LiftWEC

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

Deliverable D7.4
Assessment of Baseline Configurations

Deliverable Lead	University College Cork
Delivery Date	8th August 2022
Dissemination Level	Public
Status	Final
Version	2.0

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 851885. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

Document Information

Project Acronym	LiftWEC
Project Title	Development of a new class of wave energy converter based on hydrodynamic lift forces
Grant Agreement Number	851885
Work Package	WP7
Related Task(s)	T7.2, T7.3, T7.4, T7.5
Deliverable Number	D7.4
Deliverable Name	Assessment of Baseline Configurations
Due Date	30th November 2021
Date Delivered	8th August 2022
Primary Author(s)	Fiona Devoy McAuliffe (UCC)
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Document Number	LW-D07-04

Version Control

Revision	Date	Description	Prepared By	Checked By
1.0	29/07/2022	Draft released for internal consortium review	FDM	MF
2.0	08/08/2022	Final version for release	FDM	MF

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EXECUTIVE SUMMARY

The purpose of this deliverable is to take a closer look at the potential energy production, installation and OPEX costs for each configuration. The deliverable uses an installation (module of the EU FP7 LEANWIND Financial model) and O&M model (ORE Logistics tool) developed in UCC and further adapted for the LiftWEC project where needed. Programmed in Matlab using Excel input and output files, these operate running Monte Carlo simulations of a scenario against a time series of Metocean data. The models average results, determining the impact of uncertain weather conditions and failure rates on the installation and OPEX costs; installation time; and device power production.

When reviewing results, it is important to remember that these are estimates, without specific tested data and offshore experience for the LiftWEC device. Further information and testing are required to increase confidence in the figures. However, the deliverable is extremely useful as a comparison of the 4 baseline configurations and potential areas for improvement. Where relevant, sensitivity analysis is undertaken, identifying key bottlenecks that may be preventing these baseline designs from achieving their potential and economic targets.

The base case scenario examines the 4 configurations as part of a 20 x 1.25MW array at the Ifremer site considering the installation and O&M over a 25-year project lifetime. Extremely low availability figures indicated that the selected case study site is extremely challenging to access resulting in a) relatively long installation for 20 devices and high costs and b) low energy production during the project lifetime due to difficulties accessing devices to repair them. Sensitivity analysis verified the need to increase the weather windows available and other potential areas that could improve results including increasing the number of vessels available; reducing operation durations; and reducing failure rates.

Based on this analysis, optimised scenarios were developed for each configuration assuming the 25MW array was a first or second deployment, benefiting from learned and technical advances from previous pilot projects (single device). Results are summarised in the following table, which highlights key results in grey from light to dark in order of preference to help illustrate which configuration proves most advantageous.

Parameter	Unit	Tower	TLP	Semi-sub	Spar
Installation					
Total installation cost	Euro	**105,441,432**	**46,732,325**	**29,280,845**	**27,289,525**
Average time	years	**2.62**	**1.69**	**1.54**	**1.47**
O&M					
Total farm energy production	MWh	**1,428,849**	**1,373,717**	**1,308,553**	**1,401,953**
Total O&M project costs	Euro	**55,251,880**	**17,080,054**	**8,228,974**	**11,507,477**
Availability	%	**82%**	**83%**	**81%**	**85%**
Capacity factor	%	**26%**	**25%**	**24%**	**26%**

The Spar LiftWEC results in the lowest installation costs and time; the second lowest O&M and second highest power production; with the highest availability and capacity factor. This is due to the use of

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smaller, cheaper vessels to deploy and retrieve the device as well as having a simple connection/disconnection procedure that requires minimal time offshore and can be done at higher weather restrictions. Based on the scenarios run in this deliverable, the Spar LiftWEC configuration has the most advantages and likely to produce the lowest LCoE of the 4 configurations.

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1 INTRODUCTION

The Offshore Renewable Energy (ORE) Strategy released by the European Commission in November 2020 European Commission sets a goal of 60GW offshore wind energy capacity and 1GW of ocean (wave and tidal) capacity by 2030. This increases to 300GW and 40GW respectively by 2050. (European Commission, 2020). With no convergence or commercially proven wave energy technology, this will be an extremely difficult task.

The LiftWEC project is developing a new type of wave energy converter (the LiftWEC concept) that couples with the waves through lift forces generated by one or more hydrofoils that rotate in a single direction. While currently at TRL3, LiftWEC is expected to reach TRL 4 by the end of the project. The project is seeking to prove an LCoE of 200EUR/MWh mid-way through the project (TRL3) and 120EUR/MWh by the end of the project (TRL4) considering a commercial version of the LiftWEC concept that is designed to work in wave energy farms and supply electricity at grid-scale. LCoE goals are in line with the European strategic energy technology plan (SET-Plan), which expects wave energy technologies to reach a Levelised Cost of Energy (LCoE) of 200 EUR/MWh in 2025, of 150 EUR/MWh in 2030 and of 100 EUR/MWh in 2035. (European Commission SET Plan Secretariat, 2016).

(Têtu & Chozas, 2021) performed a reverse calculation to obtain ranges for the CAPEX and OPEX of the concept as illustrated below in Figure 1.1.

Parameter	Symbol	Value in Mid-Term Project	Value in End-of-Project	Unit
Capacity factor	C_f	30	35	%
Availability	$a_{\%}$	95	98	%
Discount rate	r	5	5	%
Lifetime	n	25	25	year
Annualisation factor	A_f	0.0696	0.06968	-
Annual energy production	AEP	2.50	2.98	MWh/kW/year
Capital expenditures	CAPEX	4200	3800	EUR/kW
Operational expenditures	OPEX	210	95	EUR/kW/year
Levelised cost of energy	LCoE	200	120	EUR/MWh

Figure 1.1 LiftWEC economic targets

WP8 are conducting LCoE analysis, most recently assessing the LCoE for 4 baseline configurations in (Chozas, Nielsen, & Pascal, 2022). The purpose of this deliverable is to take a closer look at the potential energy production, OPEX and installation costs for each configuration, running detailed Monte Carlo simulation tools against hourly time series data to provide estimated figures. Where relevant, it will also undertake sensitivity analysis, identifying key bottlenecks that may be preventing these baseline designs from achieving their potential and economic targets.

When reviewing results, it is important to remember that these are estimates, without specific tested data and offshore experience for the LiftWEC device. Further information and testing are required to increase confidence in the figures. However, the deliverable is extremely useful as a comparison of the 4 baseline configurations and potential areas for improvement.

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2 SIMULATION MODELS

2.1 INSTALLATION MODEL

2.1.1 Overview

The installation model was originally developed as a module of the EU FP7 LEANWIND project financial tool to assess the energy production and costs of offshore wind farms. This model is considered suitable to assess the installation of any offshore construction project including wind, wave or tidal energy farms. Details of the installation model and validation exercises are available in (McAuliffe, et al., 2018) (Judge, et al., 2019). It was also described in D7.2 (Flannery, D7.2 Development of Models and Operations Framework, 2020) and is summarised below.

The user specifies a substructure (fixed of floating); device; inner array and export cabling; and a substation (if relevant), inputting the duration and weather restrictions of the operations required to install each element. This can include a separate seabed preparation task prior to installing any substructure/moorings and anchors. The user can detail the operational abilities and weather restrictions for up to 3 vessels for each element, although only 1 vessel each can be specified for export and inner array cabling. The user inputs a minimum of 10 years hourly time-series Metocean data for the selected site, considering mean wind speed (m/s) and significant wave height (Hs) (m). The model will then undertake Monte Carlo simulations, bootstrapping randomly selected years of Metocean data to create different weather conditions per simulations. It will create an activity list of the elements that require installation in order of priority, for example, substructure, before device etc. Currently it is assumed that inner array cabling will begin being installed once 10 fixed devices or 1 floating device has been installed on site. The substation and export cabling are the final elements to be installed. This assumption is based on observation of real-life offshore wind farm installation activities validated in the referenced articles. There has been limited real-life deployment of wave farms and so the experience from offshore wind farms is considered to be the most relevant in this case. The average installation time and breakdown of costs is produced.

While originally developed for offshore wind, the installation model can be used to simulate the installation of any offshore structure. Therefore, no significant modifications were needed to assess the 4 baseline configurations.

2.1.2 Key assumptions and limitations

There are a few key assumptions and limitations of the installation model that must be considered when reviewing results.

The first limitation is that not all operations can be separated in the model as they would be in real life. For example, a device or devices are being towed to site using tugs and/or barges. There, a crane vessel will complete installation while the tugs/barge may transit to and from shore feeding devices to the crane vessel that remains onsite. However, the model will currently have to deploy these as one vessel that remains onsite until the installation of that consignment of device(s) is completed.

For cabling, the installation model assumes that inner array cabling installation can commence after the 10 devices are installed if they are floated out while the export cable is not installed until the final

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device. This is based on examination of installation patterns in offshore wind projects but should be subject to further consideration and refinement of the model assumptions.

2.2 OM EXPERT

Originally OM Expert was developed as part of the SFI Funded EirWind project (https://www.marei.ie/project/eirwind/) and was intended to be adapted and applied for LiftWEC. While the original model was designed for offshore wind, a wave version has been successfully developed. The model is detailed in D7.2 (Flannery, D7.2 Development of Models and Operations Framework, 2020). However, during the adaptation process, several issues arose in terms of coding bugs and unclear results. Owing to the type of software and platform, this model would have required more time than anticipated with a software developer to fix and ensure confidence in the results. Therefore, it was decided to use a different O&M model, developed in Matlab and in tandem with the wave version of O&M expert, utilising the lessons learned in OM Expert and other projects occurring at this time. This was done as a back-up to allow internal staff to de-bug and run the model as well as further develop more detailed scenarios, specific to the LiftWEC project. We will hereto refer to this as the ORE Logistics tool and a summary is included below in section 2.3.1.

2.3 OFFSHORE RENEWABLE ENERGY (ORE) LOGISTICS TOOL

The ORE logistics tool is developed in Matlab with excel input and output files. It operates in a very similar way to OM Expert, although includes additional features and flexibility while paring back other aspects. The following section outlines the different inputs, features and limitations of the model.

2.3.1 Overview

In summary, the ORE logistics tool uses Monte Carlo simulation to consider the uncertain factors of weather and failure rates, randomizing these for each iteration to produce an average estimate of power production, costs, availability and capacity factor. It then simulates a wave energy farm lifecycle including device energy production, which is interrupted when a failure occurs, or Preventive Maintenance is required. The model must then assign resources to maintain or fix a device, including vessels and technicians from a specified base.

2.3.2 Metocean data

The user inputs a time series of Metocean data that can be sorted into a specific format by a standalone Matlab programme.

2.3.3 Power production

The user must specify the device power matrix in MW. The model will track the potential power production of the device for each simulation as well as the actual production, considering failures and maintenance operations. The power matrix used for this analysis is provided in Figure 2.1.

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Device name	CycWEC	Hs/Tp										
Rating (MW)	1.25											
Power Matrix												
Significant wave height Hs (m)												
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05
1.00	0.00	0.00	0.00	0.09	0.12	0.14	0.14	0.13	0.13	0.12	0.12	0.12
1.50	0.00	0.00	0.13	0.21	0.24	0.27	0.26	0.24	0.22	0.21	0.20	0.20
2.00	0.00	0.00	0.27	0.36	0.41	0.42	0.41	0.37	0.34	0.31	0.29	0.28
2.50	0.00	0.00	0.44	0.55	0.60	0.60	0.57	0.51	0.45	0.41	0.38	0.36
3.00	0.00	0.35	0.63	0.77	0.81	0.79	0.74	0.65	0.57	0.51	0.47	0.44
3.50	0.00	0.51	0.85	1.01	1.03	0.99	0.91	0.79	0.69	0.61	0.56	0.52
4.00	0.00	0.69	1.02	1.16	1.21	1.18	1.08	0.93	0.80	0.72	0.65	0.61
4.50	0.31	0.83	1.14	1.21	1.23	1.23	1.22	1.07	0.92	0.82	0.74	0.69
5.00	0.44	0.91	1.22	1.21	1.21	1.23	1.22	1.19	1.04	0.92	0.83	0.77
5.50	0.59	0.99	1.20	1.20	1.22	1.23	1.22	1.23	1.16	1.02	0.92	0.85
6.00	0.74	1.09	1.21	1.19	1.18	1.23	1.23	1.22	1.23	1.12	1.01	0.93
	4	5	6	7	8	9	10	11	12	13	14	15
	Mean wave period Tp/Te (s)											

Figure 2.1 Power Matrix input form[1]

2.3.4 Failures and Corrective Maintenance (CM)

Similarly to OM Expert, the user can specify a number of different repair categories. These detail different repair scenarios including whether it is on/offshore, the operation duration (on/offshore), the operation weather restrictions (for example, max Hs and wind speed), the vessel and number of technicians required and the base the vessel will come from for this repair. The user can also associate a percentage power loss when failure occurs until it is repaired.

As indicated above, the user can specify whether a task can be undertaken onshore or offshore. If it is the latter, they can detail the operation duration required to retrieve/redeploy the device and onshore maintenance. This will be undertaken as 3 separate operations. Power loss will be 100% when a device is retrieved until it has been deployed again. An example of a Repair Category input is shown in Figure 2.2.

Field	Repair Category	Task description	No. of technicians required	Vessel required	Base	Operation location	Operation duration offshore	Operation duration onshore	Wave height limit for repair operation offshore	Wave period limit for operation offshore	Wind speed limit for repair operation offshore	Current velocity limit for repair operation offshore	Power loss
Unit	text	text	integer	select	select	select	hrs	hrs	m	s	m/s	m/s	%
Description	Name of repair	Additional details of repair (reference only)	No. of technicians required to carry out the operation.	To specfiy details under vessels/equipment	Select base the vessel comes from and/or repair occurs	Does the repair take place offshore or must the device be towed to shore for maintenance	Operation duration offshore e.g. if operation onshore this could represent the time required to detach the device to tow to shore	Operation duration onshore if applicable	This is a general wave height limit for completing operation offshore	This is a general wave period limit for completing operation offshore	General wind speed limit for completing operation offshore	General current velocity limit for completing operation offshore	Power loss when CM is being undertaken i.e. if the device is fully stopped until the repair is complete, the power loss is 100 %
Data limits	Min 1 - max 200	Min 0 - max 200	Min 0 - max 100	Dropdown list	Dropdown list	Dropdown list	Min 0.00 - max 1000.00	Min 0.00 - max 1000.00	Min 0.00 - max 100.00	Min 0.00 - max 100.00	Min 0.00 - max 100.00	Min 0.00 - max 100.00	Min 0 - max 100%
Input	Type 1		0	2 Tugs & 2 divers	Port O&M	Onshore	1.6	57.6	2.5	11	16	30	0%
Input	Type2		0	2 Tugs & 2 divers	Port O&M	Onshore	1.6	38.4	2.5	11	16	30	0%

Figure 2.2 Repair Category input

The user must also detail the different components of the farm that may experience failures, associating an annual failure rate and a repair category required to fix the issue based on the list previously input. They can also specify a repair cost, for example, spare parts or consumables. An example of Component input is shown in Figure 2.3. The decision to make a repair category list was made based on OM Expert as we found that often the same operation was required to address similar

[11] Note the additional zeros are due to the format of the power matrix input file.

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failures. Therefore, this reduces the number of inputs required since the user can just link the same repair category to multiple component failures.

Field	Component name	Number per device	Annual failure rate	Repair Category	Spare parts/consumables costs
Unit	text	integer	integer	select	€
Description	Name of component	Number of components on each device	Annual failure rate of component. E.g. if the component is expected to fail once in five years, the annual failure rate is 0.2.	Apply a repair defined in the previous section to the component	Cost of spares/consumables necessary for operation
Data limits	Min 1 - max 200	Min 1 - max 10	Min 0.01 - max 100.00	Dropdown list	Min 0 - max 1000000000
Input	Major structure (no warning)	1	0.04992	Type 7	45000
Input	Electrical unions/tieback	1	0.03168	Type 10	30000
Input	Minor sealing	1	0.152	Type2	3000
Input	Minor structural	1	0.020968	Type2	3000
Input	Minor primary hydraulic	1	0.75	Type3	1150
Input	Secondary hydraulic	1	0.18048	Type4	3500
Input	Generator or switchgear	1	0.03168	Type4	3500
Input	Half circuit failure	1	0.288	Type5	3000
Input	Control system	1	0.20832	Type5	3000
Input	Major sealing	1	0.025392	Type6	3000
Input	Major structural failure (idenitified through monitoring system)	1	0.024136	Type 8	35000
Input	Minor mooring	1	0.026968	Type 1	7500
Input	Major mooring	1	0.012752	Type 9	50000

Figure 2.3 Component inputs (displayed input based on (Gray, Dickens, BruceIan, Ashton, & Johanning, 2017))

2.3.5 Preventive maintenance (PM)

The user can also specify a Preventive Maintenance scenario, although currently this will not have any impact on the reliability of the device. Preventive maintenance should prevent failures from occurring to some extent by keeping the device in good repair. However, this is very difficult to model as there is no data or experience to establish a base case scenario. Up to 4 maintenance tasks can be specified in order of priority, for example, if you wish to undertake a half-life refit then this should go above an annual service as the model will then prioritise the refit and cancel the annual maintenance. The same details must be input for each PM task as for each repair category and component i.e. the operation location, duration, weather restrictions etc. but the frequency of annual occurrence rather than an annual failure rate. An example of a Preventative Maintenance task input is shown in Figure 2.4.

Field	PM category	Task description	No. of technicians required	Vessel required	Base	Frequency	Operation location	Operation duration offshore	Operation duration onshore	Wave height limit for PM operation offshore	Wave period limit for operation offshore	Wind speed limit for PM operation offshore	Current velocity limit for PM operation offshore	Power loss	Spare part/consumables cost
Unit	text	text	integer	select	select	integer	select	hrs	hrs	m	s	m/s	m/s	%	€
Description	Name of Preventive Maintenance Activity	Additional details of repair (for reference only)	No. of technicians required to carry out the operation.	To specfiy details under vessels/equipment	Select base the vessel comes from and/or repair occurs	Specify frequency of PM task per year.	Does the operation take place offshore or must the device be towed to shore for maintenance	Operation duration offshore e.g. if operation onshore this could represent the time required to detach the device to tow to shore	Operation duration onshore if applicable	This is a general wave height limit for completing PM	This is a general wave period limit for completing PM	General wind speed limit for completing PM	General current velocity limit for completing PM	Power loss when PM is being undertaken i.e. if the device is fully stopped until the repair is complete, the power loss is 100 %	Cost of any spare parts/consumables necessary for operation
Data limits	Min 1 - max 200	Min 0 - max 200	Min 0 - max 100	Dropdown list	Dropdown list	Min 0.01 - max 100.00	Dropdown list	Min 0.00 - max 1000.00	Min 0.00 - max 1000.00	Min 0.00 - max 100.00	Min 0.00 - max 100.00	Min 0.00 - max 100.00	Min 0.00 - max 100.00	Min 0 - max 100%	Min 0 - max 1000000000
Input															

Figure 2.4 Preventive Maintenance task inputs

2.3.6 Resources (vessels and technicians) and bases

Building in additional flexibility when compared to OM Expert, the user can specify up to six different vessel types and bases (ports or offshore bases). Multiple vessels of the same type can be made available, and the user can indicate whether a vessel can undertake nightwork (operate 24/7) or not (only operates in daylight hours, which the model currently assumes is from hours 7am-7pm). A vessel can be purchased (with an annual running cost) or rented (with an annual rental season during which it is available, a daily rental cost and mobilisation/demobilisation fee). An example of the Vessel inputs is shown in Figure 2.5.

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Field	Vessel classification	Number	Technician capacity	Night work	Purchased/rented	Annual running cost	Annual rental start month	Annual rental end month	Daily rental cost	Mobilisation cost	Fuel consumption	Fuel cost	Speed
Unit	text	integer	integer	select	select	€	select	select	€	€	l/hr	€/l	knots
Description	Vessel type	Number of vessels of this type available	Number of technicians vessel can carry	Can vessel undertake work at night *(only O&M model)*	Specify whether vessel is purchased or chartered	If purchased, annual cost of maintaining vessel	If rented, month that rental starts each year	If rented, month that rental ends each year	Daily cost of renting vessel	Cost of mobilising vessel if rented	Vessel fuel consumption	Cost per litre	Vessel transit speed
Data limits	Min 1 - max 200 characters	Min 1 - max 10	Min 1 - max 1000	Dropdown list	Dropdown list	Min 0 - max 1000000000	Dropdown list	Dropdown list	Min 0 - max 1000000000	Min 0 - max 1000000000	Min 0.00 - max 100000.00	Min 0.00 - max 1000000.00	Min 0.01 - max 1000.00
Input	CTV	1	12	No	Rented	0	Jan	Dec	2000	4000	0	0	30

Figure 2.5 Vessel inputs

For each maintenance task, the user can specify which vessel is needed and which base a vessel will travel from for that activity. The user specifies the number of technicians available for a task by inputting the number available and their annual salary at a given base. An annual base cost and distance to farm is also input as illustrated in Figure 2.6.

Field	Base name	Annual cost	Distance to farm	Number of technicians	Annual salary per technician
Unit	Text	€	km	integer	€
Description	Name of base	Annual cost associated with maintaining/leasing an onshore base	Distance of the base to the wind farm. Used to calculate vessel transit times.	Number of full-time technicians employed at the base available to carry out repairs.	Used to calculate the cost of technicians.
Data limits	Min 1 - max 200 characters	Min 0 - max 10000000000	Min 0.00 - max 1000.00	Min 0 - max 10000	Min 0 - max 1000000
Input	Port installation	0	50	100	0
Input	Port O&M	0	20	100	0

Figure 2.6 Base and technician inputs

2.3.7 Processing

For each simulation, the model will "boot-strap" random years of data together to create a project lifetime, for example, 25 years. It will then create a list of PM tasks and an initial list of repair tasks for each component specified by the user based on the failure rates and randomised using a normal distribution curve within a 10% standard deviation. During processing, if a failure on a device has been fixed, the model checks to see if another failure of this type might occur within the project lifetime and adds it to the repair list accordingly. The list is sorted in order of hour of failure/hour maintenance scheduled to occur.

Onshore tasks are broken down into 3 operations (device retrieval, onshore maintenance and redeployment). Offshore tasks have a single operation. For each task, the model checks if it is on or offshore. If offshore it will look for a vessel, technicians and a weather window. A weather window will include vessel transit to and from the farm; the offshore operation duration; and the weather restrictions specified for that operation. If onshore, it will look for a vessel, technicians and a weather window to retrieve the device; then specify a concurrent window to complete onshore maintenance (no weather restrictions apply); then looks for a vessel, technicians and a weather window to redeploy the device.

Currently the model only considers 1 set of weather restrictions for a single operation offshore. Transiting, the operation and returning to port must be completed within the same weather restrictions. It does not consider that a vessel could transit to site at a higher wave height (Hs) but undertake an operation at a lower Hs. This could potentially increase the actual number of windows available. However, the current assumption may be more accurate considering operations will go

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ahead based on immediate conditions and forecasting; therefore, it is likely the most sensitive weather restrictions will be considered for the full offshore task.

2.3.8 Outputs

Based on the strategy implemented for each simulation, the model will output average annual costs (vessels, technicians, base and spare parts); time-based availability (considering the time the device was available to produce energy divided by the potential time it could have produced energy); energy-based availability (considering the average energy produced divided by the total potential energy that could have been produced); and the energy production. It will also produce average totals and the capacity factor considering the energy production divided by the rate peak power.

2.3.9 Key assumptions and limitations

The model currently has some key assumptions that must be kept in mind when reviewing results. The model will always prioritise Corrective Maintenance tasks over Preventive Maintenance (PM). If PM does not occur in the year scheduled, it will be rescheduled until it coincides with another scheduled PM task. It will then be cancelled in favour of the next PM task.

Only one maintenance task can occur at one time on a device. A failure of the same type cannot occur on a device unless there are multiple components (specified by the user in the component inputs). No failures can occur while maintenance is occurring. However, if a failure occurs while waiting offshore for another failure to be fixed it still occurs and currently another separate trip will be needed to fix it whether onshore or offshore maintenance. This is unrealistic particularly for onshore maintenance since the model can end up retrieving and redeploying a device for one failure only to have to retrieve and redeploy for another. In reality, both failures would be dealt with once a device is onshore. However, this is a current limitation of the model that awaits further improvement.

Where vessels are purchased, there is a fixed annual cost. However, for rented vessels, the model will apply an annual mobilisation/demobilisation fee for any year it has been used. It will then also charge a day rate considering the number of hours the vessel spent offshore/24. However, the model does not currently consider a cost for when a vessel is waiting at port. This is likely to result in lower costs than reality and is a limitation of the current model that requires improvement and must be considered when reviewing results.

It is anticipated that some of these issues will be addressed for the final deliverable D7.5, the O&M assessment of the final configuration.

3 SCENARIO DEFINITION

3.1 SITE

The Ifremer site (Accensi & Maisondieu, 2015) is proposed as the reference site for LiftWEC, specifically the HOMERE dataset which provides data from 1994-2020. The mean water level is assumed to be 50m with an O&M port suitable for service vessels 20km from the site, while a port suitable for installation vessels is assumed to be 50km from the site. As outlined in (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) this is an extremely exposed site and incurs significant wait times for a 12-hour window at a Hs<1m. Approximately 90% of each month

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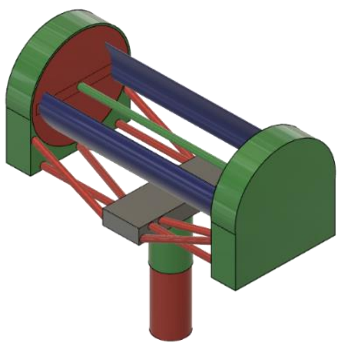
would be spent waiting for such a window. (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) demonstrated that raising the threshold to Hs<2m would improve accessibility, but access during the Winter months would still be scarce. Therefore, it is likely that HOMERE site will prove very challenging for any operations requiring significant durations and very calm conditions. However, this is likely to be the case for many proposed locations for wave farms due to the desire for deployment at highly energetic wave sites. While tow out strategies such as those employed by Pelamis are considered most suitable for this site, (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) anticipates that the device would have to utilise similar "plug and play" technologies that Pelamis went to great lengths to achieve. Quick release "hands-free" mechanisms were also strongly encouraged by several experts as revealed in (Flannery, Deliverable D7.1 Operational Design Considerations, 2020).

3.2 Project

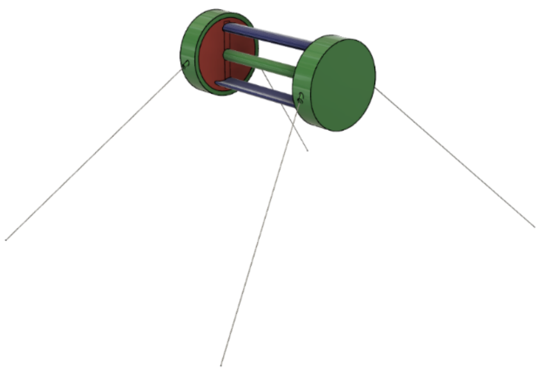
A common "base-case" scenario has been defined to assess the baseline configurations. This will examine the installation and O&M of 20 x 1.25MW LiftWEC devices at the HOMERE site. Total farm capacity is 25MW. The project lifetime is 25 years. It should be noted that this is a small array and would be aimed as a first commercial wave energy farm.

3.3 Device

The LiftWEC device will be examined as part of 4 baseline configurations illustrated in Figure 3.1. Within this deliverable device refers to the power-capture-unit (combined rotor/stator section). The design life of the device and all system components is 25 years unless otherwise stated.



CB01 – Tower LiftWEC



CB02 – TLP LiftWEC

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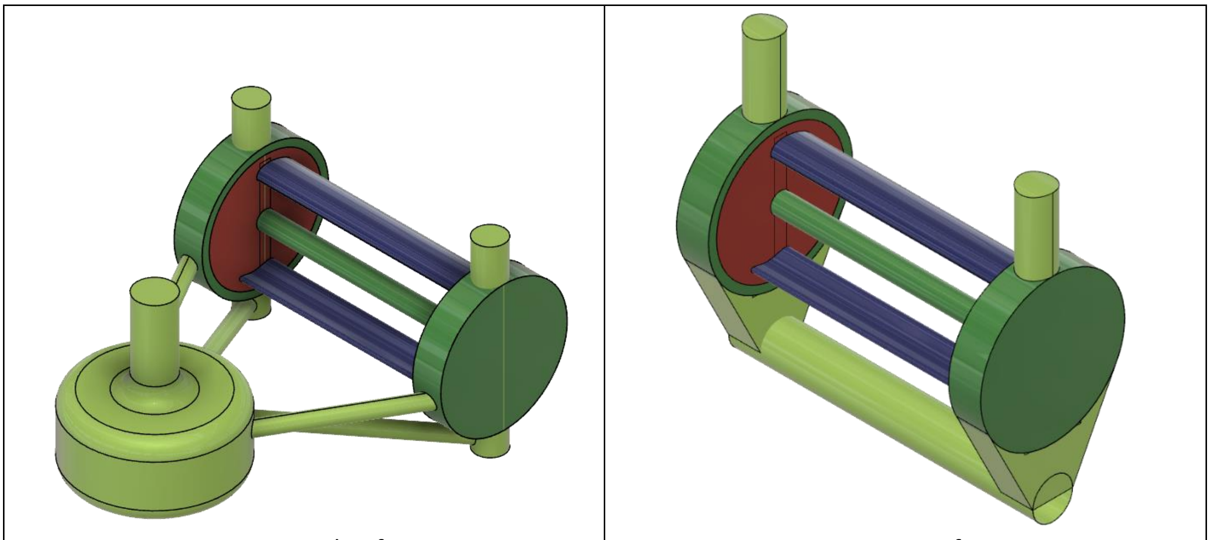

CB03 – Semisub LiftWEC | CB04 – Spar LiftWEC

Figure 3.1: Baseline Configuration Overview

While testing is ongoing to determine the LiftWEC device power performance (awaiting results of 3D testing by the end of 2022), D7.4 uses estimates based on the CycWEC device in line with (Chozas, Nielsen, & Pascal, 2022). The CycWEC device is rated at 2.5MW and is 60m span hydrofoil and 5m chord length cycloidal wave energy converter. This is similar to the LiftWEC baseline configuration that has two 30m hydrofoils. Therefore, the CycWEC power matrix has been extracted from (Siegel, 2019) and divided by 2 to represent a 1.25MW LiftWEC device. Based on internal project discussions, it has been determined that the CycWEC device is most structurally similar to the TLP LiftWEC. The same performance is assumed for the Spar LiftWEC. It is expected that the Tower LiftWEC will have better performance being fixed and having yaw control. Therefore, an increase of 10% production is assumed. However, production should be reduced by 5% for the Semi-sub LiftWEC. According to (Chozas, Nielsen, & Pascal, 2022), this is mainly due to the disturbance from the floater to the flow, even though the Semi-sub LiftWEC can weathervane.

3.4 Substation

Smaller projects can be connected directly to shore at the inter-array cable voltage with an export cable running from the last unit on the string to the point of cable landfall. Therefore, a substation has not been included in the base case scenario.

3.5 Cabling

33kv inner array and 150kv export cabling are included in the scenario.

3.6 Farm Layout

It is beyond the scope of this deliverable to determine an optimal farm layout. However, baseline configuration designs have determined a spacing of 76m between Tower LiftWEC devices; 80m between TLP LiftWEC devices; and 95m between Spar and Semi-sub LiftWEC devices. This information impacts the amount of inner array cabling installed for each scenario.

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4 TOWER LIFTWEC

According to the latest base of design, the Tower LiftWEC configuration consists of the two-hydrofoil rotor set atop a previously installed Jack-up Tower. The connection between the power capture unit and the Jack-up Tower is via a self-aligning transition piece. The Jack-up Tower is mounted atop a monopile foundation. The transition piece facilitates deployment and recovery as well as enabling yaw control. The Jack-up Tower is used both during deployment and recovery activities, and to control the rotor submergence in accordance with the wave conditions and water level.

4.1 INSTALLATION

4.1.1 Substructure

The preparatory siteworks will be undertaken by a specialist contractor following a detailed survey of the seabed. The actual siteworks undertaken is anticipated to vary with each location depends on the specific seabed and geotechnical conditions for that location.

As outlined in (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) and (Chozas, Nielsen, & Pascal, 2022), the monopile will be inserted into the seabed using hydraulic impact hammers using a Heavy Lift Vessel (HLV). For a monopile (5m diameter) at 50m water depth, it is assumed that a HLV like the Svanen (Figure 4.1) would be used. It is assumed that the monopile is floated to site using a monopile endcap and upended by the HLV.

Figure 4.1 The Svanen, upending a monopile at the Kriegers Flak wind farm 2020 (Van Oord, 2020)

Scour protection may then need to be installed following the monopile, for example, crushed rock using a rock installation vessel. However, scour protection requirements are highly dependent on the site and seabed conditions as well as the pile design (which may be designed to cope with scour). Therefore, it has not been considered in the base case scenario.

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4.1.2 Device

The prime mover will be towed to site through the attachment of temporary buoyancy tanks and the use of 2 conventional tugs. Temporary buoyancy tanks/bags are used to provide sufficient uplift to ensure the device remains afloat during transport. At the point of deployment, the Jack-up Tower should be fully extended such that the top of the Jack-up Tower sits approximately 22m beneath the mean level of the mean water level. Once on location, the temporary ballast tanks used to tow the power-capture-unit to site can be partially filled until only 4m of the Nacelle remains above the free surface. At this time, there will be a 6m gap between the bottom of the upper part of the Transition Piece (mounted on the power-capture-unit) and the top of the lower part of the Transition Piece which is mounted on the extended Jack-up Tower. The guide-lines should then be attached to permit the lowering operations to commence. Once the guide-lines are attached, ballasting operations can continue and as the power-capture-unit approaches the Jack-up Tower, the self-aligning properties of the Transition Piece should facilitate location. Once located, a semi-permanent connection can be made between the upper and lower parts of the Transition Piece. Once connected, the tops of the Nacelles will be approximately 2.0 metres below the mean water level. The temporary buoyancy tanks can then be detached from the device at which time their approximately neutral buoyancy will permit their safe retrieval. Finally, the Jack-up Tower is then used to submerge the power-capture-unit to the desired submergence depth.

While it expected that deployment could be achieved with the use of 2 tug units and 2 shallow-depth ROV units, de-ballasting on to the monopile would need extremely calm seas Hs 0.5-1m. However, this is quite restrictive and, particularly given the dynamic nature of the location (section 3.1), it is assumed that a dynamic positioning vessel with a clutch device is required or a large crane to accurately lower the WEC. (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) and (Chozas, Nielsen, & Pascal, 2022) assume that a lift/crane vessel similar to the Scaldis Rambiz is used to lift the WECs (transition piece, jack-up Tower LiftWEC and prime mover) onto the monopiles.

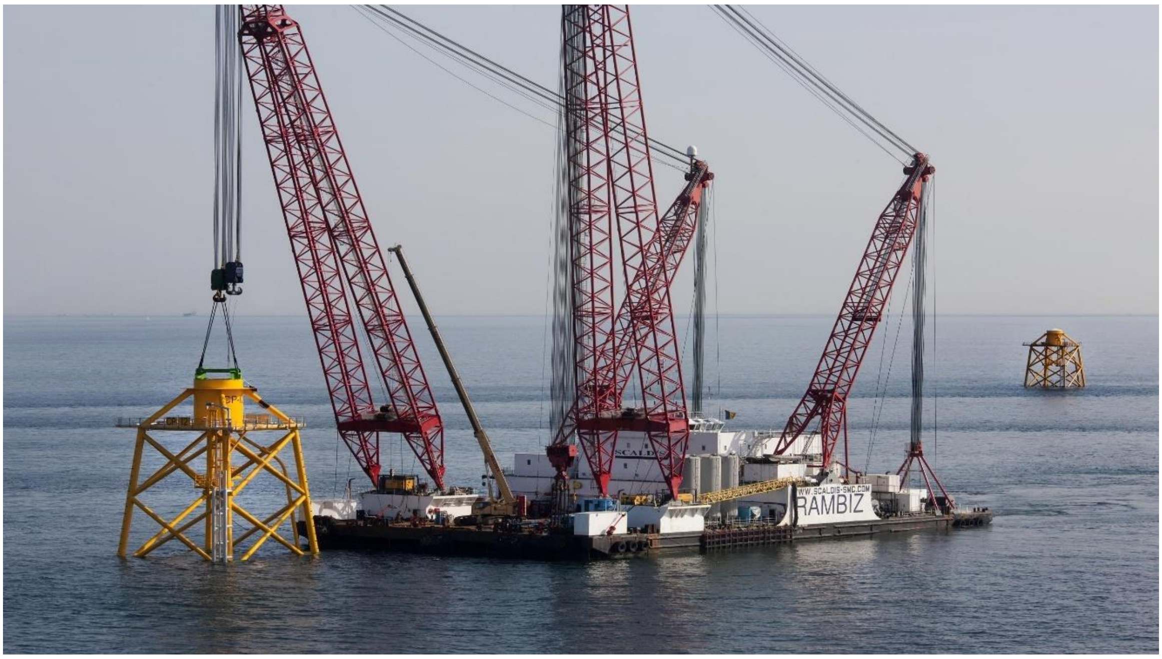

Figure 4.2 Scaldis Rambiz (DEME Group, 2022)

4.1.3 Substation

It is assumed that no substation is required for a farm of 25MW.

4.1.4 Cabling

A 150kv export cable of 30km (plus 10% for contingency) in length is installed by a cable laying vessel. 33kv inner array cabling is also installed assuming an inner array distance of 0.76km for 20 turbines results in approximately 15km of cable (plus 10% for contingency).

4.1.5 Operation, vessel and cost assumptions

Without extensive trials it is extremely uncertain how long each operation would take and the weather restrictions limiting activities. However, a base case scenario was applied based on (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) and (Chozas, Nielsen, & Pascal, 2022) as follows:

- Monopile is towed to site assuming a speed of 13km/h or 7 knots
- 12 hours installation for monopile at site
- WEC (prime mover, jack-up Tower LiftWEC and transition piece preassembled at port) towed out to site with two tug vessels at an average speed of 9.26km/h or 5 knots
- 3 days (36 hours) for crane vessel to lift and connect the power capture unit and remaining structures (jack-up Tower LiftWEC and transition piece assembled together) with support of 2 ROVs and 2 standby divers
- Cabling (export and inner array) is installed assuming 1km installed per day (12 hours) (Kaiser & Snyder, 2011)

The weather limits set as a baseline for most operations are a Significant Wave Height limit (Hs) of 1.5m and Mean Wind Speed of 14 m/s. The exception is maximum Hs of 4m for the transit to and from site of the cable laying vessel and cable laying at a max Hs of 2m and wind speed of 16m/s. Generally, the transit of large vessels is fairly unrestricted; however, the Svanen and the tugs will be towing elements, requiring calm sea states. A higher transit speed of 22km/hr (12knots) is assumed for the cable laying vessel for the same reason (it is not towing elements, therefore can transit at maximum speed).

Vessels used include:

- HLV €180,000 day rate (€360,000 mob/demob rate)
- 2 tugs at €5,000 day rate each (€10,000 mob/demob rate)
- Crane vessel at €60,000 day rate (€120,000 mob/demob rate)
- 2 ROVs at €4,000 day rate each
- 2 divers at €2,500 day rate each
- Cable laying vessel and equipment at €100,000 day rate (€200,000 mob/demob rate)

4.2 O&M

4.2.1 Strategy

O&M considered in the base case scenario includes Corrective Maintenance for small repairs and large component replacements as well as regular scheduled maintenance including annual visual inspection and a half-life retrofit. LiftWEC maintenance will be primarily on a return-to-base (RTB) strategy for all

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but the simplest procedures. 2 tugboats will be used to recover and redeploy individual power-capture-units as the reverse of the deployment procedure using the same procedures and assets. This maintenance strategy is essentially the same for the 4 baseline configurations; however, there are some expected differences which are outlined below.

Once installed, it is generally expected that deployment or retrieval should be achievable within a 2-hour window (measured from arrival at deployment location). However, it is likely given the differences in attachment procedures during installation, that the LiftWEC Tower LiftWEC would need some additional time and require a lift/crane vessel. Therefore, a base case estimate of 4 hours has been applied to recovery and redeployment operations offshore. Similarly, a window of 4 hours is also assumed for the TLP LiftWEC to account for attaching/detaching to 4 mooring lines. The 2-hour window will be set for the Semi-sub and Spar LiftWEC configurations since they will have the simplest attach/detach procedures thanks to the single-point connection. Weather limits will be set to 1.5m Hs; 8.5s Tp; and 14m/s wind speed as an initial scenario for all operations. However, it is expected that the Semi-sub and Spar LiftWEC configurations can be retrieved and redeployed in higher wave heights owing to the simple and quick attach/detach procedure. Therefore, a Hs of 2m will be applied for offshore operations. This will not be mirrored for installation assuming calmer seas will be beneficial to complete the first connection.

These assumptions are extremely uncertain without offshore experience but has been set to facilitate a proportionate comparison between the configurations.

4.2.2 Failure rates and spare part costs

Given the lack of available failure rates and spare part costs, the scenario has applied a subset of relevant parts based on the Pelamis P2 device (750kW) case study undertaken by (Gray, Dickens, BruceIan, Ashton, & Johanning, 2017) . Data is based on a testing programme undertaken over 11,000 grid connected hours at the European Marine Energy Centre (EMEC) in Orkney. While these may not directly link to the LiftWEC device design, there is not enough information available to determine other more specific information at this time. Therefore, applying a standard data set is believed to be the best and most accurate method of comparing the configurations. However, it is important to bear in mind that these are the failure rates and costs for a different device when reviewing results. The same figures are applied across the 4 configurations to provide an indicative baseline with variations to compare the configurations in the power production potential (as outlined in section 3.3) and strategy (as outlined in section 4.2.1) such as the device recovery and reinstallation time (for example, the Tower and TLP LiftWEC will require longer); and the weather restrictions (for example, attach/de-attach can be carried out at higher wave heights). However, further work is needed to produce specific and realistic data and increase certainty.

In particular, it should be noted that no failures or maintenance is foreseen on the jack-up structure or monopile for the Tower LiftWEC or the mircopiles of the TLP LiftWEC. However, failures are considered for the mooring lines of the other 2 baseline configurations based on the P2 case study. Likely failure rates and general substructure maintenance inspections for monopiles and jack-up leg systems are needed for a more accurate comparison.

4.2.3 Optimisation

In a full-scale commercial farm (c. 100MW), it is envisaged that 2-3 ‘spare’ power-capture-units would be kept at “base” for replacement of units brought in for maintenance, thus alleviating time pressures

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on O&M activities and reducing concerns over weather window availability. This has not been considered in the CAPEX estimates in (Chozas, Nielsen, & Pascal, 2022); therefore, it has not been implemented in the base case scenarios for each configuration. It will be considered in the full-scale commercial farm for the final configuration in D7.5.

4.3 Decommissioning

Decommissioning of the system refers to the removal of the device, Jack-up Tower and the monopile foundation. Recovery procedure for the power-capture-unit is as the reverse of the deployment procedure using the same procedures and assets. Removal of the Jack-up Tower will be through the use of ROVs and a HLV. The monopile and monopile End Cap may be left in place for re-use. Alternatively, the monopile End Cap will be removed along with the Jack-up Tower and the pile cut off at the seabed and the top portion removed. The driven/drilled portion of the pile will remain in place due to the seabed disruption required to remove it.

At this stage of design development modelling decommissioning is outside the scope of this deliverable. Therefore, we will consider the cost as a proportion of the overall CAPEX considering dry CAPEX costs outlined in (Chozas, Nielsen, & Pascal, 2022) and the installation costs modelled in this deliverable.

5 TLP LiftWEC

The Tension Leg Platform or TLP LiftWEC configuration consists of the two-hydrofoil rotor held in place by 4 tension-leg cables. Each cable is reacted at the seabed by a micro-piled foundation The tension-leg mooring winch system is used both during deployment and recovery operations and to provide submergence control of the rotor.

There are two drums outside the nacelle allowing the moorings lines to be like a yo-yo, adjusting the water depth / submergence of the rotor. Each cable has a total length of 80m (65m required to bring the power capture unit to the surface plus spare). When the device is submerged to 14m submergence, 55m of tension leg cable per tether is expected to be exposed. Each tension-leg cable terminates at a mechanical winch mounted within a disparately sealed section of the nacelle units. A set of mechanical locks restrict cable motion between winching activities.

The anchoring system consists of 4 structural footing elements, each of which is independently micro-piled to the sea floor using 12 inclined micro-piles. The micro-pile foundations are used to transmit the fundamental reaction forces and hydrofoil reaction torques to ground.

5.1 Installation

5.1.1 Substructure

The preparatory siteworks will be undertaken by a specialist contractor following a detailed survey of the seabed. The actual siteworks undertaken is anticipated to vary with each location depends on the specific seabed and geotechnical conditions for that location.

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Initially, surface-based micro-piling vessel is used to drill and install the micro-piles using a template. A crane vessel is then used to install the footing elements atop the protruding portions of the micro-piles and deploy suitable scour protection. The bottom of the tension-leg cable tethers can then be attached to the footing elements. The same vessel can simultaneously deploy the surface-based marker buoys while attaching the top of the tension-cable tethers to these marker buoys for ease of power-capture-unit deployment.

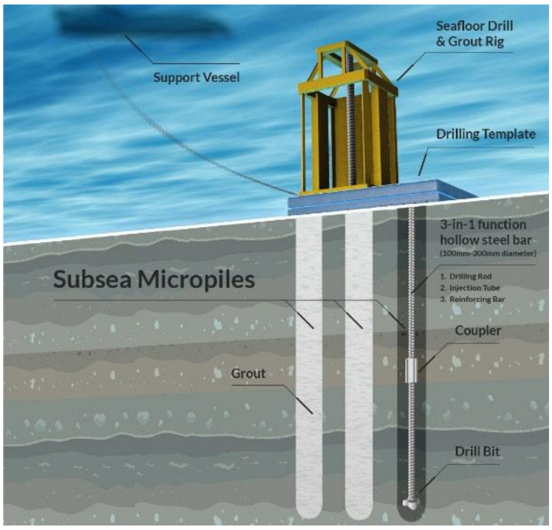

Figure 5.1 (Subsea Micropiles, 2022)

5.1.2 Device

The power-capture-unit (combined rotor/stator section) is towed to site using two conventional tug units. At the point of deployment, tension-leg cable tethers are detached from the marker buoys and attached to the short length of winch cable that is unwound from within the nacelles for the purpose of permitting tension-leg cable attachment. Once all 4 tension-leg cable tethers are attached, the winching mechanisms can be engaged, and the device is submerged to the desired depth.

5.1.3 Substation

It is assumed that no substation is required for a farm of 25MW.

5.1.4 Cabling

A 150kv export cable of 30km (plus 10% for contingency) in length is installed by a cable laying vessel. 33kv inner array cabling is also installed assuming an inner array distance of 0.8km for 20 turbines results in approximately 15km of cable (plus 10% for contingency).

5.1.5 Operation, vessel and cost assumptions

Without extensive trials it is extremely uncertain how long each operation would take and the weather restrictions limiting activities. However, a base case scenario was applied based on (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) and (Chozas, Nielsen, & Pascal, 2022) as follows:

Micropiles transported to site using a small Offshore Construction Vessel (OCV)/micropiling vessel to site assuming a speed of 22km/h or 12 knots

- 12 hours installation of micropiles at site

- 3 days (36 hours) for crane vessel to install footing elements and tension-leg mooring cables, deploying surface-based marker buoys with mooring lines attached
- Prime mover towed out to site with two tug vessels at an average speed of 9.26km/h or 5 knots
- 4 hours to connect moorings using marker buoys with support of 2 ROVs and divers
- Cabling (export and inner array) is installed assuming 1km installed per day (12 hours) (Kaiser & Snyder, 2011)

The weather limits set as a baseline for the majority of operations are a Significant Wave Height limit (Hs) of 1.5m and Mean Wind Speed of 14 m/s. The exception is maximum Hs of 4m for the transit to and from site of the micropiling, lift and cable laying vessels and cable laying at a max Hs of 2m and wind speed of 16m/s. This is because these are less sensitive operations. While it may be possible to connect the device to moorings in 2 hours for the Semi-sub and Spar LiftWEC configurations, additional time (4hours) is considered for the TLP LiftWEC considering attaching to 4 mooring points.

Vessels used include:

- Micropiling vessel €35,000 day rate (€70,000 mob/demob rate)
- Crane vessel at €60,000 day rate (€120,000 mob/demob rate)
- 2 tugs at €5,000 day rate each (€10,000 mob/demob rate)
- 2 ROVs at €4,000 day rate each
- 2 divers at €2,500 day rate each
- Cable laying vessel and equipment at €100,000 day rate (€200,000 mob/demob rate)

It has been suggested that the prime mover will be towed with smaller tug unit than others as it is considerably lighter than the other configurations (Chozas, Nielsen, & Pascal, 2022). However, given the uncertainty surrounding requirements and operations, the base case scenario will consider the same standard tugs for all configurations at the same day rates.

5.2 O&M

O&M strategy and data used for the 4 different configurations is outlined in section 4.2.

5.3 Decommissioning

Recovery procedure for the power-capture-unit is as the reverse of the deployment procedure using the same procedures and assets. The sub-seabed portions of the micro-piles will be left in place to minimize seabed disruptions. The footing elements and tension-leg cables will be retrieved using a subsea ROV and light-lift vessel. The protruding portions of the micro-piles will be cut at the seabed and recovered after the footing elements have been removed.

At this stage of design development modelling decommissioning is outside the scope of this deliverable. Therefore, we will consider the cost as a proportion of the overall CAPEX considering dry CAPEX costs outlined in (Chozas, Nielsen, & Pascal, 2022) and the installation costs modelled in this deliverable.

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6 SEMI-SUB LIFTWEC

The floating or Semi-submersible LiftWEC configuration consists of the two-hydrofoil rotor attached at both ends to a bracket substructure. This substructure is supported by a floater. The main difference of this configuration to the two previous ones is that this is a floating concept slack moored to the seabed. There are 3 mooring lines attached to a turret mooring point on the front of the structure and each mooring line connected to drag-anchors on the seabed. The mooring system allows the structure to weathervane.

6.1 INSTALLATION

6.1.1 Substructure

The preparatory siteworks will be undertaken by a specialist contractor following a detailed survey of the seabed. The actual siteworks undertaken is anticipated to vary with each location depends on the specific seabed and geotechnical conditions for that location.

Initially, drag anchors will be installed using an Anchor Handling Tug Vessel. The slack-line catenary mooring cables will then be attached to the drag anchors. The same vessel can simultaneously deploy the surface-based place-holder buoy while attaching the top of the mooring line system to this marker buoy for ease of power-capture-unit deployment.

6.1.2 Device

The power-capture-unit and the semi-submersible proper are rigidly attached and are deployed as a single unit. The entire unit is towed to site using two conventional tug units similarly to the Pelamis P2 device in Figure 6.1. At the point of deployment, the primary mooring line cable is detached from the place-holder buoy and attached to the front of the offset semi-submersible float. Once attached the sea-water pumps are used to ballast the floats and submerge the device to the desired depth.

Figure 6.1 A Pelamis P2 device being towed for installation at EMEC in 2012 (Pelamis Wave Power) (Gray, Dickens, BruceclIan, Ashton, & Johanning, 2017)

6.1.3 Substation

It is assumed that no substation is required for a farm of 25MW.

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6.1.4 Cabling

A 150kv export cable of 30km (plus 10% for contingency) in length is installed by a cable laying vessel. 33kv inner array cabling is also installed assuming an inner array distance of 0.95km for 20 turbines results in approximately 18km of cable (plus 10% for contingency).

6.1.5 Operation, vessel and cost assumptions

Without extensive trials it is extremely uncertain how long each operation would take and the weather restrictions limiting activities. However, a base case scenario was applied based on (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) and (Chozas, Nielsen, & Pascal, 2022) as follows:

An Anchor Handling Tug Vessel (AHTV) will transit to site assuming a speed of 22km/h or 12 knots

- It will install the 3 drag anchors taking 8 hours per anchor (24 hours) and deploy the surface-based place-holder buoy with mooring line attached
- The WEC (prime mover, bracket structure and floater are assembled onshore) will be towed to site with two tug vessels at an average speed of 9.26km/h or 5 knots
- 2 hours to connect moorings using marker buoys to a simple single point connection on the device with the support of divers
- Cabling (export and inner array) is installed assuming 1km installed per day (12 hours) (Kaiser & Snyder, 2011)

The weather limits set as a baseline for the majority of operations are a Significant Wave Height limit (Hs) of 1.5m and Mean Wind Speed of 14 m/s. The exception is maximum Hs of 4m for the transit to and from site of the AHTV and cable laying vessels and cable laying at a max Hs of 2m and wind speed of 16m/s. This is because these are less sensitive operations. In addition, a single point connection system should make it very quick to attach/detach the device once the anchors and mooring lines are in place. Due to the speed, it is assumed that this operation can occur in Hs up to 2m and wind speeds of 16m/s. It is assumed that it will also only require diver support, not ROVs.

Vessels will include

- AHTV €30,000 day rate (€60,000 mob/demob rate)
- 2 tugs at €5,000 day rate each (€10,000 mob/demob rate)
- 2 divers at €2,500 day rate each
- Cable laying vessel and equipment at €100,000 day rate (€200,000 mob/demob rate)

6.2 O&M

O&M strategy and data used for the 4 different configurations is outlined in section 4.2.

6.3 Decommissioning

Decommissioning of the system refers to the removal of the power-capture-unit, catenary mooring lines and the drag anchors. Recovery procedure for the power-capture-unit is as the reverse of the deployment procedure using the same procedures and assets. Mooring lines and anchors will be recovered by a light lift vessel and ROV.

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At this stage of design development modelling decommissioning is outside the scope of this deliverable. Therefore, we will consider the cost as a proportion of the overall CAPEX considering dry CAPEX costs outlined in (Chozas, Nielsen, & Pascal, 2022) and the installation costs modelled in this deliverable.

7 Spar LiftWEC

The Spar LiftWEC configuration consists of the two-hydrofoil rotor attached at both ends to a spar structure. The mooring allows the structure to weathervane. The same mooring configuration as the Semi-sub LiftWEC is assumed. It is a single-point connection type that allows connecting and disconnecting the device in a relatively short time.

7.1 Installation

7.1.1 Substructure

The preparatory siteworks will be undertaken by a specialist contractor following a detailed survey of the seabed. The actual siteworks undertaken is anticipated to vary with each location depends on the specific seabed and geotechnical conditions for that location.

Initially, drag anchors will be installed using an Anchor Handling Tug Vessel. The slack-line catenary mooring cables will then be attached to the drag anchors. The same vessel can simultaneously deploy the surface-based place-holder buoy while attaching the top of the mooring line system to this marker buoy for ease of power-capture-unit deployment.

7.1.2 Device

The power-capture-unit and the integrated spar-buoy are deployed as a single unit. The entire unit is towed to site using two conventional tug units. During towing, the system is de-ballasted and the Spar LiftWEC will float horizontally at the free water surface. At the point of deployment, the single point mooring cables are attached to the ballast tube and the ballast tube and trapezium-shaped extensions of the nacelles are ballasted using seawater until the device is vertical.

7.1.3 Substation

It is assumed that no substation is required for a farm of 25MW.

7.1.4 Cabling

A 150kv export cable of 30km (plus 10% for contingency) in length is installed by a cable laying vessel. 33kv inner array cabling is also installed assuming an inner array distance of 0.95km for 20 turbines results in approximately 18km of cable (plus 10% for contingency).

7.1.5 Operation, vessel and cost assumptions

Without extensive trials it is extremely uncertain how long each operation would take and the weather restrictions limiting activities. However, a base case scenario was applied based on (Flannery, Deliverable 7.3 Assessment of Preliminary configurations, 2020) and (Chozas, Nielsen, & Pascal, 2022) as follows:

An Anchor Handling Tug Vessel (AHTV) will transit to site assuming a speed of 22km/h or 12 knots

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- It will install the 3 drag anchors taking 8 hours per anchor (24 hours) and deploy the surface-based place-holder buoy with mooring line attached
- The WEC (prime mover, bracket structure and floater are assembled onshore) will be towed to site with two tug vessels at an average speed of 9.26km/h or 5 knots
- 2 hours to connect moorings using marker buoys to a simple single point connection on the device with the support of divers
- Cabling (export and inner array) is installed assuming 1km installed per day (12 hours) (Kaiser & Snyder, 2011)

The weather limits set as a baseline for the majority of operations are a Significant Wave Height limit (Hs) of 1.5m and Mean Wind Speed of 14 m/s. The exception is maximum Hs of 4m for the transit to and from site of the AHTV and cable laying vessels and cable laying at a max Hs of 2m and wind speed of 16m/s. This is because these are less sensitive operations. In addition, a single point connection system should make it very quick to attach/detach the device once the anchors and mooring lines are in place. Due to the speed, it is assumed that this operation can occur in Hs up to 2m and wind speeds of 16m/s. It is assumed that it will also only require diver support, not ROVs.

Vessels will include

- AHTV €30,000 day rate (€60,000 mob/demob rate)
- 2 tugs at €5,000 day rate each (€10,000 mob/demob rate)
- Divers at €2,500 day rate
- Cable laying vessel at €100,000 day rate (€200,000 mob/demob rate)

7.2 O&M

O&M strategy and data used for the 4 different configurations is outlined in section 4.2.

7.3 Decommissioning

Decommissioning of the system refers to the removal of the power-capture-unit, catenary mooring lines and the drag anchors. Recovery procedure for the power-capture-unit is as the reverse of the deployment procedure using the same procedures and assets. Mooring lines and anchors will be recovered by a light lift vessel and ROV.

At this stage of design development modelling decommissioning is outside the scope of this deliverable. Therefore, we will consider the cost as a proportion of the overall CAPEX considering dry CAPEX costs outlined in (Chozas, Nielsen, & Pascal, 2022) and the installation costs modelled in this deliverable.

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8 KEY CHALLENGES & UNCERTAINTIES

8.1 VESSELS, TECHNICIANS AND EQUIPMENT

8.1.1 Vessel cost

While a day rate of €4,000 has been applied for ROVs, this figure is extremely uncertain. This figure would depend on the type of ROV used and some sources suggest that an ROV could cost considerably more. (Jalili, Maheri, & Ivanovic, 2022) quote both £3,450 and £20-40,000 per day. Vessel rates are generally quite an uncertain input as the cost would depend on a number of elements including the type of contract the farm had with the supplier, for example, a regular maintenance agreement may result in a cheaper rate than if it was "hired as required." The type and size of vessel required would also change depending on the device size. For example, a 1.25MW design could require a lighter, cheaper tug than a 2.5MW device. Further work and input from industry is required to increase confidence in the current vessel cost assumptions.

8.1.2 Vessel availability

HLVs and crane vessels are often in high demand amongst the offshore oil and gas and ORE industries. Therefore, particularly for O&M, it is likely there would be a lead time or delay in acquiring a vessel for unplanned maintenance that is not currently accounted for in the model. Scenarios that use smaller tug vessels are less likely to experience such delays.

8.1.3 Suitability

While it is assumed that ROVs and divers would support installation and O&M activities in most scenarios, they would be particularly limited by current speeds (max 1.3 knots). These are not currently accounted for in the Metocean data.

In addition, if work in the seabed were required, 50m would be a deep dive and operators may choose to consider an upgraded ROV instead of commercial divers. However, an ROV would increase costs.

The model does not currently consider whether the standard small tugboat assumed in scenarios would be suitable to transport the ROV and divers to site, but it is possible an additional vessel would be required. This is particularly the case if a large ROV is needed as it may require more vessel capacity.

8.1.4 Other costs

Costs are to a great extent driven by vessels. Given the uncertainty of these rates and other cost elements (such as technicians, fuel and port/base costs), it was decided to keep assumptions minimal. Therefore, modelling currently only considers vessel and spare part/consumables costs. This should be kept in mind when reviewing results, as costs are likely to be higher. However, consistent use of these assumptions for all cases means that they should provide an accurate comparison between baseline configurations.

8.2 DEVICE OPERATIONS

8.2.1 Tower

Ballasting is a difficult operation and if ballasting the monopile down, you need extremely calm seas, for example, 0.5-1m Hs.

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8.2.2 TLP

The TLP LiftWEC needs a messenger line or pennant chain, which can be lifted onto deck. This could require a larger Multicat vessel (day rate at approximately €10,000) than is currently considered.

Micropiles in 50 m water depth is difficult to achieve and is precise work. Therefore, while a small OSC has been assumed, it may be that a larger DP vessel is needed for this operation.

8.3 O&M

8.3.1 Accessibility

Previous weather window analysis of the exposed HOMERE site revealed that access would be extremely limited. Accessing the site is a key issue that will determine the economic viability of any configuration. Accessing a fixed platform offshore is already dangerous and generally limited to a Hs of 2m in the offshore wind industry, although different technologies (for example, walk-to-work access systems) and larger more expensive maintenance vessels (for example, Service Operations Vessels (SOV)) indicate that this could be done at Hs of 3 and even 4m. However, accessing a fixed structure is much easier than transferring crew from floating (vessel) to floating (platform), which will require even calmer conditions (1-1.5m Hs). The current industry thinking is that strategies using quick "plug-in-and-play" connections and onshore maintenance are preferable. However, actual offshore experience is needed to confirm what is possible both in terms of operation durations and weather restrictions for the LiftWEC concept.

9 VALIDATION

As previously detailed in this deliverable, there is considerable uncertainty attached to the current scenario inputs at this stage of device development and offshore testing/experience. There are also limitations to the modelling that do not portray operations 100% accurately. Therefore, it is not intended that results should be taken as actual figures in terms of energy production or costs. Rather, by applying a base case scenario using common assumptions across the 4 baseline configures; results are used to provide a comparative assessment.

With the above in mind, this section does provide a summary of current cost breakdown and estimates for wave energy projects to provide general ranges for information purposes. This gives us an idea of what may be considered a "reasonable" result in order to assess what may be missing/inaccurate in the modelling results, requiring further refinement.

9.1 REVIEW OF LIFTWEC TARGETS

(Têtu & Fernandez Chozas, 2020) have already provided an extensive database reviewing cost estimates for wave energy projects. Based on this, (Têtu & Chozas, 2021) assume that the installation and commissioning costs for installing a foundation or moorings, offshore substation, WEC and cables typically range from 8-17% of CAPEX. Decommissioning is generally assumed to be approximately 10% of CAPEX based on offshore wind experience. OPEX is broken down into O&M (94%) and site lease and insurance (6%) costs. Annual OPEX is generally estimated anywhere from 1.5%-9% of CAPEX. However, experience from the offshore wind sector suggests 3-4.5% of CAPEX is expected for utility

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scale arrays. For the LiftWEC project, they set a target CAPEX of €4,300/kW by midway and €3,800/kW by the end of the project. Based on their percentage estimates for installation and OPEX, Table 9.1 outlines the expected results required to achieve the LCoE goals.

Table 9.1 LiftWEC economic targets

Parameter	Value Mid-Term project	Value End-of Project	Unit
Capacity factor	30	35	%
Availability	95	98	%
Discount rate	5	5	%
Lifetime	25	25	year
Annualisation factor	0.0696	0.06968	
Capital expenditures	2.5	2.98	MWh/kW/year
Installation at 13% CAPEX	4200	3800	€/kW
Decommissioning at 10% CAPEX	546	494	€/kW
Operational expenditures	420	380	€/kW
Levelised cost of energy	210	95	€/kW/year

While Table 9.1 are the target costs, energy production and availability the project is aiming for; various studies in consultation with industry experts reveal a wide range of estimates for the actual costs of wave energy projects. These can be used to some extent indicate whether our results are reasonable.

9.2 CURRENT WAVE ENERGY FARM ESTIMATES

(Fernandez Chozas, et al., 2015) reviewed estimated costs for technologies at TRL6 in conjunction with stakeholders considering 3 development stages, first array, second array and commercial scale. The study assumed the cost of a generic WEC. (Têtu & Chozas, 2021) summarise results in Figure 9.1.

Deployment Stage		Minimum Value	Maximum Value
First array	CAPEX (EUR/kW)	3600	16,300
	OPEX (EUR/kW/year)	125	1350
Second array	CAPEX (EUR/kW)	3240	13,800
	OPEX (EUR/kW/year)	90	450
	Availability (%)	85%	98%
	Capacity factor (%)	30%	35%
First commercial scale project	CAPEX (EUR/kW)	2400	8200
	OPEX (EUR/kW/year)	65	340
	Discount rate (%)	10%	10%
	Availability (%)	95%	98%
	Capacity factor (%)	35%	40%

Figure 9.1 An example of estimated CAPEX and OPEX values for different deployment stages (Têtu & Chozas, 2021)

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This study was updated 2018-2019 (Ocean Energy Systems (OES), 2019) and results are summarised in Figure 9.2.

Project Characteristics	
Project capacity (MW)	160 MW
Project lifetime	22 years
Discount rate	7%
Overall CAPEX	3100 EUR/kW
Overall annual OPEX	4% of CAPEX
Capacity factor	36%

Figure 9.2 OES 2019 study (Têtu & Chozas, 2021)

In addition a study (Danish Energy Agency and Energinet, 2016) aim to provide an estimate for what capital and operational costs of wave power converters might be in the future assuming most of the research and development challenges have been overcome, economics of scale have been realised and efficiencies in production and operation due to the learning curve effect have been achieved.

Technical and Financial Data	Units	2030	2050
Generating capacity for one power plant	MW	10–100	50–500
Length of installation of one power plant	km	1–20	5–100
Annual generated electricity production	MWh/MW	3500	4500
Availability	%	97	98
Technical lifetime	years	25	30
Capital Investment	MEUR/MW	2.2–4.5	1.6
OPEX	EUR/kW/year	60	47

Figure 9.3 Danish Energy Agency and Energinet study, 2016 (Têtu & Chozas, 2021)

To summarise the above findings, CAPEX for a first array could range from €3,500-€16,300/kw with OPEX falling within €125-1350/kW/year. A second stage array is expected to result in an availability of 85-98% with a capacity factor of 30-35%; CAPEX between €3,240-13,800/kW and OPEX of €90-450/kW/year.

These are the figures this deliverable will focus on for comparison since the device is assumed to be a rating of 1.25MW and a farm of 20 devices. This is indicative of a first or second array. It would be expected that a larger, higher rated device would be used for a first commercial scale project, for example, 2-3MW device and a farm capacity c. 100MW. D7.5 will consider a full-scale commercial project with the final configuration.

9.3 Latest Project Analysis

(Chozas, Nielsen, & Pascal, 2022) conducted initial LCoE analysis on the 4 configurations and can also be used for comparison with our results. Work assumes a single WEC deployed for a 25-year project. The results and assumptions are summarised below for each configuration. The key areas used for comparison are installation costs; OPEX; Annual energy production and Capacity Factor.

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9.3.1 D8.4 analysis of Tower LiftWEC

Table 9.2 D8.4 economic assessment Tower LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	Unit
Project lifetime	25	year
Dry weight exc. Mooring	420	ton
Generator rated power	1240	kW
CAPEX	8,270,000	Euro
Annual OPEX	500,000	Eur/year
Annual energy production	3,000	MWh/year
Capacity factor	26%	
LCoE (5% discount rate)	362	€/MWh

The CAPEX is further broken down as follows:

Table 9.3 CAPEX breakdown Tower LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	% of CAPEX
CAPEX	8,270,000	
Development & consenting	500,000	6%
WEC Structure and Prime mover	1,634,000	20%
Balance of plant	1,264,000	15%
Control	150,000	2%
Installation & decommissioning	3,894,000	47%
Contingencies	752,000	9%

According to (Chozas, Nielsen, & Pascal, 2022), OPEX was determined as 8% of CAPEX (before contingencies) as a baseline. This amounts to €250,000/year for the TLP LiftWEC and is the baseline configuration. However, it is expected that maintenance will be twice as expensive for the Tower since it is fixed requiring more expensive vessels. The Semi-sub and Spar LiftWEC configurations are estimated twice as cheap as the TLP LiftWEC with the easiest connect/disconnection operations.

Assuming decommissioning is 10% of CAPEX, then installation and decommissioning costs would be **€3,067,000 (37%) and €827,000 (10%) per WEC** respectively**.**

9.3.2 D8.4 analysis of TLP LiftWEC

Table 9.4 D8.4 economic assessment TLP LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	Unit
Project lifetime	25	year
Dry weight exc. Mooring	180	ton
Generator rated power	1240	kW
CAPEX	5,110,000	Euro
Annual OPEX	250,000	Eur/year
Annual energy production	2,700	MWh/year

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Capacity factor	25%	
LCoE (5% discount rate)	227	€/MWh

The CAPEX is further broken down as follows:

Table 9.5 CAPEX breakdown TLP LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	% of CAPEX
CAPEX	5,110,000	
Development & consenting	500,000	10%
WEC Structure and Prime mover	818,000	16%
Balance of plant	1,464,000	29%
Control	75,000	1%
Installation & decommissioning	1,770,000	35%
Contingencies	465,000	9%

Assuming decommissioning is 10% of CAPEX, then installation and decommissioning costs would be **€1,259,000 (25%) and €511,000 (10%) per WEC** respectively.

9.3.3 D8.4 analysis of Semi-sub LiftWEC

Table 9.6 D8.4 economic assessment Semi-sub LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	Unit
Project lifetime	25	year
Dry weight exc. Mooring	350	ton
Generator rated power	1240	kW
CAPEX	3,990,000	Euro
Annual OPEX	125,000	Eur/year
Annual energy production	2,490	MWh/year
Capacity factor	24%	
LCoE (5% discount rate)	158	€/MWh

According to (Chozas, Nielsen, & Pascal, 2022), the same mooring system as the LiftWEC Semi-sub LiftWEC used for the Pelamis P2 deployed at EMEC at 50-meter water depth is assumed, amounting to 300.000 EUR (WES, 2016). The following provides a breakdown of CAPEX costs.

Table 9.7 CAPEX breakdown Semi-sub LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	% of CAPEX
CAPEX	3,990,000	
Development & consenting	500,000	13%
WEC Structure and Prime mover	1,430,000	36%
Balance of plant	110,4000	28%

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Control	110,000	3%
Installation & decommissioning	487,000	12%
Contingencies	363,000	9%

Assuming decommissioning is 5% of CAPEX (lower than the fixed concepts), then installation and decommissioning costs would be **€287,500 and €199,500 per WEC** respectively.

9.3.4 D8.4 analysis of Spar LiftWEC

Table 9.8 D8.4 economic assessment Spar LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	Unit
Project lifetime	25	year
Dry weight exc. Mooring	235	ton
Generator rated power	1240	kW
CAPEX	3,600,000	Euro
Annual OPEX	125,000	Eur/year
Annual energy production	2,700	MWh/year
Capacity factor	25%	
LCoE (5% discount rate)	141	€/MWh

The following provides a breakdown of CAPEX costs.

Table 9.9 CAPEX breakdown Spar LiftWEC (Chozas, Nielsen, & Pascal, 2022)

Parameter	Value	% of CAPEX
CAPEX	**3,600,000**	
Development & consenting	500,000	14%
WEC Structure and Prime mover	1038,000	29%
Balance of plant	1,140,000	32%
Control	110,000	3%
Installation & decommissioning	487,000	14%
Contingencies	328,000	9%

Assuming decommissioning is 5% of CAPEX (lower than the fixed concepts), then installation and decommissioning costs would be **€307,000 (9%) and €180,000 (5%) per WEC** respectively.

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10 RESULTS

10.1 TOWER LIFTWEC

10.1.1 25MW Base Case

10.1.1.1 Installation

Table 10.1 Installation results – Tower LiftWEC – base case

Parameter	Value	Unit
Number devices	20	
Device rating	1250	kW
Farm capacity	25	MW
Installation	105,441,432	Euro
WEC	24,872,112	Euro
Substructure	65,396,520	Euro
Export cable	10,606,300	Euro
Inter-array cable	4,566,500	Euro
Average time	2.62	years
Number of simulations	1,000	
Installation - single WEC	5,272,072	Euro
Installation/kW	4,218	Euro

Installation costs are considerably greater than (Chozas, Nielsen, & Pascal, 2022) estimates (€3,067,000/WEC). However, assuming the same % of CAPEX (37%), a total CAPEX of 11,399/kW is in the range of the first and second array in (Fernandez Chozas, et al., 2015), €3,600-16,300 and €3240-13800 respectively, so could be considered a reasonable estimate.

Given the average time across 1000 simulations is 2.62 years for 20 devices, the challenging accessibility of the site increased costs beyond the assumptions outlined in (Chozas, Nielsen, & Pascal, 2022) (generally 3 extra days considered as waiting for weather windows and does not include cable installation).

10.1.1.2 O&M

It should be noted that each scenario was run for 100 simulations due to time restrictions. While results are expected to provide accurate indication of results, it is expected that an increase in simulations would provide a more constant average.

Table 10.2 O&M results - Tower LiftWEC – base case

Parameter	Value	Unit
Total farm energy production	905,885	MWh
Average annual farm energy production	36,235	MWh
Average annual WEC energy production	1,812	MWh

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Total O&M project costs	15,958,404	Euro
Average annual farm O&M cost	638,336	Euro
Average annual WEC O&M cost	31,917	Euro
Average time-based availability	56%	%
Average energy-based availability	56%	%
Capacity factor	18%	%

Project lifetime production and cost results significantly differ to (Chozas, Nielsen, & Pascal, 2022) estimates. The OPEX estimate for (Chozas, Nielsen, & Pascal, 2022) (€500,000/year/device or €403.23/year/kW) falls within the range indicated in (Fernandez Chozas, et al., 2015), €125-1350/kW/year for a first array and €90-450/kW/year for a second array. However, the model results in this deliverable are much lower (€25.53/kW/year). This could be for a combination of reasons.

Site accessibility is extremely challenging resulting in a low rate of maintenance occurring. This is represented by the time and energy-based availability of c. 56% and a capacity rate of 18%. This means low costs but ultimately low energy production (1,812MWh per WEC per year). (Chozas, Nielsen, & Pascal, 2022) figures assumed a capacity rate of 26% and annual energy production per WEC of 3,000MWh. (Fernandez Chozas, et al., 2015) figures for the second array assume a capacity factor of 30-35% and availability of 85-98%. It is expected that with increased accessibility, the model cost estimate and energy production would increase accordingly. This assumption will be tested in sections 10.1.2 and 10.1.3.

In addition to the above, the model does not currently consider a cost for vessel wait time at port. Considering the site accessibility issues, the inclusion of this parameter may significantly increase costs although it would not impact site availability and energy production. Other potential costs to include would be base costs for port usage, vessel fuel usage, as well as technician salaries. It would not be expected to significantly impact results since vessel charter rates are the primary cost driver, but their absence must be considered when reviewing the figures. (Têtu & Chozas, 2021) also suggest 6% of total OPEX costs are for site lease and insurance with 94% for actual maintenance. However, this would be a marginal increase in costs to €27.16/kW/year, and again no improvement in energy production.

10.1.2 Sensitivity analysis

Based on the above result several assumptions in the scenario were varied to determine their potential impact. 1 element was varied for each study. It should be noted that only 10 simulations were run for each sensitivity study due to limitations in time. A combined optimised scenario will be presented in section 10.1.3.

10.1.2.1 Increase weather restrictions to 2m Hs; 11 s Tp; and 16m/s wind speed and remove restrictions

Table 10.3 O&M results - Tower LiftWEC - Increased weather restrictions

Parameter	Value	Unit
Total farm energy production	1,011,678	MWh
Average annual farm energy production	40,467	MWh
Average annual WEC energy production	2,023	MWh

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Total O&M project costs	28,448,817	Euro
Average annual farm O&M cost	1,137,953	Euro
Average annual WEC O&M cost	56,898	Euro
Average time-based availability	58%	%
Average energy-based availability	58%	%
Capacity factor	18%	%

This results in an increased OPEX cost of 45.52/kW/year (up by 78%) and an increase of 12% in the production; 3% in availability; and 4% in the capacity factor. This suggests that accessibility is a key issue and increased weather windows are required. To further test this theory, all weather restrictions were removed. Results are as follows:

Table 10.4 O&M results - Tower LiftWEC - No weather restrictions

Parameter	Value	Unit
Total farm energy production	1,151,113	MWh
Average annual farm energy production	46,045	MWh
Average annual WEC energy production	2,302	MWh
Total O&M project costs	60,664,854	Euro
Average annual farm O&M cost	2,426,594	Euro
Average annual WEC O&M cost	121,330	Euro
Average time-based availability	66%	%
Average energy-based availability	66%	%
Capacity factor	21%	%

This results in a substantial increase across the board, verifying the impact accessibility has at this site. At first glance, you may expect an even higher increase in availability and power production with no weather restrictions. However, the device is still requiring a certain amount of maintenance based on the PM and failure rates assumed, requiring a considerable time onshore where no power is being produced. In addition, a single vessel may not be sufficient for 20 WECs with the number of failures occurring in this scenario. Therefore, the impact of failure rates, operation durations and the number of vessels have been tested in isolation in sections 10.1.2.2-10.1.2.4 and a combined optimised scenario will be presented in section 10.1.3.

10.1.2.2 A decrease of 20% in failure rates

Table 10.5 O&M results - Tower LiftWEC – Decrease failure rates (-20%)

Parameter	Value	Unit
Total farm energy production	1,011,917	MWh
Average annual farm energy production	40,477	MWh
Average annual WEC energy production	2,024	MWh
Total O&M project costs	16,363,891	Euro
Average annual farm O&M cost	654,556	Euro

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Average annual WEC O&M cost	32,728	Euro
Average time-based availability	58%	%
Average energy-based availability	58%	%
Capacity factor	18%	%

This has a similar impact on production, availability and capacity factor, but predictably less Corrective Maintenance results little cost change (only a 3% increase). Accurate failure rates for the specific LiftWEC device would increase confidence in results.

10.1.2.3 Increased the number of vessels available from 1 to 3

Table 10.6 O&M results - Tower LiftWEC – increased number of vessels available

Parameter	Value	Unit
Total farm energy production	884,503	MWh
Average annual farm energy production	35,380	MWh
Average annual WEC energy production	1,769	MWh
Total O&M project costs	46,395,584	Euro
Average annual farm O&M cost	1,855,823	Euro
Average annual WEC O&M cost	92,791	Euro
Average time-based availability	51%	%
Average energy-based availability	51%	%
Capacity factor	16%	%

Increased vessels available increase the cost by 191% (primarily due to the additional mobilisation/demobilisation costs). However, it has no positive impact on production suggesting the lack of vessels is not the key issue but rather the lack of weather windows.

10.1.2.4 Reduced the onshore and offshore operation times by 20%

Table 10.7 O&M results - Tower LiftWEC – Reduce on and offshore operation durations (-20%)

Parameter	Value	Unit
Total farm energy production	958,347	MWh
Average annual farm energy production	38,334	MWh
Average annual WEC energy production	1,917	MWh
Total O&M project costs	17,443,816	Euro
Average annual farm O&M cost	697,753	Euro
Average annual WEC O&M cost	34,888	Euro
Average time-based availability	55%	%
Average energy-based availability	55%	%
Capacity factor	17%	%

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Reduced onshore and offshore operation times could potentially increase the number of weather windows available. There is a small increase in production (6%) and costs (9%) indicating that more maintenance is occurring. However, strangely there is a slight reduction (<1%) in the availability and capacity factor. It is likely that this is due to the small number of simulations (10) compared to the base case study (100). Ultimately, it is likely the reduction in operation duration was not significant enough to impact results on their own. This is probably also true of the increase in vessels available. Therefore, the next section will consider a combination of variations, producing an optimised scenario.

10.1.3 Optimised scenario – 100 simulations

It can be assumed that the base case scenario is quite conservative along the lines of a pilot project. Improvements in technology reliability and learning from real offshore experience could result in an optimised scenario for an array scale of 25MW. Therefore, following sensitivity analysis the following variations inputs were applied to create an optimised scenario:

- Weather restrictions increased to 2m Hs; 11s Tp; 16m/s wind speed
- Failure rates reduced by 20%
- Reduced offshore operations to 2hrs duration
- Reduced onshore maintenance operations by 20%
- Increased vessel number available to 3

In addition, all Preventive Maintenance was removed. This decision was taken due to the model limitations and the site accessibility issues. Specifically, the current model does not consider any potential impact Preventive Maintenance could have on reducing the likelihood of failures. Therefore, it is simply an additional cost and downtime without any advantage in terms of avoiding unexpected failures. Therefore, at this stage it was deemed preferably to simply run the model without a PM scenario included. This also means that the model can better use resources to address Corrective Maintenance issues, which would improve energy production and availability.

It should be noted that while these inputs are considered possible assuming there has been considerable learning and further technology development from a pilot project, they are still only assumptions and would require more refinement and validation from industry and testing to increase confidence. Since the LiftWEC Tower LiftWEC requires a crane vessel, it may be difficult to get immediate access to 3 vessels of this type on a hire as required basis.

Table 10.8 O&M results - Tower LiftWEC – Optimised scenario

Parameter	Value	Unit
Total farm energy production	1,428,849	MWh
Average annual farm energy production	57,154	MWh
Average annual WEC energy production	2,858	MWh
Total O&M project costs	55,251,880	Euro
Average annual farm O&M cost	2,210,075	Euro
Average annual WEC O&M cost	110,504	Euro
Average time-based availability	82%	%
Average energy-based availability	82%	%
Capacity factor	26%	%

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Results are significantly increased with costs at €88/kW/year which is just outside the range of €90-450/kW/year quoted for a second array by (Fernandez Chozas, et al., 2015). This is still quite low, but availability is only 82% and capacity factor at 26% versus to expected range at this stage of 85-98% availability and 30-35% capacity factor. Site accessibility remains a key impediment to achieving the potential at this site. In addition, it should be remembered that this OPEX estimate does not include operational costs such as site lease and insurance; considering costs for vessel wait time at port; vessel fuel; base costs and technician salaries. D7.5 will review the absence of these costs and seek reasonable inputs for the assessment of the final configuration.

10.2 TLP LiftWEC

10.2.1 25MW Base Case

10.2.1.1 Installation

Table 10.9 Installation results – TLP LiftWEC – base case

Parameter	Value	Unit
Number devices	20	
Device rating	1250	kW
Farm capacity	25	MW
Installation	46,732,325	Euro
WEC	1,075,990	Euro
Substructure	35,479,435	Euro
Export cable	6,070,800	Euro
Inter-array cable	4,106,100	Euro
Average time	1.69	years
Number of simulations	1,000	
Installation - single WEC	2,336,616	Euro
Installation/kW	1,869	Euro

Installation costs are considerably greater than (Chozas, Nielsen, & Pascal, 2022) estimates (€1,259,000/WEC). However, assuming the same % of CAPEX (25%), a total CAPEX of 7,477/kW is in the range of the first and second array in (Fernandez Chozas, et al., 2015), €3,600-16,300 and €3240-13800 respectively, so could be considered a reasonable estimate.

Again, the time to install 20 devices is far longer than anticipated in (Chozas, Nielsen, & Pascal, 2022) (generally 3 extra days to consider waiting for weather windows), plus the addition of cable installation. Therefore, it is likely that the challenging accessibility of the site is responsible for the increased costs.

10.2.1.2 O&M

Table 10.10 O&M results - TLP LiftWEC – base case

Parameter	Value	Unit
Total farm energy production	928,489	MWh

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Average annual farm energy production	37,140	MWh
Average annual WEC energy production	1,857	MWh
Total O&M project costs	5,298,252	Euro
Average annual farm O&M cost	211,930	Euro
Average annual WEC O&M cost	10,597	Euro
Average time-based availability	56%	%
Average energy-based availability	56%	%
Capacity factor	17%	%

Estimated costs €10,597/year/WEC are significantly lower than estimates in (Chozas, Nielsen, & Pascal, 2022) (€250,000/year/WEC) and are far outside the range quoted in (Fernandez Chozas, et al., 2015). However, availability and capacity factor indicate that accessibility is proving an issue. Based on the sensitivity analysis undertaken for the LiftWEC Tower LiftWEC, an optimised scenario is presented in section 10.2.2.

10.2.2 Optimised scenario – 100 simulations

The optimised scenario for the TLP LiftWEC assumes the following:

- Weather restrictions increased to 2m Hs; 11s Tp; 16m/s wind speed
- Failure rates reduced by 20%
- Reduced offshore operations to 2hrs duration
- Reduced onshore maintenance operations by 20%
- Increased vessel number available to 3
- Removed PM tasks

It should be noted that while these inputs are considered possible assuming there has been considerable learning and further technology development from a pilot project, they are still only assumptions and would require more refinement and validation from industry and testing to increase confidence.

Results are presented below:

Table 10.11 O&M results - TLP LiftWEC – optimised

Parameter	Value	Unit
Total farm energy production	1,373,717	MWh
Average annual farm energy production	54,949	MWh
Average annual WEC energy production	2,747	MWh
Total O&M project costs	17,080,054	Euro
Average annual farm O&M cost	683,202	Euro
Average annual WEC O&M cost	34,160	Euro
Average time-based availability	83%	%
Average energy-based availability	83%	%
Capacity factor	25%	%

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There is a substantial increase across results although costs remain extremely low. However, availability and capacity factor are also still lower than would be expected for a first or second array deployment (85-98% availability and 30-35% capacity factor (Fernandez Chozas, et al., 2015)). Therefore, site accessibility remains a key impediment to achieving the potential at this site. In addition, it should be remembered that this OPEX estimate does not include operational costs such as site lease and insurance; considering costs for vessel wait time at port; vessel fuel; base costs and technician salaries. D7.5 will review the absence of these costs and seek reasonable inputs for the assessment of the final configuration.

10.3 SEMI-SUB LIFTWEC

10.3.1 25MW Base Case

10.3.1.1 Installation

Table 10.12 Installation results – Semi-sub LiftWEC

Parameter	Value	Unit
Number devices	20	
Device rating	1250	kW
Farm capacity	25	MW
Installation	29,280,845	Euro
WEC	1,048,485	Euro
Substructure	13,578,960	Euro
Export cable	9,425,600	Euro
Inter-array cable	5,227,800	Euro
Average time	1.54	years
Number of simulations	1,000	
Installation - single WEC	1,464,042	Euro
Installation/kW	1,171	Euro

Installation costs are considerably greater than (Chozas, Nielsen, & Pascal, 2022) estimates (€287,500/WEC). However, assuming the same % of CAPEX (7%), a total CAPEX of 16,732/kW is just outside the range of the first array in (Fernandez Chozas, et al., 2015), €3,600-16,300. It should also be noted that a significantly smaller proportion of CAPEX for installation was considered compared with the Tower LiftWEC and TLP LiftWEC based on (Chozas, Nielsen, & Pascal, 2022) estimates. Therefore, there is quite a lot of uncertainty surrounding this figure. However, assuming it is in the correct ballpark, it would be quite a pessimistic estimate for a floating concept. Given the time to install 20 devices despite the lower operation durations and higher weather restrictions for this scenario, it is likely that site accessibility is the main cause for the comparatively high costs of installation.

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10.3.1.2 O&M

Table 10.13 O&M results – Semi-sub LiftWEC – base case

Parameter	Value	Unit
Total farm energy production	893,969	MWh
Average annual farm energy production	35,759	MWh
Average annual WEC energy production	1,788	MWh
Total O&M project costs	4,728,026	Euro
Average annual farm O&M cost	189,121	Euro
Average annual WEC O&M cost	9,456	Euro
Average time-based availability	55%	%
Average energy-based availability	55%	%
Capacity factor	16%	%

Estimated costs €9,456/year/WEC are significantly lower than estimates in (Chozas, Nielsen, & Pascal, 2022) (€125,000/year/WEC) and are far outside the range quoted in (Fernandez Chozas, et al., 2015). However, availability and capacity factor indicate that accessibility is proving an issue. Based on the sensitivity analysis undertaken for the LiftWEC Tower LiftWEC, an optimised scenario is presented in section 10.3.2.

10.3.2 Optimised scenario – 100 simulations

The optimised scenario for the Semi-sub LiftWEC assumes the following:

- Weather restrictions increased to 2.5m Hs; 11s Tp; 16m/s wind speed
- Failure rates reduced by 20%
- Reduced offshore operations to 1.6hrs duration
- Reduced onshore maintenance operations by 20%
- Increased vessel number available to 3
- Removed PM tasks

This is slightly different to the Tower LiftWEC and TLP LiftWEC optimised scenarios owing to the higher weather restrictions and shorter offshore operation durations already assumed in the base case scenario for the Semi-sub and Spar LiftWEC configurations.

It should be noted that while these inputs are considered possible assuming there has been considerable learning and further technology development from a pilot project, they are still only assumptions and would require more refinement and validation from industry and testing to increase confidence. In particular, the weather restriction of 2.5m Hs may be too optimistic.

Results are presented below:

Table 10.14 O&M results – Semi-sub LiftWEC – optimised

Parameter	Value	Unit
Total farm energy production	1,308,553	MWh

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Average annual farm energy production	52,342	MWh
Average annual WEC energy production	2,617	MWh
Total O&M project costs	8,228,974	Euro
Average annual farm O&M cost	329,159	Euro
Average annual WEC O&M cost	16,458	Euro
Average time-based availability	81%	%
Average energy-based availability	81%	%
Capacity factor	24%	%

There is a substantial increase across results although costs remain extremely low. However, availability and capacity factor are also still lower than would be expected for a first or second array deployment (85-98% availability and 30-35% capacity factor (Fernandez Chozas, et al., 2015)). Therefore, site accessibility remains a key impediment to achieving the potential at this site. In addition, it should be remembered that this OPEX estimate does not include operational costs such as site lease and insurance; considering costs for vessel wait time at port; vessel fuel; base costs and technician salaries. D7.5 will review the absence of these costs and seek reasonable inputs for the assessment of the final configuration.

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10.4 Spar LiftWEC

10.4.1 25MW Base Case

10.4.1.1 Installation

Table 10.15 Installation results – Spar LiftWEC

Parameter	Value	Unit
Number devices	20	
Device rating	1250	kW
Farm capacity	25	MW
Installation	27,289,525	Euro
WEC	892,485	Euro
Substructure	13,178,940	Euro
Export cable	8,257,000	Euro
Inter-array cable	4,961,100	Euro
Average time	1.47	years
Number of simulations	1,000	
Installation - single WEC	1,364,476	Euro
Installation/kW	1,092	Euro

Installation costs are considerably greater than (Chozas, Nielsen, & Pascal, 2022) estimates (€307,000/WEC). However, assuming the same % of CAPEX (7%), a total CAPEX of 15,594/kW is just within range of the first array in (Fernandez Chozas, et al., 2015), €3,600-16,300. It should also be noted that a significantly smaller proportion of CAPEX for installation was considered compared with the Tower LiftWEC and TLP LiftWEC based on (Chozas, Nielsen, & Pascal, 2022) estimates. Therefore, there is quite a lot of uncertainty surrounding this figure. However, assuming it is in the correct ballpark, it would be quite a pessimistic estimate for a floating concept. Given the time to install 20 devices despite the lower operation durations and higher weather restrictions for this scenario, it is likely that site accessibility is the main cause for the comparatively high costs of installation.

10.4.1.2 O&M

Table 10.16 O&M results – Semi-sub LiftWEC – base case

Parameter	Value	Unit
Total farm energy production	920,682	MWh
Average annual farm energy production	36,827	MWh
Average annual WEC energy production	1,841	MWh
Total O&M project costs	4,619,205	Euro
Average annual farm O&M cost	184,768	Euro
Average annual WEC O&M cost	9,238	Euro
Average time-based availability	56%	%
Average energy-based availability	56%	%
Capacity factor	16%	%

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Estimated costs €9,238/year/WEC are significantly lower than estimates in (Chozas, Nielsen, & Pascal, 2022) (€125,000/year/WEC) and are far outside the range quoted in (Fernandez Chozas, et al., 2015). However, availability and capacity factor indicate that accessibility is proving an issue. Based on the sensitivity analysis undertaken for the LiftWEC Tower LiftWEC, an optimised scenario is presented in section 10.4.2.

10.4.2 Optimised scenario – 100 simulations

The optimised scenario for the Spar LiftWEC assumes the following:

- Weather restrictions increased to 2.5m Hs; 11s Tp; 16m/s wind speed
- Failure rates reduced by 20%
- Reduced offshore operations to 1.6hrs duration
- Reduced onshore maintenance operations by 20%
- Increased vessel number available to 3
- Removed PM tasks

This is slightly different to the Tower LiftWEC and TLP LiftWEC optimised scenarios owing to the higher weather restrictions and shorter offshore operation durations already assumed in the base case scenario for the Semi-sub and Spar LiftWEC.

It should be noted that while these inputs are considered possible assuming there has been considerable learning and further technology development from a pilot project, they are still only assumptions and would require more refinement and validation from industry and testing to increase confidence. In particular, the weather restriction of 2.5m Hs may be too optimistic.

Results are presented below:

Table 10.17 O&M results – Semi-sub LiftWEC – optimised

Parameter	Value	Unit
Total farm energy production	1,401,953	MWh
Average annual farm energy production	56,078	MWh
Average annual WEC energy production	2,804	MWh
Total O&M project costs	11,507,477	Euro
Average annual farm O&M cost	460,299	Euro
Average annual WEC O&M cost	23,015	Euro
Average time-based availability	85%	%
Average energy-based availability	85%	%
Capacity factor	26%	%

There is a substantial increase in results although costs remain extremely low. However, availability and capacity factor are also still lower than would be expected for a first or second array deployment (85-98% availability and 30-35% capacity factor (Fernandez Chozas, et al., 2015)). Therefore, site accessibility remains a key impediment to achieving the potential at this site. In addition, it should be remembered that this OPEX estimate does not include operational costs such as site lease and insurance; considering costs for vessel wait time at port; vessel fuel; base costs and technician salaries.

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D7.5 will review the absence of these costs and seek reasonable inputs for the assessment of the final configuration.

11 CONCLUSION - COMPARISON OF THE 4 BASELINE CONFIGURATIONS

Results for the installation and optimised O&M scenario are summarised in Table 11.1. Key results are highlighted in grey from light to dark in order of preference to help illustrate the following conclusions.

While OPEX costs are undoubtedly not considering all elements, they are comparative across the configurations since they all use the same core assumptions and model. Therefore, while OPEX results are considerably lower than expected, they do indicate that the TLP LiftWEC has significant advantages over the Tower LiftWEC. The primary difference is the use of cheaper vessels, and this key advantage is demonstrated again in the lower installation costs and in results for the Semi-sub and Spar LiftWEC configurations.

The advantage of the Tower LiftWEC is the increased power production due to the increased stability and controls. However, a comparison of the 4 baseline configurations indicates that the Spar-buoy LiftWEC has the lowest installation cost and fastest installation time; and the second lowest OPEX costs; highest availability; and a capacity factor and energy production that nearly matches the Tower LiftWEC. This is due to

- the use of smaller, cheaper vessels to deploy and retrieve the device
- having a simple connection/disconnection procedure that requires minimal time offshore
- the shorter offshore activities can be done at higher weather restrictions leading to more weather windows and improved accessibility.

Also considering it also had the lowest total CAPEX estimate in (Chozas, Nielsen, & Pascal, 2022), it is likely that the Spar-buoy LiftWEC configuration would produce the lowest LCoE.

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Table 11.1 Comparison of the 4 baseline configurations

Parameter	Unit	Tower	TLP	Semi-sub	Spar Buoy
Project lifetime	years	25	25	25	25
Number devices	integer	20	20	20	20
Device rating	kW	1250	1250	1250	1250
Farm capacity	MW	25	25	25	25
Installation (1000 simulations)					
Total installation cost	Euro	**105,441,432**	**46,732,325**	**29,280,845**	**27,289,525**
WEC	Euro	24,872,112	1,075,990	1,048,485	892,485
Substructure	Euro	65,396,520	35,479,435	13,578,960	13,178,940
Export cable	Euro	10,606,300	6,070,800	9,425,600	8,257,000
Inter-array cable	Euro	4,566,500	4,106,100	5,227,800	4,961,100
Average time	years	**2.62**	**1.69**	**1.54**	**1.47**
Installation - single WEC	Euro	5,272,072	2,336,616	1,464,042	1,364,476
Installation/kW	Euro	**4,218**	**1,869**	**1,171**	**1,092**
O&M (100 simulations)					
Total farm energy production	MWh	**1,428,849**	**1,373,717**	**1,308,553**	**1,401,953**
Average annual farm energy production	MWh	57,154	54,949	52,342	56,078
Average annual WEC energy production	MWh	2,858	2,747	2,617	2,804
Total O&M project costs	Euro	**55,251,880**	**17,080,054**	**8,228,974**	**11,507,477**
Average annual farm O&M cost	Euro	2,210,075	683,202	329,159	460,299
Average annual WEC O&M cost	Euro	110,504	34,160	16,458	23,015
Average annual O&M cost/kW	Euro	88	27	13	18
Average time-based availability	%	**82%**	**83%**	**81%**	**85%**
Average energy-based availability	%	**82%**	**83%**	**81%**	**85%**
Capacity factor	%	**26%**	**25%**	**24%**	**26%**

12 BIBLIOGRAPHY

Chozas, J. F., Nielsen, K., & Pascal, R. (2022). *Deliverable 8.4 LCOE estimate of Baseline Configurations.* LiftWEC project.

Danish Energy Agency and Energinet. (2016). *Technology Data–Energy Plants for Electricity and District Heating Generation.* Copenhagen, Denmark: Danish Energy Agency and Energinet.

DEME Group. (2022). *Technology - Rambiz*. Retrieved 07 29, 2022, from DEME Group: https://www.deme-group.com/technologies/rambiz#

European Commission. (2020). *An EU Strategy to Harness the Potential of Offshore Renewable Energy for a Climate Neutral Future.* Brussels. Belgium: European Commission. Retrieved 07 15, 2022, from https://ec.europa.eu/energy/sites/ener/files/ offshore_renewable_energy_st

European Commission SET Plan Secretariat. (2016). *SET Plan–Declaration of Intent on Strategic Targets in the Context of an Initiative for Global Leadership in Ocean Energy.* Brussels, Belgium: European Commission. Retrieved 07 15, 2022, from https://setis.ec.europa.eu/implementing-actions/set-plan-documents_en

Fernandez Chozas, J., MacGillivray, A., Raventos, A., Jeffrey, H., Nielsen, K., & Aderibigbe, D. (2015). *International Levelised Cost of Energy for Ocean Energy Technologies.* Lisbon, Portugal: Ocean Energy Systems (OES).

Flannery, B. (2020). *D7.2 Development of Models and Operations Framework.*

Flannery, B. (2020). *Deliverable 7.3 Assessment of Preliminary configurations.* LiftWEC project.

Flannery, B. (2020). *Deliverable D7.1 Operational Design Considerations.* LiftWEC project.

Gray, A., Dickens, B., Bruceclan, T., Ashton, I., & Johanning, L. (2017). Reliability and O&M sensitivity analysis as a consequence of site specific characteristics for wave energy converters. *Ocean Engineering, 141*, 493-511.

Jalili, S., Maheri, A., & Ivanovic, A. (2022). *Cost Modelling for Offshore Wind Farm Decommissioning.* Interreg European Commission.

JanDeNul. (2019). *Simon Stevin.* Retrieved 11 12, 2019, from https://www.jandenul.com/sites/default/files/equipment-item/pdfs/05.sriv_en_-_v2013-2_-_simon_stevin.pdf

Judge, F., McAuliffe, F. D., Sperstad, I. B., Chester, R., Flannery, B., Lynch, K., & Murphy, J. (2019). A lifecycle financial analysis model for offshore wind farms. *Renewable and Sustainable Energy Reviews, 103*, pp. 370-383.

Kaiser, M., & Snyder, a. B. (2011). *Offshore Wind Energy Installation and Decommissioning Cost Estimation in the U.S. Outer Continental Shelf. .* U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Herndon, VA. TA&R study .

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McAuliffe, F. D., Lynch, K., Sperstad, I., Nonås, L., Halvorsen-Weare, E., Jones, D., . . . Murphy, J. (2018). The LEANWIND suite of logistics optimisation and full lifecycle simulation models for offshore wind farms. *Journal of Physics: Conference Series, 1104*.

Ocean Energy Systems (OES). (2019). *Cost of Ocean Energy: Energy Cost Analysis and Forecasts for Ocean Energy Converters.* Lisbon, Portugal: OES.

Subsea Micropiles. (2022). *Technology*. Retrieved 07 29, 2022, from Subsea Micropiles: https://subseamicropiles.com/technology/

Têtu, A., & Chozas, J. F. (2021). A Proposed Guidance for the Economic Assessment of Wave Energy Converters at Early Development Stages. *Energies, 14*(4699), 1-14.

Têtu, A., & Fernandez Chozas, J. (2020). *Deliverable D8.1-Cost Database. Technical Report, LiftWEC– Development of a New Class of Wave Energy Converter Based on Hydrodynamic Lift Forces.*

Van Oord. (2020). *Updates*. Retrieved 07 29, 2022, from Van Oord: https://www.vanoord.com/en/updates/van-oords-heavy-lift-installation-vessel-svanen-has-arrived-kriegers-flak-wind-farm/

WindEurope. (2017). *Unleashing Europe's Offshore Wind Potential.* Brussels, Belgium: WindEurope.

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