Report of existing Installation, Operations, Maintenance and Logistics model available best suited for wave and tidal applications

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

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Abbreviations

KPI – Key Performance Indicator

IRR – Internal Rate of Return

LCoE – Levelised Cost of Energy

NPV – Net Present Value

OE – Ocean Energy

ORE – Offshore Renewable Energy

OW – Offshore Wind

OWF – Offshore Wind Farm

OWT – Offshore Wind Turbine

TEC – Tidal Energy Converter

TRL – Technology Readiness Level

WEC – Wave Energy Converter

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1. Introduction

This deliverable provides an overview of the current state of the wave and tidal energy sector (section 2), identifying the key deployment targets set by the EU and industry. Section 3 highlights the need to find cost savings in order to facilitate investment and achieve these targets. In particular, the report details where reductions could be found during the deployment and operation of wave and tidal arrays.

Given the lack of practical experience offshore, modelling and simulation are a safe, quick and cost-effective way to determine optimal procedures and strategies. The SEKLIE project will develop an open-access logistics tool that allows users to model different installation and Operation and Maintenance (O&M) operations, optimising scenarios and reducing costs.

Section 4 provides a review and analysis of existing installation, O&M and logistics models available that are best suited for wave and tidal applications. The SELKIE tool will utilise learning from the most relevant tools, including those developed for the offshore wind sector. Section 5 describes the objectives of the tool; the proposed validation and application of the model; progress to date in determining functionality requirements; and the key development milestones.

2. State of the industry

Europe's goal is to become carbon neutral by 2050 (European Green Deal). This requires decarbonising the energy system; Offshore Renewable Energy (ORE) technologies (wind, wave and tidal) can make a significant contribution. The EU foresee an installed capacity for wind of 900-1,100 GW by 2050 (ETIPWind , 2020) including 450GW for offshore wind (Onshore and Offshore Wind, 2020). Europe's Ocean Energy (OE) (wave and tidal) resource is considerable. By 2050, OE can deliver 100GW of capacity – equivalent to 10% of Europe's electricity consumption today (ETIPOcean, 2020). Wave and tidal technologies in particular will play an important role as they are flexible and predictable sources that can smooth production peaks and balance Europe's electricity grid, complementing more variable renewables e.g. wind and solar.

By 2050 the ocean energy sector (wave and tidal) is estimated to be worth €53bn a year globally, requiring 400,000 jobs in Europe (ETIPOcean, 2020). It is foreseen that the industry could play a significant role in reviving coastal communities, attracting young people back to rural areas; encouraging investment in associated infrastructures; and providing opportunities for existing local supply chain companies to diversify. Therefore, it is a market of significant interest, which Europe currently dominates and is striving to ensure EU leadership of this sphere continues.

At the end of 2018, the total OE installed capacity reached 31.4 MW. These mostly included single unit prototypes and demonstrators. Figure 1 and Figure 2 show a breakdown of tidal and wave installed capacity per developer. It should be noted that decommissioned projects/developers who have ceased operation are marked with a pattern fill.

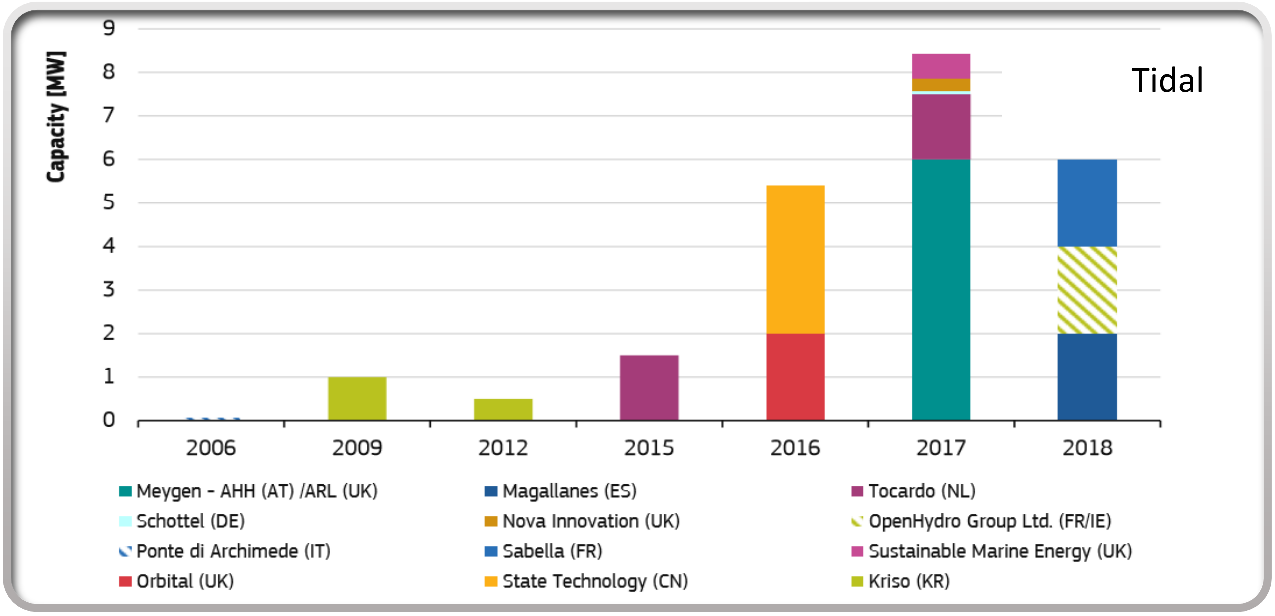

Figure 1 breakdown of tidal installed capacity per developer. Source: Joint Research Centre. (2019). Low Carbon Energy Observatory - Ocean Energy Technology Market Report.

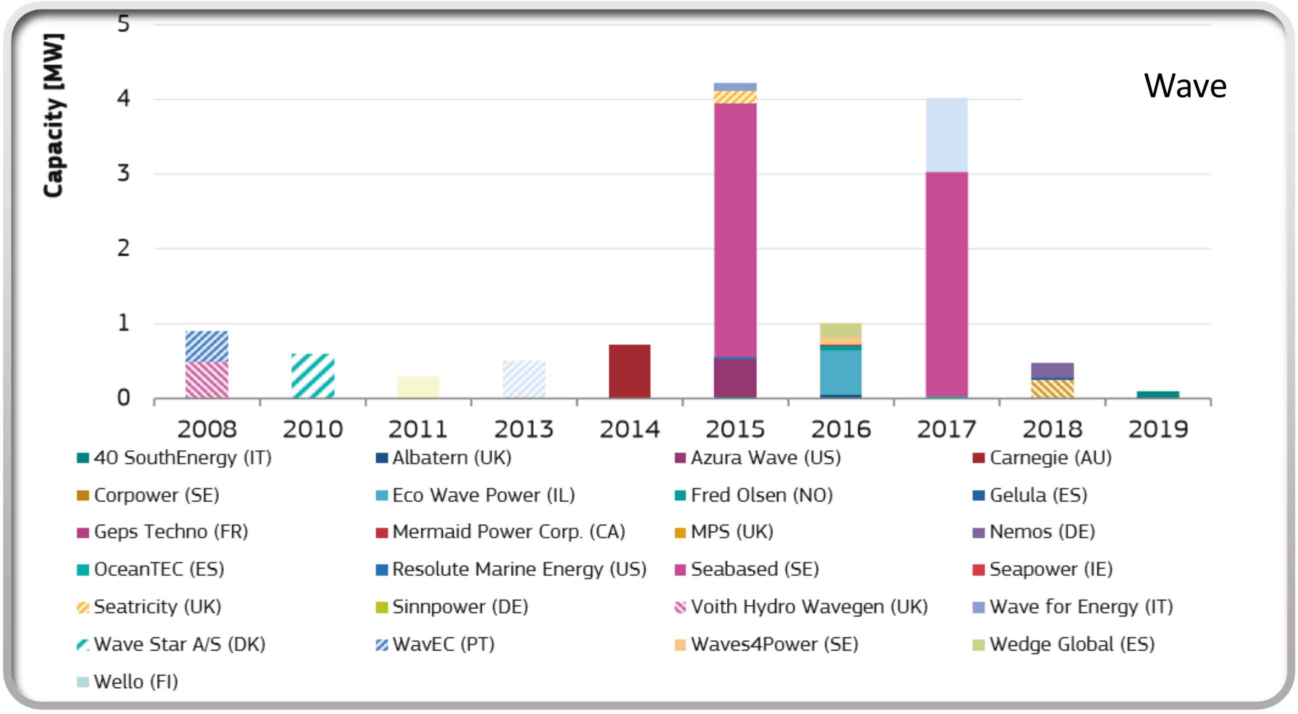

Figure 2 breakdown of wave installed capacity per developer. Source: Joint Research Centre. (2019). Low Carbon Energy Observatory - Ocean Energy Technology Market Report.

Tidal Energy Converters (TECs) have advanced to higher Technology Readiness Levels (TRLs) than Wave Energy Converters (WECs) with the first tidal farm (the Meygen project) being deployed in 2017. This comprises 4 x 1.5MW turbines. However, there were several full-scale WECs planned to be deployed in 2019-2021 e.g. the Wello Penguin, GEPS Techno's Wavegem, AW Energy's Waveroller, OPT's PowerBuoy and the Ocean Energy OWC in Hawaii. 490MW of wave energy projects are expected and a total of 3.6GW of tidal projects are in the pipeline from 2019-2027 (Joint Research Centre, 2019). Therefore, significant developments are taking place; but the industry are still a long way from achieving short term deployment goals and 2050 targets.

While tidal is more advanced than wave energy, both sectors face technological challenges particularly in terms of improving power production capacity and efficiency as well as the device reliability and survivability. Ultimately both sectors still need significant investment to tackle a range of technical challenges. This will require demonstrating large cost-reductions to minimise the risk to investors. It is estimated that early arrays will operate at a Levelised Cost of Energy (LCoE) of 34-64c€/MWh for wave and 24-47c€/MWh for tidal. (Wave and tidal energy strategic technology agenda, 2014). However, the SET plan for ocean energy sets targets of 10c€/MWh by 2030 for tidal and by 2035 for wave (ETIPOcean, 2020). Therefore, significant work is required to achieve these targets.

3. Cost-reduction potential

Minimising CAPEX costs and increasing power production would have a significant impact, reducing costs or increasing revenue respectively. While CAPEX costs are very concept specific, they generally comprise a significant proportion of the LCoE. This was demonstrated for a WEC concept in (Devoy McAuliffe, Macadré, Donovan, Murphy, & Lynch, 2015) where the platform structural, mooring and anchoring costs were 46% of the estimated LCoE. In all cases, increased power production will offset costs, improving the financial competitiveness of a device.

In addition to the above, installation and O&M operations are often highlighted as areas with significant cost reduction potential. According to (SI Ocean Cost of Energy Report), installation costs represent 18% of lifetime costs for wave and 27% for tidal arrays while O&M makes up 17% of lifetime costs for a wave array and 19% for a tidal array. When reviewing potential areas for savings, it is important to understand the key challenges for installation and O&M. These can be summarised as follows:

- **There are currently no standard practices**
  - With many concepts and few full-scale devices, there is very little practical experience that would facilitate learning and optimisation.
  - Where experience exists, there is infrequent sharing of know-how to develop best practices. There are some exceptions including data shared by the Pelamis and Aquarmarine developers with Wave Energy Scotland (WES).
- **No specialised supply chain, vessels, equipment, technicians etc.**
  - Too expensive to develop bespoke resources and infrastructure for sector in the early stages.
  - Must rely on existing supply chain for offshore industries (oil and gas; wind etc.) where demand may create bottle-necks and delays.
- **Weather windows**
  - Wave, wind and tidal current conditions pose a challenge to accessing sites and completing operations. Delays result in increased time and costs.
  - WECs in particular will be located in very energetic sites, which are difficult to access.
  - The installation/maintenance of TECs will depend on very short weather windows at slack tides.
- **Corrosion and bio-fouling**
  - WECs and TECs are typically steel devices, which must survive submerged in corrosive salt sea water.
  - Different creatures may attach to devices, affecting performance and requiring regular cleaning.
- **Health & Safety**
  - Offshore operations are very dangerous requiring best practices; experience; training and testing/simulation.

SI Ocean Cost of Energy report (Strategic Initiative Ocean Energy, 2013) further outlines some of the main issues requiring research and presenting cost reduction opportunities. These have been split into installation and O&M stages as relevant in Table 1.

Table 1 Cost reduction opportunities (Strategic Initiative Ocean Energy, 2013)

Installation	**O&M**
There is a shortage of dedicated specialist installation vessels for OE arrays. The industry would require enough deployments to justify the investment.	A major cost is to access the device so the focus should be on decreasing planned/unplanned maintenance, which will also improve yield and availability. This may be through improved reliability, strategies e.g. predictive maintenance techniques etc.
Optimising the design e.g. using one foundation structure for several turbines to share the cost of installation.	Facilitate ease of maintenance e.g. design so it is simple to recover using smaller cheaper vessels and take to a sheltered location for maintenance; or develop frames which allow submerged devices to be lifted above the surface when maintenance is required.
Developing techniques and procedures that require cheaper vessels e.g. drilling rigs or cable layers mounted on Remotely Operated Vehicles (ROVs).	Improving reliability is an important factor as offshore maintenance is costly. Offshore wind experience is that electrical/electronic components are more likely to fail than mechanical components. A variety of approaches are being pursued to reduce failures e.g. designing in redundancy so that the device can tolerate a certain number of failures to ensuring components likely to fail are in a dry and easily accessible locations.
Maximising the weather windows available by finding a balance between vessels that can operate in a wider range of conditions and lower cost but more limited options.	Suitable port infrastructure enables lower maintenance costs.
Installing floating devices should be significantly cheaper, allowing tow out with smaller, cheaper vessels.	Predictive condition monitoring using sensors on the device for early detection of potential faults are also likely to reduce costs.
	In the long term when more devices are installed it is likely that far offshore O&M bases will be established.

While a number of opportunities are identified, it is a challenge to test and optimise strategies, given the lack of real experience or readily available data. Modelling tools are the best way to identify and test the cost-benefits of different technologies and procedures, and demonstrate the feasibility to investors. The next section provides an overview of the existing installation and O&M logistics models available and that are most relevant for wave and tidal applications. It also highlights which tools could provide learning and/or be extended to facilitate assessment and optimisation of logistics for OE arrays.

4. Existing models

Table 2 provides a list of logistics tools developed relevant to OE devices identifying the varying levels of detail; flexibility; and objectives of each tool where possible to facilitate quick and easy comparison. For example, the list identifies which tools are specific to offshore wind, wave or tidal arrays as well as more general tools focused on the marine sector. It also highlights which consider O&M and/or installation activities, general logistics or generic maritime operations. The table specifies the availability of each tool e.g. is it in-house, commercial or open-access.

In terms of outputs some tools focus primarily on estimating operational durations, while others provide some basic costs estimates. The table also identifies where tools facilitate more extensive financial analysis. It should be noted that most of the tools estimate costs an, this category specifically identifies tools developed to facilitate comprehensive financial assessment producing Key Performance Indicators (KPIs) such as LCoE, Net Present Value (NPV), and the Internal Rate of Return (IRR).

Table 3 provides a basic overview for each tool and/or a reference where further information can be found. For example, it highlights where tools involve quite detailed discrete-event simulation of operations across time-series of hourly significant wave heights, wave periods, wind speeds and current speeds as relevant. A number of them also utilise methods such as the Monte Carlo simulation to allow users to understand the impact of uncertainty and risk in prediction models. This involves running multiple simulations of a single scenario, where each iteration randomises stochastic variables e.g. occurrences of failures during O&M. The fluctuation of these variables over large numbers of iterations models the potential impact of uncertain/unknown elements on time and costs. Further explanation of this method can be found in (Arnold & Yildiz, 2015).

It should be noted that Table 2/Table 3 are not an exhaustive list but focuses on offshore wind tools as well as the most recent tools with the most relevance to wave and tidal that have identified in the existing literature. This list utilises existing reviews by (Hofmann M. , 2011); (Anaya-Lara, Tande, Uhlen, & Merz, 2018); and (Judge, et al., 2019), which describe additional tools that may be of interest to readers.

Table 2 Overview of existing logistics models - scope

Model	Offshore wind	Wave	Tidal	Marine: non-specific	Installation	O&M	General logistics	Financial Analysis	Availability
2OM DSS	x					x			In-house
Balance Of Station (BOS)	x				x				In-house
DONG Energy's logistics model for O&M	x					x			In-house
DTOcean Logistics and Marine Operation (LMO) modules	x	x	x		x	x		x	Open source
Durham O&M cost model	x								In-house
ECN O&M tool and OMCE calculator	x		x			x			Commercial
ECUME	x					x			In-house
Exceedence	x	x	x					x	Commercial
ForeCoast Marine				x			x		Commercial
Fraunhofer multi-agent tool	x						x		In-house
Inn2O&M tool	x	x	x			x			In-house
LEANWIND Financial Model	x				x	x		x	In-house
LEANWIND lifecycle logistics models	x				x	x			In-house
MAINTSYS	x					x			Commercially available as a cloud-based software service, as well as through consultancy services.
Mermaid				x			x		Commercial
No name (Rinaldi, Thies, Walker, & Johanning, 2016)		x				x			In-house
No Name (Abdulla, et al., 2011)		x				x			In-house

NOWICob	x					x			In-house
O2C	x				x				Commerical - used by DNV GL as a service and not ordinarily sold/licensed as software
O2M	x					x			Commerical - used by DNV GL as a service and not ordinarily sold/licensed as software
OPUS/SIMLOX	x					x			Commercial
OutSmart	x					x			In-house
Strath-OW OM	x					x			In-house
The Wave Energy Scotland O&M Simulation model		x				x			Open source
TU Delft Integrated Decision Support Tool	x								In-house
UCC life cycle cost model	x	x				x		x	In-house
University College London O&M Strategy model	x								In-house

Table 3 Overview of existing logistics models - description

Model	Developer	Details/Reference
2OM DSS	University of Portsmouth, 2OM Interreg project	The assesses the costs of O&M considering failure rate data which may be set or varied as a stochastic variable. It currently models a single representative site with no variation of conditions. (Anaya-Lara, Tande, Uhlen, & Merz, 2018) (Li, et al., 2016)
Balance Of Station (BOS)	NREL	The NREL BOS models the CAPEX during the installation phase providing typical values, expected ranges, and assumptions made based on today's technology and best practices. Applied in (Maples, Saur, Hand, Pietermen, & and T. Obdam, 2013)

DONG Energy's logistics model for O&M	DONG Energy (owner/operator)	Little information available as in-house industry tool. (Anaya-Lara, Tande, Uhlen, & Merz, 2018)
DTOcean Logistics and Marine Operation (LMO) modules	DTOcean	Simulates installation and O&M for wave/tidal/wind/combined devices, electrical infrastructure, moorings and foundations. Uses input and outputs from other modules to feed into overall LCOE calculation. (Teillant, Chainho, Raventos, Nava, & and Jeffrey, 2014) and (CorreiadaFonseca, et al., 2020)
Durham O&M cost model	Durham University	Little information available as in-house tool. (Neate, 2014) (Anaya-Lara, Tande, Uhlen, & Merz, 2018)
ECN O&M tool and OMCE calculator	ECN	Offshore wind O&M optimization software. The tool can compare a variety of maintenance scenarios and provides the impact on the techno-economic performance. It is deterministic, taking average failures for failures, weather statistics and costs. However, an @risk add-in-module facilitates uncertainty analysis considering failure frequencies and costs. The calculator is different in terms of modelling methodology, developed to facilitate decision making during farm operation, processing operational data to determine costs and optimise resources in the near-term i.e. 1-5 years. ECN also has a number of other, more special-purpose tools (Obdam, Braam, & Rademakers, 2011) (Rademakers, Braam, Obdam, & Pieterman, 2009). The OMCE calculator has been adapted to consider tidal energy arrays (Hu & Stock-Williams, 2018).
ECUME	EDF group	This was developed based on ECN's OMCE. 2 key improvements have been made: a hidden Markov Chain model was designed to model the meteorological parameters and an event based Monte Carlo simulation was implemented to model the failures and maintenance actions. (Vincenzo Nava et. al, 2019), (Douard, Domecq, & Lair, A Probabilistic Approach to Introduce Risk Measurement Indicators to an Offshore Wind Project Evaluation – Improvement to an Existing Tool Ecume, 2012)
Exceedence	(Exceedence, 2020)	Exceedence software provides project assessment producing indicators such as LCOE, IRR, NPV, Payback and Cash flows. Can be used for wind, wave, tidal and combined technologies. The model facilitates sensitivity analysis and goal seek to optimise O&M strategies.
ForeCoast Marine	JBA Consulting	This is a web-based tool to manage metocean risks either for upcoming and live operations or considering the impact on construction and O&M strategies. (Forecoast Marine, 2020)
Fraunhofer multi-agent tool	Institute of Shipping Economics and Logistics (ISL) and Fraunhofer Institute for Factory	Several tools to support logistic planning for the wind farm industry (onshore and offshore) in collaboration with Institute of Shipping economics and Logistics (ISL) (Vincenzo Nava et. al, 2019)

	Operation and Automation (IFF)	
Inn2O&M tool	Inn2Grid (in HiWave R&D project)	Uses failure rates and metocean data to look for weather windows; compares port facilities and vessel types; onshore/offshore maintenance. (Inn2Grid project, 2017)
LEANWIND Financial Model	LEANWIND (University College Cork and SINTEF) (Judge, et al., 2019)	LEANWIND financial model - simulates the activities and costs across the farm lifecycle (installation, O&M and decommissioning) using Monte Carlo simulation to consider risk and uncertain factors e.g. failure rates, weather and costs. Determines impact of strategies on LCOE to support decision making and a variety of business models.
LEANWIND lifecycle logistics models	LEANWIND (University of Portsmouth; Hull University; SINTEF/MARINTEK)	LEANWIND developed a holistic set of optimization-based decision support tools for all life cycle phases (Installation, O&M, Decommissioning) and supply chain legs (prior to port, at port, port to site) of offshore wind farm. They are standalone tools (no software integration) and are separately defined as follows:
		-*LIVO* (Halvorsen-Weare & Nonås, LIVO Factsheet, 2017): *LEANWIND Installation Vessel Optimizer.* Propose cost/time-optimal solutions to the planning problem (vessel fleet configuration, port selection, optimal activity schedule). Weather conditions (wind/wave) and their effect on the solution is accounted for in a deterministic manner.
		-*PortIns/PortLay*: port selection and lay-out configuration
		-*PTPIns*: supply chain configuration from production to port
		-*HOWLOG* (Stålhane, Vefsnmo, Halvorsen-Weare, Hvattum, & Nonås, 2016) *and* (Halvorsen-Weare & Nonås, HOWLOG — Heuristic solver for offshore wind O&M logistic resource optimization, 2017): *Heuristic solver for offshore wind O&M Logistics resource management.* Propose cost-optimal solutions to the planning problem (Logistics resources and deployment). Weather conditions and corrective maintenance tasks are stochastic parameters
		-*PortOM*: port selection for O&M phase
		-*PTPOM*: supply chain configuration from suppliers to O&M support port
		-PortDis/IntDis: Determine optimal scheduling of decommissioning from offshore Wind Farm site
MAINTSYS	Shoreline (consultancy) / University of Stavanger	Developed through the PhD study of Ole-Erik Vestøl Endrerud in the NORCOWE research centre. (Anaya-Lara, Tande, Uhlen, & Merz, 2018) This model uses agent-based and discrete-event modelling to simulate

		the logistics of the operational phase for an offshore wind farm. This considers probabilistic failure rate analysis and models operations across a Metocean time series to consider the availability of weather windows and the impact on logistics. (Endrerud, Liyanage, & Keseric, 2014)
Mermaid	Mojo Maritime Ltd (and Uni of Exeter)	Mermaid performs a holistic analysis of the installation procedure using a variety of input data (e.g. metocean data, project information and vessel characteristics) to provide an estimate of the project length and cost. Also used for O&M methodology analysis to characterise the impact of strategy and design decisions on the weather risk profile for operations. http://mojomermaid.com/ Applied by (Morandeau, Walker, Argall, & Nicholls-Lee, 2013)
No name	(Rinaldi, Thies, Walker, & Johanning, 2016)	This reference describes an O&M model for wave energy devices based on the Monte Carlo simulation approach, varying the occurrence of faults and modelling maintenance operations to determine costs, production and availability.
No name	(Abdulla, et al., 2011)	This reference describes an O&M model for wave energy devices using the Aquamarine Power's 'Oyster' WEC. It uses the Monte Carlo method and simulate the occurrence of faults. The key output is availability.
NOWICob	SINTEF	Simulates maintenance activities and related logistics of offshore wind farms to estimate O&M costs and analyse O&M strategies. The model considers probabilistic generation of weather data (using Markov Chain modelling) and failure rates, applying a Monte Carlo simulation method. A version of this was developed as the O&M module of the FP7 LEANWIND project financial model also listed in this table. (Hofmann & Sperstad, 2013) Developed within NOWITECH and related projects but open to collaboration with industry for research. (Anaya-Lara, Tande, Uhlen, & Merz, 2018)
O2C	Garrad Hassan (DNV-GL)	Simulates installation operations against an environmental time series and uses Monte Carlo analysis to estimate durations and costs. (Smith, Thomson, & Whelan, 2010).
O2M	Garrad Hassan (DNV-GL)	This model optimises the O&M strategy to determine a balance between the cost of lost production due to downtime and the cost of resources for the maintenance strategy i.e. vessels, crew etc. The model randomly generates failures for each iteration and assigns resources to repair it and models attempts to access the farm considering environmental conditions. (Smith, Thomson, & Whelan, 2010).
OPUS/SIMLOX	Systecon (consultancy)	This model utilises Monte Carlo simulation, modelling failures to determine availability and power production (Johansson, 2013) (Anaya-Lara, Tande, Uhlen, & Merz, 2018).
OutSmart	Overspeed GmbH Co. KG	OutSmart – Offshore wind O&M strategy simulator. Based on the logistic scenario and historical weather data input by the user, the model simulates a strategy for a specific site, estimating the production losses, availability and costs.

Strath-OW OM	University of Strathclyde	The Strathclyde University offshore wind OPEX model utilises a time domain Monte-Carlo simulation approach. The focus of this model is detailed analysis of the O&M fleet including the user of helicopters. (Dalgic, Lazakis, Dinwoodie, McMillan, & Revie, 2015) (Anaya-Lara, Tande, Uhlen, & Merz, 2018)
The Wave Energy Scotland O&M Simulation model	(Wave Energy Scotland, 2020)	Developed as part of a doctoral research project. This Microsoft Excel-based O&M tool uses the Monte Carlo method to simulate the occurrence of faults on each device in a wave energy array by utilising failure rate data.
TU Delft Integrated Decision Support Tool	Developed by Delft Technical University in cooperation with Systems Navigator (consultancy)	This model is a discrete event simulation tool developed to allow users compare and optimise different O&M strategies. (Koopstra, 2015) (Anaya-Lara, Tande, Uhlen, & Merz, 2018)
UCC life cycle cost model	UCC, originated in the MARINA platform project	Examines the costs of combined wind/wave platforms across a project lifecycle. Extended to consider detailed costs of O&M activities using input from RAMS analysis and Bureau Veritas model to simulate failures and maintenance of a single platform. (O'Sullivan, 2014) and (Devoy McAuliffe, Macadré, Donovan, Murphy, & Lynch, 2015).
University College London O&M Strategy model	University College London	This model utilises Monte Carlo simulation, varying faults across iterations to determine energy production and maintenance strategy costs (Karyotakis, 2011) (Anaya-Lara, Tande, Uhlen, & Merz, 2018).

Table 2 indicates that existing tools are most commonly built to consider the general marine sector or offshore wind rather than specifically wave and tidal arrays. This is simply due to the nascent nature of the OE industry. Models also tend to consider either installation or O&M activities, with a few that assess general logistics, irrespective of lifecycle stage. However, there are a number of existing tools that could be utilised and/or further developed for the wave and tidal sector.

ForeCoast Marine and MERMaid are two commercial models that can simulate offshore operations for any device across any lifecycle stage. However, the focus is on planning activities considering access restrictions due to site metocean conditions. Results focus on the time required to complete operations rather than considering power production and detailed cost estimates. It should also be noted that these, and a large number of the tools in Table 2, are either commercial or in-house models. Therefore, cost or access can be prohibitive for developers. Where access is limited, the report highlights references where possible that describe the models and could be used as a basis for developing future tools.

Models that are developed or adapted to specifically consider wave and/or tidal arrays include the DTOcean+ tools (CorreiadaFonseca, et al., 2020); the WES O&M tool (Wave Energy Scotland, 2020); and the ECN OMCE calculator for tidal arrays (Hu & Stock-Williams, 2018). The ECN tool is adapted from their offshore wind OMCE calculator, and is not publicly available. However, both the DTOcean+ tools (developed in python) and the WES O&M tool (developed in excel – VBA) are open access and provide a considerable resource for developers as well as a basis for tool development.

The DTOcean+ suite of tools ranges from design tools for the selection, development and deployment of ocean energy systems (wave, tidal, wind, combined devices). This includes a module to assess the logistics and costs of installation and O&M operations. This could be considered the state-of-the-art tool when it is completed; however, it is still in development (project ends in April 2021). In addition, assessment of the existing installation and O&M modules indicates that the user would require a large amount of inputs to test a scenario, designing an array from start to finish in order to simulate a scenario. This is quite a labour intensive process and would need a considerable amount of time and training to complete. Given the current state of the industry, a standalone logistics tool that is not dependent on inputs from a series of detailed design models could compliment the DTOcean+ model. This would facilitate users (academics and industry) with varying levels of information available to undertake quick assessments. As additional feature could be to consider uncertainty. The DTOcean+ tools currently run a single simulation of a given scenario. However, use of a Monte Carlo simulation method would allow users to consider the impact of uncertain input data as described earlier in this section.

The WES O&M tool is a standalone tool that is open-access and utilises Monte Carlo simulation to consider the uncertainty of failure occurrence. It is specific to wave energy arrays and O&M, not considering tidal devices or installation logistics. However, it could be adapted and extended either utilising the code itself and/or learning from the tool functionality and modelling techniques. The model developers also identify two key areas where further development could focus. Currently the model uses fixed failure rates to determine how often a failure is likely to occur. However, these could be varied using a

Weibull curve approach to account for early 'infant mortality' failures or degradation of components over time (Gray, Dickens, Bruce, Ashtond, & Johanning, 2017). In addition, weather windows are currently set to 12hrs at all times. Weather windows determine whether the site can be accessed and maintenance undertaken based on the time required to transit to site and complete the operation. The model could be extended to calculate the actual required window to complete an operation rather than set to 12 hours, which could increase availability where tasks take less than 12 hours to complete and require shorter windows.

A key step to progressing the current state of the art for all OE design tools is validating them against the recent and upcoming arrays. This will be difficult for the operational logistics and lifecycle cost tools given the lack of arrays and field experience to date. The WES model has undergone some validation using data from the second-generation Pelamis WEC (750Kw) and a testing programme with over 11,000 grid connected hours. (Gray, Dickens, Bruce, Ashtond, & Johanning, 2017). Further use and validation from real life projects would increase confidence in the model and its results.

Future models can also learn from existing offshore wind installation and O&M models where they can be accessed e.g. open access or licence purchased. With the increased deployment and research into floating offshore wind, it is likely that the more recent tools could easily be converted to consider the operations required for wave and tidal arrays. The key difference required is to facilitate the use of mooring and anchoring systems that allow floating devices to be towed using small vessels such as tugs. In addition, while tidal turbines use a similar power curve to offshore wind turbines, models that calculate power production during the operational phase would need to be able to consider a power matrix for WECs. For SELKIE, WP8 have access to the LEANWIND Financial Model (specific to offshore wind, but can consider fixed and floating; simulates operations during the installation, O&M and decommissioning phases) and UCC lifecycle cost model (considers wave, wind or combined devices; does not simulate installation and O&M, requires inputs from other models).

5. SELKIE Logistics model

The SEKLIE project is developing a decision-support tool that will compliment and fill the gaps in the existing models. The tool will be open-access, user-friendly and flexible, able to assess a wide range of different technologies with varying levels of information available. This will be a key challenge considering the large range of technologies and concepts for wave and tidal energy.

The SELKIE model will consider synergies and learning from existing tools including the DTOcean+ installation and O&M modules; the WES O&M model; and existing tools for the offshore wind sector, particularly the LEANWIND Financial model. Feedback is also currently being gathered from key industry players including Sabella and OceanEnergy to ensure the model can simulate the strategies and scenarios of most interest to industry. The questionnaire used to gather feedback is included in Appendix 1. This was presented at a SELKIE Webinar 8th October 2020 and distributed via the project social media links and website.

The key objectives of the tool are to allow users to:

- model operations across the lifecycle considering uncertain factors e.g. weather windows and failures and their impact on the costs and duration of a project
- optimise the logistics required for the installation and O&M phase e.g. port, offshore vessel fleet, activity schedule etc.

The tool will be applied to

- Pilot case-studies (based on existing projects by OceanEnergy (wave) and Sabella (tidal))
- A series of generic case-studies relevant to Ireland and Wales, analyzing areas for optimisation.

D8.2 will provide a description of the SELKIE model and is due in May 2021 following the initial completion of coding. Extensive validation and testing will follow with the final version being presented during a user training course in February 2022. It should be noted that this model will interact with the GIS techno-economic model developed in WP4 and this will be described in D8.2.

6. Conclusion

This deliverable provides an initial overview of the existing installation and O&M logistics models available that are best suited for wave and tidal applications. It is clear that while a significant number exist, most tools are in-house or commercial restricting the accessibility often only to descriptions in the existing literature. However, key open-access tools including the DTOcean+ models and the WES can provide a concrete basis for the development of the SEKLIE logistics models. In addition, access to the LEANWIND Financial model and UCC lifecycle cost model will provide key learning and synergies. The SELKIE project has also prepared and distributed a questionnaire to relevant industry players. This is expected to gather key information on the functionality required in the SELKIE tool.

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Appendix 1

SELKIE

The SEKLIE project is developing a decision-support tool that will allow users to 1) simulate operations across the lifecycle considering uncertain factors e.g. weather and failures and their impact on the costs and duration of a project; 2) optimise the logistics required for the installation and Operation and Maintenance (O&M) phase e.g. port, offshore vessel fleet, activity schedule etc. This survey seeks to identify what strategies the tool should be able to test and gather information to form generic case-studies, which are of most interest to industry. Therefore, we would greatly appreciate participation from experts across the Offshore Renewable Energy supply chain. Please provide as much detail as possible/relevant to you. We would greatly appreciate any figures or rough ranges/percentages, but if that is not possible, general statements are still very much appreciated. Your feedback may be anonymous. If you choose to provide your contact email, this will be kept confidential within the consortium and only used for the purpose specified (i.e. follow up discussion on topic). The survey will be open until the 1st December 2020. Information provided will be stored on a secure site or partners' desktop computer for the duration of the SELKIE project.

- GENERAL - 1. What is your area of expertise?
  - ☐ Wave energy
  - ☐ Tidal energy
  - ☐ Offshore wind
  - ☐ Oil & Gas
  - ☐ Device manufacturing
  - ☐ Transport and logistics
  - ☐ Installation
  - ☐ O&M
  - ☐ Other - please specify
- GENERAL - 2. Would you be willing to be contacted for a follow-up discussion on this topic?

  ○ Yes ○ No
- GENERAL - 3. If yes to the above, please provide your email address to be added to our contact list.
- SUPPLY-CHAIN - 4. What are the major obstacles to deploying wave or tidal energy arrays and how could these obstacles be overcome in future? (if applicable, please include improvements in supply chain/ licensing/ governance etc.)
- SUPPLY-CHAIN - 5. What are the key port requirements for installing/decommissioning wave and tidal energy devices e.g. space, transport links?

- SUPPLY-CHAIN - 6. What are the key port requirements for O&M of wave and tidal energy devices e.g. space, transport links?
- SUPPLY-CHAIN - 7. What developments and investment may be needed for existing Irish/Welsh ports to cater for the wave and tidal industry?
- TECHNOLOGY - 8. What is your device or preferred concept currently in development/deployed (name or technology type e.g. oscillating water column)
- TECHNOLOGY - 9. Is the device
  wave - fixed wave - floating tidal - fixed tidal - floating Other
- TECHNOLOGY - 10. If fixed, please specify foundation type e.g. gravity, monopile etc.
- TECHNOLOGY - 11. If floating, please specify mooring and anchor system e.g. mooring lines, number, anchor type etc.
- SITE SELECTION - 12. What (if any) are the ideal site conditions for your preferred concept e.g. water depth, distance from shore?
- SITE SELECTION - 13. What (if any) are the seabed restrictions (e.g. seabed type)?
- ARRAY DESIGN - 14. What would be the preferred installed capacity (MW) of the first arrays (e.g. a small Offshore Wind Farm would be 100MW)?
- ARRAY DESIGN - 15. What are the space requirements for the device i.e. distance between devices?

- INSTALLATION - 16. What is the installation strategy for the device (please provide a brief description of the process)?
- INSTALLATION - 17 a. What are the vessels and equipment required?
- INSTALLATION - 17 b. What are the main costs (where possible please specify figures or ranges)?
- INSTALLATION - 17 c. What is the time required to install? (where possible, please break down into the different operations e.g. anchor installation, mooring connection etc.)
- INSTALLATION - 17 d. What are the weather restrictions e.g. max significant wave height/tidal current/wind speed? (where possible, please provide for the different activities e.g. vessel transit, foundation/mooring installation etc.)
- INSTALLATION - 18. What are the actual or estimated total installation costs per MW?
- INSTALLATION - 19. What are the main installation challenges?
- INSTALLATION - 20. If you have installed a device, what were the major lessons learned and what would you do differently the next time?
- INSTALLATION - 21. If you have installed a device, can you comment on the vessel availability and expenses (i.e. were vessels in short supply, did this create delays, what was the day rate/mobilisation costs etc.)

- INSTALLATION - ANY OTHER COMMENTS
- O&M - 22. What is the O&M strategy for the device (please provide a brief description e.g. tow back to shore for major repairs, onsite for minor repairs)?
- O&M - 23 a. What are the vessels and equipment required?
- O&M - 23 b. What are the main costs (where possible please specify figures or ranges)?
- O&M - 23 c. Can you specify the main maintenance operations for this device and their estimated durations? (corrective/preventive e.g. gearbox repair, annual inspection etc.)
- O&M - 23 d. What are the weather restrictions e.g. max significant wave height/tidal current/wind speed? (Where possible, please provide per operation e.g. towing, blade repair etc.)
- O&M - 24. What are the actual or estimated annual O&M costs per MW?
- O&M - 25. What are the main O&M challenges?
- O&M - 26. If you have maintained a device, what were the major O&M lessons learned and what would you do differently the next time?

- O&M - 27. If you have maintained a device, can you comment on the vessel availability and expenses (i.e. were vessels in short supply, did this create delays, what was the day rate/mobilisation costs etc.)
- O&M - ANY OTHER COMMENTS