Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment

Deliverable D8.4

Developing Ocean Energy standards for Business management models in Ocean Energy

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EXECUTIVE SUMMARY

This report is the outcome of Task 8.4 "Specific sector standards for business management models for the ocean energy sector", of the DTOceanPlus project. The task aims to define alternative business models for the ocean energy sector by developing a greater understanding of the **ocean energy sector's business models and recommending development routes to industrial roll-out** to improving the ocean energy sector's market opportunity**.**

The oceans represent the world's largest potential for renewable energy, with Europe at the forefront of ocean energy development, with wave and tidal energy representing the two most advanced technologies in the sector. Yet, tidal stream technologies are still at a pre-commercial stage and wave energy technologies, still at demonstration level. Thus, notwithstanding the significant progress of the sector in recent years, particularly in tidal stream, these technologies require further research, development, and innovation (RD&I) efforts to advance demonstration projects and partake in grid power's highly competitive markets. In addition, the high-up front costs and the embryonic stage of some ocean energy technologies make their development challenging.

Ocean energy in the present day has similar characteristics to the wind and solar sector of previous decades; as a developing technology, the LCOE is not cost-competitive with other alternatives for grid generation, making ocean energy a minority concern in the overall current generation mix. However, lessons can be learned from these sectors' trajectory to date, which has seen these technologies become cost-competitive and revolutionise many countries' generation mix.

The pathway to successful deployment required revenue support to bridge the initial gap to market; with costs falling through learning by doing, innovation, and economies of scale, the market matures. Thus, market-led revenue support is key; however, targeted R&D support is required to assist with the journey from concept to commercialisation. Therefore, this work highlights **the need for alternative ocean energy applications as a good entry point into the market** and to undergo product development whilst generating revenue. This could allow for additional RD&I funds to be developed by initiating small-scale projects, thereby placing ocean energy in a better position to power the main grid when the need arises. In addition, synergies exist with other offshore sectors for ocean energy to provide localised power.

The task aimed to build on Task 8.3 and define a scenario for industrial roll-out analysis. Standard approaches to business models were developed by combining the value of the DTOceanPlus suite of tools with a deep knowledge of the potential markets that ocean energy technology can be applied to and the supply chain in place to exploit the opportunities. The report demonstrates how various stakeholders' application of the design tools can support the sustainable impact of potential markets upon the sector and its commercialisation prospects by developing alternative business models. The alternative business model approaches include pricing methods that can support business, funding and support cases.

Potential scenarios for industrial roll-out are presented, with a focus on four of the most detailed alternative markets identified within Deliverable D8.1, namely: isolated power systems (islands or microgrids), offshore oil and gas, offshore aquaculture, desalination & coastal resiliency. Business modelling canvasses were developed for each potential alternative market to create a more robust business proposition and identify barriers to market access that ocean technology developers can address. However, following stakeholder engagements and market testing, there was recognition of similarities that cut across various potential markets and that standard business models may need to be applied across these distinct market sections. Therefore, the approach taken was to **categorise these alternative markets into common themes that provide a clearer sense of progression for ocean generation technologies and insight into the shared technical considerations**. These markets were reframed to consider business propositions for **partial power supply for the whole system**, **primary power supply for subsystems**, and supply applicable to regions with limited power options for **resiliency markets for remote communities**. Therefore, common themes and potential routes to market that arose from these were balancing requirements with **hybrid systems**, **multipurpose solutions**, and **unique solutions for wave and tidal**.

The alternative markets explored within this report may act as supply chain accelerators for ocean energy if collaborative projects are undertaken within these areas. Aquaculture and offshore platforms have already been identified as contenders for these activities within deliverable 8.2, primarily because of their offshore location. Any identified collaborative areas could be worked into project proposals as an added benefit. The geographical spread of the markets was reviewed within this report, identifying potentially viable markets within Europe (aquaculture, oil and gas) and more prevalent ones elsewhere in the world (microgrids, desalination). This creates a discrepancy with manufacturing and component supplier location, which necessarily needs to be local (e.g., Europe-based). These alternative markets could provide an entry point to export markets.

When looking to access alternative markets and assess the suitability of business models, ocean energy developers could consider non-traditional procurement models to overcome potential barriers such as access to capital investment, technical and operational responsibilities. These procurement models, detailed in Section 0, could alleviate concerns and open up markets that may otherwise have been unwilling to change from standard diesel-based solutions.

The work also presents **a series of potential market blockers identified** that contribute to tidal and wave energy unable to access either mainstream grid or alternative markets; some **recommendations to help alleviate some of these blockers** are outlined in section 5.3.

The open-source design tools developed in the DTOceanPlus project can contribute to the development of the ocean energy sector. The Structured Innovation design tool can assist with facilitating ways to identify and overcome blockers; the Stage Gate tool can then be used to assess and guide the technology development; followed by the Deployment and Assessment tools to design optimised arrays, facilitating a wide-scale deployment of ocean energy technologies to generate electricity for these markets.

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ABBREVIATIONS AND ACRONYMS

CAPEX	Capital expenditure
CF	Capacity Factor
CfD	Contracts for Difference
DG-MARE	(European Commission) Directorate-General for Maritime Affairs and Fisheries
DOE	(United States) Department of Energy
EMEC	European Marine Energy Centre
FIT	Feed-in-Tariff
GC	Green certificates
GHG	greenhouse Gas
HATT	Horizontal Axis Tidal Turbines
IEA	International Energy Agency
JRC	(European Commission) Joint Research Council
LCEO	Low Carbon Energy Observatory
LCOE	Levelised Cost of Electricity
O&G	Oil and Gas
OECD	Organisation for Economic Co-operation and Development with 36 member countries
OES	Ocean Energy Systems
OPDS	Ocean Powered Desalination Systems
OWC	Oscillating Water Column (WEC type)
OWSC	Oscillating Wave Surge Converter (WEC type)
PA	Point Absorber (WEC type)
PESTLE	Political, Economic, Social, Technological, Legal and Environmental (factors)
PPA	Power Purchase Agreement
R&D	Research and Development
RD&I	Research, Development and Innovation
RE	Renewable energy
REC	Renewable Energy Certificates
RPS	Renewable Portfolio Standard
RTS	Reference Technology Scenario (IEA future climate scenario)
SDS	Sustainable Development Scenario (IEA future climate scenario)
SIDS	Small Islands and Developing States
SP	Strike Price
SPD	Submerged Pressure Differential (WEC type)
TAM	Total Addressable Market
TEC	Tidal Energy Converter
TPES	Total Primary Energy Supply
TRL	Technology Readiness Level
UNHRC	United Nations Human Rights Council
WEC	Wave Energy Converter

DEFINITION OF TERMS

Alternative Markets	Where the largest opportunity for ocean energy technologies is grid power, potential alternative markets have been defined based on the US DoE 'Powering the Blue Economy' study and Deliverable D8.1, as 'steppingstone' markets to reduce costs to a level where ocean energy technologies can be cost-competitive and provide grid power, or support the establishment of smart local energy systems by enabling synergies between the potential markets identified.
Capacity factor	It is the ratio of actual electrical output over a given period of time to the maximum possible electrical output over that period. It is defined for any electricity producing installation and may vary depending on reliability issues and maintenance, design of the installation, location, local weather conditions.
Electricity generation	It refers to the process of producing electricity from sources of primary energy in power stations. The actual output is reported in energy units (e.g., kilowatt-hour) and will depend on the installation's capacity factor (CF). Assuming a fairly typical renewable energy generation CF of 35%, 1GW of installed capacity would generate around 3TWh/yr
Final energy	Energy carriers produced by conversion from a primary energy source. Some examples include electricity, fuel oil, and diesel.
Flexibility	A power system's capacity to cope with the intermittency and uncertainty of renewable energy such as solar and wind energy is introduced at different time scales without curtailment of power from these sources and reliably supplying all customer energy demand.
Installed capacity	Also known as nameplate capacity, rated capacity, or nominal capacity. It refers to the maximum output of a facility such as a power plant, a mine, or an electric generator, maintained for a reasonable amount of time and under ideal conditions. It is usually reported in units of power (e.g., watt). Actual output can be different from the installed capacity for several reasons, depending on the equipment and circumstances.
Marine energy technologies	These technologies harvest energy from the oceans and include the ocean mentioned above energy technologies and offshore wind. Therefore, the term is used interchangeably with the term "marine renewable energy technologies."
Marine renewable energy technologies	See "marine energy technologies". These terms are used interchangeably in this report.

Ocean energy technologies	Ocean energy technologies use tides, waves, and currents to produce electricity. These technologies include wave energy, tidal energy (both range and stream), salient gradient energy, and ocean thermal energy conversion.
Primary energy	Energy not subjected to any transformation or conversion processes. It is contained in raw fuels and can be classified into non-renewable and renewable. The former include oil and coal, among others, while the latter include solar, wind, and tidal.
Total Final Consumption	Global consumption of energy by end-users such as households, industry, and agriculture. It refers solely to the energy that reaches the consumer's door and does not include the energy sector's energy.
Total Primary Energy Supply	Sum of energy production and imports minus export and international bunkers, plus or minus stock changes.
Uncertainty	Lack of predictability of the future electricity output of variable renewable energy.
Variability	Intermittent and fluctuating nature of solar and wind resources leading to swift changes in electricity output.

1. INTRODUCTION

The oceans represent the world's largest potential for renewable energy. The main ocean energy forms are waves, tides, marine currents, salinity gradient and temperature gradients. Ocean Energy Europe estimated the global tidal energy resource at 1,200TWh/year, wave energy at 29,500TWh/year, having the potential to play a significant role in balancing European's electricity grid whilst contributing to reducing greenhouse gas emissions and stimulating economic growth [1].

Europe is currently at the forefront of ocean energy development, with wave and tidal energy representing the two most advanced technologies in the sector. The cumulative tidal stream and wave projects in the pipeline account for nearly 3 GW (excluding tidal range technology), with the potential to reach 10 GW of installed capacity by 2030 [1] [2].

Tidal stream technologies are still at a pre-commercial stage with 10.6 MW installed capacity globally. Tidal stream farms are being deployed at a utility scale and have proven to deliver reliable grid power. Expansion beyond the pre-commercial stage requires increased deployment, cost reduction, scale-up production, and market support.

Wave energy technologies, at demonstration level, have an installed capacity of 2.31 MW in Europe since 2010. Cumulative capacity has been increasing steadily, as the technology advance, and devices survive longer in the water. However, wave energy has not seen a convergence towards standardised designs, as with other technologies such as wind energy. As a result, these technologies require further research, development, and innovation (RD&I) efforts to advance demonstration projects and partake in grid power's highly competitive markets. In addition, the high-up front costs and the embryonic stage of some ocean energy technologies make their development challenging.

Notwithstanding this, wave and tidal stream technologies have shown significant performance and reliability improvements. Coupled with significant resource potential and valuable features such as higher predictability than wind and solar, low to no land requirements, and more uniform energy output, wave and tidal stream energy have become attractive alternatives for the global energy transition. There is an additional advantage to incorporating wave and tidal technologies to balance net-zero grids with high renewables penetrations. These technologies result in different generation profiles to solar and wind, and this complementary electricity production will benefit wider grids in balancing supply and demand more effectively.

The sector has made significant progress in recent years, particularly in a tidal stream, which has delivered two operational in-sea tidal arrays and over 50 GWh of electricity exported to the grid. This success is the fruit of decades of efforts from the industry, governments, and RD&I. However, ocean energy remains a nascent industry, struggling to reach commercialisation. However, it should be noted that ocean energy technologies are moving beyond the early stages of development, with tidal stream reaching maturity with the successful in-sea operation and wave energy at demonstration stages.

Based on the Levelised Cost of Energy (LCOE), the economics of ocean energy technologies currently cannot compete with other renewable energy technologies such as offshore wind. The high upfront costs and the emergent stage of some ocean energy technologies make their development challenging [2] [3]. Nevertheless, wave and tidal stream technologies benefit from significant resource potential and valuable features such as higher predictability than wind and solar, minimal land requirements, flexibility in deployment, and more uniform energy output. From the more mature energy technologies, e.g. wind, it is clear that the same pathway to successful deployment required revenue support to bridge the initial gap to market, with costs falling through learning by doing, innovation, and economies of scale, the market matures. Market-led revenue support is key; however, targeted RD&I support is required to assist with the journey from concept to commercialisation.

1.1. THE CASE FOR ALTERNATIVE MARKETS

Ocean energy in the present day has similar characteristics to the wind and solar energy of previous decades; as a developing technology, the LCOE is not cost-competitive with other alternatives for grid generation, making ocean energy a minority concern in the overall current generation mix. However, lessons can be learned from the trajectory of solar and wind power to the present day, which has seen these technologies become cost-competitive [4] [5] and therefore revolutionise the generation mix of many countries, allowing a significant reduction in reliance on heavily polluting fossil fuels [6].

Solar and wind energy received proof-of-concept testing in alternative markets to mainstream grid power. Solar power was used extensively on satellites, starting with the Vanguard 1 satellite [7]. The remote location of the energy demands and the higher intensity of solar light in space created a unique advantage for solar power in this application. The drive to create more efficient panels, reduce operational weight, and enable more processes powered by solar energy created a necessity to direct R&D funding towards improving the technology.

Similarly, wind energy was initially conceived to provide power to small remote farms (particularly in the United States), which were not connected to the electricity distribution network [8]. This initiative took advantage of existing windmills to create electricity in hard-to-access areas of the country. Eventually, this type of generation was rendered redundant by the rural electrification programmes of the 1930s, falling under the New Deal's attempt to alleviate significant unemployment rates.

At a later date, wind turbine installations accelerated (particularly in the United States) due to the 1973 oil crisis, beginning with the installation of thousands of wind turbines in California. This was enabled by federal and state policies, which encouraged renewable energy sources to reduce reliance on imported fuels.

Therefore, while wind turbine development was accelerated by necessity and policy intervention, the proof-of-concept was developed earlier through "micro-grid" style applications serving the agriculture sector. This previous development work, along with R&D about turbine components across other industries, put wind power in a position to answer the problems posed by the oil crisis.

A further example which is relevant to the present-day grid is the lithium-ion battery. With very low renewable content on the grid in previous decades, the only significant storage contribution was large-scale pumped hydro. Lithium-ion batteries were developed initially to power portable electronic devices, such as mobile phones. However, they have now reached a level of maturity to provide large-scale grid services, including frequency response and reserve capacity. This was motivated by the increasing renewables content, which requires greater levels of grid balancing. In addition, the emergence of electric vehicles will further drive the development of this technology into the mainstream transport market.

Therefore, alternative ocean energy applications could provide a good entry point into the market and undergo product development whilst generating revenue. Furthermore, this could allow for additional RD&I funds to be developed by initiating small-scale projects, thereby placing ocean energy in a better position to power the main grid when the need arises. In addition, synergies exist with other offshore sectors for ocean energy to provide localised power.

1.2. AIM AND OBJECTIVES

There has been a resurgence of interest in these ocean energy technologies given the highly ambitious climate-related targets set by different governments worldwide, reflected in more R&D funding available from public agencies to ocean energy projects. One of these projects is DTOceanPlus, which seeks to accelerate the development of the ocean energy sector by developing and demonstrating advanced design tools for selecting, developing, and deploying ocean energy systems, thereby aiding the understanding and identification of future opportunities.

The main objective of WP8 is to combine the wealth of knowledge gained during the project (research and marketplace reports) along with the data and information gathered from demonstrating the DTOceanPlus suite of tools against real-life demonstration scenarios to envisage the future applications of ocean energy.

This report is the outcome of Task 8.4 "Developing specific sector standards for business management models for the ocean energy sector", of the DTOceanPlus project. This task's objective is to develop a greater understanding of the **ocean energy sector's business models.** The focus includes the current business modelling approach and future approaches to improving the ocean energy sector's market opportunity. The standards will also demonstrate the model for applying the tools by other stakeholders to support their sustainable impact upon the sector and its commercialisation prospects by developing new business cases. The new standard approaches will include pricing methods that can support business, funding, and support cases. The report primarily concentrates on the technologies considered within the DTOceanPlus software, namely wave and tidal stream.

1.3. REPORT OUTLINE

This report is structured into seven main sections as described below:

- **Section 2** introduces the **business modelling methodology** and outlines the process of **market validation.** This section presents the methodology for selecting and ranking the most viable combinations of elements of the canvas in a staged approach, detailing elements to consider when describing a sector such as value proposition, infrastructure, customers segments, and revenue streams. A summary of how relevant markets were chosen is presented, along with the process by which business model options were designed and the stakeholder engagement activities involved.

- **Section 3** outlines **potential markets that ocean energy can couple to, leveraging** ocean energy project synergies to become more viable and reduce costs. These alternative markets are seen as a steppingstone for the larger scale grid-connected market.

- **Section 4** presents the innovative **business model canvasses** of the proposed markets. These have been tested through both desk-based research and stakeholder engagements.

- **Section 5** provides a discussion of the **business model canvasses**. This section identifies common themes that have emerged from these markets, barriers that are currently preventing market access and recommendations for future work to narrow the existing gap in the route to developing these new business models. The section also includes supply chain considerations and the potential for innovative purchasing options which could enable greater market access.

- **Section 6** summarises the benefits of the **DTOceanPlus tools** to the sector, and a case study is also presented illustrating the benefits of using the DTOceanPlus tools to assess alternative market applications.

- **Section 7** provides overall conclusions and perspectives, followed by references and annex tables.

1.4. THE DTOCEANPLUS TOOLS

DTOceanPlus will 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).
At a high level, the suite of tools developed in DTOceanPlus will include:

- **Structured Innovation tool (SI)**, for concept creation, selection, and design.
- **Stage Gate tool (SG)**, using metrics to measure, assess and guide technology development.

- **Deployment tools,** supporting optimal device and array deployment:
  - *Site Characterisation (SC):* to characterise the site, including metocean, geotechnical, and environmental conditions.
  - *Machine Characterisation (MC):* to characterise the prime mover.
  - *Energy Capture (EC):* to characterise the device at an array level.
  - *Energy Transformation (ET):* to design PTO and control solutions
  - *Energy Delivery (ED):* to design electrical and grid connection solutions.
  - *Station Keeping (SK):* to design moorings and foundations solutions.

- *Logistics and Marine Operations (LMO):* to design logistical solutions operation plans related to the installation, operation, maintenance, and decommissioning operations.

- **Assessment tools**, to evaluate projects in terms of key parameters:
  - *System Performance and Energy Yield (SPEY):* to evaluate projects in terms of energy performance.
  - *System Lifetime Costs (SLC):* to evaluate projects from the economic perspective.
  - *System Reliability, Availability, Maintainability, Survivability (RAMS):* to evaluate the reliability aspects of a marine renewable energy project.
  - *Environmental and Social Acceptance (ESA):* to evaluate the environmental and social impacts of a given wave and tidal energy projects.

Underlying common digital models and a global database will support these tools, as shown graphically in FIGURE 1.1.

- The benefits of using the DTOceanPlus tools to assess alternative market applications in commercialising the ocean energy sector are discussed further in section 6.

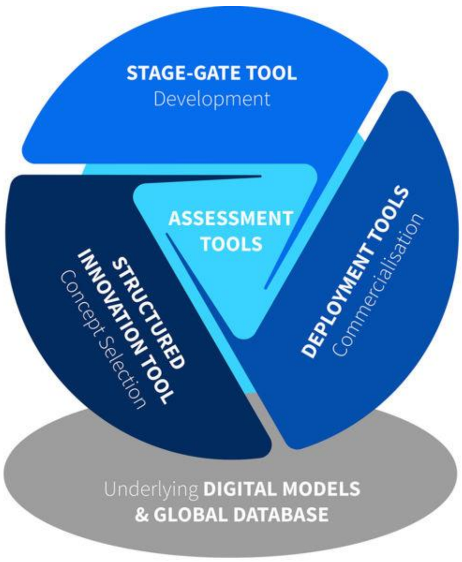


FIGURE 1.1: REPRESENTATION OF DTOCEANPLUS TOOLS

2. BUSINESS MODELLING AND MARKET VALIDATION

This section introduces the methodology used to identify, design and test business model options for ocean energies.

As shown in Figure 2.1, the business model canvas focuses on the nine key components of a business and aims to identify how these factors should interact to deliver a successful business model. The canvas encourages users to approach design holistically by considering cost and revenue structures and commercial strength, resulting in a more sustainable and scalable business model.

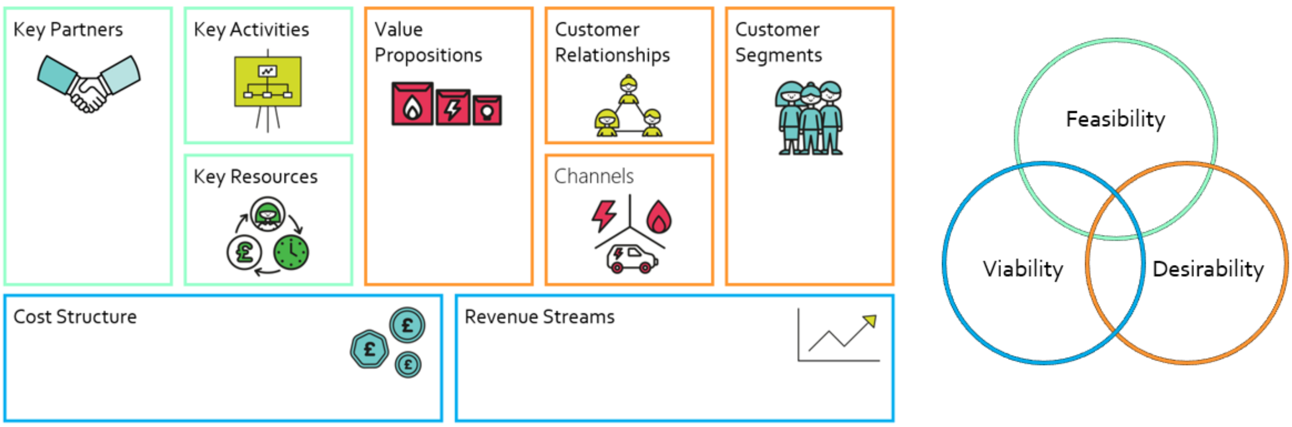


FIGURE 2.1: THE BUSINESS MODEL CANVAS & THE THREE LENSES OF INNOVATION

The components of a business model can be grouped into IDEO's Three Lenses of innovation [9] - Desirability, Feasibility and Viability, with each lens allowing for examining the strengths and weaknesses of the business model. The ideal process of innovation is the combination of the three essential characteristics and how they map onto the Business Model Canvas, as shown in FIGURE 2.1, which are:

- **Desirability (Does anyone want this?)**: desirable solutions that meet stakeholder's needs through exploring the Customers, Customer relationships, the Channels, and their Value propositions.
- **Feasibility (Can this be delivered?)**: feasible solutions that build on the strength of existing capabilities through exploring the key partners, the key resources, and the key activities.
- **Viability (Can money be made?)**: profitable and sustainable solutions built on the revenue streams and cost structures.

2.1. THE BUSINESS MODEL CANVAS EXPLAINED

2.1.1. THE BUSINESS MODEL CANVAS

The nine key components of a business model canvas are described in more detail in FIGURE 2.2. The blocks cover the four main business areas: customers, offer, infrastructure and financial viability. The diagram shows the dependencies and interactions between these two succinctly and describes the logic of how a company or concept can generate value.

Once created, the canvas can act as a strategic tool that can be implemented throughout organisational structures, processes, and systems.

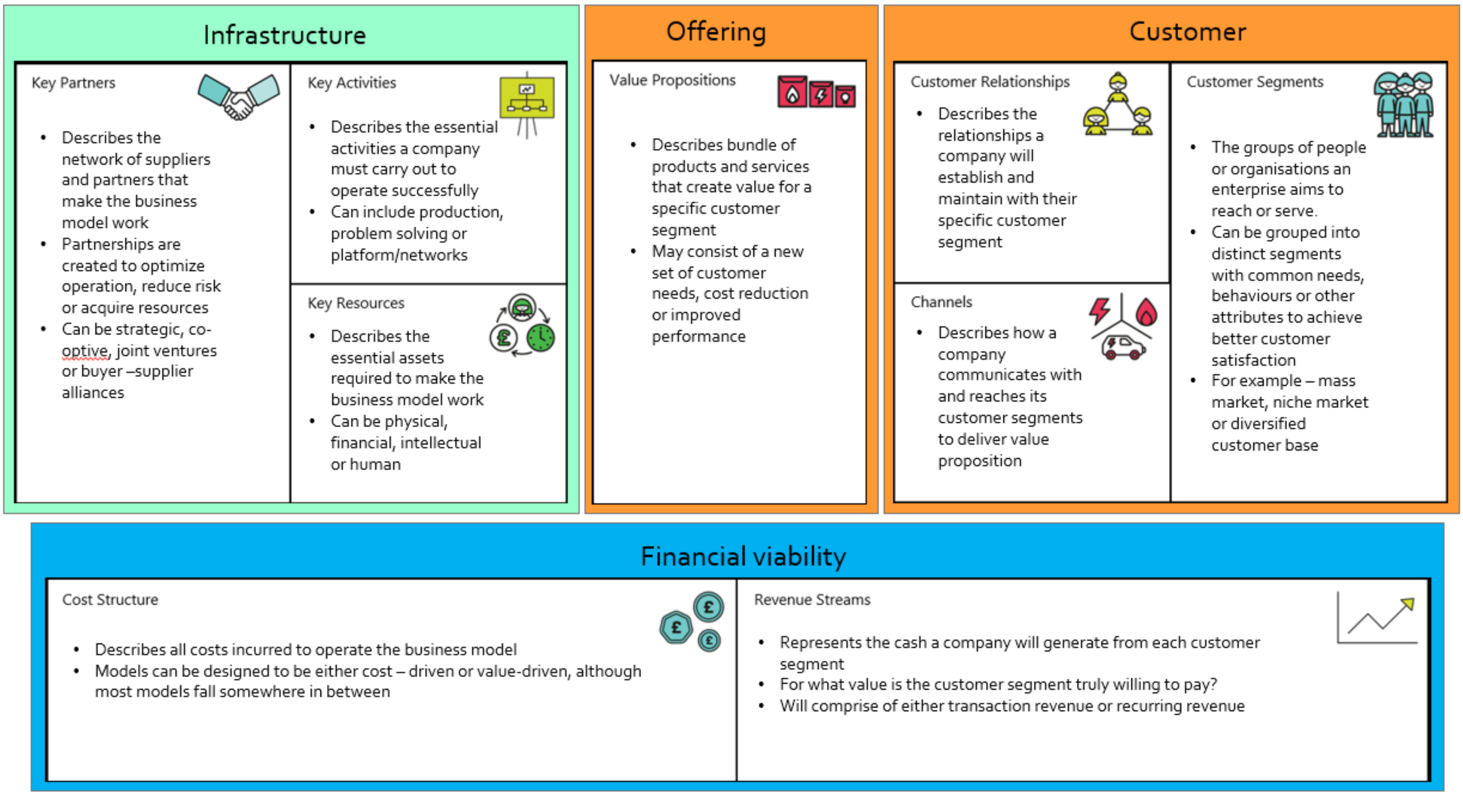


FIGURE 2.2: EXPLAINING THE BUSINESS MODEL CANVAS

2.1.2. VALUE PROPOSITION CANVAS

As shown in Figure 2.3, the plug-in tool is used in conjunction with the Business Model Canvas. It allows for exploring the Value Propositions and the target Customer Segments in more detail to evaluate the "fit" between the value created and the customers' expectations.

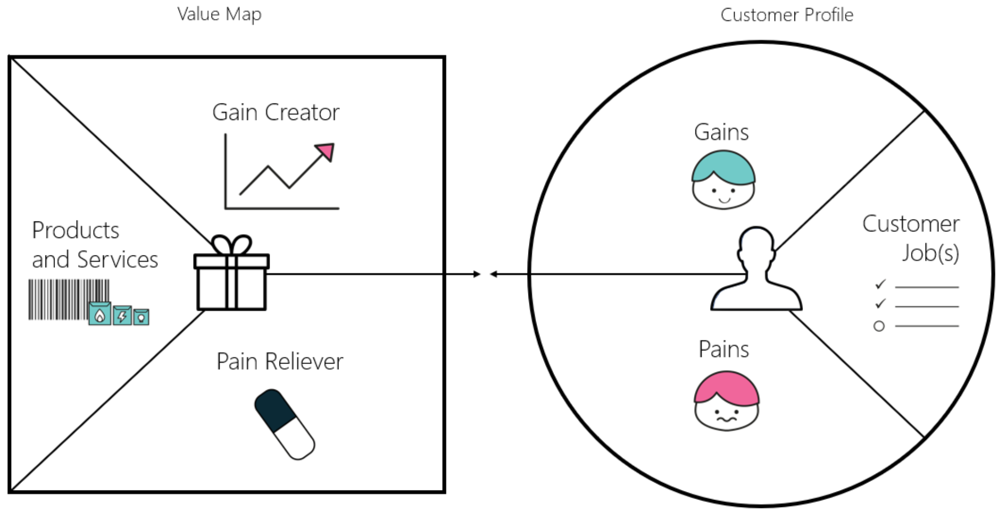


FIGURE 2.3: THE VALUE PROPOSITION PLUG-IN

2.2. EVALUATION AND MARKET VALIDATION

2.2.1. METHODOLOGY

Designing a successful business model is based on two key factors: value and certainty. Therefore, the design process is iterative, regularly testing ideas, risks and assumptions to give a greater level of certainty over potential value streams over time.

1) First, the target customer segments and their needs have to be understood to identify appropriate solutions or services that would suit them. This is called establishing a 'fit'.
2) Once a 'fit' has been established, the concept can be applied to the business model canvas to explore the three lenses of innovation (desirability, feasibility, and viability).
3) The solution or service can then be tested repeatedly until a sustainable and robust model is developed.

In a typical case, the driver for this process comes from finding the right 'fit' and building the rest of the business model. In ocean energy, the solution/service has been established, and this exercise will help determine what specific customer need the technology can address.

This can be described as an offer-driven innovation process [10] whereby ocean energy serves as a brand-new value proposition that drives the construction of the rest of the nine building blocks.

A structured methodology was created to understand the possible business models' risks and allow critical qualitative assessment. Figure 2.4 shows the process by which suitable markets for potential business models were initially identified down to a final list of recommended business models.

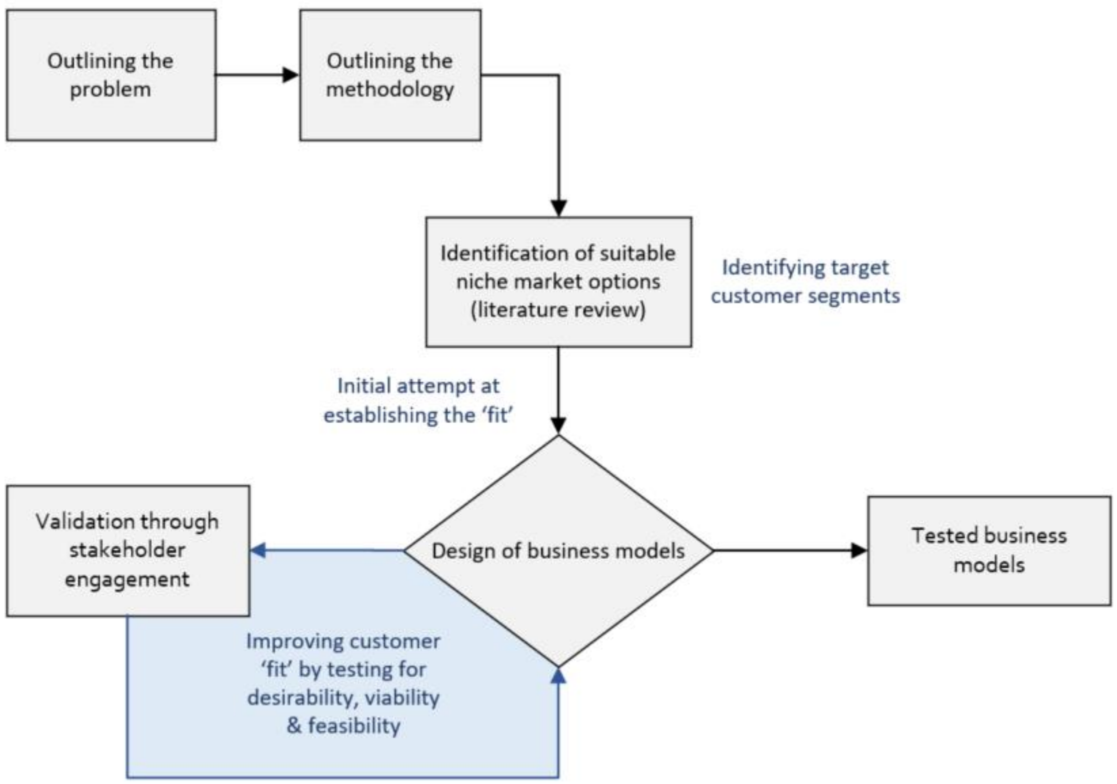


FIGURE 2.4: BUSINESS MODEL DESIGN AND VALIDATION METHODOLOGY

Each block in the diagram is explained in the following subsections.

OUTLINING THE PROBLEM

This refers to the first block in FIGURE 2.4.

A successful business model starts with clearly identifying the problem that is to be solved. If the problem is clearly identified, it can then be aligned with a specific customer need, making establishing 'fit' much simpler.

In this case, the 'problem' is the need for alternative markets to develop further ocean technologies to overcome the 'valley of death'.

OUTLINING THE METHODOLOGY

This refers to the second block in FIGURE 2.4.

Once the problem has been clearly defined, it is important to outline the method by which to arrive at a potential solution. In this case, the Business Model Canvas method is used as a tool to design strategic business model options and undergo a cyclical process of validating and improving those models until they reach an appropriate level of certainty.

IDENTIFICATION OF SUITABLE ALTERNATIVE MARKET OPTIONS

This refers to the third block in FIGURE 2.4.

Mapping an existing business model does not apply in the case of innovative ocean technologies. In this case, a creative process is required to identify a range of possible ideas and then identify and isolate the best ones. This process can also be called 'ideation' [10]. This allows the opportunity to create new mechanisms for generating value and deriving revenue.

The starting point for the 'ideation' process here was a literature review, where extensive market research was used to identify where ocean technology could fulfil an unsatisfied, new or hidden customer need.

This market research enabled to build a picture of the industry, potential customers, and competing technologies, resulting in a long list of potential alternative market options and creating a list of potential stakeholders (customers).

Section 3 will present the findings from this literature review in detail.

DESIGN AND VALIDATION OF BUSINESS MODELS

This refers to the bottom three blocks in FIGURE 2.4.

Once potential alternative market options were identified, the ideation process continued by designing possible business models for each market. This was done by using each of the nine business model building blocks as a starting point to start thinking about commercial potential, customer barriers and implementation time. This then allowed for draft prototypes to be formed, which can then be subject to market validation and testing.

The blue box in FIGURE 2.4 represents the iterative process by which the initial prototypes were tested with market validation which was then fed the design of the business models.

A breakdown of each iteration and its associated activities are summarised below in TABLE 2.1:

TABLE 2.1: ITERATIVE PROCESS TO DESIGN AND VALIDATE BUSINESS MODELS

Iteration		Objectives	Key activities	Action items/key recommendations
1	First stage business model prototypes designed based on identified markets	Identification and initial validation of suitable business model options following literature review.	**Workshop** to review and discuss options. Identification of stakeholders to be engaged with in the next stage.	Creation of first stage business model canvases
2	Validation of initial design with initial market feedback (understanding customer needs)	Understand stakeholder needs (specifically around the current approach to decarbonisation). Test appeal of potential business models looking at customer desirability, feasibility to deliver and commercial viability. Identify ways to improve the business model or increase the attractiveness of the value proposition.	Design of business model one-pagers for each identified potential market (Found in the Appendix Section 10.2 for reference). A detailed **survey** sent out to key stakeholders for market feedback and validation. Detailed **interviews** with specific key stakeholders to get market feedback and validation.	Further market research around recommendations from stakeholder engagements
3	Consolidation of initial market feedback into strengths & weaknesses for each market	Validate key themes and findings from survey and interviews. Identify critical factors that will guarantee success for ocean energy business models (Section 5.3.2).	Consolidation of market feedback from Iteration 2. **Workshop** with WP8.4 team to decide on improvements to business models and areas to be further tested.	Shortlist business model options from 6 down to 4. Reframe the customer segmentation based on market feedback. Refine 4 models based on initial market feedback.
4	Refining and validating shortlisted business models to ensure better customer 'fit'.	Further refine business models to define the value proposition and target customer. Validate refined business models with key strengths and weaknesses with the wider group. Explore and validate critical factors	**Workshop** with ESC industry experts (perspectives ranging from ocean energy, oil & gas, defence and wave and tidal energy systems).	Improve business options based on ESC industry experts feedback. Split out business models into ones that are more suited to wave technology and ones that are more suited to tidal technology

5	Presenting refined business models for final industry feedback resulting in final design iteration.	Present and validate business models with the DTOceanPlus project consortium. Collect feedback around attractiveness, feasibility and likely timelines for deployment. Explore enablers and recommendations to overcome existing market barriers	**Workshop** with academia and wave technology developers. **Workshop** held with academia and tidal technology developers.	Shortlist of refined business model options from 4 down to 3. Final improvements made to business model design.

Comprehensive results of the findings of each iteration can be found in Appendix Section 10.3. The resulting final business model canvases are presented in detail in Section 4.

2.2.2. SUMMARY OF STAKEHOLDER ENGAGEMENTS

To establish a strong 'fit' between ocean energy technology and a specific customer need, it was essential to carry out market validation with a wide range of industry representatives.

A total of 28 individuals and organisations were involved through interviews, survey and workshop activities. Throughout the design process, these stakeholders were identified from the literature review exercise, through to the relevant consortium partners, and recommended contacts that were suggested throughout.

This enabled the collection of feedback from a wide range of relevant expertise (with some stakeholders bringing expertise in multiple fields). Figure 2.5 summarises the range of expertise accessed through the contacted stakeholders. The full list of stakeholders, their relevant expertise, and what stage they were engaged in can be found in Appendix Section 10.1 for reference.

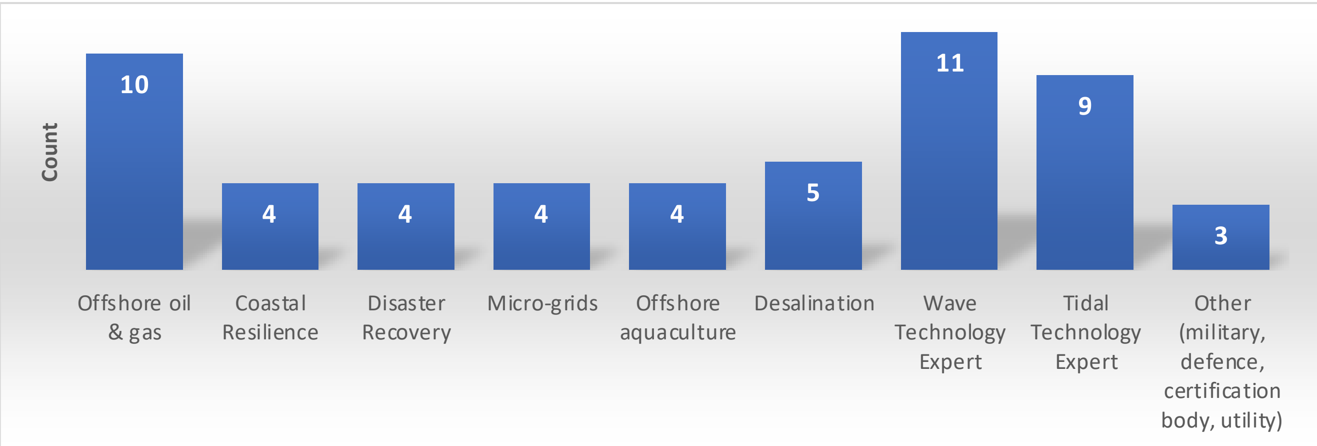


FIGURE 2.5: STAKEHOLDER EXPERTISE

3. ALTERNATIVE MARKETS FOR OCEAN ENERGY

3.1. SUMMARY OF DELIVERABLE 8.1

This report follows on from deliverable D8.1: Potential Markets for Ocean Energy [3]. This deliverable aimed to develop a better understanding of any potential markets for ocean energy technology development and exploitation. In particular, the focus of this report was on wave and tidal stream technologies.

D8.1 summarises the global energy system, ocean energy status, the future wholesale electricity market for ocean energy, and a set of alternative markets that ocean energy could enter.

D8.1 notes a greater convergence towards a technology type in the tidal stream when comparing tidal stream and wave technologies. For example, between 2002 and 2018, tidal stream energy has produced 33.7GWh, whereas wave energy has delivered 1.8GWh between 2008 and 2015. Therefore, tidal stream is regarded as the most mature of the two technologies being considered.

Investment sources are broken down for various renewable technologies, demonstrating that marine energy relies heavily on government R&D funding. In contrast, other types of renewables (solar, wind) can attract a range of asset finance, public market funding or private sector R&D. It is noted that private finance will inevitably increase as ocean generation failure risks decrease.

Analysis of grid power projections determines that in the short-term, at least, ocean energy will struggle to be cost-competitive against a range of other options. Therefore, it may be more achievable for ocean energy to access non-utility markets, which have fewer options for power provision in the short term. A list of the alternative future markets considered in D8.1 is as follows, with a greater emphasis on the initial four, for which more information is available:

- Isolated power systems/islands/microgrids
- Offshore oil and gas extraction
- Marine aquaculture and algae
- Desalination
- Coastal resiliency and disaster recovery
- Ocean observation and navigation
- Unmanned underwater vehicles.
- Seawater and seabed mining
- Marine datacentres

D8.4 aims to provide greater detail about the alternative markets which were identified within D8.1. For the purposes of this exercise, the four most detailed markets plus the coastal resiliency application were selected. Section 3.2 of this report provides background information about these five markets, some of which is repeated from D8.1. Business modelling canvasses were then undertaken for each of these markets to create a more robust business proposition and identify barriers to market access that ocean technology developers can address.

3.2. ALTERNATIVE MARKETS

This section introduces **alternative market** couplings that can leverage ocean energy projects' synergies with related markets to allow projects to become more viable and bring down costs. These alternative markets are seen as a steppingstone for the larger scale grid-connected market, both in terms of technology development/maturity and revenue generation, supporting the longer-term activity. Business models that leverage synergies with related markets are explored to allow projects to become more viable and reduce costs. The opportunities explored include offshore and coastal-located sectors, such as oil and gas platforms, aquaculture and desalination. These alternative markets are assessed by analysing their value propositions (problem to address and opportunities) and the readiness level of the market.

3.2.1. OFFSHORE OIL AND GAS

The oil and gas (O&G) market is one of the biggest energy markets globally, with every country involved in the consumption of its products and production taking place across a wide geographical range. Offshore O&G is a significant part of this market, accounting for more than a quarter of the global O&G production in 2016 [11]. Given their co-location, ocean energies (particularly wave) could assist in offshore O&G platforms' electrical requirements, both during day-to-day production and during the decommissioning phase.

INDICATIVE MARKET SIZE

Despite concerns over emissions, projections are for the O&G market to grow or remain significant over the next decades, although the exact trajectory will depend on future policies and emissions scenarios.

Crude oil production is forecast to decline by 2050, reducing from 83Mb/d to 42Mb/d [12]. It is expected that onshore production will remain the largest and most stable means of production, with offshore production scaling back 2/3 by 2050. New offshore fields are unlikely to be explored and developed given this trend, and so industry focus will primarily be on increasing the efficiency of existing wells and decommissioning offshore assets.

In contrast, offshore natural gas production is projected to be steady until 2050, driven by stronger demand for this fuel in the overall global energy system.

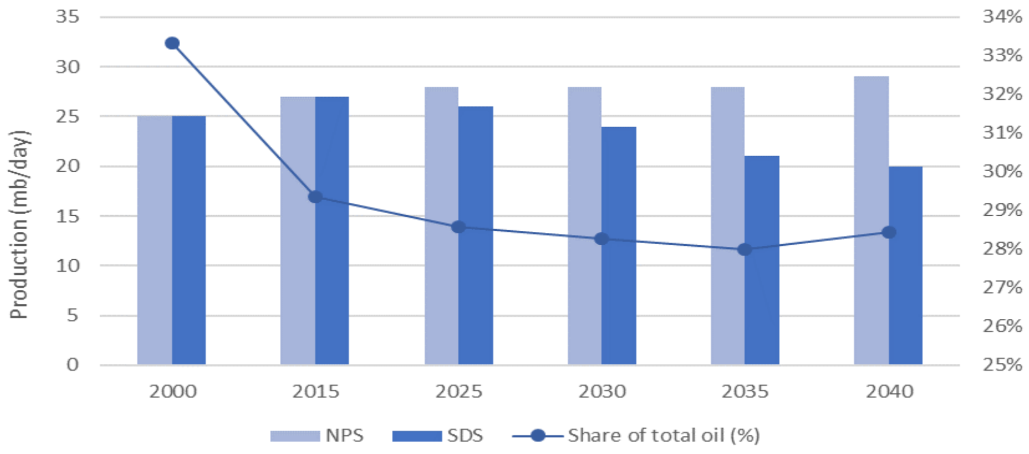


FIGURE 3.1. OFFSHORE OIL PRODUCTION IN THE NEW POLICIES (NPS) AND SUSTAINABLE DEVELOPMENT (SDS) SCENARIO [11]

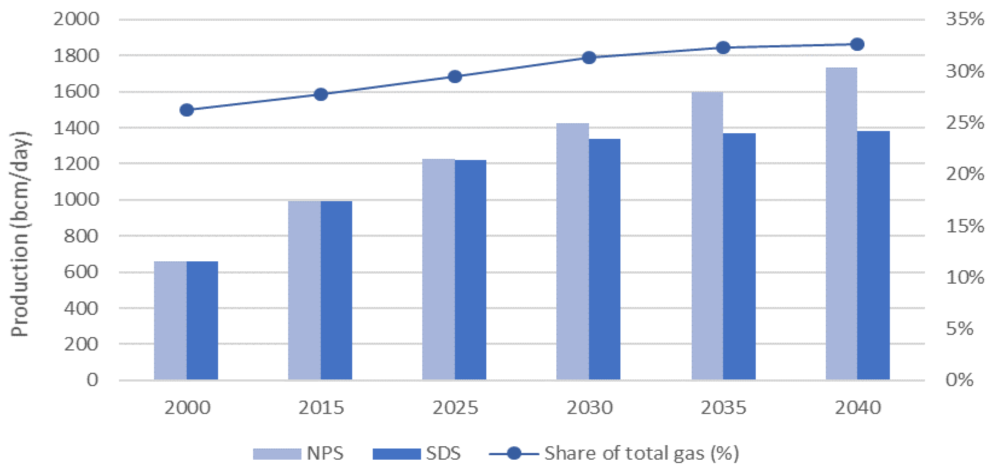


FIGURE 3.2. OFFSHORE GAS PRODUCTION IN THE NEW POLICIES (NPS) AND SUSTAINABLE DEVELOPMENT (SDS) SCENARIO [11]

TYPICAL SIZE OF PROJECTS

An uninterrupted power supply is essential for the O&G industry, and lots of equipment on and off a rig needs powering. A lot of specialised, heavy equipment is used to drill the oil. Before the operation phase, power and communication services are required for the installations. Once the oil is being produced, power is needed to extract and produce the oil. Lastly, the rig also must provide employees with their energy needs while they are housed on the rig. Large generators produce the power to desalinate water, power washing machines, provide a heating source for cooking and even process waste. FIGURE 3.3 summarises these energy flows [13].

Wood Mackenzie has produced an estimate that 5% of wellhead production is used to power platforms. This reduces sales volumes and increases carbon footprint. Further analysis of taxation, with carbon at $40 per ton and 200m tons of CO_2 produced just for power generation, showed that powering rigs from wellhead gas could cost the industry $8bn per year in carbon taxes [14]. The total market for renewables powering offshore platforms is estimated at 16TWh per year.

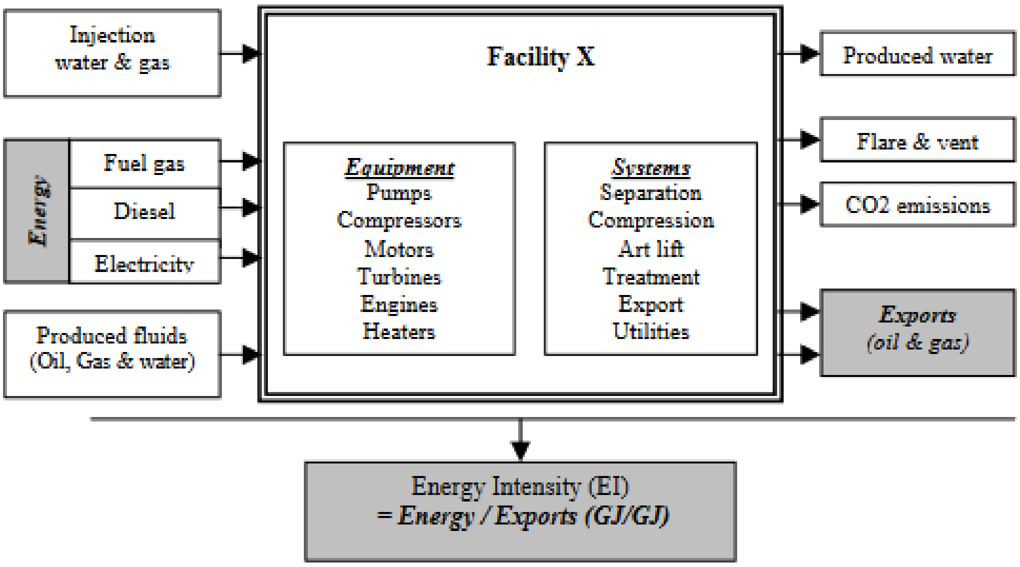


FIGURE 3.3: ENERGY TRANSFERS AND OUTPUTS FOR A TYPICAL OFFSHORE OIL AND GAS RIG INSTALLATION

Beyond the rig's power requirement, monitoring areas such as exclusions zones, motions of subsea equipment, and real-time status data require additional power to the O&G plant. Offshore O&G production may require between 5% and 15% of the total energy generated [15]. A typical drilling rig uses c. 20-30 m^3 of diesel per day, equating to c. 30-40 GWh/year energy consumption [16] [17]. With a renewable technology having 95% availability and a capacity factor of 30%, this would mean an installed rated power of 12-16 MW. An example of a platform consuming power loads of 50MW was illustrated in [18], which comprises two gas turbines at 25MW. [19] presents an analysis of electricity supply to offshore oil and gas platforms from renewable ocean wave energy.

The key options for electrification of these platforms are:

- Provision of power from onshore via HVDC cables – this is typically expensive to install.
- Local energy provision from an offshore source. This is mostly limited to offshore wind and wave.

There is a high potential to replace hydraulic components with electrified equivalents. These are typically expensive to install and maintain, making them good candidates for replacement. DNV GL has produced an example of this replacement for hydraulic fluid lines, which showed a CAPEX reduction of 15% for a total 30km step out [20]. In addition, electrifying the safety valves could further reduce CAPEX costs by 10%.

GEOGRAPHICAL LOCATION

Offshore O&G production activities occur worldwide, with over 9,000 platforms globally in the areas shown in FIGURE 3.4 [15]. Top producers are located in the Middle East, the North Sea, Brazil, the Gulf of Mexico, and the Caspian Sea [11].

FIGURE 3.4. GLOBAL LOCATIONS OF OFFSHORE OIL AND GAS PLATFORMS [15]

In Europe, most of the offshore O&G production is located in the North Sea. Operational, non-operational, and decommissioned O&G platforms in this region are shown in FIGURE 3.5. This map also depicts offshore wind farms, a potential competitor for ocean energy.

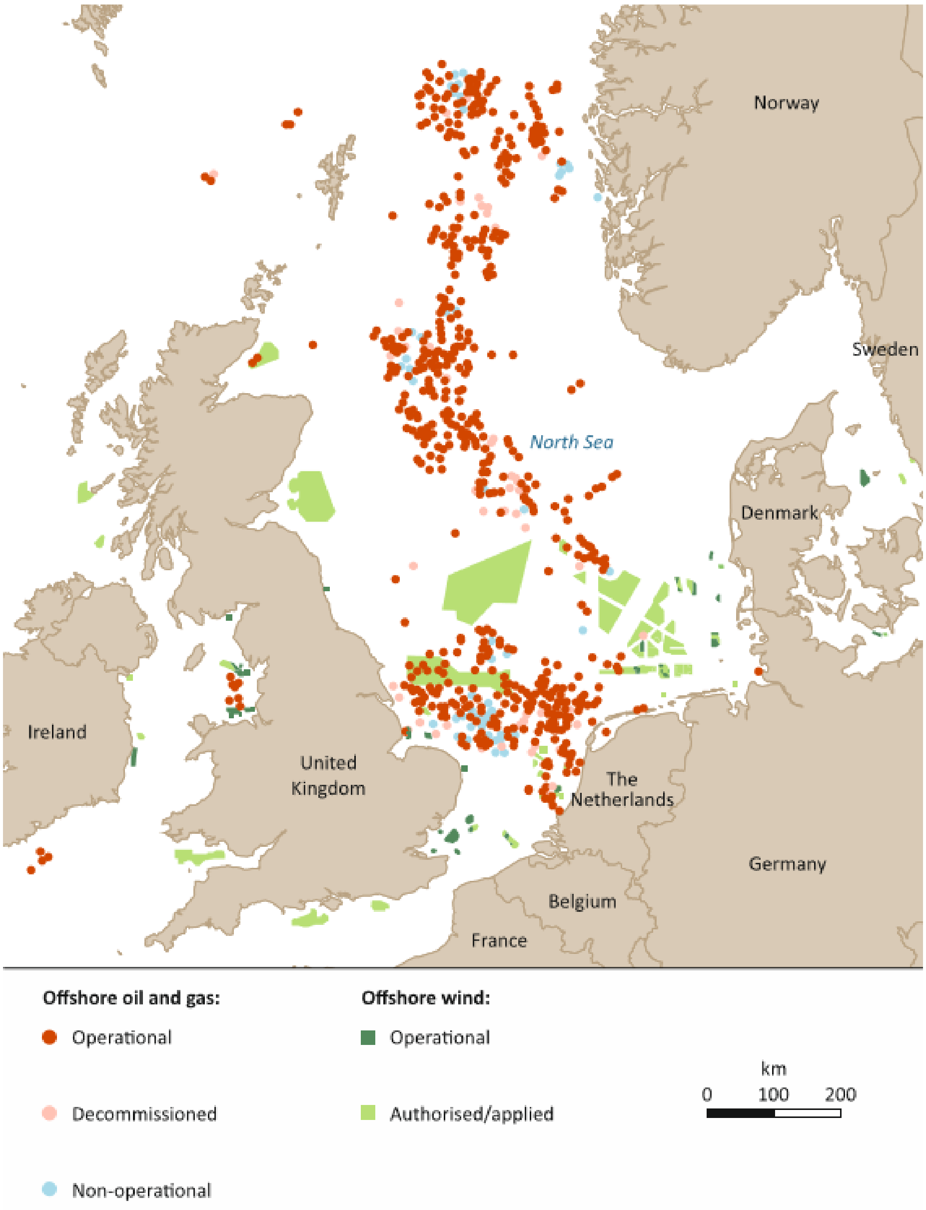


FIGURE 3.5. OFFSHORE OIL AND GAS PLATFORMS AND OFFSHORE WIND INSTALLATIONS IN THE NORTH SEA [21] [22]

A good correlation exists between rig locations and areas of strong wave resource. However, some rigs may have been deliberately located in less energetic sites to reduce CAPEX.

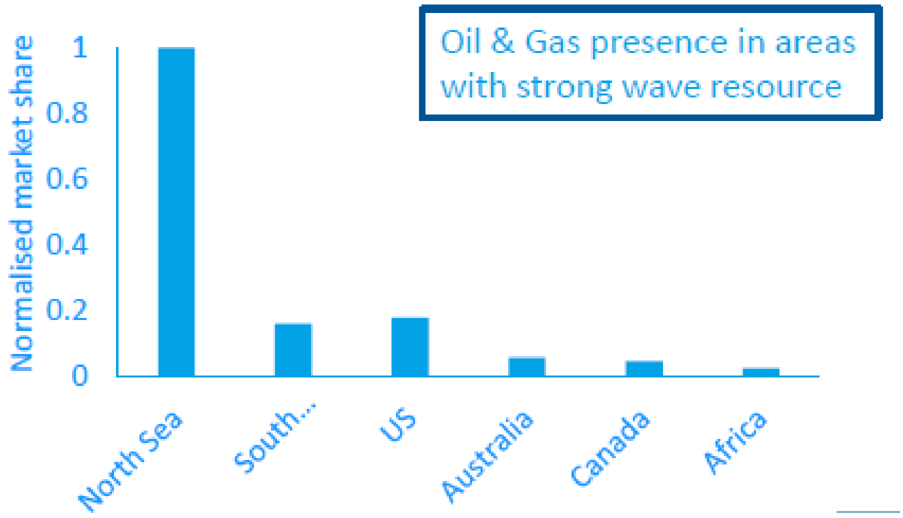


FIGURE 3.6: O&G PRESENCE IN AREAS WITH STRONG WAVE RESOURCE [16]

Water depth is very deep for some offshore rig locations, and this may be prohibitive to the deployment of wave and tidal devices. The breakdown of water depth for offshore rigs is shown in FIGURE 3.7, which shows that around a third of the rigs are located in water that is deeper than 125m. Therefore, individual site evaluations, which examine energy resource and water depth, are required in each instance to determine the suitability of ocean energy for this market.

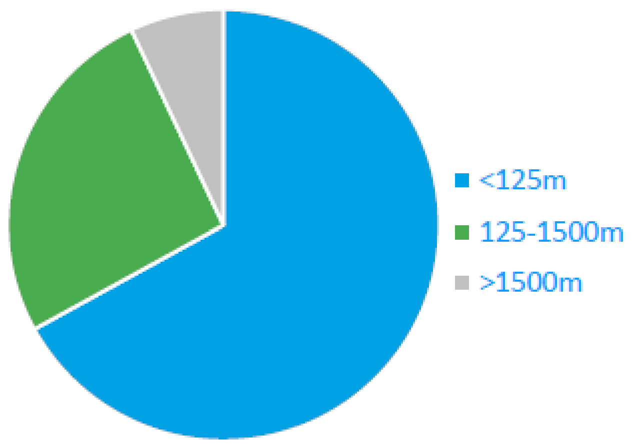


FIGURE 3.7: OFFSHORE RIGS SPLIT BY WATER DEPTH [16]

An analysis performed for the global oil and gas offshore rig market is shown in FIGURE 3.8 [23]. This analysis considered only power by wave devices. The Caspian Sea and the Persian Gulf were omitted due to very low wave potential. In FIGURE 3.8, the size of the bubbles represents the available market in terms of the number of offshore platforms. Bathymetry is less relevant in this example since the platforms are located at similar water depths regardless of the region for logistical regions. The most promising markets considered are the South China Sea and the North Sea – there is a large addressable market in the Gulf of Mexico, but the low wave resource in this region makes coupling to this market challenging for ocean energy.

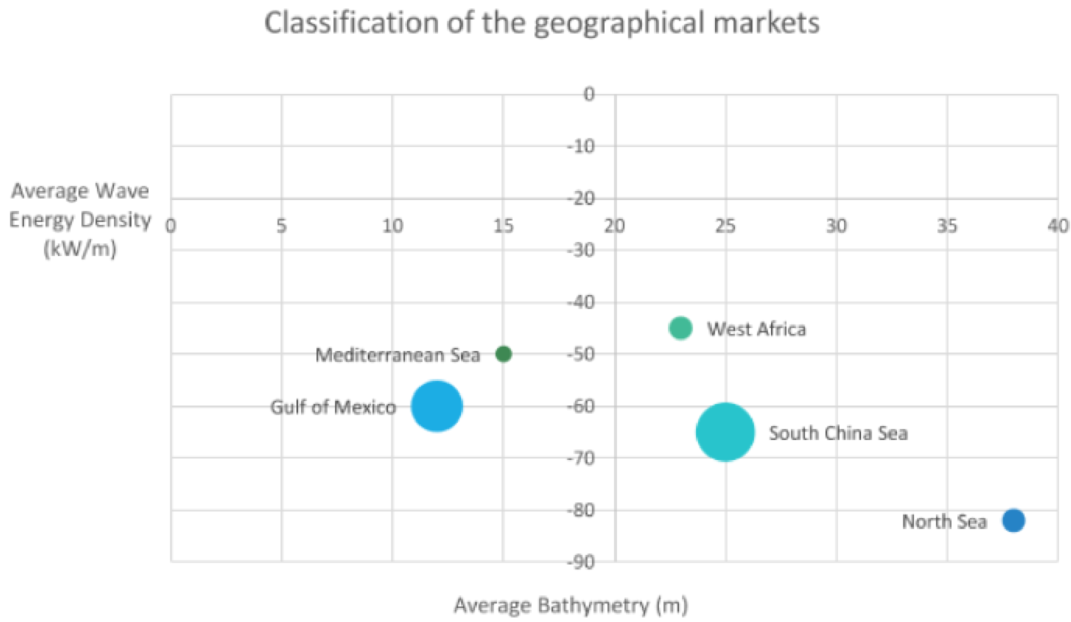


FIGURE 3.8: POTENTIAL OIL AND GAS MARKETS FOR WAVE ENERGY [23]

KEY STAKEHOLDERS

As the European and global energy sector transitions to ambitious net zero emission targets by 2050, major oil and gas companies evolve their business models to include renewable technologies [18].

Ocean Power Technologies (OPT) has developed a point absorber buoy – the PB3 PowerBuoy – which provides power to observing equipment. In August 2019, OPT deployed its device at the Huntington Oil Field, the property of Premier Oil, in the North Sea's UK central area. OPT's WEC supports Premier Oil's communications and remote monitoring services and expects to remain in place for at least nine months, demonstrating PB3 capabilities [24]. Additionally, Mocean Energy is developing and testing the Blue Star floating WEC and has joined an initiative gathering start-up firms looking to enter the O&G industry. Mocean Energy seeks to create partnerships to enable sustainable powering production for the O&G industry [25].

The O&G operator ENI, in addition to the Premier Oil project, has also joined the venture to trial the ISWEC, inertial sea wave energy converter, a WEC integrated with a photovoltaic system to produce the electricity required to offshore power plants [26]. Thus, development is created an industrial model with 100kW peak power, with the first operation planned for 2022.

There are many more organisations, having adopted net zero targets, that are looking at ways to provide low carbon power platforms such as O&G major Total who is partnering with Floating power plan to evaluate the coupling of their wave and wind platforms; Subsea 7 with GEPS Techno, Saipem with Wello's Penguin [27].

INVESTMENT MODELS IN PLACE

In 2018, it became public that Equinor was considering investing approx. 530 M€ to power supply Gullfaks and Snorre's oil fields using the company's offshore floating wind concept, Hywind [19]. The project will consist of 11 wind turbines of 8MW each, and if it runs through, Equinor will manage to cut down 200,000 t/year of CO_2 emissions from those two fields.

Another example of offshore wind collaboration with oil and gas is the WIN-WIN project, conducted by DNV GL [28]. This project has demonstrated matching of wind power to the water injection process, which enables increased oil recovery worth $500m daily. In addition, the system was cost-competitive with the current natural gas solution, based on a 20-year life cycle, with costs of 0.9EUR/bbl vs 1.2EUR/bbl.

Mocean Energy is also invested in supplying subsea power to O&G platforms using its Blue Star wave energy converter. This WEC is being developed and tested to supply power to subsea equipment instead of umbilicals.

So far, the owner of the rig makes the entire investment in the infrastructure for power supply. However, some proposals share common resources for a larger area (offshore submarine cables or large offshore wind farms). This could increase the market for ocean energy by providing a route to market and increasing competition from more conventional generating sources.

PESTLE DRIVERS

TABLE 3.1: PESTLE DRIVERS FOR OFFSHORE OIL AND GAS

Factor	Description
Political	• Policies such as emission regulations can greatly enhance the value of renewable technology integration, while policies such as fuel subsidies diminish their applicability
Economic	• Risk aversion of the sector • Competition with floating offshore wind • Renewable energy has to be economically competitive with gas turbines. • Government grants and incentives
Social	• Job creation in nearby coastal areas • The transition of industry in local areas to reduce the impact of the decline
Technological	• The most common way to supply enough power to the rig is through diesel-powered generators and gas generators. • Security of electricity supply 24/7 is required. • Other valued characteristics: high reliability, high efficiency, operating flexibility, low weight, and compactness
Legal	• Regulation and reputation are drivers for achieving greater energy efficiency
Environmental	• Environmental impacts in offshore O&G platforms are expected to increase in the upcoming years. • Saving fuel and GHG/carbon emissions • Machinery must be able to withstand harsh environmental conditions. • IOCs have set internal emissions targets, focused currently on the initial production process. • Reducing carbon emissions

INDICATIVE MARKET READINESS

In Europe, the North Sea has the highest potential for this integration. However, the market could be challenging due to competition from offshore wind.

Some technical challenges to the use of ocean energy are:

- Ocean energy has a lower capacity factor compared with gas turbines.
- The substantial power requirements during decommissioning
- The system must always be able to balance generation and load (a high degree of controllability with short response times)
- Water depths

The existing O&G platforms have relatively large power needs critical to maintaining safe and economical operations. However, there are opportunities for ocean energy to support the reduction of the carbon footprint of O&G activities, particularly by focusing on low-power processes such as monitoring and electrifying hydraulic cables.

3.2.2. COASTAL RESILIENCE APPLICATIONS

Climate change consequences such as sea-level rise, more frequent and intense storms, and other extreme weather events such as tsunamis and flooding threaten coastal areas worldwide. Extreme events may limit access to fresh water and electricity and increase public health risks, thereby disrupting communities and eventually forcing them to be displaced. With the proximity of the continuously rising global population to the coast and the potential impacts of climate change, it is imperative to integrate resiliency and disaster recovery planning into decision-making processes and adapt planning and development practices to mitigate these events. Coastal communities address these threats by developing mitigation strategies and increasing their preparedness for such events, response, recovery operations, and improving the overall resiliency of fundamental infrastructure and emergency assets.

Another potential opportunity for ocean energy is disaster recovery. For example, the US Department of Homeland Security has identified in its National Response Framework [29] the power needs that arise after an extreme event has occurred, and these include:

- Communication systems enabling public information and warning,
- Lighting, heating/cooling, and communications in emergency management centres;
- Vehicle fuel (hybrid or electric) and other means of evacuation such as boats;
- Medical assistance, refrigeration for morgues, among others;
- Water pressure and pumping services for fire management and suppression; and
- Construction and operation of temporary shelters, processing of clean potable water, and provision of emergency first aid.

Disasters are not single events with consequences limited to when a damaging action affects the electric power supply. Instead, from an infrastructure planning perspective, disasters have distinct phases, some of which could last several months or even years. The phases are 1) preparation, 2) disaster occurrences, 3) immediate aftermath, and 4) long-term aftermath [30].

Ocean energy could create valuable partnerships with coastal and harbour planning and management organisations and civilian and volunteer organisations who might be interested in seizing the ocean energy potential and investing in these technologies for shoreline protection and disaster recovery applications.

INDICATIVE MARKET SIZE

Roughly one-third of human populations live within 100 km of coastline, and continued migration toward coastal areas is expected to increase this proportion to one-half by 2030 [29].

In the US, Federal Emergency Management Agency's (FEMA) Disaster Relief Fund is one of the main funding sources for emergency response and disaster recovery, receiving base funding of $615 million in Fiscal Year (FY) 2017 and an additional $6.7 billion for major declarations [29].

Weather-related events that knock out power in the United States were estimated to have cost the economy between $18-33bn between 2003 and 2012 [31]. Roughly 679 outages occurred during weather events which affected at least 50,000 customers in each instance. Globally, losses between 1999 and 2018 due to 12,000 extreme weather events amounted to around $3.54tn [32]. Of the ten most affected countries in this period, seven are classed as developing countries with low-income groups; two were classified as upper-middle-income countries (Thailand and Dominica), and one was classified as an advanced economy (Puerto Rico).

Ocean energy developers must identify coastal resiliency plans which are compatible with the use of their technology. Typically, the methodology taken is to break the coastline up into cells, each of which has a distinct strategy to follow for a set period. Some examples of these are Shoreline Management Plans (SMPs) in the UK, Coastal Management Framework (CMF) in Auckland, New Zealand [33], and SMPs to target potential tourism hotspots in Belize [34].

Typical strategies for these areas can include:

- Building on existing defences (with either hard or soft solutions)
- Maintaining an existing line of defence
- Managed realignment (movement of people and businesses from the affected area)
- No active interventions

The solutions chosen may consist of hard and soft engineering solutions, depending upon local stakeholder preference. In Belize, there was a preference to use mangrove breakwaters due to the cost-effectiveness and tourism appeal. Conversely, Belgium determined that hard engineering solutions would be more effective than nourishment strategies [35]. The United Kingdom has traditionally relied upon large structures to protect 90% of its coastlines, but priorities may shift with the advent of alternative green solutions. The overall market size for ocean energy applications will ultimately depend upon chosen resiliency strategies, which will determine the availability of co-location (e.g. breakwater integration) and power requirements (e.g. power for nourishment vessels)

Another potential related market is humanitarian disaster recovery, focussing on the power requirements of refugee camps. These camps are typically located away from big cities and close to country borders, in regions with low access to grid connections, and so camps rely heavily upon local diesel generators. An estimate of electricity costs in US compounds is $0.60 per kWh [36]. In total, there is an estimated annual saving of $517m for the humanitarian sector from improvements to energy provision and transportation.

These camps typically generate energy in a sub-optimal way. This partially due to the preconception that camps are a temporary solution, for which diesel generation is the best solution – in reality, the average lifetime of a refugee camp is 18 years, which is within the payback period for many renewable solutions. Another part of the issue is that energy usage is unknown due to poor monitoring, which leads to sub-optimal operation of diesel generators, further elevating the overall costs [37]. Therefore, implementing renewable solutions requires better monitoring and understanding of the customer base.

TYPICAL SIZE OF PROJECTS

Typically, FEMA and state or community emergency services provide diesel generators for emergency power sources. As of 2014, FEMA had 1,012 generators in its fleet comprising 103 generator sizes, ranging from 1.5 kW to 1.825 MW [29], requiring that shipments of diesel be continually delivered into disaster zones.

The largest flood protection project in the world is Delta Works in the Netherlands. Delta Works consists of some surge barriers, including Oosterscheldekering, the largest storm surge barrier in the world (5.6 miles long). Oosterscheldekering has also been equipped with five tidal turbines, with a total capacity of 1.2 MW, enough to power 1,000 Dutch households [29].

GEOGRAPHICAL LOCATION

Extreme weather events can strike almost everywhere. Some examples are [30]:

- Earthquakes and Tsunamis in Chile, Japan, and New Zealand
- Hurricanes Ike, Gustav, Katrina, and Superstorm Sandy
- Floods in Queensland, Australia
- Forest Fires in Greece
- Ice Storms in Canada

From these examples, some are more applicable to coastal locations where wave and tidal can be deployed. These include hurricanes, flooding and tsunamis, which have historically caused widespread devastation for coastal communities. Therefore, mitigation of these events should prioritise ocean energy developers seeking involvement in resiliency markets.

While there is a wide geographical spread of areas affected by extreme weather events, islands are more sensitive to disasters. They often depend on diesel generation, and transport by ships is impeded, thus reducing the reliability of the isolated electrical system.

Between 1998 and 2016, coastal areas such as Puerto Rico, Honduras and Myanmar were most affected by extreme weather events [38].

KEY STAKEHOLDERS

Various coastal management and engineering organisations could be relevant partners. Other potential partners include civilian and volunteer organisations, such as the American Red Cross. In addition, regional and state-level utilities might invest in marine energy to ensure that small isolated coastal grids have black-start ability [29]. Other potential partners include:

- Defence/ military bases
- Local communities
- Utilities &SMEs
- Oceanic/ Weather organisations
- Technology developers
- Regulators
- UNHCR (United Nations Human Rights Council) – operator of refugee camps

Examples of existing or proposed coastal resiliency projects incorporating ocean energy tend to involve breakwater structures to house turbines. For example, the SIADAR project was proposed for construction off the Isle of Lewis in Scotland. This was intended to provide 3-4MW of electricity [39]. However, this project was cancelled in 2012 due to a lack of funding and uncertainty surrounding the subsea cable. In addition, the latter point comprised interconnector installation delays and high transmission charges to export electricity to the landing point [40].

The Mutriku Wave Energy Plant is the first European example of a breakwater wave plant. The total installed capacity is 296kW. The breakwater was constructed to protect the coastline and prevent shipping accidents, after which EVE was approached to create an integrated power plant [41]. The use of an existing breakwater allowed installation costs to be minimised. In 2020, it was announced that the Mutriku Plant had generated 2GWh of electricity since opening in 2011 – the first such achievement at any wave plant [42]. All electricity produced is sold to the grid.

The following sites have implemented renewable energy (typically solar due to the high available resource) in refugee camps. These are not directly applicable to ocean energy generation but do demonstrate a trend towards decarbonisation of the humanitarian sector:

- **Azraq, Jordan**: A 2MW solar PV plant was installed near a refugee camp in 2017 [43]. This was supported by IKEA Foundation's Brighter Lives for Refugees campaign and enabled the world's first refugee camp powered by renewable energy. This resulted in immediate savings of $2.75m per year and cut CO_2 emissions by 6,300 tons per year. As of August 2019, the plant has been extended to 5MW, and surplus energy now supports the host community.
- **Herat, Afghanistan**: This is a storage facility for foodstuff. The World Food Programme (WFP) invested $528,948 to install a hybrid wind/solar/diesel system [36]. This has reduced the operational costs, with full payback expected in 5.2 years. The expected lifetime saving is $900,000, with an associated reduction of 250,000kg of CO_2.

- **Zaatari, Jordan**: Funding from the Czech government allowed for upgrades to medium and low voltage network, and funding from the German government allowed a connection of a 12.9MW solar plant [36]. This is the largest solar plant at a refugee camp.

	Responsibilities		Requirements
Public administration	Community-wide disaster avoidance and response planning	→	An understanding of best practices and assessment of prevention plans for disaster resilience or recovery
Standards organizations	Development of standards to assist with disaster preparedness or recovery	→	Technical standards to ensure technical goals or benefits can be realized Classification standards to allow evaluation and comparison of disaster-preparedness strategies
Private companies	Company-specific disaster response planning	→	Plans to ensure business is appropriately prepared for major disasters and rapid recovery from disaster
	New products and technologies for disaster resilience or recovery	→	Products and technologies that can assist with disaster preparation or recovery, and that adhere to current technical standards to ensure maximum widespread benefit
End users/ Consumers	Education and training related to disaster preparedness and recovery	→	Detailed planning to minimize the impacts of a major disaster

FIGURE 3.9: STAKEHOLDERS NEEDS IN DISASTER RECOVERY [44]

INVESTMENT MODELS IN PLACE

The Delta Works project in the Netherlands features a 1.2MW tidal array of five turbines within one particular barrier – this had a total cost of $12.4m [45]. The project received funding from Zeeland, where the barrier is located, the Dutch government and the European Regional Development Fund. This is still being operated as a demonstrator project.

One challenge of funding renewables projects in humanitarian relief is that organisation often do not have the significant up-front capital to invest, with budgets limited to the upcoming financial year. Additionally, it may be the case that humanitarian organisations lack expertise or willingness to take responsibility for technical aspects of the system.

Some alternative payment structures have been identified which may alleviate these concerns [46]:

- **Leasing**: A monthly fee is paid for equipment
- **Power Purchase Agreement (PPA):** Fees are paid only for electricity produced via the device.

- **Pay-as-you-go (PAYG):** Rental of small devices to individual homes within settlements, as an alternative to providing grid extensions
- **Lease to own:** This allows the user to eventually own the system without initial high investment costs.

Hybrid systems for humanitarian camps are typically found to have a payback period between 2-6 years [36] (these are primarily solar-based systems at the present time). It is also noted that standardised products will be more likely to pass through the strict procurement process of these organisations.

PESTLE DRIVERS

TABLE 3.2: PESTLE DRIVERS FOR COASTAL RESILIENCE APPLICATIONS

Factor	Description
Political	• Support for critical infrastructures (telecommunication, data centres, medical facilities)
Economic	• Impact on the local economy
Social	• Provide the black-start capability to isolated portions of the grid. • Water treatment and supply such as Desalination, Emergency power supply • Negative impact on the quality of life
Technological	• Distributed power generation (local microgrids) • Mobile electricity-generating ocean platforms?
Legal	• Standards
Environmental	• Climate change is increasing extreme weather events and risks of coastal flooding from rising sea level. • Ocean energy technologies can support shoreline protection efforts by powering marinas, ports, local communities or aiding in sand replenishment of beaches. • Replace power from diesel generators. • Reduced carbon emissions

INDICATIVE MARKET READINESS

There are opportunities for ocean energy to play an important role in supporting these adaptation and mitigation strategies.

Ocean energy could be used to augment or replace power from diesel generators and provide the black-start capability to isolated portions of the grid.

Ocean energy will have to compete with solar and wind power and battery energy storage systems in these markets and prove its reliability.

3.2.3. MICROGRIDS

Microgrids are required in remote locations which are a long distance from the established network infrastructure. This isolation is typically caused by the geography of the region, e.g. island location.

The most common sources of energy for these microgrids are diesel generators. These are suitable because the fuel source can be stored and used directly according to demand.

Microgrids may also be created to serve non-residential populations, such as defence sites. These can typically require power equivalent to a small village and prefer to operate in isolation to the main grid. For example, a site with a critical function may wish to control its power infrastructure to provide additional supply security.

Aside from decarbonisation, there are other motivations for fuel-switching existing microgrids. Microgrids are most suited to locations with accessibility issues. This can make the transport of diesel fuel both expensive and dangerous. Diesel is also subject to volatile oil price fluctuations and must be stored in sizable volumes on site to guard against shortages.

Microgrids may also represent a solution to network resiliency in the face of more extreme weather conditions accelerated by global warming.

Microgrids are a growing market. There is a trend towards decentralising the energy sector, which lends itself towards microgrid solutions, where local communities develop their energy solutions. Additionally, as more of the world's population access electrical generation, the likely solution will be in the form of microgrids.

There are multiple options for powering microgrids. The most feasible generation options will depend upon geography. There are likely to be many communities isolated by water and require the installation or conversion of a microgrid. In these instances, coupling to marine resources such as wave and tidal could prove a viable option. Additional factors, such as energy cost, reliability and power quality, will determine whether wave and tidal are favoured over other feasible options.

INDICATIVE MARKET SIZE

The anticipated growth in the microgrid market is shown in FIGURE 3.10 [47]. What is unknown is the predicted proportion of these microgrids, which will be located with access to tidal and wave resources. However, as noted in section 3.2.2, one-third of the world's population lives within 100km of coastline, with this percentage anticipated to rise. Therefore, an even distribution of these technologies would require 2-3GW of microgrids to be supported in these locations by 2024. However, within this subsection of the market, other renewable technologies are competing for a market share.

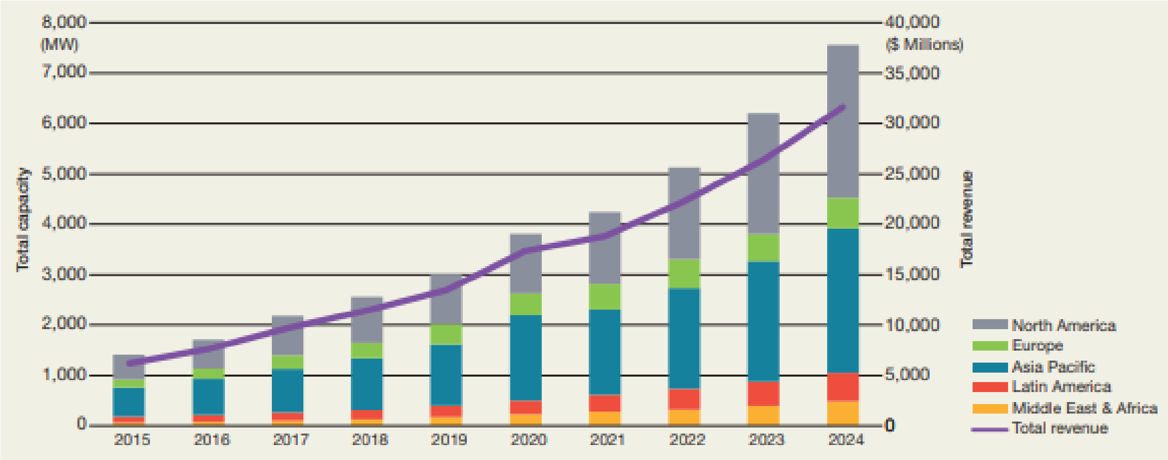


FIGURE 3.10: PROJECTION OF MICROGRID CAPACITY AND REVENUE IN GLOBAL MARKET, FROM 2015-2024 [47]

Microgrids could be used as a solution to reliability issues, which can significantly impact the local economy. For example, a 2019 blackout in California, which affected 800,000 customers, was estimated to have impacted businesses by a value of $2.4bn over 24 hours [48]. Microgrids are also seen as a solution for areas of the world with little to no access to electricity. Analysis of the global population suggests that, in 2018, there remained 810 million people with no access to electricity. This is particularly concentrated in sub-Saharan Africa, which has an access rate of only 47% [49].

TYPICAL SIZE OF PROJECTS

The energy requirement of a community using a microgrid will depend upon the local area's economic development and the size of the community.

Some examples of this variation due to economic development have been identified. Focusing on Small Island Developing States (SIDS), Timor-Leste and Guinea-Bissau have the lowest energy consumption per capita of 0.67MWh and 0.78MWh respectively, and Singapore and Trinidad and Tobago the highest with 59.6MWh and 167MWh respectively [50]. These indicate that installed microgrids must deal with very different total loads depending upon the location's specifics.

Blechinger et al. [51] mapped around 1800 small islands worldwide with populations between 1000 and 100,000. This analysis determined that these areas have a combined diesel generation capacity of 15GW, representing a significant market that could be converted to tidal and wave generation. These markets' requirements will depend upon the local motivation to switch from diesel fuel sources; this could be driven by cost predictability, power reliability, or carbon emissions and pollution targets. Until wave and tidal energy are cost-competitive on average against incumbent diesel installations, drivers for change are likely to come from reliability and environmental factors.

Isolated communities in the United States, concentrated in Alaska and island territories, have microgrid systems that range in capacity between 200kW and 5MW [52].

GEOGRAPHICAL LOCATION

As shown by FIGURE 3.10, there is a reasonable geographical distribution of microgrid technologies anticipated by 2024. However, the two dominant regions by global market share are Asia Pacific (41.3%) and North America (32.5%).

One area of North America identified as potentially benefitting from marine energy is Alaska [52]. Due to the remote nature of Alaska's communities, liquid fuel must be transported and stored locally. This is often expensive and results in cost and security of supply risks. Additionally, Alaska has a strong ocean resource, which could be used to substitute this fuel source. This correlation is shown in FIGURE 3.11 [53].

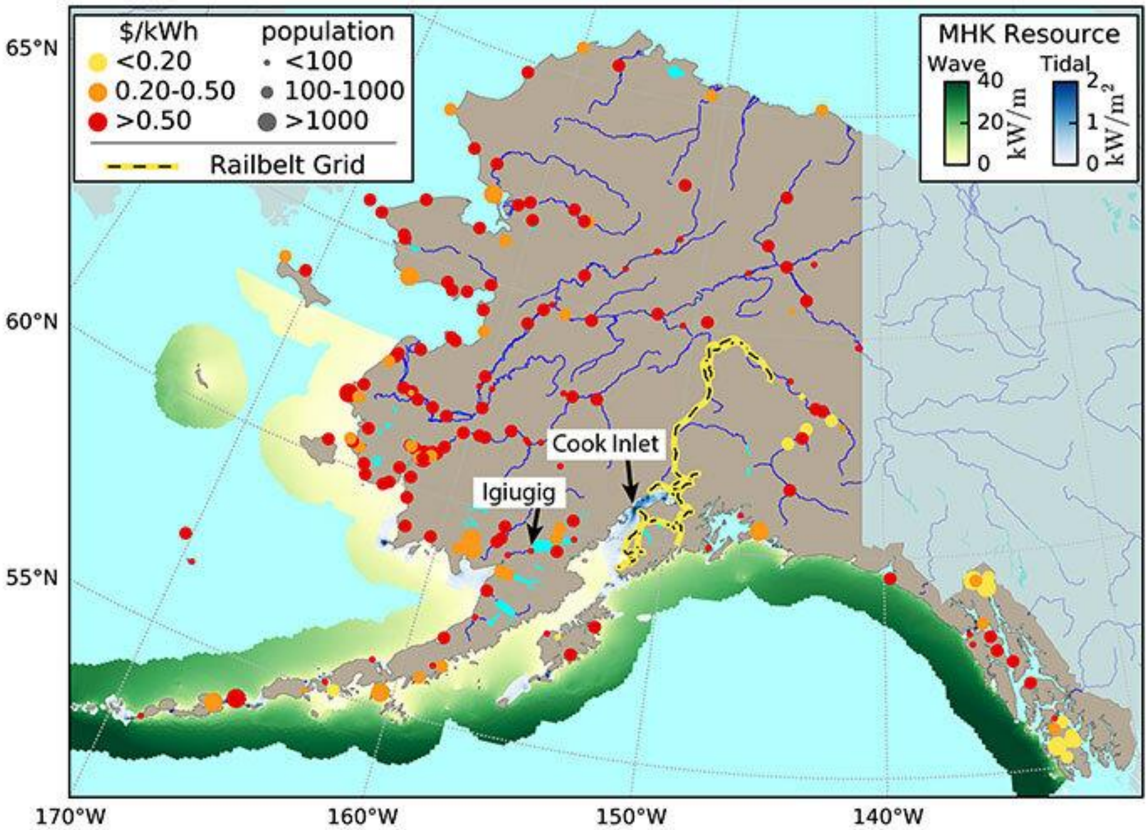


FIGURE 3.11: RURAL ALASKAN ENERGY PRICES AND MARINE ENERGY RESOURCES [53]

An extensive potential market for coupling marine technologies with microgrids is Small Island Developing States (SIDS). The Asia-Pacific region is anticipated to have the fastest growth in market value, with a Compound annual growth rate (CAGR) of 18% during a forecast period from 2017-2022 [54]. In addition, there is an additional market of small island nations in the Caribbean which can also be considered a target for these technologies to support microgrids.

Aquatera and Caelulum have assessed the potential for wave energy development in specific SIDS using wave resource and electricity consumption per capita as key indicators [55]. This identifies specific geographic locations for the development of marine energy technologies by highlighting areas with high wave resource and high electricity consumption. It also points to areas where markets may emerge as electricity consumption increases with development.

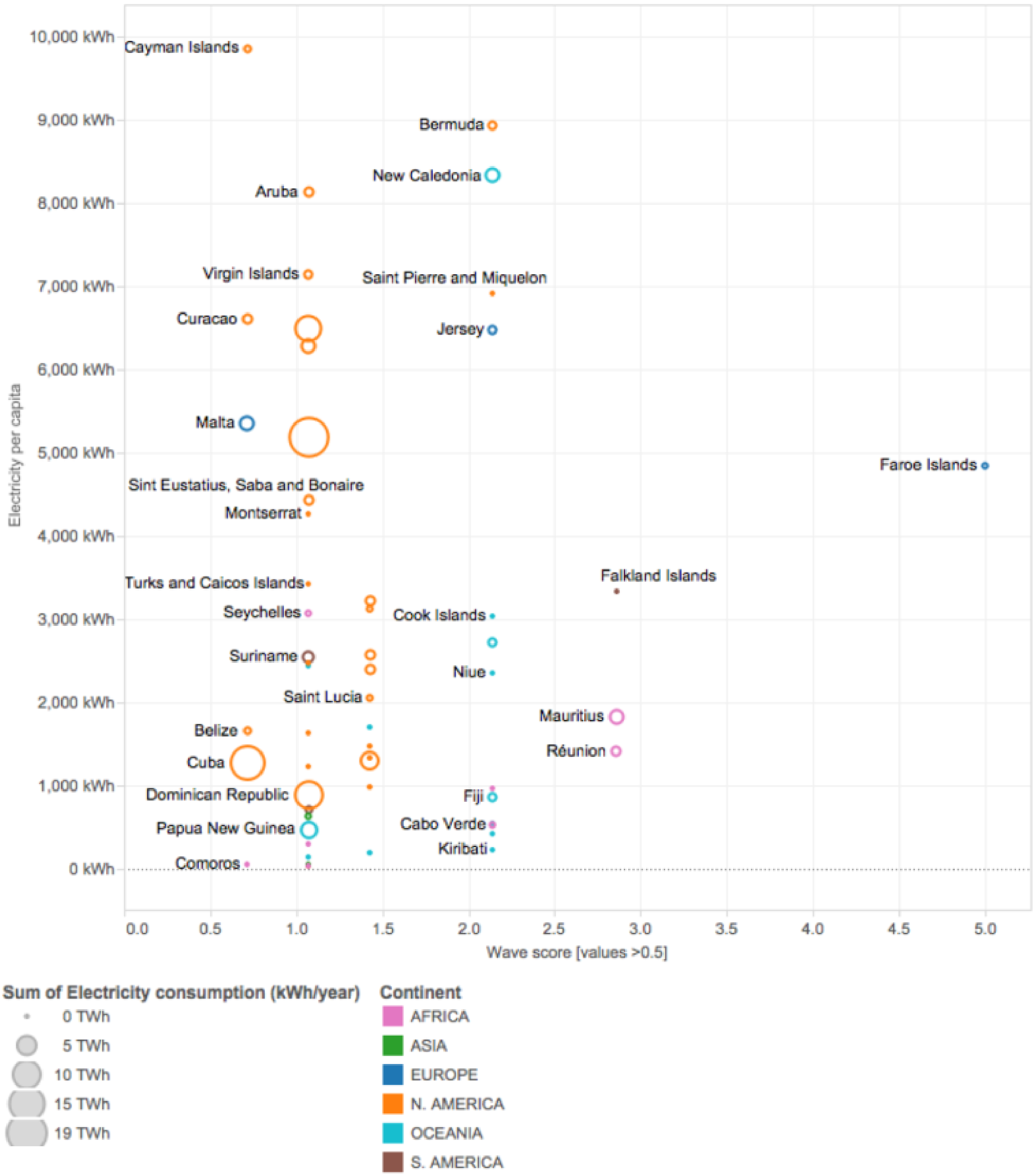


FIGURE 3.12: COMPARISON OF WAVE ENERGY RESOURCE AND ELECTRICITY CONSUMPTION PER CAPITA IN SIDS AND OTHER RELEVANT ISLANDS

An additional area that could benefit from microgrid deployment is sub–Saharan Africa. The World Bank has reported that countries in this region experience annual outages ranging from 50 to 4,600 hours. The cost of backup power, which is heavily linked to diesel prices, varies significantly between countries. For example, Zambia, landlocked, has poor access to oil resources and pays 9 cents per kWh versus the 6 cents from grid power [56]. Nigeria has the highest mean net cost of backup power in this analysis, at a $1.6bn value per year. These costs do not include additional installation and maintenance of diesel generators.

An analysis of some potential locations for wave-powered microgrids has been performed [23]. First, initial sites/communities which could utilise wave power were identified. These were then subjected to criteria about local wave energy density and the presence of Marine Preservation Areas (MPAs) [57]. A summary of this selection process is shown in TABLE 3.3. The presence of MPAs can be particularly restrictive, in some cases coinciding with the largest wave resource.

TABLE 3.3: SUMMARY OF POTENTIAL COMMUNITIES SUITABLE FOR WAVE-POWERED MICROGRIDS

Country/Region	Total communities considered	Communities meeting criteria
Canada	69	38
Alaska	61	23
Hawaii	8 islands	4 islands
Pacific Islands	3197 [58]	880
Antilles	113	9
Vietnam	17 [59]	7

To a varying extent, these communities pay a high electricity price. This is usually driven by a high proportion of diesel usage and either main grid isolation or low electrification rates. Some examples of local electricity prices from these case studies are:

- **Alaska**: Maximum electricity price of $0.45/kWh in Aleutians – some communities exceeding $0.7/kWh [23].
- **Hawaii:** Electricity tariffs vary between $0.31-0.40/kWh on the islands [60].
- **Pacific Islands:** Maximum electricity price $0.80/kWh in the Solomon Islands, the average cost of $0.46/kWh [61].
- **Antilles:** Electricity tariffs mostly fall between $0.34-0.41/kWh [62].
- **Vietnam:** Off-grid tariffs between $0.11-0.18/kWh, which are regulated [59].

In some of these communities, growing levels of renewables are being used on local grids, which would provide competition for ocean generation. Some examples of renewables pricing for these areas are:

- **Indonesia**: Competition from wind, solar PV, bioenergy, hydropower and geothermal, with prices varying from $0.075-0.2/kWh within these options [63].

- **Hawaii**: Competition from wind, solar PV, hydropower and geothermal, with prices varying from $0.104-0.175$/kWh within these options [60].
- **Pacific Islands**: Various grid-connected renewables vary in price from $0.05-0.7/kWh, with the hydro and large-scale wind being the lowest cost options [64].
- **Antilles:** Competition from wind, solar PV, hydropower and geothermal, with prices varying from $0.07-0.3/kWh [62].
- **Vietnam:** The main options for the communities considered are wind and solar PV. Wind prices are estimated at $0.1-0.11/kWh [59].

KEY STAKEHOLDERS

National governments will be relevant partners for these types of projects. Microgrids powered by local renewables can be beneficial in two types of political circumstance when covering a range of domestic and commercial properties:

- Reducing subsidies from central government to remote areas of the country to mitigate high fuel costs.
- Reducing the energy costs across most of the country in cases where a microgrid can provide large coverage (SIDS)

Additional potential beneficiaries and interested parties, considering specific site-based grid installations, include:

- Defence bases
- Data centres
- Hospitals and healthcare facilities
- University campuses
- Local government
- Utility companies
- Regulators
- Global investors/World Bank

Various types of sites may be able to benefit from the installation of a microgrid. This arrangement could offer greater energy security and various economic benefits, such as increased efficiency and the ability to control demand response and participate in flexible services [65].

Some innovators and financiers are becoming involved in microgrid and renewable energy deployment. For example, Singapore's CleanGrid Partners has announced plans to create a $100m microgrid portfolio within a 3–4-year window, targeting 125 million people in Southeast Asia who lack access to reliable and affordable electricity services [66]. While many of these use non-renewable sources such as diesel, CleanGrid Partners have stated that they investigate tidal power use.

Australian wave energy developer, Carnegie Wave Energy, is looking to develop a microgrid project in Mauritius [67]. This project is also intended to incorporate the neighbouring island of Rodrigues. Carnegie is also involved in a microgrid project at Garden Island, off the coast of Western Australia [68]. This project will produce electricity for a nearby naval base [69]. The first project remains in scoping stages, looking to deliver a roadmap [70], and the Garden Island project was redesigned to use the solar resource, with plans to incorporate wave energy at a later date [71]

Another innovator, Eco Wave Power, builds a plant on the coast of Gibraltar and has developed a pipeline for projects in multiple other countries [72]. The Gibraltar plant was built and has been running commercially for more than three years, feeding electricity onto Gibraltar's microgrid under a government's power purchase agreement.

Additionally, a marine turbine has been supplementing a microgrid's energy supply Ouessant Island (off the Western coast of France), producing 15% of the electricity requirement, and replacing diesel generators [73]. The pipeline has another two additional turbines to be established by 2021, and there is an objective to be generating 100% renewable energy in these areas by 2030.

Nova Innovation has deployed a tidal energy array at Bluemull Sound in Shetland, replacing diesel generation. The capacity of the site lease is 2MW with a duration until 2041 [74].

Everoze Partners produced an example economic case for a microgrid application for Crown Estate Scotland [75]. This was a hypothetical case study with potential applications to microgrid installations on remote islands in Scotland. The system modelled was a 200kW wave device connected by private wire to a 100-home island to offset diesel consumption and increase economic activity. With an initial mixture of diesel and wind power, wave CAPEX must be lower than £2m/MW to reduce the overall system cost. For a diesel-only grid, this benchmark increases to £4.25m/MW. The economic case further improved by reducing the installed capacity and creating cross-vector demands (such as hydrogen production), and allowing for additional revenue sources (sale of surplus energy). Additionally, Everoze acknowledged that their analysis did not consider the cost-benefit of increased economic activity and scored this proposition as a medium viability option.

INVESTMENT MODELS IN PLACE

A challenge for securing investments in microgrids is that they can be highly specific and not scalable. This is a similar situation to the Independent Power Producer market of the 1980s and 1990s. Increasing investor familiarity with risks, mitigation strategies, and the performance of existing projects will help the industry move towards a standard valuation of the technology as a whole. Without these advancements, most funding for microgrid projects will continue to derive from public and governmental sources [76].

The Carnegie Wave Energy project in Mauritius secured funding of $583,500 [67]. This funding was controlled by the Mauritian Ministry and Finance and Economic Development. The remaining balance of $133,500 was contributed in-kind from Carnegie. The Carnegie project at Garden Island was funded through a combination of equity, debt and grant funding, including a five-year, $20m loan facility from the Clean Energy Finance Corporation and an $11m grant from the Australian Renewable Energy Agency [77].

In Gibraltar, the Eco Wave Power project gathered funds from private investors [58] and received revenue from the European Union's European Regional Development Fund [78].

The US Department of Energy (DOE) has announced up to $38m of funding for a new programme, looking to design economically attractive hydrokinetic turbines (HKT) for tidal and riverine currents [79]. The programme is called Submarine Hydrokinetic and Riverine Kilo-megawatt Systems and is looking to produce hydro-kinetic turbines suited to micro-grid applications which can supply energy to remote communities, among other applications.

PESTLE DRIVERS

TABLE 3.4: PESTLE DRIVERS FOR MICROGRIDS

Factor	Description
Political	• Central government provision of fuel subsidies programmes that support isolated areas. • Interest in protecting critical infrastructure (data centres, health centres, defence bases) • Ability to establish energy independence/reliability on imported fuels
Economic	• Fuel transport costs • Interruptions in power due to fuel supply impacts the local economy. • Ability to cost optimise local power networks. • The ability of the local grid to engage in flexibility services and stack revenue streams
Social	• Quality of life affected by grid blackouts. • Imported fuel costs may be high due to transportation restrictions, which impacts customer bills
Technological	• Power to microgrid must be reliable. • Generating source must be flexible. • Generating source is competing against other renewables and must be efficient
Legal	• Control and regulation of microgrid operator • Procurement of additional services from the microgrid will require legal oversight
Environmental	• Replacement of diesel will ensure higher air quality. • Climate change is driving extreme weather events, which are increasing the chances of local grid blackouts. • Reduced carbon emissions

INDICATIVE MARKET READINESS

There is an opportunity to utilise marine power in small-scale microgrids, either by replacing an existing diesel power source or attaching a new project. In terms of the market, it is expected to expand rapidly as communities in developing countries have increased electricity demand. An ideal target for marine technologies would be in Small Island Developing States (SIDS), having access to ocean energy resources and the requirement for a small-scale grid. However, these locations are also likely to be heavily affected by requirements to ship liquid fuels over long distances, increasing local electricity prices than areas where long-haul fuel transport is not required.

Inevitably, there will also be competition from other renewable sources, which might currently be cheaper and have a more established market. However, given the inherent variability of solar and wind energy, there is potential for a secondary power source to become involved in any project, whether that be the utilisation of storage or another renewable generator. Additionally, marine technologies are advantageous for SIDS since they have relatively low landfall. The optimal mix must be determined by each site's geographic conditions and the ability to provide a reliable electricity supply.

3.2.4. OFFSHORE AQUACULTURE

The Blue Growth strategy, laid out by the European Union (EU) in 2012 [80], identified two key sectors with significant economic potential: ocean energy and aquaculture. Marine aquaculture is an increasingly prominent means of food production. According to the Food and Agriculture Organisation (FAO), global seafood demand is expected to exceed supply by 40 million metric tonnes by 2030 [81].

While the demand for seafood is growing, nearshore fish farms cannot expand due to restricted land use [81]. There are additional concerns related to disease propagation and contamination of natural fish stocks in cases of escapes from the farm. Moving further offshore is seen as a potential solution, allowing the scale of aquaculture farms to increase. However, this industry still requires energy to power monitoring equipment, navigation lighting, fish feeders and refrigeration of the harvested product.

These power needs have historically been met by diesel and kerosene generation [29]. By converting to renewables, the industry could reduce air and water quality impacts and achieve lower operating expenditure. In addition, marine renewables have co-location advantages with much of this industry, particularly focusing on farms that are distant from landfall and provide a more reliable power output than other renewable technologies.

INDICATIVE MARKET SIZE

Aquaculture in 2018 represented 46% of the total volume of global fish production [82]. As shown in FIGURE 3.13, capture production has been relatively static since the 1980s, with growth in aquaculture responsible for meeting further demand increases related to a rising world population.

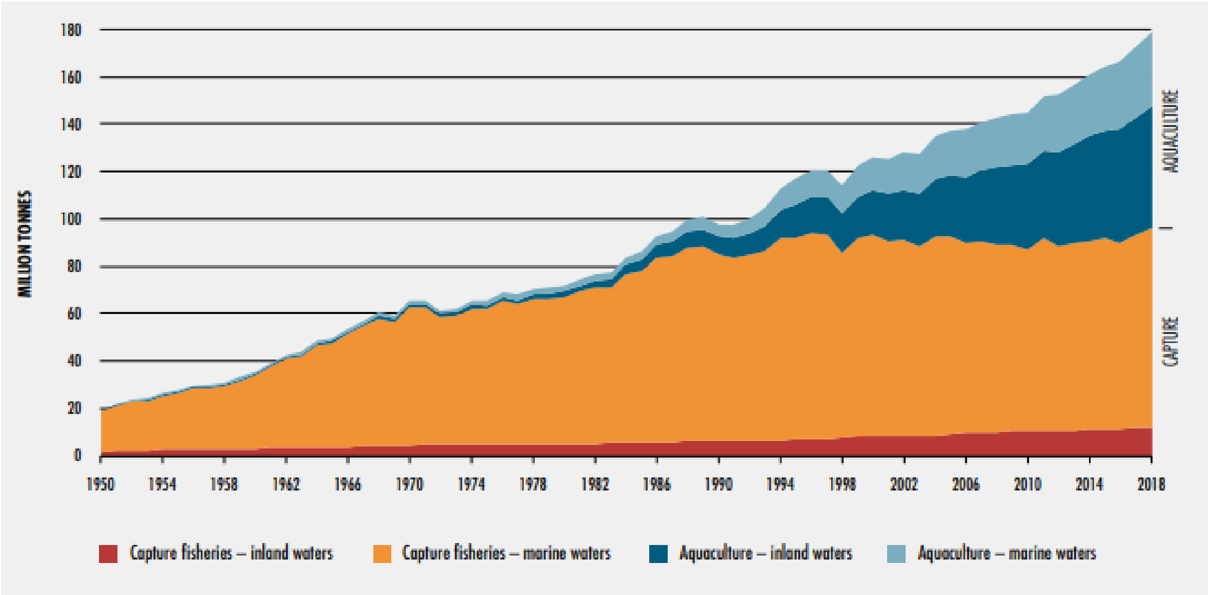


FIGURE 3.13: WORLD CAPTURE FROM FISHERIES AND AQUACULTURE PRODUCTION (1950-2018) [82]

Based on continued higher demand and technological improvements, total world fish production (combining capture and aquaculture) is expected to continue to expand outwards to a projection period of 2030. This expansion is 15% over 2018 capture volumes and will largely be driven by increased supply from aquaculture methods. The overall growth of aquaculture in this period will be 32%, with an annual growth rate of 2.3%

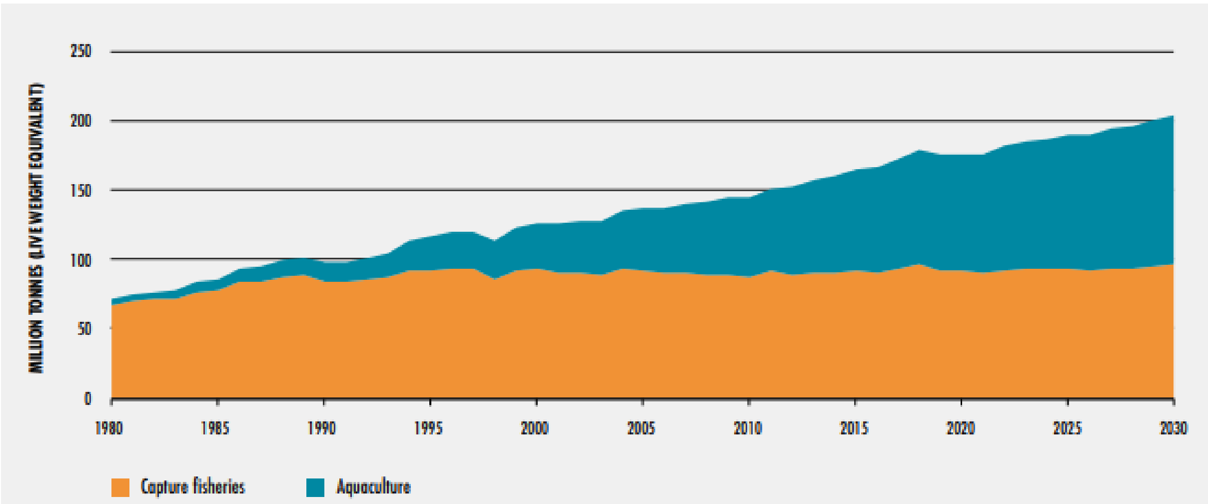


FIGURE 3.14: WORLD CAPTURE FROM FISHERIES AND AQUACULTURE PRODUCTION (1990-2030) [82]

TYPICAL SIZE OF PROJECTS

Aquaculture farm electricity demand depends heavily upon the specific processes required. These might vary depending upon the quantity of aquaculture production, the facility location, and the species which is being farmed. Three case studies [83] produced different loads and energy consumptions, shown in TABLE 3.5. These three samples vary from usage characteristics on par with an average family home to energy costs which run into thousands of pounds annually. As a comparative benchmark, the average UK household electricity demand is 71kWh/week [84].

TABLE 3.5: ENERGY USE CHARACTERISTICS OF THREE SAMPLE AQUACULTURE FARMS

Aquaculture type	Rated total load (kW)	Total load /week (kWh)	Highest consumer
Pacific Oyster Farm	9.3	79.3	Purification system
Rainbow Trout Farm	23.3	280.7	Aeration system
Marine Recirculation Farm	90.5	13,767	Recirculation system

An example from a salmon farm in Norway illustrates daily and seasonal demand variations expected in this industry [85]. Baseline demands (monitoring equipment, heating, kitchen equipment) stand at 4-5kW, whereas the peak is typically 40-50kW. In June, only baseline demand was present because no salmon were kept on the farm, and so the feeding process was not using energy. This feeding system is responsible for more than 50% of usage on the farm. There are also significant fluctuations across days, accounted for by weather conditions and sporadic usage of some equipment.

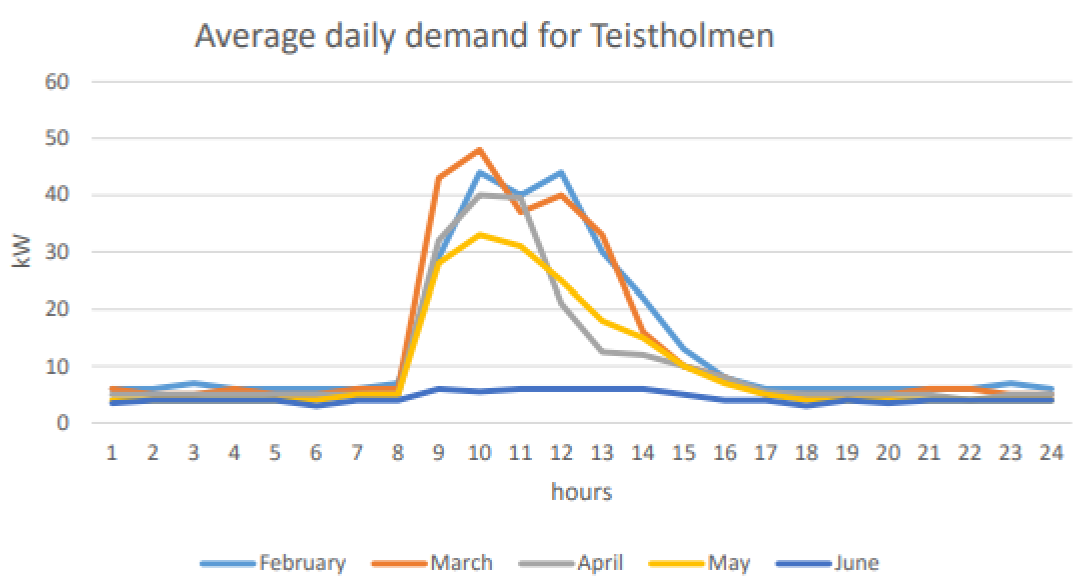


FIGURE 3.15: AVERAGE DAILY DEMAND AT TEISTHOLMEN FISH FARM [85]

GEOGRAPHICAL LOCATION

Asia dominates the global aquaculture market. China produced over 60% of the world's food fish and almost 50% of its algae in 2016. Aquaculture finfish is more spread between Asia (57%) and Europe (28%), as shown in FIGURE 3.16.

Areas that could benefit from integrating marine energy technologies in aquaculture include Europe, China, the Philippines, Japan, Taiwan, Indonesia, New Zealand and Canada. All of these countries have a large production of finfish and good ocean energy resource [15].

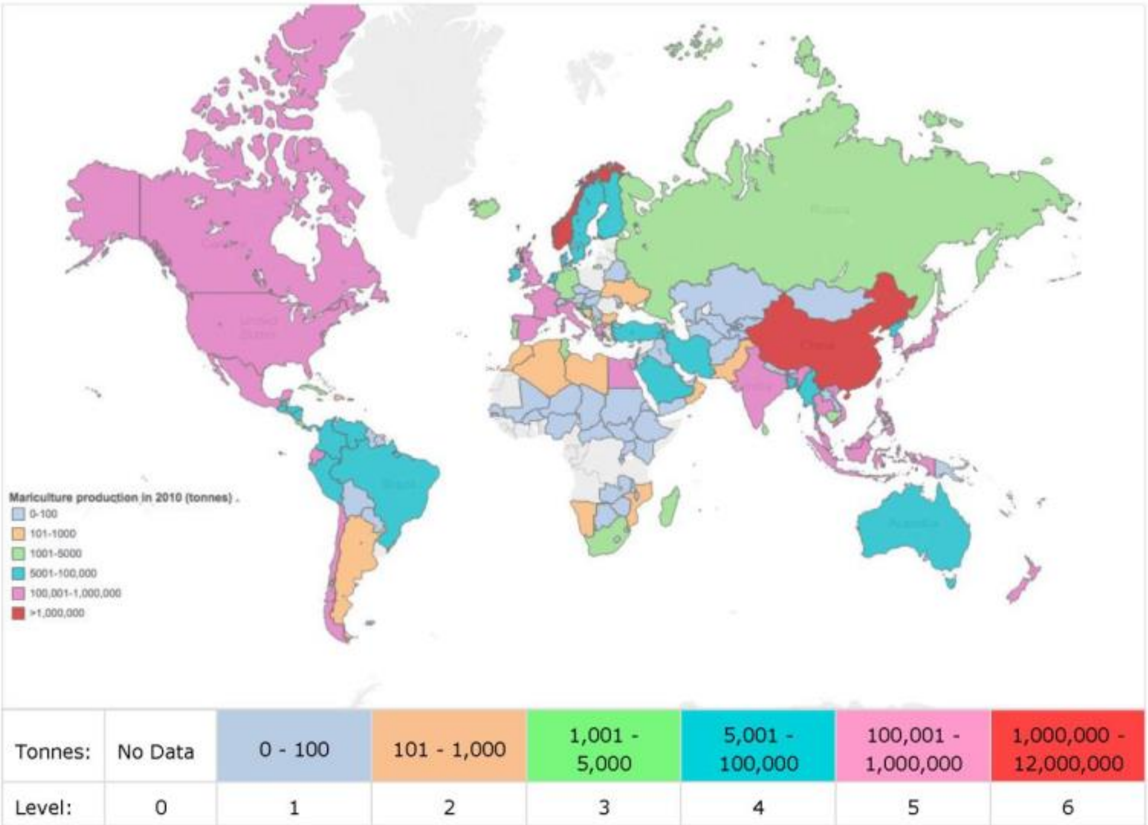


FIGURE 3.16: GLOBAL MARICULTURE PRODUCTION BY 2010 [86]

A global market analysis has been produced for finfish production coupling with wave energy [23]. Finfish growth is focused on because energy demands are more intensive than shellfish and crustaceans. This presents a greater demand for wave energy to meet. The analysis of these markets is displayed in FIGURE 3.17. The size of the bubbles in this plot represents overall production in terms of finfish volume. Chile represents one of the more promising markets, with Australia, New Zealand, and Norway also significant. The market in Spain has a poor crossover between wave resource and farm location, whereas freshwater fish dominate the United States market, so energy resources are cheaper.

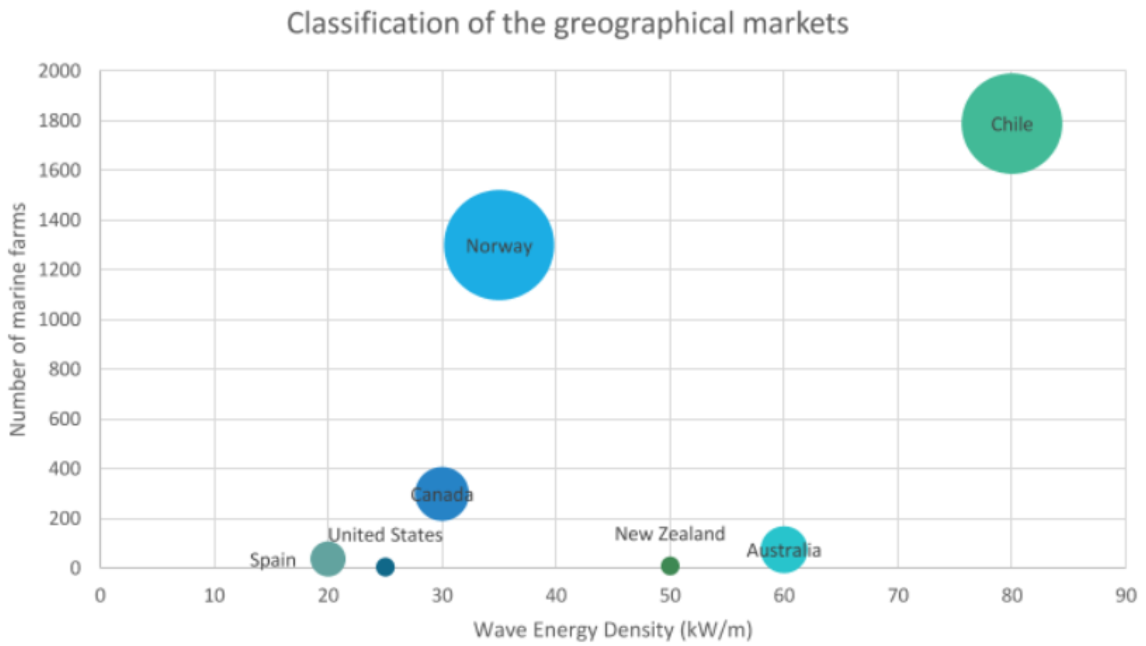


FIGURE 3.17: MARKET ANALYSIS OF GLOBAL FINFISH AQUACULTURE, CONSIDERING WAVE ENERGY DENSITY AND NUMBER OF FARMS [23]

KEY STAKEHOLDERS

Stakeholders for these types of projects include:

- National/local governments
- Food industry and supply chains
- Food and agriculture organisation – United Nations
- Policymakers for a national government
- Global investors/World Bank
- Conservation and environmental bodies
- Trading bodies (E.U.)

Some ongoing or upcoming projects in this area include:

- A consortium composed of two companies, Wave Dragon and Seaweed Energy Solutions (SES), and an independent organisation Bellona Foundation, are working on a joint wave-aquaculture project [87]. This is a seaweed farm with an identified site off the southern coast of Wales. Electricity from the wave energy converters (WECs) will also be exported to the grid.
- Albatern and AquaBioTech Group are developing a project where wave energy generators are installed close to a fish farm [87]. The wave energy converters provide power for offshore fish cages' energy needs and support the renewable energy use of the farm facilities—the planned location for this pilot in Malta. There is also a scope to include the export potential to the Maltese grid, with an expansion of generator numbers.
- Smalle Technologies are a company which produce wave power electricity generators. One of the stated immediate applications is for use in fish farms. Currently, Smalle Tech has real-

time monitoring systems deployed in sea farms and automated control systems in in-land farms [88].
- Guangzhou Institute of Energy Conversion (GIEC) has developed an aquaculture platform that generates power from waves motion [89]. This design has received patents from China, Japan and the European Union. The 120kW facility was launched in December 2015.
- In 2018 SINN Power signed an agreement with an aquaculture company, Fazenda de Camarao, to build a wave energy demonstrator in Cape Verde [90]. The planned installation would develop a customised off-grid system for the shrimp farm used, with wave converters backed by solar arrays. This forms part of Cape Verde's plan to run on renewable energy by 2025 completely.

Everoze Partners produced an analysis of a hypothetical aquaculture farm being supplied by wave power for Crown Estate Scotland (as with the example in the micro-grids market detailed in the previous section) [75]. The setup is identical to their hypothetical private wire microgrid connection but with a commercial enterprise as the customer. An identified benefit was increased shielding by wave generators of the core asset, increasing farm lifetime. In addition, it was more economically viable to run a combination of diesel and wave due to large fluctuations between peak and minimum demands. Cost parity for this modelled was achieved below wave CAPEX values of £4.9m/MW.

Due to the commercial favourability of a hybrid energy supply, there could be a requirement to involve a consultancy/third party to manage the energy requirements for the aquaculture farm. The case study also notes that aquaculture farm locations are typically chosen for sheltered conditions, which do not have excessive wave potential. The flip side of this is that coupling these technologies could open up greater ocean areas for future aquaculture farms.

Further analysis was performed for a fish farm based on data taken from the Teistholmen salmon farm [85]. This compared a diesel system, a hybrid consisting of wind, solar, storage and diesel, and a 100% renewable system consisting of wind, solar and storage. Wave is not included in the energy mix, but this case study provides a good comparison of hybrid vs pure energy supply. The key figures are presented in TABLE 3.6.

TABLE 3.6: OVERVIEW OF SYSTEM CHARACTERISTICS FOR DIFFERENT ENERGY SUPPLY [85]

	NPC (£)	CC (£)	COE (£/kWh)	RF (%)	EE (%)
Pure diesel	837,860	60,000	0.491	0	7.5
Hybrid	701,176	281,769	0.411	34	4.7
Pure renewable	1,382,559	1,009,590	0.810	100	41.4

The hybrid solution is the cheapest of the three considered. Despite a higher capital cost, fuel costs are reduced to 47% of the total project cost, down from 62% in the pure diesel case. On the other hand, the pure renewable solution becomes very expensive due to the batteries' cost to mitigate against inconsistent supply of electricity.

INVESTMENT MODELS IN PLACE

The Wales seaweed farm and Malta fish farm mentioned in the previous section were funded as part of the Marine Investment in the Blue Economy (Maribe) project, which derives from the European Commission's Horizon 2020 Blue Growth programme [91]. The nature of this funding was to encourage marine projects which combine multiple activities. In addition, trading bodies such as the European Union take an active interest in aquaculture projects' funding due to impacts on legislation such as the Common Fisheries Policy.

Additional funding sources for the Malta fish farm project include private investment, public matched equity, and R&D grants from national governments [92].

The Cape Verde shrimp farm project was funded by the aquaculture company receiving the power generated, with the local port authority and university's support.

PESTLE DRIVERS

Factor	Description
Political	• Interest in supporting local/national industry. • Motivation to increase trading position in a global market
Economic	• Creation of sustainable growth within the fishing industry • Competition from other renewables sources
Social	• The increasing world population is driving an increasing demand for food. • Changing trends in the diet in response to carbon emissions restrictions • Increased jobs can be created in coastal locations
Technological	• Power must be reliable to maintain business operations. • There is a requirement for flexible supply to match demands. This can be achieved through a flexible power system and monitoring equipment. • Other renewable sources will be competitive in this market
Legal	• Implications for common fishing areas and the policies and legal framework controlling them
Environmental	• Replacement of diesel, which can harm water quality. • Maintaining fish populations in open waters to a sustainable level • Reducing carbon emissions

INDICATIVE MARKET READINESS

Marine power provides the aquaculture industry with an opportunity to reduce harm to air and water quality and reduce reliance on imported fuels. The competition will be primarily from other renewables sources, particularly solar PVs and wind turbines, which could work towards these same goals. Marine power could enable significant growth of aquaculture farms at large distances from the nearest landfall, having better co-location advantages and accessibility than competing renewables.

Factors that will limit the reach of marine energy in aquaculture include the cost compared to other renewables and the currently available level of product maturity. Additionally, aquaculture farms and marine generation may need to be co-located in harsh environments to guarantee the best performance, resulting in system failure due to mechanical stresses.

However, the strong colocation of aquaculture farms and marine resource would indicate that there is potential. This would need to be determined on a case-by-case basis to assess suitability based on the required load profile, the deployment environment, and the facility's size.

3.2.5. DESALINATION

Desalination is a process where salts and other minerals dissolved in saline water are removed to produce water for further uses. These uses may vary from human consumption to industrial processes to irrigation in agriculture, depending upon the processing level.

Desalination is a highly energy-intensive process. One desalination method is reverse osmosis, consisting of a system with a semi-permeable membrane and a pump, which pressurises the feedwater beyond osmotic pressure. This method accounts for 69% of the volume of desalinated water produced globally [93]. The energy requirements are mainly driven by the primary membrane process, with other factors such as pre-and post-filtration being secondary concerns [52]. Energy is also required for the pumping associated with water delivery.

Conventionally, fossil fuels have been used to provide the energy required to operate desalination techniques. Only 131 desalination plants worldwide (corresponding to 1% of current global water desalination capacity) are powered using energy from renewable sources [94]. These are predominantly made up of solar and wind-based technologies. These factors indicate significant potential for implementing marine technologies in desalination techniques, particularly given the strong colocation advantages of desalination plants that use seawater.

INDICATIVE MARKET SIZE

There are 15,906 operational desalination plants that have a production capacity of 95.37 million m^3/day. The trend in worldwide production capability is shown in FIGURE 3.18 [93]. The overall trends in production capacity indicate a growing market. Additionally, the breakdown by technology indicates that the predominant desalination method is reverse osmosis, replacing thermal processes typical of the industry's early stages.

The energy consumption of these sites has fallen from 8 to 4kWh m^{-3} [95]. A further estimate of a desalination facility in Carlsbad, California, reported specific energy consumption of 3.6kWh m^{-3} [96], comparable to the lower end of this range. Given the indicative production capacity, these estimates would correspond to the potential global energy usage of 125TWh/year.

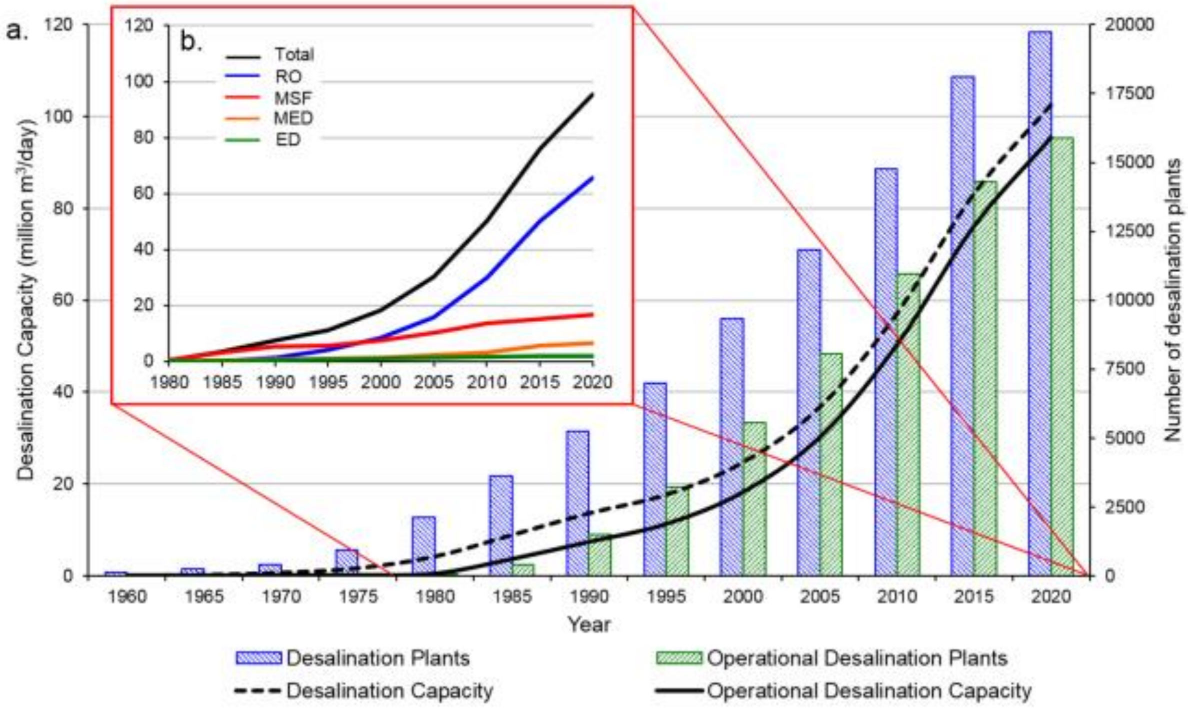


FIGURE 3.18: TRENDS IN GLOBAL DESALINATION (A) NUMBER AND CAPACITY OF TOTAL AND OPERATIONAL DESALINATION PLANTS AND (B) OPERATIONAL CAPACITY BY DESALINATION TECHNOLOGY. TECHNOLOGIES INCLUDED ARE REVERSE OSMOSIS (RO), MULTI-STAGE FLASH (MSF), MULTI-EFFECT DISTILLATION (MED) AND ELECTRODIALYSIS (ED) [93]

This market is predicted to grow in the future. This is because the world population, and water usage per capita, will both continue to rise. As a result, overall water demand is expected to increase by 58% by 2030 [97]. However, freshwater sources may not be able to keep up with this increasing demand, a factor which climate change effects could further exacerbate. To support demand increases, desalination capacity must, therefore, also increase. The anticipated growth curve for this industry is shown in FIGURE 3.19.

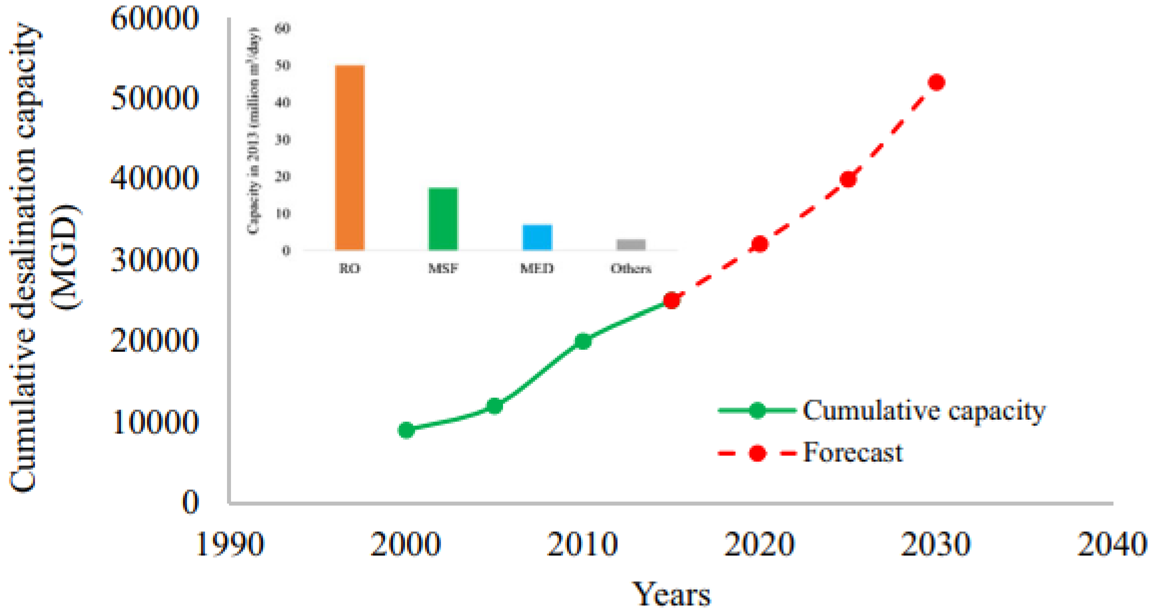


FIGURE 3.19: GLOBAL CUMULATIVE DESALINATION TREND AND FORECAST, MEASURED IN MILLION GALLONS PER DAY, UP TO 2030 [97]

TYPICAL SIZE OF PROJECTS

A specific desalination plant's energy requirement depends upon multiple factors, including the process used, the nameplate size, and the salinity of the feedwater. As a result, desalination plants in isolated areas, such as SIDS, may only have capacities of a few tens of cubic meters per day. For example, a desalination plant at La Graciosa in the Canary Islands has a production capacity of 75m^3/day [98]. At the other end of the scale, the Shuaiba 3 development close to Jeddah, Saudi Arabia, has a production capacity of 880,000m^3/day [99].

Assuming an energy requirement of 4kWh/m^3, these two extreme values correspond to average loads between 12.5kW and 146.4MW. If entirely powered by marine technologies, assuming a capacity factor of 30%, this would require installed capacities of 42kW and 488MW, respectively. The size of the installation required may determine the most appropriate renewable technology in any particular instance, in addition to other constraints.

The sector is looking to reduce its carbon footprint. This could be achieved by reducing specific energy consumption, leading to a lower requirement for electricity generation (i.e. energy efficiency improvements). However, these savings may be small, given the efficiency savings that have already been implemented and the expected growth in demand across the sector. Therefore, the demand for energy in desalination processes may not be reduced by a great proportion, so it will be easier to decarbonise the existing energy requirements by coupling them to renewable, zero-carbon electricity sources.

GEOGRAPHICAL LOCATION

FIGURE 3.20 shows the global distribution of desalination facilities with a production capacity of over 1000m³/day [93]. A large presence can be seen in the United States, China, Australia, Europe, the Middle East and North Africa. Areas that lack the desalination industry include South America and sub-equatorial Africa. As can be seen, many of these plants cluster around coastlines, making them good candidates to access marine energy. Municipal water demands tend to be more prevalent in North Africa and the Middle East, whereas other geographical regions tend to have a reasonable industrial demand for desalination plants.

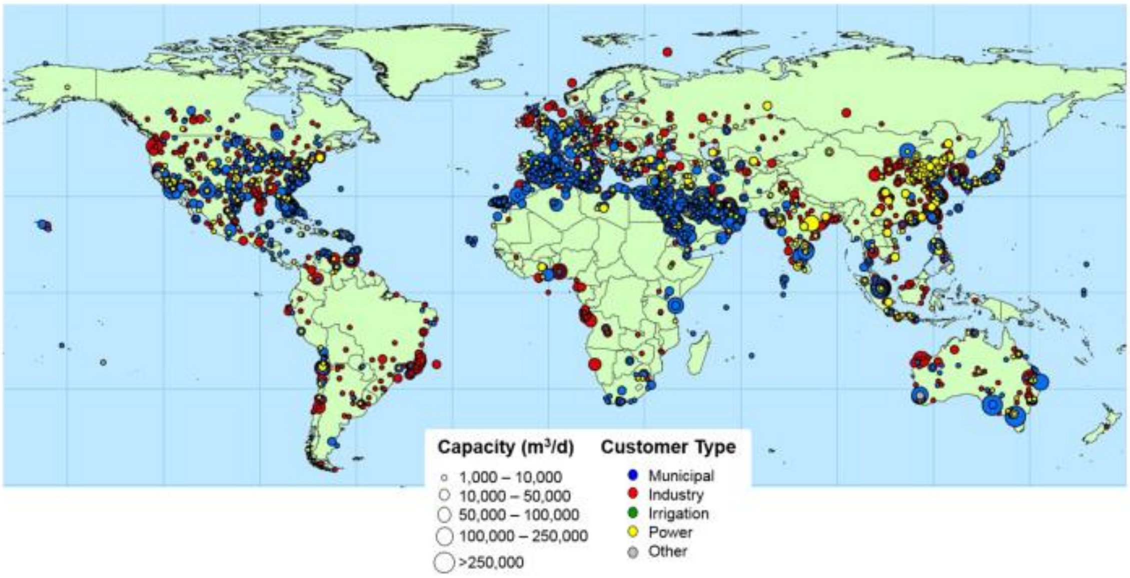


FIGURE 3.20: GLOBAL DISTRIBUTION OF OPERATIONAL DESALINATION FACILITIES AND CAPACITIES BY SECTOR USER OF PRODUCED WATER [93].

Almost half of the global desalination capacity is located in the Middle East and North Africa region (48%) [93]. Within this region, the major producers are Saudi Arabia (15.5%), the United Arab Emirates (10.1%) and Kuwait (3.7%). There are also significant contributions from the USA (11.2%) and China (7.5%). Additionally, the majority of desalination capacity (71%) is located within high-income countries.

Investment in desalination facilities could be accelerated by water shortages that result from climate change. For example, a potentially growing market in South Africa has recently experienced a 'Day Zero' threat, whereby taps to homes and businesses would have to be switched off, with controlled access to water [100]. To mitigate, Cape Town residents were asked to consume 50 litres of water per day, which is less than one-sixth of the average consumption in the USA. These shortages resulted from a combination of local population growth and climate-driven drought conditions.

KEY STAKEHOLDERS

The varied requirements for supplies of freshwater mean that multiple stakeholders may benefit from these projects, including:

- National/municipal/local governments
- Power and water utilities
- Industry
- Department of Energy
- Air and naval bases/military installations
- Agriculture
- Isolated coastal tourist resorts
- Regulators controlling the water utilities (where applicable)
- Global investors/World Bank

Some examples of ongoing and planned projects in this market include:

- Implementation of a reverse osmosis plant in Cape Verde, using Resolute Marine Energy's Wave2O technology, has been planned for 2020-21 [101]. The group of islands being targeted suffers from severe water scarcity and relies on desalination systems powered by diesel to fuel 85% of its water supply [102].
- Perth Wave Energy Project (PWEP) is an offshore development located in Garden Island, Western Australia, developed by Carnegie Wave Energy [103]. Stage two of this project involves connecting a pilot desalination plant constructed by MAK Industrial Water Solutions. This installation also links to a micro-grid which powers the Australian Department of Defence site HMAS Stirling.
- Academic researchers have developed a wave energy converter that can power a reverse osmosis desalination system called Overtopping Breakwater for Wave Energy Conversion (OBREC) [104].
- Seabased and Infocom Connect are collaborating on a wave power installation (5MW) to provide the Canary Islands desalination plant [105]. The idea is that this pilot plant may expand to meet other needs, including supplying the local grid.
- A solar-powered desalination plant was built in Witsand, South Africa, to mitigate against further drought events after water shortages in 2018 [106]. There are four desalination plants in the Western Cape province, but this is the first to be powered by renewable energy. The plant was designed to deliver 100kl of water per day. The plant was operational since December 2018 and currently produces an average of 150kl per day, with two-thirds of production from solar energy [107].

INVESTMENT MODELS IN PLACE

The Cape Verde desalination plant was given $930,000 in a grant by the African Development Bank [108]. Resolute Marine Energy has also secured funding from the US Dept. of Energy and other investors but stated that they still require a total of $9m investment to move forward with future growth plans [101].

In early 2019, the U.S. Department of Energy announced its Waves to Water Prize competition to spur innovation in wave energy-powered desalination systems [109]. This was designed to create small, modular systems suitable for remote coastal and island communities. A $2.5m prize was allocated to provide a pathway from the initial concept to a field-tested system. 20 winners for chosen later in 2019 for design stage funding, from a field of 66 eligible submissions [110]

Carnegie Wave Energy received a $13.1m grant for the PWEP project from the Australian federal government under the emerging renewable programme (ERP) [103]. The Western Australian government provided a further $7.3m under the low emissions energy development (LEED) programme). Private equity funding of $16.2m from the Australian Special Opportunity Fund, managed by Lind Partners, was also secured. The demonstration cycle for this project has since concluded [111].

The Witsand desalination plant in Cape Province was funded by a 50:50 split between the French and Western Cape provincial governments [106]. The technology was developed by a French company (Mascara Renewable Water), with water provided by a local company (TWS-Turnkey Water Solutions). The total cost of investment was R9m, equivalent to about £430,000.

Resolute Marine Energy published three proposed business plans for operating a desalination plant in South Africa [112]. In summary, these were:

- Wave-driven desalination, with electricity produced to run the plant. This could be viable for application to US government grants to cover development and testing costs. The approach would require a desalination partner.
- Hydraulic power to operate the desalination plant, with the business model focused around selling water rather than electricity. This was thought to be more appealing because the margins for water production were higher. However, this strategy would require private sector investment, which is more difficult to obtain concerning wave energy. RME have identified that most of their funding comes from the public sector, particularly the US Dept. of Energy and the Dept. of the Interior. Again, this approach would require a desalination partner.
- A black box solution, where RME owns both the energy conversion system and desalination plant. This would produce both electricity and freshwater. This could be technically challenging and require additional funds to cover the installation of a desalination plant. The water produced could then be sold directly to local communities, bypassing the utility providers.

The preferred model to follow may differ depending upon a geographical location. For example, if there is only one electricity company to sell to, then this is unlikely to yield a competitive market by following the first option. Additionally, if the supply market is already crowded, then being undercut would be a higher possibility. Finally, a black box solution is only preferable if the market lacks an established water utility operator – if one exists, it might be beneficial to utilise this expertise.

PESTLE DRIVERS

TABLE 3.7: PESTLE DRIVERS FOR OFFSHORE AQUACULTURE

Factor	Description
Political	• Local and national governments are responsible for water supply in arid areas of the world. • Long-term climate change effects on water availability, particularly where agriculture exports are affected
Economic	• An alternative supply of freshwater could boost the economy of coastal tourism resorts. • The industry relies upon freshwater supply, without which it may stagnate. • There is competition for power supply to desalination plants. For example, solar may be viable in many locations. • The ability of a desalination power provider to compete and revenue stack.
Social	• An increasing world population is driving higher water demand. • Supplies of cleaner water in areas of scarcity could drive health improvements. • Lower water costs for citizens of countries that currently have shortages
Technological	• Competition from other renewables • Supply must be reliable to ensure the business is profitable – for the water-based model, can be mitigated by water storage
Legal	• Water quality standards must be met (controlled by utility regulator)
Environmental	• Climate change is increasingly impacting water scarcity. • Replacing diesel can lead to improvements in air quality. • Reduced carbon emissions

INDICATIVE MARKET READINESS

Most of the desalination industry's global locations would indicate that solar power is the frontrunner for coupling to these facilities. Currently, 60% of operational desalination plants which use renewables are powered by solar energy [113]. Further competition could come in the form of geothermal energy in certain locations, which has a production profile that would negate storage coupling and provide more reliable operations. However, ocean energy is a viable option for the most common desalination process, reverse osmosis. The strengths of ocean energy in this market may be for water supply in SIDS with less established utility provision.

Wave technologies will need to manage the changes in electricity load created between consecutive waves. Additionally, ocean energy currently has a higher installation cost than other renewable technologies. However, water utility businesses are run on long-term models that guarantee security, and these technologies could play a part if they provide a long-term payoff and provide reliable production. This may be simpler when considering a proposition that sells water, which can be stored more easily than electricity. Additionally, these technologies' low land use and visibility will increase public acceptance in what may be a publicly funded project.

An alternative proposition for a marine-powered desalination plant may be to sell water directly to a local community. This could be more viable in an isolated area, where existing utilities have a lower reach. This smaller-scale model could allow for the proof-of-concept market that ocean energy requires by focusing on areas where the commercial proposition is overshadowed by community concerns such as security of supply.

3.3. SUMMARY OF ALTERNATIVE MARKET FINDINGS

A variety of markets have been identified through which ocean generation technologies may achieve initial deployments. These markets all share potential co-location advantages, which ocean energy, being either coastal or offshore industries. However, on the whole, these are also high-value markets, which experience accessibility issues and typically rely upon fossil fuel imports that have unreliable pricing.

Background information has been presented for each of the following markets:

- Offshore oil and gas platforms
- Coastal resiliency and disaster recovery
- Microgrids
- Aquaculture farms
- Desalination plants

This collation of background information formed part of the business model design and validation methodology and was informed by both desk-based research and interviews with relevant stakeholders. This market research was subsequently used to form a set of business model canvasses. These were subjected to an iterative process, with input from stakeholders and DTOceanPlus project partners.

The final business models from this process are outlined in Section 654. These are generalised business models, which consider abstract customer types without specific details relating to locality or bespoke requirements. These business models also do not strictly align with the markets which have been studied in section 3. Instead, the market segmentation has been reframed to consider three market propositions, which may relate to one or more of the markets considered in Section 3.

4. INNOVATIVE BUSINESS MODELS

The **Innovative business model canvasses** are presented within this section. Initially, business model canvasses were prepared for each of the alternative markets covered in section 3.2. However, following the stakeholder engagement and market testing, this was not considered the most optimal solution for addressing the problem. There was recognition that there were similarities that cut across various markets and that similar business models may need to be applied across these distinct market sections.

The approach taken was to classify these alternative markets into groups – this process is outlined in section 4.1. In addition to identifying common themes, these classifications also provide a clearer sense of progression for ocean generation technologies. Finally, business model canvasses are presented for each of these market segmentations in section 4.2.

4.1. REFRAMING THE MARKET SEGMENTATION

It is possible to broadly categorise the markets studied in this work to consider the technical challenge of implementing either wave or tidal energy. This categorisation does not account for unique aspects of the different markets (e.g. stakeholder groups, environmental impact study requirements, regulation), but it can give some insight into shared technical considerations. The markets studied can be reframed as follows:

- **Primary power for sub-system**: This is applicable for an instance where a subsystem of an application can be matched to a wave or tidal device without additional support. These are typically small-scale applications, which can be matched to ocean energy generation in the **short term**.
- **Partial power for whole-system**: In these instances, the overall demand volume and/or profile are not compatibly matched with a wave or tidal device. The overall system is therefore powered using combined storage, renewable energy and diesel options. Hence, these markets could be targeted in the **medium term**.
- **Resiliency markets for remote communities**: This is applicable for a region with limited power options, which needs to address issues pertaining to coastal erosion, protection from extreme weather events, or recovery from a disaster. These markets should be considered **long-term**, with the first step consisting of consortia formation and stakeholder engagement.

These categories can be summarised in the context of the directly applicable niche markets as per Figure 4.1.

	Primary power for subsystems	Partial power for whole system	Resiliency markets for remote communities
Offshore oil & gas	Electrification of hydraulics and monitoring		
Coastal resilience	Powering sand replenishment vessels	Breakwater generation for port infrastructure	Shoreline management plan
Microgrids		Demonstrator projects	Strategic resiliency plan
Offshore aquaculture		Partial match demand with diesel generators	Adaptable modular solutions to local needs
Desalination		Partial match demand with diesel generators	Adaptable modular solutions to local needs Adaptable infrastructure for sustainable supply

Short term Medium term Long term

FIGURE 4.1: PROPOSED BUSINESS MODELS IN THE CONTEXT OF NICHE MARKETS

4.1.1. PRIMARY POWER FOR SUB-SYSTEM

This type of market requires identifying a sub-system that matches the typical profile from a wave or tidal turbine. This can be thought of as a "niche within a niche", with ocean generation alleviating a problem for a particular aspect of the market's operational requirements.

Sub-systems are more likely to have power requirements in an achievable range of wave and tidal demonstrators, which should allow for a simpler scale-up to commercialisation within this particular market. Additionally, this is a simpler proposition from an operational perspective since interactions across multiple generation types are not required.

The most relevant market from our study is the electrification of oil and gas platforms. Rather than attempting to provide electricity for the entire operation of an offshore rig, which is of a greater scale than most ocean energy demonstrators, potential targets were electrifying existing hydraulic processes and powering monitoring activities. These should have demand profiles that are a more suitable match for ocean generation. Other examples include warning and monitoring systems, which could span several applications. Typically, the target customer will be overseeing large operations, have a reasonable research and development budget, and be looking to address a specific need within their operations.

A potential downside for this market is the lack of redundancy if the proposition is based on simplicity. Therefore, ocean generation will need to prove reliability, particularly for safety-critical applications. This is particularly true for oil and gas applications, where ocean generation will need to meet various conditions to be considered a viable part of operations.

4.1.2. PARTIAL POWER FOR WHOLE-SYSTEM

This type of solution is based on several studies that have concluded that hybrid systems offer the cost-optimal solution for the studied markets. Therefore, there will be a requirement for interaction between multiple generation types. However, there is a lower need to precisely match the supply and demand of ocean generation since a diesel generator will likely perform this function.

This type of solution may be more suitable for demonstrator projects looking to achieve economies of scale by meeting larger portions of an application's base supply.

Many of the markets studied fall under this category – in particular, microgrids, aquaculture and desalination. Coastal resiliency could fall under either whole-system or sub-system category, depending upon the use-case of the electricity generated. For example, breakwater generation could supply partial power for port infrastructure or fully operate sand replenishment vessels. The most likely customer for this market will be a private company or a utility in an industry subject to emissions and/or other environmental constraints.

4.1.3. RESILIENCY MARKETS FOR REMOTE COMMUNITIES

The final category in this segmentation requires a more holistic approach and buy-in from a variety of stakeholders. For example, areas that face risks from climate change and/or unreliable power grids should be identified and engaged with a view to creating a long-term resiliency programme. A strategy should then be pursued in these areas, with input from local actors, which looks to address these needs proactively.

Within this market, ocean energy should create added value above LCOE by providing assurances around the security of supply. Additionally, this can be enhanced by providing whole-systems thinking, which benefits the community – for instance, providing coupled desalination solutions, emergency centres, and coastal defence structures.

The customer, in this case, will likely take the form of a national or municipal government. On the other hand, this model could take the form of a community-owned solution, particularly if the wider infrastructure is being developed around the ocean energy solution being deployed.

This market is considered more long-term than the other parts of this segmentation. This is because:

- Community buy-in is required to determine priorities and market viability. Building these relationships will take time and will most likely be an iterative process.
- The solution complexity is much greater since the added value may derive from the wider infrastructure. Therefore, developing supply-chain and cross-industry relationships will take longer than dealing with a direct, single customer.
- Current coastal resiliency solutions tend to be reactive in nature. This solution would demand a more proactive approach be taken across the board.

The markets from this study that could be related to this segmentation are coastal resiliency, disaster recovery, microgrids, and, to an extent, desalination. The proposed business model for disaster recovery, outlined in section 9.3, is distinct from this proposal because it is a reactive solution. These solutions would require a proactive plan to introduce infrastructure ahead of any disaster occurring.

Despite being the most long-term, this market segmentation probably offers the most direct route to mainstream grid power. To access this market, the generation turbine must prove that it can function within a microgrid, powering multiple applications and be resilient to extreme weather conditions. Once this point is reached, the remaining objective will be to prove that scaling of power is achievable to be utilised on a larger electricity grid and reduction of LCOE.

4.2. BUSINESS MODELS FOR ALTERNATIVE APPLICATIONS

This section presents the proposed business model canvasses for each of the markets outlined in section 4.1. These have been validated through the methodology outlined in section 2 using a mixture of market research, stakeholder engagement and workshops. Also included within each section is the additional plug-in value proposition.

The border colour denotes the business model block that aligns with one of the three lenses of innovation as described in Section 2.

	Feasibility
	Desirability
	Viability

4.2.1. PRIMARY POWER FOR SUB-SYSTEM

VALUE PROPOSITION

TABLE 4.1: VALUE PROPOSITION CANVAS FOR PRIMARY POWER FOR SUB-SYSTEM MODEL

Customer segments/Value propositions	
Customer offerings	‣ Reduction in carbon emissions associated with an aspect of existing operations, enabling the company to meet internal or industry-wide targets. ‣ These will target sub-systems within offshore operations (O&G, defence, marine), where it is challenging to generate power, and the direct access of ocean energy can reduce operating costs. ‣ PPA- long-term (20 years) agreement, mediated through a contractor who fits and maintains the device. The price will be higher than other renewables, with a premium for energy access in remote environments.
Gains/ Gain creators	‣ Meeting emissions targets using technology that can overcome accessibility issues. ‣ Ability to provide extra value through digitisation and automation of processes.

Pains/ Pain Relievers	‣ Mitigation of financial losses due to the introduction of carbon taxes ‣ Lack of options to decarbonise for some offshore sites. ‣ Lower maintenance costs from replacing non-electrified components.
Relevant Markets	‣ Oil and gas platform electrification ‣ Warning systems ‣ Military/defence applications ‣ Autonomous shipping

BUSINESS MODEL CANVAS

TABLE 4.2: BUSINESS MODEL CANVAS FOR PRIMARY POWER FOR SUB-SYSTEM MODEL

Key partners

- Site operators in consultancy model
- Academic collaborators
- National governments – particularly relevant if site is a nationalised asset.
- Third-party consultancies and service providers.
- Trade bodies where relevant.

Key activities

- Investigation of matching supply to demand. Includes consideration of requirements for storage and/or other supporting renewable technologies to balance supply/demand conditions. Appropriate for consultancy model, prior to implementation.
- Assessment of renewables competition (floating wind); ocean energy may be competing with other renewables. Appropriate for a consultancy model considering a more holistic approach.
- Development of relationships between site operators, ocean energy technology developers and intermediate service provider.
- Installation of sea-bed cables.
- Site evaluation to determine the most appropriate turbine placement.
- Transfer of processes from existing fuel supply to ocean turbines.
- Installation of turbines and connecting cables.
- Maintenance of generating assets and connecting cables.
- Replacement of existing components with electrified equivalents.
- Legal and commercial support activities to create PPA contractbox...

Key resources

- Vessels capable of installing subsea cables and ocean turbines.
- Skills force capable of maintaining power supply operations. These could be contracted from the technology supplier or trained employees of the operation being targeted.
- Licensing agreement for the use of technology and seabed
- Purchase agreement for electricity produced.
- Availability of co-location – a suitable neighbouring area with conditions in which turbines can operate (conditions determined before contract initiation).

Value propositions

- Reducing emissions of offshore (remote) operations.
- Increased viability of the sector through meeting carbon targets and extending asset lifetime.
- Reduced maintenance cost through the conversion of unreliable components by electrifying.
- Added value through digitisation and automation of processes.

Customer relationships

- Consultancy model – consistent engagement, through both generation asset holder, asset operators and owners, and third-party consultancy. Monitoring of operational activities to determine optimal solutions for ocean energy generation.
- PPA agreements – minimal interactions regarding strategic use of technology, with conditions set at contract initiation. Direct contract between asset owner and service provider. Maintenance contract requirement with service providers – a channel of communication required to initiate maintenance operations.
- Mediation taking place through offshore operations contractor.

Channels

- Consultants advising on carbon reduction strategy, the role of ocean energy, and providing installation and maintenance services.
- Direct contract negotiation – bilateral agreement.
- Grant-funded projects to initiate trials and provide proof-of-concept.
- Offshore operations contractor tender

Customer segments

- Oil and gas companies with offshore rig operations
- Defence operations
- Offshore monitoring for marine companies
- Shipping
- Academia/Offshore research centres

Cost structure

- Research to develop proof-of-concept design.
- Installation and manufacturing costs.
- Maintenance costs.
- Leasing of land/seabed.
- Insurance.
- Potential storage costs.
- Replacement of components for electrified equivalents.
- Cost of retrofitting monitoring equipment

Revenue streams

- PPA – set price per MWh, including maintenance of generating asset (subcontracted to third-party). Conditions set to long-term agreement (e.g. 20+ years, or to coincide with site decommissioning)
- Consultancy model – expertise used as commodity to determine strategic value of marine technologies within an existing operation. This may not be viable for some technology developers and require a third-party consultancy/service provider. Potential to offer digitisation of existing operations for added value.
- Guarantee and maintenance agreement.

BUSINESS MODEL ASSESSMENT

This is a relevant business proposition for relatively low Technology Readiness Level (TRL) technologies, looking to provide proof-of-concept in a more complex environment. This market is also looking to target remote areas and therefore have a high cost of power. On both counts, this is more suitable for wave technologies than tidal. Companies looking to fund will be large organisations with substantial research and development budgets, looking to target a particular pain within their operations. The largest concern is finding a process that can be matched entirely to ocean generation. Storage could be used to enable this but will raise the cost of the overall project.

These types of projects will require proof of reliability in order to increase investor confidence. This is due to the critical function of some of these applications and the lack of redundancy which a hybrid system could provide.

STAKEHOLDER FEEDBACK

This proposition was presented to a range of stakeholders to gain their feedback on overall attractiveness, feasibility, and their opinion on a realistic timeline for the model to be successfully deployed in the industry. In addition, the proposition was considered from a wave perspective only, considering that it is more immediately suited to this application.

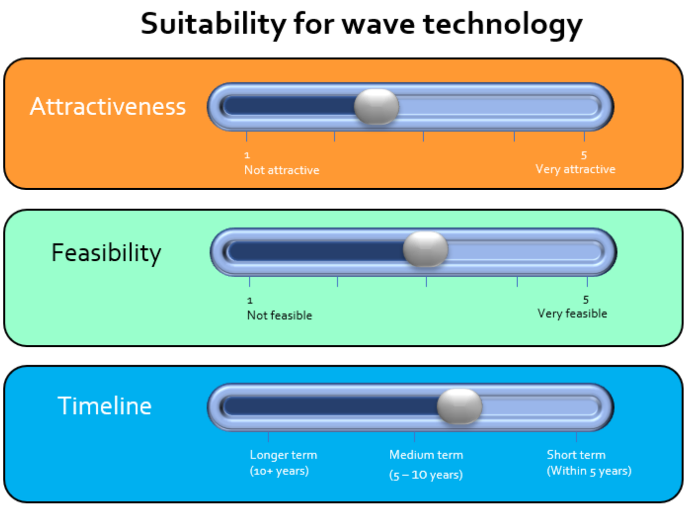


FIGURE 4.2: STAKEHOLDER IMPRESSIONS OF HOW SUITABLE THE PROPOSITION IS FOR WAVE TECHNOLOGIES *[1]

[1] Note that the stakeholder impressions represent testing of the 3 lenses of innovation- Desirability, Feasibility and Viability. Here, the parameters tested: attractiveness forms part of desirability and timeline part of viability.

4.2.2. PARTIAL POWER FOR WHOLE-SYSTEM

VALUE PROPOSITION

TABLE 4.3: VALUE PROPOSITION CANVAS FOR PARTIAL POWER FOR WHOLE-SYSTEM MODEL

Customer segments/Value propositions	
Customer offerings	▸ Consultative service to provide and monitor bespoke service, including project development, power provision, maintenance, and supply-demand balancing. ▸ PPA agreement for a fixed period at a fixed price from ocean generator, to provide power to a whole application as part of a wider energy system.
Gains/ Gain creators	▸ Operating conditions for wave and tidal generators provide better access to offshore sites, enabling offshore and nearshore industries to grow by broadening site availability. This produces better operating conditions and, therefore, a higher quality product. It also enables a larger number of sites and, therefore, productivity. ▸ Enables compliance with emissions targets for the sector.
Pains/ Pain Relievers	▸ Lower fuel price volatility (and therefore more reliable OPEX costs) and better security of supply, particularly within isolated areas ▸ Lower costs from fuel transport ▸ Fewer site visits and self-sufficient operation ▸ Lower environmental risks (diesel spills, emission regulations) ▸ Co-location with ocean generation reduces the requirement for land take
Relevant Markets	▸ Aquaculture ▸ Microgrids ▸ Desalination ▸ Disaster recovery

BUSINESS MODEL CANVAS

TABLE 4.4: BUSINESS MODEL CANVAS FOR PARTIAL POWER FOR WHOLE-SYSTEM MODEL

Key partners

- Wider supply chain and customer bases
- National and local governments – determination of job creation, growth, and strategy
- United Nations governing organisations
- Public funding bodies - EU
- Conservation and environmental bodies
- Trading bodies (E.U.)
- Certification bodies
- Project developer/utility partner

Key activities

- Installation of seabed cables
- Site evaluation to determine optimal turbine placement.
- Identifying extra needs based on supply-demand discrepancy – potential for storage or other renewables to play a role. Will require involvement of third-party consultancy.
- Quantification of pollution benefits – consultation with wider supply chain, involvement of conservation and environmental bodies
- Cost benefit analysis – ocean energy tech only, ocean energy tech + asset structure, asset structure only hybrid, renewable only, diesel only.
- Evaluate which ocean technology can best integrate with asset design and lessons learnt from other integration projects e.g. wave, tidal and wind. Identify additional opportunities to import power from relatively local (but not integrated) sites.
- Environmental impact study to determine effects on fish stock product quality.
- Dissemination to wider trade to demonstrate positive impact of hybrid solution on operations.
- Legal/commercial support to develop PPA contracts across hybrid system.

Key resources

- Local skills force to create turbine facility and connection.
- Availability of suitable conditions for turbine placement – assessed through a site evaluation.
- Software to match electricity production with facility profile and requirement for supporting technologies.
- Purchase agreement for provision of electricity.
- Environmental impact study.

Value propositions

- Low carbon, low polluting energy source replacing diesel generators.
- PPA used to guarantee price and transfer risk from asset owner.
- Lower reliance on external fuel sources, resulting in lower price volatility and higher security of electricity supply.
- In some industries, higher quality product and production volume from renewable energy creates larger margins and more profitable businesses for owners.
- Support and enabler of growth industries.
- More self-sufficient operations with reduced transport cost

Customer relationships

- Partnership with asset owner to enable maintenance access.
- PPA model – limited interactions after signing of initial contract. Maintenance access required.
- Suitability studies required upfront to determine contract conditions.
- Third-party consultancy as an option – service provider and engineering consultant to handle operations and installation respectively.
- Regular touchpoints to discuss optimising operations. Inclusion of consultancy in discussions depending upon solution complexity.

Channels

- Trade bodies
- Multi-disciplinary strategic consultancy (renewable project developer/utility partner)
- Publicly funded trails (Horizon 2020)
- Operations contractors
- Trials based in academic institutions, with industry match-funding

Customer segments

- Aquaculture farms (finfish and algae producers)
- Desalination plant operators
- Microgrid operators
- Powering 'temporary' settlements (e.g. refugee camps)

Cost structure

- Research to develop proof-of-concept design.
- Installation and manufacturing costs – potentially involving third-party consultant.
- Maintenance costs – potentially through service provider.
- Leasing of land/seabed.
- Coupled battery storage.
- Insurance
- PR and comms to highlight potential for reducing the fossil fuel demands of current niche markets.
- Environmental impact study

Revenue streams

- PPA between niche application and offshore energy producer
- Target driven bonuses based on reliability or other KPIs

BUSINESS MODEL ASSESSMENT

The business model presented allows ocean energy to provide partial energy to an alternative application, either supported by other renewables or diesel generation. Wave energy may facilitate offshore markets, whereas tidal energy may be able to couple to near-shore markets. The customer base will largely be private companies, which can benefit from both emissions and pollution reduction. The targeted companies are likely to have smaller budgets than those in the business model outlined in section 4.2.1. Incentives to decarbonise may either be political, financial and societal.

Strengths of this business model include the growing markets which can be addressed, benefits of co-location, increased product value and potential to offer wider services around digitisation and monitoring. In addition, ocean energy can accompany more advanced renewables in hybrid systems, potentially accelerating growth in the sector.

Disadvantages of this market include potentially limited funding and competition from other options. For instance, if ocean energy is looking to provide a secure supply in a renewable mix, it may be competing against storage options that currently have higher market penetration.

STAKEHOLDER FEEDBACK

This proposition was presented to various stakeholders to give their feedback on the overall attractiveness, feasibility, and opinion on a realistic timeline for the model to be successfully deployed in the industry.

The proposition was considered from a wave and tidal perspective separately, considering that both technologies are at different industry readiness rates.

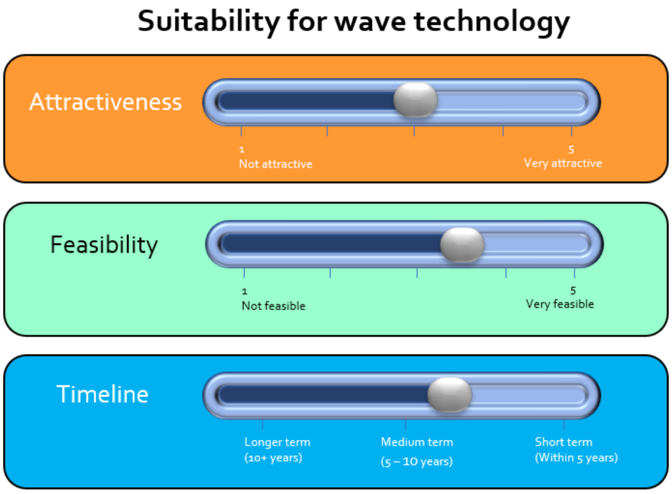


FIGURE 4.3: STAKEHOLDER IMPRESSIONS OF HOW SUITABLE THE PROPOSITION IS FOR WAVE TECHNOLOGIES

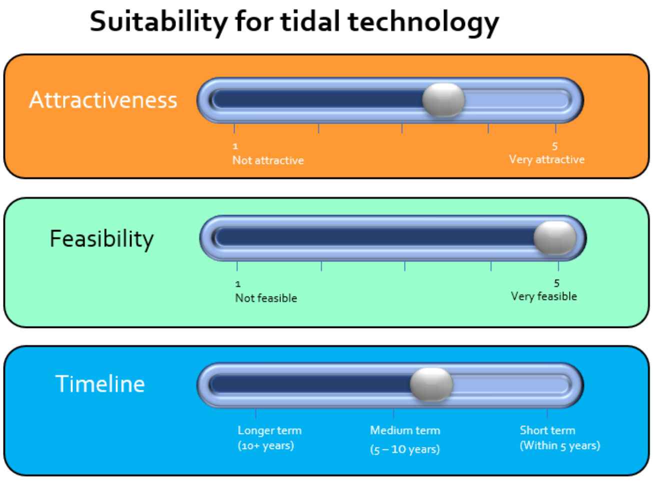


FIGURE 4.4: STAKEHOLDER IMPRESSIONS OF HOW SUITABLE THE PROPOSITION IS FOR TIDAL TECHNOLOGIES

4.2.3. RESILIENCY MARKETS FOR REMOTE COMMUNITIES

VALUE PROPOSITION

TABLE 4.5: VALUE PROPOSITION CANVAS FOR RESILIENCY MARKETS FOR REMOTE COMMUNITIES MODEL

Customer segments/Value propositions	
Customer offerings	• Creation of a long-term resiliency plan which is developed with the local community. • Adaptable and modular solutions to meet specific local needs across a wide set of timescales. • Creation of infrastructure which is powered by low carbon sources. (desalination, health, warning systems)
Gains/ Gain creators	• Economic development through increased investor confidence • Health benefits through the provision of additional healthcare infrastructure (e.g. hospitals, emergency care) • Engagement of local community in solutions.
Pains/ Pain Relievers	• Removal of uncertainty around water and energy supply/prices • Mitigations against extreme weather events • Removal of emissions and pollutants from existing solutions • Lower requirement of land-take, which may be scarce in some coastal or islanded communities.
Relevant markets	• Coastal resiliency • Disaster recovery • Microgrids • Desalination

BUSINESS MODEL CANVAS

TABLE 4.6: BUSINESS MODEL CANVAS FOR RESILIENCY MARKETS FOR REMOTE COMMUNITIES MODEL

Key partners

- Local and national government
- Tourism representatives and committees
- Disaster insurance companies
- Independent shoreline management agencies
- Civil engineering firms
- NGOs/Disaster response groups
- Foreign aid organisations
- Desalination partners

Key activities

- Development of a shoreline management plan, and assessment for suitable roles of ocean energy
- Installation of seabed cables
- Site evaluation to determine optimal turbine placement.
- Identifying wider system requirements, including other renewables and storage options.
- Evaluate which ocean technology can best integrate with resiliency solution and lessons learnt from other integration projects e.g. wave, tidal and wind.
- Creation of networks and infrastructure – includes determination of added value from a local perspective
- Development of emergency response strategies – scenario-based contingencies
- Publication of methodology/framework for resiliency plan development, so that scaling up of market can be achieved.
- Alignment of funding opportunities with long-term plan.

Key resources

- Skills force to create turbine facility and connection.
- Availability of suitable conditions for turbine placement – assessed through a site evaluation.
- Software to match electricity production with facility profile and requirement for supporting technologies.
- Environmental impact study.
- Local supply chain to support wider project delivery
- Wider infrastructure required for resiliency plan (desalination plant, medical facilities, monitoring centres etc)
- Planning team to navigate policy implications and funding mechanisms for a complex solution.

Value propositions

- Creation of a long-term resiliency plan which can be followed by a local community
- Sustainable and reliable energy supply, replacing either diesel or lack of power
- Delivery of wider infrastructure (i.e. desalination and medical facilities)
- Support for the local economy through provision of services
- Long term approach to resource management through reduction of fossil fuel use and utilisation of wave/tidal energy
- Health benefits for population through medical service upgrades

Customer relationships

- Consistent and proactive engagement with the local community. Creation of a timeline of planned work which addresses local priorities.
- Relationships managed with existing utilities
- Involvement of a project developer/service provider to manage delivery
- Engagement with local and national government to integrate solution with wider planning.
- Development of skills base and supply chain within local community to support delivery.

Channels

- Disaster relief funds
- Shoreline management agencies
- Sustainability consultants
- International membership organisations (United Nations etc.)
- Development banks (World Bank, African Development Bank etc.)

Customer segments

- Local community – comprised from residents, local tourism and other business, and agriculture
- Utility providers, where established
- Local government
- National government

Cost structure

- Resident utility billing
- Taxation (either targeted locally or nationally depending upon subsidy structure)
- Lower insurance premiums
- Savings based on energy and water efficiency
- Economic growth and increased employment, based on increased investor confidence and infrastructure support.
- Reduced government spend on disaster recovery through implementation of resiliency measures.

Revenue streams

- High capex compared to other business models due to extensive infrastructure requirements. However, this is spread across a long time period.
- Initial costs focused on plan development, and set up costs of consortium.
- Installation and manufacturing costs – potentially involving third-party consultant.
- Maintenance costs – potentially through service provider.
- Leasing of land/seabed.
- Insurance
- PR and comms to disseminate methodology for creating resiliency plans.
- Training costs for local skills base
- Environmental impact study

BUSINESS MODEL ASSESSMENT

This market is a long-term proposition designed to target communities concerned about energy supply and resiliency to natural disasters and climate events. This could be achieved using tidal and wave power, although tidal is currently better placed to consider this market. The primary customer will depend upon local factors; it could be the local community, or a national government, depending upon the structure of subsidies.

This market presents a fairly different challenge to the short- and medium-term propositions. Wide stakeholder groups are required to provide inputs, with potentially a long lead-in time before project initiation. Funding sources will also be more diverse, as will cost recovery. The stakeholder engagement should provide a good method for ocean energy to prove added value, which will benefit the business case. Also, the long lead-in time should allow a project team to match the timelines of funding sources with project development. This market is the most plausible stepping-stone towards grid power out of the three presented.

The market has tested well for attractiveness, with a clear need being demonstrated. An indicated preference was to adopt a proactive solution, which has been followed within the business model presented. By providing a service proposition based on the outcome, ocean energy can mitigate higher LCOE and trade on added value to the local community.

The main weakness for this market is the complexity of the solution, which may be off-putting, difficult to communicate, and high capital expenditure. Significant groundwork will need to be implemented to determine a valid business case, including quantifying the social value. Another potential weakness is a trend for coastal resiliency strategies to embrace soft engineering solutions, which may not be compatible with the deployment of hard-engineered structures and turbines. Project initiation will require feed-in to the development or adaptation of these strategies to determine overall project viability.

STAKEHOLDER FEEDBACK

This proposition was presented to a range of stakeholders to give their feedback on the overall attractiveness, feasibility, and opinion on a realistic timeline for the model to be successfully deployed in the industry.

The proposition was considered from a wave and tidal perspective separately, considering that both technologies are at different industry readiness rates.

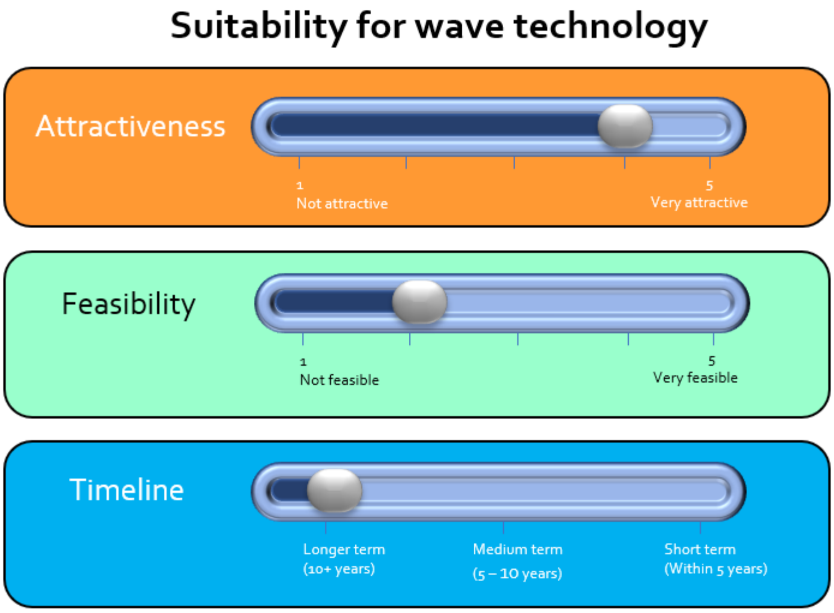


FIGURE 4.5: STAKEHOLDER IMPRESSIONS OF HOW SUITABLE THE PROPOSITION IS FOR WAVE TECHNOLOGIES

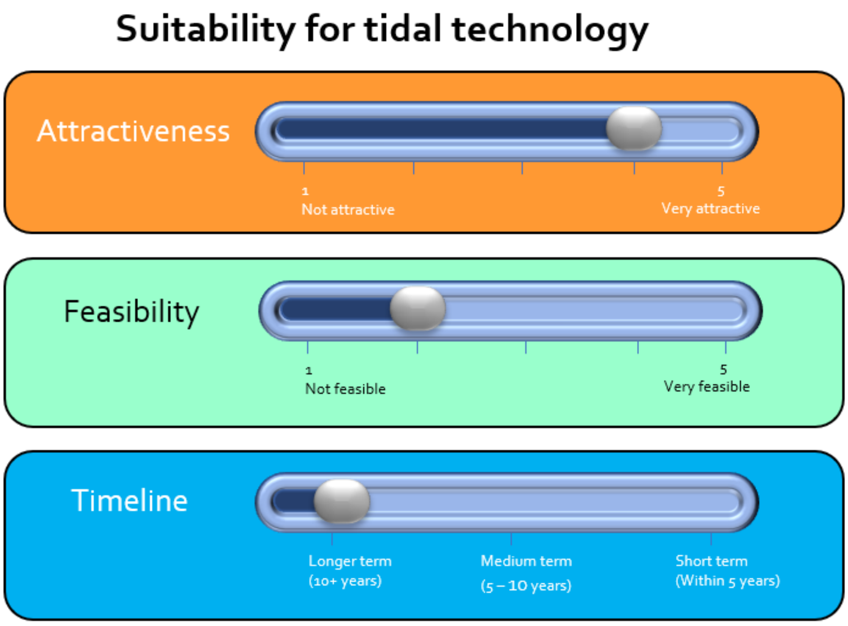


FIGURE 4.6: STAKEHOLDER IMPRESSIONS OF HOW SUITABLE THE PROPOSITION IS FOR TIDAL TECHNOLOGIES

5. DISCUSSION AND ROUTE TO DEVELOPMENT

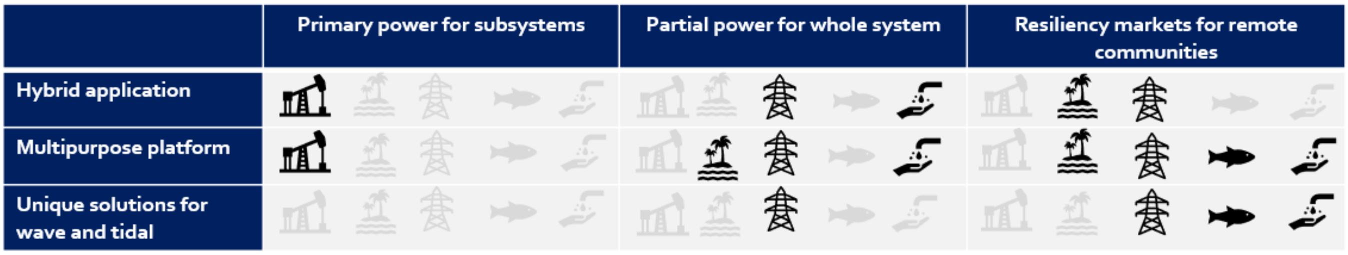
5.1. COMMON THEMES FROM VALIDATION EXERCISE

This section is intended to address some common themes that arose in validating the created business models. The summary provided is grouped into the following sections:

- Hybrid systems
- Multipurpose platforms
- Unique solutions for wave and tidal.

These are intended to provide a high-level summary, which will feed into section 5.2, which discusses barriers to market access. The points raised apply to multiple markets considered within this report and are therefore separated from the individual business models in section 4.2.

These common themes also suggest potential routes to market for each of the three proposed business models. This relationship can be seen as per Figure 5.1: Relationship between common



themes, proposed business models & niche markets

FIGURE 5.1: RELATIONSHIP BETWEEN COMMON THEMES, PROPOSED BUSINESS MODELS & NICHE MARKETS

5.1.1. HYBRID SYSTEMS

The applications investigated in this business modelling exercise currently tend to use diesel, or other fossil fuels, for their bulk power provision. An advantage of this is the ability to easily match demand and supply and adjust to fluctuating demands throughout the operating process. It could be technically feasible to meet these power demands by replacing diesel generators with either tidal or wave energy converters in a like-for-like swap. The balancing required could be achieved through a mixture of curtailment, selling excess power to the grid, or coupling to a storage system.

It is worth noting, however, that such configurations may not be cost-optimal. Curtailment implies oversizing the ocean turbine to meet the peak power needs, which may incur extensive CAPEX costs. Selling excess power to the grid may only become viable as ocean generators achieve lower LCOE; at present, this is a lower value market than the alternative applications investigated in this report, and therefore more competitive. Finally, the addition of batteries will increase the CAPEX of any installation. Therefore, each of these options could result in a shortfall of operating revenue against the initial capital investment required.

An alternative approach is to couple ocean generation with other technologies. This means that only a portion of the power provided is attributable to ocean generation – however, by using technologies with complementary electricity production profiles, the overall system may be more robust. Additionally, by installing a lower capacity wave or tidal turbine that performs a wider system, CAPEX costs can be reduced. Therefore, wave and tidal power can enhance the performance of other renewables, rather than being in direct competition.

Examples of hybrid systems have been presented within section 3.2. Typically, these investigations have determined that a system comprising multiple generation sources and storage can be more cost-optimal than using either one renewable type or the incumbent diesel set-up.

It is worth noting that these cost-optimal solutions usually feature a diesel generator in some form, primarily to meet peak power demands and avoid oversizing other parts of the system. Therefore, these short-term solutions may not be fully decarbonised, reducing the "selling-point" of the project. The attractiveness of these solutions depends upon the intermediate carbon targets various sectors and countries have set and the demand profile which must be met for each application. For an application where fossil fuels are used to meet peak power demands, the scale of emissions should be determined and compared to targets within the wider climate change programme.

Additionally, it is worth considering the costs of maintaining diesel generators and the supply chain in a hybrid system. Using diesel only for peak supply implies reducing fuel transportation costs since refuelling will occur at less frequent intervals. However, there may be standing costs and overheads associated with the maintenance of any diesel supply. These could be eliminated by completely removing diesel from the energy mix, and it will be worth performing a cost: benefit analysis for any system looking to remove diesel by comparing hybrid and renewable-only systems. If the overall diesel costs are primarily tied to fuel consumption rather than standing costs such as equipment maintenance and supply chain management, then a hybrid system will potentially be the preferential option. On the other hand, if the standing costs are dominant, then it could be preferable to remove diesel from the energy mixture altogether.

5.1.2. MULTIPURPOSE PLATFORMS

A potential application for wave and tidal energy could come in the form of multipurpose offshore platforms. These have been proposed to meet a growing need for offshore demands across multiple sectors by integrating the different functions in one unit. Advantages of this type of solution include:

- Shared investment in infrastructure (foundations, moorings, energy transfer to the mainland)
- Shared investment in resources (staffing, materials, energy consumption)
- Shared costs of services (monitoring, maintenance)

- Ability to utilise hybrid solutions and achieve cheaper generation costs through economies of scale.
- Reduced footprint of operations through optimised spatial planning.
- Reduced environmental impact.

However, several barriers might stand in the way of these types of developments. These include:

- Lack of channels to co-operate across different sectors, which do not typically interact.
- Variation in technology maturity across the required sectors could create conflicting requirements.
- Demand patterns will be more complex to determine due to the need to collect multiple datasets (a potential upside is that complementary demand patterns can smooth overall profiles across a platform)
- The agreement of a corporate PPA across different sector types and companies may be challenging from a legal perspective.
- Regulations and policies may not align across sectors – for example, environmental impact studies may have different requirements depending upon the use case.
- Planning of sea-bed leases typically is 'zoned' to a particular application – this would need to be adapted to accommodate multi-purpose platforms.

The number of challenges to creating multi-purpose offshore platforms indicates that these could not be considered a short-term solution for market entry for ocean energy. However, commercial developments are estimated to begin appearing in the mid-2020s [114]. A key driver for commercialisation would be the increased use of hydrogen within shipping, requiring offshore refuelling centres. This cross-vector demand within an offshore platform would provide a more robust solution, decreasing the requirement to sell surplus electricity into a saturated mainstream grid market.

These opportunities could therefore be considered medium to long term. It will be simpler for wave and tidal energy to address specific requirements in existing markets at present. Within a decade, if these generating technologies have advanced in terms of TRL, offshore platforms could provide an opportunity to take advantage of economies of scale by targeting concentrated demands.

5.1.3. UNIQUE SOLUTIONS FOR WAVE AND TIDAL

Wave and tidal generation are currently in different stages of development. Ocean generations are being deployed at a demonstrator (MW) scale and typically with lower Technology Readiness Level (TRL). Within these technologies, tidal stream is typically more advanced than wave, as outlined in deliverable 8.1 [3].

Another key difference between ocean technologies is the disparity in resource between wave and tidal generation. Global resource estimates for wave energy are about 25 times higher than for tidal, and so wave technology has greater growth potential if commercialisation is achieved. Furthermore, tidal is much more location-specific, with 90% of the available resource distributed across just five countries [115].

Given the spatial constraints of the tidal range and its more advanced TRL, it might be tempting for technology developers to focus on mainstream grid power instead of alternative markets. However, deployment still lags behind solar and wind, with higher LCOE.

Tidal stream developers could adopt a strategy to identify priority markets in locations with high resource. For example, it is hard to envisage support for oil and gas platforms since locations will not readily align. However, coastal applications such as near-shore aquaculture and desalination may be possibilities if these are desirable in the target location. Other options beyond those considered within this report include distilleries and breweries based on remote islands, increasingly considering decarbonisation options [116]. Locations based around the north of Scotland are particularly notable for the high tidal range – however, tidal technologies will need to compete against other options, such as the conversion of heating processes to biomass and provision of electricity from more established renewables.

The main aim for tidal technology developers is to reduce costs and achieve economy of scale. Therefore, these technologies should be targeting more ambitious demands to achieve this goal. This may preclude the short-term, small power markets described in section 4.2.1.

There may be more market options for wave developers to consider, given the less restrictive range of geographical locations available. For lower TRL technologies, access to these markets will be very beneficial to provide proof-of-concept for further investment. Wave developers will need to identify the market that most suits the device under development and then identify where these markets are required.

The main aim for wave developers should be to identify a market that suits their particular technology to deploy small scale devices. Therefore, wave developers should consider the power profile and operational conditions that can be achieved by their device when performing market identification exercises rather than a geographical limitation. Research and development directed towards serving an alternative market may offer a more tangential route to large grid power. For instance, access to a particular market may require wave devices to meet conditions and thresholds that are not required for most grids. However, any successful deployment will likely benefit the wider sector and combining improvements across multiple areas will allow for convergence towards reliable and affordable wave power if learnings from different markets are combined.

5.2. BLOCKERS

Following the DTOceanPlus workshops outlined in section 2.2.2, a series of potential market blockers were identified. These factors, below, currently contribute to tidal and wave energy being unable to access either mainstream grid or alternative markets. These have been summarised in six broad categories, as shown in FIGURE 5.2. Recommendations to help alleviate some of these blockers are outlined in section 5.3.

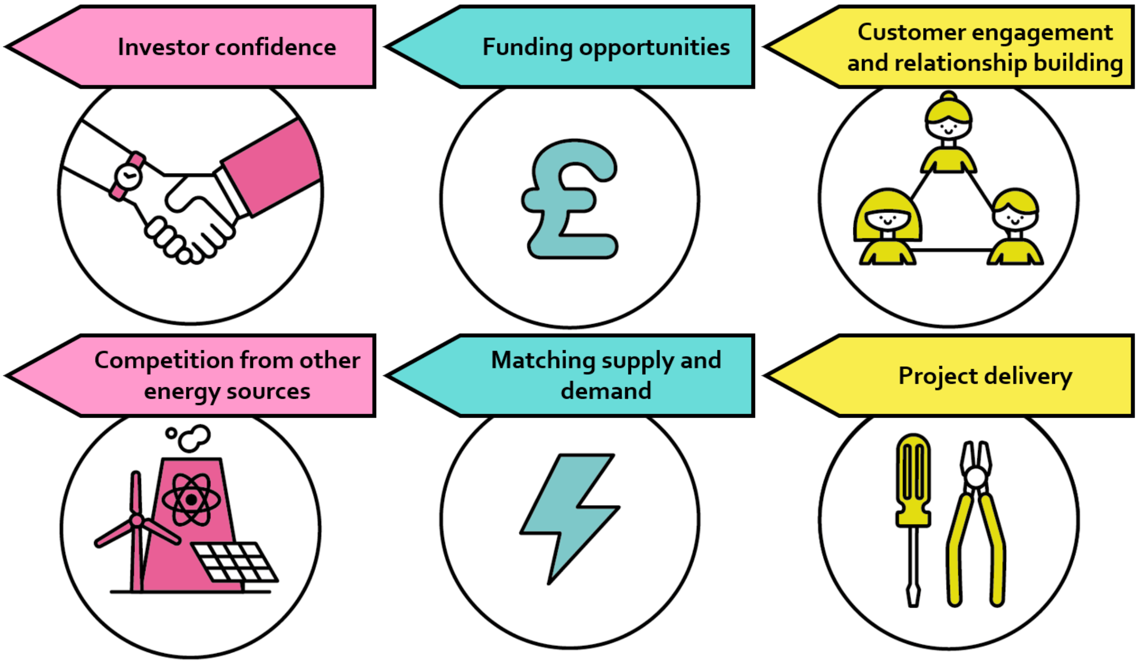


FIGURE 5.2: CATEGORISATION OF MARKET BLOCKERS EXPLORED IN WORKSHOPS

5.2.1. INVESTOR CONFIDENCE

Some of the difficulty that ocean energy faces in securing project funding relates to a lack of commercialised projects deployed. This is a problem faced by emerging technologies in any discipline – investors find it difficult to make projections of cost and performance since there is very little available data. This is also exacerbated by some historic projects which have demonstrated poor reliability and value. As a result, a programme of work is required to bolster confidence among private investors and the wider energy community to counteract this perception.

5.2.2. FUNDING OPPORTUNITIES

The lack of funding opportunities partially stems from low investor confidence since funding is less likely to come from a private source. Funding from public sources, such as Contracts for Difference mechanisms, have proven effective for launching other renewable generation types in the past decade when private investment was lacking. However, wave and tidal generation can also find themselves squeezed out of this market due to the lower LCOE of wind and solar. These issues point to the need to identify alternative funding mechanisms or reframe the problem to present a more favourable case for ocean generation.

5.2.3. CUSTOMER ENGAGEMENT AND RELATIONSHIP BUILDING

This report has identified potential alternative target markets for ocean energy. However, these are not typically operations with a high level of expertise in energy generation and are usually reliant upon simple diesel-based solutions. Therefore, an associated challenge will be the motivation of these potential customers to embrace change, even if the proposed solution requires higher complexity and potential changes to day-to-day operations.

5.2.4. COMPETITION FROM OTHER ENERGY SOURCES

As noted in the previous section, customers must be willing to adopt a new solution for their energy needs, and there may be a high level of inertia to overcome to displace diesel solutions. Even if this inertia can be overcome, other renewable options are available in all but the most remote markets. If ocean generation is competing based on LCOE, then wind and solar are likely to prevail. If the selling point of ocean generation is consistent supply, then the main competition is storage such as lithium-ion batteries. Defining the relationship of ocean energy with these alternative power sources is important in calculating the total available market in each instance.

5.2.5. MATCHING SUPPLY AND DEMAND

Many of the markets identified have complex daily and seasonal demand variations, with contributions from baseload and peaking power processes. Meeting these variations with diesel generators is reasonably simple through the use of an integrated inverter. However, using renewables to provide power is a greater engineering challenge, which must be tailored to the individual needs of each market considered.

5.2.6. PROJECT DELIVERY

This report proposes projects which, for the most part, have not been attempted before (or have only been attempted at a demonstrator scale). The translation from a first-of-a-kind project to a strong partnership will be more easily achieved if wider project delivery creates minor disruptions to standard operations. Currently, too many unknowns integrate ocean energy devices with these markets, so investment cases will be weaker until these issues are clarified.

5.3. THE ROUTE TO DEVELOPMENT

5.3.1. RECOMMENDATIONS TO OVERCOME MARKET BLOCKERS

The DTOceanPlus workshops described in section 2.2.2 looked to address future work that can be undertaken to overcome the blockers identified in the previous section. This section presents a high-level summary of these recommendations, aligned to the categories in FIGURE 5.2.

INVESTOR CONFIDENCE

- The largest contribution to investor confidence will be demonstrators conducted over long periods of time, showing ***high reliability, high efficiency, and accurate cost assessments***. Therefore, it would be useful for device demonstrators to focus on all three of these key factors before achieving cost reduction through economies of scale.
- Following on from demonstrators, technology developers should ***create attractive data-driven propositions*** using interim results, with a clear, positive narrative, and directly targets investor requirements. The role of certification in demonstrating investor readiness is a key requirement for insurance and, consequently, investor confidence.
- To achieve this data-driven approach, it is likely that ***more transparency*** will be required from technology/project developers by allowing investors to ***gain access to performance data***. However, this will inevitably need to be balanced against the need to protect confidential intellectual property.

Some additional points that may contribute to investor confidence are:

- Contracts can be set up to mitigate risk to investors. For example, a service proposition could be created based on price caps and ***guaranteed run time***. This makes the proposition more attractive for the investor if data is not available a priori to guarantee performance levels by transferring risk to the developer.
- ***Insurance requirements*** should be established at the project outset.
- The ability to work with more established renewables could create greater levels of confidence in an overall project. For example, a combination of wind and wave on a particular project could create a more robust proposition overall by using ***complementary profiles and a mixture of technology TRL***.
- For health and safety applications (oil and gas rigs etc.), ocean generation devices should ***demonstrate risk reduction*** as part of demonstrator work to create a more attractive proposition.

FUNDING OPPORTUNITIES

The first two recommendations are targeted at ***small-scale projects***, and therefore more relevant to the alternative markets outlined in this report:

- Partial/matched funding for demonstrators can be used to ***share risks for early-stage demonstrator projects***, where the concept is less proven. This could include research and development funding from organisations within the markets identified in this report.
- To overcome higher LCOE than other generating sources, wave and tidal developers should ***quantify the added value*** to improve the business case. Added value is variable depending upon the sector being targeted, and this links to customer value noted in the following section. For example, it might be possible to quantify the added value in tourism economies using energy generation with a low visual impact by canvassing the opinions and views of the local tourism sector.

The following recommendations are targeted at the advancement of ocean generation to grid-scale power by focusing on ***policy measures***:

- Ocean energy developers should build relationships with the local and national government, focusing on the evolution of decarbonisation targets and strategies. This should aim to provide a pathway and development pipeline for less developed technologies on an individual basis. This may translate into ***wave and tidal specific incentives*** (e.g. CfDs for innovative and developing technologies)
- Working with policymakers, create funding mechanisms that ***incentivise projects to use complementary renewables***.

CUSTOMER ENGAGEMENT AND RELATIONSHIP BUILDING

1) Identification of appropriate ***avenues to engage with varying customer groups*** (lobbying groups, consortia, trade bodies, etc.)
2) ***Quantification of Total Addressable Market (TAM)*** and customer requirements, including potential for ***wider service packages*** (digitisation and process electrification) and further market development (accessing offshore sites).
3) Understanding value from the ***customer perspective*** to help shape business propositions. For example, the technology developer can assess the importance of low visual impact to the investor and leverage this in a business proposition. This also includes an assessment of whether the customer will accept flexibility solutions.
4) Customers will need to be brought closer to the decision-making process. This will require the strategic assembly of a ***wider network of partners***, including environmental consultants, project developers and technology owners.

COMPETITION FROM OTHER ENERGY SOURCES

- Established renewables such as wind and solar could be partnered with ocean energy rather than direct competition. This relationship would ***take advantage of complementary profiles*** to create a more robust solution.
- These partnerships could be driven by the ***creation of aggregator platforms***, which combine multiple generation types and industries. At a smaller scale, demonstrator platforms have already been created which showcase hybrid wind and solar solutions. Wave and tidal should aim to integrate into the next stage of these platform demonstrators to quantify their added value to a wider renewable system.

MATCHING SUPPLY AND DEMAND

- The most crucial element to overcoming this obstacle is a thorough understanding of demand. Typically, the markets explored in this report have not documented their energy requirements fully since they currently use flexible power sources. Therefore, it will be essential to use ***monitoring equipment to provide data capture***, which can be used to match operational processes to power production.
- To manage demand fluctuations, wave/tidal may need to be coupled with storage solutions. Therefore, developers should ***create relationships with storage partners***, looking to increase their awareness of all options and create a service offering that can integrate this supply security.
- ***Development of aggregator platforms*** will allow for smoother and more predictable demand profiles and more flexible operations. These will be easier to manage but will take some time to develop.

PROJECT DELIVERY

- Technology developers will need to understand the ***operational impact of switching power supply*** (e.g. productivity impact). Additionally, there may be implications on device performance within a particular environment that need to be understood. Therefore, a feasibility study with detailed assessments for each market is recommended.
- As identified in D8.5 [117], most sites may require adherence to regulations and an environmental impact study. This process should be worked into a standard project initiation. In some cases, ocean technology developers may need to take a more ***active role and help to shape these policies and regulations*** to access a larger market share (e.g., environmental regulations are restrictive).
- Elements of the supply chain, discussed in Deliverable 8.2 [118], can add uncertainty to project timelines and costs. One example includes the export of power via subsea cables. These ***causes of uncertainty should be identified*** and planned at the early stages of any project.

- A ***skills base for operating a wave device*** may be required. Responsibility should be established early in the project life cycle, and training put in place to suit the requirement. This will need to be factored into project timelines and budgets.

5.3.2. KEY SUCCESS FACTORS

Based on the available material and stakeholder engagement performed within this work, a series of key factors for market success has been created for ocean energy. This is by no means an exhaustive list but represents some important boxes that ocean energy generation must tick to compete in either a global power market or the alternative markets considered within this report. If a power market satisfies many of these key success factors, it can be considered a viable target for ocean energy generators. These are outlined in Figure 5.2FIGURE 5.3, with additional rationale explaining how their requirements could lead to a viable market proposition.

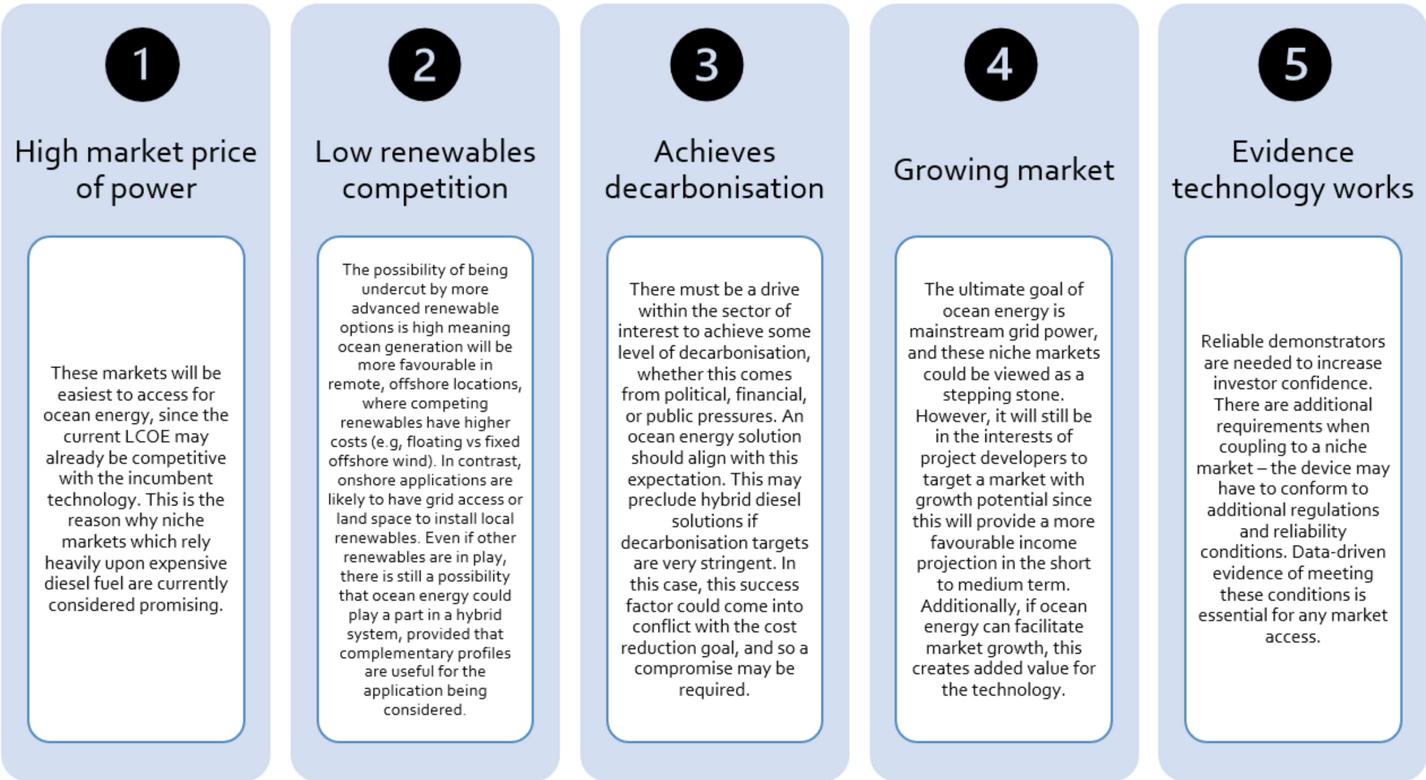


FIGURE 5.3: KEY SUCCESS FACTORS FOR MARKET ENTRY FOR OCEAN ENERGY TECHNOLOGIES

If all, or the majority, of these key success factors, are applicable for a market under consideration, this indicates a revenue stream that ocean energy generation may be able to access.

5.3.3. SUMMARY OF ROUTE TO DEVELOPMENT

In all the scenarios discussed in this report, different adaptations, such as supply and demand, localised needs, technologies, market solutions revenue, are required to be explored further for particular markets. Nevertheless, summarised in FIGURE 5.4 are some recommended routes to market development.

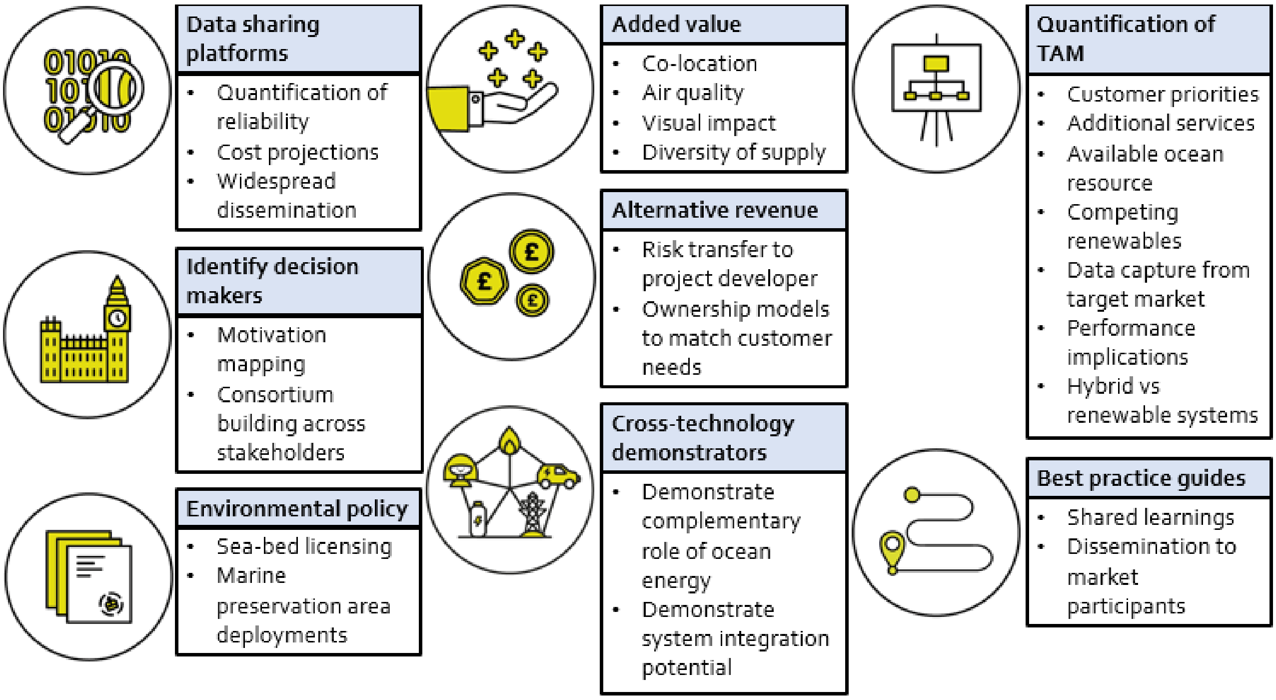


FIGURE 5.4: SUMMARY OF FUTURE WORK RECOMMENDATIONS FOR ALTERNATIVE MARKET DEVELOPMENT

5.4. SUPPLY CHAIN CONSIDERATIONS

The key components of the project supply chain for ocean energy development, as listed in DTOceanPlus Deliverable 8.2 [118], are as follows:

- Development and planning
- Manufacturing
- Installation
- Operations
- Decommissioning

Presently, the supply chain for the ocean energy sector mostly consists of the development and planning stages, with most activity taking place at the scale of research and development facilities. Due to the lack of commercial roll-out, there has been little incentive to develop the later stages of the supply chain. Geographically, supply chain elements are also concentrated within Europe, where the majority of ocean R&D has historically taken place.

As ocean energy demonstrators enjoy more success, it will be necessary further to develop the later stages of the supply chain. This will further reduce the LCOE of devices by introducing savings throughout the project lifecycle.

Ocean energy developers can take advantage of learnings from advanced sectors to accelerate supply chain development. For instance, there will be many areas of shared interest with offshore wind, which has already substantially developed its own supply chain. Another established offshore industry is oil and gas, which could share similar learnings. Other sectors identified in Deliverable 8.2 as potential collaborative partners are:

- Aerospace
- Automotive
- Aquaculture
- Energy storage
- Shipbuilding

The alternative markets explored within this report may act as supply chain accelerators for ocean energy if collaborative projects are undertaken within these areas. Aquaculture and offshore platforms have already been identified as contenders for these activities within Deliverable 8.2, primarily because of their offshore location. The other sectors considered within this work potentially have lower relevance due to onshore locations, but a detailed analysis should be performed to determine supply chain crossovers with each market. Any identified collaborative areas could be worked into project proposals as an added benefit.

Another consideration is the geographical spread of the markets reviewed within this report. Some are potentially viable within Europe (aquaculture, oil and gas), whereas others are more prevalent elsewhere in the world (microgrids, desalination). This creates a discrepancy with manufacturing and component supplier location, which necessarily needs to be local (e.g., Europe-based).

Within ocean energy project development, there is a desire to locate manufacturing close to the site of deployment. This helps to reduce transportation costs, which can be significant. However, with most manufacturing located within Europe, this could reduce the ability of the ocean energy sector to create a significant rollout.

Entering the alternative markets outlined within this report could provide an entry point to export markets. In addition, by developing small-scale projects in new locations, developing a local, parallel supply chain can be developed and utilised by grid power applications when TRL reaches 9. Increasing the geographic spread of the available supply chain will then enable ocean power to access a larger proportion of the global grid market.

5.5. OWNERSHIP MODELS

A standard procurement model tends to follow the path outlined, to begin with, the purchasing company establishing the technical specifications for the power demand. This is followed by a tendering process through which equipment is purchased. A contractor is then hired to install the system. Operations and maintenance from this point onwards are the responsibility of the purchasing company, which can either be met through internal expertise or the further hiring of contractors.

When looking to access alternative markets, ocean energy developers could consider non-traditional procurement models, which aim to overcome potential barriers:

- **Access to capital investment**: The procurement model outlined above requires the purchasing company to make a large outlay of capital in the initial stages. Depending upon the customer, access to these funds may be limited, particularly if the CAPEX of the solution under investigation is high. This is why diesel generators are still chosen, despite their greater cost over the typical operating period.
- **Technical and operating responsibility**: The procurement model above requires the purchasing company to take full responsibility for the system once installed. Depending upon the sector, internal expertise may be lacking to perform maintenance on the installed solution. This could therefore become a financial liability. Again, diesel solutions may be preferable based on this factor, given the more widespread expertise in these systems.

Alternative procurement models could alleviate these concerns and open up markets that may otherwise have been unwilling to change from standard diesel-based solutions. Some examples of these procurement models include:

- **Leasing**: The purchasing organisation pays a monthly fee for the equipment. A tender is produced that describes the power that needs to be met, after which point the technology developer takes responsibility for the device's performance.
- **Lease-to-own**: As above, but where the purchasing organisation has a preference to own the system eventually. This may allow the organisation to develop an internal capability for operations and maintenance during the lease agreement. This is more valid for long-term applications, where the purchasing organisation has low access to the initial capital.
- **Power Purchase Agreements (PPAs)**: The purchasing organisation pays only for the electricity produced by the equipment. A tender is produced, which describes the power that needs to be met, after which point the technology developer takes responsibility for the performance of the device. In addition, the concept of Innovation Power Purchase Agreements (iPPA) is another way of creating a market support mechanism for immature generation technologies that cannot directly compete on costs for PPAs.
- **Public-private partnerships**: The purchasing organisation meets their demand from a renewable energy installation that supplies electricity to a local grid. In these cases, the

renewable installation must be oversized for the application, and the existing grid supply must also be inaccessible, high-priced, or prone to reliability issues. Risk is shared between the private organisation and local/national government.

- **Service agreement**: Rather than paying for equipment time or electricity, the purchasing organisation pays for set outcomes. This could allow for tailored metrics of performance, such as production volume or running time. This transfers the responsibility of performance criteria to the developer, who is incentivised to meet the criteria specified at project initiation. This could also encapsulate added value (such as digitising operations).

When assessing the suitability of business models, it is important to assess customer preference and tailor the purchasing option. For most of the business models presented, PPAs or service agreements have been suggested – these typically require the lowest capital investment from the customer and place most responsibility on the technology developer for operation and maintenance. Therefore, these offer an attractive entry-level for new technology. However, if customers have access to greater capital or prefer to maintain control of their own operations, other procurement models are worthwhile during project initiation phases.

6. APPLICATIONS OF THE DTOCEANPLUS TOOLS

The Horizon 2020 DTOceanPlus project aims to accelerate the commercialisation of the Ocean Energy sector by filling a significant gap in the market, providing a single, integrated, open-source solution supporting the entire innovation and development process for ocean energy sub-systems, devices and arrays, aligning innovation and development processes with those used in mature engineering sectors:

- A Structured Innovation design tool will facilitate technology concept selection,
- A Stage Gate design tool will enable technology development, and
- Deployment optimisation will be implemented by Deployment and Assessment design tools.

The open-source nature of the software tools and the Open Access methodology adopted by the project ensure that the ability to exploit project results is available to a great variety of ocean energy sector stakeholders to benefits existing or new business interests.

The Structured Innovation tool within the DTOceanPlus suite of tools can be used to address and overcome some of the blockers identified in Section 5.2. The following sections will discuss how the tools' main features can contribute to this overarching aim, and particularly a Structured Innovation use case is provided with the expected outputs.

6.1. DTOCEANPLUS FEATURES

As a modular suite of tools, the DTOceanPlus can either be run together or independently in standalone mode. In standalone mode, the user will need to provide all input data that would normally come from other modules in the suite, whereas in integrated mode, data outputted from modules will be input to the other modules.

There are many potential use cases for the DTOceanPlus suite of tools, with corresponding user journeys between the different modules that have been designed to permit flexibility of use. However, three high-level use cases of the tools could be summarised in terms of the activities: Design, Assess, and Innovate (in a variety of order):

- **Design** an optimal solution of a subsystem, device, or array,
- **Assess** the performance of a subsystem, device, or array in the context of a site and project, or the status of a technology's development technology,
- **Innovate** new concepts and improvements to existing technology.

As illustrated in FIGURE 6.1, the design tools will output the following key results:

- **Structured Innovation tool**, to assist in identifying and areas of innovations and improvements;
- **Stage Gate tool**, to assess and guide the technology development using stage gate metrics,
- **Deployment tools** to design optimised arrays, facilitating a wide-scale deployment of ocean energy technologies to generate electricity for these markets,
- **Assessment tools** to generate assessment benchmarks supporting the design parameters.

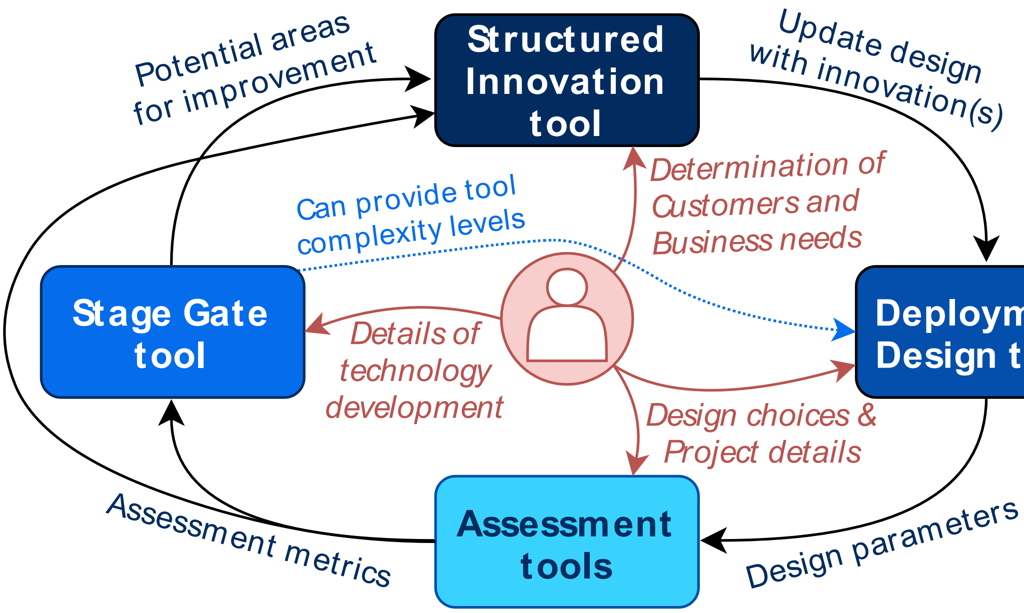


FIGURE 6.1: DTOCEANPLUS LINKAGE BETWEEN TOOLS- DATA FLOW

The main functionalities and features of each tool are summarised in TABLE 6.1 to TABLE 6.4 below, with detailed explanations that can be obtained in Deliverables [119] [120] [121] [122].

TABLE 6.1: STRUCTURED INNOVATION TOOL FUNCTIONALITIES & FEATURES

Main Functionalities	Features
Quality Function Deployment (QFD)	▸ Determine attractive areas of innovation. ▸ Define interactions & Correlation functional requirements. ▸ Defining ideality ▸ Identify organisation Impact. ▸ Specify and assess the state-of-the-art achievements
Theory of inventive problem solving (TRIZ)	▸ Identifying correlations between functions ▸ Implementing TRIZ alternative solution
Failure Mode Effects Analysis (FMEA)	▸ Identify potential failure modes. ▸ Reduce the likelihood and impact of failure
Reporting	▸ Generate an exportable report that summarises: ▸ A set of functions for concept creation ▸ A conflict and impact report ▸ Assessment of ideality and development impacts ▸ Mitigation measures to improve the design of the system

TABLE 6.2: STAGE GATE TOOL FUNCTIONALITIES & FEATURES

Main Functionalities	Features
Framework editor	▸ Review the framework and specify any thresholds for the Stage Gate assessment
Activity checklist	▸ Assess which stage gate the technology is eligible for
Applicant Mode	▸ Complete the SG assessment with qualitative and quantitative questions
Assessor Mode	▸ Simulate the assessment of a completed application
Improvement Area	▸ Identify areas of improvement and link to the SI tool
Study Comparison	▸ Compare the results of two or more stage gate studies
Report Generation	▸ Produce a PDF standardised report summarising the SG assessment

TABLE 6.3: DEPLOYMENT DESIGN TOOLS - FEATURES & FUNCTIONALITIES

Main Functionalities	Features
Site Characterisation (SC)	▸ Extract 1D direct values (no temporal dimension) from databases like bathymetry, bottom sediment types or endangered marine species ▸ Extract 1D (punctual) or 2D (longitude/latitude) temporal data from physical databases, like waves or currents databases ▸ Compute statistics on these databases
Machine Characterisation (MC)	▸ Prepare the machine data to be used in the rest of the design flow modules and to estimate the hydrodynamic coefficient for a single wave energy converter
Energy Capture (EC)	▸ Estimates the gross energy production of the array and individual machines. ▸ Estimates the "best" placement and efficiency of the farm and the machines within the given lease area.
Energy Transformation (ET)	▸ Designs the mechanical parts and performs the calculation of the PTO mechanical efficiency and loads knowing: ▸ Designs the electrical parts and computes the generator efficiency and loadings, knowing the mechanical PTO power and operation range. ▸ Designs the components for grid conditioning electrical power, selects the power converter, computes its efficiency, and generates electrical output power. ▸ Control Strategy is dedicated to traducing device motions and loadings to specific velocity distributions to be accounted for in the conversion chain.
Energy Delivery (ED)	▸ Design of transmission system. ▸ Design of array network, which includes: Clustering of devices around collection point(s), Connections within array network, and, Routing of array cables, including design of umbilical cables for floating devices. ▸ Selection of suitable components. ▸ Evaluation of network designs.
Station Keeping (SK)	▸ Mooring systems, foundation bases and anchors are designed based on the bathymetry description. ▸ Novel mooring layout configurations are made possible by the flexibility offered by the improved and customisable mooring system modelling capabilities.

	▸ Ultimate Limit State (ULS) analysis and automated mooring system design are now based on frequency domain analysis. ▸ Fatigue Limit State (FLS) analysis of mooring lines is implemented
Logistics and Marine Operations (LMO)	▸ Design of logistic solutions for the installation, maintenance, and decommissioning phases of ocean energy projects. ▸ Definition of operation plans for each operation, based on specified components, project characteristics, and user preferences. ▸ Estimation of weather delays based on operation duration, operational weather restrictions, and historical met-ocean data. ▸ Estimation of operating costs based on operation durations, weather contingencies, and vessel daily chartering costs, fuel costs, port costs and equipment costs. ▸ Selection of optimal and compatible combinations of vessels, ports and equipment that minimize operating costs.

TABLE 6.4: ASSESSMENT TOOLS - FEATURES & FUNCTIONALITIES

Main Functionalities	Features
System Performance and Energy Yield (SPEY)	▸ Calculating the efficiency and energy production. ▸ Calculating alternative metrics and power quality metrics.
System Lifetime Costs (SLC)	▸ Compile bill of materials. ▸ Economic assessment. ▸ Financial assessment. ▸ Benchmark analysis, comparing project results against reference values.
Reliability, Availability, Maintainability and Survivability (RAMS)	**Reliability assessment** ▸ Estimating the time to failure (TTF) of basic components ▸ Estimating the time to failure of subsystems and the array. ▸ Calculating the maximum annual probabilities of failure of subsystems and the array. **Availability assessment** ▸ Calculating the availability of all the devices and the average availability of the array. **Maintainability assessment** ▸ Calculating the probability that the damaged components can be successfully repaired or replaced in a period of time, given the equipment and the resources. **Survivability assessment** ▸ Calculating the probability that the critical structural/ mechanical components can survive the ultimate loads/ stresses during the design lifetime. ▸ Calculating the probability that the critical structural/ mechanical components can survive the fatigue loads/ stresses during the design lifetime.
Environmental and Social Acceptance (ESA)	▸ Endangered species mapping ▸ Environmental impacts and interaction with potential receptors ▸ Carbon footprint during the different phases of the lifecycle of the project ▸ Social acceptance

6.2. STRUCTURED INNOVATION USE CASE

The **Structured Innovation tool** is intended to provoke innovation and help represent the voice of the customer through the design process, manage risk and therefore allows developers to select the most technically and financially attractive concepts to take forward into the development process. The tool combines functions such as understanding mission and market (including the potential for commercial exploitation, competition, differentiation, social value etc.). The key results are expressed in terms of a ranking of attractive options, deviation from the key performance metrics, and acceptability rating allowing objective assessment of the design and technical risks offering both risk mitigation and cost reduction opportunities.

The Structured Innovation design tool is one of a kind beyond the current state-of-the-art that will enable the transfer and adaptation of the following integrated methodologies to the ocean energy sector:

- The Quality Function Deployment (QFD) tool will define the innovation problem, represent the customer's voice, identify trade-offs in the system, and make immediate objective assessment visible and useful.
- The TRIZ tool, a systematic inventive problem-solving method, will generate potential solutions to the contradictions to meet the user requirements.
- The outcome from QFD/TRIZ tools will generate several design requirements along with target engineering metrics. In addition, these two modules will be visually linked to study areas of opportunity and risk immediately.
- Technical risk will be framed by Failure Mode Effect Analysis (FMEA). The FMEA module will use a database of validated defect parameters to improve understanding of technical risk during the development process and offer both risk mitigation and cost-reduction opportunities.

The Structured Innovation design tool will provide a method of adding rigour and organisation to the process of innovation. This helps ensure that innovators and funders select the best (i.e. lowest risk and most likely to succeed) concepts to take into the development process.

6.2.1. DATA INPUT REQUIREMENTS

This section describes the types of input data required to run the Structured Innovation tool. To illustrate how the Structured Innovation tool can support the progression of ocean generation technologies, the following scenario is used:

> A wave energy project developer would like to assess options to partially match an offshore generation platform's electricity supply and demand. This will enable the WEC technologies to offer cost-optimal solutions, mature the technologies and achieve economies of scale by meeting larger portions of an application’s base supply. Detailed value propositions for this market is provided in Section 4.2.2

The required and optional inputs to run the Structured Innovation tool are summarised in TABLE 6.5 to TABLE 6.8 below. Note that some of the required inputs will come from other modules in integrated mode:

Functionality-1 Define objectives of the study: This functionality enables the user to define the project's top-level objective that will be the basis of the QFD/TRIZ study. This is also where the user defines the list of the customer requirements broadly. For example, in the context of developing a new product (e.g. a WEC application to meet partial power generation of a system), this is a list of customer requirements. These requirements– often general, vague, and difficult to implement directly, as illustrated in TABLE 6.5 and TABLE 6.6– are prioritised in order of importance.

TABLE 6.5: DEFINE THE OBJECTIVE OF THE STUDY

Study Objectives	
Design objectives	To identify wave application as partial power solutions for a whole system
Technology Type	e.g. Wave as a hybrid solution
Aggregation level	e.g. Device or Array
Running mode of SI tool	Standalone or Integrated

TABLE 6.6: DEFINE THE TOP OBJECTIVES

Customer requirements	Relative Importance
Security of Power supply	10
Lowest Cost of Energy	8
Reduced Commercial Risk	9
Lower environmental Risks	6

Functionality 2- Scanning the Design Space: This functionality enables the user to define the measurable functional requirements that can satisfy the customer requirements and how much each functional requirement impacts each customer requirement. In addition, the user can establish the interdependencies between functional requirements to identify areas where trade-off decisions, conflicts, and innovation may be required.

In this scenario, some of the functions that need to be met are better power provision, maintenance, and supply-demand balancing. These can be achieved with proven reliability and availability in the operating conditions of the WEC technology, compliance with emissions targets for the sector, lower transportation costs and therefore OPEX costs, and better security of supply, particularly within isolated areas.

TABLE 6.7: DEFINE FUNCTIONAL REQUIREMENTS TO MEET THE TOP OBJECTIVES

	Direction of Improvement	Target/ideal values	Target units	Engineering Difficulty	Delivery Difficulty
Availability	Up	98	%	High	Moderate
Reliability	Up	20	years	Low	Low/Moderate
Transmission Losses	Down	2	%	High	High
Transportation costs	Down	510	M€	Low/Moderate	Moderate
Storage Capacity	Up	7	MWh	Moderate	Moderate/high

Functionality 3- Identifying attractive areas of innovation: To better understand the competition or where it is worth investing in, this functionality compares solutions currently available from competitors. The competitor here refers to State-of-the-art leading-edge technology or designs, including the newest ideas or concepts – An evaluation of how other companies perform compared to the target (or ideal) values proposed. Has any of the functions deployed elsewhere? Is it worth investing in?

TABLE 6.8: SPECIFY ACHIEVEMENTS OF CURRENT STATE-OF-THE-ART CONCEPTS

	Design/Concept 1	Design/Concept 2	Design/Concept 3	Design/Concept 4
Availability (%)	50	55	40	60
Reliability (years)	14	14	18	10
Transmission Losses (%)	10	8.7	8.0	4.0
Transportation costs (M€)	1,000	924	870	1,500
Storage Capacity (MWh)	0	0.5	0.5	0

Functionality 4- Identify & assess Contradictive requirements: This functionality provides inventive inspiration for the user using the TRIZ contradictions matrix – encouraging the user to look for existing solutions to similar problems at different scales and times. This allows the user to adopt principles that might offer idealised solutions from other industries, countries, and times in history. In addition, the TRIZ methodology can ensure completeness in the key parameters that define the design space using provocative prompts to provide the well-known forty inventive principles and other tools to solve contradictions within the QFD.

Functionality 5- Assessing technical risks: Technical risks are framed using the 'concept' or 'design' FMEA component. The component provides ratings for each defect or failure in terms of severity, occurrence, and detection. In addition, the FMEA uses a database of validated defect parameters to improve understanding of technical risk during the design assessment process and offer both risk mitigation and cost reduction opportunities.

TABLE 6.9: SPECIFY FMEA OBJECTIVES AND THRESHOLD FOR ACTION

FMEA objectives	To identify wave application as partial power solutions for a whole system
Action Level	The Risk Priority Number (RPN) level for action on failure causes, e.g. 72
Mitigation Level	The threshold occurrence level for investigation of a failure mode and associated cause, e.g. OCC>4

TABLE 6.10: DEFINE DESIGN REQUIREMENTS

Design/Functional requirements
Security of Power supply
Lowest Cost of Energy
Reduced Commercial Risk
Decarbonisation target

TABLE 6.11: SCREENSHOT HIGHLIGHTING DEFINED FAILURE MODES AND ASSOCIATED IMPACTS*

On this page you are asked to define mitigations where the RPN threshold has been exceeded.

Requirement	Failure Mode	Effect	SEV	Cause	OCC	Design control	DET	RPN
Availabity	Failure to convert power as designed	Low AEP	6	damage or disruption to the system	4	corrective transition/reconfig...	4	96
Availabity	Failure to convert power as designed	Low AEP	6	damage or disruption to the system	4	Quality check on fabrication and on instrumentation commissioning	3	72
Availabity	Failure to convert power as designed	Low AEP	6	damage or disruption to the system	4	Design Verification Review	3	72
Availabity	Failure to convert power as designed	Low AEP	6	Manufacturing fault	5	corrective transition/reconfig...	4	120
Availabity	Failure to convert power as designed	Low AEP	6	Manufacturing fault	5	Quality check on fabrication and on instrumentation commissioning	3	90

* Note that the criticalities of failures are then determined using the Risk Priority Number (RPN), which is calculated by multiplying the Severity (SEV), Occurrence (OCC), and Detection (DET) rankings associated with potential each failure: RPN = SEV*OCC* DET.

This RPN is then used to prioritise risks, and suitable follow-up corrective actions are proposed to reduce the criticality of potential failures by implementing the corrective actions. These corrective actions can be obtained from the QFD alternative solutions, specific actions for the system (e.g. proposed design review, enhanced material properties), and background literature (e.g. measures implemented in other sectors).

The RPN is then re-calculated to establish the impact of corrective actions on the system and the level of criticality of the system with proposed measures. These mitigation actions should then be implemented in the design of the systems.

6.2.2. DATA OUTPUTS AND IMPACTS

The Structured Innovation tool outputs the results obtained and the deviations from the key performance metrics (including proposed innovative functions, metrics, conflicts and interrelationships, and impact). The results are expressed in terms of a ranking of attractive options, and the key performance metrics are expressed in terms of a ranking of acceptability rating that allows objective assessments of the design. A summary of the result page is shown in Figure 6.2. The optimum solutions are those with the highest impact in terms of solutions importance to meet the customers' needs, the organisational efforts required to implement the proposed functional requirements and the areas of novelty (or added value, or disruptions) beyond the State-of-the-art.

The DTOceanPlus suite of tools aims to align ocean energy innovation and development processes with those used in mature engineering sectors by facilitating technological risk reduction at all stages and all scales. The Structured Innovation tool, presented here as a use case, allows developers to select the most technically and financially attractive concepts to take forward into the development process. Technical risks are identified using the concept or design FMEA, providing ratings for each defect or failure in severity, occurrence, and detection. The FMEA uses a database of validated defect parameters to improve understanding of technical risk during the design assessment process and offers both risk mitigation and cost reduction opportunities.

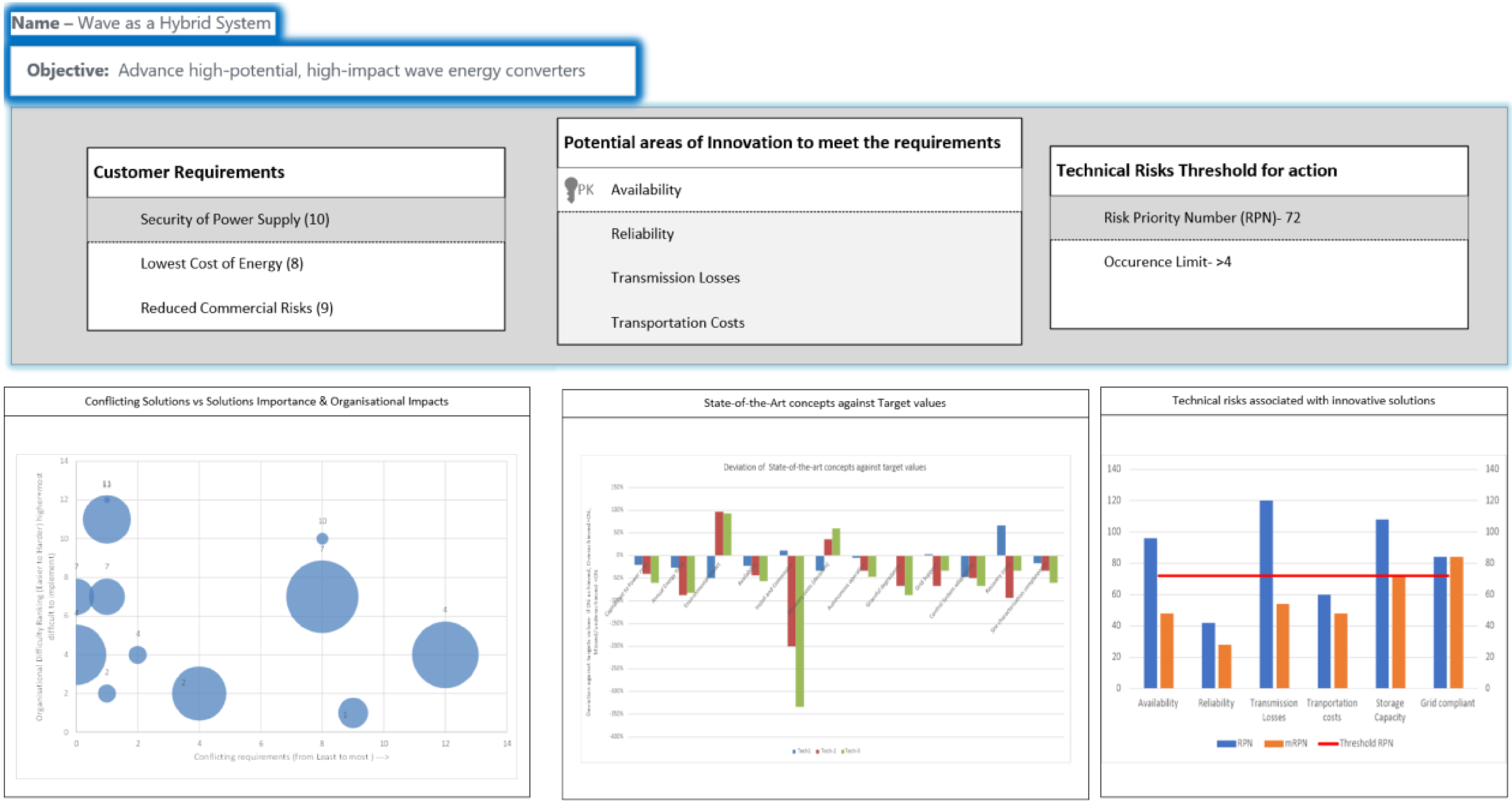


FIGURE 6.2: DASHBOARD VIEW OF THE STRUCTURED INNOVATION TOOL RESULTS

7. CONCLUSIONS

Ocean energy can play a crucial role in supporting the transition towards net-zero carbon emissions, especially with the predictable nature of the tides and complementary generation profiles of wave energy. However, as a developing technology, the LCOE is not cost-competitive with other alternatives for grid generation, making ocean energy a minority concern in the overall current generation mix.

Alternative ocean energy applications could provide a good entry point into the market and undergo product development whilst generating revenue. Furthermore, this could allow for additional RD&I funds to be developed by initiating small-scale projects, thereby placing ocean energy in a better position to power the main grid when the need arises. In addition, synergies exist with other offshore sectors for ocean energy to provide localised power.

Task 8.4 aimed to develop a greater understanding of the ocean energy sector's business models, focusing on reviewing the current business modelling approach and proposing future approaches to improving the ocean energy sector's market opportunity. A variety of markets was identified through which ocean generation technologies may achieve initial deployments. These markets all share potential co-location advantages, which ocean energy, being either coastal or offshore industries. However, on the whole, these are also high-value markets, which experience accessibility issues and typically rely upon fossil fuel imports that have unreliable pricing.

Background information of the following niche markets:

- offshore oil and gas platforms
- coastal resiliency and disaster recovery
- microgrids
- aquaculture farms
- desalination plants

was collated and formed part of the business model design and validation methodology. These were informed by both desk-based research, interviews and workshops with relevant stakeholders. This market research was subsequently used to form a set of generalised business model canvasses that considered abstract customer types without specific details relating to locality or bespoke requirements. Since these business models did not strictly align with the markets considered, the customer segmentations were reframed to consider the following three market propositions, relating to one or more of the markets considered:

- **Primary power for sub-system** – applicable for an instance where a subsystem of an application can be matched to a wave or tidal device without additional support. These are typically small-scale applications, which can be matched to ocean energy generation in the **short term**.
- **Partial power for whole-system** – where a wave or tidal device cannot match the overall demand volume and/or profile. The overall system is therefore powered using combined

storage, renewable energy and diesel options. Hence, these markets could be targeted in the **medium term**.

- **Resiliency markets for remote communities are applicable for a region with limited power options, addressing** issues pertaining to coastal erosion, protection from extreme weather events, or recovery from a disaster. These markets should be considered **long-term**, with the first step consisting of consortia formation and stakeholder engagement.

These three can be adopted sequentially as a potential roadmap to large-scale roll-outs with potential applications in each of the five niche markets.

The feedback received on these three reframed business models highlighted three potential strategies for targeted market access:

- **Hybrid systems** – meeting balancing requirements and/or coupling generation for complementary electricity production profiles.
- **Multipurpose platform** – integrating multiple functions into one solution (e.g. multipurpose platforms)
- **Unique solutions for wave and tidal** – accessing markets with power profile and operations conditions suitable for wave and/or tidal deployments.

With these in mind, a series of key factors for market success were identified that would contribute to tidal and wave energy being unable to access either mainstream grid or alternative markets. These are by no means an exhaustive list but represents important aspects that ocean energy generation must meet to compete in either a global power market or the alternative markets considered within this report. If a power market satisfies many of these key success factors, it can be considered a viable target for ocean energy generators. These factors have been summarised in six broad categories in Section 5.2 and recommendations to help alleviate some of these blockers outlined in Section 5.3.

In the scenarios discussed in Section 6, the open-source design tools being developed in the DTOceanPlus project can contribute to the development of the ocean energy sector. The Structured Innovation, as part of the suite of tools, can identify and propose innovative solutions in mitigating some of the blockers to achieve viable targets for ocean energy generation.

8. REFERENCES

[1] JRC Science and Policy, "Overview of European innovation activities in marine energy technology," European Commission, 2014.

[2] IRENA, "Fostering a blue economy: Offshore Renewable Energy," International Renewable Energy Agency, Abu Dhabi, 2021.

[3] DTOceanPlus The University of Edinburgh, "Potential Markets for Ocean Energy," European Commission, Bilbao, 2020.

[4] Wind Power Monthly, "windpowermonthly.com," [Online]. Available: https://www.windpowermonthly.com/article/1523677/energy-costs-analysis-why-wind-broke-mainstream-2018. [Accessed 20 August 2020].

[5] ARS Technica, "arstechnica.com," [Online]. Available: https://arstechnica.com/science/2019/08/wind-power-prices-now-lower-than-the-cost-of-natural-gas/. [Accessed 20 August 2020].

[6] The Guardian, "theguardian.com," [Online]. Available: https://www.theguardian.com/business/2020/apr/28/britain-breaks-record-for-coal-free-power-generation. [Accessed 20 August 2020].

[7] Smithsonian mag, "smithsonianmag.com," [Online]. Available: https://www.smithsonianmag.com/smart-news/worlds-first-solar-powered-satellite-still-there-after-59-years-180962510/. [Accessed 20 August 2020].

[8] U.S Energy Information Administration, "eia.gov," [Online]. Available: https://www.eia.gov/energyexplained/wind/history-of-wind-power.php. [Accessed 20 August 2020].

[9] I. Jefferies, " Building A Strong Business Model," 10 2014. [Online]. Available: https://static1.squarespace.com/static/568a65ddd82d5eb4328515d6/t/59e17b16f7e0ab03b6500d03/1507949828097/Building+A+Strong+Business+Model.pdf. [Accessed 21 01 2020].

[10] A. O. &. Y. Pigneur, Business Model Generation, Hoboken: John Wiley & Sons Inc, 2010.

[11] IEA, "World Energy Outlook Series Offshore Energy Outlook," 2018.

[12] DNV GL, "Energy Transition Outlook 2020: Oil and Gas," 2020.

[13] R. Vanner, "Energy Use in Offshore Oil and Gas Production: Trends and Drivers for Efficiency from 1975 to 2025," PSI Working Paper, 2005.

[14] Wood Mackenzie, "https://www.woodmac.com," [Online]. Available: https://www.woodmac.com/news/feature/why-power-oil-and-gas-platforms-with-renewables/. [Accessed 20 January 2021].

[15] Aquatera, "International emerging and niche market research for the marine energy sector Part 3: Analysis of niche markets final report to Scottish Enterprise," 2016.

[16] K. Johannensen, "Bridge markets for marine energy: gaining experience in non-utility markets," All Energy 2019; Marine Renewable Energy 3 - Moving Tidal and Wave Forward, Glasgow, UK, 2019.

[17] IPIECA, "Offshore Drilling Rigs," 2013. [Online]. Available: http://www.ipieca.org/resources/energy-efficiency-solutions/units-and-plants-practices/offshore-drilling-rigs/.

[18] University of Aberdeen, "Powering Offshore Oil and gas with marine renewables Summary Report," in *Powering Offshore Oil and gas with marine renewables*, Aberdeen, 2019.

[19] S. Oliveira-Pinto, P. Rosa-Santos and F. Taveira-Pinto, "Electricity supply to offshore oil and gas platforms from renewable ocean wave energy: Overview and case study analysis," *Energy Conversion and Management*, vol. 186, pp. 556-569, 2019.

[20] DNV GL, "Technology Outlook 2030," 2020.

[21] OSPAR, "OSPAR," 2018. [Online]. Available: https://odims.ospar.org/maps/?limit=100&offset=0. [Accessed 13 November 2019].

[22] 4C Offshore, "Global Offshore Wind Farms Database," 2018. [Online]. Available: www.4coffshore.com/offshorewind/. [Accessed 13 November 2019].

[23] T. N. &. M. d. A. I. Guinea, "Analysis of potential niche markets to overcome valley of death in wave energy development," Bilbao, 2020.

[24] Offshore Engineer, "Premier Oil Testing PB3 PowerBuoy in the North Sea," 2019. [Online]. Available: https://www.oedigital.com/news/469883-premier-oil-testing-pb3-powerbuoy-in-the-north-sea.

[25] Mocean Energy, "Mocean sets up in Aberdeen to bring green power offshore," 23 September 2019. [Online]. Available: https://www.mocean.energy/mocean-sets-up-in-aberdeen-to-bring-green-power-offshore/. [Accessed 06 January 2020].

[26] ENI, "ISWEC- The inertial Sea Wave Energy converter," ENI, [Online]. Available: https://www.eni.com/en-IT/operations/iswec-eni.html. [Accessed 08 06 2020].

[27] C. McNatt, "Founders Blog- The Potential of Wave Energy," [Online]. Available: https://www.mocean.energy/founders-blog-the-potential-of-wave-energy/. [Accessed 08 06 2020].

[28] DNV GL, "WIN WIN Joint Industry Project: Wind-powered water injection," 2016.

[29] DOE, "Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets," 2019.

[30] C. Abbey, D. Cornforth, N. D. Hatziargyriou and K. Hirose, "Powering Through the Storm: Microgrids Operation for More Efficient Disaster Recovery," *IEEE Power and Energy Magazine*, vol. 12, no. 3, pp. 67-76, 2014.

[31] Department of Energy, "https://www.energy.gov," [Online]. Available: https://www.energy.gov/articles/white-house-council-economic-advisers-and-energy-department-release-new-report-resiliency. [Accessed 20 January 2021].

[32] Germanwatch, "Global Climate Risk Index 2020," Germanwatch, Bonn, 2019.

[33] G. M. G. J. H. Millar, "Comparing Coastal Management Approaches in Distinct Locations: Case Studies from England (UK), Auckland (New Zealand), and Diego Garcia (BIOT)," in *Coastal Management 2019: Joining forces to shape our future coasts*, 2019.

[34] A. e. a. Hosking, "Shoreline Management Planning for Economic Development in Belize," in *Coastal Management 2019: Joining forces to shape our future coasts*, 2019.

[35] A. e. a. Bolle, "Comparing Hard and Soft Engineering Solutions for Marine Inlet Sedimentation and Coastal Erosion at Blankenberge and Wenduine, Belgium," in *Coastal Management 2019: Joining forces to shape our future coasts*, 2019.

[36] Moving Energy Initiative, "The Costs of Fuelling Humanitarian Aid," 2018.

[37] Practical Action, "The Power of Data: Assessing operational energy use in camps to inform the design of alternative renewable energy," 2020.

[38] D. Eckstein, M.-L. Hutfils and M. Winges, "Global Climate Risk Index 2019," Germnwatch e.V., Bonn, 2018.

[39] BBC, "news.bbc.co.uk," [Online]. Available: http://news.bbc.co.uk/1/hi/scotland/highlands_and_islands/7844782.stm. [Accessed 20 January 2021].

[40] Offshore Energy, "https://www.offshore-energy.biz/," [Online]. Available: https://www.offshore-energy.biz/uk-siadar-wave-energy-project-cancelled/. [Accessed 20 January 2021].

[41] Power Technology, "https://www.power-technology.com," [Online]. Available: https://www.power-technology.com/projects/mutriku-wave/. [Accessed 20 January 2021].

[42] Offshore Energy, "https://www.offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/mutriku-wave-plant-hits-2gwh-mark/. [Accessed 20 January 2021].

[43] UNHCR, "Global Strategy for Sustainable Energy," 2019.

[44] IEC, "Microgrids for disaster preparedness and recovery: With electricity continuity plans and systems," White paper, Geneva, Switzerland, 2014.

[45] Hydro Review, "https://www.hydroreview.com," [Online]. Available: https://www.hydroreview.com/world-regions/world-s-largest-5-turbine-tidal-array-installed-in-the-oosterschelde-barrier-the-netherlands/#gref. [Accessed 20 January 2021].

[46] UNHCR, "Renewables for Refugee Settlements: Sustainable Energy Access in Humanitarian Situations," 2019.

[47] Hitachi, "Hitachi.com," [Online]. Available: https://www.hitachi.com/rev/archive/2017/r2017_05/pdf/P26-30_Global.pdf. [Accessed 27 May 2020].

[48] Bloom Energy, "https://www.bloomenergy.com," [Online]. Available: https://www.bloomenergy.com/blog/what-is-stopping-microgrid-adoption. [Accessed 20 January 2021].

[49] Tracking SDG 7: The Energy Progress Report, "https://trackingsdg7.esmap.org/," [Online]. Available: https://trackingsdg7.esmap.org/results?p=Access_to_Electricity&i=Electricity_access_rate,_Total_(%). [Accessed 20 January 2021].

[50] The World Bank Group, "Energy use (kg of oil equivalent per capita)".

[51] C. C. P. B. H. H. R. S. C. B. P. Blechinger, "Global analysis of the techno-economic potential of renewable energy hybrid systems on small islands," *Energy Policy*, vol. 98, pp. 674-687.

[52] DoE, "Potential Martime Markets for Marine and Hydrokinetic Technologies," 2018.

[53] National Renewable Energy Laboratory, [Online]. Available: https://techxplore.com/news/2020-03-harnessing-marine-energy-scales-village.html. [Accessed 15 May 2020].

[54] Power technology, [Online]. Available: https://www.power-technology.com/comment/global-microgrids-market-to-reach-30bn-in-2022/. [Accessed 15 May 2020].

[55] Aquatera, "International emerging and niche market research for the marine energy sector," 2016.

[56] D. J. P. S. C. Farquharson, "Sustainability implications of electricity outages in sub-Saharan Africa," *Nature Sustainability*, vol. 1, pp. 589-597, 2018.

[57] Ocean Energy Systems, "www.ocean-energy-systems.org," [Online]. Available: www.ocean-energy-systems.org/ocean-energy/gis-map-tool/. [Accessed 3 March 2021].

[58] Asian Development Bank, "Pacific Energy Update 2018," Manila, 2018.

[59] USAID, "Off-grid opportunities and challenges in Vietname," 2014.

[60] Hawaii State Energy Office, "Hawaii Energy Facts & Figures - July 2019," 2019.

[61] Pacific Region Infrastructure Facility Coordination Office, "2016 Pacific Infrastructure Performance Indicators," Sydney, 2016.

[62] International Monetary Fund, "Caribbean Energy: Macro-Related Challenges," 2016.

[63] International Renewable Energy Agency, "Renewable Energy Prospects: Indonesia," Abu Dhabi, 2017.

[64] International Renewable Energy Agency, "Pacific Lighthouses - Renewable Energy Roadmapping for Islands," Abu Dhabi, 2013.

[65] Burns McDonnell, "Microgrid Effects and Opportunities for Utilities," 2016.

[66] M. Knowledge, "microgridknowledge.com," [Online]. Available: https://microgridknowledge.com/cleangrid-southeast-asia-microgrid/. [Accessed 22 May 2020].

[67] O. Energy, "Offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/mauritius-microgrid-project-gets-design-funding/. [Accessed 22 May 2020].

[68] Carnegie Clean Energy Limited, "aie.org.au," [Online]. Available: https://www.aie.org.au/data/Perth_Events/170510_AIE_Luncheon_Presentation_Jonathan_Fievez.pdf. [Accessed 22 May 2020].

[69] Renew Economy, "reneweconomy.com," [Online]. Available: https://reneweconomy.com.au/carnegie-turns-on-garden-island-micro-grid-switches-focus-back-to-wave-power-97703/. [Accessed 22 May 202].

[70] Carnegie Clean Energy, "canegiece.com," [Online]. Available: https://www.carnegiece.com/portfolio/mauritian-wave-and-microgrid/. [Accessed 30 April 2021].

[71] Carnegie Clean Energy, "canegiece.com," [Online]. Available: https://www.carnegiece.com/portfolio/garden-island-microgrid-wa/. [Accessed 30 April 2021].

[72] The Economist - World Ocean Initiative, "woi.economist.com," [Online]. Available: https://www.woi.economist.com/could-the-future-of-marine-energy-be-onshore/. [Accessed 22 May 2020].

[73] EURACTIV, "euractiv.com," [Online]. Available: https://www.euractiv.com/section/energy-environment/news/europes-first-marine-turbine-helps-reduce-ouessant-islands-carbon-footprint/. [Accessed 13 August 2020].

[74] Offshore Energy, "offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/scottish-renewables-hails-bluemull-sound-tidal-lease-extension/. [Accessed 13 August 2020].

[75] Everoze Partners Ltd, "Offshore Generation, Energy Storage & Systems Feasibility Study," 2018.

[76] Power Engineering International, "powerengineeringint.com," [Online]. Available: https://www.powerengineeringint.com/decentralized-energy/cogeneration-chp/the-bankable-microgrid/. [Accessed 22 May 2020].

[77] Renew Economy, "reneweconomy.com.au," [Online]. Available: https://reneweconomy.com.au/carnegie-to-add-solar-battery-storage-to-create-world-first-wave-integrated-microgrid-66551/. [Accessed 22 May 2020].

[78] GreenPort, "greenport.com," [Online]. Available: https://www.greenport.com/news101/europe/good-start-to-2016-for-eco-wave-power. [Accessed 22 May 2020].

[79] Energy Live News, "energylivenews.com," [Online]. Available: https://www.energylivenews.com/2020/04/14/us-injects-38m-of-funding-into-marine-technology/. [Accessed 22 May 2020].

[80] European Commission, "Blue growth- Opportunities for marine and maritime sustainable growth," Communications from the commission to the European parliament, the council, the European Economic and Social committee and the committee of the regions, 2012.

[81] M. J. B. G. K.A. Abhinav, "MULTI-PURPOSE OCEAN ENERGY PLATFORMS FOR OFFSHORE AQUACULTURE FARMS," in *CORE*, Glasgow, 2018.

[82] FAO, "The state of world fisheries and aquaculture 2020 - Sustainability in action," Rome, 2020.

[83] Aquaculture Initiative, "The Potential for Renewable Energy Usage in Aquaculture," Dundalk.

[84] OvoEnergy, "ovoenergy.com," [Online]. Available: https://www.ovoenergy.com/guides/energy-guides/how-much-electricity-does-a-home-use.html. [Accessed 13 August 2020].

[85] H. Syse, "Investigating Off-Grid Energy Solutions for the Salmon Farming Industry," University of Strathclyde Engineering, 2016.

[86] Sea Around Us, "Sea Around Us.org," [Online]. Available: http://seaaroundus.org/. [Accessed 15 November 2019].

[87] Marine Investment for the Blue Economy (Maribe), "maribe.eu," [Online]. Available: https://maribe.eu/wave-aquaculture/. [Accessed 22 May 2020].

[88] Smalle technologies, "eforcis.com," [Online]. Available: https://www.eforcis.com/berlin_en/. [Accessed 22 May 2020].

[89] F. F. Expert, "fishfarmingexpert.com," [Online]. Available: https://www.fishfarmingexpert.com/article/china-builds-wave-power-fish-farm-prototype/. [Accessed 22 May 2020].

[90] Offshore Energy, "offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/sinn-power-all-set-for-cape-verde-wave-energy-project-launch/. [Accessed 22 May 2020].

[91] Global Aquaculture Alliance, "aquaculturealliance.org," [Online]. Available: https://www.aquaculturealliance.org/advocate/can-aquaculture-flourish-in-a-more-symbiotic-sea/. [Accessed 23 May 2020].

[92] Albatern and AquaBioTech Group, "Albatern and AquaBioTech Aquaculture & Wave Energy Combination".

[93] M. v. V. V. S. Edward Jones, "The state of desalination and brine production: A global outlook," *Science of the Total Environment*, vol. 657, pp. 1343-1356, 2019.

[94] M. E. H. A. E. S. B. S. M.A. Abdelkareem, "Recent progress in the use of renewable energy sources to power water desalination plants," *Desalination*, vol. 435, pp. 97-113, 2018.

[95] P. Davies, "Wave-powered desalination: resource assessment and review of technology," *Desalination*, vol. 186, pp. 97-109, 2005.

[96] M. W. A.S. Stillwell, "Predicting the Specific Energy Consumption of Reverse Osmosis Desalination," *Water*, vol. 8, 2016.

[97] M. K. M.W.Shahzad, "A standard primary energy approach for comparing desalination processes," *npj Clean Water*, vol. 2, 2019.

[98] P. T. H.K. Sadhukhan, Small Desalination Plants, vol. 2.

[99] Aquatech, "Aquatechtrade," [Online]. Available: https://www.aquatechtrade.com/news/desalination/worlds-largest-desalination-plants/. [Accessed 19 May 2020].

[100] National Geographic, "nationalgeographic.com," [Online]. Available: https://www.nationalgeographic.com/science/article/cape-town-running-out-of-water-drought-taps-shutoff-other-cities. [Accessed 22 February 2021].

[101] Aquatech, "aquatechtrade.com," [Online]. Available: https://www.aquatechtrade.com/news/desalination/desalination-wave-powered/. [Accessed 22 May 2020].

[102] Forbes, "forbes.com," [Online]. Available: https://www.forbes.com/sites/natalieparletta/2019/07/10/wave-powered-desalination-

promises-to-deliver-clean-water-to-developing-countries-and-island-nations/#67981cb1b01e. [Accessed 22 May 2020].

[103] Power Technology, "power-technology.com," [Online]. Available: https://www.power-technology.com/projects/perth-wave-energy-project/. [Accessed 22 May 2020].

[104] D. P.Contestabile, "Coastal Defence Integrating Wave-Energy Base Desalination: A Case Study in Madagascar," *Journal of Marine Science and Engineering*, 2018.

[105] Offshore Energy, "offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/seabased-grabs-canary-islands-wave-power-chance/. [Accessed 22 May 2020].

[106] Sunday Times, "timeslive.co.za/news," [Online]. Available: https://www.timeslive.co.za/news/south-africa/2018-07-16-drought-hit-town-to-get-solar-powered-desalination-plant/. [Accessed 22 February 2021].

[107] ESI Africa, "esi-africa.com," [Online]. Available: https://www.esi-africa.com/industry-sectors/water/africas-first-sea-water-solar-desalination-plant-reaches-milestone/. [Accessed 22 February 2021].

[108] African Development Bank Group, "afdb.org," [Online]. Available: https://www.afdb.org/en/news-and-events/blue-economy-cape-verde-wins-sefa-grant-to-develop-revolutionary-wave-powered-desalination-system-15296. [Accessed 23 May 2020].

[109] Offshore Energy, "offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/wave-energy-water-desalination-competition-announced/. [Accessed 23 May 2020].

[110] Offshore Energy, "offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/us-picks-waves-to-water-prize-competition-winners/. [Accessed 23 May 2020].

[111] Carnegie Clean Energy, "carnegiece.com," [Online]. Available: https://www.carnegiece.com/portfolio/ceto-5-perth-wa/. [Accessed 30 April 2021].

[112] Resolute Marine Energy, "Resolute Marine Energy: Power in Waves," MIT Sloan Management, 2013.

[113] M. E. H. A. E. S. B. S. M.A.Abdelkareem, "Recent progress in the use of renewable energy sources to power water desalination plants," *Desalination*, 2017.

[114] DNV GL, "https://www.dnvgl.com/," [Online]. Available: https://www.dnvgl.com/to2030/technology/multipurpose-offshore-platforms.html. [Accessed 27 January 2021].

[115] S. P. N. e. al., "Tidal range energy resource and optimization - Past perspectives and future challenges," *Renewable Energy*, vol. 127, pp. 763-778, 2018.

[116] The Energyst, "theenergyst.com," [Online]. Available: https://theenergyst.com/huge-change-is-needed-right-now-brewdog-goes-carbon-negative/. [Accessed 27 April 2021].

[117] WavEC Offshore Renewables, "Deliverable D8.5- Relevant legal, institutional, and political frameworks," DTOceanPlus, Bilbao, 2021.

[118] EDP CNET, "Deliverable D8.2- Analysis of the European Supply Chain," DTOceanPlus, Bilbao, 2020.

[119] Inès Tunga, Mo Abrahams, Harres Khan, Benjamin Tatlock (ESC), "D3.2- Structured Innovation design tool – Alpha version," DTOceanPlus, Basque, 2020.

[120] WES, "Stage Gate tool- Alpha version- Deliverable D4.2," DTOceanPlus, Bilbao, 2020.

[121] Tecnalia, "Technical requirements for Deployment design tools Deliverable D5.1," DTOceanPlus, Bilbao, 2019.

[122] Tecnalia, "Technical Requirements for the Assessment Design Tools- Deliverable D6.1," DTOceanPlus, Bilbao, 2019.

[123] S. J. H. &. Alessandra, "IRENA Ocean Energy current deployment & outlook," in *"Oceans powering the energy transition: Progress through innovative business models and revenue support"*, 2020.

[124] Directorate General for Marine Affairs and Fisheries, "Market Study on Ocean Energy- Final Report," European Commission, Brussels, 2018.

[125] N. Ferguson, "International Niche Markets for Wave and Tidal Energy," in *All Energy 2016-Wave and Tidal session*, Glasgow, 2016.

[126] Water Power Technologies Office, "Powering the Blue Economy Report: Exploring Opportunities for Marine Renewable Energy in Maritime Markets," US Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, D.C., 2019.

[127] N. Voutchkov, "Energy Use for membrane seawater desalination- Current status and trends," in *ResearchGate*, 2017.

[128] U. A. Korde, "Enhancing the resilience of energy systems: Optimal deployment of wave energy devices following coastal storms," *Renewable Sustainable Energy*, vol. 11, no. 034501, p. 13, 2019.

[129] Water Power Technologies Office, "Powering the Blue Economy Report: Exploring Opportunities for Marine Renewable Energy in Maritime Markets," US Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, D.C., 2019.

[130] Offshore Energy, "offshore-energy.biz," [Online]. Available: https://www.offshore-energy.biz/eco-wave-power-bags-2-mln-in-fundraising/. [Accessed 22 May 2020].

[131] Ocean Enery Europe, "Key trends and statistics 2019," OEE, Brussels, 2020.

[132] British Standard, "BS 7000-1 Design Management systems: Guide to managing innovation," BSI, -, 1999.

9. BUSINESS MODELS FOR ALTERNATIVE MARKETS

This appendix contains the value propositions and business model canvasses for each alternative market covered in section 3.2. These were then used to input into the business models for the customer segmentation.

9.1. OIL & GAS APPLICATION

9.1.1. VALUE PROPOSITION

Customer segments/Value propositions	
Customer offerings	▸ Reduction in carbon emissions associated with existing operations to assist O&G companies are meeting internal targets. ▸ These will target sub-systems within offshore operations (electrification of hydraulics, monitoring), where it is challenging to generate power, and the direct access of ocean energy can reduce operating costs. ▸ PPA- long-term (20 years) agreement, mediated through a contractor who fits and maintains the device. The price will be higher than other renewables, with a premium for energy access in remote environments
Gains/ Gain creators	▸ Meeting emissions targets using technology that can overcome accessibility issues. ▸ Higher potential yield of wellhead gas due to the use of alternative energy source to power rig operations. Allows greater production volume from existing processes. ▸ Increased sector viability with transitioning of business into new low carbon technologies, and the ability to secure long-term use of the platform for other purposes (marine research, shipping infrastructure)
Pains/ Pain Relievers	▸ Mitigation of financial losses due to the introduction of carbon taxes ▸ Lack of options to decarbonise for some offshore sites. ▸ Lower maintenance costs from replacing hydraulic components

9.1.2. BUSINESS CANVAS

Desirability

Value Proposition	▸ Reducing emissions of offshore oil and gas rig operations. ▸ Increased viability of the sector through meeting carbon targets and extending asset lifetime. ▸ The higher yield of the core product (gas not required to power rig operations). ▸ Reduced maintenance cost through the conversion of unreliable components.
Customer Segment(s)	▸ Oil and gas companies with offshore rig operations (focused on small-scale power requirements which can be matched to ocean energy demonstrators)

Channel	‣ Consultants offering to advise on carbon reduction strategy, the role of ocean energy, and providing installation and maintenance services. ‣ Direct contract negotiation – bilateral agreement. ‣ Grant-funded projects to initiate trials and provide proof of concept.
Customer Relationships	‣ Consultancy model – consistent engagement, through both generation asset holder, rig operators and owners, and third-party consultancy. Monitoring of operational activities to determine optimal solutions for ocean energy generation. ‣ PPA agreements – minimal interactions regarding strategic use of technology, with conditions set at contract initiation. Direct contract between oil and gas rig owner and service provider. Maintenance contract requirement with service providers – a channel of communication required to initiate maintenance operations.

Feasibility

Key Resources	‣ Vessels capable of installing subsea cables and ocean turbines. ‣ Skills force capable of maintaining power supply operations. These could be contracted from the technology supplier or trained employees of the rig operator. ‣ Licensing agreement for the use of technology ‣ Availability of co-location – a suitable neighbouring area with conditions in which turbines can operate. The requirements to determine conditions before contract initiation.
Key Activities	‣ Investigation of matching supply to rig activities. Includes consideration of requirements for storage and/or other supporting renewable technologies to balance supply/demand conditions. Appropriate for consultancy model before implementation. ‣ Assessment of renewables competition (floating wind); ocean energy may be competing with other renewables or providing support to other renewable generation. Appropriate for a consultancy model considering a more holistic approach. ‣ Development of relationships between rig operators, ocean energy technology developers and intermediate service provider. ‣ Site evaluation to determine the most appropriate turbine placement. ‣ Transfer of processes from existing gas turbines to ocean turbines. ‣ Installation of turbines and connecting cables. ‣ Maintenance of generating assets and connecting cables. ‣ Replacement of hydraulic components with electrified equivalents.
Key Partners	‣ Oil and gas rig operators in consultancy model. ‣ Academic collaborators receiving oil and gas research funds. ‣ National governments – particularly relevant where the oil and gas company is a nationalised asset. ‣ Third-party consultancies and service providers. ‣ OPEC

Viability

Revenue Model	- PPA – set price per MWh, including maintenance of generating asset. Conditions set to a long-term agreement (e.g. 20+ years, or to coincide with rig decommissioning) - Consultancy model – expertise used as a commodity to determine the strategic value of marine technologies within an existing operation. This may not be viable for some technology developers and require a third-party consultancy/service provider.
Cost Model	- Research to develop proof-of-concept design. - Installation and manufacturing costs. - Maintenance costs. - Leasing of land/seabed. - Insurance. - Potential storage costs. - Replacement of hydraulic components for electrified equivalents.

9.1.3. BUSINESS MODEL ASSESSMENT

Initial thinking around supplying the oil and gas market was to target overall platform demands. However, interviews with industry stakeholders revealed several small applications, such as replacing existing hydraulics, where the role of ocean energy generation appeared to be more compatible.

The business model presented is only considered suitable for wave energy devices. Tidal devices are excluded based on few overlaps in geographic location.

The business model was well received in interviews and workshops. Several demonstrators exist (PowerBuoy, BlueStar), which indicate the feasibility of this configuration. The business model strengths include diversifying operations and alleviating reliability issues.

Some downsides identified included the recent reduction in research and development budgets for oil and gas companies, strong competition from floating wind, potential risk-averse nature of the client and potential negative public relations of partnering with a heavily emitting industry.

9.2. COASTAL RESILIENCE APPLICATIONS

9.2.1. VALUE PROPOSITIONS

Customer segments/Value propositions	
Customer offerings	▸ Integration of ocean generation turbine in breakwater scheme to share project costs. ▸ Power provision to support coastal resilience (e.g., warning systems, sand replenishment) ▸ Power provision to port infrastructure. ▸ Capacity agreement with local utility provider – obligation to hold a level of capacity for monthly payments. This capacity will take the form of storage charged by ocean energy. ▸ Consortium – gathering government, community, and business to determine strategic requirements for ocean (and other) renewables in coastal resilience scheme. Consortium pays a fixed price for service on a pre-approved disaster response mechanism. ▸ Co-operative scheme, with local community ownership. The scheme might pay a premium for security of supply offered by marine energy but more likely to represent a successful model with a diverse generation mix.
Gains/ Gain creators	▸ Prevention against extreme weather events. ▸ Job creation through proactive risk management and assurance to investors, developers, and the community. ▸ Community engagement in a low carbon energy scheme. ▸ Shared costs of planning, infrastructure, and administration from combining two solutions
Pains/ Pain Relievers	▸ Securing reliable power source for weather-related outages. ▸ Reduction in air pollution by displacing diesel. ▸ Offshore generation reduces the requirement for land take. ▸ Counteracts volatile diesel prices. ▸ Potential to save lives through the provision of warning systems and securing critical facilities.

9.2.2. BUSINESS CANVAS

Desirability

Value Proposition	▸ Utility contracts for capacity ▸ Consortium creation coupled with consultancy offer to determine the strategic value of renewable energy sources. Managed at the national level, with government budget providing fixed fees for the provision of backup services. ▸ Community co-operative scheme again coupled with consultancy offer. More suitable for diverse generation mixture if the local community are paying directly. ▸ Low carbon, low polluting energy source replacing diesel generators which might currently be used to power coastal infrastructure. ▸ Increased resiliency of supply for emergencies. ▸ Mitigation against extreme weather events. ▸ Potential to save lives through the provision of warning systems.

	▶ Creation of jobs in coastal locations by assuring investors and developers. ▶ Shared costs of planning, infrastructure, and administration from combining two solutions
Customer Segment(s)	▶ Local coastal communities (funded by national or local taxes to establish response solution or cooperative model with local investment. The tax base for the solution may depend upon the infrastructure owner – how devolved is the government planning?) ▶ Utility companies (providing services for capacity) ▶ NGOs/Disaster recovery teams/Charities ▶ Port authorities
Channel	▶ PPA to port infrastructure ▶ Capacity markets, with the local utility provider as the customer segment ▶ Consortium fee on approved frameworks. ▶ Facilitation through NGOs
Customer Relationships	▶ Ocean generators will need to sign agreements with local utilities for the provision of reserve capacity. ▶ Instigation mechanism for the requirement of supply – fast response time required. ▶ Regular assessment of available capacity to determine ability to meet contract conditions. ▶ Planning with consortium to determine priority supply based on various weather events. ▶ Engagement with consortium and consultancy to determine the strategic value of renewable mixture in the local grid. ▶ A trusted partner with more focus on community resolution and less on the commercial opportunity. ▶ Regular updates to response plan.

Feasibility

Key Resources	▶ Skills force to create turbine facility, breakwater, and connection to the local grid. ▶ Skills force to enact extreme weather event plans/make risk assessments, and make decisions about best uses of available resources. ▶ Action plan for supply provision based on scenario formulation. ▶ Availability of suitable conditions for turbine placement. ▶ Software to match electricity production with local energy requirements of critical facilities. ▶ Legal agreements to meet security of supply conditions for sensitive facilities – military bases, etc. ▶ Storage (e.g. batteries) to facilitate an anticipated sharp peak in demand corresponding to the start of a disaster event. ▶ Finance package and underwriter of payments.
Key Activities	▶ Consortium development ▶ Developing legislation with local and national governments to determine the value-added to the local economy and livelihoods is a pre-project consultation. ▶ Creating a local engagement strategy to determine priorities in disaster events. ▶ Identifying additional requirements based on supply-demand discrepancy – installation of storage facilities which can couple to ocean energy. ▶ Site evaluation to determine optimal turbine placement and optimal breakwater placement, and compromise between these two factors.

	▸ Reconfiguration of the existing network to utilise marine power source – installation of seabed cables etc. Network planning to facilitate emergency supply. ▸ Potential creation of a new microgrid in SIDS to be powered by a marine source. ▸ Contracts for capacity with utilities and independent sites ▸ Creation of framework with a consortium or co-operative model ▸ Creation of instigation mechanism – consideration of data monitoring and communications to increase efficiency. ▸ Market segmentation of where opportunities exist, e.g. high price of diesel, LCOE etc
Key Partners	▸ National and local governments ▸ Campus facilities ▸ Oceanic/meteorological organisations ▸ FEMA (US) and other national equivalents ▸ Energy storage partner ▸ Civil engineering firm required to construct breakwater

Viability

Revenue Model	▸ Reserve capacity fee to guarantee the performance of critical facilities. ▸ Agreed strike price for the port authority. ▸ Consortium fee for the provision of coastal resilience.
Cost Model	▸ Research to develop breakwater-turbine combinations. ▸ Installation and manufacturing costs for breakwater and turbine ▸ Maintenance costs ▸ Leasing of land/seabed ▸ Coupled battery storage. ▸ Network rerouting ▸ Insurance ▸ Investment in beach replenishment infrastructure and warning systems. ▸ Environmental impact studies

9.2.3. BUSINESS MODEL ASSESSMENT

The main challenge for a coastal resiliency business model is customer definition. One potential customer could be a high-value asset owner looking to protect their investment from coastal erosion and extreme weather conditions. However, as highlighted by stakeholder engagement, such assets are likely to be grid-connected, which means that ocean energy will have to compete in a lower-cost market. Until LCOE is significantly reduced, this would not be a viable option.

The more promising market in this instance is remote communities with concerns about coastal erosion. This is more likely to achieve success as part of a community-ownership model since decisions about coastal defence strategy are often highly sensitive to the local preference.

The business model could be equally valid for wave and tidal energy devices, given the coastal location. However, it should be noted that a detailed study of tidal energy locations needs to be conducted to determine if coastal resiliency is a priority in locations with a high tidal resource.

Strengths of the business model are co-location benefits (reduced CAPEX and operational costs from using defence structures). However, there are significant weaknesses, including the increased focus on soft engineering solutions to solve coastal resiliency issues, the sector's reactive nature, and heavy competition from other power sources in affected areas. In addition, the business model was only considered viable for the most remote communities, where access to energy is limited – however, funding would be more difficult to generate from these types of communities. As a result, long-term development is necessary to consider this model as a viable option.

9.3. DISASTER RECOVERY

9.3.1. VALUE PROPOSITIONS

Customer segments/Value propositions	
Customer offerings	• Provision of low carbon electricity source to power critical infrastructure (power, desalination production, medical facilities, military) in emergency events (extreme weather etc.) • Off-shore integrated desalination plant solution • Local disaster resilience solution - a standardised modular system of, e.g. 100kW and x l/day to make it easy to understand for the customer buying process. Created as a service contract. • System integration of supply chain and mobile, quick to assemble solutions. • Control system optimises between power and freshwater generation. • Ability to adapt and be flexible to site conditions and characteristics, including other services according to community engagement and utilising the modular system.
Gains/ Gain creators	• Responds to targets for low carbon alternatives and reduces pollution compared to diesel generators used to power these systems. • An adaptable system that can be tailored to local needs. • Reduced complexity of purchasing system.
Pains/ Pain Relievers	• Potential to save lives through the provision of medical care and clean water. • Enabler of critical infrastructure in extreme weather events. • Offshore generation reduces the requirement for land take. • Counteracts volatile diesel prices and uncertainty of fuel delivery in crisis.

9.3.2. BUSINESS CANVAS

Desirability

Value Proposition	• Provision of low carbon electricity source to power critical infrastructure (power, desalination production, medical facilities, military) in emergency events (extreme weather etc.) • Off-shore integrated desalination plant solution

	▸ A standardised modular system, e.g. 100kW and x l/day, is easy to understand for the customer buying process. ▸ Potential to save lives through the provision of medical care and clean water. ▸ System integration of supply chain and mobile, quick to assemble the solution. ▸ Control system optimises between power and freshwater generation. ▸ Ability to adapt and be flexible to site conditions, characteristics, and community engagement.
Customer Segment(s)	▸ Local coastal communities (funded by taxes raised at either national or local level to establish response solution or co-operative model with local investment. The tax base for solution may depend upon the infrastructure owner – how devolved is the government decision-making and planning?) ▸ Military/defence bases ▸ NGOs/Disaster recovery teams/Charities ▸ Desalination plant operators
Channel	▸ Facilitation through NGOs ▸ Contract for a fixed price on water provision and available capacity ▸ Contract conditions based on community engagement.
Customer Relationships	▸ Instigation mechanism for supply – fast response time likely required. ▸ The delivery system planned with local stakeholders. ▸ Planning with the local community to determine priority supply based on various weather events. ▸ Regular updates to response plan, including consideration of outside access, through meetings with government and military. ▸ Communications and public relations to engage the local community. ▸ Engagement with local transport network operators to arrange access.

Feasibility

Key Resources	▸ Skills force to enact extreme weather event plans/make risk assessments, and make decisions about best uses of available resources. ▸ Action plan for supply provision based on scenario formulation, with standard response formulation for each scenario. ▸ Availability of suitable conditions for turbine placement. ▸ Software to match electricity production with local energy requirements of critical facilities. ▸ Legal agreements to meet security of supply conditions for sensitive facilities – military bases, etc. ▸ Storage (e.g. batteries) to provide power before generation and manage power after deployment. ▸ Finance package and underwriter of payments ▸ Offsite and prefabricated units ▸ Patent for the technology of modular system and control mechanism
Key Activities	▸ Consortium development ▸ Creating a local engagement strategy to determine priorities in disaster events. ▸ Identifying extra needs based on supply-demand discrepancy – installation of storage facilities which can couple to ocean energy. ▸ Site evaluation to determine optimal turbine placement. ▸ Installation of seabed cables, for example, to connect storage to generation. ▸ Creation of framework with a consortium or co-operative model

	- Creation of instigation mechanism – consideration of data monitoring and communications to increase efficiency. - Understand engineering possibilities and limitations between ocean energy and desalination plant at 100 kW scale. - Market segmentation of where opportunities exist, e.g. high price of diesel, LCOE etc. - Agreement to provide services at fixed costs in the event of a disaster – possibly scenario-based. - The standardised process to enable rapid response to recovery situations
Key Partners	- National and local governments - Campus facilities - Oceanic/meteorological organisations - FEMA (US) and other national equivalents - Desalination plant suppliers for supply of fresh water in emergency events - Local engagement stakeholders – local communities to help identify areas with freshwater limits. - Energy storage partner - Logistics and transport partners – off-site or local assembly which can fit into one container to aid standardisation

Viability

Revenue Model	- Service model – fixed prices for power and water volume
Cost Model	- Research to develop proof-of-concept design. - Installation and manufacturing costs - Maintenance costs - Transportation costs - More significant decommissioning costs if this is intended to form a temporary relief. - Leasing of land/seabed. - Coupled battery storage. - Insurance - Laying seabed cables

9.3.3. BUSINESS MODEL ASSESSMENT

This market was originally conceived as a temporary solution, powering emergency facilities and creating clean potable water. However, following feedback from stakeholders and workshops, the temporary nature of this solution was changed. This was due to feasibility constraints (transportation, installation time, resource matching) and that these markets typically require solutions for up to 20 years.

Therefore, this is now considered a modular solution created as a pre-emptive solution to disasters and links more closely with the coastal resiliency market than in the initial stages. The added value against the coastal resiliency business model is providing additional infrastructure (i.e. desalination plants) and consultancy around resiliency strategies.

The business model could be linked to either wave or tidal energy, given the coastal location. But, again, assessments of areas with high tidal resource are required to determine whether there is an existing need for these services.

The key strengths of this business model were the modular solution, the nexus of water and energy solutions, and the simplified payment structure. However, there were significant weaknesses, particularly focused on project delivery. The short lead-time to rollout devices was a cause for concern, which has been mitigated by changing the business model to a pre-emptive solution. Other concerns related to the local skills and supply chain availability, competition from other sources, and the requirement to tailor generators to a wide range of conditions. Similar caveats apply to coastal resiliency to enable this market – a long-term, consortium driven approach must be undertaken to achieve viability.

9.4. MICROGRIDS/REMOTE ISLANDS

9.4.1. VALUE PROPOSITIONS

Customer segments/Value propositions	
Customer offerings	▸ PPA agreement to supply electricity to a microgrid (owned by a local utility operator) over a long-term (20 years +) fixed strike price. ▸ Ability to counter limitations regarding land availability and accessibility, where other renewables cannot easily compete. ▸ The potential service model provides a wider variety of services, incorporating desalination to target the tourist sector economic boost. Uses consortium model, as opposed to a bilateral utility provider contract.
Gains/ Gain creators	▸ Reduction in carbon emissions by replacing diesel on existing installations. ▸ Job creation associated with installation and active network management responsibilities. ▸ Ability to support multiple applications, providing a wider economic boost. ▸ Increase of market size - electricity supplies installed in locations where it is currently unavailable. ▸ Ability to optimise local networks through greater control of power generation.
Pains/ Pain Relievers	▸ Lower reliance on external fuel sources, resulting in less price volatility and higher security of electricity supply. ▸ Lower reliance on large fuel-storage facilities which have large land take. ▸ Greater reliability for sites with critical functions ▸ Offshore generation further reduces the requirement for land-take. ▸ Lower environmental risks with reduced air, noise pollution and spill risks

9.4.2. BUSINESS CANVAS

Desirability

Value Proposition	- Low-carbon, low-polluting source of energy replacing incumbent diesel generators. - Lower reliance on external fuel sources, resulting in lower price volatility and higher security of electricity supply. - Greater quality of life due to reduced blackout frequency - Greater control over operations of isolated commercial and military sites - Increased access to electricity supply/market size - Lower reliance on large fuel-storage facilities with significant land take - Economy boost from expanded operations which rely on the stable power supply.
Customer Segment(s)	- Local and national governments - Remote communities and businesses represented by either national or local taxation or cooperative scheme. - Military/defence bases - Campuses (Universities, Medical facilities, Data centres)
Channel	- Fixed price PPA agreement with local utility provider – suitable for existing microgrids - Service model encapsulating wider economy (including desalination) for new microgrids. - Consortium building for service model. - Strategic consultancy to advise on implementation. - Tourism sector – advocacy from growth areas within the community.
Customer Relationships	- Existing network operators to provide access to customers. - Regulators (where appropriate) to assess the impact on customer prices. - Local government – determination of strategy - Campus sites – understanding of energy needs and potential for using microgrid/ocean energy combinations. - PPA agreements – minimal interactions regarding strategic use of technology, with conditions set at contract initiation. The direct contract between microgrid operator and generation asset holder. Maintenance contract requirement with generation asset holder – channel of communication required to initiate maintenance operations. - Service offering – detailed iterative consultancy engagement. More frequent consortium meetings involving local businesses. Monitoring of ongoing operations to determine strategic changes.

Feasibility

Key Resources	- Skills force to create turbine facility and connection to the local grid. - The purchase agreement for the provision of electricity to the local market - Availability of suitable conditions for turbine placement. - Software to match electricity production with local energy requirements and interact with other generating resources, allowing for cost optimisation of the local grid. - Legal agreements to meet security of supply conditions for sensitive facilities – military bases, etc. Bilateral contract with a guarantee of capacity.

Key Activities	- Creation of consortium representing local businesses and governing bodies. - Site evaluation to determine the optimal location for marine turbines. - Identifying extra system requirements based on supply-demand discrepancy – potential for storage or other renewables to play a role? - Installation of seabed cables and new network - Potential creation of a new microgrid in SIDS to be powered by a marine source. - Optimisation of grid conditions through modelling of local conditions - Creation of relevant PPA deals with utility operator/discrete facilities. - Creation of a service model for the provision of additional utilities/services.
Key Partners	- National and local governments - Campus facilities - Market regulators – translation of marine power source into fair pricing for customers. - Desalination plant - Local tourism industry representatives

Viability

Revenue Model	- The power purchase agreement with local network operator/discrete sites, with a long-term horizon (20+ years), set at a pre-agreed price. - Reserve capacity guarantee pricing for sites with sensitive operations (incorporating coupled storage). - Additional provision of water services/support for tourism and industry, incorporated within a service model. Revenue stacking selling both electricity and water at a fixed price.
Cost Model	- Research to develop proof-of-concept design. - Installation and manufacturing costs. - Maintenance costs - Network rerouting - Leasing of land/seabed - Market access costs to maintain alternative revenue sources. - Coupled battery storage. - Insurance - Environmental impact study

9.4.3. BUSINESS MODEL ASSESSMENT

The intended markets are isolated communities that rely heavily upon diesel imports to generate power on a local microgrid. The two main forms of the customer to consider are island states with developing economies (SIDS) or remote provinces of developed nations (Alaska, Northern Canada). It would be unlikely that ocean energy could entirely displace diesel on these networks and form part of a wider solution.

The business model presented could be equally valid for wave and tidal energy devices.

Strengths of this business model include a clear need due to high local prices, the ability to scale devices to grid applications easily, and provides a solution to network constraints. Weaknesses include strong competition from other renewables (particular for tropical islands states), strict environmental constraints and variability in customer. The latter point impacts the most suitable technology since larger microgrids will need a more scalable technology – only tidal is likely to be competitive in these markets. Also, customer identification can be challenging; depending upon the level of grid subsidies, the local consumer may not be footing the bill for expensive diesel costs. Funding to decarbonise microgrids may therefore come from more diverse sources, complicating the business model.

9.5. OFFSHORE AQUACULTURE

9.5.1. VALUE PROPOSITION

Customer segments/Value propositions	
Customer offerings	▸ PPA agreement for a fixed period at a fixed price from ocean generator
Gains/ Gain creators	▸ A higher quality product created by replacing diesel as the primary fuel source. This reduces air and water pollution and provides a better environment for food production. This could lead to higher product pricing. ▸ Acceleration of growth industry by enabling access to offshore sites. ▸ Enabling a more sustainable fishing sector by facilitating a controlled environment. ▸ Enables compliance with emissions targets for the sector.
Pains/ Pain Relievers	▸ Lower fuel price volatility (and therefore more reliable OPEX costs) and better security of supply, particularly within isolated areas ▸ Lower costs from fuel transport ▸ Fewer site visits – aquaculture farms can function more self-sufficiently. ▸ Lower environmental risks (diesel spills, emission regulations) ▸ Co-location with ocean generation reduces the land take requirement

9.5.2. BUSINESS CANVAS

Desirability

Value Proposition	▸ Low carbon, low polluting energy source replacing diesel generators. ▸ PPA used to guarantee price and reduce the requirement on aquaculture farm to maintain supply. ▸ Lower reliance on external fuel sources, resulting in lower price volatility and higher security of electricity supply. ▸ Higher quality product and production volume create larger margins and more profitable businesses for owners. ▸ Support and enabler of growth industry to allow for more sustainable fishing.

	Synergy in the use of space facilitating the movement of cages further offshore. More self-sufficient operations with reduced transport cost
Customer Segment(s)	Aquaculture farms (finfish and algae producers)
Channel	Food and Agriculture Organisation (FAO) Strategic consultancy Publicly funded trials (Horizon 2020)
Customer Relationships	Aquaculture farms will require a partnership to enable access to the generating facility. PPA model – limited interactions after signing of the initial contract. Maintenance access required. Suitability studies required upfront to determine contract conditions. Third-party consultancy as an option – service provider and engineering consultant to handle operations and installation, respectively. Regular touchpoints to discuss maximising operations.

Feasibility

Key Resources	Skills force to create turbine facility and connection to aquaculture farm. The purchase agreement for the provision of electricity. Availability of suitable conditions for turbine placement – assessed through a site evaluation. Software to match electricity production with facility profile and requirement for supporting technologies. CSR[2] analysis of supply chain from source to shelf Environmental impact study to determine the effect of the generator on fish health.
Key Activities	Installation of seabed cables Site evaluation to determine optimal turbine placement. Identifying extra needs based on supply-demand discrepancy – potential for storage or other renewables to play a role. Quantification of pollution benefits – consultation with wider supply chain, involvement of conservation and environmental bodies Cost benefit analysis – ocean energy tech only, ocean energy tech + farm structure, farm structure only. Evaluate which ocean technology can best integrate with farm/cage design and lessons learnt from other integration projects, e.g. wave, tidal and wind. Identify additional opportunities to import power from relatively local (but not integrated) sites. Environmental impact study to determine effects on fish stock.
Key Partners	Wider aquaculture supply chain National and local governments – determination of job creation, growth, and strategy within aquaculture industry (e.g., DEFRA) Food and agriculture organisation – United Nations Public funding bodies - EU Conservation and environmental bodies Trading bodies (E.U.) Certification bodies

[2] Corporate Social Responsibility in Aquaculture

Viability

Revenue Model	- PPA between aquaculture farm and offshore energy producer
Cost Model	- Research to develop proof-of-concept design. - Installation and manufacturing costs – potentially involving a third-party consultant. - Maintenance costs – potentially through service provider. - Leasing of land/seabed. - Coupled battery storage. - Insurance - PR and comms to highlight the potential for reducing the fossil fuel demands of current aqua farms. - Environmental impact study

9.5.3. BUSINESS MODEL ASSESSMENT

The business model presented allows ocean energy to provide partial energy to an aquaculture farm, either supported by other renewables or diesel generation. Larger power demands for these farms are required in offshore locations, a growing market within the industry. Therefore, wave energy devices have better coupling potential to this market. Tidal energy may be able to couple with near-shore markets – however, farms are typically located away from strong tidal currents, so this could not be a co-located solution.

Strengths of this business model include the growing market, which could be addressed (particularly by opening up offshore locations), the potential remote nature of the power demands excluding other renewables, benefits of co-location, increased product value and potential to offer wider services around digitisation and monitoring. Weaknesses include the requirement to resolve environmental impact, which is an ongoing activity, potential lack of motivation for the sector to decarbonise, and seabed licensing issues.

9.6. DESALINATION

9.6.1. VALUE PROPOSITION

Customer segments/Value propositions	
Customer offerings	- Provision of electricity to the local utility company with a strike price (PPA – long term) - Provision of electricity to desalination plant (PPA – long term, dependent upon plant lifetime) - Black-box model – revenue from the sale of water and electricity (would require co-ownership of generating asset)
Gains/ Gain creators	- Low carbon, clean energy source in response to national/global carbon targets - More plentiful water supply and market share in areas with water shortages.

	▸ Local economy boost for isolated coastal areas, supporting key sectors such as industry, tourism and agriculture. ▸ More affordable water costs for customers, including utility providers, local municipalities, or community schemes (arising from reduced OPEX costs) ▸ Additional support for growing electricity demands elsewhere in the system
Pains/ Pain Relievers	▸ Creation of cleaner water source leading to health benefits. ▸ Reduction in water cost, with lower reliance on volatile diesel prices. ▸ Guaranteed water supply rates – not reliant upon external fuel deliveries. ▸ Reduction in air pollution by using an ocean energy source instead of diesel. ▸ Co-location reduces the requirement for land take.

9.6.2. BUSINESS CANVAS

Desirability

Value Proposition	▸ PPA to provide energy to desalination plant and wider grid. ▸ Co-ownership – PPA to grid and water sale at a fixed price to water utility. Revenue splitting between plant and generation owners. ▸ Low-carbon, low-polluting source of energy to provide potable water. ▸ Ability to provide clean water to areas with a shortage. ▸ Alleviation of both climate change and population increase effects, which can both lead to further water shortages. ▸ Potential further revenue streams from the sale of surplus electricity ▸ Creation of jobs in coastal communities ▸ Lower reliance on external fuel sources, resulting in less price volatility (reduced OPEX costs) and higher security of water supply. ▸ Reduction of water costs for customers.
Customer Segment(s)	▸ Water utility provider ▸ Local electricity provider ▸ Desalination plant ▸ Local government (when utilities are under governing control) ▸ Local tourist resorts (direct water and energy sales) ▸ Agriculture and industry (direct water and energy sales) ▸ Community-owned water scheme
Channel	▸ Publicly funded trials (Horizon 2020) ▸ Tourism and industry advocacy ▸ Clean water organisation and strategy groups ▸ Consultancy approach
Customer Relationships	▸ Business models could be through a combined asset or distinct generation/desalination split. ▸ Partnership with potable water supplier (desalination plant, utility) ▸ PPA model – limited interactions after signing of the initial contract.

	‣ Suitability studies required upfront to determine contract conditions. ‣ Access required for maintenance included within PPA – potentially involving third-party service provider. ‣ Combined asset approach – initial investment discussions ‣ Regular touchpoints to discuss maximising operations. ‣ Management of additional revenue streams and splitting between generation and plant holders

Feasibility

Key Resources	‣ Skills force to create an integrated platform for generation, desalination plant, and exports to the electricity market, responding to both requirements and market conditions. ‣ The purchase agreement for the provision of electricity to market. ‣ Licensing of operation to provide water to local markets. ‣ Availability of co-location – or means to connect generation with desalination plant at low cost. ‣ Software to match electricity production with requirements of the desalination process.
Key Activities	‣ Transfer of operations in case of existing desalination plants. ‣ Creation of new facilities – consideration of decommissioning or repurposing towards the end of asset lifetime. ‣ Consideration of modes of operation which will maximise revenue - balancing of water production with other revenue streams. ‣ Develop partnerships between desalination plants and offshore energy partners. ‣ Investigation of business models – separate desalination partner? Dependent upon the local market. ‣ Investigation of generation profile matching with requirements of a desalination plant ‣ Site evaluation to determine the optimal placing of turbines and demand profile. ‣ Assessment of water quality from the production process
Key Partners	‣ Agriculture, industry, and tourism sectors ‣ Clean water organisations – quantification of added benefits of clean water

Viability

Revenue Model	‣ PPA between desalination plant and offshore energy producer, plus PPA with local grid. ‣ Combined asset approach – sales of water and electricity to utility providers
Cost Model	‣ Research to develop proof-of-concept design/ ‣ Installation and manufacturing costs/ ‣ Maintenance costs/ ‣ Leasing of land/seabed. ‣ Cost of trading to maintain alternative revenue sources. ‣ Insurance. ‣ Potential storage costs. ‣ Environmental impact study

9.6.3. BUSINESS MODEL ASSESSMENT

The business model presented is for ocean energy to provide partial energy for a desalination plant, either supported by other renewables or diesel generation. This business model could apply to either wave or tidal.

The engagement was low for this business model, and therefore it has not been robustly tested. Nonetheless, analysis was performed by the internal project team. The strengths are increasing pressure on water availability, driven by climate change and population, a predictable energy profile that complements ocean technology generation, and the potential to pressurise seawater and reduce the desalination process's overall electricity demand. The main weakness is the geographical location of demands, typically in low ocean energy resource and high solar availability. This point is emphasised by the prominence of solar in renewable desalination pilots. Furthermore, desalination is an energy-intensive process, most suitable to scalable technologies – therefore, this may be more suitable for tidal if the resource is large enough to create economic viability.

10. MARKET VALIDATION AND BUSINESS MODEL DESIGN

The following appendix contains the unabridged details from the iterative market validation and business model design activity.

10.1. STAKEHOLDER SUMMARY

Market	Offshore oil & gas	Coastal Resilience	Disaster Recovery	Micro-grids	Offshore aquaculture	Desalination	Wave Tech Expert	Tidal Tech Expert	Other	Interview	Survey	Workshop
DNV GL	x				x	x				x		
Oil and Gas Technology Centre	x									x		
Centre for Environment, Fisheries & Aquaculture Science					x					x		
Cluster Energia	x	x	x	x	x	x				x	x	
HR Wallingford/ William Allsop ltd.		x	x							x	x	
Major Energy Users Council (NI)	x			x						x		
The Crown Estates/ OREC	x									x		
Ocean Power Technologies	x									x		
Practical Action Consulting			x							x		
Sustainable Energy Africa		x		x		x				x		
The Cyprus Institute						x				x		
Nova Innovation								x		x		
Orbital Marine								x		x		
CorPower Ocean							x			x		
Wave20							x				x	
Energias De Portugal	x						x	x	x	x		x
MARMOK project							x				x	
Sabella											x	x
Tecnalia							x	x			x	x

Enel	x										x	x
Bureau Veritas									x		x	
Wave Energy Scotland							x					x
University of Edinburgh	x	x	x	x	x	x	x	x				x
France Energies Marine							x	x			x	
Offshore Renewables Catapult							x	x			x	
Defence/Systems Engineer (ESC)									x			x
Offshore Renewables/ Oil & Gas Expert (ESC)	x						x	x				x
Renewables/ Local Energy Expert (ESC)							x	x				x

The 'other' category includes stakeholders covering military, defence, utility and certification applications.

10.2. PROTOTYPE BUSINESS MODEL DIAGRAMS

These business model diagrams were created at the beginning of the iterative process as reference material for stakeholder interviews and survey activity.

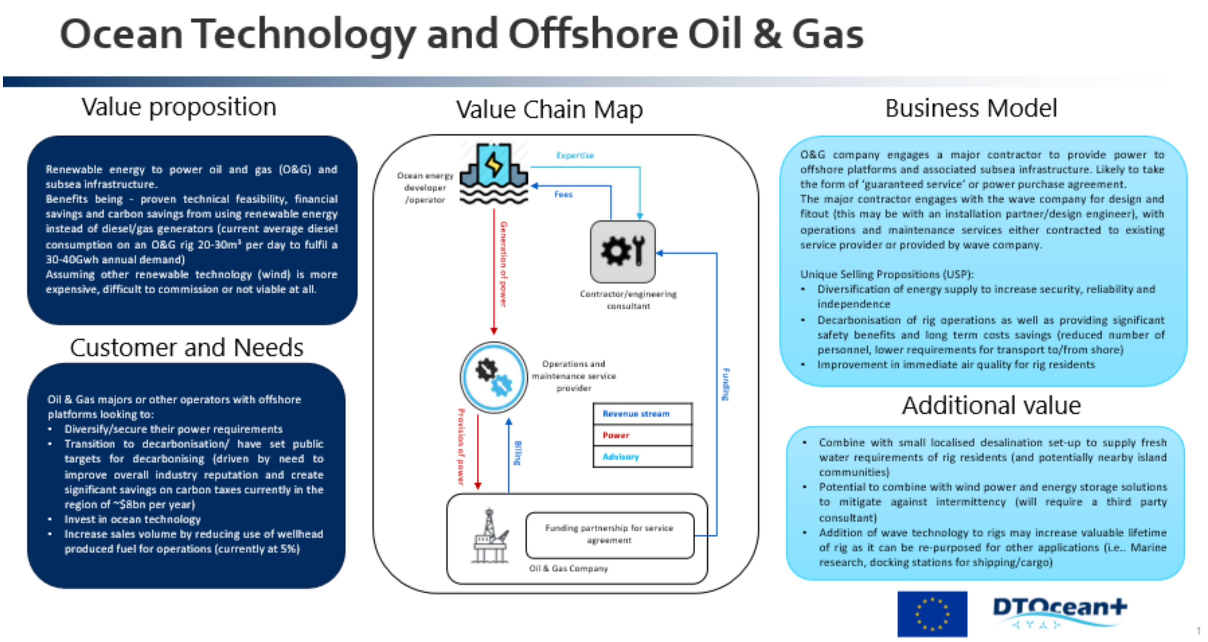


FIGURE 10.1: OFFSHORE OIL & GAS BUSINESS MODEL DIAGRAM

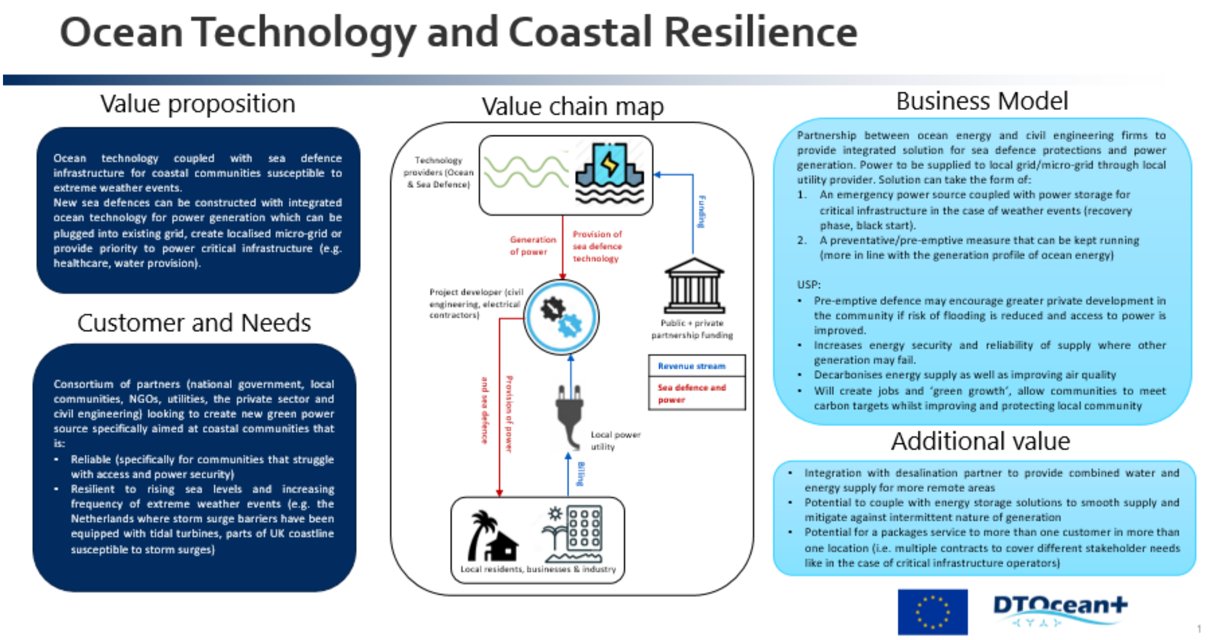


FIGURE 10.2: COASTAL RESILIENCE BUSINESS MODEL DIAGRAM

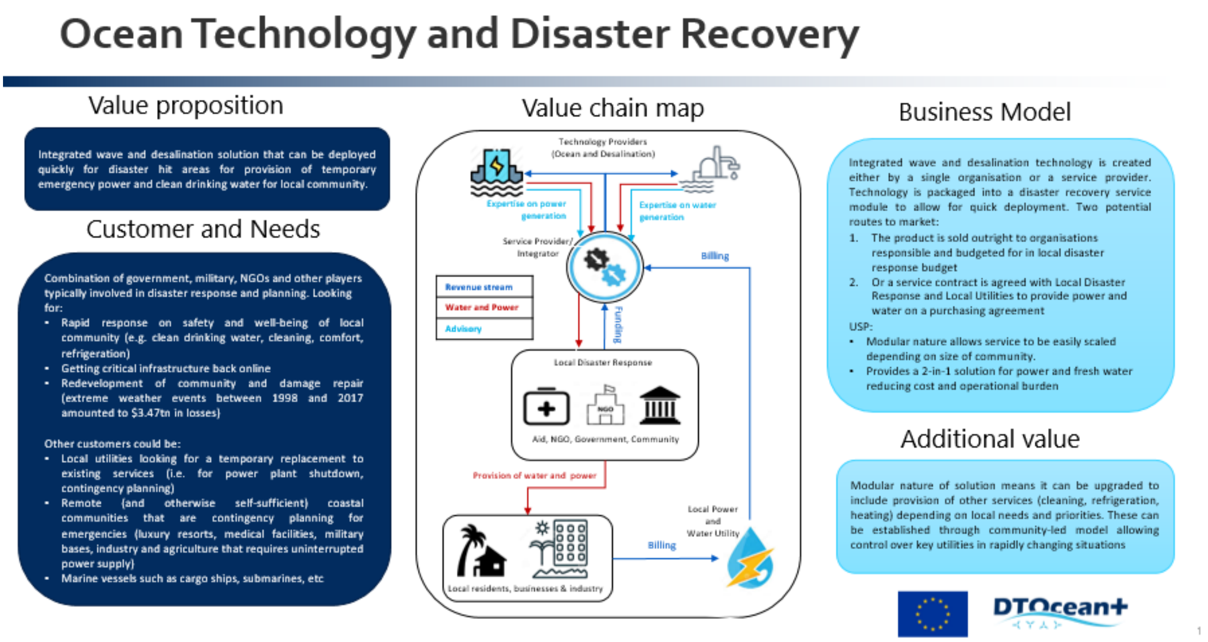


FIGURE 10.3: DISASTER RECOVERY BUSINESS MODEL DIAGRAM

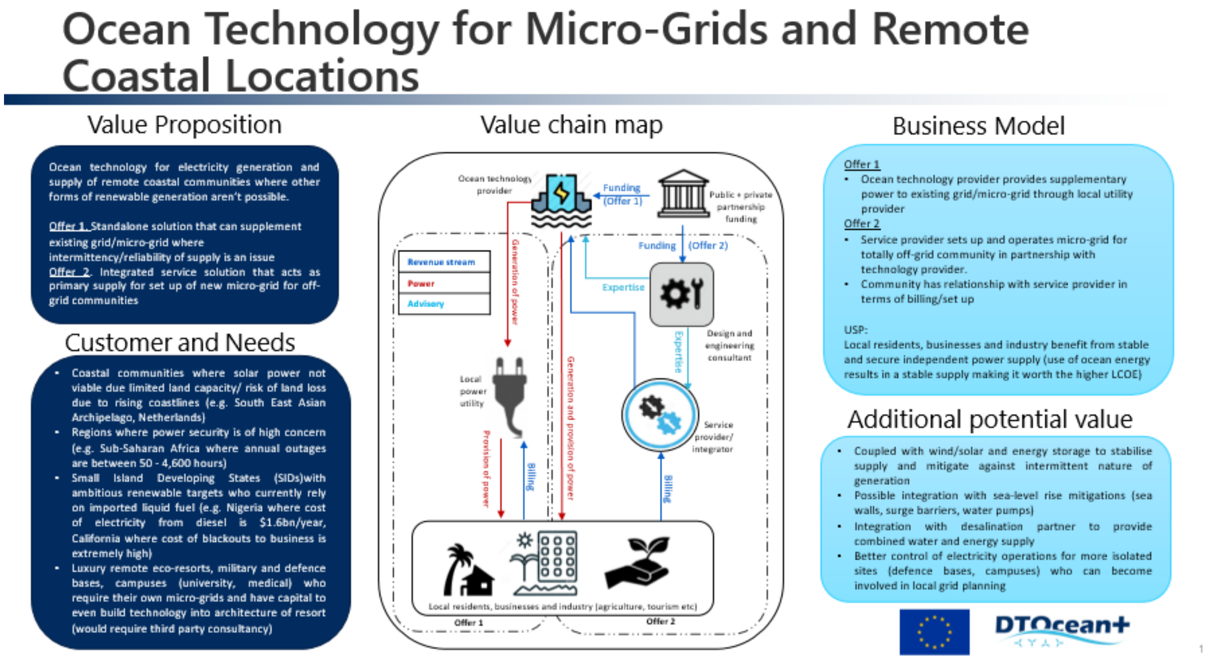


FIGURE 10.4: MICROGRIDS AND REMOTE COASTAL LOCATIONS BUSINESS MODEL DIAGRAM

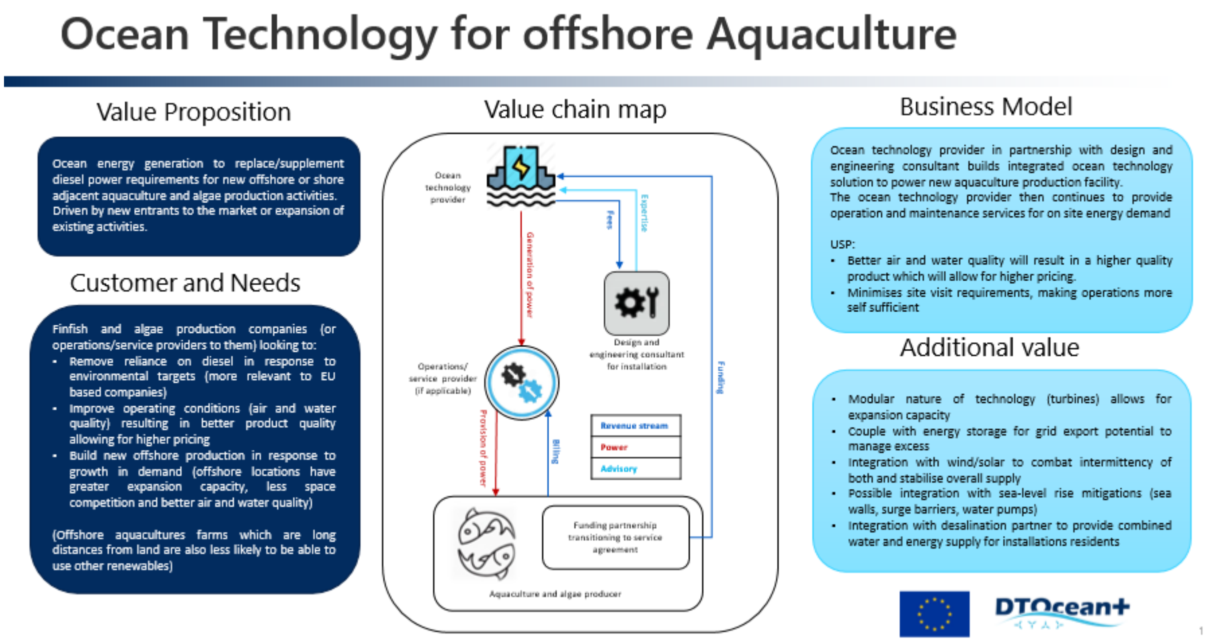


FIGURE 10.5: OFFSHORE AQUACULTURE BUSINESS MODEL DIAGRAM

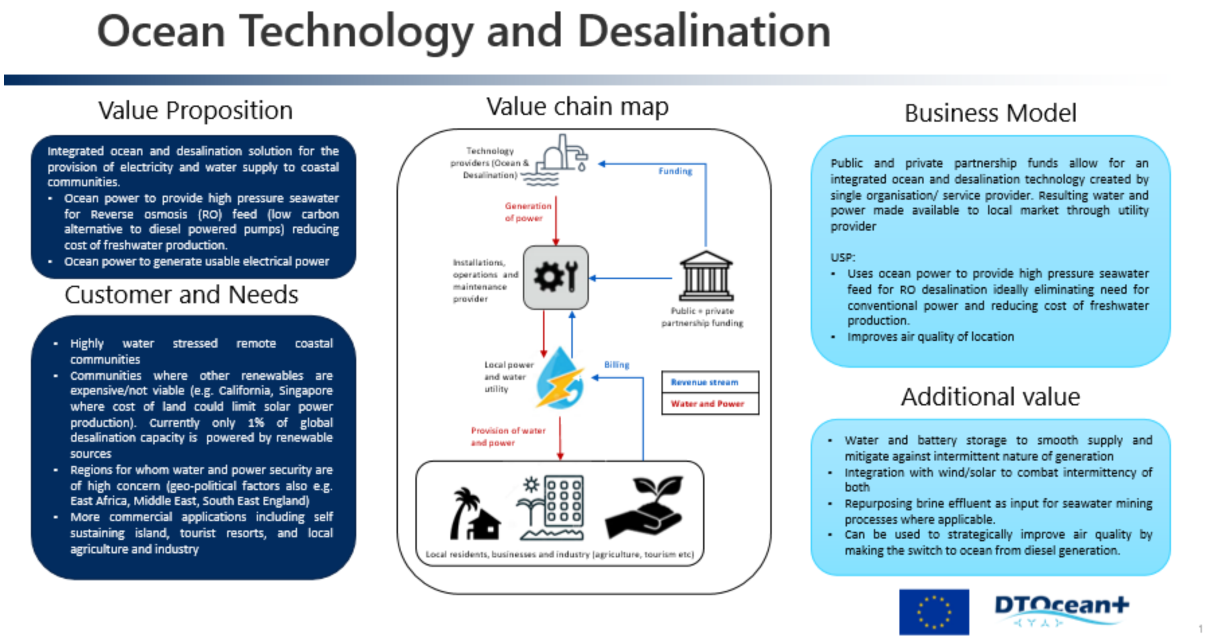


FIGURE 10.6: DESALINATION BUSINESS MODEL DIAGRAM

10.3. SUMMARY OF INTERVIEW RESULTS

10.3.1. INITIAL EXPERT INTERVIEWS

TABLE 10.1: SUMMARY OF FINDINGS FROM STAGE 2

Market	Strengths	Weaknesses	Recommendations
Offshore oil and gas	▸ Will benefit from future cost reductions. ▸ Can be used to meet small scale power demand applications on rigs. ▸ Increased demand for offshore power - autonomous vehicles and communications that is difficult to serve. ▸ Supporting services around umbilicals and the associated cost of repairs /maintenance.	▸ Technology unlikely to be commercially viable on a large scale within five years. ▸ Unlikely to be able to meet the overall high demand for rigs. ▸ Investor confidence in market low ▸ Very location-specific (wave) ▸ Reliable source of power (e.g. umbilicals) requiring maturity. ▸ The industry generally low-risk appetite – favours established technology. ▸ Current climate – not much budget available for R&D within the sector ▸ Reputational issues with ocean tech – history of failure ▸ Strong competition from other more established renewables (offshore wind)	▸ Consider smaller scale applications within rig operations (e.g. powering safety, surveillance equipment, subsea AUVs for monitoring) ▸ Consider role in the decarbonising life cycle of the rig (decommissioning, repurposing) ▸ Possibility of integrated application (wave, storage and data communications)

Coastal resilience	- Integrated technology – benefits of co-location and reduction of cost	- Will likely result in a high cost of generation (high CAPEX and installation and maintenance considerations) - Would likely only apply to new resilience measures (very difficult to integrate ocean tech into existing measures) - Reliant on too many environmental factors (wave conditions, weather windows, sand environment, erosion - General industry practice is seeing a move from hard engineering solutions to soft engineering solutions	- Consider specific stakeholders for whom high costs can be overlooked in favour of the security of supply (e.g. protecting high-value installations such as airports or power stations, densely populated low-lying areas, areas that experience large amounts of financial loss due to storm damage/rising sea levels) - Consider repurposing/powering of ports and buildings – possibility for integration here. - Could have an application in small scale coastal warning systems – small but continuous supply
Disaster recovery	- Modular nature – USP - Would it make the solution easy to scale? - Cost of energy, not the main driver		
Micro-grids and remote coastal locations	- Less intermittent and more predictable than other renewables - If integrated with other renewables would ensure security and stability of supply - Potential to integrate with desalination	- Heavily reliant on the subsidy funding environment	- Consider other applications where cost may not be a limiting factor (military bases, university campuses, remote luxury resorts, data centres)
Offshore aquaculture	- Clear market growth in growing global demand for fish/associated products. - Offshore conditions will directly influence the quality of produce (better air and water conditions) – can charge more. - Clear customer – fish producers. Who would be willing to pay if they can charge more for their product? - The technology could act as a refuge for fish (artificial reefs) - Offshore conditions – reduced demand for power.	- No policy incentive to encourage. - Seabed licensing issues (is co-location legally possible) - Potential outcomes of environmental impact assessment (how does the ocean generator impact the fish's health? Impact of turbines, noise, flicker) - Even though there is a growing demand for fish – this could be met by fisheries increasing their efficiency rather than moving offshore	- Consider associated support vessels also – transport of feed/resources. Can this be electrified and powered by the ocean?
Desalination	- Once the initial cost is recovered, this will enable desalination plants to reduce their running costs massively. - Growing population – increased need for a secure supply of freshwater		

10.3.2. FINAL EXPERT INTERVIEWS

	Strengths of proposed value propositions	Weaknesses of proposed value propositions
Wave energy developers	• O&G application has promise, and they are aware of ongoing discussions to support operations in this industry. • O&G application has the most potential for scale-up as overall energy demand on offshore rigs is high. • Remote location/island community application – the potential here but only as a steppingstone to utility-scale application	• O&G rigs not normally placed in areas with high wave resource. • Aquaculture application – demand will be too small for big wave developers focusing on grid-scale power. • Aquaculture application – site conditions are more likely to be mismatched with fish farms less likely to be tolerant to wave conditions (min wave height usually required to generate wave energy) • Usually, wave energy developers will test their design in different locations rather than bespoke design technology. • Likely to also be competition from storage solutions for grid balancing applications. • Most developers main vision is to create devices ultimately that can be scaled up, and most alternative applications tend to be smaller scale which conflicts with their vision
Tidal energy developers	• Big O&G companies have lots of funds sunk into long term seabed leasing – developing offshore tidal may be of interest to the long term. • Potential applications for populations who oppose offshore wind turbines due to aesthetics	• Tidal stream is extremely location specific and focused on conventional power to grid applications. • Regardless of scale/change in application/end-user fact, the technology cost is still too high. • Aquaculture application – again tends to avoid areas with a high tidal range. Location mismatch likely to be a factor

10.4. WORKSHOP RESULTS

10.4.1. INITIAL BUSINESS MODEL DESIGN WORKSHOPS

The following solutions were developed as part of the stage 1 workshop, held with participants from the DTOceanPlus consortium. Short-term solutions represent methods to gain market entry, whilst longer-term propositions are intended to help technologies achieve economies of scale.

TABLE 10.2: SUMMARY OF SOLUTIONS FROM STAGE 1 WORKSHOP

Intermediary solutions	**Knowledge Sharing Network** This solution aimed to increase the sector's outreach to communities with limited resources over the next 2-3 years. In addition, targeting markets with low expertise in power generation could create a pathway for demonstrator deployment by lowering the barriers to technical knowledge for customers and providing means of communication so that technology developers can better understand customer requirements. This would be combined with media campaigns to influence public policy and public relations. The investment required to establish this network should be low and build upon existing assets.

	Smaller-scale solutions The development of smaller, mobile and modular solutions could help open up high-cost markets to ocean energy. Additionally, these solutions should provide added value over other alternatives, e.g. profile, ease of procurement, accessibility. An initial starting point could take the form of a 100kW modular solution for deployment in microgrids.
Medium-term solutions	**Service models** This proposal would integrate ocean generators with a service to generate revenue against an 'outcome' rather than by cost against energy delivered. For example, the technology developer could support the integration of multiple generation types and charge a service fee while gaining testing and development time in a real application. Using learnings from a knowledge-sharing network could help to define what the conditions of this service might become.
Long term solutions	These should be focused on policy mechanisms that can support entry into the mainstream grid power market. Examples include: ▸ **FiTs** Long-term contracts for renewable energy producers, which provide greater certainty for investors. These are included in consumer bills. ▸ **Tax credits:** Benefit claimed through the taxation system, based on emissions measurements/prevention. ▸ **CfD:** Fixed-price contracts that guarantee investment. This could include accessing pots for innovative technologies to avoid competition against established renewables. ▸ **Innovation PPAs**: Tax relief system for customers entering PPAs with innovative technologies. The customer assumes the risk and negotiates with supplier based on the extent of the tax relief. ▸ **Mandates:** Legal requirement to form a fixed percentage of supply portfolio from renewable sources. This may put ocean energy in competition with other renewables unless there is an explicit requirement to diversify across portfolio.

Following the T8.4 workshop help in February 2020, three initial business model concepts for aquaculture, desalination, and islanded communities have been summarised in the tables within this technical note and have informed the key hypothesis, which requires testing. However, the sector is not without its challenges, and of these, the most widely agreed during the workshop were:

- ***Cost*** – LCOE is not currently competitive with other renewable energy sources.
- ***Technology Performance & Reliability*** – associated with the ability of the technologies to deliver the required performance, the stakeholder and investor perceptions.
- ***Trust*** – there is an insufficient track record of successful deployments required to build the trust and confidence of investors.
- ***Investment model*** – Large upfront CAPEX required with no guarantee of long-term payback.
- ***Reaching and informing stakeholders*** – very few project developers exist in the market. Technology developers tend to take on both roles.

10.4.2. WORKSHOPS TO TEST INITIAL BUSINESS MODELS

TABLE 10.3: SUMMARY OF FINDINGS FROM STAGE 3

	Key points	Critical factors for success	Shortlisted for Stage 3 (with preference indicator)
Offshore oil and gas	▸ Decided to focus on powering specific small-scale applications around the rig: ▸ Subsea vehicles ▸ Wellheads ▸ Monitoring/surveillance equipment ▸ Supplementary power could still be required (integration with other power sources) ▸ Storage may still be required	▸ Other renewable not feasible ▸ Low power requirement/long-endurance application ▸ Appropriate physical location (especially for tidal) ▸ Offshore cable too long to feasibly import power from onshore. ▸ High regulatory pressure (non-financial drivers) ▸ Security of supply high priority ▸ Reliability is proven. ▸ Wider value can be proven (reduced operational costs)	Yes 4
Coastal resilience	▸ Could consider power 'soft engineering' solutions (e.g. powering sand dredgers) ▸ Extreme weather conditions would impact the reliability of the solution. ▸ Design challenges are significant due to the integrated nature of the solution. ▸ CAPEX would be extremely high, with operations and maintenance costs difficult to predict and quantify	▸ Security of supply paramount ▸ Areas that require long term coastal resilience measures (or have high-value installations, high-density population) ▸ Areas with particularly high financial losses associated with weather-related coastal events	No
Disaster recovery	▸ Are there better, more competitive solutions? ▸ What are the current disaster recovery solutions for emergency power and water?	▸ Technology requires extensive feasibility testing with developers. ▸ Manufacturers need to engage with producing smaller units. ▸ Needs to be competitive with current disaster recovery solutions	Yes 2
Micro-grids and remote locations	▸ What is international funding available for the decarbonisation of these areas? ▸ Would overcome network constraints and lack of system flex. ▸ The solution being proposed is too broad. ▸ Potential challenges around marine protection/preservation ▸ The financing structure would require a significant amount of thought if it were to be replicable. ▸ Consider more alternative applications (military, eco-resorts, data centres)	▸ Other renewables are not an option. ▸ An innovative mechanism exists to reduce capital outlay.	Yes 3
Offshore aquaculture	▸ Energy spend is a small part of the overall spend (especially for offshore operations) ▸ Alternative within a niche – could explore the possibility of integrating with marine	▸ Proven increase in quality of fish (can you price the product higher for payback?)	Yes 1

	research/providing technology for environmental impact assessments. ▸ No universal policy drivers ▸ The requirement to look at current fish farm operations to prove whether the solution will lower OPEX.	▸ The organisation has to have a genuine desire to offshore. ▸ Organisations with ambitious decarbonisation targets	
Desalination	▸ Load mismatch issues (demand for water does not always match with high wave activity/tidal patterns) ▸ Scalability needs to be considered – how easy would it be to scale up with growing demand? ▸ Need to test whether the implementation of the solution would save enough money to make it desirable (further validation on energy efficiency) ▸ Not enough validation from interviewed stakeholders to take this concept forward	▸ Communities with a very high cost of freshwater (struggle with access/availability) ▸ Areas with very high energy costs to power their desalination	No

TABLE 10.4: SUMMARY OF FINDINGS FROM STAGE 4

	Key points	What next
Offshore aquaculture	▸ Intermittency could still pose an issue. Matching demand in offshore production with generation profile ▸ Lack of evidence of decarbonisation targets within industry ▸ Does ocean tech impact water quality for the better?	▸ Need to prove increased product quality. ▸ Understand the power requirements of offshore fish farming in more detail. ▸ Understand decarbonisation targets for industry. ▸ Possible river applications to help test the technology
Modular solution for disaster recovery	▸ Way too ambitious, and feasibility will have to be considered. ▸ Reality – extremely technologically challenging. ▸ Who ends up owning the solution? How would the service agreement look? ▸ Cable to shore considerations ▸ No evidence of existing technology (demonstrators)	▸ Look at current solutions for disaster recovery – can ocean energy supplement these? ▸ Think about what infrastructure would have to be in place for this solution to work quickly. ▸ Think about pneumatic devices – ready to go temporary solutions (almost a disposable quick and easy power source) ▸ Engage with RedR – engineering disaster relief charity.
Coastal location (micro-grids)	▸ Reliability concerns. If the technology is not yet reliable – how can it be a long-term solution? ▸ There are significant materials limitations (in the construction of the solution) ▸ Would have to design for the most extreme conditions (would make it very expensive)	▸ Worth talking to specific companies who have high decarbonisation targets (i.e. part of their core brand) and what their appetite for this solution maybe
Small scale applications for offshore oil and gas operations	▸ Have not considered the Impact of ocean technology on the immediate area around the rig (hydrodynamics) ▸ Has the potential to become quite complex. ▸ Small scale – less benefit from economies of scale	▸ Look at the potential for hybrid solutions with battery storage. ▸ Who would take on the risk/fund the solution? ▸ Need to demonstrate wider value to rig operations, e.g. operational costs

The general themes that came through were:

- The nature of the technology and competitor landscape makes it very difficult to take to market.
- The technology (particularly materials) would require significant investment to be reliably suitable for many of these applications.
- Therefore, we should consider many more temporary/short-term solutions that may well be on a much smaller scale to allow some of the technological limitations to be tested.
- We should consider options that allow ocean technology to be integrated into other renewables to mitigate intermittency and increase the security and reliability of supply.
- We should consider separate applications for tidal and wave. Tidal generation technologies are further ahead in their development and may apply in different locations/circumstances.
- Can split the applications by either floating or fixed.

Other markets that may be worth considering:

- Defence (military)
- Powering ports
- Autonomous shipping (smart coasts)
- Academic applications – monitoring/research

We determined five general criteria that would make a 'good market'. There is a potential for these to become key criteria against which we measure our final solutions in the next steps.

- Locations with a high cost of power or issues with access to power
- Where other renewables are unavailable
- There is a good (and growing) addressable market.
- Evidence that the technology solution works (demonstrators exist)
- Does successfully achieve decarbonisation.

10.4.3. WORKSHOPS WITH CONSORTIUM TO TEST FINAL BUSINESS MODELS

<table>
<tr><td>Representatives</td><td colspan="3">University of Edinburgh (Policy & Innovation Group)
Enel Group
Tecnalia
Wave Energy Scotland</td></tr>
<tr><td rowspan="2">Comments on proposed business models</td><td>Aquaculture</td><td>Offshore O&G</td><td>Disaster response</td></tr>
<tr><td>The model will benefit from a more detailed design.
Can be a data-monitoring service as well as a supply of power.
Algae production possibilities
Combining two new and unproven technologies
Will offshore expansion line up with advancements in wave technology?
Is it co-location? How close is generation to the fish production</td><td>Would this be competing with grid power due to location?
The possible reputational impact of being linked with the O&G market (if ocean energy is marketed as 'green')</td><td>It probably will not just be a steppingstone to grid power.
Can we think of this solution as a service as its temporary?
Value in this being a permanent solution and not just temporary.
Solar could be a significant competitor.</td></tr>
<tr><td rowspan="3">Scoring results</td><td>Attractiveness</td><td>Attractiveness</td><td>Attractiveness</td></tr>
<tr><td>Feasibility</td><td>Feasibility</td><td>Feasibility</td></tr>
<tr><td>Timeline: Medium-term market</td><td>Timeline: Medium-term market</td><td>Timeline: Long term market</td></tr>
<tr><td>Review of enablers/blockers for the highest scoring market (offshore O&G applications)</td><td colspan="3">Technology and supply chain readiness
Successful demonstrators are key to drive confidence. Will prove tech works reliably for a reasonable cost?
How can developers convince the market that lower costs are achievable without disclosing confidential IP?
Investor confidence
Detailed feasibility studies from developers required.
Availability of R&D funds and willingness to invest from certain sectors.
Complex integration

Cultural policy and landscape
Integrate ocean energy into decarbonisation strategy, which would drive uptake of more alternative applications of wave technology.</td></tr>
</table>

	Fulfilling a 'need.' ▸ Further work can be done to understand decision-makers and influencers and what their motivations are. ▸ Bring in customer earlier on in the technology development journey to be closer to the decision-making process. **Competition from other more established renewables** ▸ Aggregating offshore platforms ▸ Working with competitors to increase market confidence (although what is the incentive for competitors to want to aggregate)
Final recommendations	▸ Demonstrators are vital even for alternative markets (there needs to be proof that the underlying technology works) ▸ Quantification of value beyond LCOE could be beneficial in strengthening the business case. ▸ Take lessons from the development of other offshore industries (offshore wind but more specific developments in tidal generation) ▸ Put more thought into the design of the supply chain to remove uncertainty from the proposed models. ▸ Treat alternative markets themselves as an end goal (and hence a revenue opportunity) rather than just a steppingstone to grid-scale applications. ▸ Guarantees on performance and reliability – anywhere the proposed model involves service design in addition to the provision of technology

<table>
<tr><td>Representatives</td><td colspan="3">Bureau Veritas
University of Edinburgh (Policy & Innovation Group)
EDP
Enel
Tecnalia
Sabella</td></tr>
<tr><td rowspan="2">Comments on proposed business models</td><td>Aquaculture</td><td>Disaster response</td><td>Coastal resilience</td></tr>
<tr><td>▸ General agreement with strengths and weaknesses
▸ Can be used to contribute to partial or total removal of diesel- however, it is more likely that the full cost of diesel needs to be removed fully to be beneficial.
▸ Need clear and consistent monitoring for environmental assessment.
▸ Need to factor in settling in time for the environment around the technology.</td><td>▸ The most proven tidal devices to date are quite large and require a long build and lead times. Could a floating device be more applicable?
▸ To what extent do environmental impacts factor in an emergency solution?
▸ It would possibly require a very wide range of types/sizes of device 'sitting on the shelf to</td><td>▸ Timing issues and matching generation profile to demand.
▸ Need to clearly define how tidal tech can contribute to softer engineering methods for coastal resilience (i.e. beach nourishment etc.)
▸ Where there is a dual purpose keeping the vision defined can be a challenge
▸ Potential opportunity in charging vessels in remote locations</td></tr>
</table>

	‣ Fish farms tend to avoid highly energetic areas – focus on location coupling that combines sufficient tidal energy with fish farm demand	cover the possible range of conditions. ‣ Technical challenges in creating a solution that could work in multiple locations	
Scoring results	Attractiveness	Attractiveness	Attractiveness
	Feasibility	Feasibility	Feasibility
	Timeline: Short to medium term market	Timeline: Long term market	Timeline: Short term market
Review of enablers/blockers for the highest scoring market (aquaculture)	**Technology and supply chain readiness** ‣ It is feasible to harness ocean currents with tidal turbines. ‣ The case for flexibility/storage in matching supply and demand (is storage a barrier, and would innovation in storage technology help overcome this) **Investor confidence** ‣ Better suited insurance products/guarantees would build investor confidence. **Complex integration/location specifics** ‣ Can be addressed by fully understanding the real needs of aquaculture. ‣ Identify which specific products favour tidal conditions (maximum currents aquaculture can operate in vs minimum currents required to generate tidal power) ‣ Understand the size of the potential market. **Cultural policy and landscape** ‣ Willingness to change/shift to alternative sources of power. ‣ Decarbonisation is a low priority for aquaculture producers unless written into regulation (EU targets means limited market awareness and confidence) **Fulfilling a 'need.'** **Competition from other more established renewables** **Marine impact** **Beyond the LCOE** ‣ Quantifying the benefits of co-location (air quality, low visual impact, contribution to diversity of supply, GHG reduction, noise reduction, resilience to extreme weather)		
Final recommendations	-		

10.4.4. RESULTS OF VOTING ACTIVITIES FROM CONSORTIUM WORKSHOP

TABLE 10.5: SUMMARY OF WAVE & TIDAL WORKSHOP VOTING ACTIVITIES GROUPED BY ATTRACTIVENESS, FEASIBILITY AND TIMELINE

Wave energy

Attractiveness			
	Aquaculture	Offshore O&G	Modular solution
1 to 2 (Least)	1	1	1
2 to 3	3	1	1
3 to 4	2	2	1
4 to 5 (Most)	0	1	2

Feasibility			
	Aquaculture	Offshore O&G	Modular solution
1 to 2 (Least)	0	0	4
2 to 3	3	3	2
3 to 4	3	2	0
4 to 5 (Most)	0	2	0

Timeline (count)			
	Aquaculture	Offshore O&G	Modular solution
Short term (Now to 5 years)	1	1	0
Medium-term (5 to 10 years)	4	4	0
Long term (10+ years)	0	0	5

Tidal energy

Attractiveness			
	Aquaculture	Disaster response	Coastal resilience
1 to 2 (Least)	3	3	2
2 to 3	2	5	0
3 to 4	4	0	3
4 to 5 (Most)	2	0	5

Feasibility			
	Aquaculture	Disaster response	Coastal resilience
1 to 2 (Least)	0	3	3
2 to 3	0	5	3
3 to 4	1	1	0
4 to 5 (Most)	7	0	3

Timeline			
	Aquaculture	Disaster response	Coastal resilience
Short term (Now to 5 years)	2	2	9
Medium-term (5 to 10 years)	6	1	0
Long term (10+ years)	0	7	1

10.5. WORKSHOP MURALS

The following appendix contains copies of the Mural boards worked through for the workshop sessions.

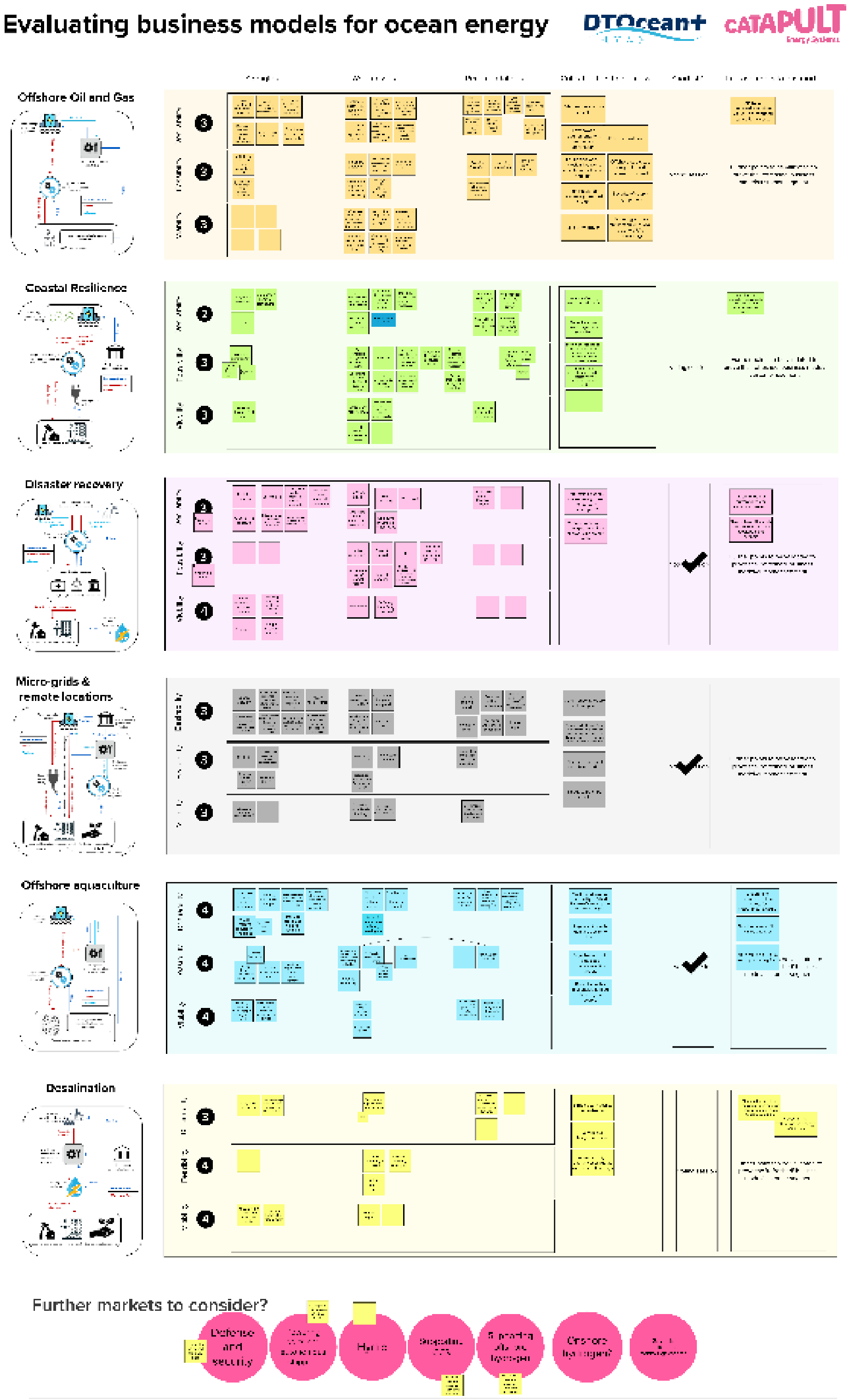


FIGURE 10.7: WAVE & TIDAL ENERGY INTERNAL WORKSHOP SESSION-1 - MURAL BOARD

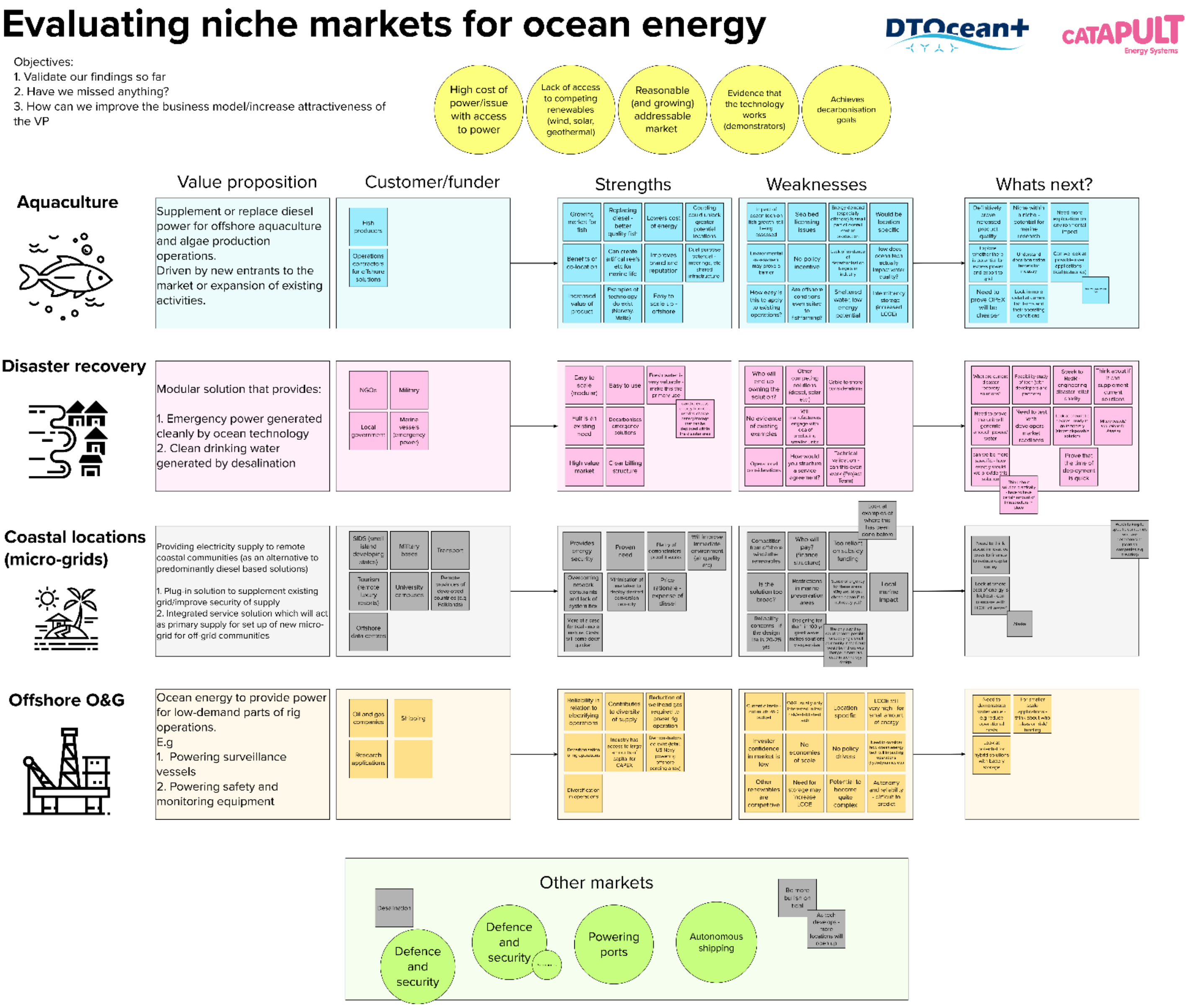


FIGURE 10.8: WAVE&TIDAL ENERGY INTERNAL WORKSHOP SESSION 2 - MURAL BOARD

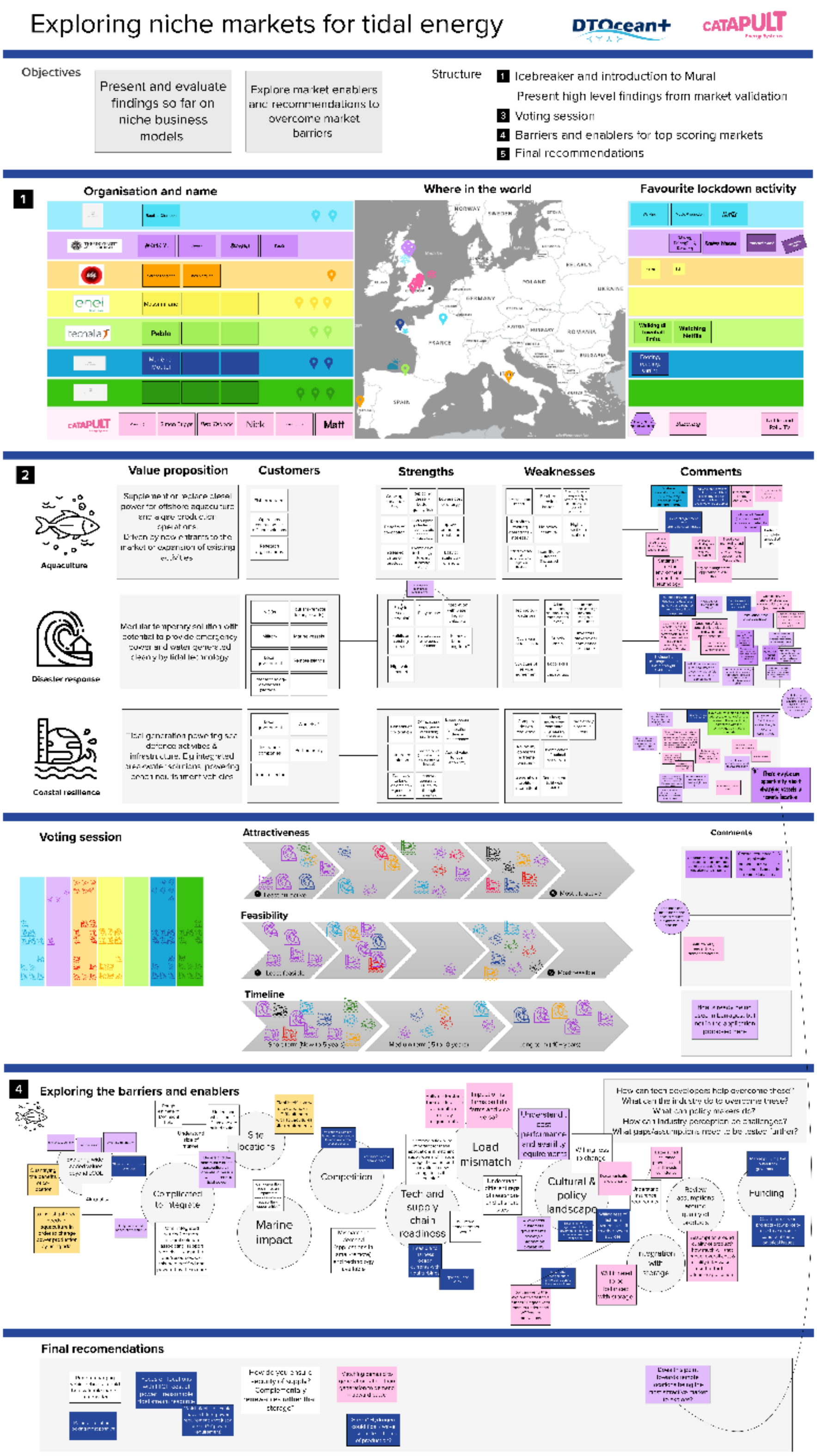


FIGURE 10.9: TIDAL ENERGY CONSORTIUM WORKSHOP SESSION - MURAL BOARD

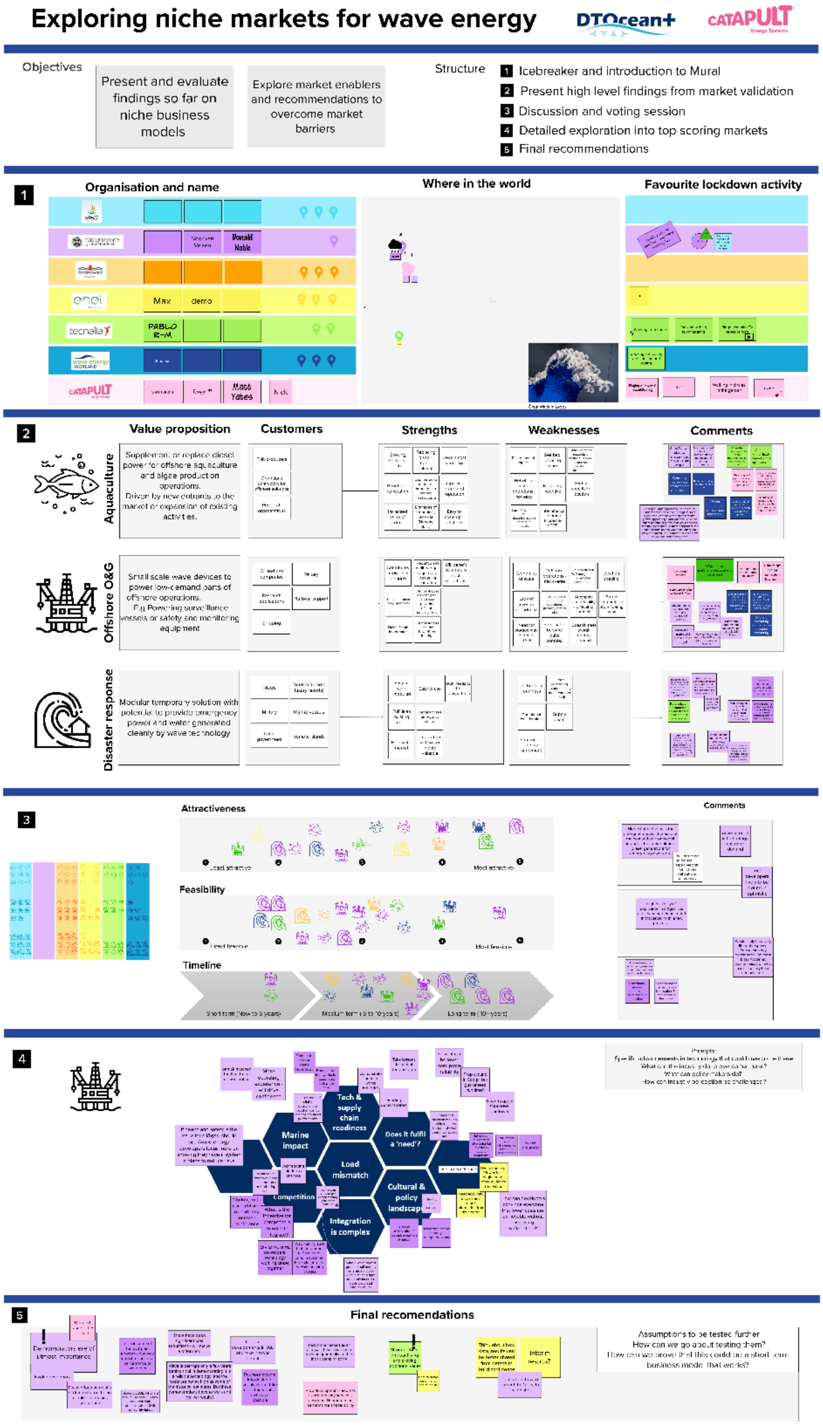


FIGURE 10.10: WAVE ENERGY CONSORTIUM WORKSHOP SESSION - MURAL BOARD

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