Carbon Reduction Potential of Novel Offshore Renewable Energy Technologies

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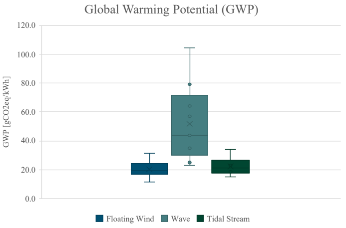
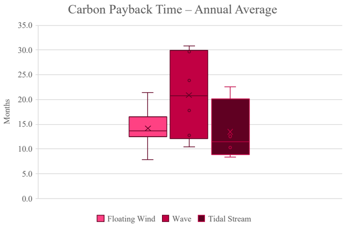
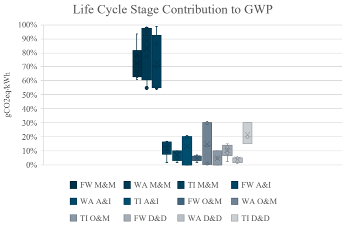
Global Warming Potential and Carbon Payback Time

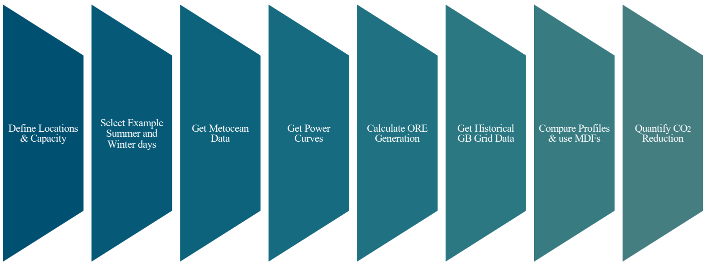
- At the current rate of global warming, **1.5°C of warming will occur around 2040,** with the Paris Agreement resulting in **3-4°C warming by 2100** [1].
- **Decarbonising power, reducing energy use,** and **electrifying energy end-use** are key mitigations in 1.5°C pathways [2].
- **Life Cycle Assessments (LCAs)** assess a system's environmental impacts such as **Global Warming Potential (GWP).**
- GWPs for **novel offshore renewable energy (ORE)** technologies are **higher than other low carbon generation forms** but still decarbonise power: median **Carbon Payback Times (CPTs)** are around **1 to 2 years.**
- My PhD will research **how much CO_2** novel ORE technologies can **displace from the GB grid,** how this **affects CPT**, and what role these technologies have for achieving **Net Zero** by 2050.







Initial Investigation – Hypothetical Future Scenario



Define Locations & Capacity

Select Example Summer and Winter days

Get Metocean Data

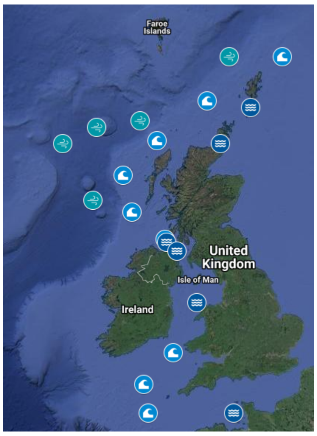
Get Power Curves

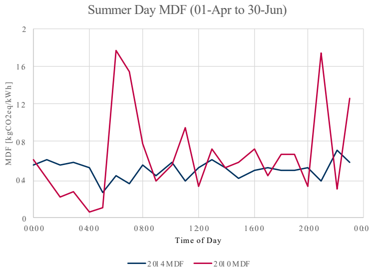
Calculate ORE Generation

Get Historical GB Grid Data

Compare Profiles & use MDFs

Quantify CO_2 Reduction





- **Marginal Displacement Factor (MDF):** empirically determined measure of avoided emissions [$kgCO_2eq$] per unit [kWh] of low carbon electricity generated.

Findings

	2014 MDFs			**2010 MDFs**		
Displacement / kWh [$kgCO_2eq/kWh$]	**Floating Wind**	**Wave**	**Tidal**	**Floating Wind**	**Wave**	**Tidal**
Summer Day	0.51	0.50	0.52	0.62	0.68	0.50
Winter Day	0.47	0.47	0.47	0.57	0.57	0.64
Summer Day	**1.01**	**1.00**	**1.04**	**1.22**	**1.34**	**1.00**
Winter Day	**1.01**	**1.00**	**1.00**	**1.01**	**1.00**	**1.13**

	2014 MDFs			**2010 MDFs**		
Carbon Payback Time [years]	**Floating Wind**	**Wave**	**Tidal**	**Floating Wind**	**Wave**	**Tidal**
Summer Day CPT	0.8	1.6	0.8	0.6	1.2	0.8
Winter Day CPT	0.8	1.7	0.9	0.7	1.4	0.7
Average 'Marginal CPT'	**0.8**	**1.6**	**0.9**	**0.7**	**1.3**	**0.8**
Conventional CPT	**1.1**	**2.2**	**1.2**	**1.1**	**2.2**	**1.2**
CPT Improvement	**28%**	**27%**	**29%**	**41%**	**43%**	**38%**

$$GWP\ [gCO_2eq/kWh] = \frac{Lifetime\ Emissions\ [gCO_2eq]}{Lifetime\ Energy\ Generation\ [kWh]}$$

$$CPT\ [years] = \frac{Lifetime\ Emissions\ [kgCO_2eq]}{Emissions\ Displaced\ per\ Year\ [kgCO_2eq/year]}$$

$$Marginal\ CPT\ [years] = \frac{Technology\ GWP[kgCO_2eq/kWh] * Design\ Life\ [years]}{Daily\ MDF\ [kgCO_2eq/kWh]}$$

Conclusions & Further Work

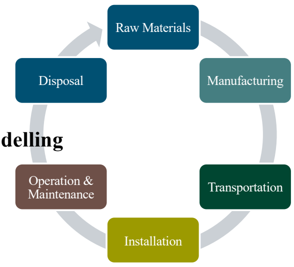
Literature Review

- **Life Cycle Assessment can inform decision making** for novel renewable energy technologies
- Novel ORE technologies have **higher GWP** relative to other low carbon options such as onshore wind, fixed offshore wind and nuclear
- **Materials & Manufacture Stage main contribution** to GWP
- **Carbon Payback Time** is in the order of **1 to 2 years**

- **Initial Investigation – Hypothetical Future Scenario**
  - Empirical data used to **quantify potential displacement**
  - **CPT improves if displacement considered:** largest in high carbon grid
  - **Optimal technology varies:** energy resource, location & demand profile dependent

Further Work

- **Complete LCAs** with **industry input**
- **Develop realistic future scenarios**
- **Optimise site selection**
- Combine MDFs and **energy systems modelling**
- Develop **tools for decision-makers**



Raw Materials

Manufacturing

Transportation

Installation

Operation & Maintenance

Disposal

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[1] Allen, M.R., O.P. Dube, W. Solecki, F. Aragón-Durand, W. Cramer, S. Humphreys, M. Kainuma, J. Kala, N. Mahowald, Y. Mulugetta, R. Perez, M. Wairiu, and K. Zickfeld, 2018: Framing and Context. In: Global Warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

[2] Rogelj, J., D. Shindell, K. Jiang, S. Fifita, P. Forster, V. Ginzburg, C. Handa, H. Kheshgi, S. Kobayashi, E. Kriegler, L. Mundaca, R. Séférian, and M.V. Vilariño, 2018: Mitigation Pathways Compatible with 1.5° C in the Context of Sustainable Development. In: Global Warming of 1.5° C. An IPCC Special Report on the impacts of global warming of 1.5° C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

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A Structured Innovation Tool for the Wave Energy Sector

Introduction

Within the wave energy sector, the continuing lack of design consensus has led to a rethink on the development process. This includes a more structured approached to development and demonstration. In other established sectors, structured innovation approaches are also used in the initial concept creation stage. The analysis of many alternatives helps to avoid narrowing the design focus too early.

The aim of this research was to create a structured innovation tool that can be used to scan the parameter space and identify concepts that warrant further investigation (**Fig 1**).

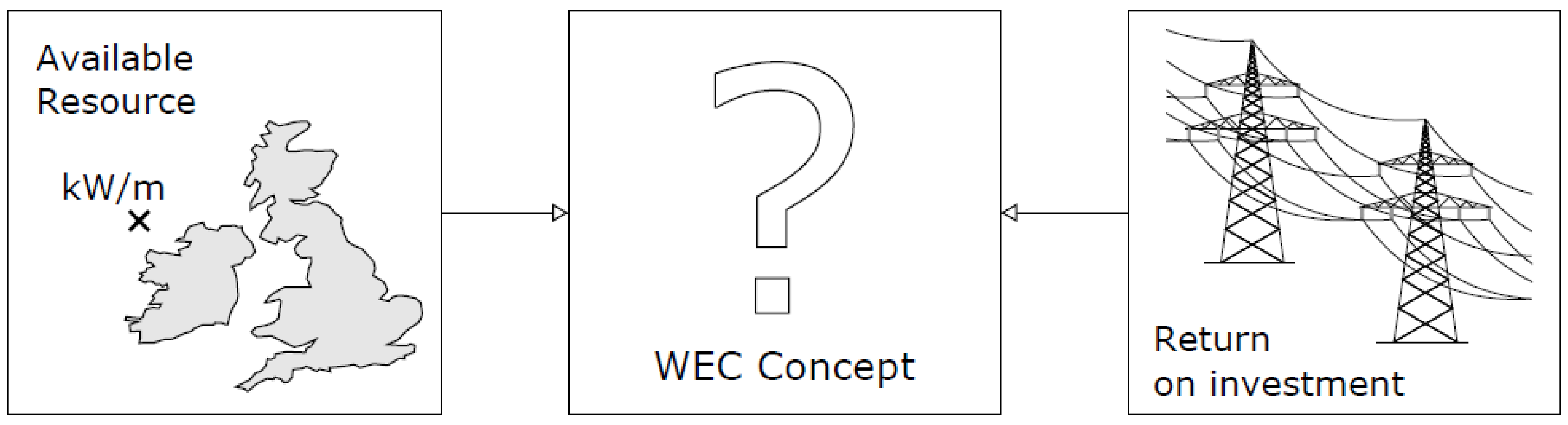


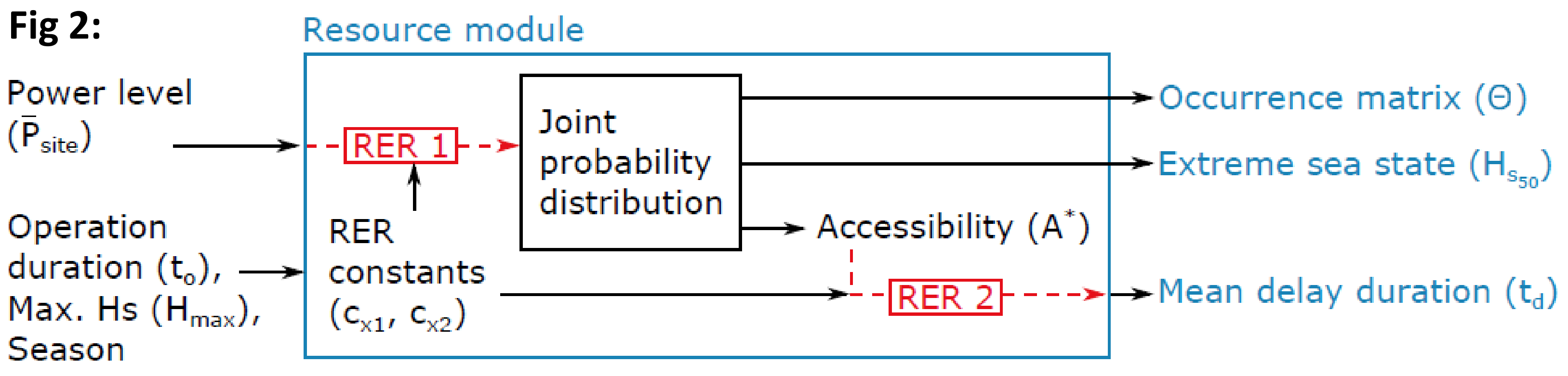
Fig 1: identify concepts for a target return on investment and an available resource.

The main objectives were to create a tool that:

- allows for any possible combination of input parameter values,
- can be used to evaluate a (mostly) continuous parameter space,
- is useable at the earliest stages of development for concept creation.

Resource Module

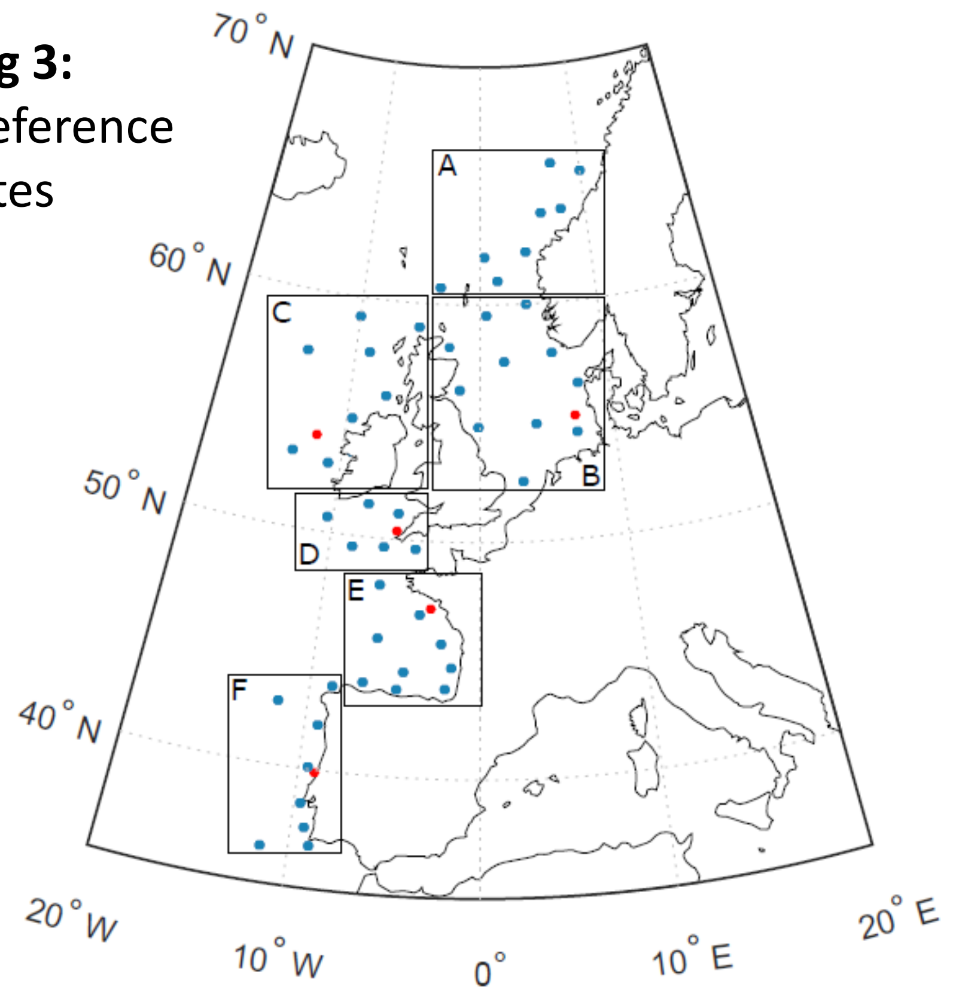
Fig 2:



A resource module was developed to provide resource characteristics that are needed in the evaluation of cost and performance but which are not site specific (**Fig 2**).

Two `Resource Estimating Relationships' (RERs) were found through statistical regression of reference data from a number of European sites (**Fig 3**). These are used to generate resource data that is easily manipulatable for different regions and site power levels (**Fig 4**).

Fig 3: Reference sites



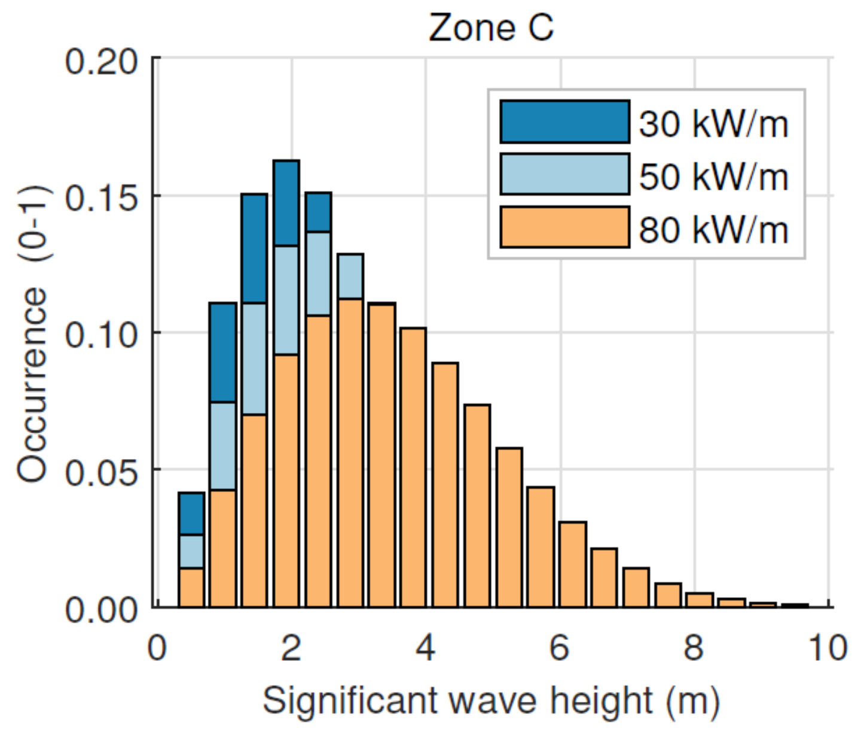
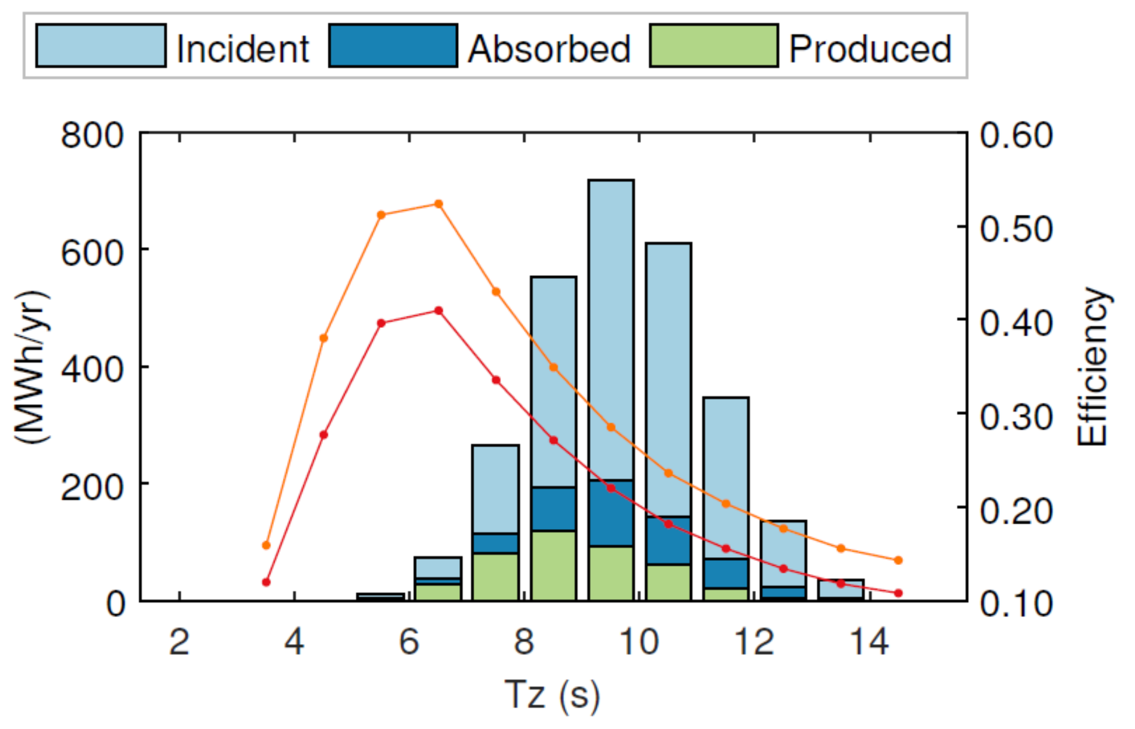


Fig 4: Distribution of wave height for different resource levels (annual average power.)

Cost and Performance Modules

The WEC evaluation is based on scalable parametric expressions that determine the components of cost of energy. First a power matrix is constructed for the available resource and typical profiles of WEC and PTO efficiency (**Fig 5**), then six cost centres are calculated based on the input WEC and deployment parameter values (**Fig 6**).

Fig 5: Power matrix built in stages using archetypal efficiency curves.



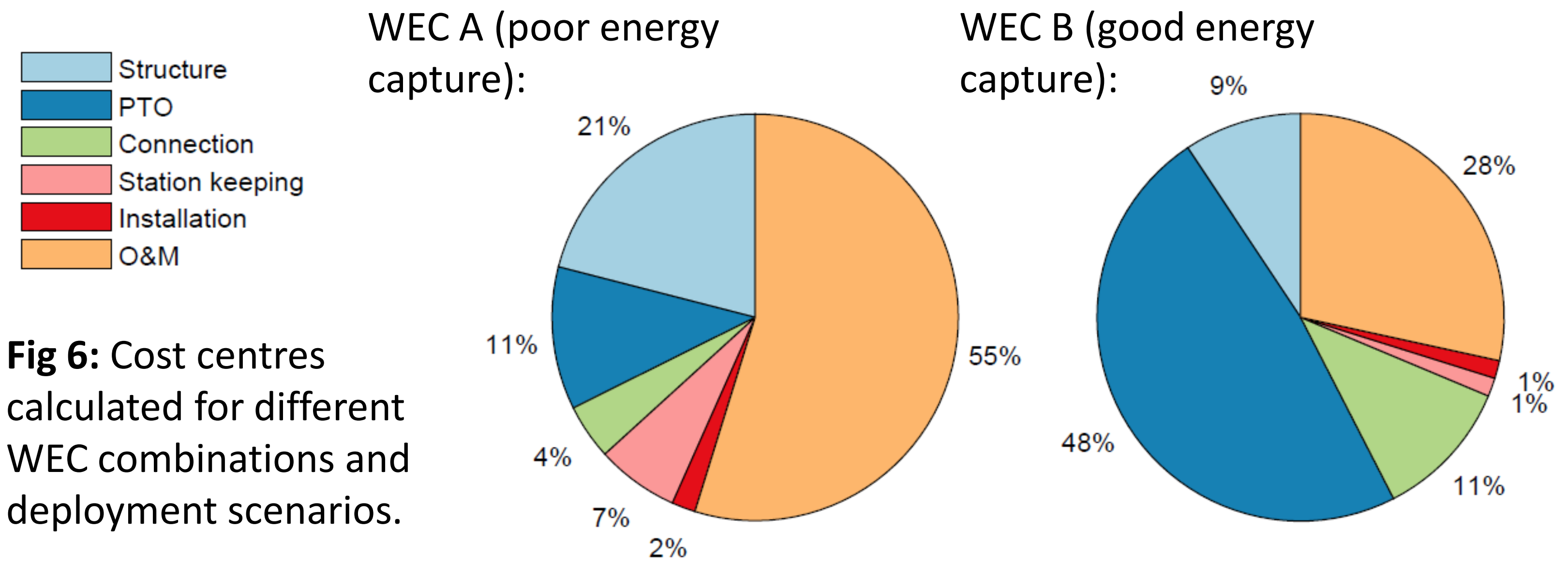


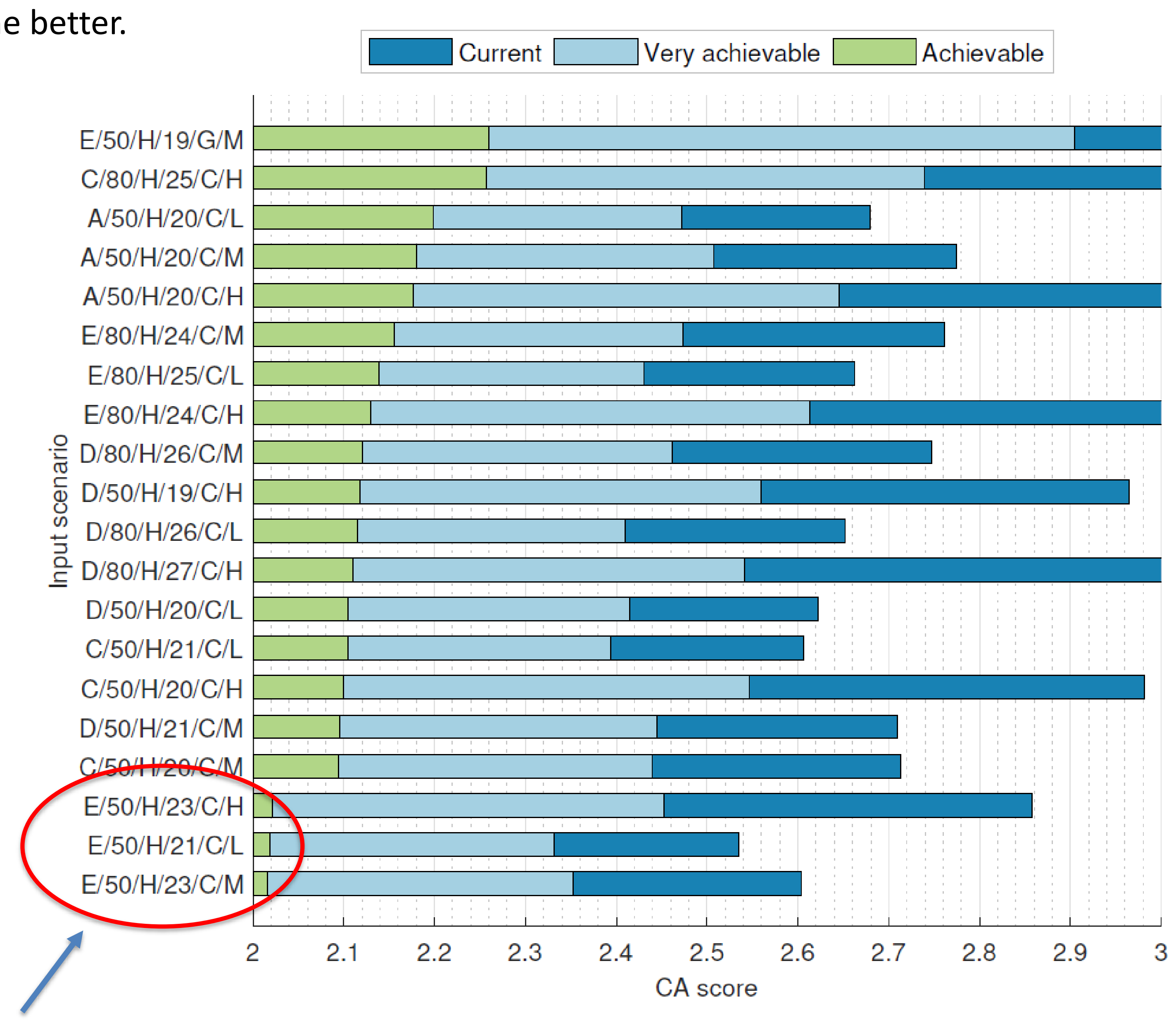
Fig 6: Cost centres calculated for different WEC combinations and deployment scenarios.

Results

The main output of the tool is a ranking of parameter value combinations (**Fig 7**), based on two scores for:

- **Commercial attractiveness score (CA):** the LCoE normalised for a cost-competitive target value.
- **Technical achievability score (TA):** based on technology maturity. Used to determine achievable levels of improvement from baseline values.

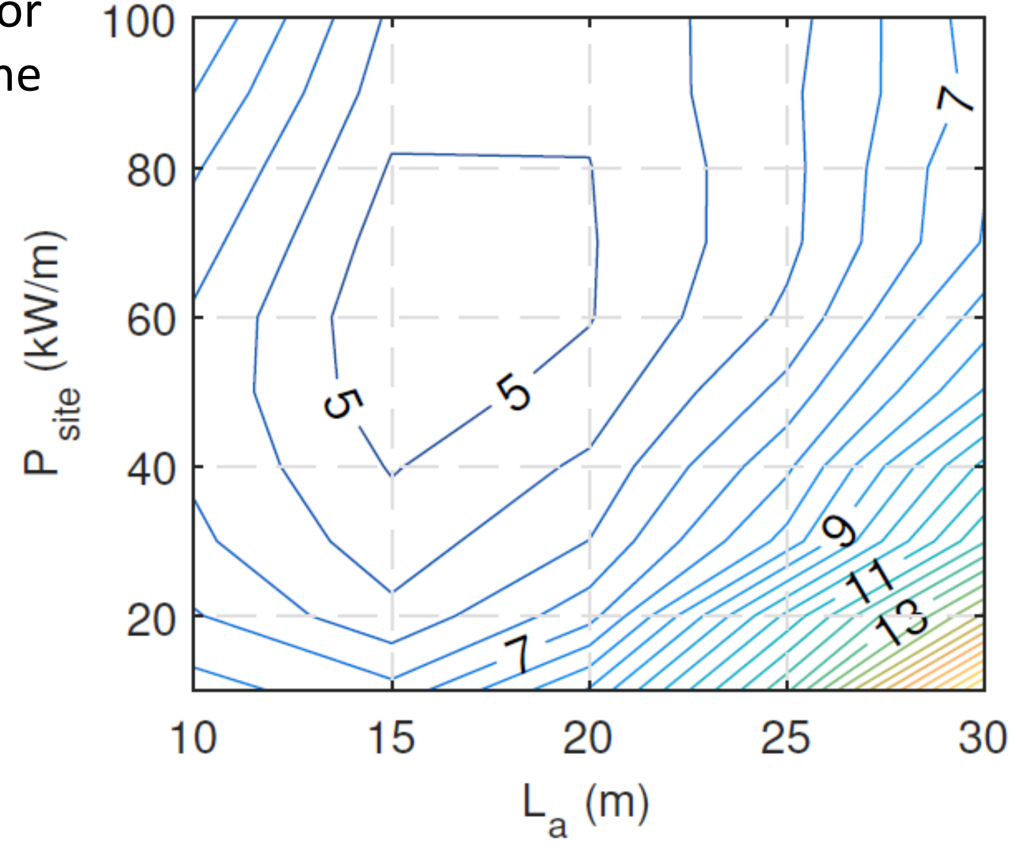
Fig 7: CA scores for a heave-WEC with achievable levels of improvement. The lower the score the better.



Best results: zone E, 50 kW/m site power level, 21-23 m diameter and concrete structure. Poor hydrodynamic performance meant that no one PTO type was obviously better.

The tool can also be used to search for optimums. In **Fig 8** an optimum site power level and scale (active width) is observed for that particular combination of input WEC and deployment parameter values.

Fig 8: CA vs. power level and scale.



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Fourth Annual Conference
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Novel energy conversion technologies for development of the Wave Energy sector

Introduction

This PHD project brings together the fields of technology innovation studies, wave energy converter (WEC) evaluation techniques and novel energy conversion technologies (shown in Figure 1).

These will be used to assess and provide development pathways for the application of new conversion technologies in the wave energy sector.

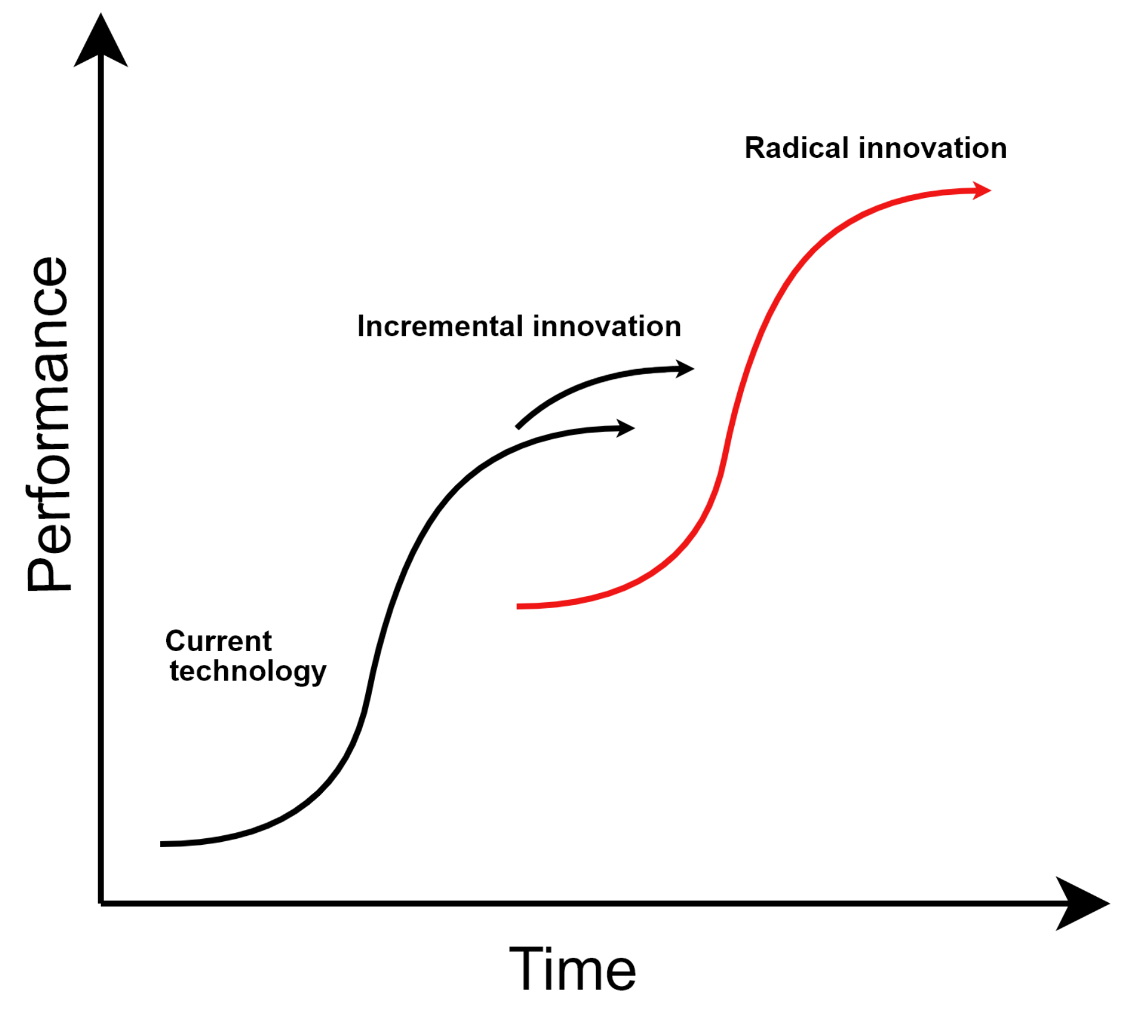

Figure 2 – Incremental and radical innovation pathways

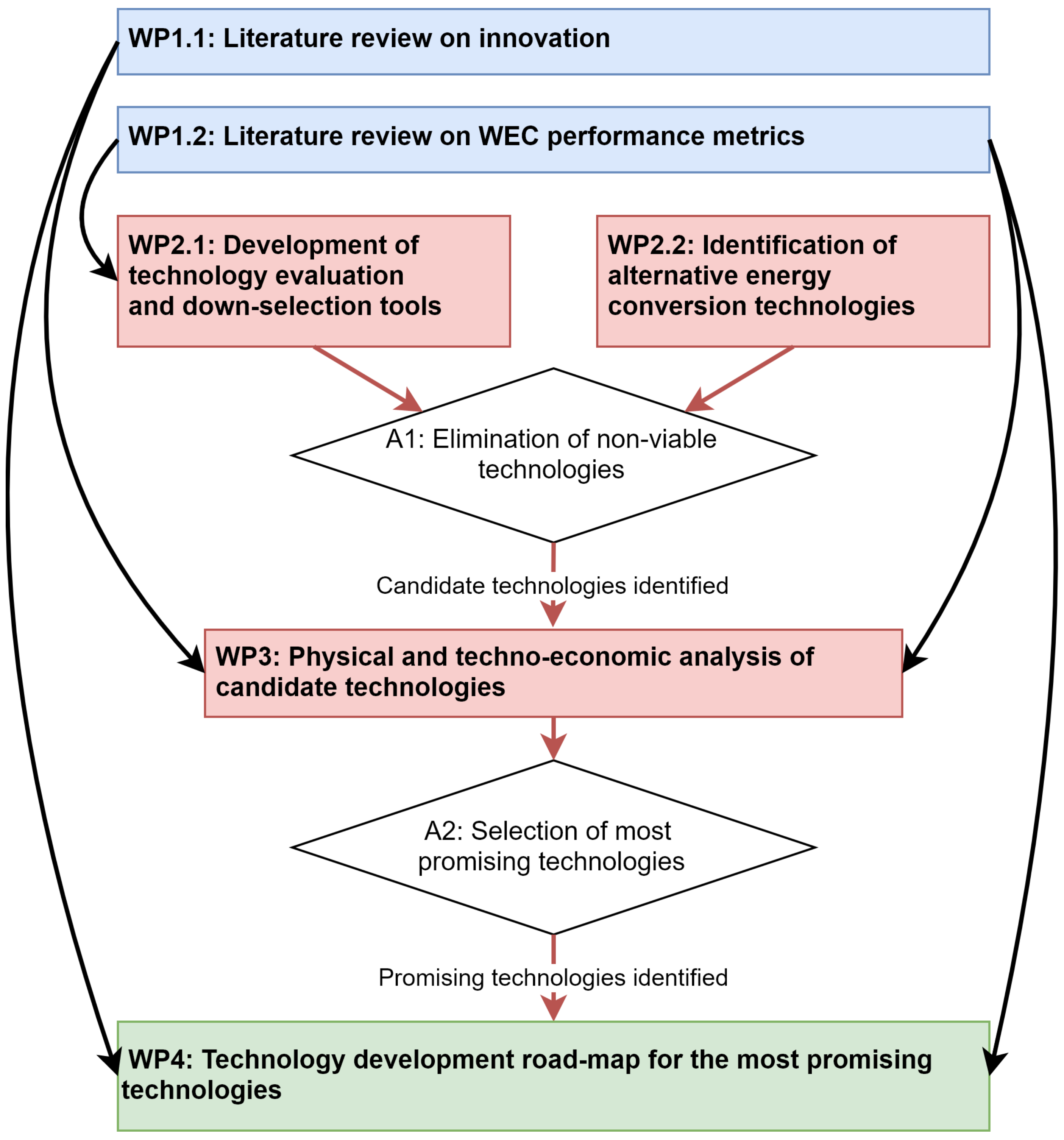

Figure 3 – Project flowchart with key work packages

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1.Weber, J. (2012). WEC Technology Readiness and Performance Matrix – finding the best research technology development trajectory. International Conference on Ocean Energy, ICOE, (OCTOBER 2012), 1--10.

2.Winskel, M., Markusson, N., Jeffrey, H., Candelise, C., Dutton, G., Howarth, P., … Ward, D. (2014). Learning pathways for energy supply technologies: Bridging between innovation studies and learning rates. Technological Forecasting and Social Change, 81(1), 96–114. https://doi.org/10.1016/j.techfore.2012.10.015

3.http://www.emec.org.uk/services/pathway-to-emec/technology-readiness-levels/

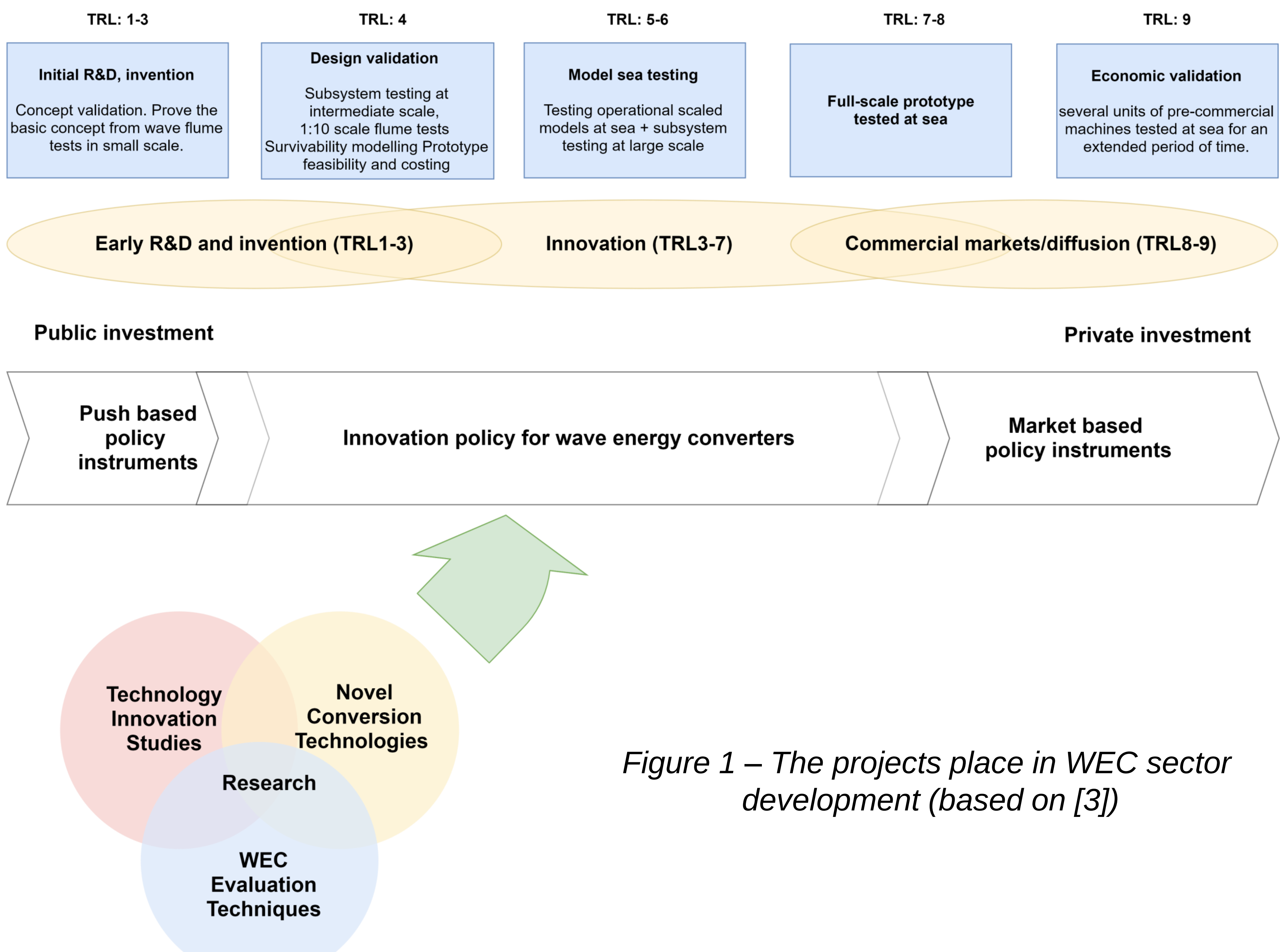

Figure 1 – The projects place in WEC sector development (based on [3])

The project

Technology development in the wave energy sector has broadly followed a high-risk ‘TRL push’ pathway [1] characterized by a small number of high TRL prototypes based on relatively conventional designs and technologies [2], this is yet to result in a commercially viable device. This project aims to identify development pathways (with a focus on radical innovation (Figure 2)) for the wave energy sector by brining together the research elements in Figure 1.

This project will consist of 4 broad work packages shown in the workflow diagram in Figure 3:

1. **Literature review** on (i) innovation dynamics and the tools/studies used to assess technology innovation (ii) the metrics used to assess WEC performance
2. **Down-selection methodology** that assesses and eliminates unsuitable conversion technologies for transfer to the wave energy sector
3. **Physical and techno-economic analysis** of most promising conversion technologies
4. **Technology roadmap** that considers the most promising technologies identified in the down selection process and identifies commercialization development pathways and policy recommendations to achieve these

Next steps:

- Investment analysis for different WEC development pathways
- Further analysis of innovation dynamics under different policy instruments
- Review and design of wave energy converter performance metrics
- Novel conversion technologies identification

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WaveSAX energy device: experiences from the sea tests at Civitavecchia harbour (Italy)

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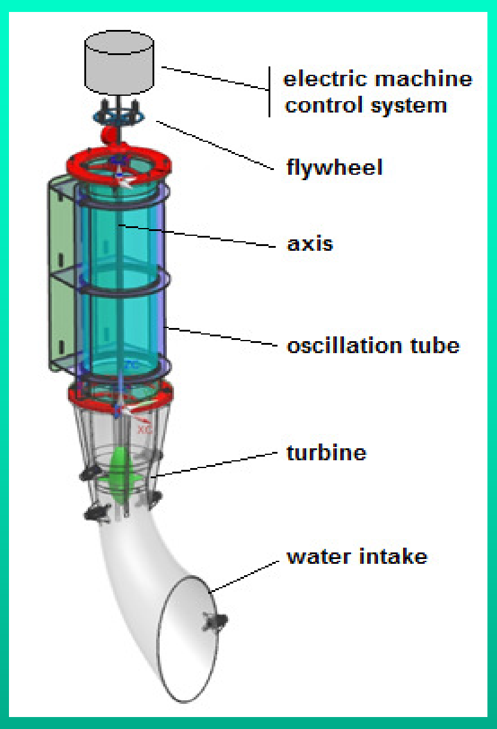
[2] University of Tuscia, Laboratory of Experimental Oceanology and Marine Ecology, DEB (Italy)

1 Aim of the research


WaveSAX (1:5) device



Device sketch

Port of Civitavecchia

The present work outlines the experiences gained from testing the WaveSAX device at the breakwater of the Civitavecchia Port, during October 2018. In particular, it addresses to the electric power generation, the underwater noise emission measurements, the wave energy prediction, the evaluation of materials performance and the results of LCA (Life Cycle Assessment) studies

3 Underwater noise emission measurements

Test 0 ➡ **Device turned off**

Measured noise reflects the background noise of the environment at the device installation point

Test 1 ➡ **Device turned on**

Noise emitted at different turbine speed (rpm)

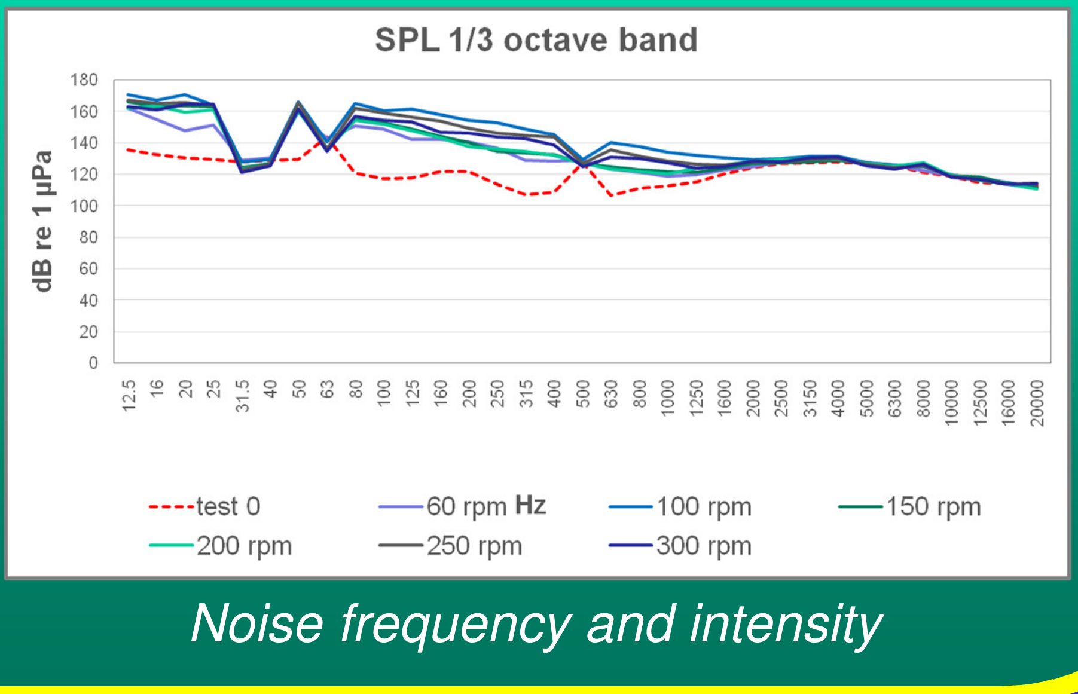
Test 0 showed a quite high natural background noise due to the waves breaking on harbor breakwater

Underwater noise increased significantly with WaveSAX in operation (Mann Whitney test, $p<0.01$) of an average increment of 14 dB re 1μPa

Different turbine speed seems not affecting the noise emission (Mann Whitney test, $p>0.05$)

Further measurements considering additional turbine working conditions will allow to better identify the noise emission impact on marine ecosystems

Acoustic recordings (60s long) were taken using a pre-calibrated omnidirectional hydrophone Teledyne Reson TC4013 (receiving sensitivity, –211dB ± 3dB re 1V/μPa; frequency response, 1Hz to 170kHz),

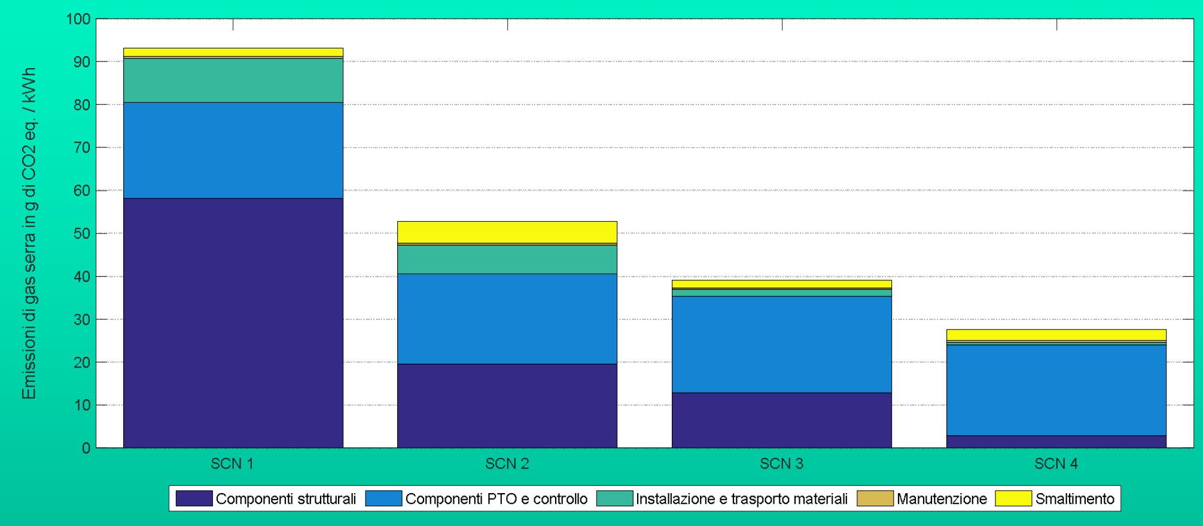


Noise frequency and intensity

5 LCA - Life Cycle Assessment

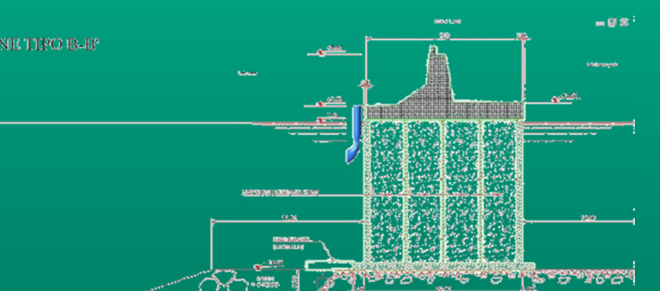
The LCA (Life Cycle Assessment) analysis was conducted to support the choice of materials for the construction of the first WaveSAX (1:1) prototype. The objective of the analysis is the evaluation of different device configurations, both in terms of materials and installation schemes

Emission of equivalent CO2 / kWh



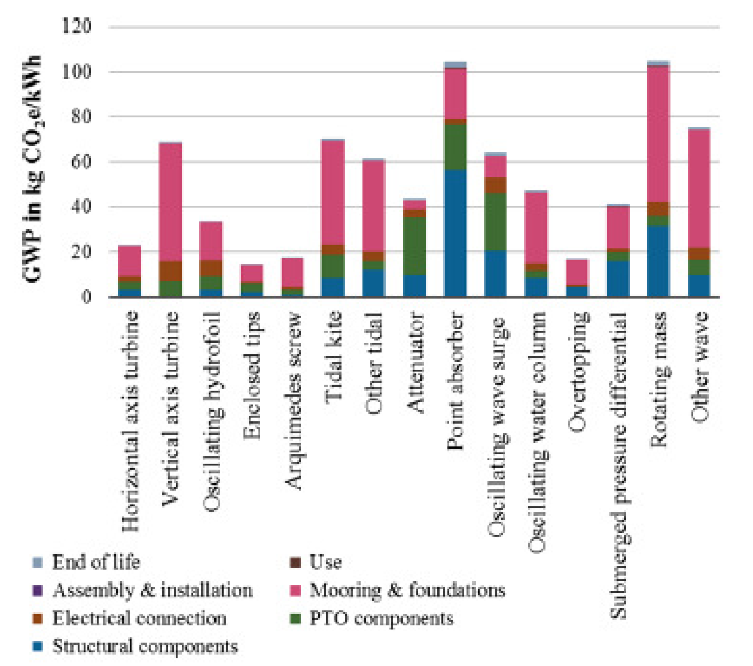
Configurations:
1 – External INOX
2 – External Composite
3 – Incorporated INOX
4 – Incorporated Composite

Installation schemes



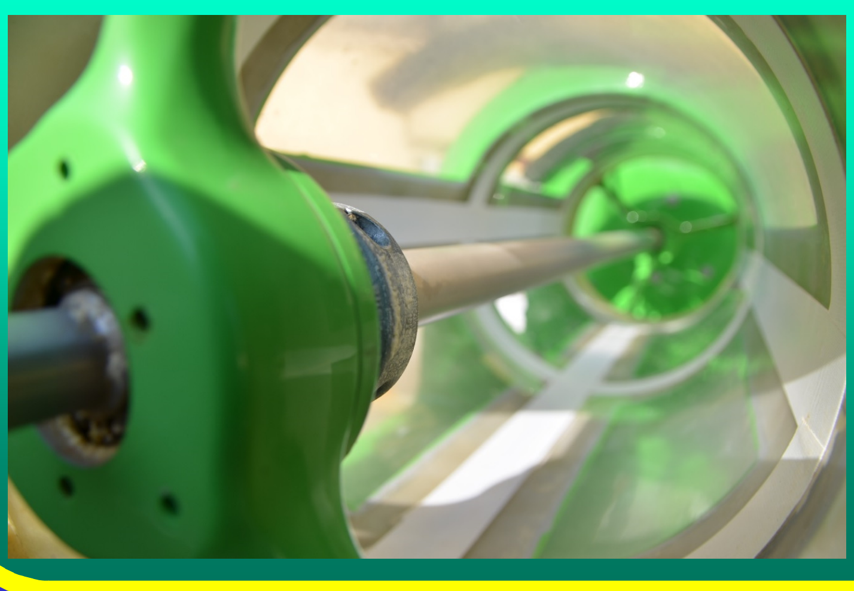
External

Incorporated



Comparison with other ocean energy devices

6 Performance of materials

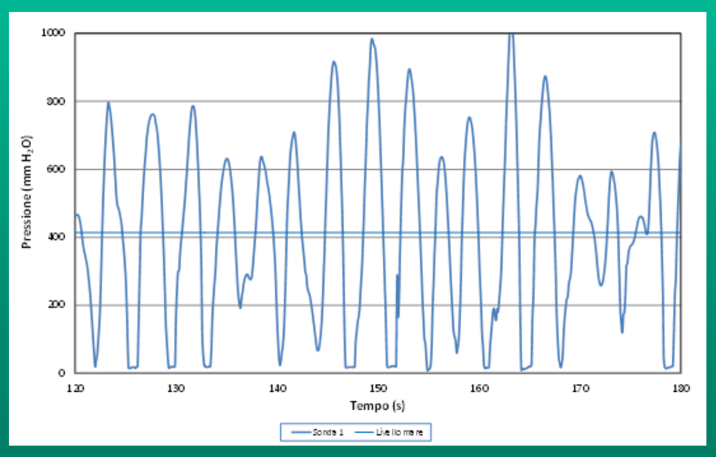


The materials used to construct the WaveSAX (1:5) were chosen assuming a short period permanence in sea water. No antifouling spray has been used. After one month testing in the sea, initial process of fouling in the turbine blades has been detected. On the other side, no damage was seen in metallic parts thanks to zinc anode protection

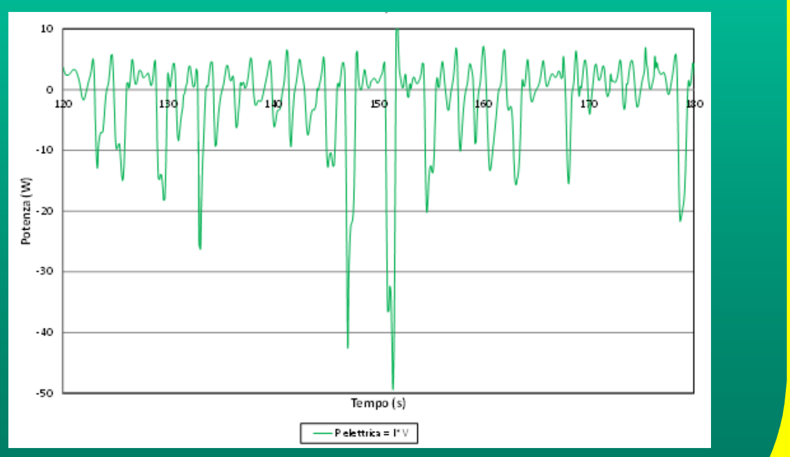

WaveSAX turbine

2 Power generation


View of the WaveSAX (1:5) device during the sea tests



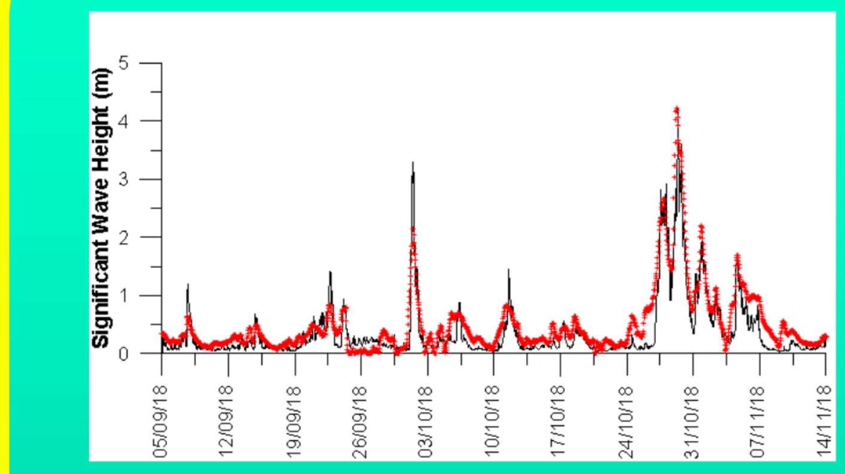
Measured wave height (mm) in front of the device, during a certain sea test period



Measured electric power (W) at the entrance of the battery, during the same test period

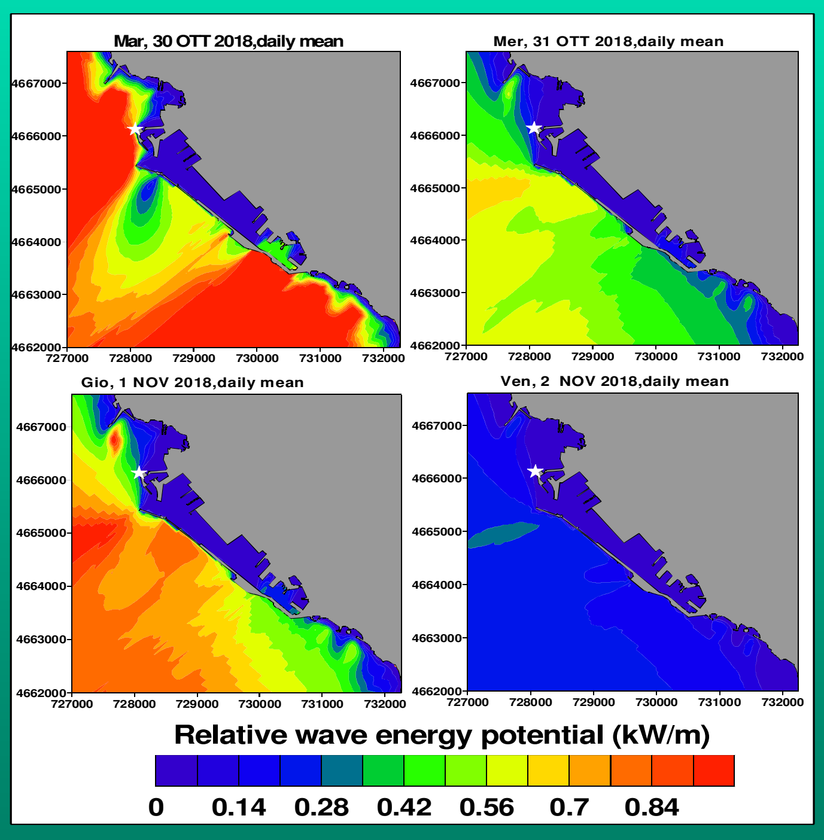
4 Wave energy prediction

Model validation



The comparison between measured (ADP) and computed data highlighted that SWAN model simulates the wave height with high accuracy (R2= 0.8405)

Wave Forecast System results



Within the tests period, the event occurred the 29th October showed the highest value of wave energy potential, particularly in correspondence with the installation point of the WaveSAX device

7 Conclusions

Despite in Italy the wave energy resource is generally lower than in the open seas and oceans, there is a growing interest in the technological development of the sector, facing important challenges and opportunities. In particular, the realization of devices suitable for the Mediterranean waves, taking advantage of coastal infrastructure for the installation. Evaluation of electric power generation at the battery terminals showed a very satisfactory performance of the device working in real sea conditions. Further measurements considering the WaveSAX (1:1) will allow to better identify the noise emission impacts. Characteristics of the construction materials have to be improved in order to minimize device damage, preserving at the same time the marine ecosystems. The installation scheme that considers the WaveSAX incorporated in the coastal structure, and using composite material, showed the minimum impact in terms of equivalent CO2/kWh

Acknowledgements

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development - General Directorate for Electricity Market, Renewable Energy and Energy Efficiency, Nuclear Energy in compliance with the Decree of April 16th, 2018.

WEC.0

Better Wave Energy Converters through Early-stage Performance and Cost Design

Rockall Research Limited
WaveVenture
mocean energy
CORPOWER OCEAN
CENTRALE NANTES

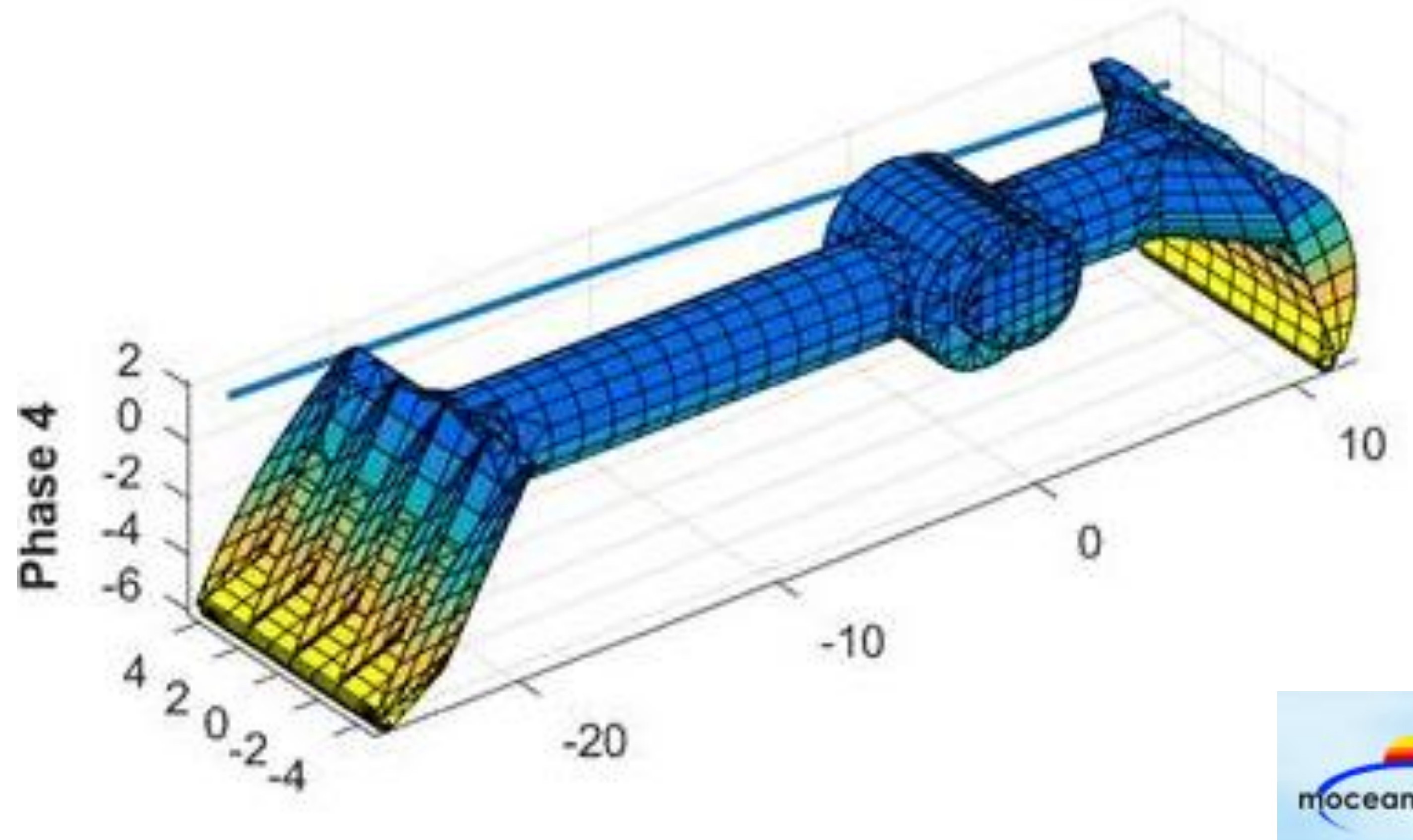
Overview

The WEC.0 project aims to significantly improve WECs and the WEC development process by focusing on fundamental, early-stage performance and cost analyses. Device performance is addressed through the development of an innovative hydrodynamic analysis method that examines the flux of energy from waves to the moving body. Costs are addressed through the development of advanced operational simulations and the evaluation of metrics.

Hydrodynamic analysis

The hydrodynamic related goals are to provide tools that will help to improve or optimise the device by:

- developing methods that provide insight into the fundamental physics and processes of wave energy absorption,
- assisting in the design of the prime mover,
- building upon existing tools rather than competing with them.



The approach to the hydrodynamic problem is to map the flow of power, or energy flux, through the hull surface of a WEC, which will reveal the portions of the hull which absorb power and to what degree. This will also identify portions of the hull that experience force but do not absorb power.

Cost Analysis

Current state-of-the-art cost modelling integrates engineering and logistics simulation with economic analysis. However, reliable early-stage cost assessments and operational simulations are under-developed and step change improvements are needed in these areas.

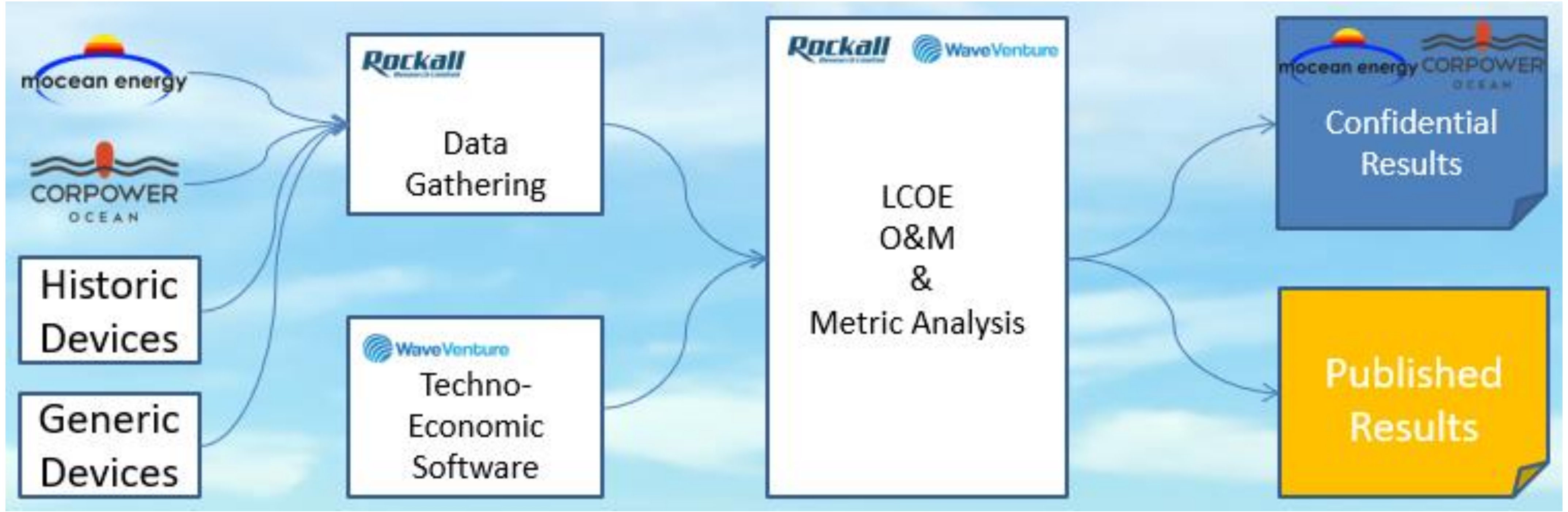
The cost focused goals are to:

- improve upon the state-of-the-art techno-economic model with respect to simulation of marine operations and estimation of installation, removal and operational costs (OPEX),
- investigate a variety of early-stage cost indicators such as mass, surface area, point loads, pressure loads and system design,
- evaluate the correlation of selected cost indicators to more detailed cost estimates provided by historical data and a techno-economic model.

Get involved

We are very interested in working with developers, funding bodies, component suppliers or other stakeholders in the wave energy industry to ensure we produce the most accurate and relevant models.

For more information visit http://wec0.eu or email wecpointoh@gmail.com



Historic Devices

Generic Devices

Data Gathering

Techno-Economic Software

LCOE
O&M
&
Metric Analysis

Confidential Results

Published Results

Scottish Enterprise
Swedish Energy Agency
seai SUSTAINABLE ENERGY AUTHORITY OF IRELAND
Région BRETAGNE
OCEAN ERA-NET