driven into the soil a considerable amount (a similar order of magnitude as the water depth). This will result both a large and heavy structure that will require a more expensive heavy lift vessel. There are few vessels existing that could handle the necessary height and weight. The Svanen heavy lift vessel (shown below) was used in the simulation.

Figure 4-1: Van Oord's Heavy lift vessel Svanen [source (“Vesselfinder.com,” 2020)*]*

Feeder barges or tug vessels towing the monopiles would be required to deliver the foundations to the heavy lift vessel. A smaller lift vessel the Rambiz was used to lift the WECs onto the monopiles.

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Table 4: Vessel Characteristics

Name	VesselType	Travel_speed (knots)	Max_Hs_transit (m)	Max_Hs_posit (m)	Max_Uw_posit (m/s)
Isaac NewtonIAC	CableLaying	12.5	3.6	2.4	19.2
Rambiz	Installation	5	1.5	1.5	8
Multicat tugs (2) a	Tug	4.5	2	2	16
Svanen	Installation	7	3	2	16

Name	PositionTime (hrs)	DePositionTime (hrs)	Fuel_consump_transit (tonne/hr)	Fuel_consump_stationary (tonne/hr)	Fuel_cost (€/tonne)
Isaac NewtonIAC	2.5	2.5	1.8	0.45	640
Rambiz	4	4	1.8	0.45	500
Multicat tugs (2) a	2.5	2.5	1	0.25	640
Svanen	2.5	2.5	2	0.5	640

Name	Mobilisation/Demobilisation cost (€)	Operational day rate (€)	Day rate at port (€)	MaintenanceInterval (hrs)	MaintenanceDuration (hrs)
Isaac NewtonIAC	3.60E+05	180,000	180,000	504	72
Rambiz	120,000	60,000	60,000	504	72
Multicat tugs (2) a	50000	25,000	25000	168	72
Svanen	360,000	180,000	180,000	504	72

4.2.1

Monopile Results

Table 5: Installation results for the monopile scenario

Total installation costs	euro	€172,842,674
Total survey & monitoring costs	euro	€ -
Total port costs	euro	€3,869,969
Total project management costs	euro	€29,717,951
WEC only	euro	€33,266,216
Foundation only	euro	€108,301,291
Export cabling only	euro	€28,271,922
Inter-array cabling only	euro	€1,601,860
Earliest installation start date	ddmmyyyy	01/05/2021
Latest installation start date	ddmmyyyy	02/05/2021
Earliest installation end date	ddmmyyyy	25/07/2022
Latest installation end date	ddmmyyyy	06/06/2028
Average time	days	1316
Seabed prep	days	272
Foundations	days	552
WECs	days	544
Export cable	days	152

Average Installation cost is 172 million euros, of which the monopiles, WECs and export cable constitute 108, 33 and 28 million respectively. The average installation time is 1316 days. The foundations requiring the most expensive vessel make up by the far the greatest cost of the installation.

4.3 INSTALLATION MODEL FLOATING

Anchor Handling Tugs were assigned to carry out the seabed preparation for the mooring connecting points. Once the seabed is prepared the CycWEC device (and it's jack up legs foundation) are towed to site using conventional vessels. Each device was assigned two multicat tugs at a dayrate of €12,500 per tug. This is a slightly higher estimate (as well as an additional vessel) than that used for the Pelamis device of approx. €5,000 (Gray et al 2017). This estimate was chosen to be on the conservative side as while the Pelamis was a heavy device, it had a shape and draft that was conducive to towing. It is assumed for now that additional effort is required for the CycWEC device.

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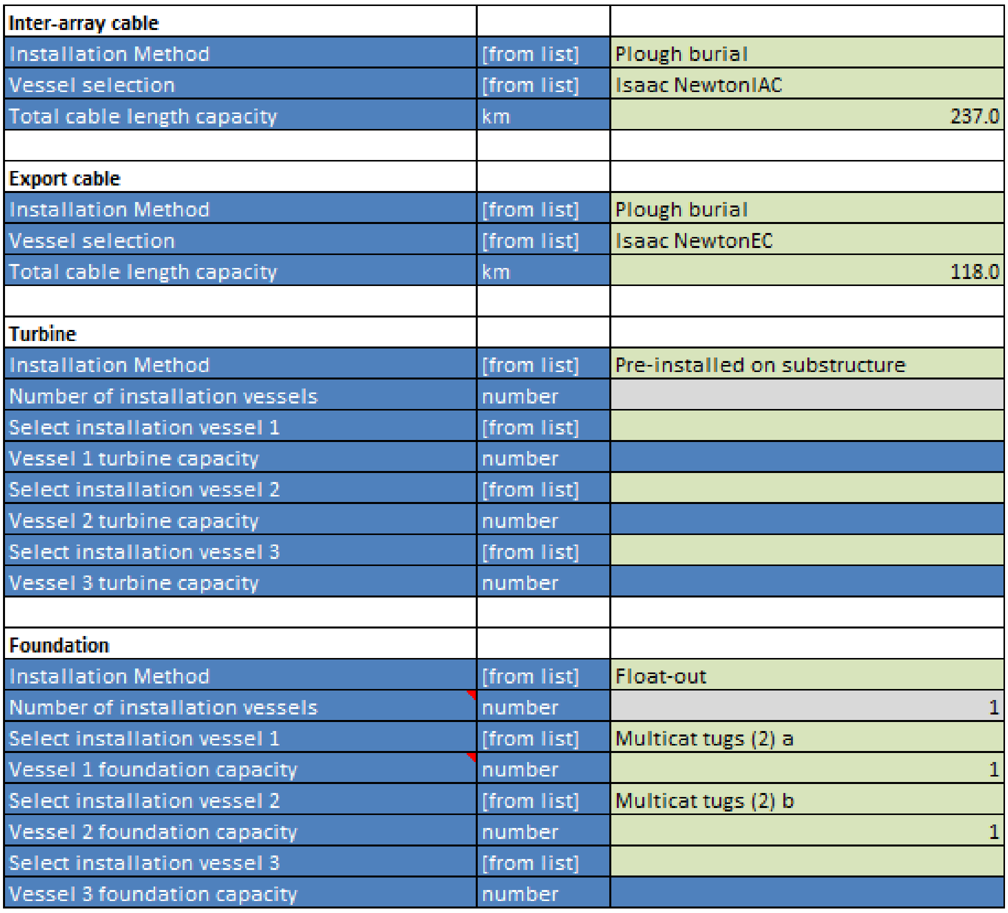

Inter-array cable		
Installation Method	[from list]	Plough burial
Vessel selection	[from list]	Isaac NewtonIAC
Total cable length capacity	km	237.0
Export cable		
Installation Method	[from list]	Plough burial
Vessel selection	[from list]	Isaac NewtonEC
Total cable length capacity	km	118.0
Turbine		
Installation Method	[from list]	Pre-installed on substructure
Number of installation vessels	number	
Select installation vessel 1	[from list]	
Vessel 1 turbine capacity	number	
Select installation vessel 2	[from list]	
Vessel 2 turbine capacity	number	
Select installation vessel 3	[from list]	
Vessel 3 turbine capacity	number	
Foundation		
Installation Method	[from list]	Float-out
Number of installation vessels	number	1
Select installation vessel 1	[from list]	Multicat tugs (2) a
Vessel 1 foundation capacity	number	1
Select installation vessel 2	[from list]	Multicat tugs (2) b
Vessel 2 foundation capacity	number	1
Select installation vessel 3	[from list]	
Vessel 3 foundation capacity	number	

Figure 4-2: Installation details for floating configuration

4.3.1 Floating Results

Average Installation cost is 93 million euros. However the combined cost of towing the Jack-up legs (foundation) and WECs is vastly reduced to 10 million euros. The main proportion of installation cost for this configuration is in seabed preparation at 53 million euros. This is the work required to prepare the seabed for the jack-up legs to connect to. Expensive Anchor Handling Tugs were assigned to do this task. The model is conservatively using 12 hours per mooring connection (8 hours per anchor point might achievable as in floating wind) for a total of 48 hours per device. The code is not currently built to allow for individual anchors i.e. installing one or two in a window, so this seabed preparation figure can be revised downward in future model estimates. Additionally, as no seabed preparation time was assumed for the monopile (dense sandy seabed), this may not be comparing like with like. Certainly, seabed preparation for this configuration must be considered, however this estimation is on the conservative side, until more information is acquired and the installation model is improved upon. The average installation time is 424 days, which is approximately one third that for the monopile.

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Table 6:Installation results for the CycWEC float out scenario

Total installation costs	euro	€ 93,070,708
Seabed prep only	euro	€ 53,658,934
WEC only	euro	€ -
Foundation only	euro	€ 10,310,137
Export cabling only	euro	€ 26,930,186
Inter-array cabling only	euro	€ 2,037,618
Earliest installation start date	ddmmyyyy	30/04/2021
Latest installation start date	ddmmyyyy	01/05/2021
Earliest installation end date	ddmmyyyy	10/07/2021
Latest installation end date	ddmmyyyy	10/05/2025
Average time	days	424
Seabed prep	days	243
Foundations	days	283
WECs	days	0
Export cable	days	141
Inter-array cable	days	9

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5 INSTALLATION SENSITIVITY ANALYSIS

Sensitivity analysis is performed to confirm the models are working as expected and to determine the impact of key model assumptions on results. The floating CycWEC was used as the base case scenario before altering certain input parameters. For example the figure below shows the percentage change to installation cost when the number of WECs installed is change from the base case of 20 devices. A ~15 % reduction in cost (85% of base case installation cost) can be found if the total number of installed WECs was reduced to 10 devices, while a ~20 % increase is associated with increasing the number of WECS to 30. The installation costs referred to, is purely the vessels technicians, etc required to carry out the installation. This does not include the dry CAPEX costs associated with increase the number of WECs. The fact that a 50% reduction in the number WECs, only yields a 15% reduction in installation costs is indictive of the weather window problem. i.e. expenditure on vessels stuck at port is a significant feature for all scenarios tested.

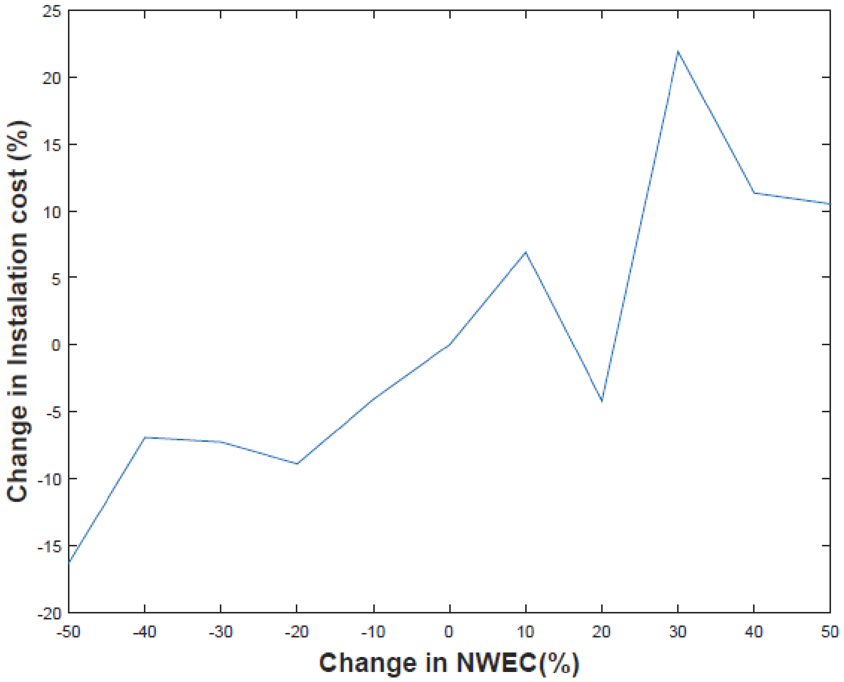

Figure 5-1 Installation module sensitivity analysis: Percentage change in installation costs versus changes to the number of WECs installed

There exists some oscillation in the graph which is likely due to the relatively low number of Monte Carlo simulations run (50) for each case study. As can be seen below the total cost is directly proportional to the total installation time. These minor fluctuations (e.g 28 WECs being cheaper 26) are a result of insufficient number of Monte Carlo simulations (several of the 50 simulations received better than average weather conditions) and would correct themselves if a larger number of simulations were run for each different scenario. From previous experience convergences occurs closer to 1000 simulations although this is a time consuming task for each variation that can be made.

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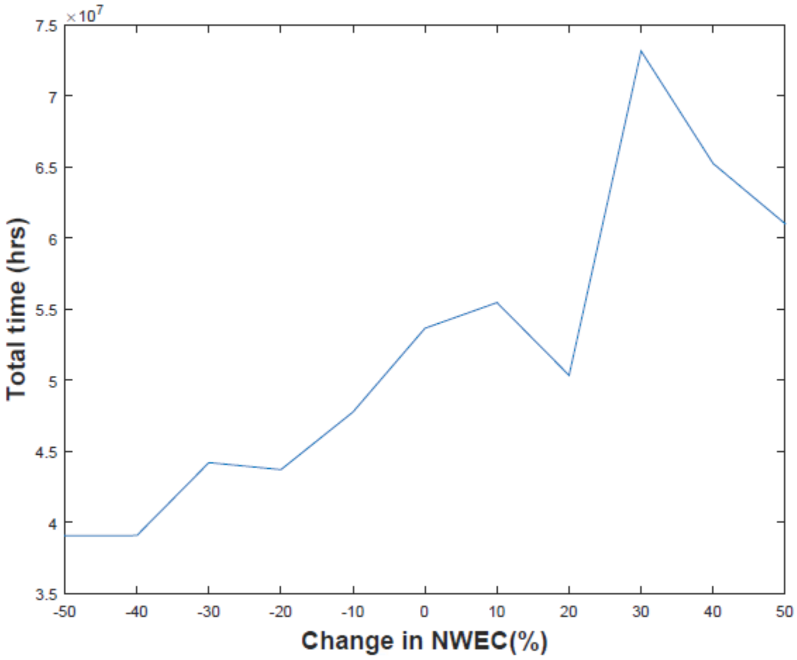

Figure 5-2: Change in installation time (hours) versus changes to the number of WECs installed

Figure 5-3 shows the change in installation cost when changes ae made universally to allowable Hs limits. If the limits could be pushed out by 100%, allowing operations in rougher seas then an approximately 60% reduction in installation cost could be achieved. If the Hs limits are further reduced however, the installation becomes more expensive until a point is reached where there are insufficient weather windows to complete the installation. This reveals the importance of weather windows for all phases of development.

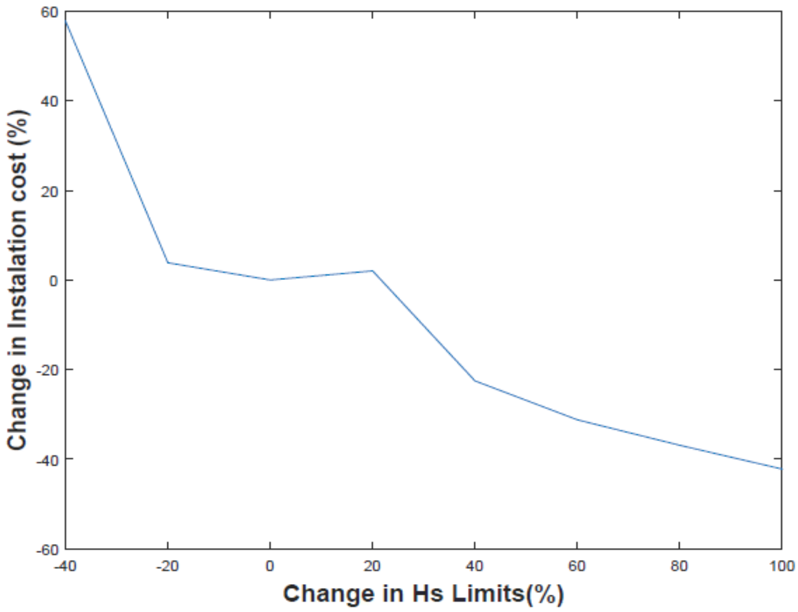

Figure 5-3:Change in float out installation cost versus changes to the allowable Hs limits

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6 OPERATIONS & MAINTENANCE

6.1 O&M CATEGORIES

6.1.1 Minor repair & Inspection

Surface Access Fixed Structure

Th possibility of accessing the device for inspection as well as minor repair work would be advantageous, however it must be done with safety paramount. Standard Crew Transfer Vehicles (CTV) can generally access a fixed structure in Hs less than 1.5m (although some operators claim 2m Hs is possible). From a special access gangway (with some degree of motion compensation) deployed from a Service Offshore Vehicle SOV, 2m Hs is standard with 2.5 m probable (Shenton, 2016) (and claims of up to 4m!). One must be careful with developer claims however and it's best to wait until the technologies/methods have been demonstrated although the benefits of higher limits can certainly be accounted for in models. It is also worth noting that the majority of access relating research is related to offshore wind which are generally in more benign sites that wave farms.

Surface Access Floating Structure

Surface access to a floating structure is naturally far riskier than to a fixed structure. Although some floating wind structures may allow for surface access if the relative motion between the floating platform and access vessels are beneath a safe limit: floating wind devices are large platforms designed to dampen platform motions and generally placed in less energetic sites that wave devices. It may be the case that the proposed chevron configuration (being of sufficiently large surface area) might allow for some degree of access. In addition to accessibility, there is also the issue of workability, that is whether a human operator can carry out their duties whilst subjected to the motions of the structure. Scheu, et al (2018) note that low frequency motions (<1 Hz) are conducive towards sea sickness. Ultimately however, as shown from the weather window analysis, the type of low Hs sea states that would be required (even if access could be safely performed) are few and far between, meaning that this approach would lead to a bottleneck in achievable O&M operations. It is not recommended to pursue the option of surface access to floating wave platforms until it has a proven track record.

6.1.2 Major Repair :Tow Back or Lift

While broadly similar categories of using smaller towing vessels or larger heavy lift vessels, exist for O&M, there are some significant differences. For example the two configurations discussed previously (and shown side by side in the figure below) share strategies of being raised above the water level for inspection and minor maintenance. When it comes issue of major maintenance/repair the configurations will have very different costs due to heavy lift and tow back strategy respectively. Due to heavy lift operations requiring much calmer seas (as well far more expensive vessels), this approach will incur significantly more O&M costs

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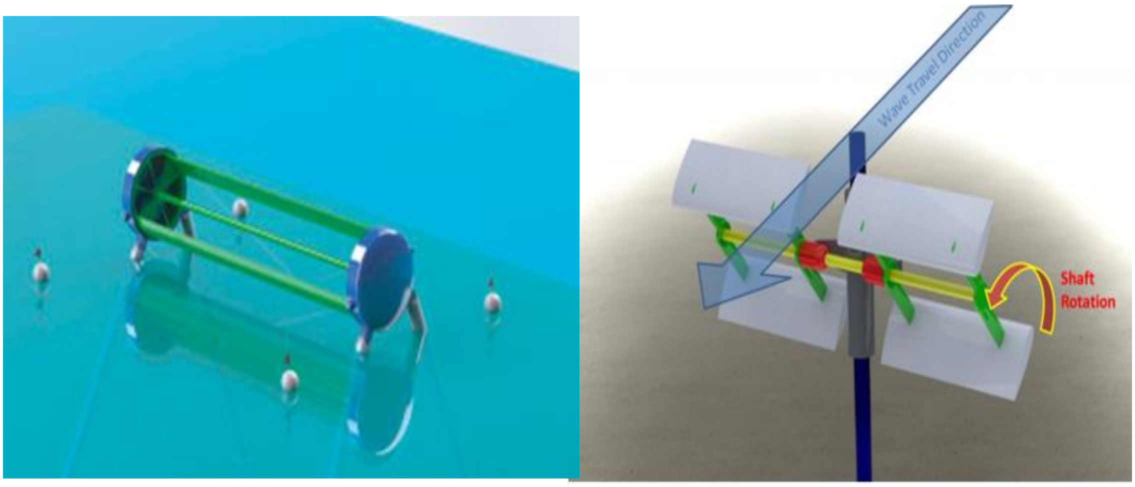

Unfortunately due to delays in developing the O&M expert tool, as well as persisting issues with tow back O&M (version 1 was not explicitly set up for onshore maintenance). It is not currently possible to quantitively estimate OPEX differences between configurations.

7 DISCUSSION AND CONCLUSION

Installation scenarios were run for a fixed foundation monopile:a device requiring heavy lifting operations as well a scenario where the WEC and foundation could be towed to site. It has been shown that the heavy lift scenario would take a longer time to install and incur significant increases in cost when compared to the float out installation. The figures quoted for the installation should be considered indictive results. It's highly likely the figures could be reduced with some optimisation. This is a multiparameter problem but the most important being the number of days the vessel is chartered for. Naturally every effort would be made to reduce downtime by selecting suitable installation windows (bearing in mind that these summer windows will be shared by the majority of other offshore work, meaning market forces limit flexibility). The proposed site is by design relatively energetic, meaning there will be downtime while waiting for weather windows. During this downtime expenditure could be x €/day for a conventional tug or 20-50 x for a larger vessel.

The results of the installation study, nevertheless, show that using tow out vessels is vastly cheaper than using expensive heavy lift vessels. This is line with the current wisdom/design approach. The crux of the matter lies in vessel charter costs. It's also worth noting that if considering a wind farm: the sea depth at the site location (50m) is at the transition point between fixed and floating options, with floating expected to be more cost effective. While it might be possible to install an extra large fixed structure for a wind turbine. The rational for doing so, would be that since the turbine could be +10MW, the payoff in energy harvest might justify the expense. This is not likely to be the case for a WEC with a much lower MW capacity.

The CycWEC type device has the benefit of surface access for O&M and would therefore benefit from the technologies and lessons learned from fixed offshore wind O&M (although the wave farm is likely to be more energetic than a wind farm by design). This would allow relatively cheap crew transfer vehicles (CTVs) to be deployed from the nearest service port. It must be remembered however that this reduced O&M costs comes at a cost of a large increase in CAPEX costs of the CycWEC devices. Each device can be considered a jack-up vessel: vessels which are usually chartered (or if possible shared between wind farms to reduce cost). A 100MW farm consisting of twenty 5MW CycWEC devices is likely to induce a large CAPEX cost. It remains to be determined whether the expected in reduction in OPEX cost would justify the increased CAPEX for the CycWEC configuration.

While the CycWEC configuration can be thought of as floating setup with solid mooring lines, several LiftWEC configuration propose standard floating mooring arrangements. Whether a floating support system can meet the demands of station keeping, load shedding and storm survival etc remains to be evaluated. From the marine based lifecycle activities considered within this report it would suggest that towing operations are greatly preferably compared to costly configurations that require heavy lift vessles. This is in accordance with the recent design philosophies of offshore renewables, avoiding expensive (and scarce) lifting vessels in preference for conventual vessels.

Indeed even if the LiftWEC foundation required a fixed support structure (incurring additional CAPEX cost) it would be greatly preferable if the WEC had some form of quick release/plug and play element from its foundation such that cheaper O&M techniques could be used. This would be attempting to rationalise/tolerate an increased installation cost, if it were possible to borrow from floating configurations features, for a reduced OPEX cost.

While more quantitative work is required for the O&M phase of operations, early indicators would seem to suggest that configurations using tow out/back strategies are preferable for the selected site. Future work should lead to more conclusiveness in this matter. Another way of reducing OPEX is to reduce where possible it’s instances in the first place.

The combination of reliability and fault tolerance is key to achieving reliable operation and high levels of availability for power production in the hostile marine environment and minimizes the need for and frequency of maintenance interventions (Yemm et al., 2012).

The design philosophy’s for OPEX could therefore be summarised as follows;

- Reduce the instances when maintenance is required by using reliable components, redundant and fault tolerant designs combined with an effective preventative maintenance strategy
- In the instances where maintenance is required: Use methodologies that allow operations to be (safely) carried out, in higher Hs sea states such that weather window numbers are improved, reducing downtime.
- In the instances where maintenance is required: Reduce the time out at sea through quick release mechanism and modular “plug and play” components.

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