SELKIE

Modified Installation, Operations, Maintenance and Logistics model for Irish and Welsh wave and tidal technologies and locations

Work Package 8: Installation, Operations & Maintenance and Logistic models

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Abbreviations

CM	Corrective maintenance
EBA	Energy-base availability
LCOE	Levelized Cost of Energy
MC	Monte Carlo Simulation
O&M	Operation and Maintenance
OE	Ocean Energy
ORE	Offshore Renewable Energy
PM	Preventative maintenance
TBA	Time-base availability
TEC	Tidal Energy Converter
TRL	Technology Readiness Level
WEC	Wave Energy Converter
WES	Wave Energy Scotland
WW	Weather Window

Table of Contents

List of Tables

Table of Figures

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. [1]. With no convergence or commercially proven wave energy technology, this will be an extremely challenging task.

The SELKIE project aims to aid the wave and tidal energy industry in accelerating the deployment and commercialisation of technology, specifically in the Irish and Welsh regions. The project activity will establish a cross-border network of developers and supply chain companies in Ireland and Wales and create a set of multi-use technology, engineering and operation tools, templates, standards and models for use across this sector. Selkie will test and validate the technology tools on two pilot demonstration technologies, one wave and one tidal. Project resources will be used to undertake meaningful technology transfer of these tools and they will be made open access post-project.

This suite of tools includes the SELKIE O&M and logistics model, which allows users to model operations across a project lifecycle, determining energy production and costs. The model uses Monte Carlo simulation, varying weather and failure rates for each iteration, to account for the impact of these uncertain factors. The tool allows users to optimise the logistics required for the installation and O&M phase e.g. the selection of ports, offshore vessel fleet, operational strategy etc. Building on learning from existing models, it provides stakeholders an open access, user-friendly, and flexible tool that can be applied to a wide range of wave and tidal technologies. Outputs can be used as inputs into the SELKIE GIS TE tool to determine the overall financial viability of the project scenario by providing determinants such as Levelised Cost of Energy (LCoE).

A detailed description of this tool can be found in Deliverable 8.2. The tool can be accessed at https://github.com/fdevoymcauliffe/Selkie including a sample study with user guides and video tutorials for model setup at https://www.youtube.com/watch?v=MfNGgdKoQ3s and the application using the sample study at https://www.youtube.com/watch?v=HhsyKylzwPI. The sample is based on the Pelamis2 device and FarrPoint metocean data provided as part of the Wave Energy Scotland model [2] and summarised in Gray et. Al [3]. This tool was tested with the aid of two validation case studies, determined with the help of OceanEnergy and Sabella as well as wider industry consultation via workshops. The details of the validation case study are IP sensitive and cannot be detailed in a public deliverable. However, this report presents a generalised wave and a tidal array scenario, developed based on the validation case studies and using a Welsh and an Irish site to a) demonstrate the application of the SELKIE tool and b) provide industry with recommendations and advice for developing a commercial wave and tidal energy array in these locations.

Using the SELKIE O&M and logistics tool, the report will examine the estimated energy production, installation and OPEX costs for a Wave Energy Converter (WEC) pilot farm based on a generic oscillating water column device. The scenario uses the OE Buoy device matrix found in [4]. It will then look at a second stage deployment and a full-scale commercial deployment, highlighting advantages of scaling up as well as potential challenges and bottlenecks, ultimately providing recommendations and advice for developers. D8.4 will undertake a similar exercise for tidal technology, while an optimised O&M and logistics scenario for each site and wave and tidal technology will be presented in D8.5.

When reviewing the scenarios, it is important to remember that these are generic case studies. The information is primarily publicly available data, adapted based on educated estimates with the aid of industry input and advice. This is due to the IP-sensitive nature of information used in the validation case studies, but also the lack of real operational data, given the limited offshore experience for wave and tidal energy technologies. Further experience and information would increase confidence in the inputs and the subsequent model results. However, the SELKIE tool's ability to run user-defined scenarios in a timely fashion, provides an extremely useful baseline for industry to begin examining and adapting their strategies.

2 Wave energy case study – Ireland and Wales

2.1 Site selection and data

Two case study sites were selected in consultation between WP4, 8 and industry participants as summarised in Table 2.1.

Table 2.1 SELKIE - wave and tidal generic case studies

Location	Technology	Site	Data years	Port	Distance Port to site
Ireland	Wave – oscillating water column with drag embedment anchors	West Wave Lat 52.745°N Lon 9.729°W	2000-2019	Foynes	45km
Wales	Wave – oscillating water column with drag embedment anchors	West Pembrokeshire Lat 51.475°N Lon 5.134°W	2000-2019	Pembroke Dock	27km

Data was provided by the GIS Technoeconomic tool (WP4) and was sourced as follows:

2.1.1 Wind Data

The ECMWF ERA5 dataset was chosen to model the wind climate. The product combines vast amounts of historical observations into global estimates using advanced modelling and data assimilation systems. It covers the entire globe, with a spatial resolution of ~ 30 km and an hourly temporal resolution (one value every hour). The variables downloaded were the '10m U-component of wind (u10)' and the '10m V-component of wind (v10)'. These were manipulated in MATLAB to give the wind speed (m/s). The time series applied was 2000-01-01 00:00:00 to 2019-12-30 23:00:00.

Link to data source:

https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

2.1.2 Wave Data

The Atlantic – Iberian Biscay Irish – Ocean Wave Reanalysis (Product Identifier - IBI_MULTIYEAR_WAV_005_006) was used to model the wave climate. The model is based on the MFWAM model developed by Meteo-France (MF). It is fed by the ERA 5 reanalysis wind data from ECMWF, covers the extents 19°W – 5°W; 56°N – 26°N and has a spatial resolution of 0.05° x 0.05°, or ~ 3 to 5 km. It has an hourly temporal resolution. The variables used were 'Spectral significant wave height (Hm0)', 'Spectral moments (-1,0) wave period (Tm-10)' and 'Wave period at spectral peak / peak period (Tp)'. The time series applied was 2000-01-01 00:00:00 to 2019-12-30 23:00:00.

Link to data source:

https://resources.marine.copernicus.eu/product-detail/NWSHELF_REANALYSIS_WAV_004_015/INFORMATION

2.1.3 Site location

Figure 2.1 and Figure 2.2 illustrate the site and port location for the 2 wave energy technology case study sites: West Pembrokeshire and West Wave respectively.

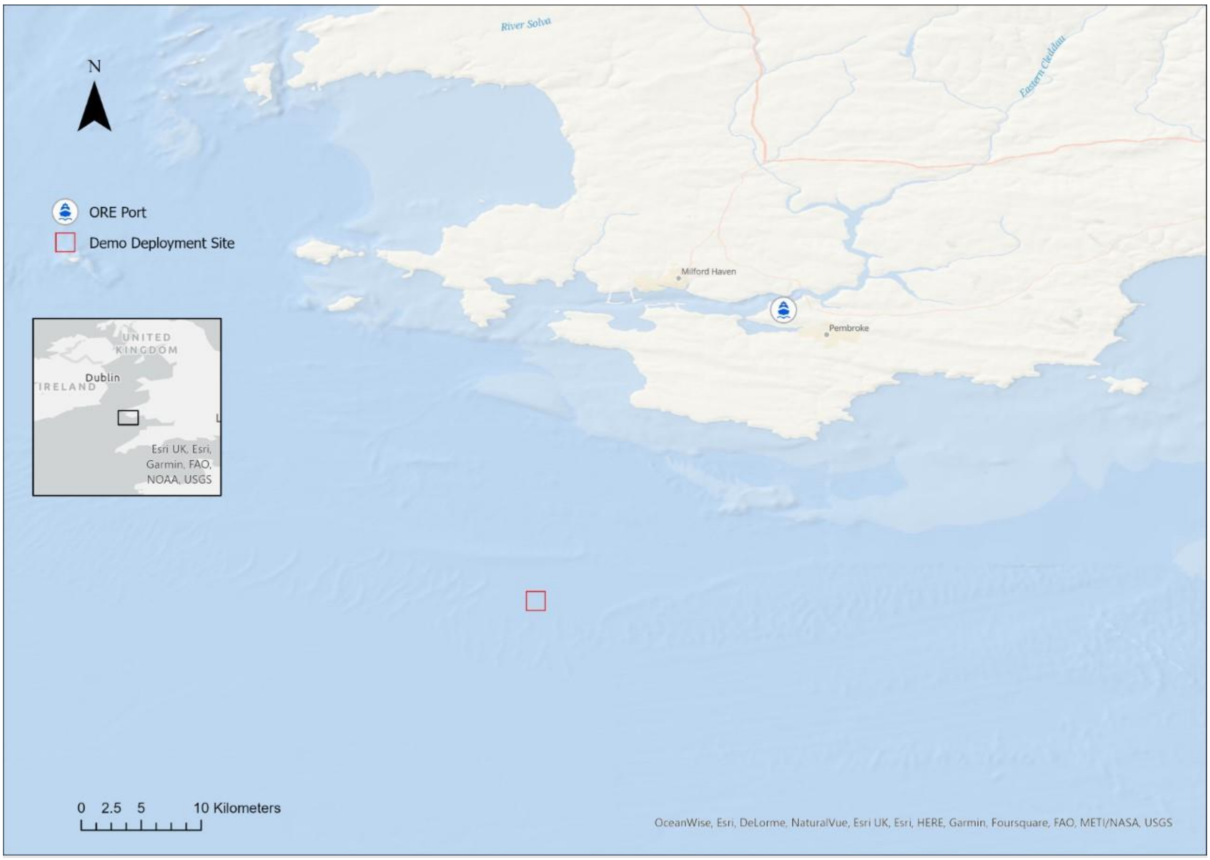

Figure 2.1 West Pembrokeshire - demo deployment site and ORE port.

Figure 2.2 West Wave - demo deployment site and ORE port.

Table 2.2 and Figure 2.3 provide an overview of site statistics based on 20 years of data. This overview indicates that the West Wave site has more dynamic conditions with an average significant wave height (Hs) of 2.34m and wave period (Tp) of 10.86s versus 1.75m Hs and 9.55s Tp at West Pembrokeshire. This could potentially lead to higher production, provided the West Wave site accessibility allows for good device production availability.[1]

Table 2.2 Site statistics.

	Unit	Average	Max	Min	Std	75th percentile	50th percentile	25th percentile
West Pembroke-shire Site	Hs(m)	1.75	10.03	0.16	1.11	2.27	1.47	0.94
	Tp (s)	9.55	23.48	2.07	2.95	11.50	9.58	7.53
West Wave Site	Hs(m)	2.34	11.96	0.26	1.44	3.02	2.00	1.29
	Tp (s)	10.86	23.57	2.90	2.47	12.41	10.72	9.10

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[1] Availability is a) the amount of time a device is available to produce energy divided by the amount of time in the period or b) the amount of energy a device produces divided by the potential energy production in the period assuming zero interruption i.e. downtime.

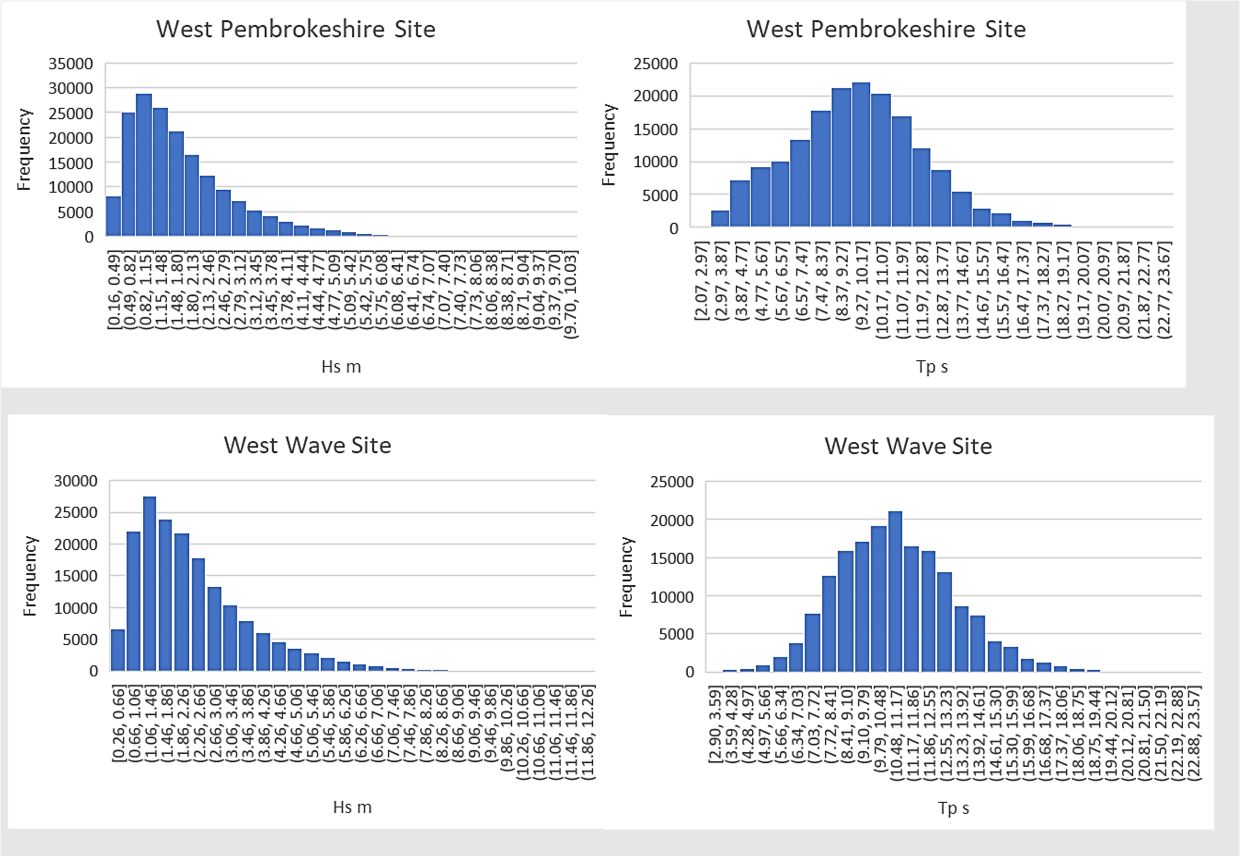

Figure 2.3 Site statistics.

2.2 Overview of case studies

Table 2.3-Table 2.9 provide details of the inputs used for each case study. Table 2.3-Table 2.7 include inputs common to both, while Table 2.8-Table 2.9 outline inputs that vary between studies. Inputs have been determined based on discussions with industry; assumptions based on experience and expertise from previous projects; and particularly using the case study detailed for the Pelamis P2 device in [3]. However, it should be noted that any figures provided by industry have been generalised and all inputs must be viewed as a "best guess." The aim is to provide a realistic scenario that could be further improved with increased industry validation and direct offshore experience.

Table 2.3 Project, device & base.

Item	**Unit**	**Value**
Project lifetime	*years*	25
Losses	*%*	2
Device	*text*	Oscillating Water Column [4]
Distance between devices	*km*	0.8
Annual technician salary	*€*	50,000

Table 2.4 Vessels.

Item	Unit	Value	Value	Value
Vessel classification	*text*	Multi-purpose Workboat (MW)	2 tugs (tug)	Anchor Handling Tug Vessel (AHTV)
Technician capacity	*number*	8	8	12
Nightwork	*Yes/No*	No	No	No
Hire as required	*Yes/No*	Yes	Yes	Yes
Daily rental cost	*€*	4,000	10,000	30,000
Mobilisation cost	*€*	8,000	20,000	60,000
Fuel consumption	*l/hr*	100	100	250
Fuel cost	*€/l*	0.5	0.5	0.5
Vessel speed	*knots*	18	8	12

Table 2.5 Installation strategy.

Item	Unit	Value
Substructure		
Technicians required	*number*	4
Vessel	*text*	AHTV
Number per vessel	*number*	1
Operation duration	*hours*	48
Wave height limit	*m*	1.5
Wave period limit	*s*	8
Wind speed limit	*m/s*	12
Device		
Technicians required	*number*	6
Vessel	*text*	2 tugs
Number per vessel	*number*	1
Operation duration	*hours*	3
Wave height limit	*m*	1.5
Wave period limit	*s*	8
Wind speed limit	*m/s*	12

Table 2.6 Repair categories.

Item	Unit	Value	Value	Value	Value
Repair category	*text*	Type1	Type2	Type3	Type4
Task description	*text*	CM	CM	CM	CM
Number of technicians required	*number*	2	4	4	2
Vessel	*text*	MW	tug	tug	tug
Operation location	*text*	Offshore	Onshore	Onshore	Onshore
Operation duration – offshore	*hours*	6	30	30	3
Operation duration - onshore	*hours*	n/a	300	240	48
Wave height limit	*m*	1.5	1	1	1.5
Wave period limit	*s*	8	8	8	8
Wind speed limit	*m/s*	12	12	12	12

Table 2.7 Components.

Item	Component name	Number per device	Annual failure rate[2]	Repair category	Spare part/consumable cost
Unit	*text*	*number*	*number*	*text*	€
Value	Minor mooring line	6	0.1	Type 1	10000
Value	Mooring replacement	6	0.2	Type 2	33000
Value	Turbine bearing	2	0.04	Type 1	6700
Value	Major structural	1	0.04	Type 2	1700000
Value	Major mooring failure	6	0.04	Type 2	67000
Value	Minor structural	1	0.03	Type 4	10000
Value	Minor electrical	1	1.45	Type 1	6700
Value	Major electrical	1	0.04	Type 3	80000
Value	Generator	1	0.73	Type 1	6700

Table 2.8 Case study specific inputs (a).

Case study number	Site	Port – location/distance (km)	Device rating (kW)[3]	Number of devices	Farm capacity (MW)
CS1.1	West Wave	Foynes/45km	1440	1	1.44
CS1.2	West Pembrokeshire	Pembroke/27km	1440	1	1.44
CS2.1	West Wave	Foynes/45km	1440	10	14.4
CS2.2	West Pembrokeshire	Pembroke/27km	1440	10	14.4
CS3.1	West Wave	Foynes/45km	1440	50	72
CS3.2	West Pembrokeshire	Pembroke/27km	1440	50	72
CS4.1	West Wave	Foynes/45km	2880	50	144
CS4.2	West Pembrokeshire	Pembroke/27km	2880	50	144

Table 2.9 Case study specific inputs (b).

Case study number	Annual base costs	Number of technicians	Number of Vessels	Additional installation costs	Additional OPEX costs
CS1.1 & 1.2	60,000	8	1 of each	10% of total	10% of total
CS2.1 & 2.2	180,000	12	2 of each	10% of total	10% of total
CS3.1, 3.2, 4.1 & 4.2	250,000	36	6 of each	10% of total	10% of total

Spare part/consumables costs increase by 50% to consider a larger device in CS4.1 and 4.2. In addition, it is assumed that as the size of the farm increases, the annual port/base costs (e.g. rental of offices and space, use of equipment etc.); number of technicians; and number of

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[2] Failure rates are primarily based on [4] and [10] with a mix of industry expertise to adjust them for a general OWC- type WEC assumed in this case study.

[3] While the reference device used is rated 2880kW, it is assumed that a pilot demonstration project device would be smaller. Therefore, the matrix has been divided by 2 and a device rated at 1440kW is assumed for CS1-3. CS4 will look at the potential impact of increasing device size and capacity.

vessels available will also increase. An additional installation cost and an additional OPEX cost have been included in the scenarios to account for elements including a) project management, insurance and contingency costs for installation and b) general operations costs for OPEX e.g. insurance and site lease. Estimates are based on experience of similar indicative figures in the offshore wind industry but have not been validated. At this time, they are meant to indicate a proportionate growth in fixed cost.

It should be noted that the model only considers the device and substructure. According to [5], installation of the turbine and substructure for an offshore wind turbine equates to 23% of the total installation cost (Figure 2.4). Therefore, results were adapted to consider an additional 77%.

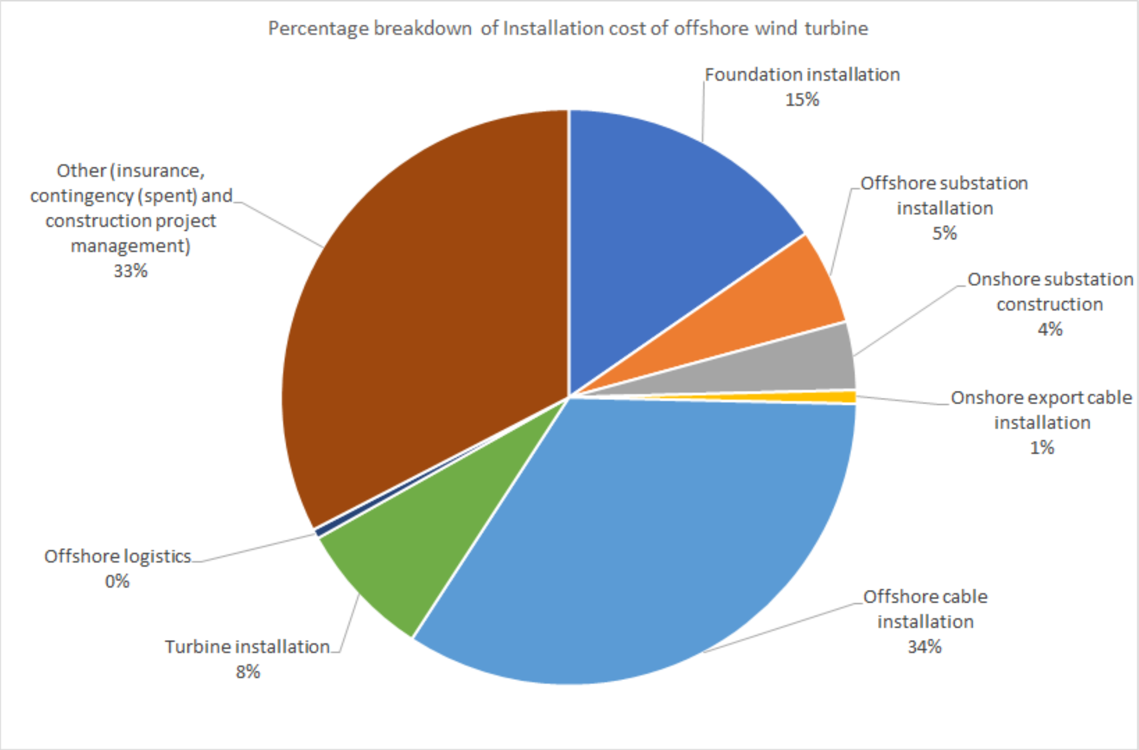


Figure 2.4 Installation cost breakdown for 1GW offshore Wind Farm [5].

2.3 Results - summary

10 simulations were run for each case study. The average across all simulations is presented in Table 2.10.

Table 2.10 Case study results – overview.

Scenario	Installation cost – turbine and substructure €/kW	Installation cost €/kW	OPEX €/year/kW	OPEX €/kWh	Average Annual Energy (MWh)	Time-based Availability
CS1.1	448.37	1949	389	0.54	1,030	90%
CS1.2	448.12	1948	394	0.96	589	95%
CS2.1	106.15	462	93	0.13	10,032	87%
CS2.2	105.90	460	99	0.25	5,669	91%
CS3.1	102.79	447	63	0.10	47,167	83%
CS3.2	69.08	300	69	0.18	28,175	90%
CS4.1	51.39	223	34	0.05	95,096	81%
CS4.2	34.54	150	38	0.10	56,741	89%

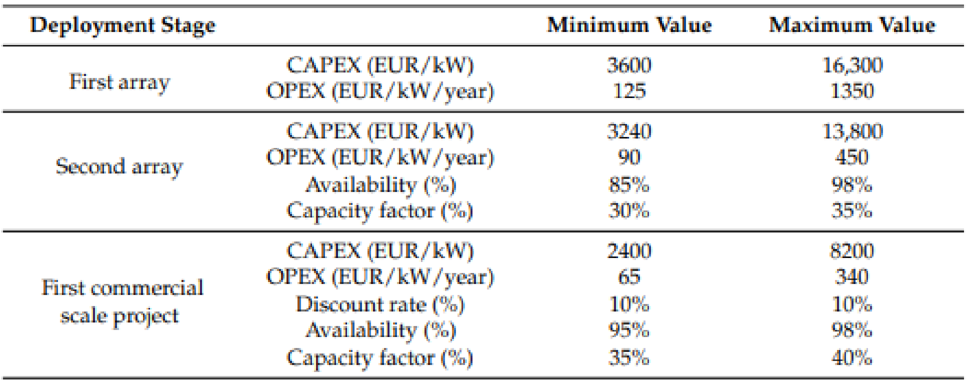
Results clearly indicate that conditions at the Irish West Wave site have more power production potential compared to the Welsh site across the 4 scenarios. However, West Wave also has more challenges in terms of access for maintenance since availability is consistently lower than case studies at West Pembrokeshire. Results also indicate that as the size of farm increases, availability is a growing challenge despite the increased vessels and technicians available. Sensitivity analysis was conducted to determine the optimal number of vessels and technicians required to achieve a high availability. However, improvements are limited and, once a ceiling has been reached, larger farms need to focus on improving availability through other means in order to maximise energy production and profit. Section 3 provides a full review of results, placing them in the wider context of industry estimates and expectations, as well as analysing the lessons these case studies may have for developers.

3 Validation and analysis

3.1 Validation

As outlined in the introduction, the model has been tested with the aid of two validation case studies, determined with the help of OceanEnergy and Sabella as well as wider industry consultation via workshops. The primary objectives were to ensure that the model could simulate accurate use cases and that it is working correctly. These objectives were achieved. The details of the validation case study are IP sensitive and cannot be detailed in a public deliverable. Therefore, the scenario used for this case study is a generalised wave energy array scenario, developed based on the wave validation case study and studies in the existing literature. It is important to note that given the generalised nature of the scenario, results must be viewed as indicative figures. However, to determine whether they are within a reasonable range, this section compares results with estimated costs provided in the literature.

[6] reviewed estimated costs for WEC technologies at TRL6 in conjunction with stakeholders considering 3 development stages, first array (e.g. 1-2 devices for a pilot project), second array (e.g. 5-10 devices), and commercial scale (>100MW). The study assumed the cost of a generic WEC. [7] summarise results in Figure 3.1.



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 3.1 An example of estimated CAPEX and OPEX values for different deployment stages [7].

[8] have provided an extensive database reviewing cost estimates for wave energy projects. Based on this, [7] estimate that the installation and commissioning costs for installing a foundation or moorings, offshore substation, WEC and cables typically range from 8-17% of CAPEX. Using these assumptions, installation could be anywhere between

- €288-2771/kW for a first array;
- €259.2-2346/kW for a second array; and
- €192-1394/kW for a first commercial scale project.

OPEX costs considering annual maintenance as well as general operational costs (e.g. insurance, port costs, office rental etc.) are estimated to be between:

- €125-1350/kW/year for a first array;
- €90-450/kW/year for a second array; and
- €65-340/kW/year for a commercial project.

While no availability % estimate is quoted for the pilot array; it is expected that an availability of 85-98% would be achievable for a second array; increasing to 95-98% availability for a first commercial scale project.

These figures are large ranges and must be viewed as a best guess estimate given the lack of real offshore experience or a specific technology. However, while full validation is not possible at this stage of wave energy technology development, these estimates are useful to determine whether our model results are within expected ranges. Where they do not, this may highlight whether there are potential issues with the scenarios and data used; the model logic and/or assumptions; and/or industry estimates themselves.

Figure 3.2 suggests that while they are within expected ranges according to [7], OPEX costs for the pilot study are on the lower side of estimates. BVG Associates “Guide to an offshore wind farm” ([5]) assumes that annual maintenance and service activities for the device equates to approximately 43% of the total annual OPEX costs (Figure 3.3). The wave scenarios currently consider maintenance of the device and the substructure (mooring lines), as well as some operational costs in terms of technicians and base costs, plus an additional 10% of the total OPEX. Operational costs require further validation to increase confidence and the scenario does not consider maintenance of the electrical system. This may be the reason for the low OPEX results. However, they may also illustrate the economic advantages of using smaller, cheaper vessels to install and maintain floating devices compared to expensive Heavy Lift Vessels (HLVs) or DP vessels required for fixed structures (e.g. fixed offshore wind or tidal).

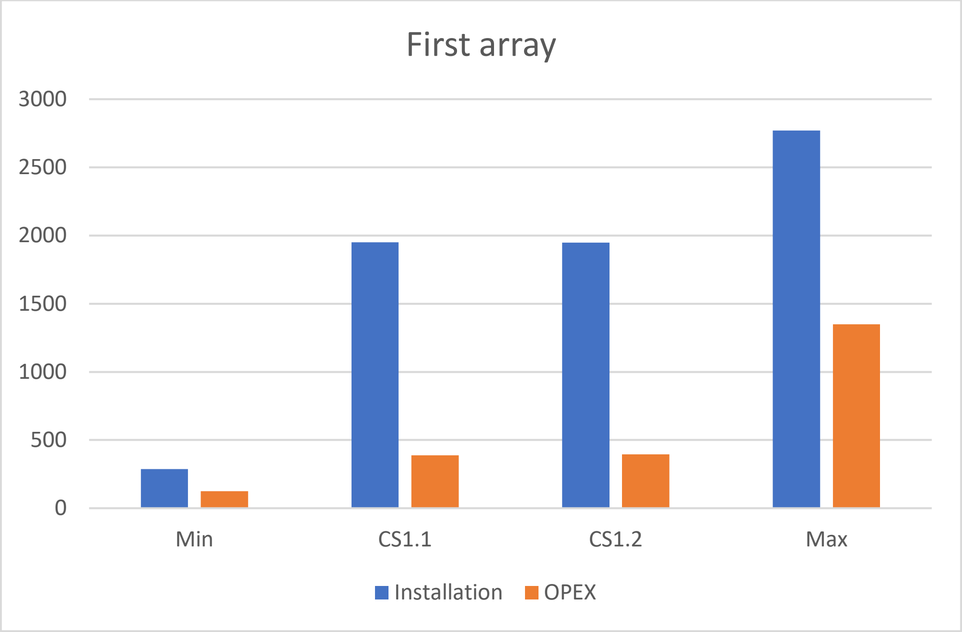


Figure 3.2 CS1.1 (West Wave) and CS1.2 (West Pembrokeshire) validation.

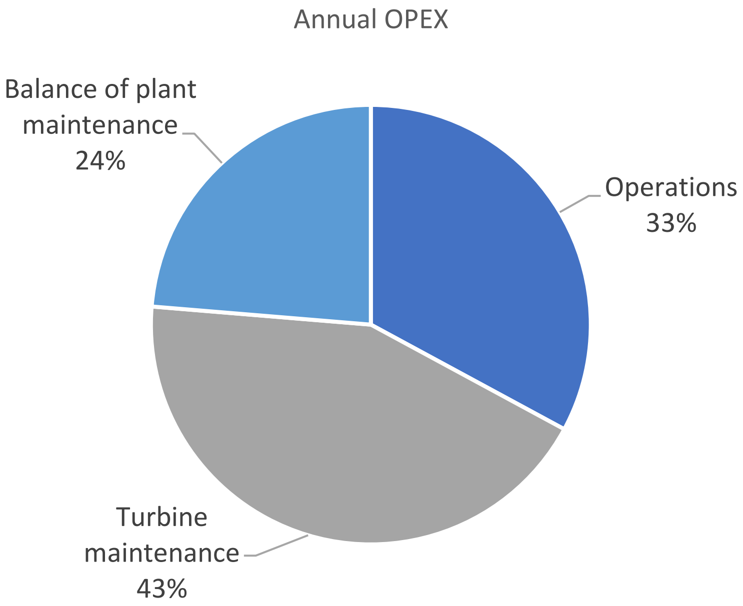


Figure 3.3 Annual OPEX cost breakdown for 1GW offshore Wind Farm [5].

Figure 3.4 summarises results for a second array. Installation and OPEX costs are within expected ranges, with the latter very close to the minimum estimates. Again all figures require more validation to increase confidence in their accuracy but this could also be due to the use of small, cheap vessels to install and maintain the WEC. Availability at both sites is within the expected ranges for an early commercial array, although the West Wave site (Ireland) is lower than West Pembrokeshire. This is expected considering site conditions. This will be further examined in Section 3.2.1. Installation costs are lower while OPEX costs are higher for the Welsh location due to the higher accessibility to install and maintain devices.

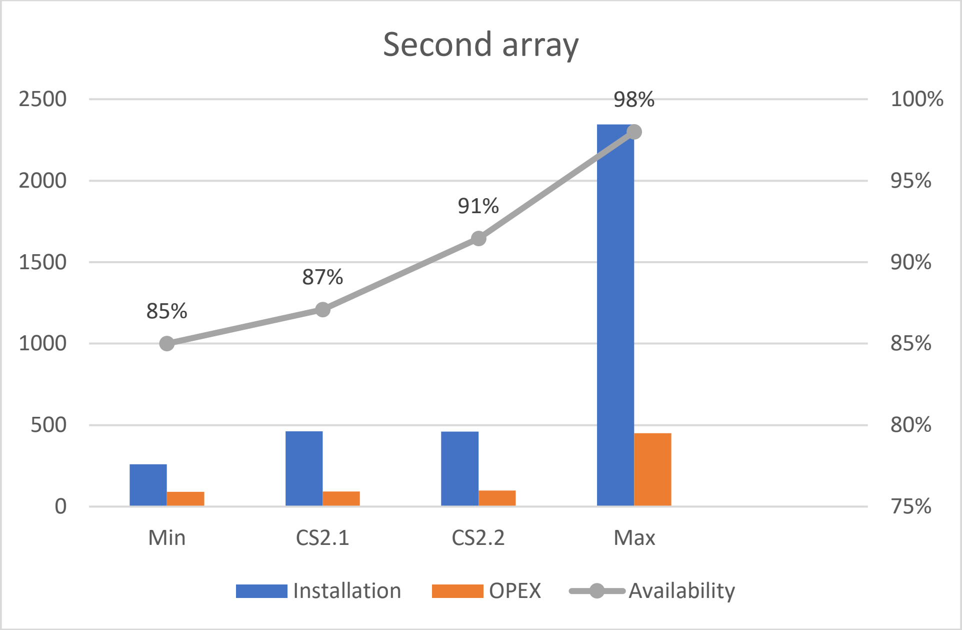


Figure 3.4 CS2.1 (West Wave) and CS2.2 (West Pembrokeshire) validation.

Figure 3.5 provides an overview of results for a first commercial array. Trends continue from the early commercial array with reductions in installation cost/kW with OPEX/kW. OPEX results are very close to (CS3.2) /below (CS3.1) the minimum estimate.

An increased device size was tested to consider a commercial farm >100MW. The increase in device size in CS4.1 and CS4.2 exaggerates trends, reducing costs per kW by approximately 50% in line with the 50% increase in device capacity (Figure 3.6). While installation for CS4.1 and CS4.2 is within the min-max estimated range; OPEX for both studies are now below the minimum expected at a first commercial stage project.

Availability is below expectations at commercial scale and there is a distinct trend as availability decreases at both sites when moving from pilot (CS1) to early (CS2) and full commercial scale (CS3 and 4), despite an increase in the number of vessels and technicians available. Results indicate that accessibility becomes an increasing issue as the size of farm grows. This may be due to a number of elements and will also be examined further in the analysis (section 3.2).

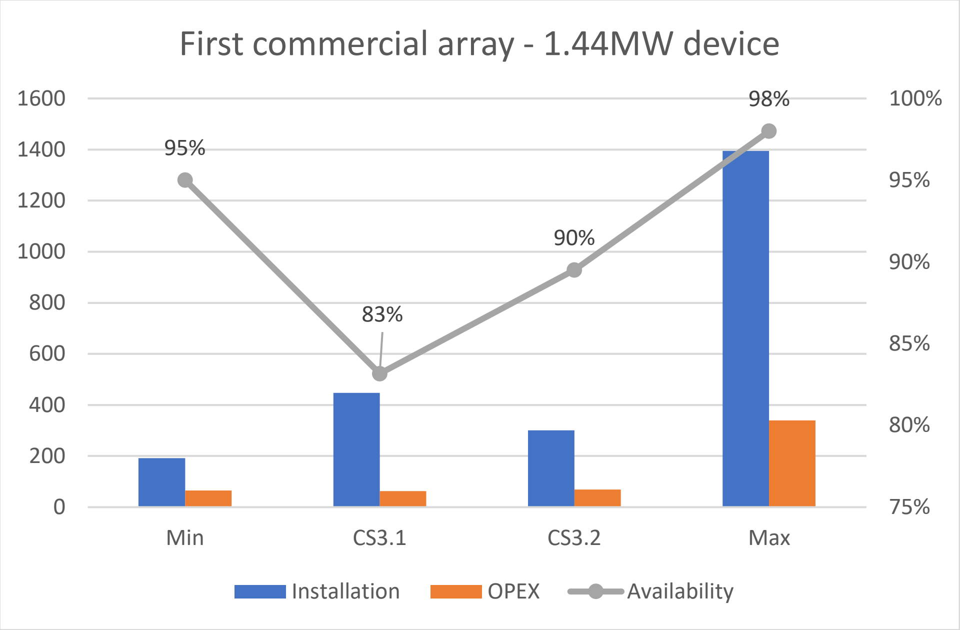


Figure 3.5 CS3.1 (West Wave) and CS3.2 (West Pembrokeshire) validation.

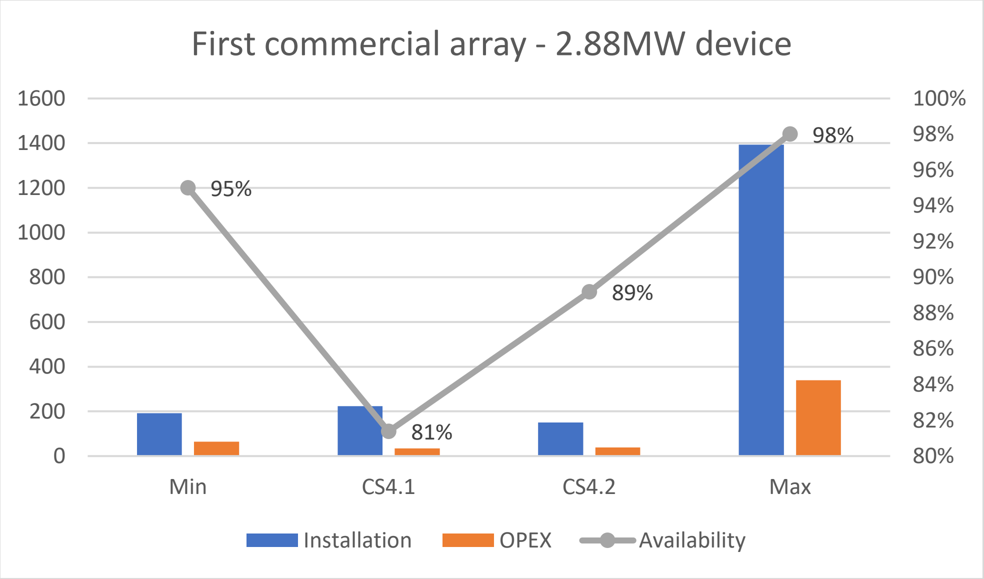


Figure 3.6 CS4.1 (West Wave) and CS4.2 (West Pembrokeshire) validation.

3.2 Analysis

3.2.1 Potential at Welsh and Irish sites

Results indicate that the Irish West Wave site has more power production potential (Figure 3.7), as the device produces approximately 58% more energy than at West Pembrokeshire on average across the 4 scenarios. It should be noted that the capacity factors are extremely low for the WEC device (c. 10% at West Wave and 5% at West Pembrokeshire). In reality, the device would be designed for the specific site to maximise efficiency and determine the optimal capacity. This would be a key factor in the success of a pilot or commercial deployment. However, this level of optimisation is beyond the scope of this deliverable.

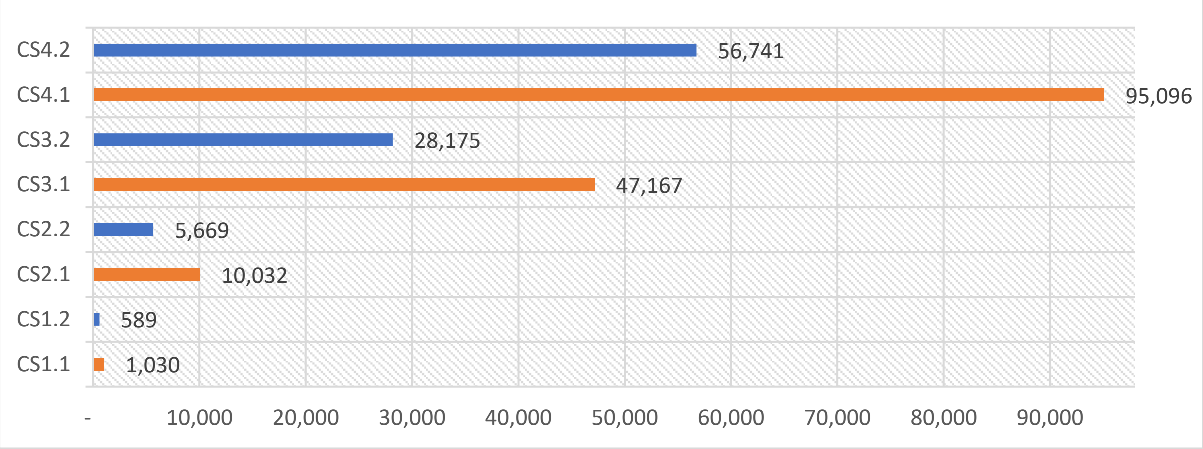


Figure 3.7 Energy production (MWh) (West Wave – orange / West Pembrokeshire – blue).

While production is higher at the West Wave site, it is also more challenging in terms of access for maintenance since time-based availability (Figure 3.8) is approximately 6% lower than availability at the West Pembrokeshire site on average across the 4 scenarios. This is to be expected considering the dynamic conditions in the Atlantic Ocean on the west coast of Ireland, as illustrated in Section 2.1, which reports an average significant wave height (Hs) of 2.34m based on 20 years of data. In contrast, the average Hs for West Pembrokeshire is 1.75m. O'Connor et. al estimate that year-round accessibility on the West Coast of Ireland is only 40-50% for 2.5m Hs [9]. Therefore, while rich in wave energy resource, sites in this location would need to carefully consider ways to minimise the need for offshore activities; the time required to complete activities; and increase the operational weather limitations of activities in order to take advantage of production potential. This will be further examined in Section 3.2.2

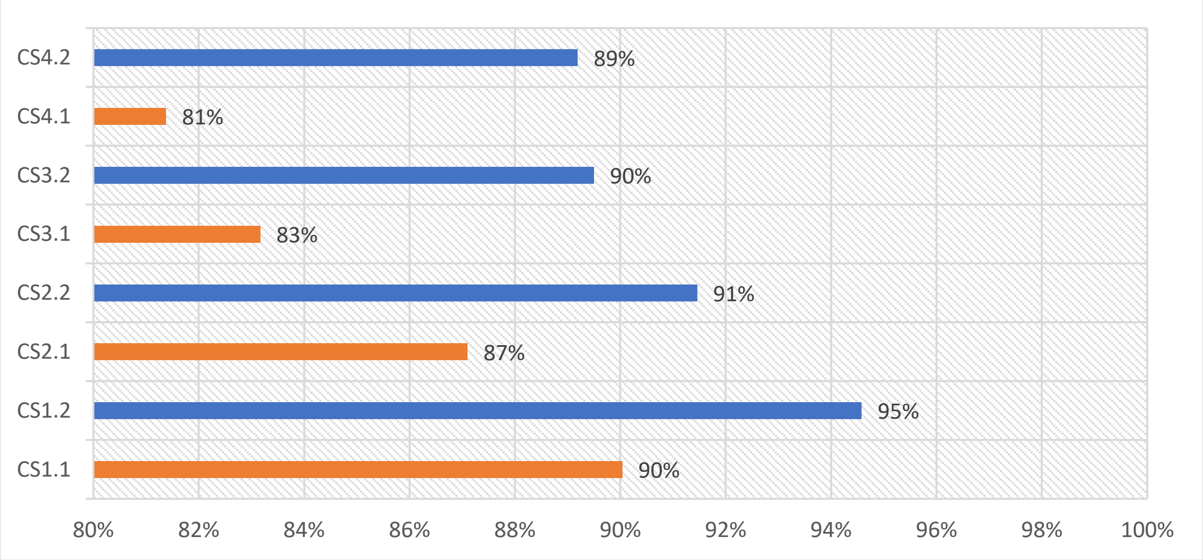


Figure 3.8 Time-based availability (%) (West Wave – orange / West Pembrokeshire – blue).

Costs are compared for each scenario and site in Figure 3.9. While installation costs are similar for the pilot and early commercial studies, lower accessibility at the West Wave site results in higher installation times and costs than West Pembrokeshire, particularly for the commercial scale arrays. Conversely, OPEX costs are higher at the Welsh site because there is more accessibility given site Metocean conditions, allowing more maintenance to occur.

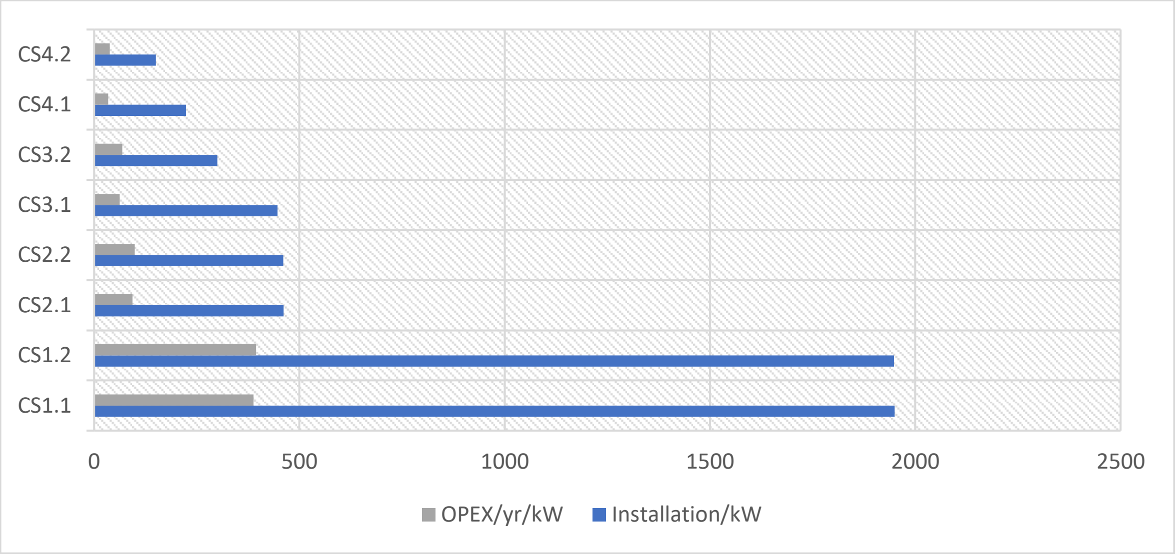


Figure 3.9 Costs/kW.

However, higher OPEX costs and accessibility are not offset by greater production at West Pembrokeshire since the Irish site achieves higher production, despite lower availability. This is illustrated in Figure 3.10, which maps costs against the energy produced for each scenario.

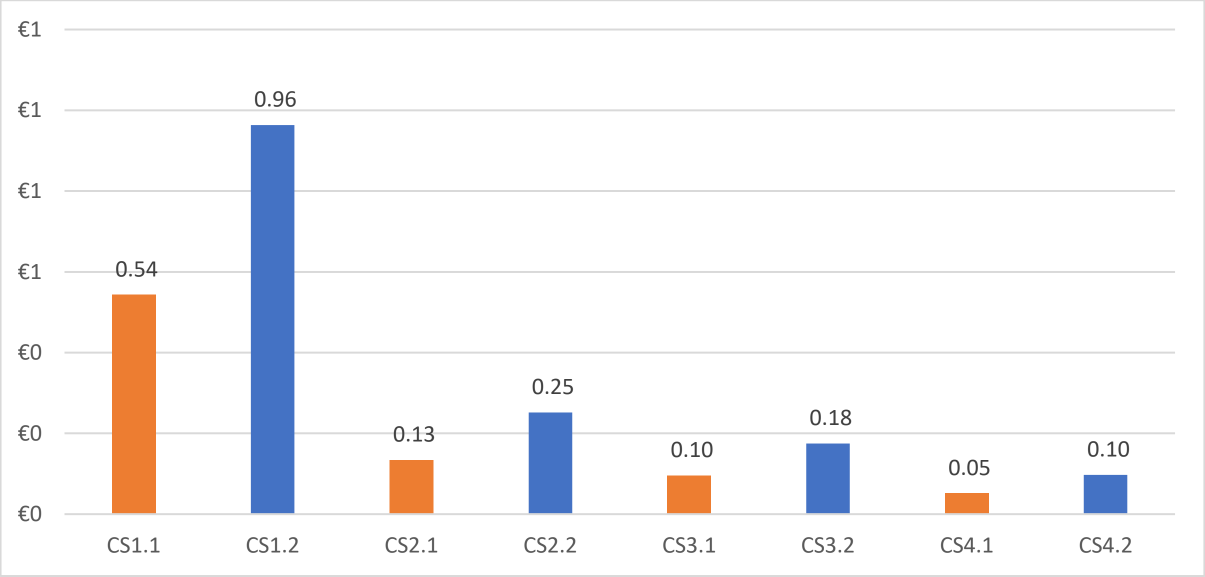


Figure 3.10 OPEX per kWh (West Wave – orange /West Pembrokeshire – blue).

3.2.2 Changes related to going from pilot to commercial farm

Case study results show economies of scale when moving from a pilot array of 1.44MW and 1 device (CS1.1-1.2); to a second array of 14.4MW and 10 devices (CS2.1-2.2). This is evident in Figure 3.11-Figure 3.14 as costs per kW and per device decrease while farm capacity increases from CS1-2. Savings can also be seen when moving to 50 devices in the full commercial scale arrays (CS3-4). However, it is interesting to note that there are less significant savings between the 10 and 50 device scenarios, suggesting that economies of scale are more important for developers making the leap between pilot and early commercial scale farms. CS4 results suggests that issues with availability and accessibility could be offset by the deployment of larger devices at full commercial scale. Therefore, device size/capacity could be a key factor for the success of a commercial deployment.

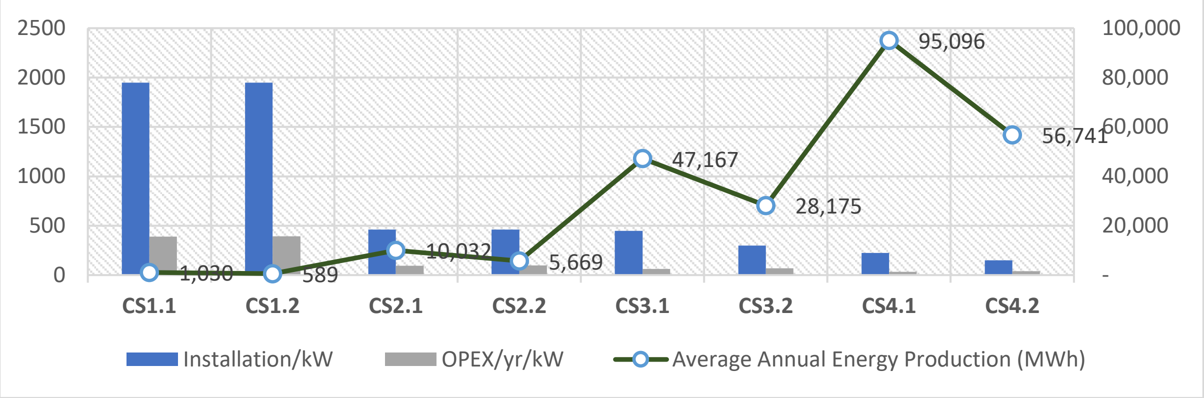


Figure 3.11 West Wave site results – costs per kW.

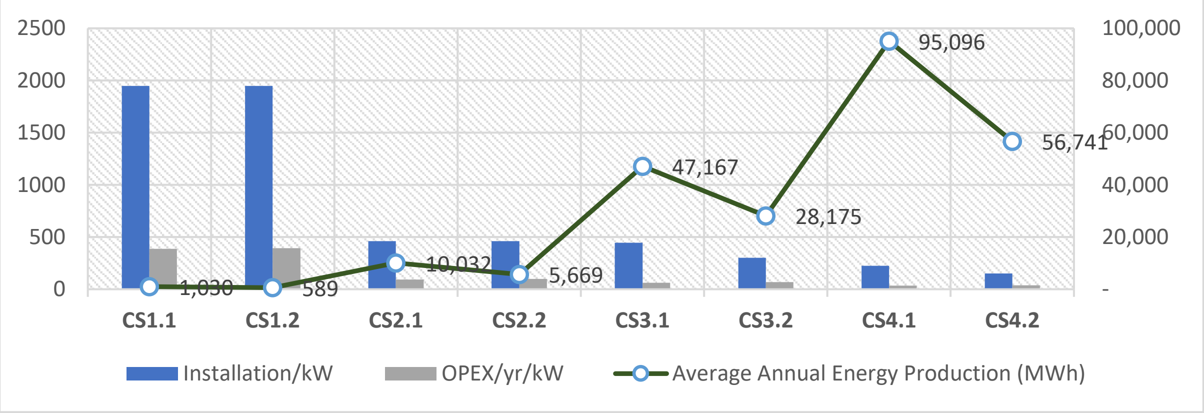


Figure 3.12 West Pembrokeshire site results costs per kW.

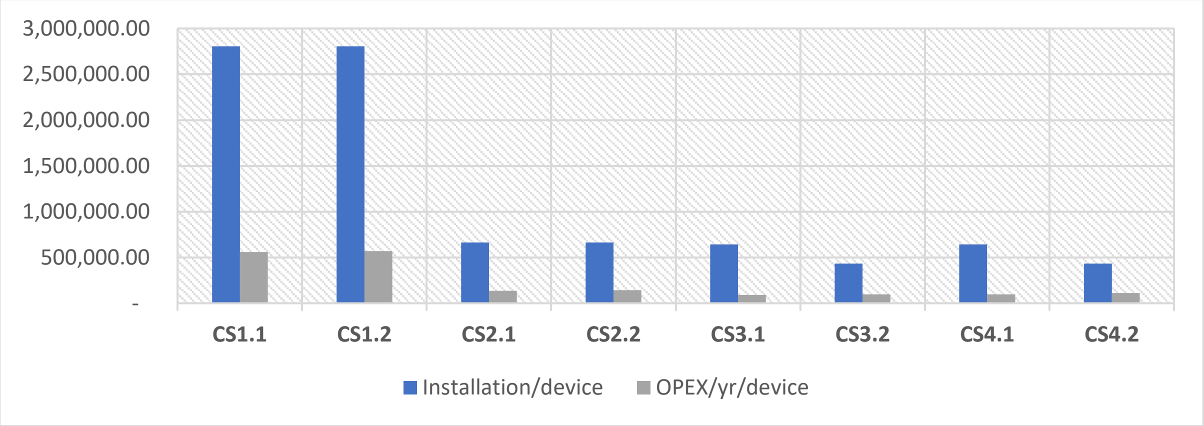


Figure 3.13 West Wave site results – costs per device.

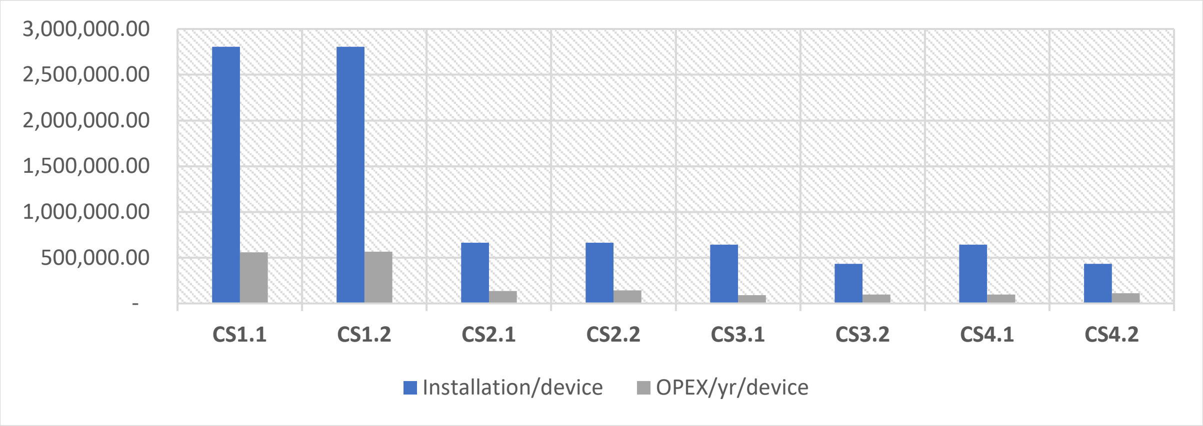


Figure 3.14 West Pembrokeshire site results – costs per device.

Where are the economies of scale found, particularly in CS1 and 2? For installation, this is largely due to the advantage of resource sharing. For example, hiring a vessel at a day rate to install 10 devices will ultimately be cheaper than hiring the same vessel to only install 1 device. In this case study the device hook-up to pre-installed moorings is assumed to take 3 hours offshore. Therefore, a vessel can potentially complete 2-3 device hook ups in a day, reducing overall costs and time.

For O&M, resource sharing will also be an advantage. However, costs may also be lower as the farm size increases because less maintenance may be occurring proportionately. Based on the decreasing availability as farm size grows (Figure 3.8), it is likely that the increased number of devices and subsequent increase in failures is putting more strain on resources and increasing the time waiting for maintenance. This reduces costs, but not for the better since it also reduces production. It should be noted that the model currently considers 100% production loss when a failure occurs, and this assumption will not be the case for all component failures. In addition, the model assumes a vessel will only address one failure occurrence on a device at a time. In reality, if more than one failure has occurred, they would all be addressed in one maintenance task. However, within the limitations of our model and scenario assumptions, it would appear that while energy production does increase as farm size grows (Figure 3.7), the full site potential is not being utilised. The following paragraphs examine the key bottlenecks found for the Irish and Welsh case studies when moving from pilot to commercial scale.

This study increased the number of vessels and technicians available when moving from pilot to commercial scale. However, it must be remembered that there is limit to the number of vessels that will be available to a farm. Modelling also showed that even an unlimited number of resources cannot achieve the high availability targets for these scenarios. This is because there are not enough weather windows available to complete the maintenance required for this farm size. For example, an unlimited number of vessels still need to wait for a weather window before they can access the site. Meanwhile devices are not producing energy while other devices may continue to fail. This build-up of failures and the resulting downtime will have a higher impact for a larger farm. Developers will need to look at ways to reduce the need for maintenance; increasing the operational weather condition limits; and optimising the maintenance strategy (e.g. less time spent offshore) in order increase availability and maximise energy production when moving to the commercial stage. For example:

- Improved reliability and technical learning curves: The failure rates may reduce given the likely improvements in technology and reliability that generally occur during progress from a pilot to commercial scale farm.
- Improved standardised procedures and operational learning curves: Experience could reduce the operational durations and increase the weather limits required to complete installation and repairs.
- Maintenance strategy: While developers may not undertake preventive maintenance for a pilot farm, the introduction of scheduled, regular servicing could reduce failures and their resulting costs, while maximising production and revenues.

These elements have not yet been considered in scenarios; however, D8.5 will demonstrate their potential impact in terms of increased availability and/or cost savings. The deliverable will also seek further areas for optimisation including the vessel fleet and rental/purchase scenarios. While it is likely a pilot array will hire vessels, larger scale commercial farms could consider purchasing vessels for long term cost savings.

4 Conclusion

This report presents a generic WEC case study, simulated at an Irish and Welsh site. A key objective is to determine the potential for WEC deployment at representative sites for Ireland and Wales as well as providing recommendations for developers, particularly when considering scaling up from a pilot to a commercial array.

Results indicate that installation costs are within expectations, although they tend towards the higher end of estimates for the pilot case studies (CS1). In contrast, OPEX costs are very low and sometimes less than projected figures. Both require further refinement, input from industry, and real offshore experience to improve confidence. While they cannot be fully validated, they are sufficient to provide some interesting conclusions, comparison between sites, and indicate key trends when scaling from pilot to commercial array farms. The key findings are presented below.

Power production suggests that the Irish site has the advantage in terms of energy production potential; but lower availability indicates that the Welsh site is more accessible for maintenance. Installation costs were higher for the Irish site, since it took longer to install devices due to the more dynamic conditions. In contrast, accessibility issues meant that more maintenance was undertaken at the Welsh site. Resulting in higher OPEX. However, higher costs and availability were not offset by energy production for the Welsh site, with the Irish site achieving half the OPEX cost per kWh.

In general terms, the comparatively low costs may indicate the advantages of using cheaper vessels to install maintain floating devices. The move from pilot (CS1) to the early first array (CS2) of 10 devices have clear cost savings in terms of economies of scale. However, while the move from 1 to 10 devices shows a significant reduction per kW and per device, there are much smaller savings from 10 to 50 devices (CS3 and 4). This suggests that developers should examine the ideal farm size considering the potential site-specific challenges as farm size increases.

D8.5 will look at key areas that may be impacting availability including weather restrictions, failure rates, operational durations, and maintenance strategy to show the potential impact these assumptions have on results. The report will seek to highlight other potential areas for optimisation e.g. purchasing vessels rather than hiring. Analysis will apply possible learning curves when moving from pilot to commercial scale to produce an optimised commercial scale scenario that seeks a viable solution e.g. 95% availability.

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