Chapter 22. Other Marine-Based Energy Industries

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1. Marine Renewable Energy Resources: Background

This chapter concerns ocean processes that are viable sources of renewable energy in various forms, such as offshore wind, waves, tides, ocean currents, marine biomass, and energy from ocean thermal differences among different layers (Appiott et al., 2014). Most of these energy forms are maintained by the incoming heat from the sun, so they represent indirect solar energy. Tidal energy is an exception, driven by the varying gravitational forces that the moon and sun exert on both the earth and its oceans (Butikov 2002). Marine renewable energy offers the potential to meet the increasing global energy demand, while reducing long-term carbon emissions. Although some marine renewable energy resources are still in a conceptual stage, other sources have been operational with varying degrees of technical and commercial success. The following section briefly discusses various forms of marine renewable energy sources that are currently in operation or in a demonstration phase.

1.1 Offshore Wind Power: Background

Offshore wind power relates to the installation of wind turbines in large water bodies. On average, winds blow faster and more uniformly at sea than on land, and a faster and steadier wind means less wear on the turbine components and more electricity generated per turbine (Musial et al., 2006). The potential energy produced from wind is proportional to roughly the cube of the wind speed. As a result, a marginal increase in wind speed results in a significantly larger amount of energy generation. For instance, a turbine at a site with an average wind speed of 25 km/h would provide roughly 50 per cent more electricity than the same turbine at a site with average wind speeds of 22 km/h.

Offshore wind power is also the most developed form of marine renewable energy in terms of technology development, policy frameworks, and installed capacity. Turbine design and other project elements for offshore wind have benefited significantly from research on and experience with land-based wind energy projects and offshore oil and gas development (Steen and Hansen, 2014). It is already a viable source of renewable energy in many regions and is attracting global attention because of its large-scale resource potential, also often close to major electrical load centers in coastal areas. In light of these factors, offshore wind energy appears to have the greatest immediate potential for energy production, grid integration, and climate change mitigation.

1.2 *Ocean Wave Energy: Background*

As the wind flows over the ocean, air-sea interface processes transfer some of the wind energy to the water, forming waves which store this energy as potential energy and kinetic energy (Special Report on Renewable Energy Sources and Climate Change, 2011). The immense power of waves can be observed at the coast, where this energy can have considerable impacts on coastal landscapes, shoreline topography, and infrastructure. Efforts are now underway to tap this resource for electric generation using wave energy conversion (WEC) devices. WECs transform mechanical energy from the surface motion of ocean waves or from velocity fluctuations below the surface into electrical current.

1.3 *Tidal Power: Background*

Tides are regular and predictable changes in the height of the ocean, driven by gravitational and rotational forces between the Earth, Moon, and Sun, combined with centrifugal and inertial forces. Many coastal areas experience roughly two high tides and two low tides per day (called “semi-diurnal” tides); however in some locations there is only one tidal cycle per day (these are “diurnal” tides Special Report on Renewable Energy Sources and Climate Change, 2011). Tidal power can be harnessed either through a barrage or through submerged tidal turbines in straits or sounds. Tidal barrages involve the use of a dam across an inlet. Sluice gates on the barrage allow the tidal basin to fill on the incoming high tides and to empty through the turbine system on the outgoing tide (U.S. EIA, 2013).

Energy extraction using tidal barrages is derived from the potential energy created when elevation differences develop between two water bodies separated by a dam or barrage, which is analogous to the way a turbine operates in a hydroelectric plant on a dammed river. Conversely, submerged tidal turbines that operate without a barrage only rely on the kinetic energy of the freely moving water. Because water is about 800 times denser than air and is more corrosive, tidal turbines must be much sturdier than wind turbines (U.S. EIA, 2013).

1.4 *Ocean Current Energy: Background*

Ocean currents are the continuous flow of ocean waters in certain directions, driven or controlled by wind flows, salinity, temperature gradients, gravity, and the Earth’s rotation or coriolis; (U.S DOE, 2013). Although surface ocean currents are generally wind driven, most deep ocean currents are a result of thermohaline circulation – a process driven by density differences in water due to temperature (thermo) and salinity (haline) in different parts of the ocean. Currents driven by thermohaline circulation move much slower than surface currents (NOAA, 2007). Many large and powerful ocean currents, such as the Gulf Stream off the east coast of the United States and the Kuroshio Current off the east coast of Japan, represent an enormous source of untapped energy that can be harnessed through large underwater turbines.

1.5 Ocean Thermal Energy Conversion (OTEC): Background

The OTEC system produces electricity from the natural thermal gradient of the ocean between the surface and subsurface ocean waters in tropical and subtropical regions. Heat stored in warm surface water is used to create vapor to drive a turbine and generator, and cold, deep water pumped to the surface recondenses the vapor (Avery and Wu, 1994). The OTEC heat engine is usually configured to operate as a thermodynamic Rankine vapor cycle in which a low-boiling-point working fluid (such as ammonia) is evaporated by heat transfer from the surface seawater and produces electricity by expanding through a turbine connected to a generator. The vapor exiting the turbine is condensed with the cold deep water. This is the Closed-Cycle process. The Open-Cycle process uses expendable water/seawater as the driving fluid, under low (<0.1 Atmosphere) pressure. After the flash evaporation of the fluid, fresh, potable water may be collected on the condensers, while new seawater is being evaporated upstream. Additional freshwater may be collected in a second exchanger utilizing the remaining Delta-T after the first stage. Thus, the Open-Cycle process generates both electricity and potable water.

The OTEC systems have been demonstrated to work successfully, but no large-scale plant has been built yet. A benefit of OTEC is that it produces constant base-load electricity, in contrast to other forms of ocean energy sources that fluctuate according to varying winds and currents.

1.6 Osmotic Power: Background

Salinity gradient energy is an often-overlooked potential source of renewable energy from the ocean. The mixing of freshwater and seawater that occurs where rivers and streams flow into the salty ocean releases large amounts of energy. Various concepts on how to make use of this salinity gradient have existed for over twenty years. One such concept is Pressure-Retarded Osmosis (PRO), in which seawater is pumped into a pressure chamber where the pressure is less than the osmotic pressure difference between fresh river water (low salinity water) and seawater (higher salinity water). Freshwater then flows through a semi-permeable membrane and increases the volume (or pressure) within the chamber; a turbine is spun as the pressure is relieved. Early technologies were not considered to be promising, primarily because they relied on expensive membranes. Membrane technologies have advanced, but they remain the main technical barrier to economical osmotic energy production (Appiott et al., 2014). Also, water on both sides must be low in particulates and other solids, eliminating many rivers from being a potential freshwater source.

1.7 Marine Biomass Energy: Background

Some researchers are looking towards marine biomass, including seaweeds and marine algae as a viable source of biofuel. Interest in marine biomass is driven both by the potential productivity of microalgae, which is tenfold greater than that of agricultural crops, and because, unlike first-generation biofuels, microalgae do not require arable land or freshwater, nor do they compete with food production (NERC, 2014). Marine ecosystems are highly productive because they cycle energy and nutrients much more rapidly and efficiently than terrestrial ecosystems. Marine algae are photosynthetic aquatic plants that use light as the energy source and seawater as a growth medium. Algae can be harvested and processed into biofuels, including biodiesel and bioethanol.

Biodiesel is a non-toxic and biodegradable fuel that is being used in existing diesel engines without requiring significant modification. Bioethanol can also be used as fuel when mixed with gasoline. Algae grown for biofuels can also provide a sink for carbon dioxide, thereby contributing to climate change mitigation (replacing fossil CO_2 with biogenic CO_2 emissions). Algae are an economical choice for biodiesel production because of their wide availability and low cost. Despite these advantages, however, offshore production of algae is still developing and most algae production takes place onshore.

2. Resource Assessment and Installed Capacity (Global and Regional Scales)

2.1 Offshore Wind Capacity

An assessment of the world's exploitable offshore wind resources has placed the estimates around 22 TWa[1] (Arent et al., 2012) which is approximately nine times greater than the International Energy Agency's (IEA) 2010 estimate of average global electricity generation (IEA, 2012). According to a report by the United States National Renewable Energy Laboratory (NREL), offshore wind resource potential for contiguous United States and Hawaii for annual average wind speeds greater than 7.0 m/sec and at 90 m above the surface is 4,150 GWa (Schwartz et al., 2010). Similarly, a report by the European Environmental Agency (EEA) calculated the technical offshore wind power potential, based on the forecasted costs of developing and running wind power projects in 2020 at 2,850 GWa (EEA, 2009). This figure does not account for spatial use conflicts in developing the wind resource offshore.

As of 2012, large-scale commercial offshore wind projects and demonstration-scale or pilot projects are already operational in the Belgium, China, Denmark, Finland, Germany, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland and United States of America (EWEA, 2008; RenewableUK, 2010; 4C Offshore, 2013; WWEA, 2014). Currently, the North Sea region is considered to be the global leader in offshore wind, both in installed and planned capacity and in technical capability. By the end of 2013, the offshore wind industry has achieved a cumulative global installed capacity of 7,357 MW (WWEA, 2014). Offshore wind turbines can be either bottom-mounted or floating. Currently, most offshore wind projects are bottom-mounted; floating wind turbines are still in the demonstration phase. Moreover, most installations are near the shore in relatively shallow waters due to the higher

[1] TWa: The average number of terawatt-hours, not terawatts, over a specified time period. For example, over the course of one year, an average terawatt is equal to 8,760 terawatt-hours, or 24 hours x 365 days x 1 terawatt.

cost of transmission cabling further offshore, and due to the technical and economic challenges of installing turbines in deeper waters.

Figure 1. Photo credit: Principle Power. The WindFloat Prototype (WF1) floating wind turbine, deployed by Principle Power in 2011, 5km off the coast of Aguçadoura, Portugal. The WF1 is outfitted with a Vestas v80 2.0 MW offshore wind turbine. As of December 2015, the system has produced in excess of 16 GWh of renewable energy delivered to the local grid.

2.2 Wave Energy Capacity

The global exploitable wave energy resource is estimated at around 3,700 GWa (Mørk et al., 2010), which is large enough to meet the average global electric generation (IEA, 2012). Wave energy can be harnessed using either floating or fixed conversion devices. Floating devices convert the wave energy by coupling it to a hydraulic system as the device is lifted up and down by the movements of the waves. Fixed devices generally use the oscillating water column generated by the wave to push air (or water) through a turbine. Other types of wave energy technology, such as overtopping devices and attenuators, are also undergoing testing and demonstration.

The world's first grid-connected wave energy device, a 500 kW unit in Scotland (United Kingdom) called the Islay Limpet, has been operating successfully since 2000 (UKDTI, 2004). The Aguçadoura Wave Farm, the world's first utility-scale wave energy project, was launched off the coast of Portugal in September 2008. This installation, developed by PelamisWave Power, utilized three 750 kW devices with a total capacity of 2.25 MW (RenewableUK, 2010). The project operated for two months before technical problems forced the developers to abandon it.

Figure 2. Waves4power OWC plant in operation offshore Sweden (Reprinted with permission from Waves4power AB).

2.3 *Tidal Energy Capacity*

The global tidal energy resource is estimated to be 3,000 GWa by the World Offshore Renewable Energy Report 2004-2008 (UK DTI, 2004), however, less than 3 per cent of this energy is located in areas suitable for power generation. Tidal energy is feasible only where strong tidal flows are amplified by factors such as funneling in estuaries, making it highly site-specific (UK DTI, 2004). Traditionally, tidal energy has been harnessed using large barrages in areas of high tidal ranges. Many countries, such as Canada, China, France, Republic of Korea, Russian Federation and the United Kingdom have sites with large tidal ranges that are viable for tidal energy capture facilities. The Sihwa Lake Tidal Power Station in the Republic of Korea, which has been operational since August 2011, is the world's largest tidal power barrage with a capacity of 254 MW, surpassing the 240 MW Rance Tidal Power Station in France, which has been generating power since 1967. Numerous projects have also been proposed in other areas, including in the Severn Estuary in the United Kingdom (Hall, 2012).

As part of its technology development initiative, the United States Department of Energy (US DOE) has funded research into several new types of technology, including a turbine under development by Verdant Power Inc. Verdant Power was the first company in the United States of America to be granted a license for a commercial tidal energy project, and looks to build upon an earlier demonstration project in New York's East River with an installation of up to 30 turbines along the strait that connects Long Island Sound and the Atlantic Ocean in the New York harbour.

2.4 Ocean Current Energy Capacity

There are no commercial grid-connected turbines currently operating, although a number of prototypes and demonstration units are under development. In 2014, the United States Bureau of Ocean Energy Management (BOEM) issued a lease to Florida Atlantic University (FAU) for testing ocean current turbines. FAU's Southeast National Marine Renewable Energy Center (SNMREC) plans to deploy experimental demonstration devices in areas located 10 to 12 nautical miles offshore Florida (Bureau of Ocean Energy Management, 2014).

2.5 Ocean Thermal Energy Conversion (OTEC) Capacity

OTEC technologies have been tested as early as the 1930s. However, OTEC has been limited to small-scale pilot projects, and has yet to encourage much investment and commercial development (US DOE, 2008). Research initiatives in the France, India, Japan and United States of America and elsewhere are currently examining and testing different types of OTEC technologies (Lockheed Martin Corporation, 2012). A modern-type, but very small OTEC plant was constructed in Hawaii, United States, in 1979 (Kullenberg et al., 2008), and similar demonstration projects have been proposed by other nations (IOES, 2015). Most experience is derived from land-based plants. For floating installations, reference material is mostly derived from design studies, but with successful demonstrations in Hawaii (MiniOTEC, OTEC-1) and Okinawa, Japan (OTEC Okinawa, 2014).

2.6 Osmotic Power Capacity

The world's first complete prototype osmotic power plant was launched in Norway in 2009 by Statkraft. This plant is located in Tofte, southwest of Oslo. According to the company's assessment, osmotic-power technologies remain several years away from commercial viability (Kho, 2010). Statkraft recently (2014) decided to shelve development plans.

2.7 Marine Biomass Energy Capacity

Research into algae production has largely been guided down three tracks: open and covered ponds, photobioreactors, and fermenters; the first two are the most widely pursued. Siting algae farms in ocean areas has also been investigated (Lane, 2010). In the United States, the National Aeronautics and Space Administration (NASA) is investigating the feasibility of growing algae in floating photobioreactors on the outer (geomorphic) continental shelf or in the open ocean. The Offshore Membrane Enclosures for Growing Algae (OMEGA) system would use freshwater algae and wastewater in the photobioreactors to produce biofuel while also cleaning wastewater, creating oxygen, and providing a sink for carbon dioxide (NASA, 2012). As the technology is developed further and States with favourable growing conditions begin to look towards marine renewable energy, this option may become commercially viable in the future.

3. Environmental Benefits and Impacts from Offshore Renewable Energy Development

Marine renewable energy installation and generation invariably has environmental impacts, both positive and negative. These impacts depend on the installation size and footprint, location, and the use of specific technology. A major positive impact of ocean renewable energy is the provision of low-carbon electricity. Analysis suggests that the carbon intensity of offshore wind and marine hydrokinetic resources, such as wave and tidal power, is more than an order of magnitude lower than fossil fuel generation. In a life cycle analysis, greenhouse gas emissions from wave energy projects average between 13-50 gCO_2eq/kWh[2], tidal current projects emit approximately 15 gCO_2eq/kWh, and offshore wind projects between 4-6 gCO_2eq/kWh (Raventós et al., 2010); these are to be compared with emissions closer to 800-1000 gCO_2eq/kWh for coal power plants and 400-600 gCO_2eq/kWh for natural gas power plants (POST, 2006 and 2011).

Other environmental benefits include no emissions of toxic air or water pollutants (such as NO_x [Nitrogen dioxide], SO_2 [sulfur dioxide], mercury, particulate matter, and thermal pollution from cooling water discharge) and minimal land-use disturbance with the exception of land-use changes related to assembly, equipment loading/offloading and cable landfalls along the coast. In addition, there are potential biodiversity benefits from the installation of offshore turbines or marine energy conversion devices. Offshore renewable energy (ORE) structures increase the amount of hard substrate for colonization and provide marine organisms with artificial reefs. Such structures also create increased heterogeneity in the area: this is important for maintaining species diversity and density (Langhamer, 2012). Investigations have found greater fish abundance in the vicinity of offshore turbines compared to the surrounding areas (Wilhelmsson et al., 2006). One negative impact is that invasive species can find new habitats in these artificial reefs and possibly adversely influence the native habitats and associated environment (Langhamer, 2012).

The broader environmental impacts from marine renewable energy can be understood in the context of an ecological risk assessment framework developed by the United States Environmental Protection Agency (EPA). This approach provides a conceptual model for developing a systematic view of possible ecological effects (McMurray, 2008). The terminology needed for this model requires defining stressors and receptors. Stressors are features of the environment that may change due to installation, operation, or decommissioning of the facilities, and receptors are ecosystem elements with a potential for some form of response to the stressor(s) (Boehlert and Gill, 2010). Stressors can be considered in terms of different stages of development (survey, construction, operation, and decommissioning) as well as the duration, frequency, and intensity of the disturbance. Project size and scale are also

[2] gCO_2eq/kWh : grams of CO_2 equivalent per kilowatt hour of generation.

determining factors in the magnitude of stressors and receptors. Within this framework, we discuss various ecological impacts in the following sections.

Potential negative impacts on flora and fauna including marine mammals, birds, and benthic organisms, as well as impacts on the larger ecosystem may occur from offshore renewable energy (OREI) development. Some of these impacts are limited to the construction phase, while other impacts span operation and decommissioning phases (Linley et. al., 2009). Potential impacts include habitat loss or degradation at various stages of a project life cycle; injurious noise and displacement of marine mammals from pile driving of wind and tidal-stream generators. Tide power turbines may also induce local seabed scouring and/or changes to the current regime, with unintended consequences for biota. Turbine construction may induce mortality due to physical collision with the OREI structures; effects of operational noise; and electromagnetic field (EMF) impacts from submerged cables (U.S. Department of Interior, 2011).

Noise created during pile-driving operations involves sound pressure levels that are high enough to impair hearing in marine mammals and disrupt their behaviour at a considerable distance from the construction site (Thomsen et. al., 2006). During pile driving for the Horns Rev II offshore wind project in Denmark, a negative effect was detected out to a distance of 17.8 km (Brandt et. al, 2011). Although it has been observed that marine mammals temporarily abandon the construction area, they tend to return once pile driving operations cease. Acoustic impact on marine mammals is a major concern and an important topic of assessment and mitigation strategies in many States. More information is required almost everywhere to understand impacts on and responses by marine organisms to such stresses.

Fixed and moving parts of Ocean Renewable Energy (ORE) devices can lead to fatal strikes or collisions with birds and aquatic fauna. Blades used in marine turbines, such as those in ocean current or tidal energy devices, are relatively slow-moving and therefore not considered to pose a significant threat to wildlife (Scott and Downie, 2003). However the speed of the tip of some horizontal axis rotors could be an issue for cetaceans, fish, or diving strike birds (Boehlert and Gill, 2010). Operation of the SeaGen tidal energy device in Strangford Lough, United Kingdom, considered the presence of seals and porpoises and the potential threat of blade strikes; to minimize strike risk, the turbine was shut down when the presence of seals was observed within 30 meters (Copping et al., 2013). Similarly, investigation of long-tailed geese and ducks in and around the Nysted offshore wind project in Denmark suggests that flocks employ an avoidance strategy. Research suggests that the percentage of flocks entering the wind project area decreased significantly from pre-construction to initial operation. Overall, less than 1 per cent of ducks and geese migrated close enough to be at any risk of collision (Desholm and Kahlert, 2005). This avoidance strategy or adjustment of flight paths, a form of receptor, has also been observed in other projects, such as Horns Rev (NERI, 2006). It is important to highlight that the additional distances travelled by migratory birds to avoid these wind farms were relatively trivial (around 500 m) compared to their total migratory trajectory of 1,400 km. However, construction of further utility-scale projects could have a cumulative impact on the population, especially when considered in combination with other human actions (Masden et. al., 2009).

Submerged cables carrying electricity from ORE devices to onshore substations emit low-frequency Electric and Magnetic Fields (EMF). Marine and avian species are sensitive and responsive to naturally occurring magnetic fields; these are commonly used for direction-finding using the Earth's geomagnetic field. Anthropogenic sources of EMFs are an overlay to naturally occurring sources, and as these sources become increasingly common, there are potential impacts on marine organisms. Industry standards for the design of submarine cables require shielding, which restricts directly emitted electric fields, but cannot shield the magnetic field component of EMFs (Boehlert and Gill, 2010). Moreover, an alternating current (AC) magnetic field has a rotational component that induces an additional electric field in the surrounding environment. There is evidence that EMF's from wind farms can cause disturbance to air traffic control radar systems (De la Vega et al., 2013).

Magnetic fields are strongest over the cables, decreasing rapidly with vertical and horizontal distance from the cables. In projects where the electric current is delivered along two sets of cables that were separated by at least several meters, the magnetic field appeared as a bimodal peak (Normandeau et al., 2011). Studies suggest that behavioural effects of EMF on species occur, although the impacts vary significantly among species.

Thermal aspects of electricity-transmission cables should also be considered. When electric energy is transported, a certain amount is lost as heat, leading to an increased temperature in the cable surface and subsequent warming of the surrounding marine environment (Merck and Wasserthal, 2009). Temperature changes can affect benthic organisms, although data on measureable impacts are sparse. Increased temperatures can also attract marine organisms, exposing them to a higher amount of EMF radiation.

In addition, there are other potential impacts such as chemical effects from potential spills or leaching of anti-fouling paints from ocean renewable energy devices (Boehlert and Gill, 2010), or impacts on benthic creatures and certain fish species which have not yet been fully investigated and assessed. Many such effects are localized, depend on marine and avian biodiversity in a region and can be understood only through comprehensive site-specific environmental impact assessment. Substantial work is proceeding to gather and disseminate available information and data on ecological impacts of ocean energy devices. The International Energy Agency-Implementing Agreement on Ocean Energy Systems (OES) Annex IV[3] is maintaining the Tethys database, an important reference for both developers and policy makers (http://tethys.pnnl.gov/).

4. Socioeconomic Benefits and Impacts from Offshore Renewable Energy Deployment

[3] Annex IV. Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal and Current Energy Systems, Tethys.pnnl.gov.

Socioeconomic impacts cover a range of issues, including access to the ocean, visual impacts amenity, impact on coastal and offshore cultural heritage sites, and other uses of the ocean, including recreational tourism and fisheries, related to offshore renewable energy sites. In many regions, these issues have been examined within the context of comprehensive marine spatial planning. Marine spatial planning provides an understanding of the extent to which certain activities take place in an area identified for offshore renewable energy development and provides a baseline assessment of critical ecological and cultural sites.

Sociological surveys of coastal residents, ocean users and other stakeholders have been widely used to assess perceived and experienced impacts from offshore renewable energy facilities. Survey results from two operational offshore wind projects in Denmark, Hons Rev and Nysted, indicate a generally positive attitude among coastal residents (Ladenburg et al, 2006). Relative open access to the projects for marine resource extraction could be a reason for high levels of public approval of the projects. Also, the visual impact of the installations may not have affected those people who were surveyed, since wind farms have caused a loss of amenity in other areas (see below). Both the projects provide access to sailing and fishing within their waters. The Nysted offshore wind project provides access for fishing with net and line, Horns Rev allows only line fishing, and bottom-trawling fishing is prohibited in both projects. Fishing can be further restricted as setting of lobster traps may be limited near cables and turbines. Wave, tidal power, and ocean current energy sources have not yet been commercially deployed at a large enough scale to enable an assessment of potential socio-economic impacts.

The effect of impaired visual amenity from ORE deployment can affect property prices, result in loss of recreational value, and reduce demand for tourism in coastal areas. It can also affect historic and culturally significant resources. These impacts are expected to be more prominent for an offshore wind project than for a wave, tidal, or ocean current installation, as the latter will be underwater and of smaller scale, for similar capacity. Research in the United Kingdom, England and Wales, which have extensive offshore wind capacity, concludes that offshore wind projects have a measureable impact on property prices. The impact is more pronounced in areas which are closest to the wind projects. On the other hand, a small increase in housing value is also seen in areas where wind projects are not visible, indicating a potential economic benefit to landowners near non-visible wind project operations due to an increased rental rate (Gibbons, 2014). This latest assessment is consistent with earlier published studies, which strongly suggest that, given a choice, consumers prefer offshore wind projects sited away from the coast and, in some cases, completely out of sight (Ladenburg and Lutzeyer, 2012).

Utility-scale offshore renewable energy projects can use significant ocean space and impose restrictions for navigational purposes. A large project, if placed along an existing navigational route, can increase the distance that ships and boats would be required to travel. The extent of transit through offshore renewable energy projects depends on safety issues and ease of access. In Denmark, transit through offshore wind energy projects is possible via certain routes; in Germany, navigation is allowed as close as 500 meters (Albrecht et al., 2013). The International Association of Marine Aids to Navigation and Lighthouse Authorities has promulgated recommendations on how to mark different types of offshore renewable energy installations so that they are conspicuous under different meteorological conditions. This, along with proper charting of installations and associated cables, can limit navigational risks (Detweiler, 2011).

Planning, construction, and maintenance of offshore renewable energy operations have the potential to create direct and indirect employment in various sectors including manufacturing, construction, operation, and maintenance. In 2013, offshore wind represented 3.6 per cent of the United Kingdom's electricity supply, contributed close to 1 billion United Kingdom pounds to the economy and supported 20,000 jobs, including 5,000 direct jobs (Offshore Renewable Energy Catapult, 2014). As the industry continues to grow, it has the potential to add thousands of new jobs, not just in the United Kingdom, but around Europe and other parts of the world that form a critical link to the supply chain. In Europe, offshore wind energy and ocean energy create 7-9 job-years/MW[4] during construction and installation. In addition, offshore wind projects can generate up to 11 job-years/MW in manufacturing, and 0.2 jobs/MW for operation and maintenance during the operational years of a project. These figures are comparable to those for conventional sources like coal, although offshore wind and other marine renewable sources have no job-creation potential related to fuel extraction, processing, and transportation for the life of a project (Energy [r]evolution, 2012).

Above and beyond the employment generation factor, offshore renewable energy also offers other intrinsic economic and electrical system integration benefits. For instance, many offshore renewable energy projects are sited, or proposed, close to densely populated coastal areas. Proximity to major electrical load centres can significantly reduce the cost of transmission and offset transmission congestion. Moreover, ocean renewable sources, particularly offshore wind power, offers the additional value proposition of load coincidence in many regions (Bailey and Wilson, 2014).

5. Offshore Renewable Energy Assessment Capacity Gaps

A capacity gap is a lack of information that, if available, would or could identify whether environmental effects [of a project] will have substantial negative impacts (McMurray, 2012). In many regions, sufficient knowledge exists in the near-shore and offshore waters to provide an initial baseline assessment, although it is often insufficient to provide a site-specific impact assessment. Significant capacity gaps exit in assessing environmental, social, and economic impacts from deploying devices in the marine environment. Most forms of ocean renewable energies have still not reached commercial scale, although some are at a high Technological Readiness Level (TRL).

[4] Job-years per MW denote the total amount of labour needed to manufacture equipment or construct a power plant that will deliver a peak output of one megawatt of power (The Energy Policy Institute, 2013).

Certain marine environments and species present additional challenges in addressing capacity gaps. For instance, it is technically difficult to obtain information on benthic biota, as compared to species in the pelagic zone. Due to the lack of high-quality benthic information, resource managers and developers are often required to conduct time-consuming and resource-extensive surveys before siting decisions can be finalized. In the pelagic zone, marine migratory species pose additional challenges for site characterization. Further site-specific research is required to understand migratory species such as whales to ensure that project siting has minimal impact on migratory routes or traditional foraging grounds. Similarly, impacts on avian species in the offshore environment, particularly migratory bird species and bats, have not been fully understood and require further research and assessment.

In the absence of operational utility-scale projects, it is often difficult to determine the socioeconomic impacts of an emerging renewable energy technology. One way to address such capacity gaps is to make long-term monitoring an integral part of the construction and operation phase, though if long-term monitoring regimes are too costly developers may be dissuaded from pursuing commercial projects. Studies and surveys assessing impacts before and during the operation of a project can provide valuable information on impacts, and can suggest substantive mitigation measures to address those impacts.

The knowledge and capacity gaps should be addressed within a comprehensive framework that considers all ecological resources and human uses in an area. This framework, also referred to as marine spatial planning, provides a process for analysing and allocating spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process (UNESCO, 2014). States are increasingly using marine spatial planning as the tool for identifying and siting offshore renewable energy projects. More importantly, the collaborative processes at the heart of marine spatial planning foster relationships and linkages among ocean uses, stakeholders and resources managers to enhance the quality of scientific information and traditional knowledge available. This collaboration and information exchange can lead to better-informed siting decisions and can minimize social and environmental impacts.

6. Conclusion

Offshore renewable energy is an immense resource awaiting efficient usage. Technological progress to harness the resource is steadily increasing around the world. When fully developed and implemented, ocean renewable energy can enhance the diversity of low-carbon energy options and provide viable alternatives to fossil fuel sources. For developing countries and new growing economies, installing renewable energy systems represents a viable path towards a low-carbon future.

To achieve a commercial break-through such that ocean renewable energy becomes cost-competitive, many governments have funded Research and Development (R&D) projects and provided financial support for technological developments and demonstrations within this sector. Traditional commercial funding sources are often insufficient to achieve this goal in the long-term, so innovative strategies are required. In addition, higher education courses on ocean renewable energies must be promoted, and research to understand and mitigate potential environmental and socio-economic impacts of these new technologies must be conducted. Given its immense potential, offshore renewable energy is well positioned to be part of a carbon-constrained energy future.

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