# Opportunities and Challenges in Developing Ocean Energy Sources

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The optimal utilization of renewable energies is a crucial factor toward the realization of sustainability and zero carbon in a future energy system. Tidal currents, waves, and thermal and salinity gradients in the ocean are excellent renewable energy sources. Ocean tidal, osmotic, wave, and thermal energy sources have yearly potentials that exceed the global power demand of 22,848 TWh/y. It is expected that a better insight into ocean energy and a deep understanding of various potential devices can lead to a broader adoption of ocean energy. It is also clear that further research into control strategies is needed. Policy makers should provide financial support for technologies in the demonstration stage and employ road mapping to accelerate the cost and risk reductions to overcome economic hurdles.

Keywords: wave energy ; salinity gradient ; tidal energy ; tidal current ; tidal turbine ; conversion technology

## 1. Socio-Economic Performance

The growth and emergence of ocean energy could result in more employment opportunities, notably in linked industries such as in oil and gas, maritime, and offshore energy [1]. Knowledge and skills transfer from one industry to another could help establish a stable and reliable ocean energy supply and value chain within the region. This local supply chain would assist in building the sector and could reduce the initial costs of harvesting the energy from the ocean. Ocean energy is also more price stable than its competitors oil and gas. As a result, long-term employment and job stability can be predicted once the sector has matured [2]. Ocean energy is a renewable source of electricity; however, it faces various hurdles, ranging from technological issues to issues impacting its operation and maintenance [3], in a hostile ocean environment characterized by high salinity and extreme weather [4].

The technological difficulties stem from the high cost of the deployment and maintenance of offshore equipment. Due to the plethora of marine space users and environmental effects issues, space on offshore platforms is restricted. As a result, ocean energy devices and systems must be modular and resistant to tropical sea conditions. There is a push to reduce the cost of deployment and maintenance by ensuring that devices can survive for a long period in the water with minimal repair and replacement [2]. The environmental implications of wave energy converters may be difficult to assess due to the still low and limited deployment; however, it has been long enough to fully assess the environmental implications both on land and at sea.

The cost of generating electricity from ocean energy is significantly higher than that of traditional energy sources [5]. In addition, the multiplicity of components necessitates industrial cohesion and constrained supply networks. Therefore, synergies with other offshore businesses would benefit and strengthen the ocean energy industry in terms of planning and technology development. Similarly, additional dedicated infrastructure such as ports and transmission grids might be built to support the installation, operation, and maintenance of ocean energy converters [6].

Furthermore, because ocean energy is still a novel technology, project estimations and estimates (including planning, installation, maintenance, and repair) are confined to laboratory-scale deployment rather than commercial-scale implementation [7]. Even in places such as the EU and the UK, where ocean energy technologies are more established, the accuracy of capital and operational cost projections is an issue. This is because ocean energy harvesting is comprised of several technologies, the bulk of which are still under development. In 2015, Ocean Energy Systems (OES) published a landmark study on the levelized cost of energy (LCOE) of the wave, tidal, and OTEC technologies at various levels of development. **Table 1** shows the various cost projections for distinct ocean technologies such as wave, tidal, and the OTEC, based on the OES study, at various deployment stages.

**Table 1.** Summary data averaged for each deployment and technology type, based on the International Levelized Cost of Energy for the Ocean Energy Technologies report by the International Energy Agency-Ocean Energy Systems (IEA-OES)

[8].

| Deployment Stage | Variable | Wave | | Tidal | | OTEC | |
|---|---|---|---|---|---|---|---|
| | | Min | Max | Min | Max | Min | Max |
| First array/first project | Project capacity (MW) | 1 | 3 | 0.3 | 10 | 0.1 | 5 |
| | CAPEX (USD/kW) | 4000 | 18,100 | 5100 | 14,600 | 25,000 | 45,000 |
| | OPEX (USD/kW·y) | 140 | 1500 | 160 | 1160 | 800 | 1440 |
| Second array/second project | Project capacity (MW) | 1 | 10 | 0.5 | 28 | 10 | 20 |
| | CAPEX (USD/kW·y) | 3600 | 15,300 | 4300 | 8700 | 15,000 | 30,000 |
| | OPEX (USD/kW·y) | 100 | 500 | 150 | 530 | 480 | 950 |
| | Availability (%) | 85% | 98% | 85% | 98% | 95% | 95% |
| | Capacity factor (%) | 30% | 35% | 35% | 42% | 97% | 97% |
| | LCOE (USD/MWh) | 210 | 670 | 210 | 470 | 350 | 650 |
| First commercial-scale project | Project capacity (MW) | 2 | 75 | 3 | 90 | 100 | 100 |
| | CAPEX (USD/kW) | 2700 | 9100 | 3300 | 5600 | 7000 | 13,000 |
| | OPEX (USD/kW·y) | 70 | 380 | 90 | 400 | 340 | 620 |
| | Availability (%) | 95% | 98% | 92% | 98% | 95% | 95% |
| | Capacity factor (%) | 35% | 40% | 35% | 40% | 97% | 97% |
| | LCOE (USD/MWh) | 120 | 470 | 130 | 280 | 150 | 280 |

## 2. Social Influence

There is a social divide between public support for renewable energy development, which leads to local job creation, reduced electricity costs, lower carbon emissions, enhanced energy security, and successful planning and application approval. Power plants for renewable energy are frequently met with low public approval, which at the very least slows down, if not completely prohibits, initiatives. The visual effects, denial of climate change, a desire to avoid commercialization of coastal waterways, and harm to tourism, fisheries, recreation, and navigation operations are all factors [9][10].

## 3. Design, Installation, and Operation

Compared to land-based structures, the design, operation, and installation of any structure or facility in an ocean environment is always a problem. The importance of design in the case of ocean energy is much greater, as ocean energy is anticipated to actively interact with the ocean waves in a precise way to harvest energy from them. In addition to being able to handle operating pressures, the performance and survivability of ocean energy during extreme loading circumstances such as hurricanes and storms are critical.

Biofouling (moorings and floating or submerged components of the device) and corrosion are the most typical difficulties that ocean energy devices will confront [11]. Seawater's corrosive character [12] can also be a challenge for several aspects of ocean energy. Therefore, at the design stage, complete operation and maintenance strategies for ocean energy systems must be well-planned and devised, which will undoubtedly add to the lifecycle cost. Accessing the facility offshore is another critical concern for operation and maintenance planning [13]. Offshore energy industry knowledge such as experiences in offshore wind, oil, and gas industries [14] can help to understand the risks and costs associated with sustaining an offshore plant. As a result, a system with well-spaced maintenance activities will be a suitable option, lowering the expenses involved with repeatedly mobilizing staff to the plant.

Some studies are attempting to model the reliability of ocean energy devices and prospective failure rates. Thies et al. devised a system for simulating component reliability and failure rates under specified operational settings [15]. Device testing in environments that may simulate real-world situations is a requirement for determining device and component reliability [16]. Annual running and maintenance costs for ocean energy devices can be as high as 3.4–5.8% of capital expenditure, compared to 2.3–3.7% for offshore wind [17]. There have only been a few full-scale devices deployed; hence, there is limited practical experience. Installation of ocean energy devices must be simple and quick to reduce the installation costs [16]. In the case of tidal devices, this is also necessary because installation must take place at slack tide, which is short.

## 4. Grid Connection and Integration

Grid concerns, on the other hand, may not be a major concern in all markets. Because the grid infrastructure is adjacent to ocean energy resources along their coasts, many European countries such as France, Portugal, Spain, and the Netherlands may have an edge in building ocean energy projects [18]. Many countries see marine energy as a possible electricity source, as indicated in [19], in order to cut carbon emissions and diversify their electricity sources. Ireland, for example, has set a goal of 500 MW of ocean energy in its energy portfolio by 2020 [20]. Blavette et al. [19] summarized some important points and advice. The wind energy industry may have viewed the introduction of additional grid code criteria for wind as unfair or unjustified [21]. However, in the case of ocean energy, a close working relationship between grid operators and developers in the development of grid code requirements should benefit both sides [22][23] (see **Figure 1**). Grid operators may find it challenging to understand the possible grid impact of all the many brands of ocean converters because of their diversity. More communication with the ocean energy business may result in the establishment of more appropriate criteria that will satisfy both parties. Involvement of the ocean energy sector in the establishment of these specifications, on the other hand, would also increase developer acceptance. Furthermore, it may improve the industry's grasp of the whole range of power system stability challenges.

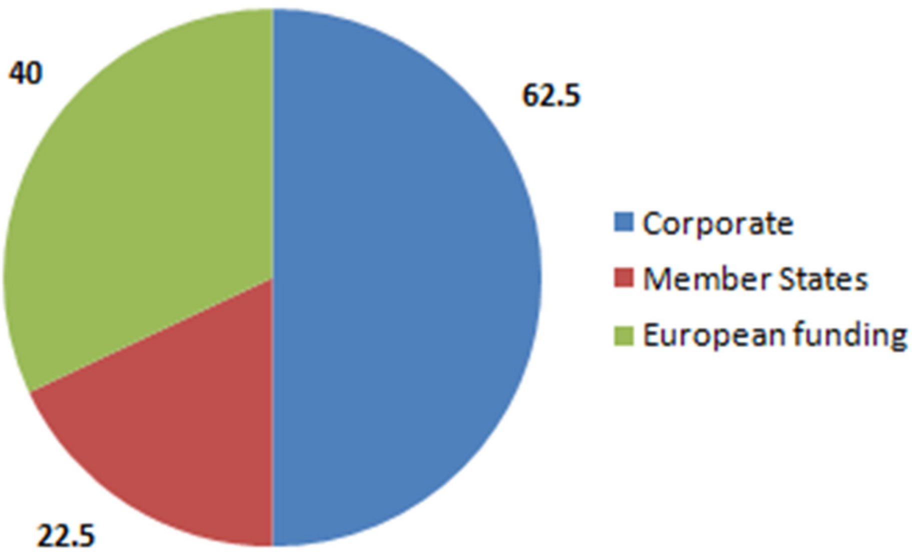


**Figure 1.** Total research and development investment in wave and tidal energy projects in 2011 (in M EUR).

In order to integrate new energy sources, requirements must evolve. In the case of ocean energy converters, it is proposed that this evolution be broken down into multiple steps that will be defined in partnership with industry and grid operators. Future requirements are recommended to grow in the same way that wind turbine requirements do (i.e., based on the experience gained at each stage of the grid integration process and the level of penetration of ocean energy in the energy mix). Developing fixed requirements to be applied from low to high penetration levels would be unreasonable and irrelevant [24].

At the initial stage, the first phase of grid integration is concerned with the time when the ocean energy's contribution to the energy mix is low and hence does not pose a danger to the stability of the power system. Soft grid requirements are proposed during this time; therefore, the developers can enhance their technology by testing it in real-world scenarios with a grid connection [19]. In the following phases, when wind energy becomes a large part of the energy mix in some areas, tighter criteria are imposed such as low voltage fault ride-through or frequency control requirements. Similarly, harsher limitations will need to be adopted later, depending on the extent of the penetration of ocean energy [19].

## 5. Policy and Regulations

Many countries with ocean access are planning to develop ocean energy as part of their long-term energy goals. The EU has put in place support mechanisms to help with the development of ocean energy, with 66 MW of projects expected to be operational by 2018 [24]. **Table 2** lists some of the governmental policy instruments for ocean energy in the EU [25].

**Table 2.** Governmental policy instruments for ocean energy.

| Policy Instrument | Country | Example Description |
| --- | --- | --- |
| | **Targets** | |
| **Legislated targets, aspirational targets, and forecasts** | **United Kingdom** | **3% of UK electricity from ocean energy by 2020** |
| | **Ireland** | **500 MW by 2020** |
| | **Portugal** | **550 MW by 2020** |
| | **Government funding** | |
| **Research and development programs/grants** | **United States** | **U.S. DoE hydrokinetic program (capital grants for R&D and market acceleration)** |
| **Prototype deployment and capital grants** | **United Kingdom** | **Marine Renewable Proving Fund (MRPF)** |
| | **New Zealand** | **Marine Energy Deployment Fund (MEDF)** |
| | **Production incentives** | |
| **Feed-in-Tariffs** | **Portugal** | **Guaranteed price (in USD/kWh or equivalent) for ocean energy-generated electricity** |
| | **Ireland/Germany** | |
| **Renewables Obligations** | **United Kingdom** | **Tradable certificates (in USD/MWh or equivalent) for ocean energy generated electricity** |
| **Prizes** | **Scotland** | **Saltire prize** |
| | **Infrastructure developments** | |
| **National marine energy centers** | **United States** | **Two centers were established (Oregon/Washington for wave/tidal and Hawaii for OTEC)** |
| **Marine energy testing centers** | **Most western European and North American countries** | **European Marine Energy Center (EMEC). There are about 14 centers under development worldwide** |
| **Offshore hubs** | **United Kingdom** | **Wave hub, connection infrastructure for devices** |
| | **Other regulatory incentives** | |
| **Standards/protocols** | **United Kingdom** | **A national standard for ocean energy (as well as participation in the development of international standards)** |
| **Permitting regimes** | **United Kingdom** | **Crown estate competitive tender for** |
| **Space/resource allocation regimes** | **United States** | **FERC/MMS permitting regime in U.S. outer Continental Shelf** |

Ocean energy offers a unique utilization that can support various energy networks. It enables the Global Renewable Energy Islands Network (GREIN) clusters on islands, which include water desalination [18]. Capacity or generation targets; capital grants and financial incentives including prizes; market incentives; industry development; research and testing facilities and infrastructure; and permitting, space, and resource allocation regimes, standards, and protocols are the six categories of policies that apply to ocean technology [26]. In addition, creating resource mapping, increasing capital grand funding, expanding international collaboration, and fostering research, development, and demonstration are all policies that can assist in overcoming the technological hurdles for ocean energy [18]. To overcome the economic barriers, policymakers might provide financing support for technologies in the demonstration stage and use road-mapping to speed cost and risk reductions [18]. Because tidal stream energy cannot currently be funded purely through commercial means, public subsidization measures such as feed-in tariffs (FIT) can help promote its development [5].

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