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

Report number: D8.4 Tidal Pilot – Model recommendations for Commercial Stage

Version number: 1

Release Date: 27.03.2023

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Distribution level: Open access

This project has received funding from the European Union's European Regional Development Fund ***through the Ireland Wales Cooperation programme***

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Document information

Version	Date	Document History	Prepared by	Reviewed by	Approved by
0.1	20/08/2022	Draft sent for review	Mitra Kamidelivand (UCC)	Fiona Devoy McAuliffe	
0.2	15/12/2022		Mitra Kamidelivand		
0.3	15/02/2023	Final version	Mitra Kamidelivand	Kevin Leyen	

Abbreviations

AEP	Annual Energy Production
CM	Corrective maintenance
EBA	Energy-base availability
LCOE	Levelized Cost of Energy
MC	Monte Carlo Simulation
MTTR	Mean Time to Repair
O&M	Operation and Maintenance
OE	Ocean Energy
ORE	Offshore Renewable Energy
PM	Preventative maintenance
SC	Case Study
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

List of Figures

1 Introduction

Europe plans to retain its first place as the leader in the ocean energy sector. In the Offshore Renewable Energy (ORE) strategy released in November 2020, the European Commission set 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]. The ORE target capacity is ambitious, but its implementation remains a challenge. Recent statistics published by Ocean Energy Europe [2] show that cumulative wave energy installation in 2021 reached to 12.7 MW, but only 1.4 MW is currently in the water. The installation capacity of tidal stream energy reached to 30.2 MW, and 11.5 MW is currently in the water. With several tidal stream arrays in operation, tidal energy is approaching widespread deployment [3], however, projects need to reach to operational stage much more quickly.

The SELKIE project aims to aid the wave and tidal energy industry in accelerating the deployment and commercialisation of its 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 tool, which will allow users to model operations across a project lifecycle to determine energy production and costs as well as running scenarios to optimise the logistics required for the installation and O&M phase.

A detailed description of this tool can be found in Deliverable 8.2. The tool itself can be accessed at GitHub [1] including a sample study with user guides and a video tutorial[2]. 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, a generalised wave and a tidal array scenario have been developed based on these case-studies 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.

This report focuses on tidal energy projects and, in a similar approach to D8.3 for pilot wave scenarios, it uses the SELKIE O&M and Logistics tool and examines:

- the energy production, O&M and installation costs of pilot tidal energy scenarios based on the 500 kW Sabella D15 horizontal tidal steam turbine at Welsh and Irish locations
- the effect of a second stage deployment and a first commercial deployment on the O&M costs and energy production

[1] https://github.com/fdevoymcauliffe/Selkie
[2] https://www.youtube.com/watch?v=MfNGgdKoQ3s & https://www.youtube.com/watch?v=HhsyKylzwPI

- potential opportunities and challenges of scaling-up tidal to provide recommendations for developers

The results of D8.3 and D8.4 will direct the content of D8.5 where an optimized O&M and logistics scenario for each site for wave and tidal technology will be presented. When examining the output from the scenarios, one should be aware that these are generic in nature. The input data used by the O&M tool to create the scenarios is based on published data, industry advice and educated estimations. This is because of the commercial sensitivities from some of this data, and also because there has been very little real-world-use of wave and tidal energy technology. In the future more information will be available. It is however the case that the O&M tool can provide useful results for industry so that, for example, strategies for maintenance planning can be explored.

2 SELKIE O&M and Logistics tool – summary

The Selkie O&M and logistics decision-support tool will allow users to simulate operations considering uncertain factors e.g. weather and failures, and their impact on the costs and power production of a project. It allows users to create scenarios and therefore to identify optimised requirements 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 Techno-Economic tool to determine the overall financial viability of the project scenario.

The tool is available for download on GitHub including a system requirement and set up guide, as well as a How to Use Guide and video, providing a sample wave energy study. This sample is based on the Pelamis2 device and FarrPoint metocean data provided as part of the Wave Energy Scotland model[3] and summarised in [4] .

The High-level overview of the SELKIE O&M and Logistics tool is shown in Figure 2-1.

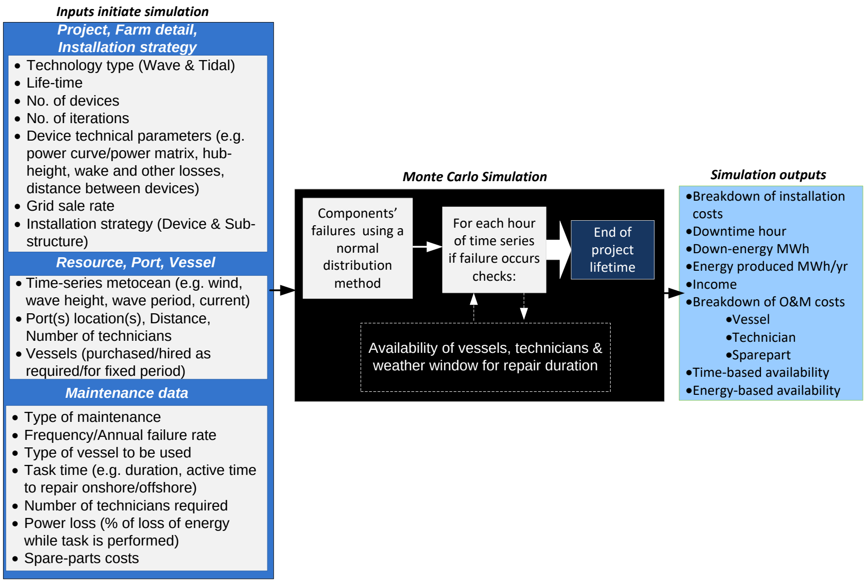

Figure 2-1 High-level view of the SELKIE O&M and Logistics model.

[3] https://www.waveenergyscotland.co.uk/

3 Tidal energy case study – Ireland and Wales

3.1 Location characteristics and site data

Four case study sites, for wave and tidal case studies, were selected in consultation between WP4 and industry participants as summarised in Table 3-1.

Table 3-1 SELKIE - wave and tidal generic case studies.

Location	Technology	Site	Data years	Port	Port distance (km)	Water Depth (m)
Ireland	Wave – oscillating water column with drag embedment anchors	WestWave Lat 52.745°N Lon 9.729°W	2000-2019	Foynes	45	73
Wales		West Pembrokeshire Lat 51.475°N Lon 5.134°W	2000-2019	Pembroke Dock	27	54
Ireland	Tidal – fixed horizontal stream turbine	Wicklow Head Lat 52.917° Lon 5.89°W	2000-2019	Dublin	12	26
Wales		Morlais West Anglesey Demonstration Zone Lat 53.291°N Lon 4.743°W	2000-2019	Holyhead	8	41

This report focuses on the tidal stream energy project at the Wicklow Head and Morlais sites in Table 3-1.

The location maps and weather data of the two locations were provided by the GIS Techno-Economic tool (WP4). The sources of the weather data are listed below:

Current Data

The NorthWest European Shelf Ocean Physics Analysis and Forecast product (Product Identifier - NORTHWESTSHELF_ANALYSIS_FORECAST_PHY_004_013) was used to model the tidal climate. This model is based on NEMO (Nucleus for European Modelling of the Ocean) and is forecast by both the UK Met Office North Atlantic Ocean forecast model and by the CMEMS Baltic forecast product (Product Identifier - BALTICSEA_ANALYSISFORECAST_PHY_003_006) and the ECMWF Numerical Weather Prediction model. The model has a spatial resolution of 0.014° x 0.03°, or ~ 0.4 – 1.5 km. It has an hourly temporal resolution. The variables used were the 'Northward Current Velocity in the Water Column (vo)' and the 'Eastward Current Velocity in the Water Column (uo)'. These were manipulated in MATLAB to give the current speed (m/s). The time series applied was 2020-01-01 00:00:00 to 2020-12-31 23:00:00 for downloading each.
Link to data source:
https://resources.marine.copernicus.eu/product-detail/NORTHWESTSHELF_ANALYSIS_FORECAST_PHY_004_013/INFORMATION

The measurement heights of current velocity for Wicklow Head and Morlais sites are 13m and 20m, and the water depths of these two sites are approximately 26m and 41m, respectively.

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

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

The maps of site and port location for the two tidal stream case studies in Wicklow Head and Morlais are shown in Figure 3-2 and Figure 3-2.

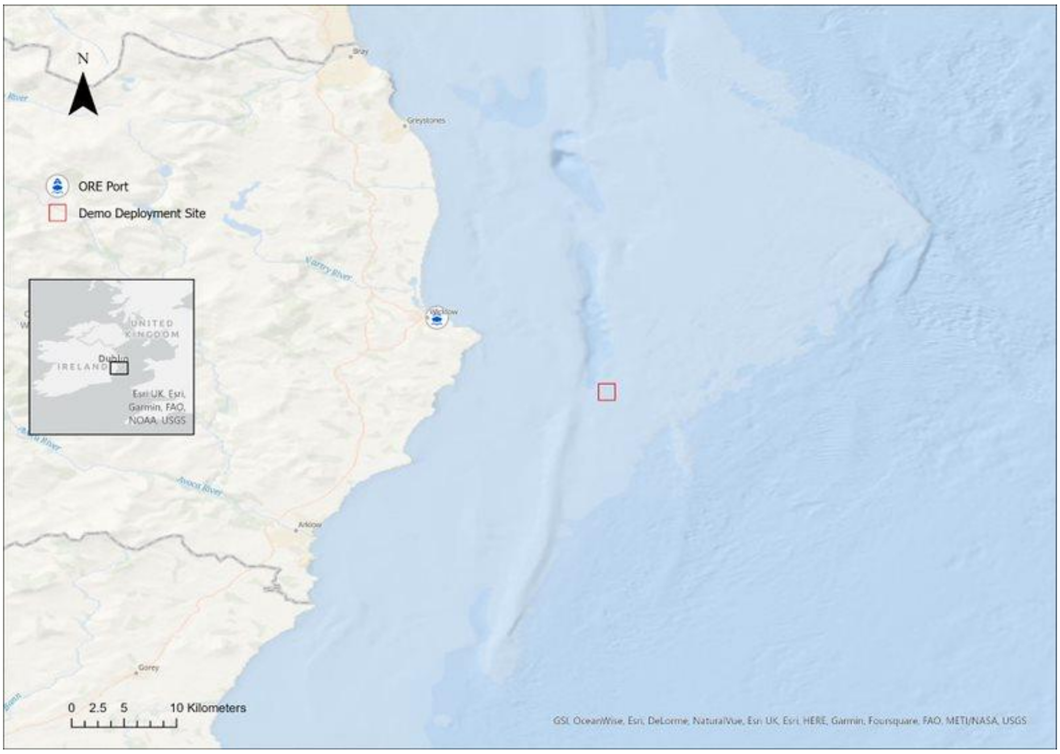

Figure 3-1 Map of projected tidal stream farm sites in Wicklow Head.

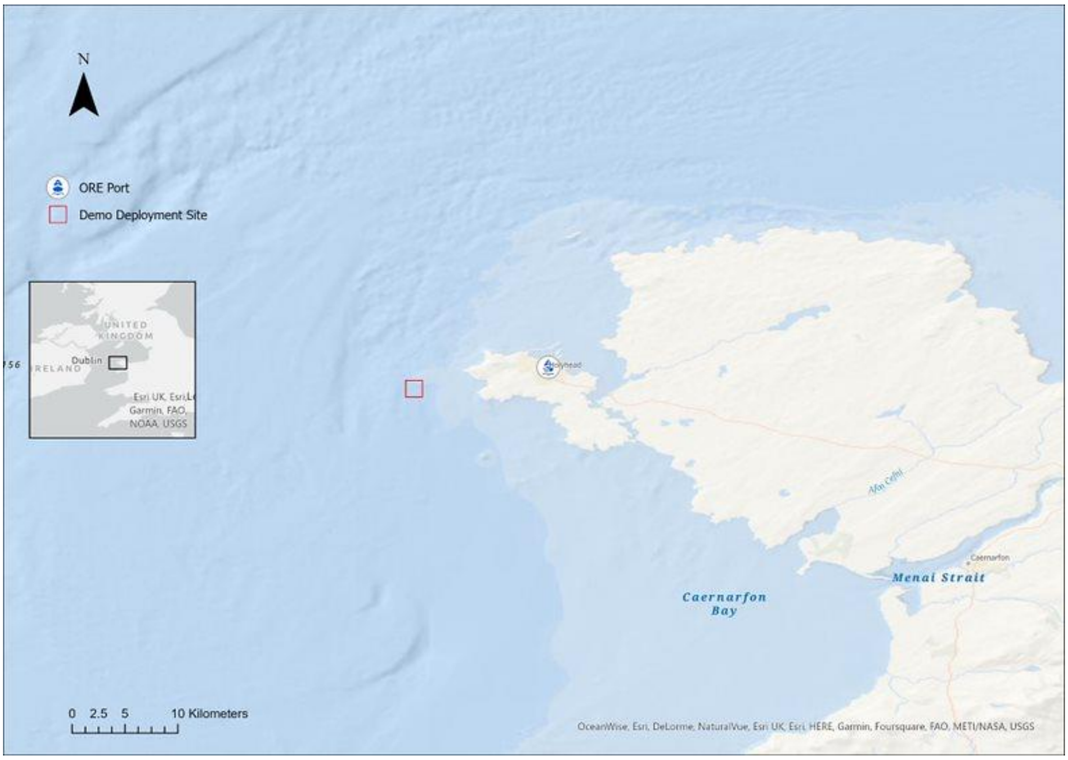

Figure 3-2 Map of projected tidal stream farm sites in Morlais.

Histograms and statistics of the tidal case study sites in Wicklow Head and in Morlais are presented in Figure 3-3.

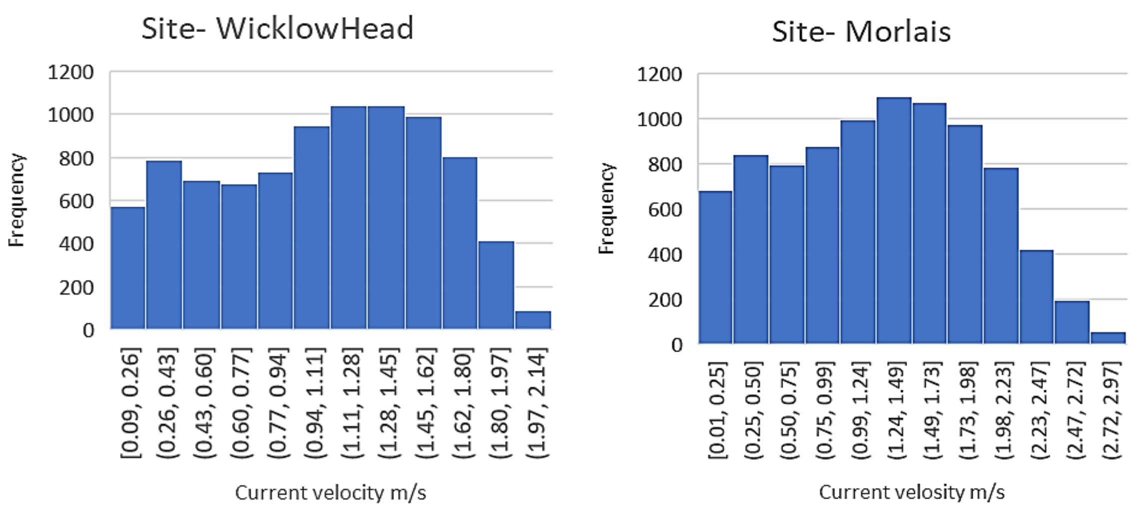

Figure 3-3 Histograms of the tidal case study locations in Wicklow Head (Ireland) and Morlais (Wales).

Table 3-2 presents a summary of the the two tidal sites statistic.

Table 3-2 Statistics of current velocity in two tidal case study locations.

	Current speed m/s						
Site	**Average**	**Max**	**Min**	**Std**	**75th percentile**	**50th percentile**	**25th percentile**
Wicklow Head site	1.06	2.14	0.09	0.50	1.47	1.11	0.64
Morlais site	1.26	2.97	0.01	0.68	1.79	1.28	0.71

The histogram of the current velocity at the sites in Figure 3-3 and the statistics in Table 3-2 indicate that Morlais has more frequent occurrence of faster current than Wicklow Head. The mean, maximum and 75th percentile of annual incident power density (maximum kinetic power)[4] of the Morlias site is considerably higher compared to Wicklow Head as explained below:

- Annual incident power density in Morlais: mean 1.9 kW/m^2; maximum 13.4 kW/m^2; 75th percentile 3.0 kW/m^2.
- Annual incident power density in Wicklow Head: mean 1.1 kW/m^2; maximum 5 kW/m^2; 75th percentile 1.6 kW/m^2.

3.2 Overview of tidal energy case studies

Table 3-3 explains the six case study projects which are modelled using Sabella D15 500 kW tidal stream turbine[5] as a reference, and input data which is detailed in the rest of this section.

[4] The power density per unit area of flow in kW/m^2 = (0.5* sea water density * cube of current speed)/1000.

[5] https://www.sabella.bzh/en/solutions/technology

Table 3-3 Case study scenarios description.

Case study (Scenario) number	Site	Port – location and distance (km)	Number of devices	Project capacity (MW)
CS1.1	Wicklow Head	Dublin-12km	2	1
CS1.2	Morlais	Holyhead-8km	2	1
CS2.1	Wicklow Head	Dublin-12km	20	10
CS2.2	Morlais	Holyhead-8km	20	10
CS3.1	Wicklow Head	Dublin-12km	100	50
CS3.2	Morlais	Holyhead-8km	100	50

The data used is mainly based on generalised industry inputs, some expert opinions and educated assumptions. Therefore, the results should be considered indicative rather than definitive. However, these inputs were sufficient to create realistic scenarios that could be further improved with increased industry validation and commercial tidal project experience.

Project details, vessel data, base data and installation strategy are outlined in Table 3-4, Table 3-5, Table 3-6, and Table 3-7.

Table 3-4 Project general data.

Item	Unit	Value
Project life-time	*years*	25
Wake Losses	*%*	5
Transmission losses	*%*	2
Device name	*text*	Sabella D15
Distance between devices	*km*	1
Annual cost per technician	*€*	50,000

The consideration of losses will have a significant effect on the energy production and thus, on energy-based availability[6]. The losses inputs in Table 3-4 are based on the generalized input data by industry.

Table 3-5 Vessel data.

Vessel		
Item	**Unit**	**Value**
Vessel classification	*text*	DP Multipurpose: Dynamic Positioning multipurpose vessel equipped with 250 t crane.
Number	*number*	1 (CS1.1 & C1.2) 2 (CS2.1 & C2.2) 5 (CS3.1 & C3.1)
Technician capacity	*number*	50
Nightwork	*Yes/No*	No (for maintenance activities)
Hire as required	*Yes/No*	Yes

[6] The ratio of energy actually produced, e.g. in kWh, to energy potentially expected, in e.g. kWh [11] .

Daily rental cost	€	20,000
Mobilisation cost	€	50,000
Lead time	*hr*	48
Mean fuel consumption	*l/hr*	300
Fuel cost	*€/l*	0.5
Vessel speed	*knots*	12

Table 3-6 Base data.

Case study number	Annual base costs	Number of technicians *(Installation and O&M)*	Additional installation costs	Additional annual OPEX costs
CS1.1 & CS1.2	60,000	8	50,000	50,000
CS2.1 & CS2.2	180,000	10	250,000	150,000
CS3.1, CS3.2	250,000	12	800,000	300,000

In Table 3-6, an additional installation cost and an additional annual OPEX cost have been included in the scenarios to account for elements, for example, project management, insurance, contingency costs for installation of turbine and foundation, and annual general operational costs. These figures also increase as farm size grows as shown in the table. These estimates are based on expert opinions but have not been validated. At this time, they are meant to indicate a proportionate growth in fixed costs.

Table 3-7 Installation strategy.

Substructure/Foundation		
Item	**Unit**	**Value**
Technicians required	*number*	4
Vessel	*text*	DP Multipurpose
Number of vessel	*number*	1
Operation duration	*hours*	18
Wave height limit	*m*	2
Wind speed limit	*m/s*	20
Device		
Item	**Unit**	**Value**
Technicians required	*number*	2
Vessel	*text*	DP Multipurpose
Number per vessel	*number*	1
Operation duration	*hours*	12
Wave height limit	*m*	2
Wind speed limit	*m/s*	20

The repair categories and component inputs are explained in Table 3-8 and

Table 3-9. Except for the subsea umbilical repair category, all the repair activities will be undertaken onshore meaning that the device will be retrieved and reinstalled after being repaired.

Table 3-8 Repair categories.

Repair Category	No. of Technicians required	Operation location	Operation duration offshore (hrs)	Operation duration onshore (hrs)	Hs (m)	Wind (m/s)	Power loss %
Nacelle Body Major	2	Onshore	9	60	2	20	100
Support Structure Major	6	Onshore	9	500	3	20	100
Blade Minor Repair	2	Onshore	9	7	2.5	20	100
Pitch system Major	4	Onshore	9	44	2.5	20	100
Pitch System Minor	2	Onshore	9	6	2.5	20	100
Gearbox Major	4	Onshore	9	45	2.5	20	100
Drivetrain Major	4	Onshore	9	60	2.5	20	100
Generator Major	4	Onshore	9	140	2.5	20	100
Generator Minor	2	Onshore	9	5	2.5	20	100
Control System Major	4	Onshore	9	45	2.5	20	100
Electrical System Minor	2	Onshore	9	5	2.5	20	100
Subsea Umbilical Major	4	Offshore	70	0	3	20	100
Power Converter Major	4	Onshore	9	50	2.5	20	100
Power Converter Minor	2	Onshore	9	5	2.5	20	100

Table 3-9 Components.

Component Name	Number per Turbine	Annual Failure Rate %	Repair category	spare part (€)
Nacelle Body	1	2.7%	Nacelle Body Major	35,000
Support Structure	1	1.4%	Support Structure Major	200,000
Blade	3	1.9%	Blade Minor Repair	10,000
Pitch System	1	0.8%	Pitch system Major	8,000
Pitch system	1	37.6%	Pitch System Minor	3,000
Gearbox	1	0.9%	Gearbox Major	70,000
Drivetrain	1	9.7%	Drivetrain Major	45,000
Generator	1	0.5%	Generator Major	25,000
Generator	1	10.1%	Generator Minor	10,000
Control system	1	0.2%	Control System Major	4,000
Power converter	2	0.4%	Power Converter Major	15,000
Power converter	2	30.0%	Power Converter Minor	7,000
Electric system	1	3.7%	Electrical System Minor	3,500
Subsea Umbilical	1	0.1%	Subsea Umbilical Major	100,000

Around 83% of failure rates in

Table 3-9 are categorized as minor failures; the spare-part cost of minor repair is between €3,000 and €10,000; the minor repair time is between 23 and 25 hours, including retrieve-reinstallation hours (see Table 3-8); repair time for major failures (the rest 17% of failure rates) is greater than 25 hours and the spare-part cost is between €15,000 and €200,000 for different components.

4 Results

4.1 Result analysis

In this section the results of the case study simulations are presented and discussed. Ten simulations were run for each case study. The average result across all simulations is presented in Table 4-1.

Table 4-1 Case studies average results.*

Case Study[1]	Project capacity (MW)	Installation costs (turbine & foundation) (€/kW)	O&M costs (€/kW/y)	Annual energy Production AEP (MWh)[2]	Energy-based-availability (EBA)	Time-based -availability (TBA)
CS1.1	1	650	867	920	91%	97%
CS1.2	1	649	882	1,490	91%	97%
CS2.1	10	193	398	9,179	91%	97%
CS2.2	10	192	406	14,857	90%	97%
CS3.1	50	128	323	45,406	90%	96%
CS3.2	50	127	323	73,203	89%	96%

*All figures are rounded, and graphs of these results are provided in the Appendix.
[1]Case studies in the Wicklow Head site, Ireland: CS1.1 (1MW), CS2.1 (10 MW), CS3.1 (50 MW); Case studies in the Morlais site, Wales: CS1.2 (1MW), CS2.2 (10 MW), CS3.2 (50 MW).
[2]The mean annual theoretical (maximum) energy production per device (not shown in the table) is around 507 MWh in Wicklow Head and 823 MWh in Morlais.

High-level overview of the results in Table 4-1 shows:

i) There is clearly a higher potential for **energy production** in the Morlais site than in Wicklow Head, this can be seen for all case studies with around 62% more energy in Morlais which mainly relates to the location characteristics (as explained in Section 3.1) as well as to the port distance and vessel types which are explained later in this section. For these case studies, Morlais site is a more suitable energetic site for tidal projects compared to the Wicklow Head site.

ii) From a first 1 MW project (CS1.1 and CS1.2) to a 10 MW project (CS2.1 and CS2.2), and from a 10 MW project to a 50 MW project (CS3.1 and CS3.2), the **average annual O&M costs per MWh** reduce by around 54% and 19%, respectively in both two sites (see Figure 4-1). Although the economies of scale would considerably reduce the OPEX of a 50 MW tidal farm, the costs are still high and are not commercially viable. The possibilities for commercial development will be examined in the next deliverable.

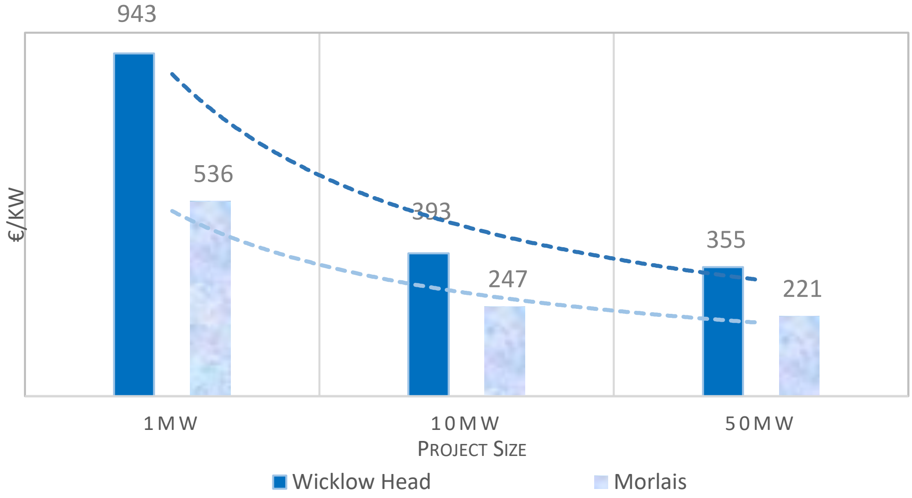

Figure 4-1 O&M of case study in Wicklow Head and in Morlais.

iii) There is a significant reduction in **the installation costs** (turbine and infrastructure) from a 1MW project to a 10 MW project (by ~70%), and to a 50 MW project (by ~34%) as shown in Figure 4-2.

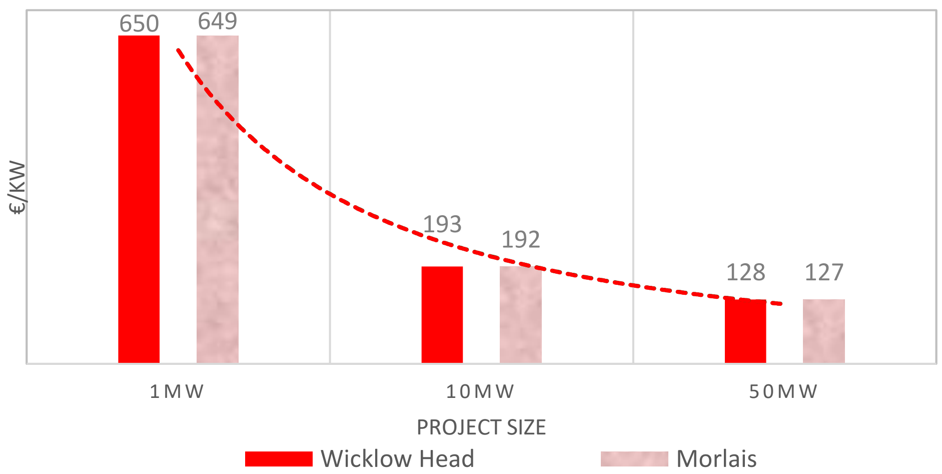

Figure 4-2 Installation costs of turbine and foundation in the case studies.

The figures (Figure 4-1 and Figure 4-2) illustrate that there is **a limit to the improvement in O&M and installation costs due to increasing economies of scale** (volume). Each site will have characteristics determining how quickly this limit may be approached, and each will require individual investigation to find the optimal deployment size. For these case studies which are based on the 500 kW Sabella tidal turbine, the results suggest that an optimal deployment size of the tidal project could be around 50 MW in these locations. However, in addition to the maximum number of turbines installed, the design of a tidal energy farm must take into account other factors, for example the downstream and lateral distance between turbines, the water depth and any environmental impact of the farm[5].

iv) There is not a significant difference between the **availability factor** (TBA and EBA) for the two sites, mainly because of the vessel types considered in the model. For tidal devices, which will be retrieved and carried to shore for repair tasks, DP vessels are considered. These vessels can operate in Hs 2.5m for most of the repair categories (see Table 3-8), which significantly reduces the effect of the weather on downtime. Based on the input data in Table 3-8 and

v) Table 3-9, the 'direct downtime' (down time due to the consideration of failure rate, operation durations offshore-onshore and vessel transit time) is on average 174-176 hours/device/year for the two locations. This can cause around 2% downtime, so the effect of weather windows waiting time is only 1-2% for all case studies in Table 4-1.

Furthermore, as can be seen in Table 3-3, **the port distance** of the Morlais site from Holyhead port (8 km) is 33% shorter than the Wicklow Head site from Dublin port (12 km); this will reduce the vessel transit time and thus the length of the weather window for the Morlais site. This counteracts the fact that the Morlais site has a harsher marine environment than the Wicklow Head site.

Further discussion of the results will be provided in the next section where the model output is compared to the literature data.

5 Validation and results comparison

5.1 Literature input

As discussed in the introduction, the model's results were verified in two case studies of wave and tidal energy, using information supplied by OceanEnergy, Sabella and from consultations with industry workshops. The information showed that the model worked effectively, and its results were validated. Due to the sensitivity of the IP, the details of the two case studies cannot be put into a publicly available deliverable. The case studies presented in this report are generalised projects based on data in the literature and any confidential data used has been removed/summarised e.g. the failure rate of tidal components and the power-curve of the tidal stream device. Therefore, the results must be read as being indicative guideline figures. However, the results of the report have been compared with estimated costs provided in the publicly available literature and have been found to be reasonable as described below.

The ranges of OPEX and CAPEX costs for generic tidal energy devices in different deployment stages are presented by [6] and are summarized in Table 5.1.

Table 5-1 The range of CAPEX and OPEX costs for generic tidal stream energy at different deployment stages [6].

Deployment stage	Variable	Min	Max
First array/first project	Project capacity (MW)	0.3	10
	CAPEX (€/kW)	4,598	13,162
	OPEX (€/kW per year)	144	1,046
Second array/second project	Project capacity (MW)	0.5	28
	CAPEX (€/kW)	3,876	7,843
	OPEX (€/kW per year)	135	478
	Availability [1]	85%	98%
First Commercial Scale (to be installed by 2030)	Project capacity (MW)	3	90
	CAPEX (€/kW)	2975	5048
	OPEX (€/kW per year)	81	361
	Availability	92%	98%

* An exchange rate of 0.902 is used to convert US$ (2015) to €.

[1] This is considered as time-based-availability (TBA) which is under the influence of downtime due to O&M activities rather than energy-based- availability (EBA) which is under the influence of downtime as well as any other energy losses (e.g. wake and transmission).

Based on Table 5.1, a reasonable estimate of the mean costs of CAPEX and annual OPEX for a first commercial scale tidal project could be around €4000/kW and €220/kW, respectively. Clearly, there is wide range of ±60% for the cost estimates for OPEX.

The OPEX cost of MeyGen phase 1A farm, consisting of four 1.5 MW tidal turbines, is reported as £1.4m [7], approximately 260 €/kW, and a typical OPEX/kW for a 10MW tidal stream array is estimated at around 130€/kW, with a lower (optimistic) and upper (pessimistic) bounds of about 135€/kW and 210€/kW [7] respectively.

The typical CAPEX/kW for a 10MW tidal stream array is estimated at around 3600€/kW, with a lower (optimistic) and upper (pessimistic) bound of about 3000€/kW and 4400€/kW [7].

These figures for CAPEX and OPEX are within the range of Table 5.1.

Installation costs in the case study analysed in the report only include turbines and foundations. Other installation, such as offshore and onshore electrical systems and cables, which are considerable, are not modelled.

The literature is reviewed to get a reasonable estimate of:

a. the total installation costs for tidal stream energy projects as a percentage of CAPEX, and then,
b. the installation costs of turbines and foundations as a percentage of total installation costs.

The LCOE percentage breakdown in [6] shows that installation cost accounts for 20% of CAPEX at the early stage of development and 15% of CAPEX at the commercial stage. According to the BVG-CATAPULT database for offshore wind[7] , the installation of a mature commercial offshore wind project accounts for 27% of CAPEX. In [8], the installation of a 1.5 MW tidal stream turbine is 25% of CAPEX. Based on the data found in the literature and expert judgements, it is assumed that the installation costs of a first project, a second project and a commercial project is 25%, 18% and 16% of CAPEX, respectively.

Data on the installation costs of turbines and foundations for tidal energy is not available. In the BVG-Catapult database, for offshore wind farms, the installation of turbines and foundations accounts for 23% of the total installation cost.

Derived from the literature data above and using the CAPEX data in Table 5-1, the range of total installation costs as well as the installation costs of turbines and foundations is presented in *Table 5-2*.

Table 5-2 Installation costs for generic tidal stream energy at different deployment stages[1].

	Installation costs (Total) €/kW		**Installation costs €/kW (Turbine & Foundation)**	
Deployment stage	**Min**	**Max**	**Min**	**Max**
First array/project	1,149	3,290	264	757
Second array/project	698	1,412	160	325
First commercial scale	476	808	109	186

[1]Calculated from the CAPEX data in Table 5-1 multiplied in the percentage of installation as discussed in text.

5.2 Results comparison with the literature

The literature data in Section 5.1 is compared with the calculated O&M and installation costs (total) for the case studies in Figure 5-1, Figure 5-2 and Figure 5-3.[8]

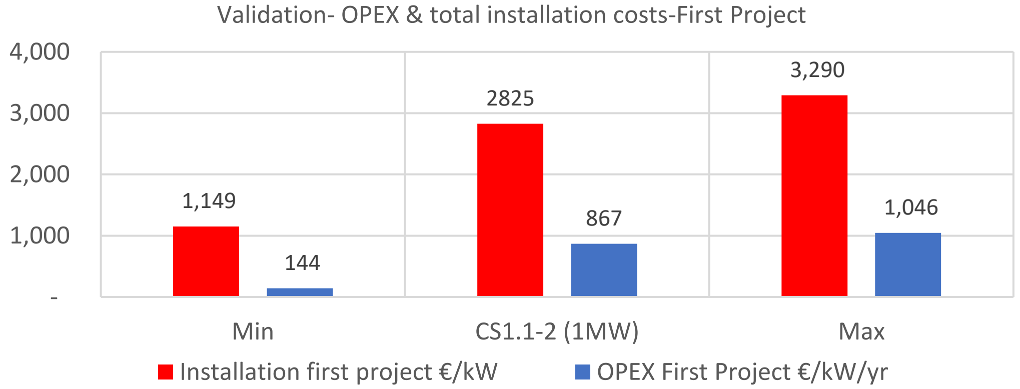

Figure 5-1 Validation of OPEX and installation cost of a 1 MW case study project in Wicklow Head and Morlais (CS1.1 and CS1.2).

[7] https:// guidetoanoffshorewindfarm.com/wind-farm-costs

[8] The installation costs of the case study project in the two sites are almost identical. The OPEX of case studies in Morlais is higher by around 2-3% compared to the OPEX of same case studies in Wicklow Head. In the figures the higher OPEX (i.e. OPEX of Morlais) is compared with the literature data.

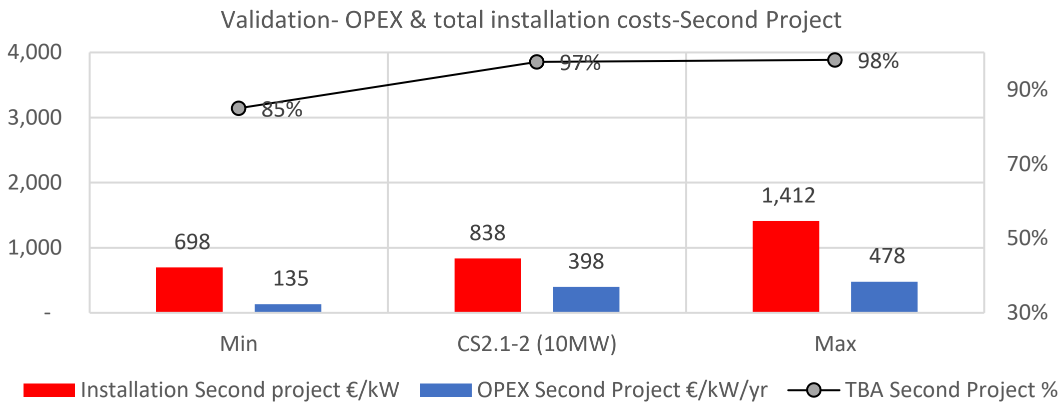

Figure 5-2 Validation of OPEX and installation costs of a 10 MW case study tidal project in Wicklow Head and Morlais (CS2.1 and CS2.2).

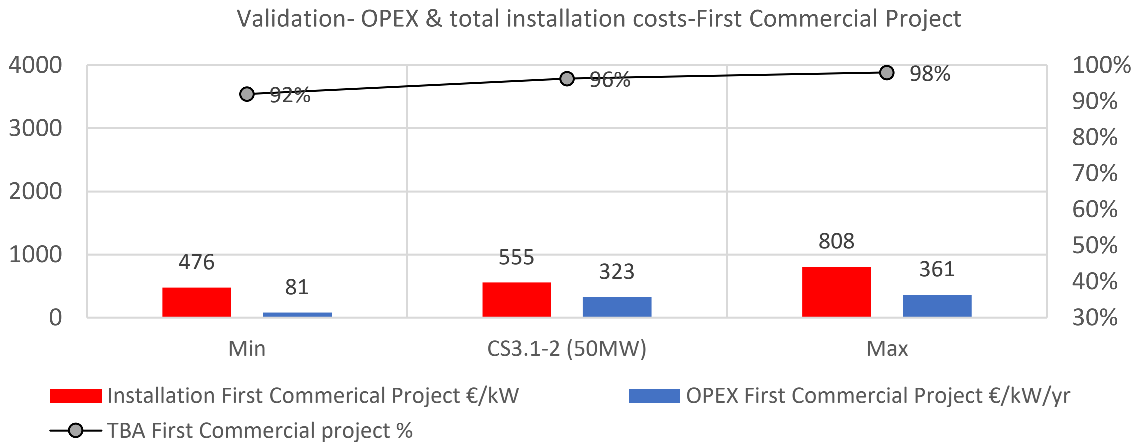

Figure 5-3 Validation of OPEX and installation costs of a 50 MW case study tidal project in Wicklow Head and Morlais (CS3.1 and CS3.2).

With respect to OPEX and total installation costs, analysing the model results as compared to the literature data, Figure 5-1, Figure 5-2 and Figure 5-3, shows that:

i) The OPEX and installation costs from the model for all case studies are within the literature range.

ii) The OPEX of the second and especially the commercial case studies (Figure 5-2 and Figure 5-3), are closer to the maximum range, which is not surprising considering the requirement of expensive vessel operations for the maintenance activities. The impact of vessel costs on the O&M costs will be further analysed in D8.5, for example by changing the number of vessels and also by considering the purchase of at least one vessel.

iii) With respect to time-based availability, comparing the model with the literature ranges above shows that although the results for availability are within the range of those in the literature, they are closer to the maximum values. Factors such as failure rates, distance from the port, weather conditions and type of vessels can considerably affect the availability of any offshore energy project. For example, the availability factor of an offshore wind turbine which is closer to the coast can be within the range of a modern onshore wind turbine of 95% to 97% [9]. For the case study here, as mentioned earlier, the high availability factor could be due to the type of the DP vessel considered in the model which has a high offshore operational accessibility[9] and a relatively a short distance of the port in Wicklow at 12 km and Morlais at 8km. Nonetheless, the farm availability results in the model could have been underestimated because the failure rates of some of the balance of the plant, for example, substation infrastructure and export cables have not been included in the model. Furthermore, for all case studies the initial components' failure rates do not change from a pilot scale to a commercial scale. In the next deliverable (D8.5), a sensitivity analysis of the failure rates will be carried out to investigate the effect of some of these assumptions on the O&M costs and availability of a commercial project. For tidal energy projects where most of the repairs will be carried out onshore (i.e., 100% power loss for any failure mode), improving the reliability is crucial in reducing unexpected failures and therefore improving energy revenues.

5.3 Insights from offshore wind

In the long-term perspective, commercial tidal energy will need to compete with other offshore energy sectors such as the established wind energy sector. Evidently the estimated OPEX of €313/kW/year to €323/kW/year for the first commercial tidal case studies in this report (see Table 4-1) is substantially higher than the OPEX ranges of offshore wind energy. In the recent Offshore Wind Market Report [10], the range of OPEX for offshore wind is reported as $70–$80/kW/year [10] (~€61-€70/kW/year), and it is anticipated that OPEX will decrease 7%–16% from 2020 values by 2025 and 14%–29% by 2030 as shown in Figure 5-4 [10].

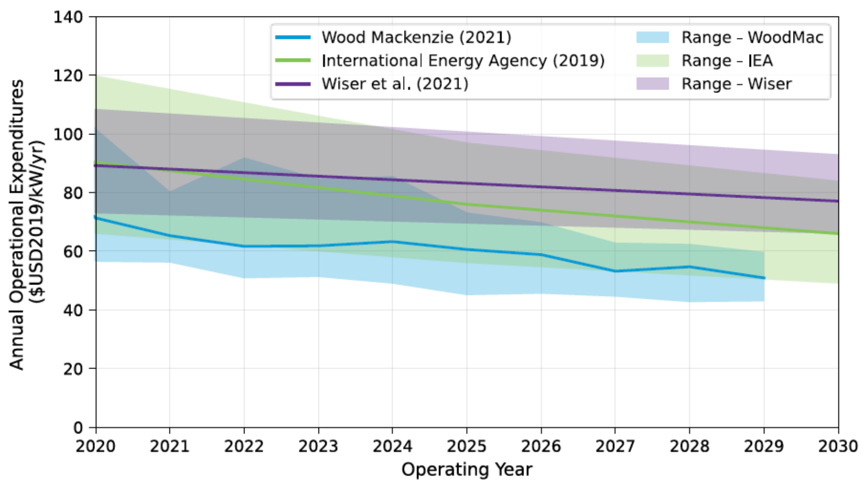

Figure 5-4 Global offshore wind energy OPEX [10].

[9] Note that the literature does not provide availability of the pilot project, however, due to the selection of the DP vessel type for the case studies and constant components failure rates for all case studies, the availability of pilot project is high and not significantly different from upscaled projects.
[10] Average exchange rate of US$ to € in 2020: 0.877.

Potential contributors to the cost reductions can include increased turbine size (economies of scale), increased farm size (economies of volume and economies of scale) as discussed in this report, increased reliability (fewer unexpected failures), adapting remote monitoring systems (enabling earlier detection of potential failures and facilitating preventive maintenance), improved access (e.g. shortening vessel transit time), and reducing the time taken for installation and maintenance activities (e.g. through experience and learning rate).

Some of these opportunities to improve the OPEX and the availability of a commercial tidal project will be examined in D8.5.

6 Conclusion

The core objectives of this report were: *i)* to use the SELKIE O&M and Logistics tool to create credible scenarios for tidal energy using generic data from industry, literature and educated assumptions; *ii)* to determine the potential for tidal deployment at representative sites for Ireland and Wales, and *iii)* to provide recommendations considering scaling up from a pilot to a commercial project.

The report created some generic scenarios based on the Sabella 500 kW tidal stream turbine for, a first pilot, a second upscaled tidal project and a first commercial scale tidal project at the Irish and Welsh sites which were shortlisted in WP4.

Results showed that upscaling a 1 MW pilot tidal stream project to 10 MW (and then to 50 MW) could reduce the O&M costs and installation costs by 54% (and 21%), and 70% (and 34%), respectively. A tidal stream project in Morlais (Wales) would produce on average 62% higher power than the same project in Wicklow Head (Ireland). This advantage is due to having, on average, a greater tidal current speed in the region.

The selection of vessel types for carrying out the O&M activities, the failure rates and the distance from the port, can affect the operational availability of the farm, and therefore the energy production. This study considered a DP multi-purpose vessel with a high operational weather accessibility in terms of significant wave height. The DP vessel seems appropriate for the tidal O&M activities because almost all repairs will be carried out onshore, meaning that the (fixed) tidal device needs to be disconnected from its structure and carried to the onshore port facilities. However, the high availability of 96-97% for the tidal scenarios due to using a DP vessel will incur significant costs, requiring either a reduction in component failure rates (by improving reliability) or purchasing a vessel to lower O&M costs for a commercial scale project.

In the next deliverable, more scenario evaluations will be conducted to identify key cost reduction areas and improve the energy production. A final optimal commercial scale project will be suggested.

7 Bibliography

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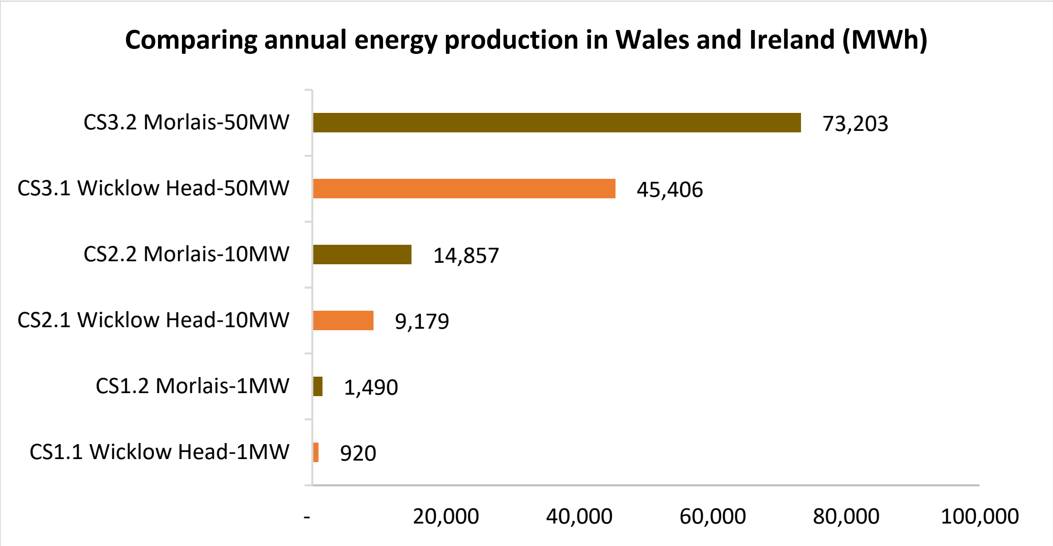
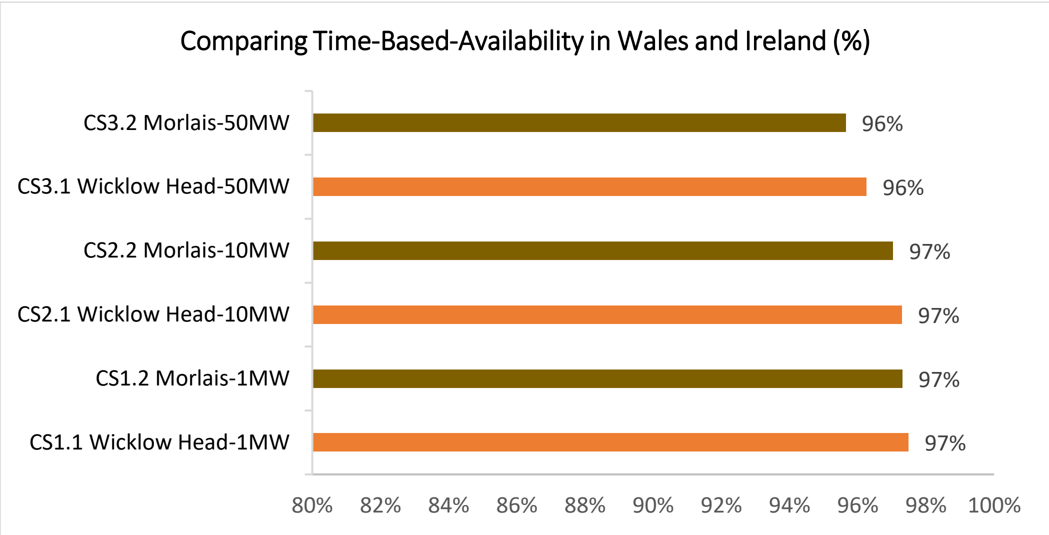
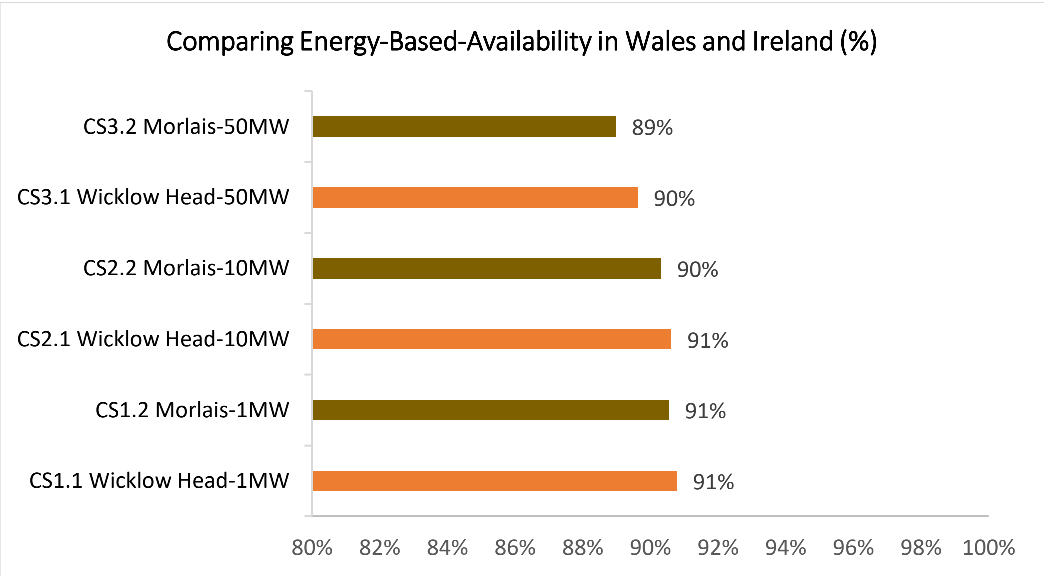
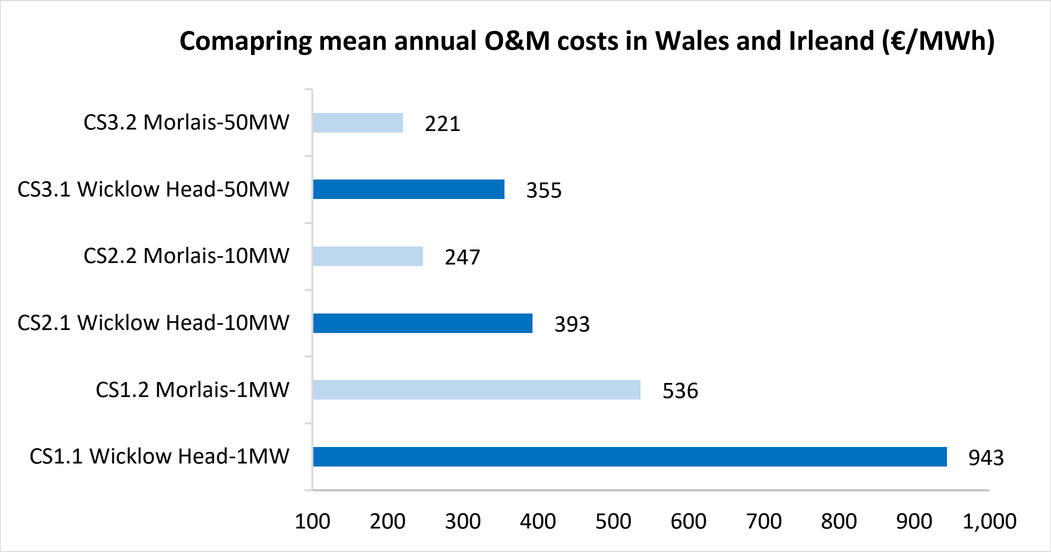
8 Appendix

Graphs of tidal case studies results in Table 4-1.

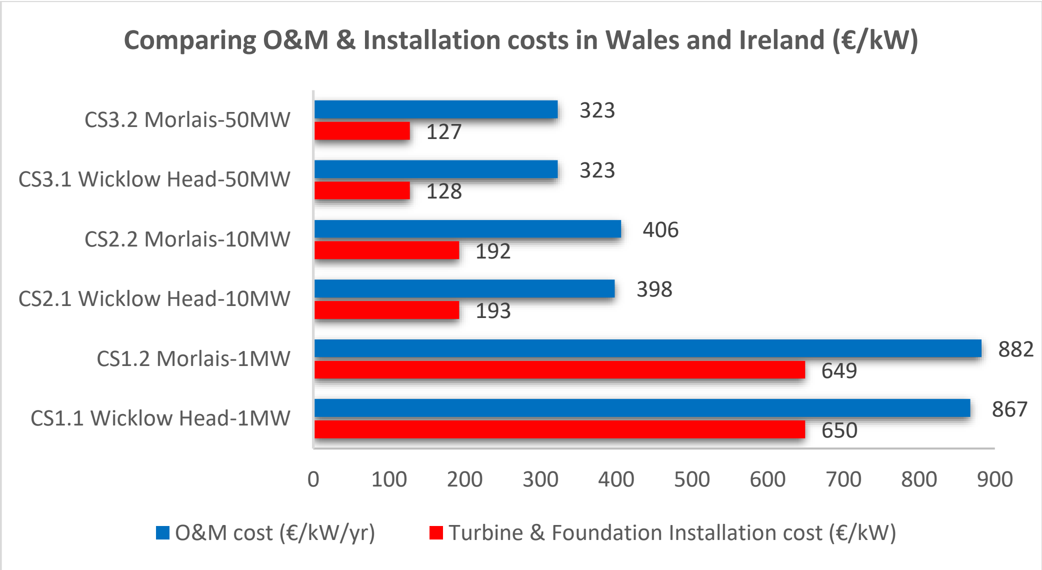








Comapring mean annual O&M costs in Wales and Irleand (€/MWh)
CS3.2 Morlais-50MW
221
CS3.1 Wicklow Head-50MW
355
CS2.2 Morlais-10MW
247
CS2.1 Wicklow Head-10MW
393
CS1.2 Morlais-1MW
536
CS1.1 Wicklow Head-1MW
943
100
200
300
400
500
600
700
800
900
1,000



Comparing O&M & Installation costs in Wales and Ireland (€/kW)
CS3.2 Morlais-50MW
323
127
CS3.1 Wicklow Head-50MW
323
128
CS2.2 Morlais-10MW
406
192
CS2.1 Wicklow Head-10MW
398
193
CS1.2 Morlais-1MW
882
649
CS1.1 Wicklow Head-1MW
867
650
0
100
200
300
400
500
600
700
800
900
O&M cost (€/kW/yr)
Turbine & Foundation Installation cost (€/kW)