WP2 Standardisation of Offshore Energy System Testing

D2.8 Ocean Energy Technology Guidance Report

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Authors	Frances Judge (UCC_MAREI), Mairéad Elliot (Bluewise Marine), Louise O'Boyle (Bluewise Marine), Caitlin Long (EMEC), José Candido (Wavec), Donal Noble (UEDIN), Thomas Davey (UEDIN), Fernando Salcedo (TECNALIA), Joseba Lopez-Mendia (TECNALIA), Michael O'Shea (UCC_MAREI)
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List of acronyms

Acronym	Description
ADCP	Acoustic Doppler Current Profiler
ARENA	Australian Renewable Energy Agency
CAPEX	Capital Expenditure
CCE	Characteristic Capital Expenditure
CIG	Collaborative Innovation Group
CRI	Commercial Readiness Indix
CRL	Commercial Readiness Level
CW	Capture Width
CWR	Capture Width Ratio
DCCOE	Discounted costs cost of energy
DRI	Distributed Research Infrastructure
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
FAIR	Findable Accessible Interoperable Reusable
FIT	Feed-In Tariff
GAD-CFD	Generalised Actuator Disk Computational Fluid Dynamics
GIS	Geographic Information System
IEC	International Electrotechnical Commission
ITTC	International Towing Tank Conference
LACE	Levelised Avoided Cost of Electricity
LCOE	Levelised Cost of Energy
LCOESt	Levelised Cost of Stored Energy
LMO	Logistics and Marine Operations
MEA	Marine Energy Alliance
MEC	Marine Energy Converter
NPV	Net Present Value
O&M	Operations and Maintenance
OPEX	Operational Expenditure
OPIN	Ocean Power Innovation Network
ORE	Offshore renewable energy
OWC	Oscillating Water Column
PIF	Price Increase Factor
PIV	Particle Image Velocimetry
PTO	Power Take-Off
RAMS	Reliability, Availability, Maintainability, Survivability
SCOE	Society's Cost of Energy
SLCOE	System Levelised Cost of Energy
SME	Small and Medium sized Enterprises
TAP	Technolgoy Assessment Process
TCOE	Total Cost of Energy

TE	Techno-Economic
TPL	Technology Performance Level
TRL	Technology Readiness Level
UCOE	Undiscounted Cost of Energy
USP	Unique Selling Point
VRE	Variable Renewable Energy
WEC	Wave Energy Converter

1 Introduction

The journey of an offshore renewable energy (ORE) device from an idea on paper to a commercial deployment is long, expensive and usually beset by numerous difficulties and dead ends. Physical testing is expensive and suitable test facilities are not available in every country. Furthermore, the guidance available for conducting physical testing is limited, and standardised processes for each stage of development have not yet been fully developed. It is not always clear what technological advancement should be prioritised at each stage of development and where money is best spent. Many developers, despite having a device that performs well, have difficulties securing the finance necessary to progress to the next stage of development. Developers of wave energy converters (WECs) are particularly susceptible to the pitfalls outlined above due to the sector in general being at an earlier stage of development compared with the tidal and floating wind sectors.

Technology Readiness Levels (TRLs) are the globally accepted index for benchmarking and tracking a technology's development from conceptualisation to full system demonstration. ORE developers must ensure their technology meets certain performance criteria to progress through the TRLs. However, achieving these performance metrics, while crucial, will not necessarily result in success. Other factors such as cost and a good business plan are also essential to ensure progression.

This deliverable aims to assist ORE developers in their journey to commercial deployment by providing an overview of the different frameworks as well as individual metrics that can be used to assess offshore renewable energy devices through all stages of development. The metrics range from those that measure performance, and technical and economic feasibility, to metrics that can be used to determine how ready a developer is to progress their business commercially. Freely available resources that can help ORE developers progress through the TRLs are presented. Many of these resources are the results of other collaborative projets funded by the EU.

2 Evaluation of developing ORE technologies

2.1 Technology Readiness Levels (TRLs)

The Technology Readiness Level (TRL) index was originally developed by NASA and is now widely used in many sectors including offshore renewable energy (ORE). The stage of development of an ORE device is often defined in terms of its TRL. A basic explanation of TRL 1-9 as applied in the ORE sector is given in Table 1. TRLs describe technical performance only, and do not account for factors such as the cost of the energy produced by a device. They therefore do not represent a pathway to success that can be readily used by technology developers.

Table 1 Technology Readiness Level (TRL) description

TRL	Description
TRL 1	Basic principles postulated/observed but no experimental proof available
TRL 2	Technology concept formulated, including all key sub-systems (and scale). Concept and application are defined.
TRL 3	Experimental proof of concept. First laboratory tests complete (likely scale 1:100 – 1:25). Analytical model performance validated by experiments. Initial optimization of design within representative environmental conditions.
TRL 4	Technology validated in laboratory. Small scale integrated prototype in a laboratory environment (likely scale 1:10 – 1:125) using realistic relevant environmental conditions to validate the expected performance of the technology (including e.g. power, loads, survivability, control etc.) across main environmental parameters (wave, tidal, wind etc.).
TRL 5	Technology validated in relevant environment. Large scale almost fully integrated prototype (likely scale 1:3 – 1:15) tested in laboratory/benign site with configuration and components similar to that expected at full-scale.
TRL 6	Technology demonstrated in relevant environment
TRL 7	System prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment

In a report for the Sustainable Energy Authority of Ireland, ESBI produced a detailed document outlining the different requirements that a wave energy converter should meet at each TRL under the following headings:

- Functional Readiness
- Lifecycle Readiness
- ESBI Verification Checklist
- Indicative: Spend, Power Revenue, Funding, Duration, Team

A copy of the document has been included in Appendix A of this report.

2.2 Technology Performance Levels (TPLs)

The Technology Performance Level (TPL) is a metric that describes the techno-economic performance of an ocean energy device and is thus a useful means of capturing where a device is on the pathway to a commercial deployment. The concept was originally presented by [1], [2] for wave energy converters and further developed at the National Renewable Energy Laboratory (NREL), USA. TPLs quantify the techno-economic performance by considering factors such as:

- Acceptability
- Power absorption, conversion, and delivery capability
- System availability
- Capital expenditure (CAPEX)
- Operational expenditure (OPEX)

A description of each TPL is provided in Table 2. A TPL of 1-3 is categorised as low-performance and represents technologies that are not economically viable. Medium-performing technologies at TPL 4-6 are characterised by potential economic viability under certain market and operational conditions. High-performing technologies at TPL 7-9 are economically viable and competitive as a source of renewable energy.

Table 2 Technology performance level characteristics [1]

<table>
<tr><th rowspan="2">TPL</th><th colspan="2">Category</th><th rowspan="2">TPL Characteristics</th></tr>
<tr><th colspan="2">Characteristics</th></tr>
<tr><td>9</td><td rowspan="3">high</td><td rowspan="3">Technology is economically viable and competitive as a renewable energy form</td><td>Competitive with other energy sources without special support mechanism</td></tr>
<tr><td>8</td><td>Competitive with other energy sources given sustainable support mechanism</td></tr>
<tr><td>7</td><td>Competitive with other renewable energy sources given favourable support mechanism</td></tr>
<tr><td>6</td><td rowspan="3">medium</td><td rowspan="3">Technology features some characteristics for potential economic viability under distinctive market and operational conditions. Technological or conceptual improvements may be required.</td><td>Majority of key performance characteristics & cost drivers satisfy potential economical viability under distinctive and favourable market and operational conditions</td></tr>
<tr><td>5</td><td>In order to achieve economical viability under distinctive and favourable market and operational conditions some key technology implementation improvements are required.</td></tr>
<tr><td>4</td><td>In order to achieve economical viability under distinctive and favourable market and operational conditions some key technology implementation and fundamental conceptual improvements are required.</td></tr>
</table>

3	low	Technology is not economically viable	Minority of key performance characteristics & cost drivers do not satisfy potential economic viability
2			Some of key performance characteristics & cost drivers do not satisfy potential economic viability
1			Majority of key performance characteristics & cost drivers do not satisfy and present a barrier to potential economic viability

2.2.1 Technology development trajectories using TPLs

TPLs are combined with TRLs by [2] to develop potential technology development trajectories. Figure 1 shows extreme and therefore generally unrealistic development trajectory examples. The yellow trajectory represents readiness before performance, where the technology reaches a high TRL before becoming commercially viable. Moving from a low to a high TPL would likely require fundamental system improvements. Making these changes from a starting point high on the TRL scale is extremely costly and time-consuming.

In contrast, the cost associated with the green trajectory is much lower, as fundamental system changes are carried out at low TRLs, and therefore at lower cost. However, this scenario is also unrealistic due to the uncertainties associated with the characteristics of the system, which can only be addressed by progressing through the TRLs. Furthermore, the most direct route to a TRL and a TPL of 9, i.e., the black trajectory, may not be optimal when cost, time and risk are considered.

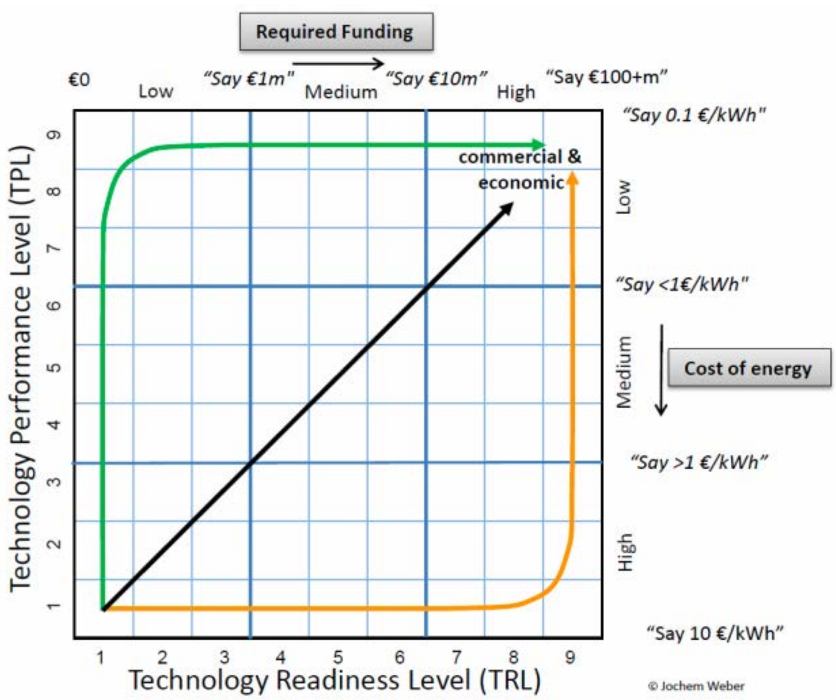

Figure 1 Generic WEC technology development trajectories [2]

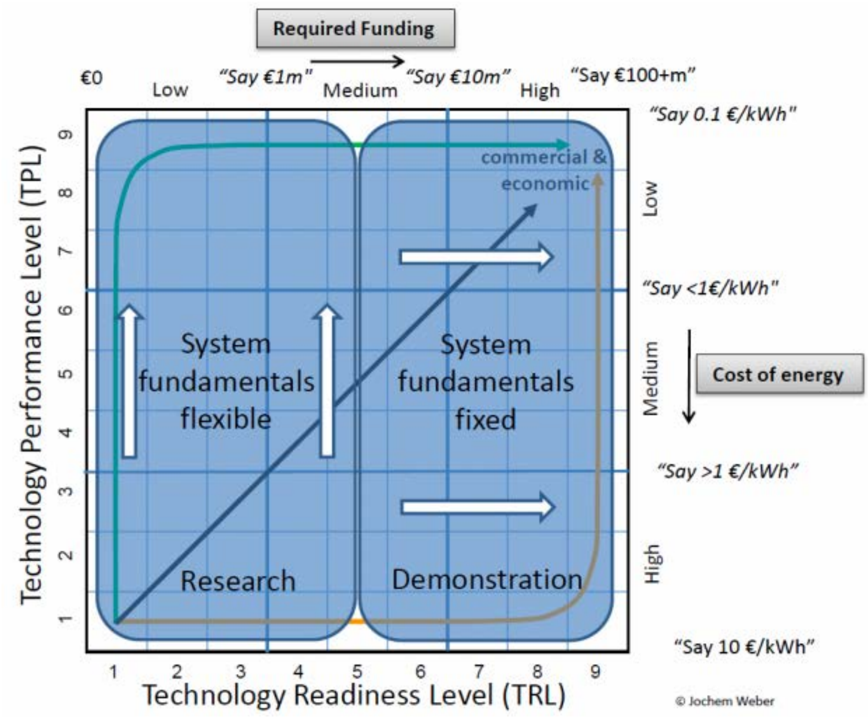

Figure 2 Generic WEC technology development domains

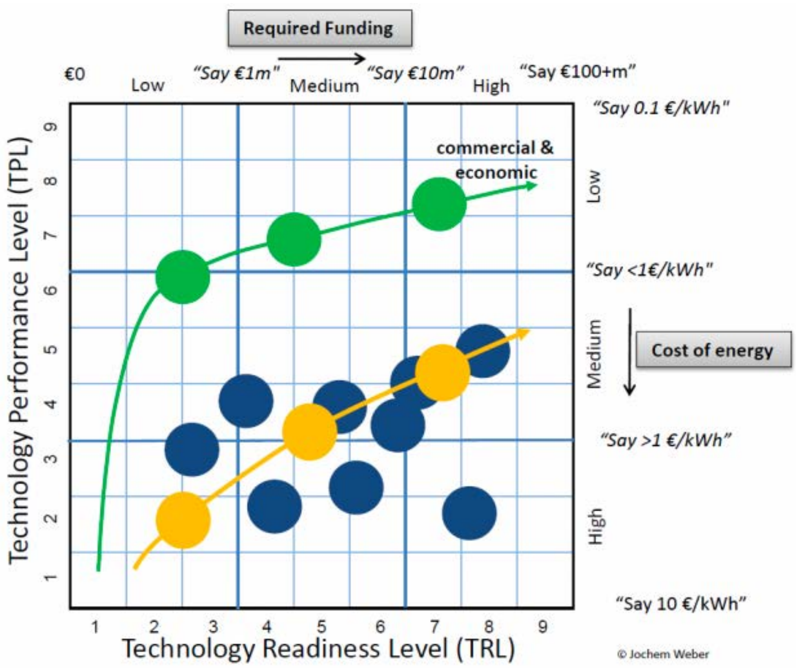

Figure 3 Comparison of development trajectories. Improved realistic development trajectory (green) following the guiding principle of 'performance before readiness' [2].

By considering the development domains shown in Figure 2, [2] proposes an ideal development trajectory that follows the green line in Figure 3. In this figure, the yellow and blue data points represent the current development status of two anonymous, state-of-the-art (at the time of publication of [2]) WEC technologies. The ideal trajectory operates under the guiding principle that developers should strive to increase economic performance (i.e., TPL) as far as possible at low TRLs when fundamental system changes can be accomplished at low cost, before increasing technology readiness. Although proposed with WECs in mind, this strategy is applicable to the development of all renewable energy technologies.

2.3 IEA-OES Task 12: Performance Metrics International Framework for Ocean Energy

The IEA-OES Task 12 was set up to develop a framework for evaluating and guiding the development of wave and tidal energy technologies through all stages of development. To achieve this, clear definitions were required for

- Stage activities – i.e., the engineering activities carried out by developers
- Evaluation Criteria – the parameters used to evaluate achievement
- Evaluation Method – the process used to calculate the criteria

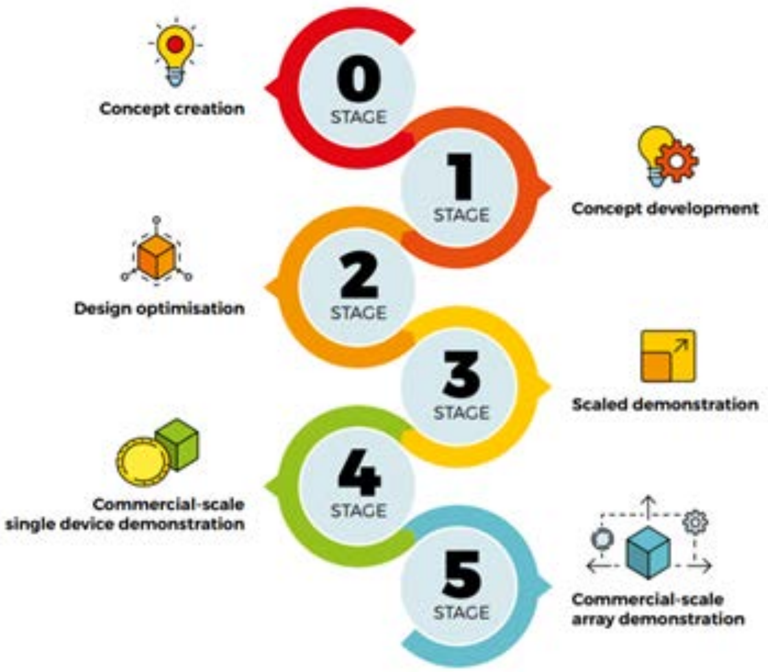

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Figure 4 IEA-OES Task 12 Stages for ocean energy technology development

While TRLs and TPLs are useful descriptors when tracking progression of a technology, it is often difficult to determine where an ORE technology falls on the scale when different subsystems are at different stages of development, and what are the steps that must be taken to proceed to the next level. The IEC [3] present five development stages which provide a simpler and more intuitive wave of categorising different technologies. The IEA-OES Task 12 also follows the IEC stages, with the inclusion of an additional Stage 0 as shown in Figure 4. The link between the stages and TRLs is shown in Table 3.

Table 3 Six-stage technology development process

Stage	Description of activity	TRL
Stage 0	Concept creation	1
Stage 1	Concept development	2-3
Stage 2	Design optimisation of scaled devices	4
Stage 3	Scaled demonstration	5-6
Stage 4	Commercial-scale single device demonstration	7-8
Stage 5	Commercial-scale array demonstration	9

To determine evaluation criteria for each stage of development, Task 12 incorporated aspects from both the TRL and TPL indices and proposed nine evaluation areas as described in Table 4, in which the associated evaluation criteria are also listed.

For each stage of development, comprehensive stage activities are presented in [4] for each of the evaluation areas. The results of the IEA-OES Task 12 are presented in [4] and form the basis for open-access tools developed in the DTOceanPlus project discussed in Section 5.1.1.

Table 4 IEA-OES Task 12 Evaluation area definitions

Evaluation area	Definition	Evaluation criteria
Power Capture	Power Capture is the process of extracting energy from the natural resource by the interaction with a device and making it available as an input to a power take-off (PTO).	Wave energy: - Power capture - Capture length Tidal stream energy: - Power capture - Power coefficient
Power Conversion	Power Conversion represents the second step in the power conversion chain, whereby the mechanical power captured by the device is converted to electricity.	- Power conversion efficiency
Controllability	Controllability is defined as the ability for control systems to be implemented to a subsystem or device and incorporates evaluation of the benefits control can deliver and the reliance of a subsystem or device on it.	- No specific criteria as the benefits of improved control are typically evaluated through other evaluation areas (e.g. power capture and survivability)
Reliability	Reliability is defined as the "probability that an item can perform a necessary function under given conditions for a given time interval".	- Mean time to failure - Failure rate
Survivability	Survivability is a measure of the ability of a subsystem or device to experience an event ('Survival Event') outside the expected design conditions, and not	- Design conditions boundary - Likelihood of exceeding an acceptable level of

	sustain damage or loss of functionality beyond an acceptable level, allowing a return to an acceptable level of operation after the event have passed.	damage or loss of functionality, with or without taking suitable protective action
Maintainability	Maintainability is defined as the "ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance".	- Range of acceptable environmental conditions; - Mean time to repair; - Cost to repair or maintain.
Installability	Installability is defined as is the ease with which a component, subsystem or device can be prepared, deployed at the operational open-water site and commissioned, resulting in a condition of operational readiness. Installability also includes the ease with which the component, subsystem or device can be recovered.	- Range of acceptable environmental conditions for installation; - Mean time to install; - Transit speed; - Cost to install
Manufacturability	Manufacturability is defined as the ability for the technology to be manufactured quickly, cheaply and with minimum waste, and therefore its compatibility with the supply chain's capability, readiness and maturity.	- Manufacturing readiness level (MRL) - Time to manufacture - Cost to manufacture
Affordability	Evaluation of Affordability relates to the cost of electricity generated from the wave or tidal stream resource.	- CAPEX - OPEX - LCOE

3 Technical metrics for ORE developers

3.1 Performance metrics

3.1.1 Common metrics applied to ORE devices

There are numerous metrics applied to ocean energy devices to determine the performance. Performance assessment typically begins with determining the power capture of the device. This, along with the capture width ratio form the basis for evaluating power conversion of a wave energy converter in the IEA-OES Task 12 framework discussed in Section 2.3. For a tidal device, the evaluation criteria consist of power capture and the power coefficient, C_p. Power performance can then be linked to the cost by considering metrics such as absorbed energy per unit mass, or per unit surface area.

3.1.1.1 Power capture

The power capture of a WEC is represented by a matrix of the average power capture in defined sea states; i.e. combinations of discrete values of significant wave height (Hs) and energy period (Te).

For a tidal energy converter, power capture is represented by a power curve generated by plotting mean power capture against mean current speed for flood and ebb tides.

3.1.1.2 Capture Width Ratio (CWR) - Wave

The capture width ratio (CW) is defined as the ratio of wave power absorbed by the device, P (in kW) to the power of the incident waves, J (in kW/m) i.e.,

$$CW = \frac{P}{J}.$$

It is therefore the width of wave crest that is completely captured and absorbed by the WEC. The CWR is a measure of hydrodynamic efficiency and is obtained by dividing the W by the width of the device, *B*, i.e.

$$CWR = \frac{P}{JB}.$$

3.1.1.3 Power coefficient (Cp) - Tidal

The power coefficient is defined as

$$C_p = \frac{Power\ Capture\ (kW)}{Available\ Power\ (kW)},$$

Where the available power = $\frac{1}{2}\rho A U^3$ in which ρ is the density of seawater, *A* is the swept area of the power capture device, and *U* is the mean current speed.

3.1.1.4 Performance metrics linked to cost

By relating the absorbed energy to the cost of a device, developers can get a clearer idea on whether a concept has the potential to be commercially viable. [5] used the following metrics to compare several wave energy converters:

- Annual absorbed energy
- Absorbed energy per characteristic mass [kWh/kg]
- Absorbed energy per characteristic surface area [MWh/m2]
- Absorbed energy per characteristic PTO force [kWh/M]

Although metrics like kWh/kg etc. can be helpful to some extent they can also be very skewed by other factors such as choice of material or the expense associated with using different approaches so they can be misleading.

Other criteria which are not covered by the above include:

- Market size, i.e. is the technology too niche or can it access most of the market?
- Inherent safety characteristics
- Inherent permitting characteristics
- Inherent grid compliance characteristics
- Load shedding over rated power, e.g. some form of pitch control for larger tidal turbines.

3.1.2 Metrics used to assess the Wave Energy Prize

The Wave Energy Prize was an 18-month public design-build-test competition sponsored by the US Department of Energy that kicked off in 2015. The goal of the competition was to develop more efficient WEC designs that would double the energy capture from waves and reduce the overall cost of wave energy. Out of the ninety-two teams that participated initially, nine made it to the final and four achieved the goal of doubling the energy capture. All finalists tested their devices at a wave facility in Maryland. The following sections present the metrics that were designed especially for the Wave Energy Prize and used to judge the competitors.

3.1.2.1 ACE

The ACE metric was designed to assess entrants to the Wave Energy Prize in an equitable manner. It is applicable to low-TRL WEC concepts, where insufficient information is available to calculate the LCOE. ACE represents. the equivalent wave crest width, for which the wave energy converter can absorb all incoming wave energy, that can be built per million dollars spent on load bearing structure [6].

The ACE metric is calculated from

$$ACE = \frac{\overline{ACCW}}{CCE},$$

where $\overline{ACCW}$ is the average climate capture width, and CCE is the characteristic capital expenditure. As detailed in [6], ACCW is calculated from

$$ACCW_j = \frac{\sum_{i=1}^{n} \Xi_{ij} \langle AP(i) \rangle}{\langle C_p(j) \rangle},$$

where n is the number of sea states, Ξ_{ij} is the scaling factor for sea state *i* and location *j*; $\langle AP(i) \rangle$ is the average power absorbed by the WEC for sea state *i* measured at the closest point in the PTO where wave energy flux is first converted to mechanical power; and $\langle C_p(j) \rangle$ is the average annual incident wave energy flux for site *j*.

CCE is given by

$$CCE = \sum_{k=1}^{L} m_k \, . \, MMC_k,$$

Where L is the number of key structural materials in the WEC and m_k is the total mass of structural material *k*. MMC_k is the manufactured material cost per unit mass of material *k*, and therefore represents all the costs associated with building a full-scale prototype. The CCE is calculated for each structural component and its expanded version for each material includes parameters such as the representative structural thickness of the material, the density of the material and the material surface area. For a full breakdown of these equations, refer to [1], [6].

3.1.2.2 HPQ

The HPQ metric was applied in the Wave Energy Prize to account for device performance characteristics not included in the ACE, but that would typically affect the calculation of the LCOE. It is defined as

$$HPQ = ACE \cdot [I_{MF} \cdot I_{WC} \cdot I_{AP-P2A} \cdot I_{ES} \cdot I_{RS} \cdot I_{AC}]$$

Where the performance impact factors, I, are defined as

- I_{MF}: based on the statistical peak of the mooring force and accounts for mooring load intensity
- I_{WC}: statistical peak of the mooring watch circle, and accounts for station keeping ability
- I_{AP-P2A}: ratio of statistical peak-to-average of absorbed power, and accounts for variability of absorbed power
- I_{ES}: number of end-stop impact events, and accounts for frequency and severity of mechanical end-stop impacts
- I_{RS}: absorbed power in realistic seas
- I_{AC}: accounts for the adaptive control effort.

All of the factors listed above except for I_{AC} were calculated from measurements and event counts made during wave basin testing. The I_{AC} values were based on the observed complexity of the controller used in the device. Further details on how the impact factors were determined are given in [6].

3.1.3 Metrics applicable to floating wind

The metrics applied to the assessment of floating wind platforms are fundamentally different to wave or tidal energy converters, as in this case the platform is not generating energy. The goal when designing and testing a floating wind platform is to provide a stable base for supporting a wind turbine that limits the motions of the nacelle to acceptable levels. Therefore, tank testing campaigns for floating wind platforms tend to focus on measuring the response in each of the 6 degrees of freedom to the applied wind and wave conditions and determining the mooring line loads. These data are then used to validate numerical models and characterise the dynamics of a full-scale platform.

The key factors in determining whether a floating wind solution will progress to commercial uptake are

- **Installability:** While a traditional spar might be the most stable solution, it is only practical in regions with very deep-water ports (e.g., Norway). Developers must design solutions that lend themselves to deployment from a wide range or ports, i.e., devices with a shallow draft in the installation phase that can be ballasted to achieve the required stability at site.
- **Maintainability (OPEX):** the cost of maintaining a floating wind turbine over a wind farm lifetime makes up a significant portion of the lifetime costs. Reducing the maintenance of the platform is therefore key to reducing the overall Levelised Cost of Energy (see Section 3.2.1). This may be accomplished by reducing the loads the platform is subjected to during operation, through turbine control or mooring load reduction devices. Active ballasting can increase stability, and therefore reduce loading on the turbine which can in turn reduce fatigue and lower maintenance costs. Key to the development of the floating wind sector will be the ability to perform large scale maintenance at sea, rather than towing back to shore [7].
- **CAPEX:** The capital cost of the support structure is a greater portion of the total in a floating compared to a fixed wind scenario, due to the earlier stage of development of the sector and the more complex engineering required. Reducing the CAPEX of floating platforms through the use of more cost-effective materials like concrete, and the streamlining of the design through increased understanding of the loadings are key to the commercialisation of floating wind.
- **LCOE:** The factors discussed above all feed into the calculation of the Levelised Cost of Energy (LCOE). This is discussed further in the next section.

3.2 Techno-economic metrics

The techno-economic metrics outlined in the following sections aim to quantify the lifetime costs of a device by considering CAPEX, installation costs, OPEX, decommissioning costs, as well as other financial, economic, or social and environmental factors.

3.2.1 Levelised Cost of Energy (LCOE)

Among the metrics applied in the techno-economic assessment of ocean energy, the levelised cost of energy (LCOE) is pivotal. The LCOE is, in fact, the most widely used economic indicator to compare the lifetime costs of alternative electricity generation sources/technologies. The LCOE, typically given in €/MWh, may be taken as the discounted lifetime costs of asset ownership, per discounted cost of generation (e.g. [8]), so that

$$LCOE = \frac{\sum_{t=1}^{n} \frac{C_t + O_t + V_t + f}{(1+d)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+d)^t}} \quad (1)$$

Here C_t represents the capital costs, O_t and V_t respectively the fixed and the variable operational costs at year t, f represents the fuel costs, d is the project discount rate, n the project lifetime, and E_t the energy generated during year t. It should be noted that capital expenditure is usually the initial investment completed in year 0, with generation and operational expenditure starting from year 1.

3.2.1.1 Limitations of LCOE

LCOE has multiple shortcomings, mostly associated with the simplicity of its calculation, high-sensitivity variables, abstraction from reality and in the lack of clarity regarding assumptions and justifications, with comparative results often contradictory and with great variation. Financing risks are a relevant obstacle in a project's execution and are usually not accounted for in the LCOE. The metric also does not consider generation and revenue risks, such as whether the cost per MWh will be recouped by a feed-in tariff (FIT) or by the electricity market price alone. It is a static measure, providing a snapshot generation price that does not temporally align with how dynamic energy markets fluctuate daily [9]. Financing methods are also kept consistent in calculating the cost of capital, and do not account for variations in project financing options that real institutions can present [10]. High interest rates can favour low capital projects and can reduce the viability of renewables in emerging markets, and or underemphasize financing issues. The calculation also hides regional variability, as it ignores certain costs and revenues which can vary widely between geographies [11]. For a detailed examination on the calculation of LCOE, refer to [12].

3.2.2 Undiscounted cost of energy (UCOE)

The undiscounted cost of energy (UCOE) is an alternative formulation of the standard LCOE metric, which does not take into consideration the discount rates conventionally applied to costs and energy generation, and therefore overlooks the impact on value of the timing of cash flows. Simply put, the UCOE is the total costs (capital & operational) divided by the energy production, so that

$$UCOE = \frac{\sum_{t=1}^{n} C_t + O_t + V_t}{\sum_{t=1}^{n} E_t} \quad (2)$$

This metric is suitable to compare similar technologies, but it is not applicable for the accurate comparison of different generation types.

3.2.3 Discounted costs cost of energy (DCCOE)

The discounted costs cost of energy (DCCOE) is yet another alternative formulation of the LCOE, in which the sum of capital and operational costs is discounted but the energy generation is not, i.e.

$$DCCOE = \frac{\sum_{t=1}^{n} \frac{C_t + O_t + V_t}{(1+d)^t}}{\sum_{t=1}^{n} E_t} \tag{3}$$

This metric tends to produce lower values than standard LCOE due to the undiscounted energy production. This is particularly evident for longer lifetime projects where end-of-life generation tends to be heavily discounted in the LCOE calculation. Unlike the LCOE which delivers a minimum energy price that enables the project to achieve a zero NPV, the DCCOE metric does not straightforwardly corresponds to a price required for a project, and therefore hampers a useful reading [8].

3.2.4 Total cost of energy (TCOE)

The total cost of energy (TCOE) corresponds to the UCOE metric plus financing costs F_t, applied to the capital costs alone on an annuity basis, with operating costs assumed to be paid through annual revenues and thus not incurring financing costs [8] (see eq. (4)).

$$TCOE = \frac{\sum_{t=1}^{n} C_t + O_t + V_t + F_t}{\sum_{t=1}^{n} E_t} \tag{4}$$

Although the metric's approach reflects the reality of a large fraction of project financing, it is not consistent with conventional investment evaluation where all costs are discounted.

3.2.5 System LCOE (SLCOE)

The discounted cost of energy metrics provide a break-even price at which to sell electricity, matching a zero project NPV. However, such metrics do not include key areas that impact the development of variable renewable energy (VRE) projects, such as integration and profile costs, detailed in [13]. According to [10], financial and economic systems have a large impact on the electricity price, but the quality of electricity seldom changes and is not reflected in the LCOE calculation. [9] equally suggests that levelised cost comparisons between dispatchable and variable generating technologies are inconsistent and inaccurate, as the generated energy from VRE is often produced when it is not required, whereas the value of dispatchable generation is usually higher, with VRE LCOE calculations often overvaluing variable generation such as ocean energy. [13] revealed that, in simulations, high shares of wind power saw integration costs rivalling generation costs and concluded that integration of differing generation profiles, variations in the market value of supplied electricity, and expected life-cycle costs of different generation technologies are necessary to establish meaningful and practical comparisons. This new integration method would then have follow-on implications for future research and policy maker, in successfully realising the low carbon but highly variable future of renewable energy.

The System LCOE (SLCOE) metric combines the existing LCOE calculation with the costs of integrating the renewable energy in the grid,

$$sLCOE = LCOE_{vre} + \Delta \tag{5}$$

The marginal integration costs Δ are defined as the increase of total integration costs C_{int} when marginally increasing the shares of E_{vre}, given by:

$$\Delta = \frac{d}{dE_{vre}} C_{int} \tag{6}$$

Integration costs, however, are not consensually definable, in particular from a quantitative perspective, as the costs that are specifically imputable to VRE integration are nor clearly discriminable. [13] suggests a mathematical approach which accounts for overproduction costs, full-load hour reduction (conventional power now under-used due to VRE) and backup costs (generation on standby in case VRE generation falls). The study concluded that, for high shares of VRE, integration costs can be in the same order as generation costs and thus limit the economic potential of ocean energy without clear policy guidelines. The adoption of metrics such as the SLCOE, if adequality and consistently applied, can help guiding policy makers and system planners in designing a cost-efficient power system [13].

3.2.6 Levelised Cost of Stored Energy (LCOE$_{St}$)

The capacity to store energy will be critical in future energy systems integrating increasingly larger shares of VRE such as ocean energy, which will require storage to temporally align generation with load profiles. [14] proposes a formulation of the levelised cost of storage (LCOE$_{St}$) based on the total ownership costs over the investment period divided by the delivered energy which is modified depending on whether the storage technology is supplying electricity to the grid or providing balancing services for variable renewable energy generation technologies [15]:

$$LCOE_{St} = \frac{\sum_{t=1}^{n} C_{St}}{n_{St} \sum_{t=1}^{n} E_{IN,St,t}} + K_T \frac{p_{int,0}}{n_{St}} \tag{7}$$

where,

$$K_T = \frac{\sum_{t=1}^{T} E_{int,t} \frac{(1 + PIF_{p_{int}})^t}{(1+i)^t}}{\sum_{t=1}^{T} E_{int,t} \frac{1}{(1+i)^t}} \tag{8}$$

where K_T is the price change over the years with a constant price increase factor *PIF* (usually 2%), C_{St} is the cost of storage, n_{St} is the round-trip efficiency of storage, p_{int} is an internal transfer price weighting the value of stored energy per period, $p_{int,0}$ is the internal price at the beginning of the period, and E_{int} is the input energy. The lower limit of LCOE using this calculation equates to maximum energy turnover, and is defined as 100% storage device utility, with each deviation leading to higher values of LCOE$_{St}$. Higher charge rates were found to have more of an impact on LCOE$_{St}$ than round trip efficiency, through quicker discharge of the batteries.

This method could become increasingly necessary, as VRE shares increase, and storage is required to correct the temporal offset between generation and final end use. [9] defends this as a key solution to solve the intermittent problems associated with VRE and conventional LCOE, with energy storage potentially increasing the value of ocean energy generation in a scerario four-fold, by shifting the generated off-peak energy to meet peak-demand.

3.2.7 Levelised Avoided Cost of Electricity (LACE)

The levelised avoided cost of electricity (LACE) considers the value of the plant in generating electricity to the grid when displacing the generation from another, usually conventional, generation source. This project value is then summed over the financial life and annualized by dividing by the average annual output to arrive at the LACE. Simply put, this metric is given by

$$LACE = \frac{Lifecycle\ cost\ of\ avoided\ project}{Lifetime\ energy\ generation\ from\ avoided\ project} \quad (9)$$

The LACE metric is useful for a comparison between technologies, and it can be combined with LCOE and $LCOE_{St}$ to establish value-cost ratios for further cross-generational analysis [15].

3.2.8 Society's Cost of Energy (SCOE)

SCOE was proposed by Siemens [16] as a metric with a wider scope for assessing generation technologies against conventional sources of energy, encompassing generation, integration, and social impacts into the standard LCOE framework, in an attempt to account for costs and benefits on a macro-economic level. These additional inputs are defined in Table 2, with their respective impact on the SCOE.

Table 2 Society's cost of energy parameters and their impact [16]

SCOE component	Impact	Example
LCOE	+	OPEX, CAPEX, fuel
Hidden subsidies	+	Reduced fossil fuel tax (UK) Waste disposal, emergency relief costs
Transmission costs	+	Grid reinforcement due to VRE
Variability costs	+	Backup capacity payments (i.e., to CCGT)
= System LCOE (SLCOE)	True cost of electricity	
Social costs	+	Drop in house prices around power plants or wind farms
Economy and employment	-	Direct, indirect, and induced job creation
Geopolitical impact	+	Hedging against fuel prices
= Society's costs of electricity	Macro-economic cost of electricity	

The great majority of the input elements in Table 2 increase the metric's value, with only the indirect, direct, and induced job creation having the opposite effect of reducing overall costs for society.

SCOE projection case studies were carried out by Siemens, with the results for the UK and Germany presented below.

Table 3 SCOE projection for United Kingdom, 2025 [16]

SCOE component	Nuclear	Coal	Gas	Photovoltaics	Onshore wind	Offshore wind
LCOE	79.2	115.3	82.9	105.2	55.4	95.0
Inc. CO_2	0.0	58.4	26.0	0.0	0.0	0.0
Subsidies	59.8	2.5	0.5	0.0	0.0	0.0
Transmission	0.0	0.0	0.0	6.6	2.0	2.0
Variability	0.9	0.5	0.0	15.2	14.3	13.4
System LCOE	140.0	118.3	83.5	127.0	71.6	110.4
Social costs	0.1	0.1	0.1	0.0	4.8	0.0
Employment	-33.0	-10.5	0.0	-49.4	-16.1	-49.4
Geopolitical impact	0.0	1.7	5.4	0.0	0.0	0.0
SCOE	107.2	109.6	89.0	77.6	60.4	60.9

Table 4 SCOE projection for Germany, 2025 [16]

SCOE component	Nuclear	Coal	Gas	Photovoltaics	Onshore wind	Offshore wind
LCOE	79.2	80.3	67.3	100.2	55.4	95.0
Inc. CO_2	0.0	23.4	10.4	0.0	0.0	0.0
Subsidies	47.4	0.0	0.4	0.0	0.0	0.0
Transmission	0.0	0.0	0.0	10.8	3.2	2.8
Variability	1.0	0.5	0.0	15.4	14.5	13.6
System LCOE	127.6	80.8	67.8	125.4	73.1	111.4
Social costs	0.1	0.1	0.1	0.0	4.0	0.0
Employment	-34.1	-6.2	0.0	-49.3	-19.4	-49.0
Geopolitical impact	0.3	2.5	5.9	0.0	0.0	0.0
SCOE	93.8	77.2	73.8	77.1	57.8	62.3

Table 3 and 4 follow a similar trend, with SCOE increasing for nuclear mostly due to subsidies, and with geopolitical impact having a more evident influence on the SCOE of gas. The SCOE is higher than the LCOE for onshore wind thanks to the added integration and social costs. All other generation sources present lower SCOE than LCOE, representing a reduction of approximately 38.5% in the case of offshore wind, mostly due to benefits from job creation together with minimal social and geopolitical costs.

3.3 Applicability of performance and techno-economic metrics at each TRL

Table 5 presents a summary of the metrics discussed in this chapter and indicates at which TRL each metric is generally applicable for wave, tidal and floating wind devices.

Table 5 Applicability of performance and techno-economic metrics at each TRL

TRL	1	2	3	4	5	6	7	8	9	Wave	Tidal	Wind
Power capture	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Capture width ratio		✓	✓	✓	✓	✓	✓	✓	✓	✓		
Capture coefficient		✓	✓	✓	✓	✓	✓	✓	✓		✓	
Absorbed energy per char. mass		✓	✓	✓	✓	✓	✓	✓	✓	✓		
Absorbed energy per char. PTO force			✓	✓	✓	✓	✓	✓	✓	✓		
ACE			✓	✓	✓	✓	✓	✓	✓	✓		
HPQ			✓	✓	✓	✓	✓	✓	✓	✓		
CAPEX				✓	✓	✓	✓	✓	✓	✓	✓	✓
OPEX				✓	✓	✓	✓	✓	✓	✓	✓	✓
Energy yield				✓	✓	✓	✓	✓	✓	✓	✓	✓
LCOE							✓	✓	✓	✓	✓	✓
UCOE							✓			✓	✓	✓
DCCOE							✓			✓	✓	✓
TCOE							✓			✓	✓	✓
SLCOE							✓	✓	✓	✓	✓	✓
$LCOE_{St}$							✓	✓	✓	✓	✓	✓
LACE							✓	✓	✓	✓	✓	✓
SCOE							✓	✓	✓	✓	✓	✓

4 Metrics for commercial readiness

4.1 Commercial Readiness Level (CRL)

Technology Readiness Levels provide a framework for developers to reduce technical risk as their technology develops. While developers work to overcome technical challenges, there are often significant barriers relating to commercial uncertainty and risk throughout the technology development process that may end up being the deciding factor as to whether commercial deployment is achieved (e.g., access to capital).

While there is extensive knowledge and literature on the commercialisation process, there is not a widely implemented framework that benchmarks the commercial readiness of ORE technologies. Table 6 presents Commercial Readiness Levels (CRLs) as described in the US Department of Energy's Technology to Market Plan [17]. This system has recently been implemented by the Marine Energy Alliance (MEA) to assist SMEs whose technology is at TRL 3-4 progress in terms of commercial maturity and grow their business.

Table 6 Commercial Readiness Level (CRL) descriptions

CRL	Description
1	Knowledge of applications, use-cases, & market constraints is limited and incidental, or has yet to be obtained at all.
2	A cursory familiarity with potential applications, markets, and existing competitive technologies/products exists. Market research is derived primarily from secondary sources. Product ideas based on the new technology may exist but are speculative and unvalidated.
3	A more developed understanding of potential applications, technology use-cases, market requirements/constraints, and a familiarity with competitive technologies and products allows for initial consideration of the technology as product. One or more "strawman" product hypotheses are created and may be iteratively refined based on data from further technology and market analysis. Commercialization analysis incorporates a stronger dependence on primary research and considers not only current market realities but also expected future requirements.
4	A primary product hypothesis is identified and refined through additional technology-product-market analysis and discussions with potential customers and/or users. Mapping technology/product attributes against market needs highlights a clear value proposition. A basic cost-performance model is created to support the value proposition and provide initial insight into design trade-offs. Basic competitive analysis is carried out to illustrate unique features and advantages of technology. Potential suppliers, partners, and customers are identified and mapped in an initial value-chain analysis. Any certification or regulatory requirements for product or process are identified.
5	A deep understanding of the target application and market is achieved, and the product is defined. A comprehensive cost-performance model is created to further validate the value proposition and provide a detailed understanding of product design trade-offs. Relationships are established with potential suppliers, partners, and customers, all of whom are now engaged in providing input on market requirements and product definition. A comprehensive competitive analysis is carried out. A basic

	financial model is built with initial projections for near- and long-term sales, costs, revenue, margins, etc.
6	Market/customer needs and how those translate to product needs are defined and documented (e.g., in market and product requirements documents). Product design optimization is carried out considering detailed market and product requirements, cost/performance trade-offs, manufacturing trade-offs, etc. Partnerships are formed with key stakeholders across the value chain (e.g., suppliers, partners, customers). All certification and regulatory requirements for the product are well understood and appropriate steps for compliance are underway. Financial models continue to be refined.
7	Product design is complete. Supply and customer agreements are in place, and all stakeholders are engaged in product/process qualifications. All necessary certifications and/or regulatory compliance for product and production operations are accommodated. Comprehensive financial models and projections have been built and validated for early stage and late-stage production.
8	Customer qualifications are complete, and initial products are manufactured and sold. Commercialization readiness continues to mature to support larger scale production and sales. Assumptions are continually and iteratively validated to accommodate market dynamics.
9	Widespread deployment is achieved.

The MEA process (currently ongoing) involves assessing SMEs against CRLs 1-4 and providing assistance towards progressing through the CRLs. The criteria used are described in Table 7 (summarised from MEA D1.3.2 [18]).

Table 7 CRL criteria applied by Marine Energy Alliance (MEA)

CRL	Criteria
CRL 1	• **Business model** or plan exists including clear technical/commercial milestones • **Sales plan** exists covering potential sales of product and/or IP • **Funding plan** exists covering funding requirements for next 2-5 years • **Resource plan** exists covering resource requirements for next 2-5 years
CRL 2	• Potential application for deployment of the technology in various markets has been identified • Some knowledge of competing technologies and products in the chosen markets
CRL 3	• Potential product requirements for target markets now and for the next 5-10 years approx. have been identified from primary market research
CRL 4	• Key product requirements have been identified from discussions with end-users for the next 5-10 years. • Value proposition is clear from mapping of expected product attributes against market requirements. • LCOE model supports value proposition and is utilised to aid design optimisation • Unique features/advantages of the technology are understood, and initial IP approach defined

	• Potential suppliers, partners and customers have been identified and the initial value chain analysis mapped • Certification or regulatory requirements for the product have been identified

4.2 Commercial Readiness Index (CRI)

The Australian Renewable Energy Agency (ARENA) identified the importance of having a benchmarking process specifically for renewable energy technologies and have developed a Commercial Readiness Index (CRI), described in the 2014 report "Commercial Readiness Index for Renewable Energy Sectors" [19]. The report states that while technical risk is addressed as developers progress through the TRLs, commercial risk and uncertainty becomes significant at the demonstration and deployment phase (> TRL 7). Therefore, the first level of the CRI spans from when the feasibility of the technology has been proven (TRL 2) to a commercial trial (TRL 8-9) and progresses to Level 6 where the technology is classified as a 'Bankable asset class' (see [19]). A description of each of the six CRI levels is given in Table 8.

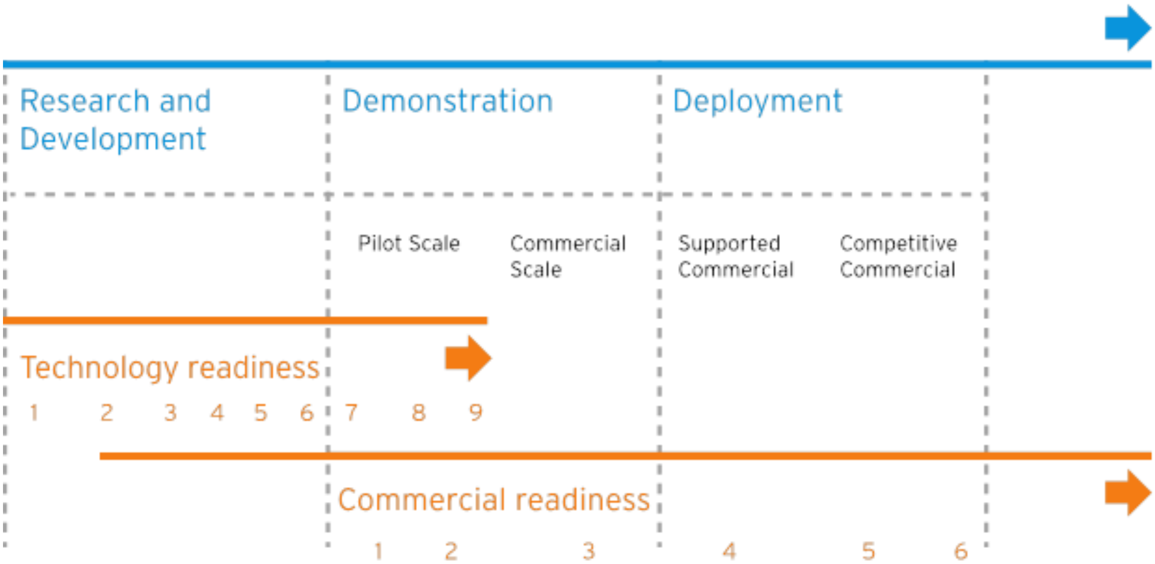

Figure 5 TRL and CRI alignment [19]

Table 8 CRI Status Summary Level (overall market maturity)

CRI	Status Summary Level description
1	**Hypothetical commercial proposition:** Technically ready but commercially untested and unproven. Commercial proposition driven by technology advocates with little or no evidence of verifiable technical or financial data to substantiate claims.
2	**Commercial trial:** Small scale, first of a kind project funded by equity and government project support. Commercial proposition backed by evidence of verifiable data typically not in the public domain.
3	**Commercial scale-up** occurring driven by specific policy and emerging debt finance. Commercial proposition being driven by technology proponents and market segment participants – publicly discoverable data driving emerging interest from finance and regulatory sectors.

4	**Multiple commercial applications** becoming evident locally although still subsidised. Verifiable data on technical and financial performance in the public domain driving interest from variety of debt and equity sources however still requiring government support. Regulatory challenges being addressed in multiple jurisdictions.
5	**Market competition driving widespread deployment** in context of long-term policy settings. Competition emerging across all areas of supply chain with commoditisation of key components and financial products occurring.
6	**Bankable asset class** driven by same criteria as other mature energy technologies. Considered as a "Bankable" grade asset class with known standards and performance expectations. Market and technology risks not driving investment decisions. Proponent capability, pricing and other typical market forces driving uptake.

At each CRI status summary level there are eight independent indicators that reflect the main commercialisation barriers faced by the developers of renewable energy technologies. These are:

- Regulatory environment
- Stakeholder acceptance
- Technical performance
- Financial performance – Costs
- Financial proposition – Revenue
- Industry supply chain and skills
- Market opportunities
- Company maturity

Each of the indicators above are described in detail in Appendix A of the ARENA report [19]. A summary of each of the indicators at CRI 1 is given in Table 9.

Table 9 Description of indicators at CRI 1 (TRL1-8)

Indicator	Summary for CRI 1
Regulatory environment	Regulatory processes including planning, permitting, OH&S, and specific Australian standards such as electrical connection are undefined. Timing and cost of network connection and/or fuel certification assumed in modelling but not known.
Stakeholder acceptance	Stakeholder support or opposition is hypothetical.
Technical performance	Performance forecasts based on proponent modelling.
Financial performance – Costs	Cost data (if available) based on projections and forecasts with little or no prior data to substantiate.
Financial proposition – Revenue	Revenue data based on projections and forecasts with little or no prior data to substantiate.
Industry supply chain and skills	Supply chain not fully considered with key elements typically from specialist source, often under technology proponent specification.

Market opportunities	Critical stage for a technology to move from a promising technical solution to a prospective commercial opportunity. Investment case for commercial trials supported by evidence of peer reviewed business plans with verifiable cost and revenue estimates, market size and early channel to market identified. Key risks identified both within and external to the proponents sphere of control.
Company maturity	Established energy players not yet part of sector. Management capability is dependent on individual proponents

4.2.1 Application to policy makers

The IEA-RETD TCP commissioned a study [20] that used the CRI framework to assess the commercial maturity of renewable energy technologies in order to identify policy approaches that would stimulate ORE deployment. This was achieved using two case studies (one wind, one solar) and by conducting multiple interviews in with relevant stakeholders.

The study identified three different policy approaches that are used to support ORE developers (as illustrated in Figure 6):

- Push policies that support ORE R&D. These usually take the form of capital grants; projects such as MaRINET2 also fall into this category.
- Pull policies that support demand-generation initiatives (such as Feed in Tariffs and tax incentives)
- Enabling policies that create frameworks and infrastructure which support the development and deployment of ORE technologies.

The study found that the most important policies for emerging ORE markets were subsidies for electricity production that were not limited by a capacity cap (pull policies).

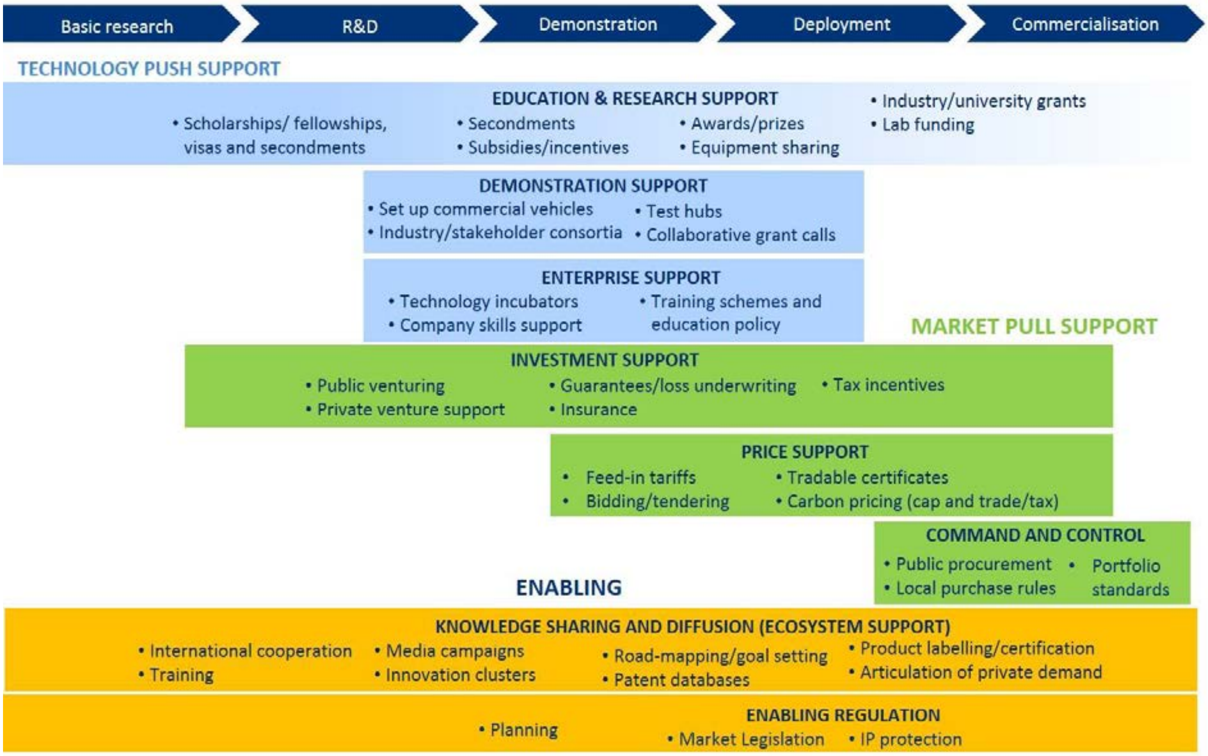

Figure 6 Relevance of push, pull and enabling policies to different stages of commercialisation (Source: [2])

5 Resources available to ORE developers

There is a significant research effort underway across many EU-funded projects to produce open-source tools and services that aid offshore renewable energy developers in their development processes. Details of some of the key projects and resources available are provided in the following sections.

5.1 Technical resources

5.1.1 DTOcean

The DTOcean project, which ran between 2013 and 2016 (EU FP7 framework Grant Agreement № 60859) produced a first generation of freely available open-source design tools for wave and tidal energy arrays. The integrated suite of tools were split into five modules or stages:

- Hydrodynamics: designs the layout of converters in a chosen region and calculates their power output.
- Electrical sub-systems: designs an electrical layout for the given converter locations and calculates the electrical energy exported to shore.
- Moorings and foundations: designs the foundations and moorings required to secure the converters at their given locations.
- Installation: designs the installation plan for the energy converters and the components required to satisfy the electrical sub-system and moorings and foundations designs.
- Operations and maintenance: calculates the required maintenance actions and power losses resulting from the operation of the converters over the lifetime of the array.

The above tools were brought together by a global decision tool containing optimisation routines that could evaluate each stage of the design, and the design as a whole, using three thematic assessments:

- Economics: produces economic indicators for the design, in particular the Levelised Cost of Energy (LCOE).
- Reliability: assesses the reliability of the components in the design over the array lifetime.
- Environmental: assesses the environmental impact of each stage of the design.

The DTOcean tools are available through the GitHub repository https://github.com/DTOcean/dtocean

5.1.2 DTOceanPlus

The H2020 funded DTOceanPlus project (Grant Agreement № 785921) developed an open-source integrated suite of second-generation design tools for ocean energy technologies, building on the original DTOcean tools.

The DTOceanPlus tools support the entire technology innovation and advancement process at various stages of maturity from concept, through development, to deployment. They will be applicable across a range of technology levels, namely: sub-system, device, and array.

DTOceanPlus will help to accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open-source suite of design tools for the selection, development, deployment, and assessment of ocean energy systems (including sub-systems, energy capture devices and arrays)

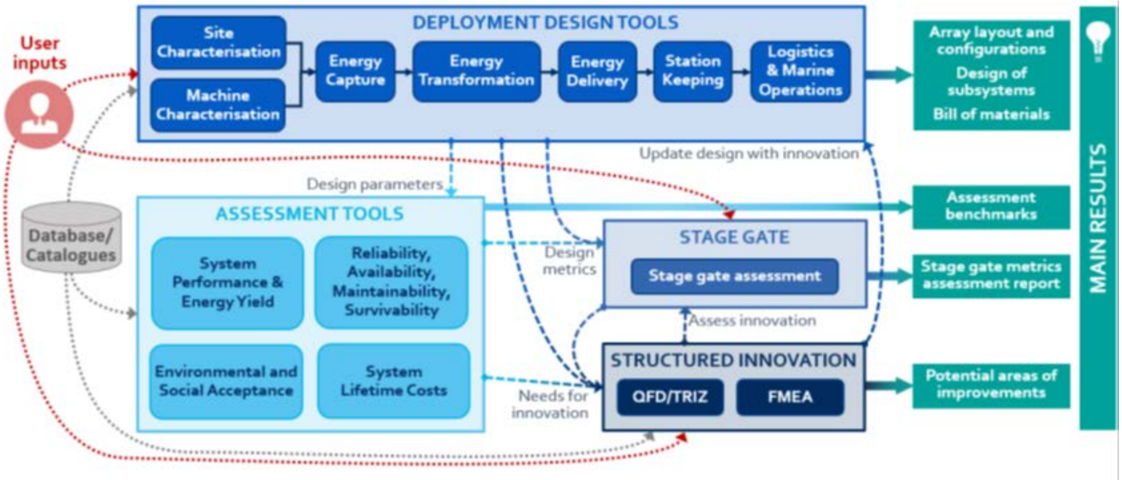

Figure 7. REPRESENTATION OF THE DTOCEANPLUS MODULES, MAIN LINKAGES, AND OUTPUTS

The suite of tools developed in DTOceanPlus include:

- **Structured Innovation Tools**, for concept creation, selection, and design.
- **Stage Gate Tools**, using metrics to measure, assess and guide technology development. These tools are based on the outputs of IEA-OES Task 12 by applying the evaluation criteria discussed in Section to each of the evaluation areas at each stage of development. The tool allows the user to identify the stage of development of their device, as well as what areas need to be addressed in order to progress to the next stage.
- **Deployment Tools**, supporting optimal device and array deployment:
  - *Site Characterisation* (e.g. metocean, geotechnical, and environmental conditions);
  - *Energy Capture* (at an array level);
  - *Energy Transformation* (PTO and control);
  - *Energy Delivery* (electrical and grid issues);
  - *Station Keeping* (moorings and foundations);
  - *Logistics and Marine Operations* (installation, operation, maintenance, and decommissioning).
- **Assessment Tools** are also available that quantify key parameters:
  - *System Performance and Energy Yield*;
  - *System Lifetime Costs;*

- *System Reliability, Availability, Maintainability, Survivability (RAMS);*
- *Environmental and Social Acceptance*.

The DTOceanPlus tools together with detailed documentation, guidelines for installation and use, and other project outputs are available through the DTOceanPlus website https://www.dtoceanplus.eu.

5.1.3 Tools from the SELKIE project

Selkie[1] is a cross-border project aimed at boosting the wave and tidal energy industry in Wales and Ireland. Part of the project involves developing a set of multi-use technology, engineering and operation tools, templates, standards and models that can be used across the marine energy sector. All the tools are described on the Selkie website[2] and are presented briefly below.

5.1.3.1 GIS Techno-Economic Tool

A geographic information system (GIS) techno-economic tool for wave and tidal stream site selection is currently being developed as part of the Selkie project. The tool includes a GIS containing site data for Ireland and Wales that aides strategic decision making when selecting sites for wave or tidal technologies. Embedded in the GIS is a techno-economic (TE) calculator that enables the user to assess project feasibility at a given site.

The GIS-TE tool will be open-source and populated with open-source datasets when released in 2022. It will contain up-to-date GIS layers describing the opportunities, constraints and restrictions, enabling the user to pinpoint optimum locations for specific types of wave or tidal energy converters

5.1.3.2 O&M and Logistics Models

A Logistics and Operations and Maintenance (O&M) decision-support tool is currently being developed in Selkie which will allow users to simulate operations considering uncertain factors, e.g., weather, failures, and the impact on the costs and power production of a project. It will allow 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. The tool will be an open-access, user-friendly and flexible, and will be applicable to a wide range of wave and tidal technologies. Outputs from the tool can be used as inputs to the GIS-TE tool described above to determine the overall financial viability of a given project scenario. The tool will be launched in Spring 2022 along with full documentation, instructions, and a workshop for user training.

5.1.3.3 GAD-CFD tool for tidal arrays

Selkie partner Swansea University are developing a computationally efficient tool for simulating the performance and wake characteristics of horizontal axis tidal turbine arrays with a view to providing an open access and clearly documented tool for the ORE community. The Generalised Actuator Disk Computational Fluid Dynamics (GAD-CFD) tool

[1] https://www.selkie-project.eu
[2] https://www.selkie-project.eu/selkie-tools/

aims to facilitate individual device design as well as array layout optimisation. Detailed information and a demonstration of the tool is available on the Selkie website; a series of videos explaining how to install and use it are available at https://www.youtube.com/playlist?list=PL034xBvNLbjgQllpLW83CGEUVn4dNIWDv . At the time of writing, the tool was undergoing final testing, and will be released for general use in 2022.

5.1.3.4 Foundations and mooring design tool

An open-source tool that will assist with the design of foundations, anchors and mooring systems for marine energy projects is being developed in the Selkie project. The tool will be a web-based decision-support tool designed to facilitate concept design, cost estimation and option studies for foundations, anchors and mooring systems. The tool will integrate with the other tools being developed in the Selkie project.

5.1.3.5 Methodology for drone derived surface current measurements

An output of Selkie is the development of a methodology that will enable the extraction of surface currents at tidal stream sites using existing open-source particle image velocimetry (PIV) software and video data collected by commercially available quadcopter drones. It is envisaged that the tool will enable low-cost scoping of new sites which will be of particular benefit in areas with insufficient access to vessels of hydrographic equipment such as remote island communities or developing nations. Furthermore, the anticipated spatial resolution will enable easy generation of maps showing surface current patterns which will complement ADCP techniques as well as facilitating device micro-siting and providing data for validation of numerical models.

5.1.4 O&M and logistics models

Different approaches can be used to characterise the OPEX for both pilot and commercial farms. The simplest approach to OPEX modelling is just to take OPEX as a percentage of CAPEX. Advanced models typically have as an input the probability of failure for each component and/or sub-system. Depending on the objective and the complexity of the tools, different type of decisions can be supported:

- Operational: decisions made on daily basis
- Tactical: decisions made yearly
- Strategic: decision made before the project start in operation

In addition to the Selkie tools described in the previous section, other open-access O&M or logistics tools are:

- DTOceanPlus: Logistics and Marine Operations Tool. Expanding on the previous DTOcean version, the LMO module was improved in respect to the vessel selection methodology and the waiting on weather algorithm, providing more meaningful results and a way to quantifying uncertainty. Preventive and corrective maintenance activities were included, namely tow to port maintenance options, and vessel, equipment and port data were updated. Additional flexibility was also implemented to provide the user a way to customise the operations according to their preferences

- Wave Energy Scotland Operations and Maintenance Simulation Tool [21]: intended to provide developers of wave energy technology with the framework to estimate operational expenditure and undertake sensitivity studies into the design of their devices and O&M strategies.

5.1.5 RESOURCECODE: Marine Data Toolbox

RESOURCECODE[3] is an integrated marine data toolbox containing 27 years of resource data from the majority of western Europe which is entirely open access. The toolbox, due to be launched in Q4 2021, consists of modelling and software tools which have been validated with satellite and in-situ MetOcean data.

The toolbox includes a calibrated, verified, hindcast dataset on a flexible mesh providing comprehensive wave data across Western Europe. Data analysis tools have been developed to provide improved statistical analysis techniques for resource assessment, performance estimates, weather windows, bathymetry etc. The RESOURCECODE consortium draws upon academic and technical expertise from across Europe and is funded by the Ocean Energy ERA-NET COFUND. For more information, including a demonstration of the toolbox see the project website noted above.

5.1.6 Technology Assessment Process

EMEC's Technology Assessment Process (TAP) provides a standardised framework for the assessment of new and emerging wave and tidal energy developers allowing technology to be benchmarked in a number of key areas.

EMEC work with developers across a range of uncertainties and risks associated with costs and performance. This approach significantly de-risks technologies before they reach prototype testing stage and allows developers to focus on the areas that are most important, resulting in a less expensive, faster and more focused development pathway.

The TAP methodology is designed to track progress and build evidence of performance as technological ideas progress from one stage of development to another. An evidence-based dossier – the Technology Passport – will help to map the developer's journey through the development process, identifying milestones towards technology commercialisation and development support opportunities.

There are a number of benefits to developers undertaking TAP:

- Improved focus and risk management;
- Corroboration of competitive prospects at each stage of the development journey.

Undertaking a TAP can allow investors and funders to be better informed when making investment decisions with improved confidence and reduced risk. This can allow investment to be matched to feasible technical ideas. In addition, this will allow greater visibility of respective technical strengths when evaluating competing ideas. TAP can also be used as a

[3] https://www.emec.org.uk/projects/ocean-energy-projects/tool-development/resourcecode-project/

mechanism to undertake periodic independent reviews of a technology and therefore provide on-going confidence for investors/funders.

EMEC has also developed a benchmarking process within the MEA and OESA projects, which in essence offers a simplified version of the TAP, which is particularly suited to lower TRL technologies but can also be applied up to TRL8. This simplified process requires less time inputs from both the technology developer and the assessor, and highlights the key issues for the development of the technology as well as potential providers for external assistance if this is needed. This has been used within MEA to help select appropriate technologies at TRL2-5 for support at the award stage and then to re-benchmark these technologies after the support has been provided. The benchmarking is based on the TPL, TRL and CRL approaches as appropriate.

5.1.7 MaRINET2 e-Infrastructure

An e-infrastructure was created as part of the MaRINET2 project. This virtual research environment and repository contains valuable datasets, guidance reports and publications focussed on the testing of offshore renewable energy technologies.

The e-infrastructure is freely accessible and contains a collection of downloadable databases emanating from the MaRINET2 project including experimental descriptions and results. The e-infrastructure provides a platform to support future R&D and inform technology, particularly device design through FAIR access of research data.

It contains the following data types and associated metadata:

- MaRINET2 Round Robin Testing datasets, reports, and metadata
- Marine in-situ environmental data (e.g., wave rider buoy ADCP data from EMEC)
- Wind lidar data (e.g., Froya wind scanner data)

In addition, the academic publications utilising these datasets will also be available on the e-infrastructure as well as guidance reports and various other MaRINET2 reports related to testing of ORE.

For further information on the e-infrastructure see the below link, which is also available through the MaRINET2 Website (https://explore.openaire.eu/search/advanced/research-outcomes?f0=relprojectid&fv0=corda__h2020::c1957405f8d8bf48e1ac0f8326209d8b&type=publications&qf=false&sortBy=resultdateofacceptance,descending).

5.2 Consultancy and business development resources

5.2.1 Marine Energy Alliance services

The Marine Energy Alliance (MEA) is a four-year project running until March 2023 and supported by Interreg North West Europe. It aims to de-risk the progress to technical and commercial maturity of early stage (TRL 3-4) ORE technology companies with a view to de-risking the next stages of development towards commercialisation. This is achieved by providing a combination of specialised services of both a technical and a business nature to applicant SMEs. The technical services provided include:

- Low TRL test planning and result interpretation
- Low TRL prototype testing
- Low TRL technology development and verification plan
- Numerical simulation and validation
- Technical design optimisation
- Cost of system assessment (i.e., techno-economic assessments)
- Regulatory feasibility assessment

The commercial services provided by MEA include:

- Unique Selling Point (USP) definition,
- Business case development
- Commercial strategy development
- Launching customer segment identification
- Investment and funding strategy development
- LCOE modelling and optimisation
- Market insights
- Techno-economic concept assessments.

It should be noted that Marine Energy Alliance is not open to further applications from SMEs. Further information of the Marine Energy Alliance project is available here: https://www.nweurope.eu/projects/project-search/nwe-mea-north-west-europe-marine-energy-alliance/

5.2.2 Ocean Power Innovation Network

The Ocean Power Innovation Network (OPIN) is a 4-year Initiative running until 2022 with financial support from the Interreg Northwest Europe European Research and Development Fund (ERDF). The OPIN Project delivers business supports in the form of Annual symposiums, workshops, and master classes as well as financial supports for travel to take part in OPIN activities.

The OPIN Project also offers an evidence-based Technology Assessment Process (TAP) to SMEs. During this process technology developers will have an opportunity to discuss their technology with a small team of OPIN partners free of charge and to avail of expertise on design principles, de-risking development, route to commercialisation and technology transfer opportunities. The SME is not required to provide any financial contribution to the cost of the TAP.

SMEs may also participate in Collaborative Innovation Groups (CIGs) through the OPIN project. A Collaborative Innovation Group (CIG) is a small group of SMEs, often working with research entities and / or large companies, to solve specific problems which are barriers to deployment of ocean energy and offer opportunities for new products, services or markets. CIGs should focus on challenges which cannot or have not been solved by one SME alone and aim to include complementary skills and expertise. The SME is not required to provide any financial contribution to the cost of the CIG save from time commitment to participate in meetings and discussions.

Further information on the OPIN Project is available here: https://www.nweurope.eu/projects/project-search/opin-ocean-power-innovation-network/#tab-1

6 Reducing risk

The following sections outline ways in which ORE developers can reduce risk, which is key to securing finance to progress to the next stage of development.

6.1 Reducing risk and securing investment through certification

The goal of certification for any technology (or product) is to bring it to market by submitting it to an internationally recognised certification body for an assessment. The objective for such an assessment is to provide businesses with the assurance that having submitted their technology through an independent verification and validation process, it conforms to a set of codes or standards it claims to meet. An added benefit for adopting this approach ensures that any inherent technical (and potentially financial) risks have been independently identified, quantified, and suitably mitigated. This promotes an additional layer of confidence that the technology in that it is feasible and hence worthy of investment. Certification therefore is the key to better global acceptance and investment in products.

An acceleration in the development of marine energy technologies globally makes it is one of the fastest growing energy-production industries. With an abundance of designs and energy conversion techniques now available, the need to ensure international standards are adopted and practiced consistently to support global trading of components and systems, can never be overestimated. With this in view, the IEC has begun the process of developing international standards for marine energy (i.e. IEC TS 62600) along with an international conformity assessment framework (i.e. IECRE) to monitor and support the practice of implementing the marine energy standard.

The IECRE[4] conformity assessment framework for marine energy supports the certification of such technologies (and their respective components), thereby affording them global acceptance in terms of viability, reliability, and efficiency in terms of safety and performance. The process for certification begins with an application made to a Renewable Energy Certification Body (RECB) for marine energy accepted by the IECRE system. The application consists of a request for marine energy certification through the IEC TS 62600-4 Technology Qualification process. The Technology Qualification process is the default procedure through which all marine energy technologies (or their components) are initially assessed. More details of the IECRE certification process are available in the IECRE operational document OD 310-4 [22]. Upon completion of the certification process, the technology is awarded with a Conformity Statement by the IECRE, indicating that the technology (or component) under assessment meets or exceeds requirements of the standard against which it was assessed. A list of IECRE accepted RECBs for marine energy is available on the IECRE website [23].

[4] https://www.iecre.org/sectors/marineenergy/

Investors in new technologies seek assurance that they will receive the desired return on their investment, and independent certification bodies fulfil the role by providing confidence in achieving that goal. Furthermore, insurance bodies may also offer lower insurance premiums for technologies that have been certified by independent certification bodies, which is of benefit to technology developers. Hence, while marine energy technologies can benefit from being submitted to multiple tests, at multiple test sites over varied environmental conditions over their design phases, in order for them to gain recognition in view of securing larger investment, they need to be certified by an independent certification body approved by an international conformity assessment system that transcends national or regional boundaries.

6.2 Reducing risk through standardisation

Standardisation is key in reducing risk in the ORE sector. Offshore renewable energy consists of many emerging technologies, and therefore there is a lack of mature standards and guidance for the development and testing of these devices. The MaRINET2 report D2.1 [24] and a follow-up publication [25] identify a shortfall in the published guidance available for laboratory testing of ORE devices. For floating wind for example, much of the existing literature is derived from the oil and gas industry and published by the ITTC. The ITTC guidelines in general are relatively high level and do not provide standardised procedures for laboratory testing. Similar gaps exist for testing wave and tidal energy converters.

6.2.1 MaRINET2 round robin

The MaRINET2 round robin test programme was designed to identify the effects individual laboratory facilities (wave tanks, current flumes, structural rigs etc.) have on the performance of ORE devices. The programme tested generic devices (wind, wave and tidal as well as crosscutting components) under the same test conditions in a variety of facilities. The analysis between facilities considered all sources of variance from experimental setup, dimensional disparity, instrumentation, and post-processing methodology. The ultimate aim of the round robin programme was to provide an understanding on the causes of variation between facilities in order to develop a standardised approach to offshore renewable energy laboratory testing. Such a standardised approach has been further developed through the MaRINET2 report D4.3 MaRINET2 Standard Testing Procedures Manual (due for release via the MaRINET2 website at the end of 2021) using the learnings from the round robin programme. In the wave round robin programme for example, one of the key learnings was that the way in which waves are calibrated differs between facilities, and has a significant impact on the results. For full details of the round robin findings, refer to MaRINET2 report D2.5 (due for release at the end of 2021), publications [26]–[29], and the MaRINET2 special issue of the Journal of Marine Science and Engineering available at https://www.mdpi.com/journal/jmse/special_issues/mar_renew_Infrast .

While MaRINET2 has done much to identify and close the gaps in published guidance and standards for ORE developers, significant further work is needed to improve available standards and guidance, and ultimately achieve implementation of standardised test procedures across all test facilities. The MaRINET2 findings must be incorporated into technical specifications, and eventually, standards. This can be achieve by engaging with technical committees, e.g. TC114 who are responsible for the IEC 62600 standards. The IEC standards are reviewed and updated through maintenance teams typically comprised of National Committee members. The period between revisions can vary from several years to decades, depending on the maturity of the relevant industry to which the standard refers. The date at which standards are due for review is known as the Stability Date; for the IEC 62600 series, this ranges from the end of 2021 to 2024. It is within these windows that engagement with National Committees on the gaps should be undertaken, through direct participation, engagement with National Committee members, presentation of results at conferences, and publication of academic articles.

To incorporate recommendations for ITTC, the approach is different. The ITTC holds a triennial conference, whereby changes to their guidance can be approved by the executive committee. However, between conferences, specific technical committees such as the Specialist Committee on Hydrodynamic Modelling of Marine Renewable Energy Devices must meet at least four times. It is within these meetings that recommendations and terms of reference are set for the forthcoming conferences. To have the recommendations identified herein considered, liaison with this committee is recommended. The committee's presentation for the 29th ITTC in June 2021 includes reference to MaRINET2 bench marking through the round robin programme.

The gaps identified by the MaRINET2 round robin programme should lead to an update of existing marine energy standards. The constant improvement of standards and guidelines are necessary in the ORE industry, which is in constant evolution. Even though documentation of related, more mature industries can be applied to some extent, the recent technology development projects have outlined the fact that a dedicated set of best practices for ORE devices testing and handling is also necessary.

Until such time as standards are available for tank testing of ORE devices, developers should refer to [25] for a comprehensive list of available guidance documents, as well as MaRINET2 publications report D4.3 MaRINET2 Standard Testing Procedures Manual and D2.5 Round Robin Findings and Recommendations (due for publication at the end of 2021).

6.3 Risk assessments

A risk assessment, prior to deployments is necessary to anticipate any issues threatening the integrity of the marine energy converter (MEC), security of the workers, or costs of the operation.

HIRA is a common tool allowing to target the risks and potential issues susceptible to occur before, during and after deployment of marine energy devices.

Guidelines for Health and Safety in the Marine Energy Industry provide an application of these standardised methods to specificities of the sector. These risk assessment methods must consider the aspects specific to the infrastructures deployed in open sea, often based on the resource they aim for:

- Wind
- Tidal
- Wave
- Other (Thermal, salinity, etc.)

Today, the risk assessment field is mostly inherited from other existing marine sectors (Oil and gas, cruise etc.). Few recommendations and guidelines can be found dedicated specifically to the MECs. Therefore, among the progresses that industrials and research laboratories are aiming for, there is a significant part allocated to production of proper risk assessments methodologies for different steps of Marine Renewable Energies technologies development.

Different sources exist for completion of such tasks, including DNV GL and IEC 114 standards. These guidelines are applied in several fields of marine industry but can still be used for MRE deployment operations. Detailed guidelines on marine risk assessments with a focus on mobile offshore installations are available in [30].

7 Scaling up for offshore deployment

7.1 Introduction

The commercial focus on development of ocean energy technology has never been more prominent. However, despite this, the sector is still in a development phase with only a few companies having progressed their technologies to full scale trials and commercial deployments. Real sea validation is an essential step for developers following a successful laboratory test regime. In the absence of real sea trials, technology development and financial models will remain at a development stage based on research tools such as laboratory testing or numerical modelling. Validation of these tools through systematic comparison against data obtained from real sea trials is critical to develop robust forecasting tools with confidence bounds.

Test centres play an important role in facilitating ocean energy's route to reaching commercialisation providing developers with a supported and often lower cost environment for real sea validation and technology development. This includes performance validation but also demonstration and experience of installation and recovery, demonstration of operations and maintenance techniques, component reliability and survivability. Deployment at a test centre is also importantly very time efficient, with many test centres offering near plug and play solutions at sites which are usually pre-consented for deployment of Ocean Energy devices for the purpose of technology development and testing. This by-passes the need for developers to select, plan and develop their own demonstration zone. A successful test campaign at a test centre and resulting validation of financial models supports developers in improving investor confidence ultimately and leveraging financial investment from both the private and public sphere, moving them closer to market

Using the current literature on technology development criteria, a technology developer who demonstrates at a test centre falls into the following evaluation criteria as referenced in this report.

In terms of the **IEA-OES stages** (Figure 4) the use of test centres begins at Stage 3: Scaled demonstration, right through to Stage 5: Commercial scale array demonstration. When using the **TRL scale**, demonstration at test centres fall into the TRL 5 – 8 range, depending on how advanced the system becomes. Use of test centres for device validation under the **CRI index** as described in Section 4.2 of this report, falls into CRI level 1 to CRI level 3.

7.2 The benefits of using a test centre

The use of test centres can present multiple benefits to technology developers. These include:

- Access to an historical site-specific metocean data set
- Access to on site equipment and data. Some test centres make their onsite equipment available to developers for use e.g., wave rider, ADCPs
- Access to data collection infrastructure
- Benefit from working with a team of technical experts in ORE testing

- Availability of marine operational knowledge and expertise
- Access to test centres knowledge of the local supply chain
- Simplified consent regime for offshore deployment
- Shorter timescales compared to developing an independent demonstration site
- Economies of scale within the MRE industry as a whole where multiple developers can benefit from site infrastructure e.g., ACDPs, Wave riders etc.
- In some cases, ability to connect to the grid
- Support and advice relevant to funding opportunities for a deployment
- Interaction with local researchers to leverage scientific research studies
- Increased investor confidence from using test centre who recognise the importance of staged development.

7.3 What to expect when accessing a test centre

Each test centre has their own access requirements which need to be met before access is granted to the test site. These requirements will be communicated during initial discussions with the test site Access Coordinator. In general, the following basic details will be required:

- What is your previous testing history?
- What is the type, weight, and dimensions of your device?
- What is the type, weight, and dimensions of your mooring system?
- How long do you need to access the site?
- Do you need access to the grid?
- What are the main objectives of your testing plan?
- Is your prototype device built? What is its current status?
- How will you deploy your device?
- How will you decommission the device?
- How often will you be accessing the device when onsite?
- What is your operations/maintenance strategy/H&S Strategy?
- Do you have funding in place to support your testing plan?
- What are your data requirements for your deployment?
- What type of communications do you require for your deployment?
- Has your device been certified by a third party?
- What insurance cover do you have?

For a comprehensive insight into what to expect and prepare for when moving from laboratory to real sea testing please refer to the MaRINET2 Deliverable 2.6 Guidelines for Test Applicants [31].

7.4 List and characteristics of European offshore test sites

Europe benefits from a large network of test centres all with unique site characteristics, expertise, and facilities to suit most MRE technology types at varying developmental stages.

7.4.1 EU and UK offshore test sites

A list of test sites that are currently available for scaling up from the laboratory for testing in real operational conditions is given in Table 10.

Table 10 European open water test sites

Test Site	Location	Technology Types	Details
AGUÇADOURA	Aguçadoura, Portugal	Wave Energy	n/a
Atlantic Marine Energy Test Site (AMETS)	Belmullet, Ireland	Wave Energy, (Pending) Floating Offshore Wind Energy	https://www.oceanenergyireland.com/testfacility/AMETS.html
BiMEP	Northern, Spain	Wave Energy,	https://www.bimep.com/en/
Danish Wave Energy Centre- Dan Wec	Thisted, Denmark	Wave Energy	http://www.danwec.com/
Marine Energy Test Area (META)	Pembrokeshire, United Kingdom	Wave Energy, Floating Offshore Wind Energy, Enabling technologies	https://www.meta.wales/
Marine Energy Test Centre, Met Centre	Norway	Floating Offshore Wind Energy	https://metcentre.no/
Mutriku	Northern Spain	Wave Energy (OWC PTOs)	
Paimpol-Bréhat	Brittany, France	Tidal Energy	https://testsites.bretagneoceanpower.fr/en/
SEENEOH	Bordeaux, France	Tidal Energy	https://seeneoh.com/en/home-en/
SEM-REV	Nantes, France	Wave Energy, Floating Offshore Wind Energy, Enabling technologies	https://lheea.ec-nantes.fr/english-version/test-facilities/sem-rev-offshore-test-site
SmartBay Test Site	Galway, Ireland	Wave Energy, Floating Offshore Wind Energy, Enabling technologies	www.smartbay.ie
The European Marine Energy Centre: EMEC	Orkney, United Kingdom	Wave Energy, Tidal Energy, Enabling technologies	https://www.emec.org.uk/facilities/
The Oceanic Platform of the Canary Islands- Plocan	Canary Islands, Spain	Wave Energy, Floating Offshore Wind Energy, Enabling technologies	https://www.plocan.eu/en/test-site/
Fab Test	Falmouth, United Kingdom	Wave Energy, Floating Offshore Wind Energy	https://www.fabtest.com/

Queen's University Belfast Tidal Test site	Strangford Lough, Northern Ireland	Tidal Energy	https://www.qub.ac.uk/schools/NBE/Research/ResearchClusters/EnvironmentalChangeandResilience/MarineResearchGroup/Facilities/TestSites/

8 The future for accessing test facilities

A full list of the test facilities involved in MaRINET2 is provided in Appendix B. A comprehensive list of all the marine research infrastructures throughout Europe is available from the Eurocean database. There are 113 infrastructures categorised as 'Flumes and test labs for ocean engineering' located in Denmark, France, Germany, Greece, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Sweden, and the United Kingdom. A full list is provided in Appendix C of this report.

Figure 8 Eurocean database of infrastructures: Flumes and test labs for ocean engineering

Through five calls over the space of five years, 145 different user groups availed of free transnational access to world class laboratory and field-testing sites through MaRINET2. Going forward, it is unclear at present whether there will be a third iteration of MaRINET. Technology developers that require funded access to test facilities should contact the individual facilities to inquire whether any funding schemes are available for physical testing. For example, in Ireland the Sustainable Energy Authority of Ireland (SEAI) provides free access to the Lir National Ocean Test Facility in University College Cork through an annual access programme.

It is envisaged that ultimately, access to test facilities in Europe will be managed through a Distributed Research Infrastructure known as MARINERG-i.

8.1 MARINERG-i

The objective of the MARINERG-i initiative is to develop a Pan-European Distributed Research Infrastructure (DRI) built on the MaRINET (FP7) and MaRINET2 (H2020) integrating activities. Both projects allowed for the development of a long term international networking activity and the creation of an advanced community.

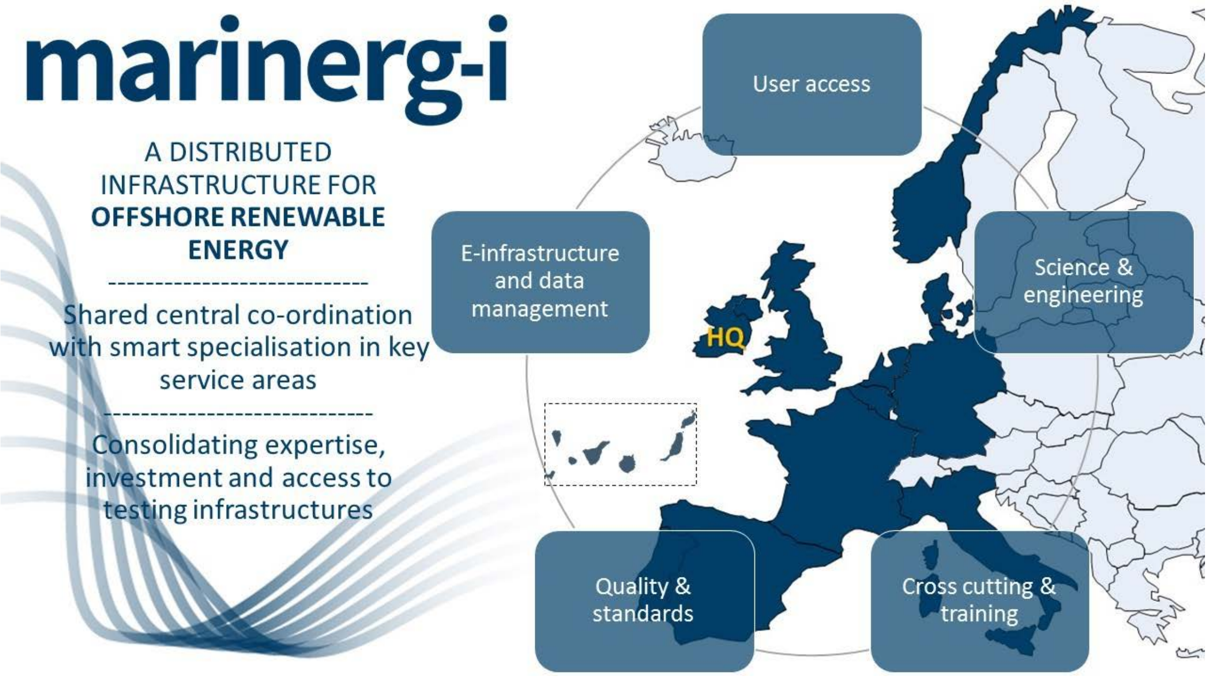

Figure 9 MARINERG-i concept

The H2020 MARINERG-i project was the first step in forming an independent legal entity of distributed testing infrastructures, united to create an integrated centre for delivering offshore renewable energy. The main outcome of the project was the submission of an application to get the proposed MARINERG-I DRI included on the ESFRI roadmap. This application was successful, and the MARINERG-I consortium are now preparing to become established as an independent legal entity known as a European Research Infrastructure Consortium (ERIC). During the preparation phase (2022-2025), it is anticipated that there will be a pilot programme for providing access to test facilities.

Figure 10 MARINERG-i core services

It is envisaged that once the DRI is established and achieves European Research Infrastructure Consortium (ERIC) status (2026-2027 approx.), it can then begin trading and providing services, with the help of financial supports. From this period, ORE developers will be able to apply to a centralised system for either funded or non-funded access to a facility that meets their requirements. It is anticipated that the DRI will become fully operational and self-sustaining from 2031.

The core services that will be provided by the MARINERG-I DRI are listed in Figure 10. The e-infrastructure will initially be based on the MaRINET2 pilot e-infrastructure project, and learnings from MaRINET2 will be used to inform its further development. The goal is to develop a MARINERG-I portal, through which users can apply for access to facilities, apply for training courses, download open-access data, upload data and make use of a virtual research environment. For an overview of the services accessible through the portal, see Figure 11

The MARINERG-i DRI mission is to drive the development of innovative ORE technologies by:

- Streamlining research, testing, training and user access
- Adopting common codes of practice for uniformity in testing performance metrics, validation and certification
- Implementing an e-infrastructure platform for remote access & secure data and analytical services
- Accelerate the development of the ORE industry by leveraging and combining local/regional knowledge and capacity.
- Inform national and EU policy and infrastructure investment strategies to sustain global leadership and reputation in the ORE sector.

The MARINERG-i strategic research agenda is aligned with the priorities identified by ongoing EU initiatives (the Green Deal, Ocean Energy Roadmap, SET plan, ETIP Ocean, ETIP Wind). It is designed to reflect end-users' requirements in terms of scientific development and improved testing methods in order to:

- de-risk technologies

- reduce uncertainties and improve reliability and survivability of devices
- optimise the efficiency of ORE converters whilst also optimising marine operations and maintenance so as to reduce the Levelised Cost of Energy (LCoE) and accelerate the commercial deployment of devices.

Figure 11 Overview of the proposed MARINERG-i portal

9 Conclusions

The MaRINET2 project has accomplished a huge amount in terms of progressing the offshore renewable energy sector by providing access to test facilities to technology developers, conducting research aimed at improving test processes, providing guidelines for those carrying out testing, providing training and producing open-access datasets that will benefit the ORE community. In order for the impact of MaRINET2 to be as far-reaching as possible, the experience of the users and the findings from the round robin research programme must be incorporated into technical specifications, and eventually, standards. This can be achieved by engaging with technical committees, e.g. TC114 who are responsible for the IEC 62600 standards.

There are many metrics in use that enable quantification of the technical readiness of an ORE device. However, in addition to technical readiness, ORE developers need to consider the commercial readiness of their devices in order to maximise the chances of progressing to commercialisation. A good business plan is essential for securing finance, without which even the best device will not succeed. It is recommended that developers make full use of the free resources described in this report to self-assess their technologies, and consider providing feedback to the developers of these tools and resources. It is also recommended that developers engage with certification bodies at an early stage in order to reduce risk.

Access to test facilities in the future will largely be accomplished through the MARINERG-i Distributed Research Infrastructure (DRI) which is currently listed as a new Research Infrastructure project on the ESFRI Roadmap. It is anticipated that the MARINERG-i DRI will begin operating in 2026 and will be self-sustaining and delivering a full suite of services for the ORE sector by 2031.

10 References

[1] J. Weber, R. Costello, and J. Ringwood, "WEC technology performance levels (TPLs)- metric for successful development of economic WEC technology.," 2013, Accessed: Mar. 26, 2018. [Online]. Available: http://eprints.maynoothuniversity.ie/6793/.

[2] J. Weber, "WEC Technology Readiness and Performance Matrix - finding the best research technology development trajectory," in *Proceedings of the 4th International Conference on Ocean Energy, Dublin, Ireland*, 2012, vol. 17.

[3] IEC, "TS 62600-103:2018 Guidelines for the early stage development of wave energy converters - Best practices and recommended procedures for the testing of pre-prototype devices." IEC, 2018.

[4] J. Hodges *et al.*, "An International Evaluation and Guidance Framework for Ocean Energy Technology," 2021.

[5] A. Babarit, J. Hals, M. J. Muliawan, A. Kurniawan, T. Moan, and J. Krokstad, "Numerical benchmarking study of a selection of wave energy converters," *Renew. Energy*, vol. 41, pp. 44–63, 2012, doi: https://doi.org/10.1016/j.renene.2011.10.002.

[6] F. R. Driscoll *et al.*, "Methodolgy to Calculate the ACE and HPQ Metrics Used in the Wave Energy Prize," Golden, CO, 2018. doi: https://doi.org/10.2172/1426063.

[7] I. Bayati and L. Efthimiou, "Challenges and Opportunities of Major Maintenance for Floating Offshore Wind," 2021. [Online]. Available: https://w2m8n2q3.rocketcdn.me/wp-content/uploads/2021/12/WFO_OM-WhitePaper-December2021-FINAL.pdf.

[8] J. Aldersey-Williams and T. Rubert, "Levelised cost of energy – A theoretical justification and critical assessment," *Energy Policy*, vol. 124, no. C, pp. 169–179, 2019, [Online]. Available: https://econpapers.repec.org/RePEc:eee:enepol:v:124:y:2019:i:c:p:169-179.

[9] P. L. Joskow, "Comparing the costs of intermittent and dispatchable electricity generating technologies," *Am. Econ. Rev.*, vol. 101, no. 3, pp. 238–241, 2011.

[10] K. Branker, M. J. M. Pathak, and J. M. Pearce, "A review of solar photovoltaic levelized cost of electricity," *Renew. Sustain. energy Rev.*, vol. 15, no. 9, pp. 4470–4482, 2011.

[11] S. Shah and M. Bazilian, "LCOE and its Limitations," *Energy Growth Hub*, 2020.

[12] F. D. McAuliffe, M. Noonan, and J. Murphy, "Levelized Cost of Energy Assessment for Offshore Wind Farms—An Examination of Different Methodologies, Input Variables, and Uncertainty," *ASCE-ASME J Risk Uncert Engrg Sys Part B Mech Engrg*, vol. 7, no. 4, Sep. 2021, doi: 10.1115/1.4052269.

[13] F. Ueckerdt, L. Hirth, G. Luderer, and O. Edenhofer, "System LCOE: What are the costs of variable renewables?," *Energy*, vol. 63, pp. 61–75, 2013.

[14] I. Pawel, "The cost of storage–how to calculate the levelized cost of stored energy (LCOE) and applications to renewable energy generation," *Energy Procedia*, vol. 46, pp. 68–77, 2014.

[15] US Energy Information Administration, "Levelized Costs of New Generation Resources in the Annual Energy Outlook 2021," 2021. [Online]. Available: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

[16] Siemens, "SCOE - Society's Cost of Electricity: How society should decide on the optimal energy mix," 2014. https://pt.slideshare.net/christophneemann/scoe-societys-cost-of-electricity-how-society-should-decide-on-the-optimal-energy-mix (accessed Nov. 26, 2021).

[17] ARPA-E, "Technology to Market Plan: Template and Instructions." [Online]. Available: https://arpa-e.energy.gov/technologies/tech-to-market/planning.

[18] D. Moodie and A. Baldock, "Marine Energy Alliance Deliverable 1.3.2: Benchmarking Framework," 2020.

[19] ARENA, "Commercial Readiness Index for Renewable Energy Sectors," 2014. [Online]. Available: https://arena.gov.au/assets/2014/02/Commercial-Readiness-Index.pdf.

[20] IEA RETD TCP, "Commercial Readiness Index Assessment – Using the method as a tool in renewable energy policy design (RE-CRI)," Utrecht, 2017. [Online]. Available: http://iea-retd.org/wp-content/uploads/2017/06/IEA-RETD-RE-CRI-Report.pdf.

[21] Wave Energy Scotland, "IDCORE EngD - Operations and Maintenance Simulation Tool." https://library.waveenergyscotland.co.uk/other-activities/design-tools-and-information/tools/om-simulation-tool/ (accessed Dec. 02, 2021).

[22] IECRE, "IECRE Operational Document: IECRE OD 310-4," 2020. [Online]. Available: https://www.iecre.org/documents/refdocs/pdf/od-310-4ed1.0.pdf.

[23] "RE Certification Bodies (RECBs)." https://www.iecre.org/dyn/www/f?p=110:7:::::P7_ORG_TYPE:RECB (accessed Dec. 02, 2021).

[24] S. Draycott and D. R. Noble, "Test recommendations and gap analysis report, MaRINET2 Deliverable 2.1," 2018. doi: 10.13140/RG.2.2.22509.90081.

[25] D. R. Noble *et al.*, "Standardising Marine Renewable Energy Testing: Gap Analysis and Recommendations for Development of Standards," *Journal of Marine Science and Engineering* , vol. 9, no. 9. 2021, doi: 10.3390/jmse9090971.

[26] J. Ohana *et al.*, "Round robin tests of a hinged raft wave energy converter," 2021.

[27] T. Davey *et al.*, "Round Robin Testing: Exploring Experimental Uncertainties through a Multifacility Comparison of a Hinged Raft Wave Energy Converter," *J. Mar. Sci. Eng.*, vol. 9, no. 9, 2021, doi: 10.3390/jmse9090946.

[28] S. Gueydon *et al.*, "Round Robin Laboratory Testing of a Scaled 10 MW Floating Horizontal Axis Wind Turbine," *J. Mar. Sci. Eng.*, vol. 9, no. 9, 2021, doi: 10.3390/jmse9090988.

[29] B. Gaurier *et al.*, "MaRINET2 Tidal Energy Round Robin Tests—Performance Comparison of a Horizontal Axis Turbine Subjected to Combined Wave and Current Conditions," *Journal of Marine Science and Engineering* , vol. 8, no. 6. 2020, doi: 10.3390/jmse8060463.

[30] Det Norske Veritas, "Marine risk assessment," 2002. [Online]. Available: https://www.hse.gov.uk/researcH/otopdf/2001/oto01063.pdf.

[31] F. Judge *et al.*, "MaRINET2 D2.6: Final guidelines for test applicants," 2021. [Online]. Available: https://www.marinet2.eu/wp-content/uploads/2021/11/D2.6-Final-guidelines-for-test-applicants-FINAL.pdf.

Appendix A

Technology Readiness Levels for Supply Chain Study for WestWave

Wave Power Conversion Systems: ESBI Technology Readiness Definition – Generic Summary Level

Notes: More specific verification requirements should be derived for particular wave power conversion technologies.
Where mentioned, "scale" refers to a physical Froude scaling of wave heights, periods and device dimensions relative to commercial product.

ESBI TRL 1: Configuration described

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Basic principles observed and reported **System Definition:** • Oscillator(s) with wave absorbing hydrodynamic interface identified • Oscillator(s) with acceptable / controllable mechanical impedance identified • Reacting bodies / PTO opportunity identified • Relevant physical processes identified • Station-keeping/foundation opportunity identified	**Purpose(s) of technology identified** **Market:** Electricity generation, water desalination, pumping, ec.	**Consistent with ESBI Requirements:** ☐ Concept sketch with annotations and device description. ☐ Uses of the technology identified.	**Spend:** Negligible **Power Revenue:** None **Funding:** None **Duration:** 2-14 days **Team:** Inventor

ESBI TRL 2: Technology Development Stream Initiated

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology concept and/or application formulated. **System Definition:** Principal dimensions and main components identified. Target water depth and wave resource requirements identified. Basic geotechnical requirements identified. Scope of system and external interfaces defined. **Performance/Costs:** Simple calculations and read across from existing data to estimate power production performance and size of major structural elements. **Mechanical Integrity:** Configuration consistent with survivability for the target ocean environment.	**Market Identified** **Site Identification:** Suitable sites identified for large scale mobilisation of technology. **Lifecycle considerations:** The concept configuration should include consideration of manufacturability, deployability, access for maintenance, operability and decommissioning. Health and safety hazards should be identified and designed out where possible. **Customer Interface:** Point of sale of product and interface with customer is defined. (e.g. national grid connection point, etc)	**Consistent with ESBI Requirements:** ☐ Concept configuration drawing ☐ Concept report defining system layout, function, site requirements and appreciation of lifecycle implications. ☐ Performance and cost calculations /estimates indicating realistic targets. ☐ Device configuration and sizing consistent with offshore experience.	**Spend:** €10-50k **Power Revenue:** None **Funding:** None **Duration:** 2-3 months **Team:** Inventor

ESBI TRL 3: Initial Product Verification - 1:100 to 1:25 scale laboratory testing

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Analytical and experimental critical function and/or characteristic proof-of-concept. **HMRC Development and Evaluation Protocol PHASE 1** **Performance:** Experimental Ocean Basin Laboratory testing at 1:25 – 1:100. Absorbed power measured in monochromatic and synthesised irregular sea states (as per HMRC D&E.P). **Performance:** Numerical simulation model in time domain – inviscid hydrodynamics, rigid body motions and idealised control forces to predict power absorbed by device. **Survival:** Moorings Analytical Simulation Model: Representative survival events to predict design wave response and define initial mooring sizing and induced loads. **Survival:** Experimental Ocean Basin Laboratory Testing at 1:100 scale or greater with qualitative assessment of survival aspects: acceptable mooring loads, sea-keeping, greenwater, slamming, etc. **System Definition:** Principal dimensions and inertial information, ensuring static stability, acceptable dynamic behaviour, etc. PTO degree of freedom defined (eg as linear PTO including stroke and peak force requirements, air turbine including peak volume flows and damping coefficients)	**Initial capital cost and power production estimates / targets established** **Site Identification:** Wave Resource measured / analysed for target market sites. Indicative resource scatter plots obtained and justified. Consistent water depth and seabed geology should be considered. **Cost Estimates / Targets:** Based on critical dimensions and tonnage, an initial cost breakdown / commercial cost targets with documented justification for capital expenditure. **Energy Production Estimates / Targets:** Use of power matrix to predict energy production. Allowances/targets for converting absorbed power to product should be established.	**Consistent with ESBI Requirements:** ☐ Power Matrix based on measured absorbed power for representative control forces at 1:25 to 1:100 scale or greater. ☐ Numerical simulation model for rigid body oscillator with simple representative control methods. ☐ Verification report comparing measured characteristics and numerical predictions. Physical and numerical modelling assumptions are presented. Comments on validity of energy production modelling methods are given. ☐ Report(s) showing cost targets for commercial capital expenditure, justified by realistic structural weight and material costs.	**Spend:** €0.5m **Power Revenue:** None **Funding Mix:** Govt Research Grants & Company founder investments. **Duration:** 6-9 months **Team:** 1-2 staff plus experimental and simulation Support

ESBI TRL 4: Laboratory and Analytical Verification – 1:25 scale or larger laboratory testing

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology component and/or basic technology subsystem validation in a laboratory environment. **HMRC Development and Evaluation Protocol PHASE 2** **Control and Performance:** 1:25 scale or greater experimental ocean basin activity including control forces representative of actual PTO capability. Absorbed power measured for representative control force behaviour. **Survivability:** End-stop control (if relevant): Survival condition defined and tested at 1:25 scale or greater. (e.g. ballasting, detuning oscillator, "locked" PTO loads, etc) **Survivability:** Moorings. As representative a mooring system as possible should be used during 1:25 (or greater) scale physical modelling. Simulation verification and where tank capability permits this should be verified experimentally in representative storm waves. **Naval Architecture:** Basic assessment showing that marine standards can be met and manufacturability achievable. **PTO / Operational end-stop control:** Full scale PTO defined. Scaled laboratory bench-testing of simplified but representative PTO in conjunction with use of simulation to extrapolate to full scale behaviour – control force capability and mechanical conversion efficiency analysed by a combination of scaled experiment and simulation. **Electrical Powertrain / Power Export:** The means of converting mechanical power for export and the transmission of this power to market should be defined. Calculations / basic simulations of export efficiencies complete. **System Definition (commercial):** System breakdown and high level definition of subsystems: e.g. Collector Subsystem, Mechanical PTO System, Electrical Conversion System, Power Export System, Position Mooring System requirements established. Major internal interfaces identified between subsystems as well as clarity of system level external interface (e.g. grid code compliance requirements, marine navigation).	**Preliminary Lifecycle design** **Health & Safety:** Risk assessment (HAZID) projected for all phases of technology in-service lifecycle. Design change process implemented to minimise or eliminate risk wherever possible. (e.g. eliminate offshore intervention, offshore crew transfers, diver operations, working at height, etc) **Manufacturability:** Naval architecture / Shipyard input: Storyboard for manufacture and assembly of full-scale system, based on one or more existing manufacturing facilities. Design change process implemented to enable manufacturability (e.g. reduce crane requirements, facilitate welding operations, avoid complex steel forming, etc.) **Deployability:** Storyboard of operations required to install and commission full scale technology at target site based on available vessels and facilities. **Operability:** Requirements for telemetry and SCADA system for remote supervisory control of system. Instrumentation requirements identified. **Maintainability:** Components categorised by life / level of maintenance required. Decisions on maintenance strategy: intervals and decision to maintain on-site or disconnect and tow to shore. **Reliability:** Qualitative FMEA at system level. Design change for reliability wherever potential problems emerge. **Array Layout:** Array spatial assessment for target site integrating multiple systems, allowing for mooring system footprint, power export system and estimate of resource affected area. **Economic Viability:** Business model developed for small array using updated CAPEX and OPEX targets and justification. Energy production estimated using updated knowledge including conversion and export efficiencies.	**Consistent with ESBI Requirements:** ☐ Power Matrix based on measured absorbed power for representative control forces at 1:25 scale or greater. ☐ Control strategy shown to protect operational system from end stop events, in irregular waves. ☐ Survival mode measured mooring / foundation / interface loads matching survival simulation predictions. ☐ Scaled and simplified experimental PTO results validating simulation of the same system. (hydraulic, turbine, etc) ☐ Use of validated PTO simulation to extrapolate conversion efficiencies to full scale system in irregular waves. ☐ For baseline converter system, all subsystem requirements defined and interfaces identified. ☐ Schematic of power export system up to point of system external interface based on a small array of devices. ☐ SCADA, control and instrumentation requirements defined. ☐ Health & Safety Risk assessment ☐ High level Maintenance plan ☐ System Level FMEA, inspection and redundancy strategy. ☐ Array schematic for sample commercial site & consistent moorings. ☐ Business model for commercial array project based on latest CAPEX, OPEX and Power production estimates.	**Spend:** €0.5 – 1.0m **Power Revenue:** None **Funding Mix:** Govt Research Grants & Angel Investors. Less likely from some small strategic investment (VC, utility, system integrator) **Duration:** 9-12 months **Team:** 4-8 staff plus experimental and simulation Support. Plans underway to bring capability into team.

ESBI TRL 5: Reduced Risk Subsystem Verification - 1:15 to 1:4 scale subsystems tested in a laboratory or fetch-limited site.

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology component and/or basic technology <u>subsystem</u> validation in a relevant environment. **HMRC Development and Evaluation PHASE 3 (Lab Tests / fetch-limited site)** **Absorber:** *Performance:* Experimental verification of 1:4-1:15 scale (or larger) moored structure in large basin facility or benign site. Measurement of dynamic response to operational sea-state excitation. Conservative control methods may be employed at this stage. Measured response behaviour compared to expectations from numerical simulation for validation. Validated simulation used to extrapolate performance to full-scale with fully operational control. *Survivability:* Experimental 1:4-1:15 scale (or larger) moored structure exposed to scaled storm events in the sea. Mooring forces measured and compared to numerical model predictions. **PTO / End-stop control:** Experimental verification of PTO system at 1:4 (or larger) Froude scale power levels in laboratory environment (or within scaled sea-trial oscillator). **Power Export:** Experimental verification at 1:4 scale or larger of any unconventional components. (e.g. mechanical integrity of electrical risers in large waves/shallow water, marinised electrical substations, 11kV wet mate connectors) **Naval Architecture:** Static and Dynamic stability and other naval architecture concerns are addressed. Early structural layouts for commercial scale complete. Detail designs for TRL 6 scale structure. **Operability / SCADA:** SCADA and telemetry developed to support large scale experiments control and data acquisition. **System Definition (commercial):** System and interface definition for commercial scale system is further detailed and updated with supplier feedback and test information. **System Definition (next phase):** Full detail design definition for 1:4 (or larger) scale system and subsystems suitable for procurement exercise for TRL 6 testing. Experimental schedule for TRL 6 testing drafted.	**Supply-chain Mobilisation** Major Subsystem Integrators consulted and actively working on meeting subsystem requirements **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of scaled sea / lake / basin trial activity. Design/Process changes implemented to eliminate identified risks. Event Log in place to catch arising risks and hazardous events. Impacts on commercial product considered. **Health & Safety / Insurability:** In respect of sea / lake trials, inspections and reports by a marine surveyor / classification society should be used to obtain all insurance deemed necessary. **Interface Management:** Supply chain feedback and interaction used to define important interfaces and to iterate the system level definition. **Maintainability / Deployability (commercial):** Intervention and deployment operations described. Warranty Surveyors assessment of planned marine operations is available. **Manufacturability (commercial):** Consultation with potential suppliers on fabrication and assembly at commercial scale. Design update as required. **Manufacturability (next phase):** Structural design, fabrication, assembly and fit-out of TRL 6 structure at advanced stage of planning with suppliers consulted. **Deployability (next phase):** TRL 6 Installation & Removal Operations of foundation, mooring systems and device from quayside to experimental site are defined. **Economic Viability:** Updated business model using supplier derived cost estimates and where possible, quotations.	**Consistent with ESBI Requirements:** ☐ Simulation predictions of device motion shown to match measured response of structure in basin / sea. ☐ PTO conversion simulation and large scale experimental testing indicating that the required conversion efficiency can be achieved for power flows associated with irregular waves. ☐ Updated power matrix based on validated simulation & PTO conversion efficiencies. ☐ Scaled storm survival and acceptable mooring loads. Measurements consistent with simulation predictions. ☐ SCADA for remote control of an offshore system developed. ☐ Health & Safety HAZID / HAZOP reports and effected design changes. Event log procedure in place. ☐ Marine surveyors consulted for large scale experimental work. Appropriate insurance obtained for activity. ☐ Warranty surveyor assessment of proposed deployment and intervention marine operations. ☐ Commercial system definition updated with supplier derived data. ☐ TRL 6 hardware system definition, experimental plan, fabricators and marine operations suppliers in place. ☐ Commercial business model updated with converted energy production and supplier derived cost estimates.	**Spend:** €3-5m **Power Revenue:** None **Funding Mix:** Govt Research Grants. Strategic investment (VC, utility, system integrator) **Duration:** 12-18 months **Team:** 10-15 staff covering simulation, control, structural, electrical design & definition, commercial & procurement. Plus subcontract support & steel fabrication.

ESBI Technology Partnership Readiness Level 1 Achieved

ESBI TRL 6: Reduced-Risk full System Verification - 1:4 scale or larger in a limited fetch sea trial.

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Technology <u>system</u> model or prototype demonstration in a relevant environment. **HMRC Development and Evaluation PHASE 3 (Sea Trials)** Representative (1:4 scale or larger) full system (excl power export) deployed and operating at a sea test site. **PTO / End-stop control:** Experimental PTO system deployed should be as required to test aspects of control and absorbed power. Heavily instrumented 1:4 Froude scale power output (or larger) operating within the system at sea to produce electricity. Electricity need not be exported. **Performance:** Experimental Sea Trials of technology configuration in scaled wave resources (1:4 scale or larger – e.g. Galway Bay). Based upon electrical power at the device terminals (pre-export), verification of a range of operating conditions in the power matrix should be carried out. The deviation from idealised simulation predictions due to relevant environmental phenomena should be established. **Power Quality:** Simulations of generator and power export system, supported by experimental mechanical (e.g. shaft) and electrical power measurements in the relevant environment. Results showing that grid code compliance (e.g. IEC 61000, IEC61400-21, etc) is achievable. **Survivability:** Site should be selected so that the 1:1 year return period storm is similar to or more severe than a scaled 1:100 year return period storm at commercial scale. The test mooring subsystem should be representative of commercial intent and certifiable. Survival mode features (e.g. detuning) should be tested. Measurements taken for model validation. **Marine Environment:** The effect of marine environment on the device growth and corrosion protection systems to be considered. Learning applied to commercial definition. **System Definition (commercial):** System and interface definition for commercial scale system is further detailed and updated with customer/supplier feedback and test information. **System Definition (next phase TRL7):** Low level requirements definition of commercial scale system and all subsystems, sufficient to enable detail design exercise to commence. Marine Operations storyboard and requirements document. Experimental schedule for TRL 7 testing drafted.	**Customer interaction** Discussions with potential owner-operators of technology to establish project requirements. **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of sea-trial activity. Design/Process changes implemented to eliminate identified risk. Event Log in place to catch arising risks and hazardous events. Impacts on commercial product considered. **Health & Safety / Insurability:** In respect of sea trials, inspections and reports by a marine surveyor / classification society should be used to obtain all insurance deemed necessary. **Reliability:** Detailed FMEA to sub-system levels including supplier input on major subsystems. **Failure / Issue reporting System:** Failure & Issue reporting system in place for duration of the deployment to record all operational faults and issues that arise. FMEA, design/process change enacted to reflect arising issues. **Operations & Maintenance:** Supervisory control of the device from shore should be demonstrated. Operations plan and lifecycle maintenance and intervention schedule for typical commercial project is supported by potential O&M suppliers. Customer buy-in that O&M plan meets their requirements. **Manufacturability:** Advanced plans for supply of TRL7 subsystems, fabrication and assembly. Supplier quotations / cost estimates available. **Deployability:** Advanced plans for one-off deployments with a view to validating commercial intentions. (geotechnics, vessel,etc) **Economic Viability:** Updated economic model based upon customer requirements for early projects. Use of supplier derived costs and where possible, quotations. OPEX cost including supplier derived information for marine operations & vessel hire should be included.	**Consistent with ESBI Requirements:** ☐ Power matrix based on measure of absorbed power in the relevant environment at 1:4 scale or larger. ☐ Commercial Power matrix extrapolated through simulation of converted power at grid connection point. (verified by 1:4 scale experiments) ☐ Electrical system simulation demonstrates grid compliant power using measured electrical power as an input. ☐ Health & Safety HAZID / HAZOP reports and effected design changes. Event log procedure, acceptable insurance and certification in place. ☐ Mooring and structural integrity demonstrated in maximum operating conditions and storm survival conditions. ☐ Detailed FMEA and failure reporting system in place. Marine environment effects logged and appropriate design / process change action taken. ☐ Updated commercial system definition. O&M plan formulated in detail by suppliers. Customer vetting of O&M. ☐ TRL 7 detailed system definition complete. Hardware suppliers identified. ☐ TRL 7 installation operations detailed with a view to validating commercial intentions. ☐ Customer agreed commercial project economic model. CAPEX/OPEX costs consistent with supply chain indications. Energy production consistent.	**Spend:** €5m **Power Revenue:** None **Funding Mix:** Govt Research Grants. Strategic investment (VC, utility, system integrator) **Duration:** 12-18 months **Team:** 15-20 staff covering simulation & control, structural, electrical design & definition, commercial & procurement. Plus subcontract support & steel fabrication.
ESBI Technology Partnership Readiness Level 2 Achieved			

ESBI TRL 7 – Ocean Operational Readiness – 1:2 scale (or larger) in an open ocean environment

<table>
<tr><th>Functional Readiness</th><th>Lifecycle Readiness</th><th>ESBI Verification Checklist</th><th>Indicative :</th></tr>
<tr>
<td>Technology <u>system</u> prototype demonstration in an operational environment.

HMRC Development and Evaluation Protocol PHASE 4
Representative (1:2 scale or larger) end-to-end system deployed and operating grid-connected at an ocean test site (EMEC or similar).

Operability: Initial conservative operational restrictions in place as necessary. Conservative control methods slowly relaxed with operational experience. Validation of some power matrix points based on commercial control methods.

Performance: Comparisons of measured power with predictions from simulation of absorbed power, converted power and exported power using identical control methods. Power Matrix established based on power at grid connection point, using verified simulation to quantify the effect of using commercial control methods. Performance data to cover important points (e.g. at extremities) of the power matrix / operating envelope. Measured data using non-conservative operational control should be included.

Survivability (Operational): Ability to maintain safe control of the device is demonstrated (end-stops, overspeeds, etc).

Survivability (Storm): Structure certified as necessary to meet all relevant requirements of appointed classification society to deploy and operate at ocean test site.

Power Quality: Grid Connected and control / power quality studies undertaken with a view to achieving grid code compliance. Power System simulation verified from measurements. Results demonstrating that farm grid code compliance is achievable.

Health Monitoring: System in-place and any issues arising to be logged in a reporting system. Examples include:
• Load Monitoring (moorings, PTO interfaces, etc)
• Wear surfaces: bearings, seals, lubricant contaminants
• Umbilical & Mooring cable rope inspections
• Marine Growth , Corrosion

System Definition (commercial): Detail design complete and ready for procurement exercise for a pre-commercial demonstration (TRL 8)</td>
<td>Ocean Experience

Health & Safety: Risk Assessments (HAZOP / HAZID) complete for all phases of demonstration project. Design/Process changes implemented to eliminate identified risk. Event Log in place to record hazardous events.

Insurability / Marine Warranty: Device certified by classification society to meet insurance conditions. Marine Warranties received for all marine operations associated with installation, deployment and scheduled maintenance. Plan to bring underwriting costs in-line with commercial requirements.

Environmental: Environmental study complete and monitoring underway. Permitting process established for future projects.

Reliability: Health monitoring / Failure / Issue reporting System updated with ocean project experience. FMEA updated as necessary and design/process change action taken to mitigate all issues highlighted for future projects.

Operability: Commercial SCADA interface and operational procedures for the device in place.

Maintainability: Marine operations required for scheduled maintenance and repair intervention are demonstrated. Improvements (cost-cutting, weather window restrictions, safety) defined to meet commercial operations requirements.

Deployability: Installation operations and civil works at test site are demonstrated. The impacts on possible variations at future sites are studied in detail (scale, depth, geotechnics and environmental loads).

Manufacturability: Supplier appraisal and contracting for pre-commercial demonstrator.

Economic Viability: Update of costs and power production in economic model as appropriate.</td>
<td>Consistent with ESBI Requirements:

☐ Safe control of device demonstrated at extremeties of operating envelope.

☐ Power matrix based on measured electrical power in the operational environment at 1:2 scale or larger.

☐ Commercial Power matrix extrapolated through simulation (verified by 1:2 scale experiments) of converted power at grid connection.

☐ Appropriate level of certification achieved and insurance obtained. Mooring system and structure behave as expected in storm conditions.

☐ Measured power used as input to electrical power system model to demonstrate grid code compliance.

☐ Environmental scoping reports and monitoring data available.

☐ Commercial SCADA and remote supervisory control demonstrated.

☐ Health & Safety Risk Assessment and event logs received with appropriate mitigating action taken.

☐ Health monitoring / Failure reporting log available. FMEA updated and mitigating action taken on design / marine operations procedures.

☐ Supply chain report and plan for TRL8 hardware delivery in place.

☐ Detailed definition of TRL8 pre-commercial demonstrator available.

☐ Economic model updated with latest costs and performance indications.</td>
<td>Spend:
€10-15m

Power Revenue:
€0-100k /an

Funding Mix:
Govt Grant Aid. Strategic investment (VC, utility, system integrator)

Duration:
12-24 months

Team:
20-40 staff covering marine operations, mechanical fitting, reliability, safety, etc.</td>
</tr>
<tr><td colspan="4">ESBI Technology Partnership Readiness Level 3 Achieved</td></tr>
</table>

ESBI TRL 8 – Pre-Commercial Project Readiness – 1:1 commercial scale single device hardware tested and demonstrated

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Actual Technology system completed and qualified through test and demonstration. **HMRC Development and Evaluation Protocol PHASE 5** Full scale end-to-end system (designed for the target market environmental conditions) deployed and operating at an ocean test site (Belmullet or similar). **Performance:** Operational experience sufficient to densely populate the Power Matrix table based on electrical power measured at grid point of connection, in accordance with IEC62600-100. Variations in power production for relevant environmental phenomena should be studied (wave direction, currents, etc.). Suitable assumptions to be used for pre-commercial power matrix should be defined and justified. **Power Quality:** Grid Code Compliance demonstrated through on-site testing (e.g. IEC 61000, IEC61400-21, etc) **Operability:** SCADA and operational procedures in place to permit 24 hour operation of device (preferably by utility partner). The operating envelope should be as commercial. **Survivability:** There should be no requirement to restrict on-site presence due to weather events. Mooring, foundation and anchoring system should be designed and operated as intended for commercial deployments. Geotechnical & depth differences between the deployment and commercial sites should not require further mooring development. **Health Monitoring:** System in-place and any issues arising to be logged in a reporting system. Examples include: • Load Monitoring (moorings, PTO interfaces, etc) • Wear surfaces: bearings, seals, lubricant contaminants • Umbilical & Mooring cable rope inspections • Marine Growth , Corrosion Parameters such as the above to be compared with expectations from simulation, etc. **System Definition:** Drawings and specifications sufficient to procure all subsystems. Requirements document for power export system for arrays. Installation and maintenance manual defining all marine operations.	**Actual Marine Operations completed and qualified through test and demonstration.** **Health & Safety:** Risk Assessments (HAZOP / HAZID) complete for all phases of demonstration project. Design/Process changes implemented to eliminate identified risk. Event Log in place to catch arising risks. **Maintainability:** All scheduled maintenance operations successfully completed, including electrical infrastructure where appropriate. **Reliability:** In-service data available for power station availability. Design / Process change action taken to mitigate all issues highlighted by the failure reporting system during deployment. FMEA database updated and data on subsystem failure rates gathered. **Environmental:** Results of Environmental monitoring report showing acceptable impact. **Supply Chain / Manufacturability:** Appraisal of supplier performance on project delivery and capacity to expand production towards commercial projects. **Insurability / Marine Warranty:** Device certified by classification society to meet insurance conditions. Marine Warranties received for all marine operations associated with installation, deployment and scheduled maintenance. Plan to bring underwriting costs in-line with commercial requirements. **Economics:** CAPEX and OPEX values updated in commercial economic model. Pre-commercial project (TRL9) financing: Hardware pricing and operations pricing agreed to support a >5MW pre-commercial array to achieve TRL 9. Pre-commercial project co-financing opportunities in place.	**Consistent with ESBI Requirements:** ☐ Measured power matrix results including variability. Report detailing environmental influences on performance and method for predicting energy production at a commercial site. ☐ Installation & scheduled maintenance operations completed and consistent ☐ Health & Safety Risk Assessment and event logs received with appropriate mitigating action taken. ☐ Health Monitoring System in place. Failure Reporting Log received. FMEA updated with appropriate mitigating action taken. ☐ 24-7 operability achieved ☐ Mooring system deployable at commercial site. ☐ Suitable Insurance cover received for assets and operations. ☐ Acceptable environmental impact demonstrated. ☐ Commercial economic model updated with latest cost & production estimates ☐ Supply chain for all subsystems and services is capable of expansion to deliver pre-commercial (TRL9) activity. ☐ Pre-commercial TRL9 project economic model formulated, opportunities highlighted and co-financing partners in place.	**Spend:** €10-15m **Power Revenue:** €100k–500k /an **Funding Mix:** Govt Grant Aid. Institutional and Strategic investment (VC, utility, system integrator). Possibly partially raised against owner operator power purchase agreement. **Duration:** 12-24 months **Team:** Up to 60 staff, expanded to cover marine operations, mechanical fitting, reliability, safety, commercial contracts, etc.
ESBI Pre-Commercial Project Readiness Level Achieved			

ESBI TRL 9 – Commercial Project Readiness – 1:1 commercial scale small farm (5MW or greater) operational experience.

Functional Readiness	Lifecycle Readiness	ESBI Verification Checklist	Indicative :
Operational performance and reliability of an array demonstrated **Operability:** Farm supervisory control handed over to a Utility / Owner-operator partner. **Performance (Measured):** Operational array of 5MW or larger wave farm. Farm power matrix at grid connection point confirmed and compared to individual device power matrix. Device interaction understood and accounted for. **Performance (Simulated):** Simulation capability used to extrapolate from measured performance to a larger farm production in a resource at a consented site. Energy production predicted with allowances made for sources of deviation from power matrix summary statistics as well as electrical topography. **Power Quality:** Grid Code Compliance demonstrated through on-site testing (e.g. IEC 61000, IEC61400-21, etc) **Health Monitoring:** System in-place and any issues arising to be reported in Issue reporting system. Examples include: • Load Monitoring (moorings, PTO interfaces, etc) • Wear surfaces: bearings, seals, lubricant contaminants • Umbilical & Mooring cable rope inspections • Marine Growth • Corrosion Parameters such as the above to be compared with expectations from simulation etc and deviations should be logged. **System Definition:** Product specification suitable for tender response. Design definitions, drawings etc for all subsytems and their integration for a wave farm.	**Fully de-risked business plan for utility scale deployment of arrays** **Health & Safety:** Risk Assessments for all phases of project lifecycle complete. Event logs up-to-date and design / process change action taken to mitigate all issues highlighted. **Maintainability:** All scheduled maintenance operations successfully completed and costs recorded, including electrical infrastructure where appropriate. Methods should represent commercial intent at this stage. **Reliability:** In-service data available for power station availability. Design / Process change action taken to mitigate all issues highlighted by the failure reporting system. Quantified FMECA database and repair intervention cost estimates. **Environmental:** Consenting and environmental monitoring activity complete. Benign impact on environment demonstrated sufficiently to show no obstacles to consenting and operations on commercial scale sites. **Insurability / Marine Warranty:** Underwriter's quotations for insuring assets and scheduled marine operations are available. **Economics:** Pricing of quayside hardware & installation operations given for a commercial project. Pricing of scheduled maintenance and intervention activity given for commercial operation. **Warranty:** Systems suppliers can stand over suitable commercial warranty based on power matrix guarantee and availability of hardware.	**Consistent with ESBI Requirements:** ☐ Health & Safety Risk Assessment and event logs received with appropriate mitigating action taken. ☐ Failure Reporting Log received with appropriate mitigating action taken. ☐ Wave farm energy production report received with measured power matrix. Based on a project proposal for a given site, with known resource: ☐ Wave farm energy production estimates based on measured farm power matrix. ☐ Quayside hardware specification and pricing. ☐ Installation & scheduled maintenance operations scope and pricing. ☐ Balance of plant (electrical, civil works etc) costs based on quotation. ☐ FMEA and reliability assessment undertaken giving repair cost liability. ☐ Insurance costs available ☐ Warranty available and liabilities backed up by provider's balance sheet. Considering all of the above and the available wave energy tariff: ☐ An acceptable project rate of return is achievable on project proposal.	**Spend:** €40-60m **Power Revenue:** €1m – 2m /an **Funding Mix:** Govt Grant Aid, particularly for generic electrical infrastructure. Owner-operator (utility) finance or finance raised against power purchase agreement. VC investments. **Duration:** 24 months – 20 yrs **Team:** Up to 100 staff depending on sub-contracting strategy. Mobilised supply chain at subsystem level. Strong support from a utility / owner-operator partner.
ESBI Commercial Project Readiness Level Achieved			

Appendix B

List of MaRINET2 facilities

The following is a list of test facilities available in MaRINET2. For details on each facility, please refer to www.MaRINET2.eu

Table 11 List of test facilities available in MaRINET2

	Wave	Tidal	Offshore Wind	Electrical/ Grid integration	Cross-cutting
Small laboratory	UCC_MaREI Ocean Emulator	UCC_MaREI Wave & Current Flume	UEDIN Curved Basin	UCC_MaREI Ocean Emulator	UNEXE_Dynamic Marine Component Test Facility
	UCC_MaREI Wave & Current Flume	LABIMA Wave & Current Flume	MARIN Concept Basin	TECNALIA – Electrical PTO	TECNALIA – Component Corrosion Test Platform
	AAU Wave & Current Basin	MARIN Concept Basin	MARIN Shallow Water Basin		CTC – Marine Corrosion Test Site 'El Bocal'
	LABIMA Wave & Current Flume	MARIN Shallow Water Basin	AAU Wave & Current Basin		
	UEDIN Curved Basin	Cantabria Wave-Current Tsunami Flume	DTU Windscanner		
	MARIN Concept Basin		Cantabria Wave-Current Tsunami Flume		
	MARIN Shallow Water Basin		Surrey Enflo wind tunnel		
	QUB Wide Wave Basin				
	Cantabria Wave-Current Tsunami Flume				
	Strathclyde Kelvin lab				

Large laboratory	FZK Large Wave Flume	NUIG Large Structures Test Cell	UoP Ocean Basin	UCC_MaREI Ocean Emulator	NUIG Large Structures Test Cell
	UCC_MaREI Deep Ocean Basin	CNR-INSEAN Wave and Towing Tanks	SSPA Maritime Hydrodynamics Laboratory	ORE Catapult HV Lab	UNEXE_Dynamic Marine Component Test Facility
	OCEANIDE_BGO FIRST Basin	OCEANIDE_BGO FIRST Basin	OCEANIDE_BGO FIRST Basin	SINTEF Smart Grid Lab	CTC – Marine Corrosion Test Site 'El Bocal'
	UEDIN FloWave Ocean Basin	UEDIN FloWave Ocean Basin	UEDIN FloWave Ocean Basin		IFREMER Materials Testing Laboratory
	MARIN Offshore Basin	MARIN Offshore Basin	MARIN Offshore Basin		ORE Catapult Marine Facility
	IFREMER Basin of Boulogne-sur-Mer	IFREMER Basin of Boulogne-sur-Mer	CRIACIV Wind Engineering Laboratory		UL MRE_ROV
	IFREMER Brest Deep Wave Tank	CNR-INSEAN Circulating Water Channel	IFREMER Brest Deep Wave Tank		
	UoP Ocean Basin	UoP Ocean Basin	ECN Hydrodynamic and Ocean Engineering Tank (waves & wind)		
	CNR-INSEAN Wave and Towing Tanks	SSPA Maritime Hydrodynamics Laboratory	CNR-INSEAN Wave and Towing Tanks		
	SSPA Maritime Hydrodynamics Laboratory		ORE Catapult 50m Blade Test Facility		
	ECN Hydrodynamic and Ocean Engineering Tank (waves & wind)		DTU Windscanner		

	Cantabria Coastal & Ocean Basin	Cantabria Coastal & Ocean Basin	Cantabria Costal & Ocean Basin		
Medium-scale site	Uppsala University Islandsberg	DMEC Den Oever Inshore Tidal Testing	DTU Windscanner	EMEC PTO Test Rig	EMEC Integrated Monitoring Platform
	BiMEP Mutriku Wave Power Plant	QUB Portaferry Tidal Test Site		BiMEP Mutriku Wave Power Plant	UNEXE FabTest
	EMEC Scale Wave Test Site	EMEC Scale Tidal Test Site			
	QUB Portaferry Wave Test Site				
Large-scale site	PLOCAN Marine Test Site	DMEC Marsdiep Offshore Tidal Testing	PLOCAN Marine Test Site	PLOCAN Marine Test Site	PLOCAN Marine Test Site
	BiMEP – Biscay Marine Energy Platform	EMEC Full Scale Tidal Site	BiMEP – Biscay Marine Energy Platform	BiMEP – Biscay Marine Energy Platform	BiMEP – Biscay Marine Energy Platform
	ECN SEM-REV Sea Test Site		ECN SEM-REV Sea Test Site	ECN SEM-REV Sea Test Site	ECN SEM-REV Sea Test Site
	EMEC Full Scale Wave Site		SmartBay Ireland Galway Bay Test Site	EMEC PTO Test Rig	EMEC Integrated Monitoring Platform
	SmartBay Ireland Galway Bay Test Site		DTU Windscanner	WAVEC PICO Plant	SmartBay Ireland Galway Bay Test Site & Ocean Observatory
					WAVEC PICO Plant

Appendix C

List of European laboratory facilities for ocean engineering

The following list of laboratories is taken from the Eurocean database, available at https://www.eurocean.org/ .

Table 12 List of flume and test laboratories for ocean engineering from Eurocean database

	Name	Subcategory	Country
1	"DMEC Inshore Den Oever Site"	-	Netherlands
2	Aalborg 3D-wave and current basin	Wave and current basin	Denmark
3	AMETS Atlantic Marine Energy Test Site (Full Scale)	Wave testing	Ireland
4	Artelia Wave flume 40 x 1	Flume	France
5	Artelia Wave flume 40 x 1,2	Flume	France
6	AWI hyperbaric pressure tank	Pressure Tank	Germany
7	B600 towing tank	Flume	France
8	BiMEP, Biscay Marine Energy Platform	Wave testing	Spain
9	Blade Test 1	-	United Kingdom
10	Centrale Nantes offshore test site	Offshore wind testing	France
11	CEPYC Large wave channel	Flume	Spain
12	CIEMito Wave flume	Flume	Spain
13	CIEMLAB 2D Wave flume	Flume	Spain
14	CNR-INM Circulating Water Channel	Flume	Italy
15	CNRM-GAME Large multilayer stratified flume	Flume	France
16	COAST Coastal Basin	Wave and current basin	United Kingdom
17	COAST Ocean Wave Basin	Wave and current basin	United Kingdom
18	COAST Sediment Wave Flume	Wave and current flume	United Kingdom
19	COAST Tilting Flume	Wave and current flume	United Kingdom
20	COC (Wave-Current Flume)	Flume	Spain
21	COCOTsu (Wave-Current-Tsunami Flume)	Flume	Spain
22	CORELAB (Laboratory for the non destructive analysis of sediment cores and solid materials)	Test lab	Spain
23	CPV (Channel Variable Slope)	Flume	Spain

24	CRIACIV	-	Italy
25	DanWEC test site	Ocean salinity	Denmark
26	Delta Flume	-	Netherlands
27	Deltares Atlantic Basin	Flume	Netherlands
28	Deltares GeoCentrifuge	-	Netherlands
29	Deltares Rotating Annular Flume	-	Netherlands
30	Deltares Scheldt Flume	Flume	Netherlands
31	Deltares Water & Soil Flume	Flume	Netherlands
32	DTU Large current flume with a carriage	Flume	Denmark
33	Dynamic Marine Component (DMaC) Test Facility	Test rig	United Kingdom
34	EnFlo Stratified Flow Meteorological Wind Tunnel	-	United Kingdom
35	ETSIN Towing / Seakeeping tank	Flume	Spain
36	Galway Large Structures Test Cell	Materials and structures tests	Ireland
37	Genoa Experimental Marine Station (GEMS)	Test lab	Italy
38	Genoa Experimental Marine Station (S)	Natural ageing tests in marine conditions	Italy
39	Grosser Wellenkanal (GWK), Large Wave Flume	Flume	Germany
40	HSVA Arctic Environmental Test Basin	Ice model tank	Germany
41	HSVA Large Ice Model Basin	Ice model tank	Germany
42	HSVA Large towing tank	Flume	Germany
43	ICEA Maritime Facilities - 2D wave flume	Flume	Italy
44	IFREMER 1000 bar ACB hyperbaric tank	Pressure Tank	France
45	IFREMER 1000 bar hyperbaric tank	Pressure Tank	France
46	IFREMER 1000 bar TDI hyperbaric tank	Pressure Tank	France
47	IFREMER 2400 bar hyperbaric tank	Pressure Tank	France
48	IFREMER Circulating water-wave flume	Flume	France
49	IFREMER Materials and Structures Lab	Materials and structures tests	France
50	INSEAN Wave Tank	Flume	Italy
51	IRPHE Wave channel	Flume	France

52	Isitv Wave flume	-	France
53	Islandsberg marine test site	Wave testing	Sweden
54	ISMAR Experimental marine station (SMS)	Natural ageing tests in marine conditions	Italy
55	IWES Offshore test facility - Helgoland	Test lab	Germany
56	IWES Offshore test facility - River Weser	Test lab	Germany
57	IWES Offshore test facility - Sylt	Test lab	Germany
58	IWES Offshore test facility - Willemschaven	Test lab	Germany
59	Kelvin Hydrodynamics Laboratory	Flume	United Kingdom
60	LABIMA - Laboratory of Maritime Engineering	Flume	Italy
61	LEGI Coriolis rotating platform	Rotating platform	France
62	LIC - Laboratorio di Ingegneria Costiera (Coastal Engineering Laboratory)	Ocean salinity	Italy
63	LIC Channel with flood wave generation	Flume	Italy
64	LIC Very large flume	Flume	Italy
65	LIC Wave channel	Flume	Italy
66	Lir-NOTF Deep Ocean Basin	Flume	Ireland
67	Lir-NOTF Wave and Current Flume	Flume	Ireland
68	LNEC Rotating Annular Flume	-	Portugal
69	M2C Wave flume Blue	Flume	France
70	M2C Wave flume Orange	Flume	France
71	Marin Shallow water basin	Wave and current basin	Netherlands
72	Marine Corrosion Test Site El Bocal (MCTS El Bocal)	-	Spain
73	Marine Test Site	-	United Kingdom
74	MARINTEK CWT (Circulation Water Tunnel)	Test section	Norway
75	MARINTEK Marine Structures Laboratory	Materials and structures tests	Norway
76	MISTRAL Floating offshore wind – Fos sur Mer	Offshore wind testing	France
77	Mutriku Wave Power Plant	Wave testing	Spain
78	Narec Large Scale Wave Flume	Flume	United Kingdom
79	National Maritime College of Ireland	-	Ireland
80	NHC Water tank	Water tank	United Kingdom

81	NHC 100 bar chamber	Pressure Tank	United Kingdom
82	NHC 200 bar chamber	Pressure Tank	United Kingdom
83	NHC 220 bar chamber	Pressure Tank	United Kingdom
84	NHC 800 bar chamber	Pressure Tank	United Kingdom
85	Nissum Bredning Test Site	Wave testing	Denmark
86	NOC Immersion tank	Immersion tank	United Kingdom
87	NOC Pressure Test Tank PV1 & PV2	Pressure Tank	United Kingdom
88	Norwegian Smart Grid Laboratory	-	Norway
89	NTUA Deep water wave tank	Flume	Greece
90	NUIG Tidal Basin	Tank	Ireland
91	NUIG Wave Flume	Flume	Ireland
92	OCEANIDE wave flume	Flume	France
93	PLOCAN MARINE TEST SITE	Wave testing	Spain
94	PLOCAN Undewater Vehicles Base Facility (VIMAS)	-	Spain
95	Power take-off test rig	Test rig	Ireland
96	PYTHEAS/IRPHE Large wind-wave channel	Flume	France
97	QUB Portaferry Tidal Test Centre	-	United Kingdom
98	SEENEOH Bordeaux Estuarine tidal energy	Tidal testing	France
99	SINTEF North Sea center Flume tank	Flume	Denmark
100	TECNALIA - Tecnalia Research & Innovation	Test rig	Spain
101	Tecnalia Electrical PTO Lab	-	Spain
102	The Atmosphere	Pressure Tank	Netherlands
103	TTC Offshore site	Tidal testing	Netherlands
104	TTC Sluice gates	Tidal testing	Netherlands
105	TTC Tow tests	Tidal testing	Netherlands
106	Turbine Test rigs	Ocean salinity	Germany
107	UEDIN Curved Wave Tank	Wave testing	United Kingdom
108	UNEXE DMaC (Dynamic Marine Component Test Facility)	-	United Kingdom
109	UNEXE Fab Test (Falmouth Bay marine energy test site)	Wave testing	United Kingdom
110	Univ Coruna Large wave channel	Flume	Spain
111	Univ Valencia Wave channel	Flume	Spain
112	Wave Radar	Ocean salinity	Italy
113	WindScanner.eu	Offshore wind testing	Denmark