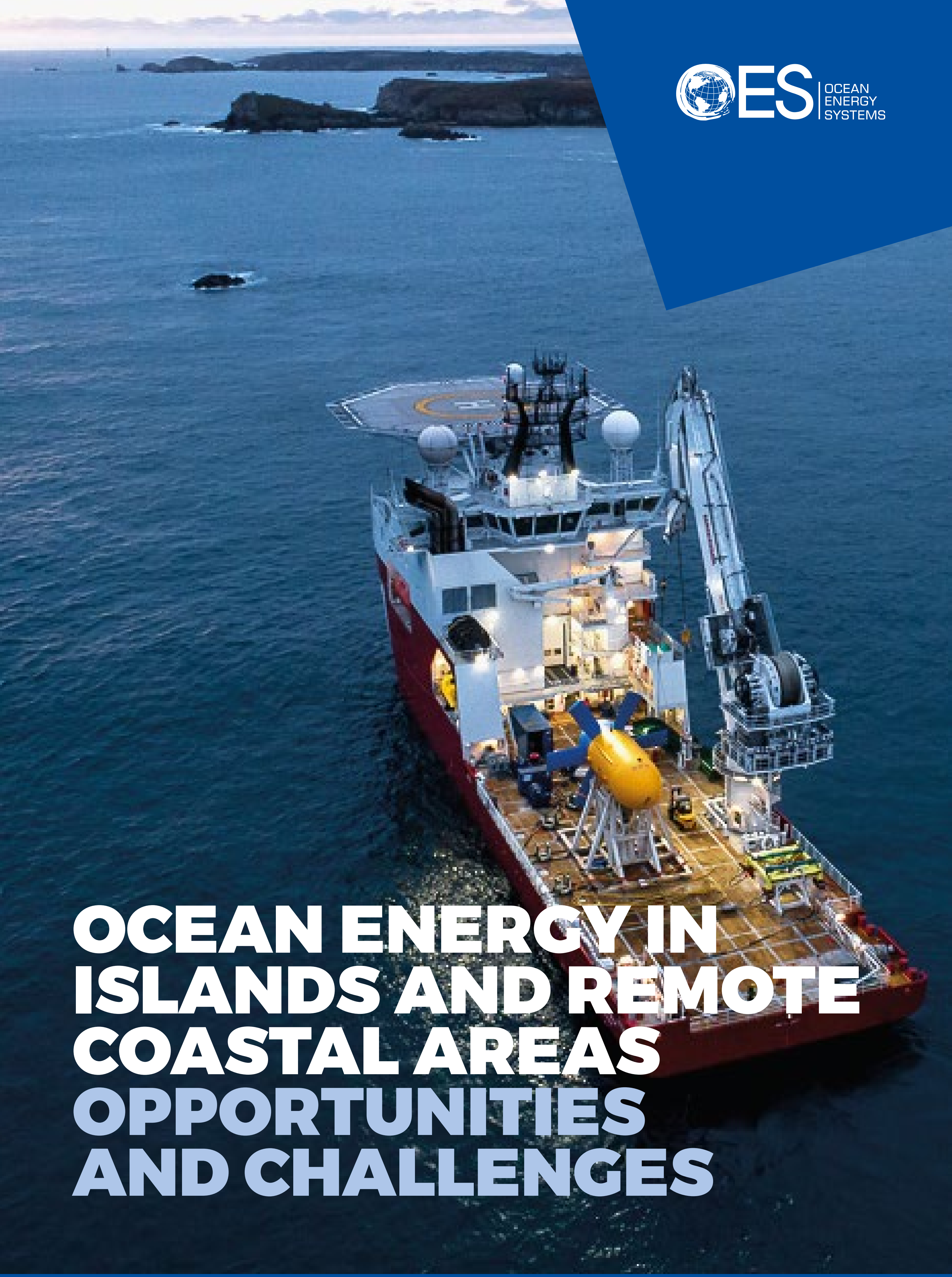


OES
OCEAN
ENERGY
SYSTEMS

# OCEAN ENERGY IN ISLANDS AND REMOTE COASTAL AREAS
## OPPORTUNITIES AND CHALLENGES

Technology Collaboration Programme
by iea

**Published by:**
The Executive Committee of Ocean Energy Systems (OES)

**Editors:**
Henry Jeffrey, Yann-Hervé De Roeck and Ana Brito e Melo

**Designed by:**
Formas do Possível | www.formasdopossivel.com

**Suggested Citation:**
OES (2020), Ocean Energy in Islands and Remote Coastal Areas: Opportunities and Challenges. IEA Technology Collaboration Programme for Ocean Energy Systems, www.ocean-energy-systems.org

**Acknowledgements:**
This report was prepared by the Policy and Innovation Group at the University of Edinburgh and is authored by Maria Vanegas Cantarero.
The report benefited from the input of Dr. Srikanth Narasimalu (NTU) and Simone Meme (PLOCAN), from the three workshop reports organized in Singapore, France and Hawaii.

**Disclaimer:**
The OES, also known as the Technology Collaboration Programme for Ocean Energy Systems, functions within a framework created by the International Energy Agency (IEA). Views, findings and publications of OES do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

Cover Page: Sabella D10 tidal turbine during installation in Fromveur Passage, near Ushant island
(Courtesy: SABELLA/BALAO)

# CONTENTS

Executive Summary ........ 4
Acronyms ........ 5

01

**INTRODUCTION** ........ 6
**1.1** Context and Motivations of the Study ........ 7
**1.2** Scope and Structure of the Report ........ 7

02

**OCEAN RENEWABLE ENERGY** ........ 8
**2.1** Ocean Energy Potential ........ 9
**2.2** Ocean Energy Technologies ........ 10

03

**CHALLENGES AND ENABLERS** ........ 12
**3.1** Socio-Environmental ........ 14
**3.2** Legal and Regulatory ........ 15
**3.3** Infrastructure ........ 16
**3.4** Financial and Economic ........ 17

04

**OPPORTUNITIES FOR OCEAN ENERGY** ........ 18

05

**CONCLUSION** ........ 22

References ........ 24

# EXECUTIVE SUMMARY

Islands and remote coastal areas are often subjected to the misconception that they require scaled-down continental solutions. Nonetheless, these areas face a different reality than their continental counterparts and, therefore, may require localised solutions. The livelihoods of their inhabitants depend on the use of limited natural resources and much trade with the mainland, albeit through small and sometimes intermittently available channels of exchange and transport. Common economic activities in islands and remote coastal areas include fisheries, tourism, and maritime transport. Some islands and remote coastal areas perform small manufacturing activities, mostly to meet local needs. Furthermore, some islands, particularly those considered small developing states (SIDS), face several development challenges due to the size of their economies and their remote and small nature: poor access to clean and affordable energy and water, exposure and vulnerability to natural disasters, among others.

Islands and remote coastal areas face energy challenges that require attention. These regions tend to meet their energy needs through exchanges with mainland via submarine cables or their own fossil fuel-based generation facilities. Both alternatives pose problems that include vulnerability to the volatility of fuel prices, high carbon footprint, low fuel mix diversity and risks of disruptions in supply. Moreover, these regions are increasingly vulnerable to climate change and sea-level rise, which amplifies the challenges that they already face. Resilience and mitigation as well as sustainability are key concerns in islands and remote coastal areas. Low-carbon economies and clean energy technologies pose a relevant opportunity for these regions to address some of their concerns and challenges. Particularly, these regions are looking at seizing their renewable energy potential to face the challenges of the energy trilemma: security of supply, environmental sustainability, and energy affordability.

Ocean energy technologies can be an appealing option for these energy markets, offering advantages compared to other renewable energy technologies such as low visual and environmental impacts and predictability. Furthermore, islands and remote coastal areas tend to coincide with good resource potential for some of these technologies and, due to the high costs of incumbent energy technologies, ocean energy could face fewer difficulties to compete with more mature technologies in these markets.

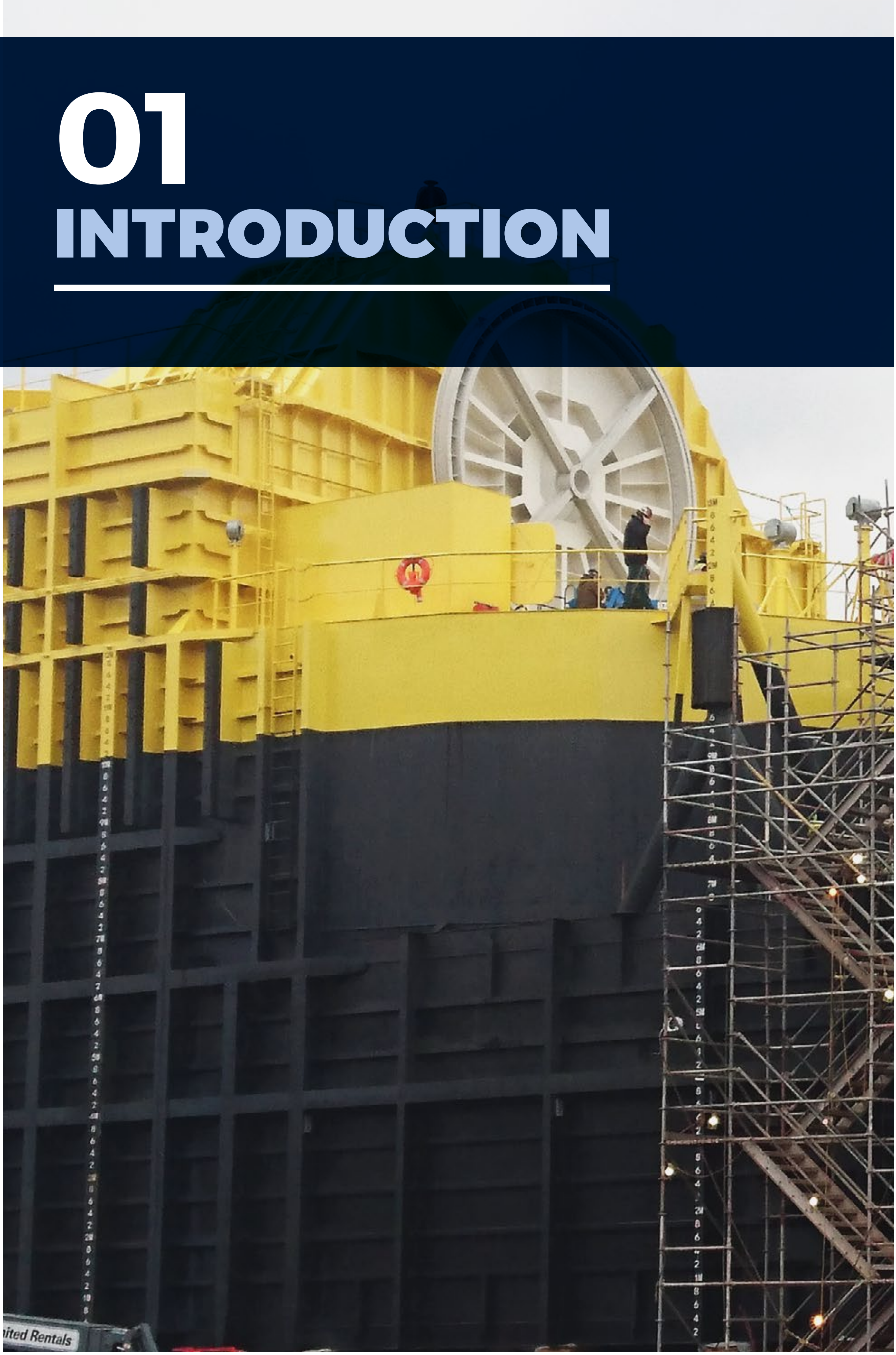
Potential challenges to the adoption of ocean energy technologies in these markets have been identified and include: socio-environmental issues such as misinformation and social acceptance, regulatory and political barriers due to the relatively nascent nature of the ocean energy sector where support mechanisms are missing, infrastructure (both hard and soft) not in place in these isolated regions, and a lack of financial incentives to aid the economic feasibility of the technologies. To overcome some of these challenges, this report discusses opportunities to enable the integration of ocean energy technologies into the energy systems in islands and remote coastal areas and create synergies between the economic and energy sectors.

# ACRONYMS

**EMEC** • European Marine Energy Centre
**GHG** • Greenhouse gas
**IEA** • International Energy Agency
**IPCC** • Intergovernmental Panel on Climate Change
**IRENA** • International Renewable Energy Agency
**LCOE** • Levelised Cost of Energy
**ORE** • Ocean Renewable Energy
**OTEC** • Ocean Thermal Energy Conversion
**TRL** • Technology Readiness Level
**UN** • United Nations
**UN CDP** • United Nations Committee for Development Policy
**OES** • Ocean Energy Systems
**SDS** • Sustainable Development Scenario
**SIDS** • Small Islands and Developing States
**SLO** • Social Licence to Operate
**WEC** • Wave Energy Converter

# 01

# INTRODUCTION



OE35 Buoy under construction at an Oregon shipyard before being towed to the US Navy Wave Energy Test Site, in Hawaii Courtesy: Ocean Energy Ltd

## 1.1 CONTEXT AND MOTIVATIONS OF THE STUDY

The Intergovernmental Panel on Climate Change (IPCC) has brought attention to the need for a rapid and far-reaching transition to renewable energy systems to limit global warming to 1.5˚C (IPCC, 2018). Due to the synergies and trade-offs between climate change and sustainable development agenda, such a transformation would not only halt global warming but reduce the number of people exposed to climate-related risks and susceptible to poverty. The IPCC estimates that approximately 70-85% of the electricity in 2050 must be supplied from renewable energy sources to curb the increasing greenhouse gas (GHG) emission levels. This is a strikingly different number from the current levels. In 2017, approximately 28% of the world's electricity was generated from renewable energy sources, primarily hydropower (IEA, 2019a).

To significantly reduce the current levels of $CO_2$ emissions, countries and governments around the world are aiming to swiftly seize the energy potential of the renewable resources at their disposal. Regions at disproportionately higher risk due to climate change, such as small island developing states (SIDS) and Least Developed Countries[1], are particularly looking at the exploitation of indigenous renewable resources to relieve power constraints and promote economic growth. These regions have built their economies and cultures based on their vast ocean resources. These resources are central to the achievement of the 2030 Sustainable Development Agenda as well since they can be sustainably exploited for economic development, job creation, food security and meeting these regions' energy requirements.

Ensuring environmental sustainability of the oceans and coastal areas while promoting development, social inclusion, and the preservation or improvement of livelihoods is a concept that has been termed the 'blue economy' (World Bank and UN Department of Economic and Social Affairs, 2017). The establishment of a blue economy provides islands and remote coastal areas with an opportunity to adapt their needs to the local resources available. Offshore renewable energy is a key component of the blue economy. In particular, ocean renewable energy (ORE) can be beneficial to many blue economy markets given:

- Its ability to provide both electrical and hydraulic power;
- the opportunities for co-design and integration with other infrastructure including coastal resilience and disaster recovery;
- The potential to establish local supply chains and enable linkages to global supply chains and markets;
- The opportunity to develop a local skilled workforce, enable social inclusion, and promote science, technology, innovation and multidisciplinary research; and
- Their low visual impact compared to other offshore energy technologies.

Focusing on islands and remote coastal areas, this report sheds light into the opportunities and challenges posed by the integration of ocean energy technologies into the energy systems in these regions drawing lessons learned from scientific publications, research projects, and a series of workshops organised by the Technology Collaboration Programme on Ocean Energy Systems (OES). The report highlights potential market opportunities for ocean energy technologies that may be of interest for developers and investors, policymakers, and researchers. Additionally, it aims to inform islands and remote coastal areas and present them with brief descriptions of ocean energy technologies and their contribution to tackling climate change, building resilience, and facing sustainable development challenges while providing a platform for the development of the ocean energy sector.

## 1.2 SCOPE AND STRUCTURE OF THE REPORT

The report is structured as follows:

- **Chapter 2** provides an overview of the available resource and energy potential and the current status of ocean energy technologies, namely wave, tidal (stream and range) and ocean thermal energy conversion (OTEC).
- **Chapter 3** presents the barriers and challenges to the integration of ocean energy technologies into current energy systems in islands and remote coastal areas are grouped into four categories: socio-environmental, legal/political, infrastructure, and financial. In addition, alternatives and recommendations to tackle these challenges are presented.
- Finally, **Chapter 4**, elaborates on opportunities for the development of the ocean energy sector. Potential market opportunities of interest for developers, investors, policymakers, and researchers are described in this chapter.

---

[1] A list of small island developing states is available in the United Nations (UN) Sustainable Development Goals Knowledge Platform website (UN, 2019), whilst the list of Least Developed Countries as of December 2018 is published by UN Committee for Development Policy (UN CDP, 2018).

## 02

# OCEAN RENEWABLE ENERGY

Crestwing's wave energy prototype *Tordenskiold* at sea northeast of the Hirsholm islands in Kattegat, outside Frederikshavn, Denmark Courtesy: Crestwing

**Oceans remain the most underexploited source of renewable energy. Waves and tides store kinetic energy that can be converted into electricity, whilst ocean water can also serve as solar collector and capture thermal energy from the sun (Melikoglu, 2018). Tidal current or wave generators can harvest kinetic energy representing a source of predictable, renewable energy given the cyclical nature of tides and the predictability of waves (Sasaki, 2017; SETIS, 2014). Osmotic power plants and thermoelectric generators can produce electricity from salinity and thermal gradients or draw energy from the deep ocean for heating and cooling (Khan, Kalair, Abas and Haider, 2017).**

## 2.1 OCEAN ENERGY POTENTIAL

The ocean energy resource potential is vast. There are different estimates of the theoretical resource potential available globally ranging from 20,800 TWh/year to 170,400 TWh/year (Khan et al., 2017), as shown in Table 1. Nonetheless, it must be highlighted that these figures are an order of magnitude less when technical, geographical, environmental, economic, and/or regulatory constraints are considered. Notwithstanding this, there is no doubt that there is considerable potential for energy extraction in oceans around the world.

The resource potential varies depending on the specific technology and the location. Table 1 compiles estimations of the theoretical resource or energy potential available globally and in selected regions for different ocean energy technologies. In the case of wave energy, the global theoretical resource has been estimated at over 29,500 TWh/year, with approximately 2,800 TWh/year located in Western and Northern Europe (Lehmann et al., 2017; Mork et al., 2010). The technically extractable global wave energy resource has been estimated to be around 2,000 and 5,500 TWh/year (Cornett, 2008; Pelc and Fujita, 2002). This resource could supply between 8% and 23% of the world's electricity demand in 2017[2].

The estimates of the theoretical resource or power potential vary as well. Some references provide estimates for both tidal range and current whilst others focus on one of these two technologies. Charlier and Justus (1993) estimated the global ocean currents theoretical power potential at 5 TW. The International Renewable Energy Agency (IRENA) (2014) reported that the technically harvestable tidal energy power potential is estimated by several sources at around 1 TW, with tidal stream having a much larger percentage of this figure than tidal range. Kirke and Coiro (2019) presented two estimates of the

---

[2] The world's electricity consumption in 2017 was 23,696 TWh (IEA, 2019b).

TABLE 1

Resource (or Energy) potential in selected regions for ocean energy

| Region | Ocean Energy | Wave | Tidal | | Thermal (OTEC) | Osmotic |
|---|---|---|---|---|---|---|
| | | | Stream | Range | | |
| **Global** | 32 TW [1]<br>20,800 – 170,400 [2]<br>76,350 [3-6] | 29,500 [4,7,8] | 5 TW [11]<br>1 TW [12] | | 44,000 [5]<br>10,000 – 87,600 [2] | 1,650 [6]<br>2,000 [15] |
| | | | 434 GW [17] | 120 – 400 GW [17] | | |
| **Europe** | | 2,800 [4] | | 1,466 [16] | | |
| **US** | | 898 – 1,229 [8-10] | | 619 [16] | | |
| **Canada** | | 83 GW [14] | 365 [13] | 21,467 [16] | | |

Note: Units are TWh/yr unless otherwise specified.

Sources: [1] (Wahyudie et al., 2017) [2] (Khan et al., 2017) [3] (Huckerby et al., 2016) [4] (Mork et al., 2010) [5] (Nihous, 2007) [6] (Skråmestø et al., 2009) [7] (Edenhofer et al., 2011) [8] (Lehmann et al., 2017) [9] (Jacobson et al., 2011) [10] (National Research Council (U.S.) et al., 2013) [11] (Charlier and Justus, 1993) [12] (IRENA, 2014) [13] (Tarbotton and Larson, 2006) [14] (Gunn and Stock-Williams, 2012) [15] (Soerensen and Weinstein, 2008) [16] (Neill et al., 2018) [17] (Kirke and Coiro, 2019)

theoretical resource potential, one for tidal stream of 434 GW and one for tidal range between 120 GW and 400 GW. Most of the tidal (both stream and range) resource or power potential identified is located in the US, Canada, the UK, and France (Hammons, 2011; Neill et al., 2018; Tarbotton and Larson, 2006). However, there is also resource potential in other regions including the Philippines, Indonesia, Malaysia, Chile (Abundo et al., 2011; Bonar et al., 2018; Guerra et al., 2017; Ribal et al., 2017).

The resource or power potential of ocean thermal energy and salinity gradient power has been studied less frequently and in less detail than in the cases of wave and tidal energy. The available literature suggests that the theoretical resource potential of ocean thermal power conversion lies between 10,000 and 87,600 TWh/year (Khan et al., 2017; Nihous, 2007). Most of this resource is located between the Northern and Southern Tropic although not many regional or local studies are available. The global theoretical resource potential for osmotic power lies between 1,650 TWh/year and 2,000 TWh/year (Khan et al., 2017; Skråmestø et al., 2009). Salinity gradient power has its greatest potential at the mouths of major rivers, where freshwater flows out to the sea and salinity vertical stratification occurs. Nonetheless, as in the case of ocean thermal energy, regional or local estimates are not often readily available in the literature.

It is important to highlight that these estimates are derived from the application of different resource assessment methodologies and, therefore, may not be suitable for direct comparisons. The figures must be used with caution. Nonetheless, this information is an initial representation of the resource and power potential and should serve as motivation for further and more detailed research. For instance, a detailed assessment of the resource or power potential in the regions surrounding islands (particularly those not connected to the grid) and remote coastal areas for all ocean energy technologies is still necessary.

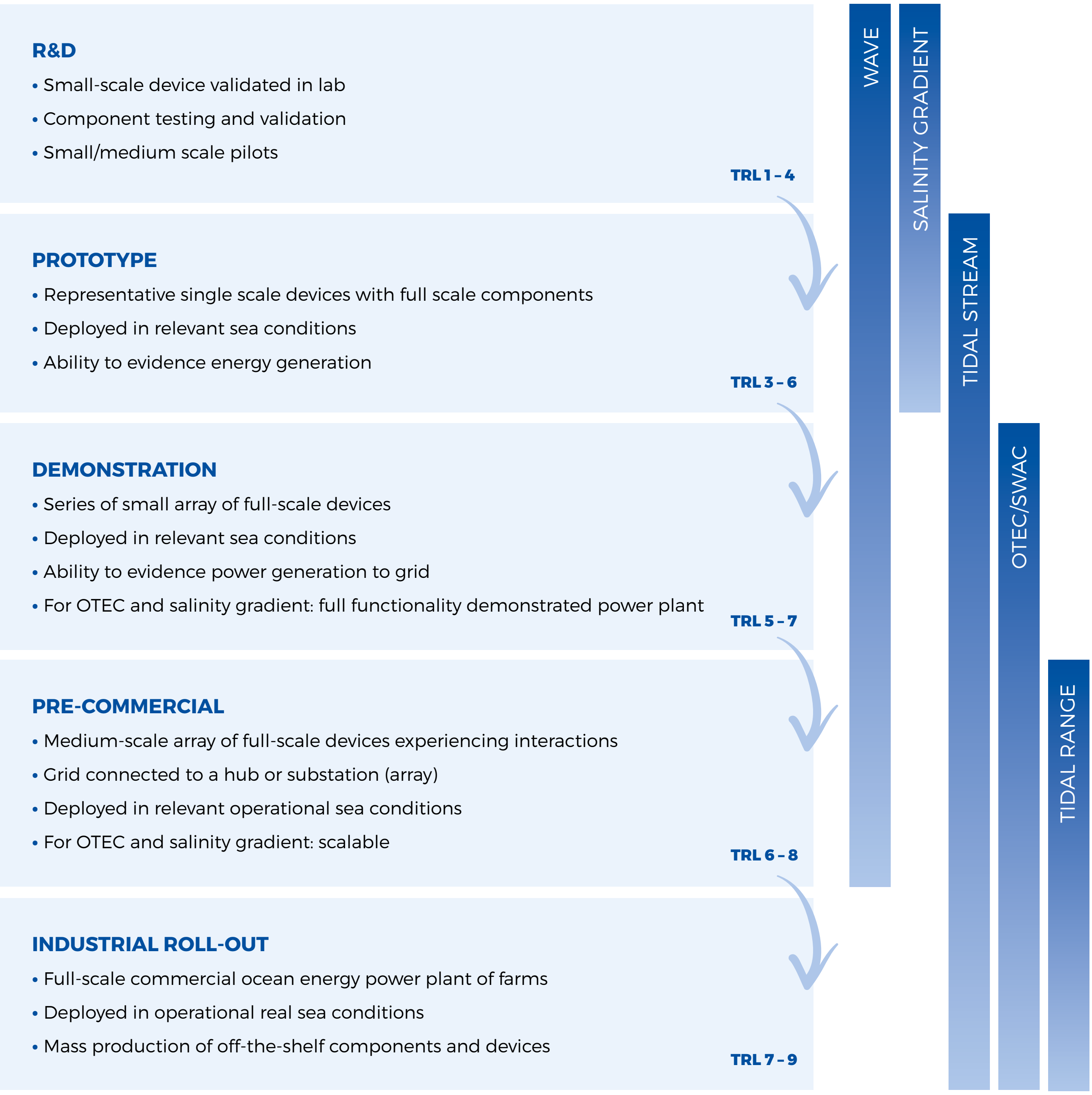
## 2.2 OCEAN ENERGY TECHNOLOGIES

Technological advancements enable the harvest of energy from ocean energy sources. A wide range of devices have been developed to seize the resource and power potential available. The European Marine Energy Centre (EMEC) has compiled a list of over 300 wave and tidal devices alone developed in the last few years (EMEC, 2020a, 2020b). Most of these are at an early/medium development stage.

Europe is at the forefront of ocean energy technology development. This region agglomerates approximately two-thirds of the world's tidal energy developers and a slightly higher share of the world's wave energy developers (Magagna, 2019). Other relevant regions in terms of ocean energy technology development include the North America, Asia and Oceania.

FIGURE 2.1

Phases of Technology Readiness Levels for Ocean Energy Technologies



**R&D**

- Small-scale device validated in lab
- Component testing and validation
- Small/medium scale pilots

**TRL 1 - 4**

**PROTOTYPE**

- Representative single scale devices with full scale components
- Deployed in relevant sea conditions
- Ability to evidence energy generation

**TRL 3 - 6**

**DEMONSTRATION**

- Series of small array of full-scale devices
- Deployed in relevant sea conditions
- Ability to evidence power generation to grid
- For OTEC and salinity gradient: full functionality demonstrated power plant

**TRL 5 - 7**

**PRE-COMMERCIAL**

- Medium-scale array of full-scale devices experiencing interactions
- Grid connected to a hub or substation (array)
- Deployed in relevant operational sea conditions
- For OTEC and salinity gradient: scalable

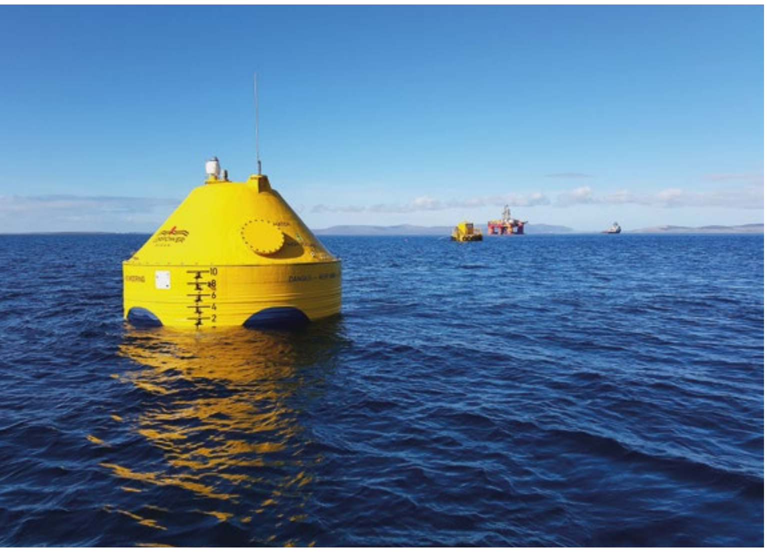
**TRL 6 - 8**

**INDUSTRIAL ROLL-OUT**

- Full-scale commercial ocean energy power plant of farms
- Deployed in operational real sea conditions
- Mass production of off-the-shelf components and devices

**TRL 7 - 9**

Sources: Adapted from Magagna (2019) and Ocean Energy Forum (2016)



Corpower C3 Wave Energy Converter tested in Orkney, UK Courtesy: Corpower

Nova Innovation M100 during assembly in Shetland Islands, Bluemull sound, UK Courtesy: Nova Innovation

Ocean energy technologies have reached different Technology Readiness Levels (TRL) as shown in Figure 2 1. Among these, tidal range is the only technology that has reach commercial scale with two plants at TRL 9. Since 1967, there has been a 240 MW tidal barrage at La Rance in northern France, whilst, in 2011, South Korea inaugurated a 254 MW tidal barrage at Sihwa Lake. These two power plants have contributed to disseminate the benefits of ocean energy and raise society's awareness of these technologies. Furthermore, since these plants have enabled synergies between the power sector and transport or coastal protection, their levelized cost of energy (LCOE) has reached (mainland) grid parity, thereby debunking the myth of the lack of economic competitiveness of these technologies. Nonetheless, most of the resource potential for tidal range energy is located in hotspots in the Northern hemisphere. Technologies such as wave energy, tidal stream energy, OTEC, seawater air conditioning (SWAC) and/or salinity gradient may be more viable for islands and remote coastal areas.

As of April 2020, the European Marine Energy Centre (EMEC) (2020a) has identified over 250 different wave energy concepts. There is an evident lack of design consensus within the sector. The different concepts are between an R&D and pre-commercial stage. Most of these concepts are point absorber devices. Some of these have reached a TRL of 7 (Magagna, 2019). Other concepts gaining popularity include attenuators, oscillating bodies and overtopping devices. Nonetheless, there are many concepts that have been developed that do not fall under any of these categories. Due to the nature of the wave resource, some types of devices may be more suitable for some sites than others.

Tidal stream devices often resemble submerged wind turbines, as they work on similar principals. Devices can be classified into six main types, namely horizontal axis turbine, vertical axis turbine, oscillating hydrofoil, Archimedes screw, enclosed tips/shrouded, and tidal kite devices. EMEC (2020b) has identified nearly 100 different device concepts as of April 2020. Nevertheless, unlike in the wave energy sector, there is an apparent convergence towards horizontal axis turbines in the tidal stream energy sector. These devices have reached TRLs of 8 and some technologies are attempting to complete the TRL path (Magagna, 2019).

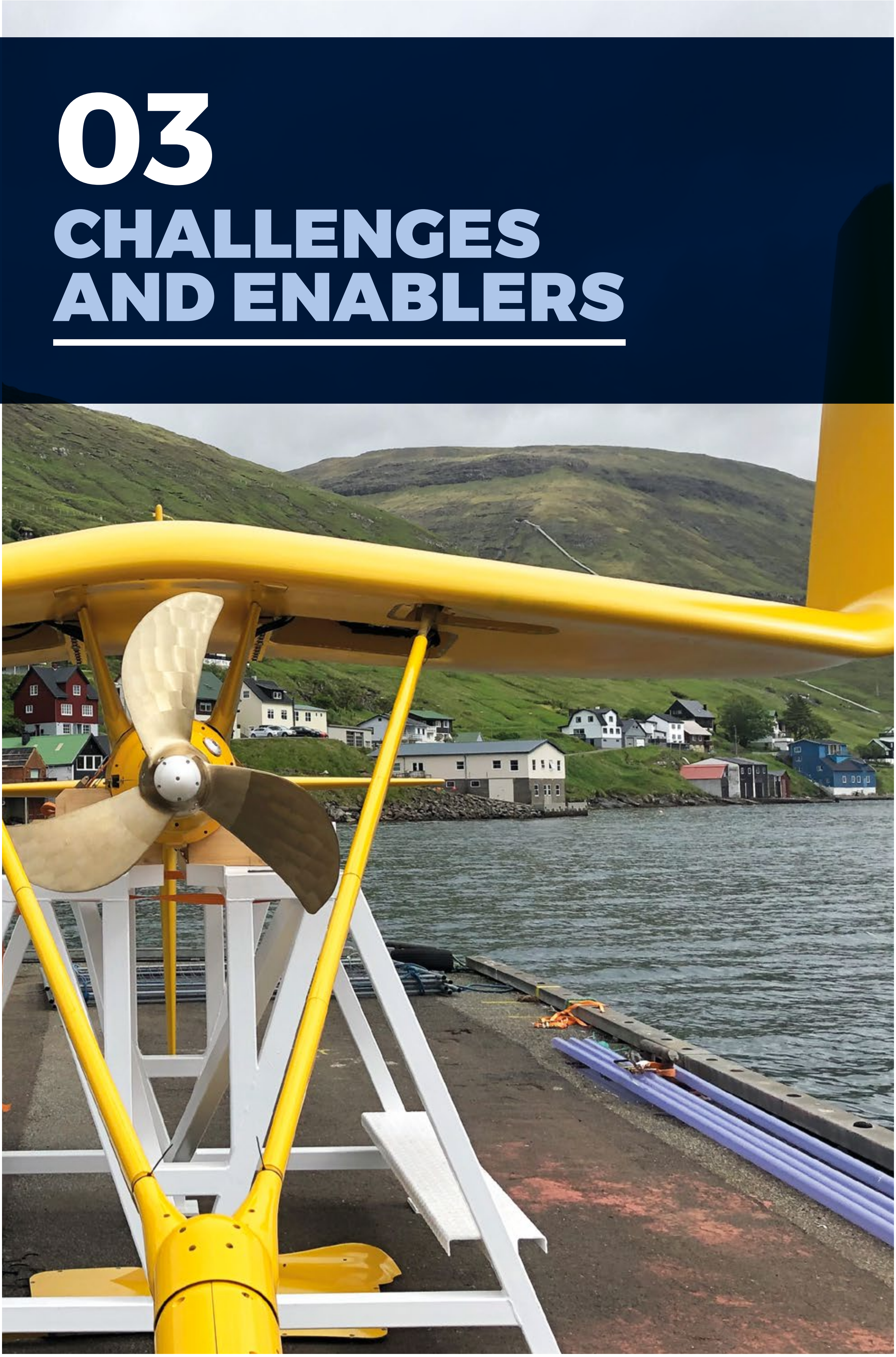
OTEC is suitable for tropical coastal areas where the temperature difference between the warmer, top layer of the ocean and the colder, deep ocean water is about 20°C (Soerensen and Weinstein, 2008). As such, it represents a particularly interesting technological alternative for islands and remote coastal areas located between the Tropics of Cancer and Capricorn. The principle behind this technology was discovered in 1881 and the first OTEC plant was built in Cuba in 1930 (Soerensen and Weinstein, 2008). OTEC technological advancement advanced in 1979 when the Natural Energy Laboratory of the Hawaiian Authority installed a pilot plant (Melikoglu, 2018). Since then, these technologies have been sparsely deployed due to their high costs (Osorio et al., 2016). There is a lack of experience in plant construction on an industrial scale given that only prototypes exist today, yet the technology is proven and has reached a TRL of 8. SWAC and seawater heat pumps are other emerging alternatives to increase both the renewable energy share and the energy efficiency of tropical islands and remote coastal areas. These technologies have reached TRLs of 9 and 8 respectively, however, the high capital costs have hindered their wider deployment.

OTEC laboratory at NIOT, India Courtesy: National Institute of Ocean Technology

Okinawa Prefecture Deep Sea Water OTEC Demonstration, Kume Island, Japan Courtesy: Okinawa Prefecture

# 03

# CHALLENGES AND ENABLERS



Minesto' tidal kite to be deployed at Faroe Islands Courtesy: Minesto

**As ocean energy technologies progress, there are challenges that must be faced and barriers that must be overcome. There are mechanisms and strategies that can aid the development and strengthening of the ocean energy sector. This section summarizes both barriers and enablers identified by a wide range of stakeholders during a series of workshops organized by the Technology Collaboration Programme on Ocean Energy Systems (OES) and other partners between 2017 and 2019. Some of these are analogous to the ocean energy sector in general. However, most of them refer to the case of ocean energy in islands and remote coastal areas.**

**The challenges and alternatives here presented can be categorized into socio-environmental, legal or regulatory, infrastructure-related, and financial.**

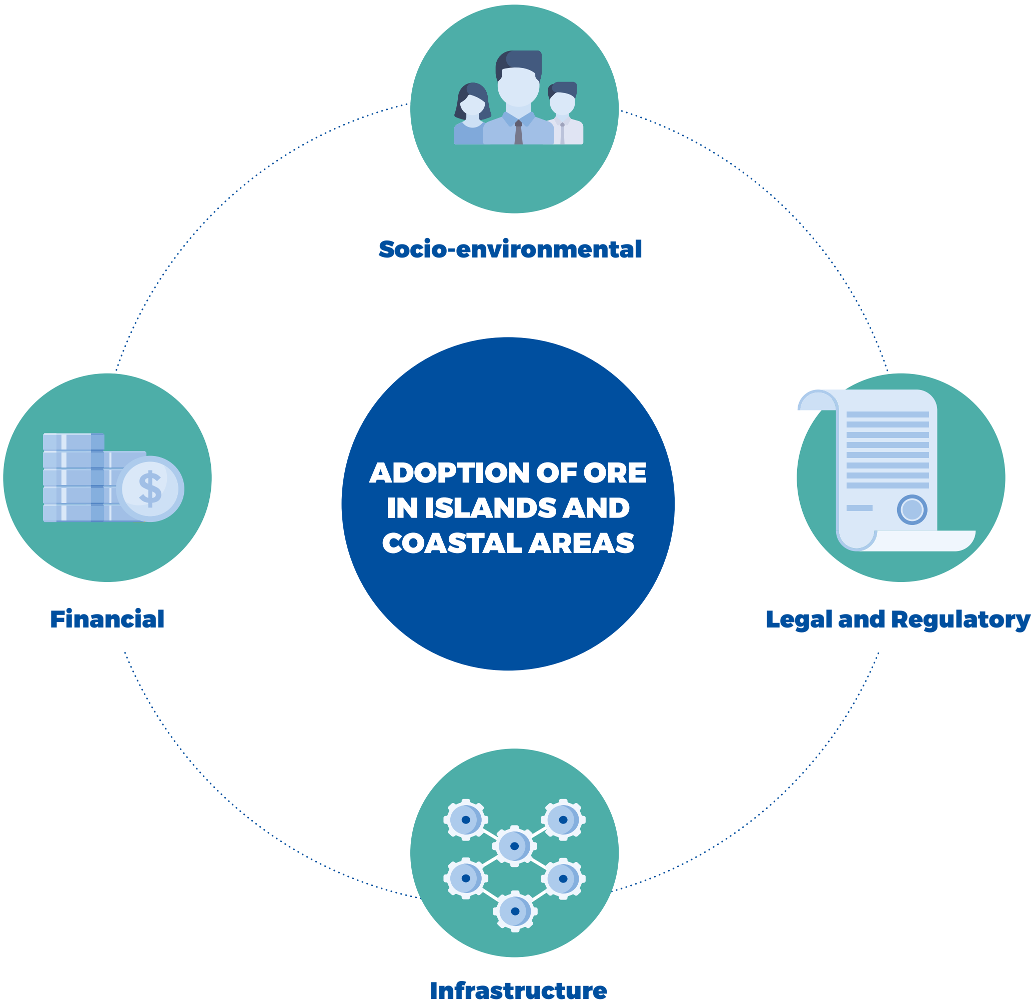


FIGURE 3.1

Barriers and enablers for the adoption of ocean renewable energy in islands and remote coastal areas

## 3.1 SOCIO-ENVIRONMENTAL

In terms of society and the environment, the first challenge faced is the lack of awareness. Due to a scarcity of easily understandable information for stakeholders, governments, and end-users, both social acceptance and public engagement are hindered. When society does not understand the implications and benefits of ocean energy technologies, misconceptions may arise. It is then unlikely that there will be support or willingness to engage with such energy technologies. Similar to the case of wind energy and the NIMBY ('Not in my backyard') phenomenon, ocean energy projects have encountered resistance in local communities that oppose the deployment of such technologies on the grounds of concerns related to visual and environmental impacts. In these cases, research has shown that fostering engagement with local stakeholders is fundamental for the development and deployment of emerging energy technologies (Devine-Wright, 2013). The focus must be on facilitating social acceptance and public participation. Actions that may be beneficial in these situations include but are not limited to:

- Providing easily comprehensible information to all stakeholders, governments, and end-users describing and explaining the technologies, their benefits, and implications;
- Enabling spaces or platforms for an easier exchange of information and expertise;
- Including the local communities in earlier discussions and decision-making;
- Engaging with the local stakeholders to understand and address their concerns; and
- Incorporating local concerns and needs in the design and scope of the projects to strengthen the sense of ownership and participation in the stakeholders, governments, and end-users.

Another issue has been *spatial planning*. Ocean energy projects may compete with other uses of the sea space such as military areas, tourism, fisheries, and protected areas. The oversight of ocean energy deployments from national marine spatial planning (MSP) represents an obstacle and hampers the viability of these projects. MSP can ease licensing and consenting for both project developers and local governments and can help avoid conflicts and delays. This can become an important tool to help guarantee the sustainability of ocean energy projects in islands and remote coastal areas.

Another challenge in these regions is that the probability of *natural disasters* and the hazard of such disruptions is relatively high. In fact, these regions are among the most vulnerable to climate events (Eckstein, Hutfils and Winges, 2018). Ocean energy technologies deployed in such locations may have to endure hurricanes, tsunamis, among others. Thus, to be viable energy alternatives for islands and remote coastal areas, the technologies must improve their reliability and survivability as well as be adapted to the specific environment where they are being deployed. Ocean energy converters can also be implemented as an alternative supply of power during emergency responses, serving as an instrument for mitigation and adaptation to climate change.

Additional recommendations to aid the adoption of ocean energy technologies in islands and remote coastal areas include: carrying out a dedicated and extensive environmental monitoring process throughout all the phases of the projects; a preferred approach for seabed mounted devices to limit the impact on sea users, avoid any visual impact, and decrease the potential effects of natural disasters on the converters; and carrying out comprehensive environmental lifecycle assessments.

An important and final takeaway in terms of social and environmental aspects of the adoption of ocean energy in islands and remote coastal areas is the potential of these technologies to address the basic needs of the communities in the form of niche applications. This has benefit to both the end-users and the ocean energy sector and will be addressed in more detail in section 4.

## 3.2 LEGAL AND REGULATORY

The regulatory and political aspects of the adoption of ocean energy cannot be neglected. Limited experience with these technologies and in consenting this type of energy projects can hinder development. An enabling and supporting regulatory framework is crucial.

Unfortunately, given the emerging nature of ocean renewable energy, most local communities lack *sector-specific policies* to support its development and deployment. There is a need for a legal framework that covers international law, environmental impacts, rights and ownership, consenting processes, and the management of marine space and resources to enable the establishment and development of the ocean energy sector and guarantee the sustainability of the projects.

Policies applicable to similar, yet more mature, renewable energy technologies such as offshore wind and small hydropower can serve as guides. Nonetheless, these policies must be adapted to ensure alignment with the operating principals and TRLs of ocean energy devices. In this regard, spaces and platforms for networking, exchange of knowledge and expertise, as well as sharing of policy-making experiences between governments, society, and industry can be helpful to increase the regulatory familiarity and confidence towards ocean energy technologies.

With supporting policies in place, the next step would be accelerating and easing the consenting processes which, usually, are very time intensive. An interesting alternative is the 'one-stop-shop' approach that has streamlined the UK's consenting process (Wright et al., 2016). The implementation of such an approach can be challenging on its own and experience shows that formalizing communication channels between authority bodies as well as a strong political will can be beneficial for the effective development of 'one-stop-shop' systems.

An emerging concept that may be of interest for the development of ocean energy is the 'Social Licence to Operate' (SLO). This concept refers to the societal expectations on the impacts and benefits of industry and government practices that result in the willingness for developers to go beyond the requirements of formal regulations. Originally, this concept emerged in the mining sector, however, the ocean energy sector has been exploring it recently. Experiences in Australia have shown that holding an SLO can be fundamental in the governance of marine resources (Cullen-Knox, Haward, Jabour, Ogier and Tracey, 2017). Such an approach could be of assistance to overcome both socio-environmental and legal barriers explored in this report.

Orbital Marine Power tidal current turbine in Orkney islands, UK Courtesy: Orbital Marine Power

Wave Swell Energy (WSE) prototype under construction (superstructure) to be installed on King Island, Tasmania Courtesy: Wave Swell Energy

## 3.3 INFRASTRUCTURE

The adoption of ocean energy in islands and remote coastal areas faces challenges related to hard and soft infrastructure as well. In the case of hard infrastructure, the main barrier is the small size and instability or lack of *local power grids*. In many cases, islands and remote coastal communities lack the conditions to integrate ocean energy. Ocean energy projects may need to consider including micro-grids as part of their scope to become a valuable alternative for these off-grid communities. Coupling with energy storage systems may also help guarantee security of supply and the balance between supply and demand.

Another challenge is the *increased operational expenses* (OPEX) of ocean energy projects due to the remoteness of the locations where these are deployed. An alternative to this is to enable improvements in the reliability and deployability of the technologies. Technological advancements such as remote monitoring equipment and remote-control systems may be of interest for ocean energy projects to reduce OPEX. Another alternative that goes in hand with the next challenge faced by these projects in islands and remote coastal areas is the *adaptation of technology designs* so that the devices can be produced and assembled locally. Evidently, this would bring socio-economic benefits for the communities and the ocean energy sector; however, a local supply chain is necessary, and, at the moment, there is difficulty in finding qualified local suppliers. In some locations, the few local suppliers available may adopt monopolistic practices due to the lack of competitors, resulting in increased costs for the developers. Similarly, the diversity of designs among ocean energy devices hampers standardization which could reduce the need for highly qualified manpower and expensive transportation, thereby having a positive impact on project costs.

Islands and remote coastal communities should join efforts with the ocean energy sector to create clusters to ease the establishment of a local supply chain and aid the development of the sector. These clusters may include research and development (R&D) centres as well to help the local capacity-building processes. Local suppliers require support and training to meet the needs of the ocean energy sector. Therefore, a government-industry collaboration to establish a local supply chain and ease access to local and qualified suppliers would be key for the ocean energy sector and the development of these communities.

## 3.4 FINANCIAL AND ECONOMIC

The emerging nature of ocean energy technologies and the remoteness of islands and coastal areas pose financial and economic challenges. Furthermore, the *lack of cost references* or project-related information (e.g., construction time) makes the financial appraisal of ocean energy projects challenging and does not contribute to building confidence in the technologies, limiting the funding options available. Estimates from deployment and testing projects show that ocean energy may still require to achieve *cost reductions* to improve their economic feasibility. Nevertheless, most islands and coastal areas are already paying high prices for water and energy due to their reliance on fossil fuels and more complex transportation needs. This presents an attractive opportunity for emerging energy technologies such as ocean energy.

To appeal to ocean energy developers and deployment opportunities, islands and remote coastal areas need to provide incentives such as tax exemptions or feed-in-tariffs that can contribute to the development of the ocean energy sector. Some locations may have existing incentives to support the introduction of renewable energy that could be applicable to ocean energy. However, the less mature nature of the latter compared other renewable energy technologies makes targeted financial support necessary. This is particularly relevant considering that ocean energy technologies must be able to compete with subsidized conventional generation systems as well.

The lack of knowledge regarding the ocean energy business and the limited economic data available from deployments and testing projects reduce the bankability of the projects and impede adequate economic assessments. Ideally, such economic evaluations and their corresponding cost-benefit analyses should include externalities such as emissions reduction, job creation, supply independence, among others. In this sense, the wide range of benefits of ocean energy to islands and remote coastal areas can be better understood, displayed and conveyed. Additionally, ocean energy projects could be coupled with a smart energy system approach and smart grid solutions to improve the efficiency of the systems, guarantee security of supply, and reduce the prices of energy and water for the local communities.

Moreover, raising awareness and improving the understanding of investors, lenders, insurers, and policymakers about ocean energy will improve the bankability of the projects. These stakeholders must understand the technology diversity. Similarly, understanding and establishing business models that limit risk or share risk among participants and contributors can be advantageous for the profitability of the projects. In line with that, the rigour of the project indicators must be increased to reduce risks as well.

Finally, local governments should identify appropriate policies and support mechanisms that directly address the key financial and economic barriers outlined in this report. A potential strategy would be to review the lifetime of fossil fuel plants to evaluate the direction of new investments in the local energy mix.

SIMEC Atlantis Energy turbine deployed in Scotland's Pentland Firth (Meygen project) Courtesy: Simec Atlantis Energy

# 04

# OPPORTUNITIES FOR OCEAN ENERGY

Marmok A-5 wave energy device tested at bimep, Spain Courtesy: IDOM

**Ocean energy technologies currently struggle to compete with more mature renewable energy technologies such as onshore wind and solar in the utility market. Islands and other off-grid markets may present opportunities for ocean energy developers to deploy their technologies while providing environmentally friendly energy to local communities. These markets are paying high electricity prices compared to mainstream markets for two reasons: firstly, electricity is currently supplied by diesel generators and, secondly, electricity consumption per capita is (very) low, which dampens price responsiveness.**

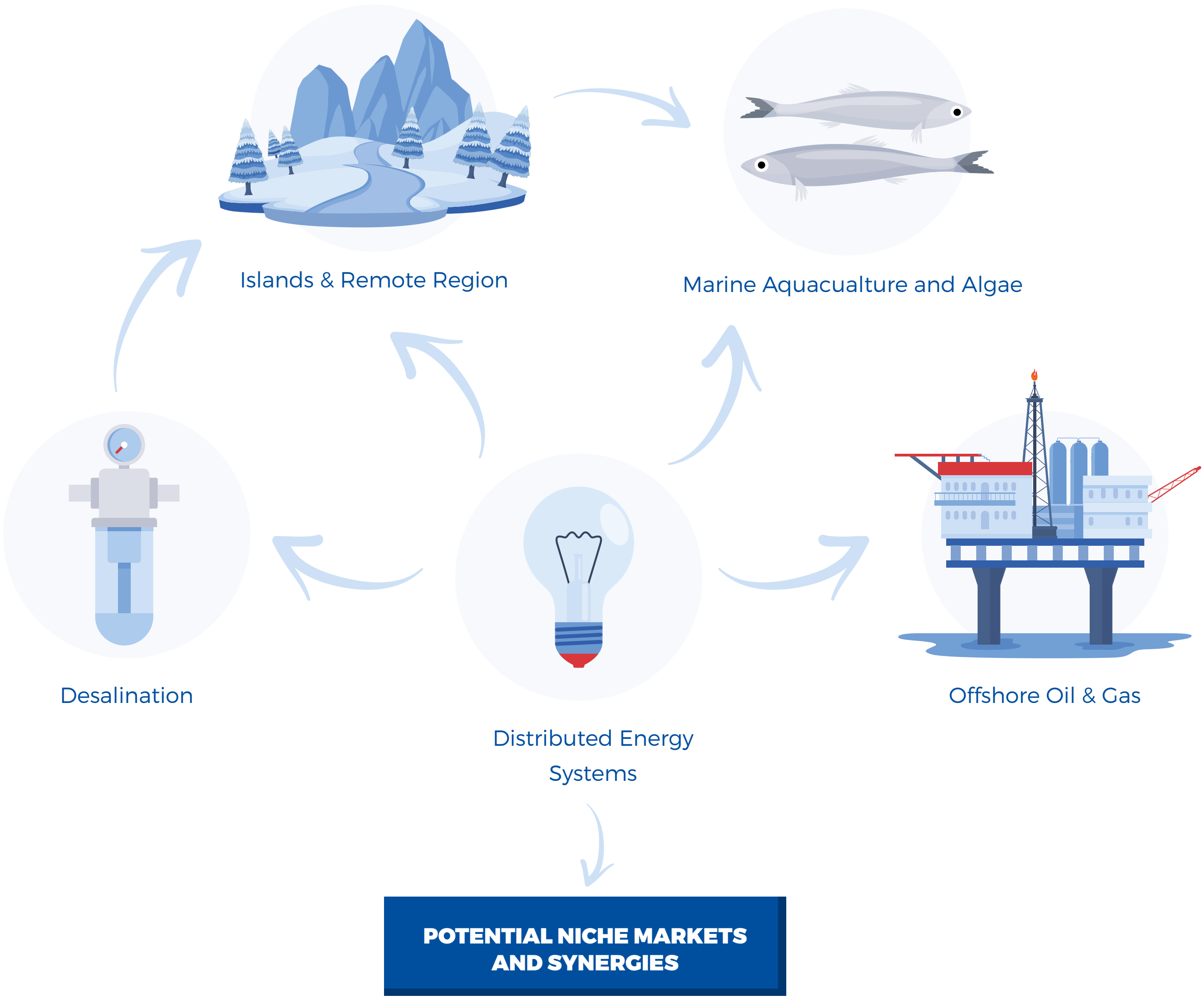


FIGURE 4.1

Potential off-grid markets for ocean energy technologies

Sources: Author based on (Vanegas Cantarero et al., 2020)

Neptune Renewable Energy device tested at Leith docks in Edinburgh
Courtesy: Neptune Renewable Energy

The development and establishment of the blue economy, i.e., "*the sustainable use of ocean resources for economic growth, improved livelihoods and jobs, and ocean ecosystem health*" (World Bank and UN Department of Economic and Social Affairs, 2017), represents an opportunity for sustainable ocean energy technologies to play an important role in social and economic development. The potential off-grid markets summarized in Figure 4 1 are derived from opportunities identified within the blue economy strategy or synergies with other industries.

Specific opportunities have been identified for islands and remote coastal areas starting by combinations of ocean energy technologies with applications such as **desalination** (Davies, 2005; Gude, 2015), **offshore aquaculture** (Iglesias et al., 2009), **hydrogen production** (Jacobson et al., 2015) or even **coastal defence** (Abanades, Greaves and Iglesias, 2014). All these opportunities highlight the importance of adapting human needs to local resources availability and technological designs. There are several research initiatives both in industry and academia looking into such hybrid systems along the coasts of South America, Europe, the USA, among others (Floating Power Plant A/S, 2019; Ganea, et al., 2017; Haces-Fernandez, Li and Jin, 2019; Kalogeri et al., 2017; Perez-Collazo, et al., 2019; Rusu and Onea, 2019). The timeframe in which some of these opportunities could be seized are detailed in Table 2.

TABLE 2

Market opportunities for ocean energy technologies in islands and remote coastal areas

| | Near term | Emerging | Future |
|---|---|---|---|
| **Power at sea** | | | |
| Ocean Observation and Navigation | ✓ | | |
| Underwater Vehicles Charging | ✓ | | |
| Marine Aquaculture | | ✓ | |
| Marine Algae | | ✓ | |
| Mining Seawater Mineral and Gasses | | | ✓ |
| **Resilient coastal communities** | | | |
| Desalination | ✓ | | |
| Disaster Resiliency and Recovery | | ✓ | |
| Community-scale Isolated Power Systems | ✓ | | |

Sources: *LiVecchi et al.* (2019)

Islands and remote coastal areas can be categorized into **industrialized islands** and **small islands and developing states (SIDS)**. The former are locations with established test sites and that have the key role and responsibility of leading the transition to sustainable and renewable energy systems. Industrialize islands have generally specific incentives and support mechanisms in place to enable the implementation and optimization of energy technologies and business cases. These locations have adopted approaches and strategies such as Smart Energy Systems (SES). Ocean energy technologies can be deployed in such locations to power the blue economy. The financial support in place in these locations can be extended or targeted to help addressing the risk associated to high capital expenses at this stage of the technology development.

Two examples of these pioneering industrialized islands are the Orkney islands, UK and Samsø, Denmark. The Orkney islands host the European Marine Energy Centre (EMEC), are producing renewable hydrogen, and are creating a local smart electricity grid as part of their efforts to embrace renewable energy. Samsø is known as Denmark's renewable island because of its green profile. The island generates 100% of its electricity today from offshore and onshore wind power and biomass. However, the island is also implementing an integrated energy system with storage and demand-side management as well as electric mobility. Islands like Orkney and Samsø have been project demonstrators adopting technology innovations and gathering expertise with emerging technologies. As such, these sites serve as platforms to raise awareness about the benefits and impacts of these technologies and inform stakeholders. Ocean energy technologies have been often deployed in the Orkney islands and could be deployed as well in other similar sites where the resource is available to demonstrate their applicability, performance and rentability.

Small islands and developing states (SIDS) are a diverse group of remote locations usually in tropical climate conditions. These locations can be single islands such as Cuba or Jamaica, groups of islands such as Fiji or Comoros, or archipelagos such as the Maldives. For SIDS, the adoption of renewable energy is a means to enable sustainable development. The key issues faced by these regions include energy poverty and access to modern energy services such as electricity and non-solid fuels for cooking. These regions usually rely heavily on imported fossil fuels and are paying some of the highest energy costs in the world (mostly due to high fuels transportation costs (Weisser, 2004).

Waveroller under installation in Peniche, Portugal Courtesy: AW-Energy

To tackle these challenges, some SIDS have established highly ambitious renewable energy targets aiming to decarbonize their entire power systems by 2025 or 2030 (Dornan, 2015), or are seeking to provide clean, modern energy services to the population (Surroop et al., 2018). To meet these targets, some islands have established support mechanisms such as feed-in-tariffs and renewable energy auctions. For example, Bahrain, Seychelles, and Tonga have held renewable energy auctions successfully awarding 100 MW of solar capacity, 4 MW of floating solar PV, and 6 MW of solar PV respectively (REN21, 2019).

Although most SIDS generate their electricity from fossil fuels (mainly coal and petroleum products); some SIDS have integrated a large share of renewable energy in their electricity mixes, e.g., Suriname (60%), Belize (45%), Fiji (45%), Papua New Guinea (34.5%), French Polynesia (32%), Samoa (30%), Tuvalu (28%), and Mauritius (22%) (World Bank Group, 2020a). These islands have been adopting wind and solar PV primarily. However, their positive experiences with these technologies could increase their willingness to adopt ocean energy technologies as well. Moreover, these islands have regulatory frameworks that are supporting the integration of clean energy technologies and, thus, could facilitate the deployment of emerging technologies such as wave, tidal stream or OTEC.

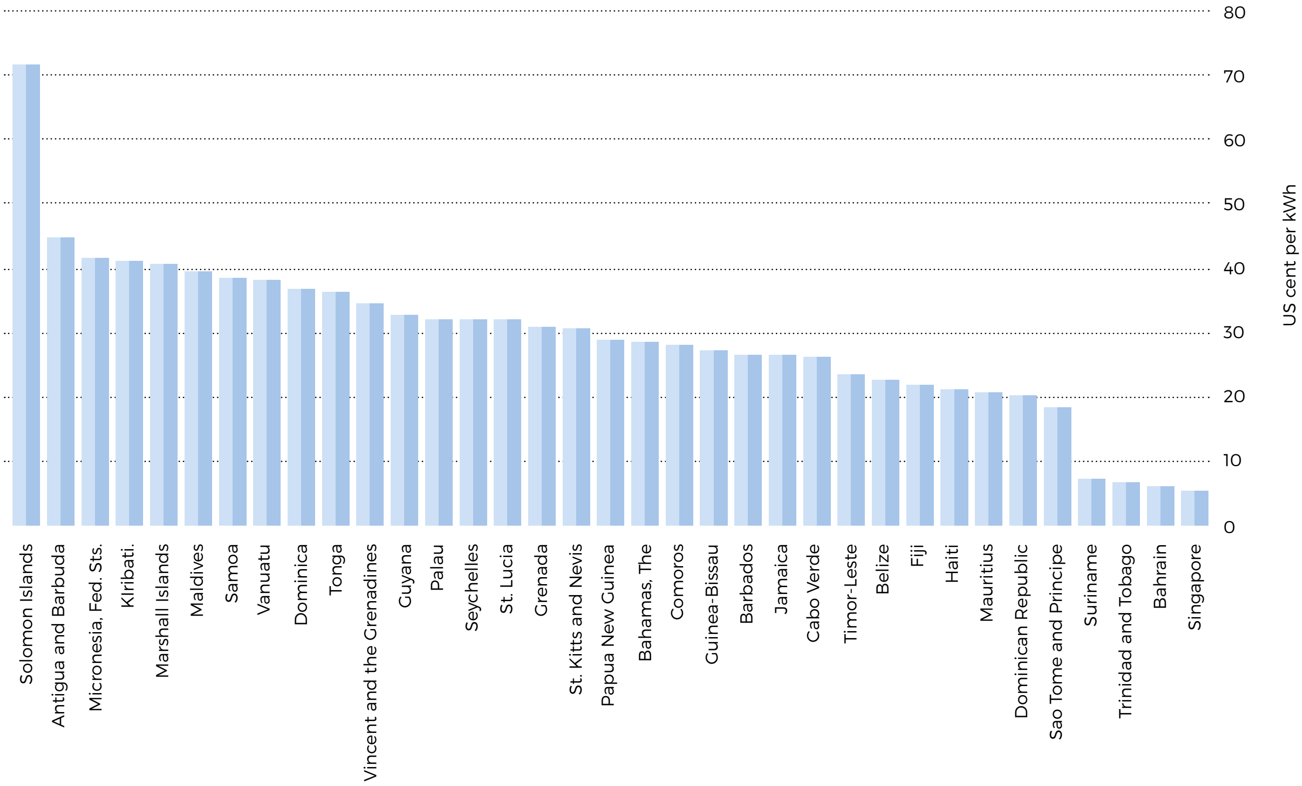
An interesting case is that of Mauritius, which has exhausted its large-scale hydropower potential and must look for alternative sources to generate low-carbon electricity (Elahee, 2013). Studies suggest that there is a high potential for OTEC and wave energy in Mauritius (Hammar, et al. 2012).

Another interesting case is that of the Maldives. These islands struggle with replacing diesel generators due to the size of their electricity market. Standalone systems are not economically feasible given how scattered these islands are and investing in intermittent renewable energy would imply overcapacity issues and insecurity of supply (van Alphen, van Sark and Hekkert, 2007). Studies have proposed water-energy systems where renewable energy systems are coupled with desalination plants to face these issues (Liu at al. 2018). This could be an opportunity for ocean energy developers seeking to test their technologies and supplying the power and water needs of the Maldives. Similarly, a potential synergy can be built between islands where the price of electricity is high, such as the Solomon Islands, Antigua and Barbuda, the Federated States of Micronesia, and others shown in Figure 4 2, and ocean energy developers. In these islands, ocean energy technologies that, at the moment, are not competitive in the utility markets may be already cost competitive given the current high generation costs.

LHD Tidal Current demonstration project being developed near Xiushan island, China Courtesy: LHD Technology

**FIGURE 4 2**

Price of electricity in selected SIDS, 2020



Source: Adapted from (World Bank Group, 2020b)

# 05

# CONCLUSION

Wave energy device deployed at Kamarajar port in Chennai, India Courtesy: National Institute of Ocean Technology

**Although ocean energy technologies have not reached the commercialization stage, significant progress has been made in the last decades resulting in improvements to the reliability and performance of the ocean energy devices and attracting interest and support for further development. These technologies have a cost reduction potential that requires additional research and development. However, they could form part of the portfolio of low-carbon energy technologies leading to decarbonisation.**

The small and remote nature of islands and coastal areas presents a compelling argument for the exploitation of their ocean energy resource potential. The energy systems in these locations face challenges that include security of supply and access to modern, clean, and affordable energy. This report has shown how ocean energy can be a means to overcome some of these challenges. By combining some of the benefits of ocean energy technologies such as the minimum visual and environmental impact and the predictability of the resource, these small and isolated energy systems can meet their energy needs, reduce their carbon footprint, and diminish their vulnerability to the volatility of oil prices. Synergistically, ocean energy technologies can benefit from the conditions offered by some islands and remote coastal locations that have relatively moderate energy consumption profiles, high resource potential, and are paying high prices for electricity relative to the mainland.

Nonetheless, the deployment of ocean energy technologies in small islands and remote coastal areas faces potential challenges. This report has summarised some of these challenges and laid out potential alternatives to overcome them. In summary, ocean energy technologies are not widely known or understood in islands and remote coastal areas which may lead to lack of support and policies to facilitate their adoption. Furthermore, the emerging nature of ocean energy technologies threatens investors' confidence and raises questions about the bankability of the projects and the capability of the devices to stand the extreme weather conditions and natural hazards present around small islands and remote coastal areas. Nevertheless, ocean energy technologies offer the possibility to serve as a supply of power during emergency responses, integrate the local communities and their needs in the design and scope of the projects as well as develop local skills and a local supply chain. Challenges and alternatives regarding socio-environmental, regulatory, infrastructure, and financial issues are further discussed in the report.

**The report aims to inform policymakers, increase investor confidence, and highlight the benefits of ocean energy as part of a common strategy to reduce the path to the commercialization of ocean energy technologies and facilitate the energy transition as well as sustainable development in small islands and remote coastal areas.**

# REFERENCES

Abanades, J., Greaves, D. and Iglesias, G. (2014), "Coastal defence through wave farms," *Coastal Engineering*, Vol. 91, pp. 299–307, Elsevier, https://doi.org/10.1016/j.coastaleng.2014.06.009.

Abundo, M. L. S. et al. (2011), "Energy potential metric for rapid macro-level resource assessment of tidal in-stream energy in the Philippines," *2011 10th International Conference on Environment and Electrical Engineering* (pp. 1–4), IEEE, https://doi.org/10.1109/EEEIC.2011.5874712.

van Alphen, K., van Sark, W. G. J. H. M. and Hekkert, M. P. (2007), "Renewable energy technologies in the Maldives-determining the potential," *Renewable and Sustainable Energy Reviews*, Pergamon, https://doi.org/10.1016/j.rser.2006.02.001.

Bonar, P. A. J. et al. (2018), "Assessment of the Malaysian tidal stream energy resource using an upper bound approach," *Journal of Ocean Engineering and Marine Energy*, Vol. 4/2, pp. 99–109, Springer, https://doi.org/10.1007/s40722-018-0110-5.

Charlier, R. H. and Justus, J. R. (1993), *Ocean Energies: Environmental, Economic, and Technological Aspects of Alternative Power Sources*, Elsevier, New York.

Cornett, A. M. (2008), "A Global Wave Energy Resource Assessment," *18th International Offshore and Polar Engineering Conference*, International Society of Offshore and Polar Engineers, Vancouver, Canada, http://polar.ncep.noaa.gov/waves/validation.html. (accessed February 27, 2020).

Cullen-Knox, C. et al. (2017), "The social licence to operate and its role in marine governance: Insights from Australia," *Marine Policy*, Vol. 79, pp. 70–77, Elsevier Ltd, https://doi.org/10.1016/j.marpol.2017.02.013.

Davies, P. A. (2005), "Wave-powered desalination: Resource assessment and review of technology," *Desalination*, Vol. 186/1–3, pp. 97–109, Elsevier, https://doi.org/10.1016/j.desal.2005.03.093.

Devine-Wright, P. (2013), *Renewable energy and the public: From NIMBY to participation, Renewable Energy and the Public: From NIMBY to Participation*, Taylor and Francis, https://doi.org/10.4324/9781849776707.

Dornan, M. (2015), "Renewable Energy Development in Small Island Developing States of the Pacific," *Resources*, Vol. 4/3, pp. 490–506, MDPI AG, https://doi.org/10.3390/resources4030490.

Eckstein, D., Hutfils, M.-L. and Winges, M. (2018), *Global Climate Risk Index 2019.*, Bonn, https://germanwatch.org/files/Global Climate Risk Index 2019_2.pdf (accessed March 4, 2020).

Edenhofer, O. et al. (eds.). (2011), *Renewable Energy Sources and Climate Change Mitigation: Special Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, https://www.ipcc.ch/report/renewable-energy-sources-and-climate-change-mitigation/ (accessed May 1, 2020).

Elahee, M. K. (2013), "Potential of Hydropower in Mauritius: Myth or Reality?," *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, Vol. 35/10, pp. 921–925, Taylor & Francis Group , https://doi.org/10.1080/15567036.2010.514592.

EMEC. ( 2020 a), "Wave Developers," *Marine Energy*, http://www.emec.org.uk/marine-energy/wave-developers/ (accessed April 27, 2020).

EMEC. ( 2020 b), "Tidal Developers," *Marine Energy*, http://www.emec.org.uk/marine-energy/tidal-developers/ (accessed April 27, 2020).

Floating Power Plant A/S. ( 2019), "Products & Services of Floating Power Plant," http://www.floatingpowerplant.com/products/ (accessed March 4, 2020).

Ganea, D. et al. (2017), "A Joint Evaluation of the Wind and Wave Energy Resources Close to the Greek Islands," *Sustainability*, Vol. 9/6, p. 1025, MDPI AG, https://doi.org/10.3390/su9061025.

Gude, V. G. (2015), "Energy storage for desalination processes powered by renewable energy and waste heat sources," *Applied Energy*, Vol. 137, pp. 877–898, Elsevier Ltd, https://doi.org/10.1016/j.apenergy.2014.06.061.

Guerra, M. et al. (2017), "Tidal energy resource characterization in Chacao Channel, Chile," *International Journal of Marine Energy*, Vol. 20, pp. 1–16, Elsevier, https://doi.org/10.1016/J.IJOME.2017.11.002.

Gunn, K. and Stock-Williams, C. (2012), "Quantifying the global wave power resource," *Renewable Energy*, Vol. 44, pp. 296–304, Pergamon, https://doi.org/10.1016/J.RENENE.2012.01.101.

Haces-Fernandez, F., Li, H. and Jin, K. (2019), "Investigation into the possibility of extracting wave energy from the Texas coast," *International Journal of Energy for a Clean Environment*, Vol. 20/1, pp. 23–41, Begell House Inc., https://doi.org/10.1615/InterJEnerCleanEnv.2018019929.

Hammar, L. et al. (2012), "Renewable ocean energy in the Western Indian Ocean," *Renewable and Sustainable Energy Reviews*, Vol. 16, pp. 4938–4950, https://doi.org/10.1016/j.rser.2012.04.026.

Hammons, T. J. (2011), "Energy Potential of the Oceans in Europe and North America: Tidal, Wave, Currents, OTEC and Offshore Wind," *Electricity Infrastructures in the Global Marketplace*, InTech, https://doi.org/10.5772/37841.

Huckerby, J. et al. (2016), *An International Vision for Ocean Energy. Version III.*, www.ocean-energy-systems.org (accessed April 29, 2020).

IEA. (2019a), *Electricity Information 2019: Overview.*, Paris.

IEA. ( 2019 b), "Data ad Statistics," *IEA Data Services*, https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy consumption&indicator=Electricity final consumption (accessed February 27, 2020).

Iglesias, G. et al. (2009), "Wave energy potential in Galicia (NW Spain)," *Renewable Energy*, Vol. 34/11, pp. 2323–2333, Pergamon, https://doi.org/10.1016/j.renene.2009.03.030.

IPCC. (2018), "Summary for Policymakers," in  and T.W. (eds. . Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor (ed.), *Global Warming of 1.5°C. An IPCC Special Report* (In Press.).

IRENA. (2014), *Tidal Energy: Technology Brief.*, Abu Dhabi.

Jacobson, M. Z. et al. (2015), "A 100% wind, water, sunlight (WWS) all-sector energy plan for Washington State," *Renewable Energy*, Vol. 86, pp. 75–88, Elsevier Ltd, https://doi.org/10.1016/j.renene.2015.08.003.

Jacobson, P. T., Hagerman, G. and Scott, G. (2011), *Mapping and Assessment of the United States Ocean Wave Energy Resource.*, Golden, CO (United States), https://doi.org/10.2172/1060943.

Kalogeri, C. et al. (2017), "Assessing the European offshore wind and wave energy resource for combined exploitation," *Renewable Energy*, Vol. 101, pp. 244–264, Elsevier Ltd, https://doi.org/10.1016/j.renene.2016.08.010.

Khan, N. et al. (2017), "*Review of ocean tidal, wave and thermal energy technologies*," Renewable and Sustainable Energy Reviews, Elsevier Ltd, https://doi.org/10.1016/j.rser.2017.01.079.

Kirke, B. and Coiro, D. P. (2019), "Tidal and Current Energy," in T. Sant & D. Coiro (eds.), *Renewable Energy from the Oceans - From Wave, Tidal and Gradient Systems to Offshore Wind and Solar*, Institution of Engineering and Technology.

Lehmann, M. et al. (2017), "Ocean wave energy in the United States: Current status and future perspectives," *Renewable and Sustainable Energy Reviews*, Elsevier Ltd, https://doi.org/10.1016/j.rser.2016.11.101.

Liu, J. et al. (2018), "Powering an island system by renewable energy—A feasibility analysis in the Maldives," *Applied Energy*, Vol. 227, pp. 18–27, Elsevier Ltd, https://doi.org/10.1016/j.apenergy.2017.10.019.

LiVecchi, A. et al. (2019), *Powering the Blue Economy: Exploring Opportunities for Marine Renewable Energy in Maritime Markets.*, Washington, D.C.

Magagna, D. (2019), *Ocean Energy Technology Development Report 2018.*, Luxemburg, https://doi.org/10.2760/158132.

Melikoglu, M. (2018), "Current status and future of ocean energy sources: A global review," *Ocean Engineering*, Elsevier Ltd, https://doi.org/10.1016/j.oceaneng.2017.11.045.

Mork, G. et al. (2010), "Assessing the global wave energy potential," *29th International Conference on Ocean, Offshore Mechanics and Arctic Engineering*, Shanghai, China.

National Research Council (U.S.) et al. (2013), *An evaluation of the U.S. Department of Energy's marine and hydrokinetic resource assessments.*

Neill, S. P. et al. (2018), “Tidal range energy resource and optimization – Past perspectives and future challenges,” *Renewable Energy*, Vol. 127, pp. 763–778, Pergamon, https://doi.org/10.1016/J.RENENE.2018.05.007.

Nihous, G. C. (2007), “A preliminary assessment of ocean thermal energy conversion resources,” *Journal of Energy Resources Technology, Transactions of the ASME*, Vol. 129/1, pp. 10–17, American Society of Mechanical Engineers Digital Collection, https://doi.org/10.1115/1.2424965.

Ocean Energy Forum. (2016), *Ocean Energy Strategic Roadmap: Building Ocean Energy for Europe*.

Osorio, A. F. et al. (2016), “Beyond electricity: The potential of ocean thermal energy and ocean technology ecoparks in small tropical islands,” *Energy Policy*, Vol. 98, pp. 713–724, Elsevier Ltd, https://doi.org/10.1016/j.enpol.2016.05.008.

Pelc, R. and Fujita, R. M. (2002), “Renewable energy from the ocean,” *Marine Policy*, Vol. 26/6, pp. 471–479, Pergamon, https://doi.org/10.1016/S0308-597X(02)00045-3.

Perez-Collazo, C. et al. (2019), “Monopile-mounted wave energy converter for a hybrid wind-wave system,” *Energy Conversion and Management*, Vol. 199, p. 111971, Elsevier Ltd, https://doi.org/10.1016/j.enconman.2019.111971.

REN21. (2019), *Renewables 2019 Global Status Report.*, Paris, https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf (accessed March 6, 2020).

Ribal, A. et al. (2017), “Tidal Current Energy Resource Assessment around Buton Island, Southeast Sulawesi, Indonesia,” *International Journal of Renewable Energy Research*, Vol. 7/2, pp. 857–865, Gazi Univ., Fac. of Technology, Dep. of Electrical et Electronics Eng.

Rusu, E. and Onea, F. (2019), “A parallel evaluation of the wind and wave energy resources along the Latin American and European coastal environments,” *Renewable Energy*, Vol. 143, pp. 1594–1607, Elsevier Ltd, https://doi.org/10.1016/j.renene.2019.05.117.

Sasaki, W. (2017), “Predictability of global offshore wind and wave power,” *International Journal of Marine Energy*, Vol. 17, pp. 98–109, Elsevier Ltd, https://doi.org/10.1016/j.ijome.2017.01.003.

SETIS. (2014), *Ocean Energy In brief.*, Brussels.

Skråmestø, Ø. S., Erik Skilhagen, S. and Kofod Nielsen, W. (2009), *Osmotic Power-Power production based on the osmotic pressure.*

Soerensen, H. C. and Weinstein, A. (2008), “Ocean Energy: Position paper for IPCC,” in O. Hohmeyer & T. Trittin (eds.), *IPCC Scoping Meeting on Renewable Energy Sources*, IPCC, Luebeck.

Surroop, D., Raghoo, P. and Bundhoo, Z. M. A. (2018), “Comparison of energy systems in Small Island Developing States,” *Utilities Policy*, Vol. 54, pp. 46–54, Elsevier Ltd, https://doi.org/10.1016/j.jup.2018.07.006.

Tarbotton, M. and Larson, M. (2006), *Canada Ocean Energy Atlas (Phase 1) Potential Tidal Current Energy Resources Analysis Background.*

UN. (2019), “List of SIDS - Sustainable Development Knowledge Platform,” https://sustainabledevelopment.un.org/topics/sids/list (accessed February 17, 2020).

UN CDP. (2018), “List of Least Developed Countries (as of December 2018),” United Nations Committee for Development Policy.

Vanegas Cantarero, M. M. et al. (2020), *Deliverable D8.1 - Potential Markets for Ocean Energy.*, https://www.dtoceanplus.eu/Publications/Deliverables/Deliverable-D8.1-Potential-Markets-for-Ocean-Energy (accessed March 3, 2020).

Wahyudie, A. et al. (2017), “Simple bottom-up hierarchical control strategy for heaving wave energy converters,” *International Journal of Electrical Power and Energy Systems*, Vol. 87, pp. 211–221, Elsevier Ltd, https://doi.org/10.1016/j.ijepes.2016.10.010.

Weisser, D. (2004), “On the economics of electricity consumption in small island developing states: A role for renewable energy technologies?,” *Energy Policy*, Vol. 32/1, pp. 127–140, Elsevier BV, https://doi.org/10.1016/S0301-4215(03)00047-8.

World Bank Group. ( 2020 a), “Renewable electricity output (% of total electricity output) | Data,” *World Development Indicators*, https://data.worldbank.org/indicator/EG.ELC.RNEW.ZS (accessed March 10, 2020).

World Bank Group. ( 2020 b), “Getting Electricity: Price of electricity (US cents per kWh) (DB16-20 methodology) | DataBank,” *Doing Business*, https://databank.worldbank.org/reports.aspx?source=3001&series=IC.ELC.PRI.KH.DB1619 (accessed March 10, 2020).

World Bank and UN Department of Economic and Social Affairs. (2017), *The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries.*, Washington DC.

Wright, G. et al. (2016), “Establishing a legal research agenda for ocean energy,” *Marine Policy*, Vol. 63, pp. 126–134, Elsevier Ltd, https://doi.org/10.1016/j.marpol.2015.09.030.

## OVERVIEW OF OES

Ocean Energy Systems (OES) is the short name for the Technology Collaboration Programme on Ocean Energy Systems under the International Energy Agency (IEA).

The OES connects organisations and individuals working in the ocean energy sector to accelerate the viability, uptake and acceptance of ocean energy systems in an environmentally acceptable manner.

The work of the OES covers all forms of energy generation in which sea water forms the motive power through its physical and chemical properties, i.e. wave, tidal range, tidal and ocean currents, ocean thermal energy conversion and salinity gradients.

The **International Energy Agency (IEA)** works to ensure reliable, affordable and clean energy for its 29 Member Countries and beyond. Founded in 1974, the IEA was initially designed to help countries co-ordinate a collective response to major disruptions in the supply of oil such as the crisis of 1973/4. While this remains a key aspect of its work, the IEA has evolved and expanded. It is at the heart of global dialogue on energy, providing authoritative statistics and analysis.

The IEA examines the full spectrum of energy issues and advocates policies that will enhance the reliability, affordability and sustainability of energy in its 29 Member Countries and beyond. The four main areas of focus are:

- energy security: promoting diversity, efficiency and flexibility within all energy sectors;
- economic development: ensuring the stable supply of energy to IEA Member Countries and promoting free markets to foster economic growth and eliminate energy poverty;
- environmental awareness: enhancing international knowledge of options for tackling climate change;
- engagement worldwide: working closely with non-member countries, especially major producers and consumers, to find solutions to shared energy and environmental concerns.

**Technology Collaboration Programmes (TCPs)** are independent, international groups of experts that enable governments and industries from around the world to lead programmes and projects on a wide range of energy technologies and related issues. TCPs currently cover topics related to:

- efficient end-use (buildings, electricity, industry, transport);
- cleaner fossil fuels (greenhouse-gas mitigation, extraction, supply, transformation);
- renewable energy and hydrogen (technologies and policies for deployment);
- cross-cutting issues (modelling, technology transfer, project financing);
- fusion power (safety, physics, materials, technologies).

**www.ocean-energy-systems.org**