frontiers | Frontiers in Marine Science

TYPE Review
PUBLISHED 31 October 2022
DOI 10.3389/fmars.2022.988513

OPEN ACCESS

EDITED BY
Juan Jose Munoz-Perez,
University of Cádiz, Spain

REVIEWED BY
Saptarshi Bhattacharya,
Pacific Northwest National Laboratory (DOE), United States
Jose Santos Lopez Gutierrez,
Polytechnic University of Madrid, Spain
Rebecca O'Neil,
Pacific Northwest National Laboratory (DOE), United States

*CORRESPONDENCE
Ping Hu
329981724@qq.com

SPECIALTY SECTION
This article was submitted to Marine Affairs and Policy, a section of the journal Frontiers in Marine Science

RECEIVED 07 July 2022
ACCEPTED 11 October 2022
PUBLISHED 31 October 2022

CITATION
Bhuiyan MA, Hu P, Khare V, Hamaguchi Y, Thakur BK and Rahman MK (2022) Economic feasibility of marine renewable energy: Review.
Front. Mar. Sci. 9:988513.
doi: 10.3389/fmars.2022.988513

Economic feasibility of marine renewable energy: Review

Miraj Ahmed Bhuiyan[1], Ping Hu[2]*, Vikas Khare[3], Yoshihiro Hamaguchi[4], Barun Kumar Thakur[5] and Muhammad Khalilur Rahman[6]

[1]School of Economics, Guangdong University of Finance and Economics, Guangzhou, China, [2]School of Economics, South China Business College of Guangdong University of Foreign Studies, Beijing International Aerotropolis Technology Research Institute Guangzhou Branch, Guangzhou, China, [3]School of Technology, Management and Engineering NMIMS, Indore, India, [4]Department of Management Information, Kyoto College of Economics, Kyoto, Japan, [5]Department of Economics, FLAME University, Pune, India, [6]Faculty of Entrepreneurship and Business, and Angkasa-Umk Research Academy, Universiti Malaysia Kelantan, Kota Bharu, Malaysia

This paper aims to comprehensively review the economic feasibility of Marine Renewable Energy. Five major continents are at different development stages of implementing MREs commercialization; Europe is in the most advanced, while Africa is at the initial stage. The Levelized Cost of Energy is usually used to make decisions and measure the plant's economic feasibility. Literature suggests that MRE technology is still costly, and many emerging countries are sensitive to the income and use of MRE. Among various types of MREs, wind energy is the most feasible for many countries. Offshore wave energy is still at the pre-commercialization stage for many developing countries. Tidal energy plants can be economically viable depending on a reduction in investment cost and high capacity factors. Most of the world's tidal flows have too low a speed to operate a turbine of commercial size for ocean thermal energy. In conclusion, the factors hindering MRE development are pointed out, and future challenges are discussed.

KEYWORDS

marine renewable energy, economic feasibility, review, renewable energy, economic impact

Introduction

Marine Renewable Energy (MRE) refers to a form of Renewable energy (RE) that is installed and operated at sea and requires connection to offshore grid and distribution systems. As renewable energy is comparatively environment friendly, more countries are using Renewable Energy (RE) sources as their energy source (Bhuiyan et al., 2022). But producing renewable electricity is still more expensive than coal, the same price as fossil methane, and cheaper than conventional oil. The dramatic fall in RE's cost and price promotes the alternative use of fossil fuels by RE in electricity generation (Kåberger, 2018). In early 2000, conventional renewable energy technologies had the potential to cut both generation costs and carbon emissions (Sims et al., 2003). The development of alternative energy sources has seen increased interest in recent years due to the rising costs of fossil fuels and worries about the environmental effects of greenhouse gas emissions (Abolhosseini et al., 2014). This phenomenon of low-cost RE electricity is replacing other sectors. Even though introducing RE sources does not hinder economic growth for developing and developed nations (Bhuiyan et al., 2022), the nation's income and economic situation significantly impact renewable energy use in the long run (Salim and Rafiq, 2012). Emerging economies like China, Brazil, India, the Philippines, Turkey, and Indonesia are sensitive to the income and use of RE.

MRE technologies have a 7400 EJ/yr potential and much-surpassing present and future human energy demands (Ellabban et al., 2014). It is necessary to examine and differentiate between the theoretical resource, the technological resource, and the practical energy potential for MREs (Board et al., 2013). Theoretically, most maritime countries are physically feasible for MRE. By 2050, Ocean System Energy (OES) estimates that 337 GW of MRE will be available worldwide. But where MRE is still relatively new, project predictions and estimates (including planning, installation, maintenance, and repair) are confined to the laboratory size rather than actual commercial-scale MRE deployment (OES, 2022). Feed-in-Tariff (FiT) is considered a motivational factor for developing REs on both the large and small scale (Sovacool, 2009; Mabee et al., 2012). However, in an interesting study in Malaysia, it shows that MRE requires a higher implementation cost (€0.06–0.60/kWh depending on the type of MRE technology) compared to FiT rates of solar photovoltaic (ranging from €0.20 to 0.28/kWh) (Lim et al., 2015). Even in locations where MRE technologies are more established, such as the EU and the UK, the accuracy of capital and operational cost estimates remains a concern. This is because MRE is made up of a variety of technologies, the majority of which are still in the development stage (OES, 2018). In this paper, assessment parameters of marine energy systems have been characterized into five categories: Economic Analysis, Socio-Economic Analysis, recent trends in MRE, Types of MRE, and studies on countries or region-based studies (Figure 1).

The energy industry relies on economic models to estimate and evaluate various RE technologies' energy costs to make investment decisions. The comparison between various costs (capital cost, operating & maintaining cost, fuel cost) and the useable forecasting year between MREs and other REs should be measured. In addition to utility-scale electricity and complex engineering technologies, financial challenges, and economic feasibilities, other countries' MRE experiences should be studied to choose an alternative energy supply form. The Levelized Cost of Energy (LCOE) is commonly used to make decisions (Hemer et al., 2017). In this paper, LCOE comparisons among various MREs are presented. LCOE is related to the use of the reliability analysis of marine energy technology, and reliability directly or indirectly affects the cost of the marine energy system. The loss of load probability of the marine energy system is based on the peak hour load or the number of consumers who take the supply from the marine power plant, and this factor is related to the overall system's financial analysis. Let and are the supply and load demand of the marine energy system and (directly or indirectly related to the economic factors) denotes the reliability index of the marine energy system. The reliability index is given by

$$\mathbf{R_t{=}P_r(S_t \geq L_t)} \tag{1}$$

$$\mathbf{R_t{=}1{-}(Loss\ of\ Load\ \ Pr\,obability\ of\ Marine\ Energy\ Sysyem)} \tag{2}$$

Equation (2), in the other form, can be written with respect to economic analysis and can be presented in the extended form as:

$$\mathbf{R_t = \frac{1}{\sum_{i=1}^{n} T_i} \sum_{i=1}^{n} P_r(S_t \geq L_t) T_i,} \tag{3}$$

In equation (3), the operation period of the marine energy system T is distributed into 'n' intermissions, and each intermission has a duration of T_i and the prerequisite energy demand is presented as L_t. Ocean power plants' loss of load probability shows the length of time on which ocean energy generating capacity is inadequate. For the ocean energy system, the residual energy production capability is denoted as G_i , the fraction of time is presented as t_i . In that case, energy demand exceeds G_i can be resolute from the load curve L. Therefore, the loss of load probability is given by

$$\mathbf{LOLP{=}\sum_{i} P[G{=}G_i]\ P\ [L{>}G_I]{=}\sum_{i} \frac{p_i t_i}{100'}} \tag{4}$$

In equation (4), p_i is the probability related to the number of failed generating units of the marine power plant at the time t_i. The electrical utility calculates reliability indexes annually in every marine power plant. The following reliability index directly or indirectly affects the decision-making criteria of the tidal power plant. The Expected Frequency of Load Curtailment (Fault/Year) of the marine power plant is represented by

$$\mathbf{EFLC{=}\sum_{k=1}^{m} \gamma_k} \tag{5}$$

Equation (5) is helpful to the decision-making process through the reliability index directly or indirectly. Therefore, the Expected Duration of Load Curtailment (Hours/Year) and the Expected Energy Not Supplied (kWh/Year) of the marine power plant are given in equation(6) and equation (7) as

$$\mathbf{EDLC{=}\sum_{k=1}^{m} \gamma_k t_k} \tag{6}$$

$$\mathbf{EENS{=}L.(EDLC)} \tag{7}$$

In equation (6) and equation (7),γ_k nd $t_k$are the load curtailed at a considered load, and k and L are the item's failure rate and failure duration, respectively. However, the

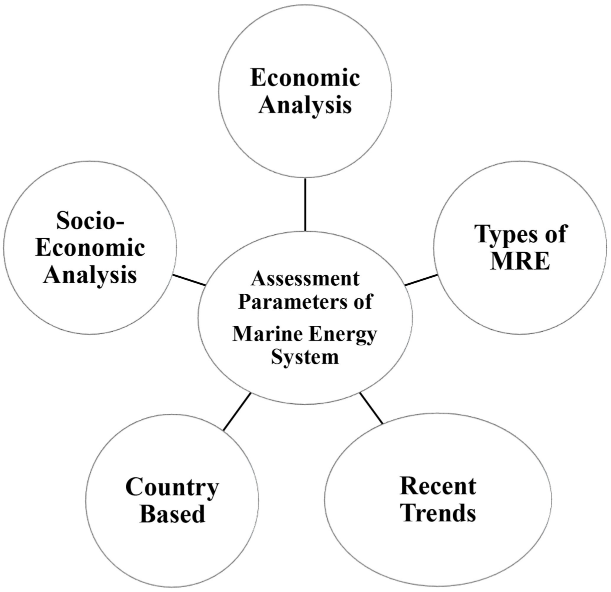

FIGURE 1
Assessment Parameters of Marine Energy System.

interest rate, energy prices, and annual energy production are the factors that have the biggest impacts on the project's financial success (Segura et al., 2018).

Recently, MRE technologies have been getting much intention from the government (Hou et al., 2019). and academia. Some researchers conducted for specific MRE plants, locations, or countries. Vega (2002) tested the cost-effectiveness of Ocean Thermal Energy Conversion (OTEC) but didn't consider other MRE types. Manasseh et al. (2017b) showed the integration of MREs with the needs of coastal societies. In that article, they analyzed the potential benefits of combining MRE technology with infrastructure demands for coastal protection and other local conditions. Allan et al. (2008) examined and projected the economic and environmental impact of MREs only for Scotland. Quirapas and Taeihagh (2021) assessed opportunities, risks, and socio-economic benefits in Southeast Asia regarding ocean renewable energy development. Dalton et al. (2015) assessed Economic and socio-economic methods for ocean renewable energy from Public and private perspectives. Jenniches (2018) collected a literature review assessing the regional economic impacts of a few RE sources. Bricker et al. (2017) tested the Economic feasibility of tidal stream and wave power in post-Fukushima Japan. Rodrigues et al. (2021) conducted a cost-benefit analysis of tidal energy for Ria, Formosa, Portugal. However, no such research article/review collection was published in a peer-reviewed journal concerning the economic feasibility of MRE technologies worldwide or in a particular region. Astariz and Iglesias (2015) collected another review on the economies of wave energy.

Following the introduction, the paper is presented in six sections. The second section describes the various economic and socio-economic benefits of MREs. The third section comprises different forms/types (wind, tidal, wave, and ocean currents) of MRE's economic feasibility studies. The next sections present country-wise MREs' economic feasibility studies. We have selected countries from Asia- Pacific (China, Japan, Thailand, India, Pakistan, Australia), Europe (U.K., Scotland, Ireland, Germany, Portugal, Denmark), North America (USA), Middle East (Turkey, Iran), and Africa (Nigeria). Section five illustrates the advancement in the literature on recent trends in MREs. The paper concludes with some suggestions, environmental aspects of MREs, and the future scope of the study.

Economic & socio-economic benefits of MREs

MREs can have direct and indirect economic benefits. MRE initiatives that use correct community-driven methodologies might improve rural communities' livelihoods by delivering the electricity needed to meet their socio-economic demands (Quirapas and Taeihagh, 2021). Developing the MRE sector also has socio-economic implications regarding job creation, inter-industry learning, economic resilience, and investment (Quirapas and Taeihagh, 2021). The study reveals that the marine and coastal leisure and recreation industries, which were previously assumed to have a little economic impact, are now the second-largest sector in the UK maritime economy and account for the most significant number of jobs (Stebbings et al., 2020). The MREs environment can also add value to economic and cultural resources, contributing to sustainable economic development for larger coastal areas and small islands (UN, 2010). MRE investments can give social and economic advantages and help coastal and port infrastructure, energy diversification, and resilience (LiVecchi et al., 2019). Given the promotion of domestic solid inter-industry links, MRE establishment can have significant and favorable benefits on GDP and the environment over the lifespan of the projects (Allan et al., 2008). MRE industry deployment may attract investments and collaborative initiatives that will help to develop regional skills, technical experience, and MRE knowledge. Multi-stakeholder investment initiatives (e.g., test-beddings and demonstration sites) are a good example (Choo, 2017).

In addition to the economic and other related benefits and alternatives of other RE sources, MREs can help to achieve various sustainable development goals (SDGs) (UN, 2010), especially SDGs 7, 13, and 14: "access to affordable and clean energy, combatting climate change and its impact and sustainable use of oceans, seas, and marine resource" (UN, 2015). MRE training and development programs "tailored" to rural areas might include not just the technical parts of ORE (Ocean Renewable Energy) but also innovative business models for generating additional revenue from the energy system (Quirapas and Taeihagh, 2021).

There are possibilities that marine energy might make a substantially larger contribution to energy generation in the medium to long term. Thus, countries like the UK are particularly interested in marine energy and can play a leadership role in the industry on a global scale (Jeffrey et al., 2013). Even though the current size and structure are unknown, the marine economy contributes almost double the previously estimated amount to the UK economy (Stebbings et al., 2020). MRE can also be used for purposes other than power. One of the most pressing challenges, particularly in off-grid rural islands, is the lack of portable drinking water. The MRE system may be customized to create a multi-output system, such as a wave-driven desalination system, that uses ORE resources to generate drinking water (W20 project, 2022), (WEC device using PTO system) (Nolan and Ringwood, 2006) and energy at the same time. Current research and development focus on systems combining ORE, power, and portable water production (Ferreira and Estefen, 2011; Leijon and Boström, 2018). Small islands and isolated places are typically not linked to the national grid and rely only on diesel generators for power. Consumers will be prepared to pay the price as long as ocean energy can fulfill the islands' energy demands (Quirapas and Srikanth, 2017). Quirapas and Srikanth (2017) mentioned that participants at an MRE workshop in Singapore believed that "adoption of such new technologies is simpler if ocean energy can supply alternate sources of electricity, supplement existing forms of subsistence, and might be a viable sector for job generation for island inhabitants."

MRE development, on the other hand, could have negative social and economic consequences if it is not carefully and sensitively sited and implemented, including conflicts with existing marine uses (such as local fishing and recreation), visual obstruction, and economic effects if the local supply chain is not engaged and leveraged (Bonar et al., 2015). Major ecological concerns include modifications to wave climates, flow patterns, and marine habitats with increasing underwater noise and collision risk (Bonar et al., 2015; Copping et al., 2020). There is evidence that Low-cost offshore wind farms, forms of MRE, might increase both energy security and GDP but would have a negative impact on seafood production and export sector, fishing productivity & processing, aquaculture sectors etc. (Qu et al., 2021). In addition, where subsidy is needed for high-cost farms, it would have a negative impact on GDP (Qu et al., 2021).

Types of MREs

Waves, tidal range, tidal currents, ocean currents, ocean thermal energy conversion, and salinity gradients are six primary sources of renewable marine (ocean) energy (Harper et al., 2016), each having different origins and needing different conversion technologies (Ellabban et al., 2014). Except for tidal barrages, all ocean energy technologies are at the conceptual stage of development or are in the pre-commercial prototype and demonstration stage (Ellabban et al., 2014). In this section, we have demonstrated the economic feasibility of various types of MREs. We have also included the combined (hybrid) energy system.

Wind energy

On-shore and offshore are two different forms of wind energy. Like any other source of energy generation, Offshore wind energy (OWE) has both positive and dire consequences (Snyder and Kaiser, 2009). Wind energy generated 1% of the world's power generation for the first time in 2007 (Breeze, 2008), mostly from on-shore firms (Esteban et al., 2011). One reason could be that offshore wind energy is more expensive to plan, design, build, operate, and maintain (O&M) than on-shore wind energy. The offshore environment is far more unpredictable and complex than the on-shore one, making it both more expensive and riskier. Personnel going to and from offshore turbines increases equipment and equipment expenses and insurance costs due to greater dangers in the offshore environment (Ladenburg and Dubgaard, 2007; Snyder and Kaiser, 2009). Offshore wind project capital costs are determined by marine vessel day rates, which are volatile, and offshore foundations require more steel for jackets and pilings than on-shore foundations (Snyder and Kaiser, 2009). Navrud (2004) suggested Substituting wind power by improving existing hydropower to assess the external cost of wind power development in Norway. Offshore wind energy is advantageous to other energy because its production/physical scales are larger offshore, and winds are theoretically more stable offshore, allowing much larger robust plants for the economy of scale.

Ranthodsang et al. (2020) evaluated the wind power potential and economic feasibility surrounding Phuket Island in Thailand. Their results reveal that offshore wind power plants with 3.3 MW wind turbine generators may produce over 13 GWh of energy each year Under the Very Small Power Producer (VSPP) scenario for 10 MW wind power plants with the lowest LCOE of 0.188 USD/kWh and FiT between 0.314 to 0.688 USD/kWh. The region between 45 and 56 degrees South has the maximum power density (3190 W/m2) and capacity factor (70 percent), as well as the lowest LCOE (72–100 USD $/MWh) in Chile (Mattar and Guzmán-Ibarra, 2017). Because of its wind power density (between 700 W/m^2 and 900 W/m^2), capacity factors between 40 and 60 percent, and LCOE between 100 and 114 USD$/MWh, the area between 30 and 32°S was assessed to be an ideal place for developing an offshore wind project in the country (Mattar and Guzmán-Ibarra, 2017). Another study results revealed that the Persian Gulf may generate over 2980 GWh per year, but farms cannot compete with global electricity production rates at a 15% interest rate; however, by lowering the interest rate to 5%, the southern, southwestern, and a portion of the northern shoreline can generate offshore wind electricity (Amirinia et al., 2017). Maandal et al. (2021) assessed the techno-economic condition of the Philippines. They have found a 25.0372 km^2 offshore region, and the LCOE is between USD 157.66/MWh and USD 154.1/MWh in the Philippines. The break-even energy price for an offshore wind farm ranges from PHP 8.028/kWh to PHP 8.306/kWh for the country.

Alvarez-Farizo and Hanley (2002) looked in a study at the environmental costs of wind energy development in a significant natural heritage region in Spain and suggested that willingness to the environmental cost is 21-38 Euros per family per year. Ladenburg and Dubgaard (2007) calculated citizens' willingness to pay for relocating turbines further from the coast of Denmark. They discovered that, compared to an 8 km baseline, respondents were ready to spend 46, 96, and 122 Euros per year per home to shift a hypothetical wind farm to 12, 18, or 50 kilometers from the shore. Ek (2002) discovered that Swedish homeowners are happy to pay 29 Euros per year for wind turbines located offshore and 12 Euros per year for those located in the lowlands rather than the highlands. In a comparable survey done on Cape Cod, Haughton et al. (2003) discovered that 22% of respondents were prepared to pay an average of $286 for windmills not to be erected, whereas 9% were willing to pay an average of $112 for windmills to be built. Per individual, the average net willingness to pay was $75. These findings imply that the public perceives offshore wind turbines as a visual blight before they are installed. Mentis et al. (2016) believe that wind-generated electricity is cost completive in India, but to estimate the potential penetration of wind power into the country's energy system, a comprehensive calculation of the quantity of wind energy that might be technically and economically captured is required. Even the cost of permitting & engineering processes, more advanced technology, and the roughness of the sea surface make offshore wind energy more expensive (Esteban et al., 2011). Jang et al. (2022) conducted a Techno-economic analysis and the Monte Carlo method on hydrogen production by offshore wind power. Their analysis shows that distributed cases are competitive compared to centralized and on-shore production cases. However, it stays economically viable throughout the asset's life cycle (Kulkarni and Edwards, 2022). A similar life cycle assessment was done by Wang H. et al. (2022) recently. They have analyzed a wind firm's economic and environmental feasibility in china. Their findings demonstrate that the hydrogen production system's ideal power is higher when economic and environmental benefits are considered (19.8 MW) than when only economic benefits are taken into account (17.5 MW). Offshore wind MREs are still not economically feasible for a short time and still require technical development, government financial support, and more FiTs (Kougias et al., 2019). However, the cost of offshore wind will decrease 21–46% by 2030 in china (Wang Y. et al., 2022). Advanced R&D in hydrodynamics, engineering, and operation would make it feasible in the coming years (Kougias et al., 2019).

Tidal energy

Compared to other types of MREs, the tides may be predicted using extremely precise astronomical calculations. Tidal generation is nearly flawlessly predictable, making it a viable alternative to wind power (Denny, 2009). While gravity is the weakest of the natural forces, the tides set massive volumes of water in motion, albeit at uneconomically slow speeds in most parts of the world (Manasseh et al., 2017b). However, in a few places worldwide, water flow speeds caused by tides may be pretty high. Thus, site selection is an important parameter for tidal energy to get maximum utility. When tidal flow rates are high, a standard FT can be used (Lago et al., 2010), but tidal flow velocities are too low in most places worldwide to spin a turbine with a decent economic efficiency (Manasseh et al., 2017b). Due to ice interaction issues and uncertainties, Lewis et al. (2021) presumed that tidal energy production beyond 25 km is not economically possible due to challenges with connecting to shore. Among 426 potential tidal energy sites have been identified in China, with 242 of them suitable for tidal energy dams with installed capacities ranging from 200 to 1000 kW in 2011 (Shi and Guo, 2012). But many tidal energy plants are not economically feasible in Europe (Magagna and Uihlein, 2015) and China (Shi and Guo, 2012). In the case of Ria, Formosa, and Portugal, Rodrigues found that under the current benefit, the project is not economically feasible (Rodrigues et al., 2021). Denny (2009) calculated the break-even capital cost for tidal power generation on a real electricity system back in 2009. He found that to produce a net profit for his case study, capital expenses for tidal production would have to be less than €510,000 per MW installed, which is now an unreasonably low capital cost. Thus, he concluded that tidal production is not now a viable choice for the example system (Denny, 2009).

There is a significant difference between tidal barrage and flow-based resources. A tidal barrage is a useful structure to capture the energy from moving water due to tidal forces. Since it captures energy from moving water, it is also known as a flow-based resource. However, tidal energy plants can be economically feasible depending on a reduction in investment cost, increased capacity factors (Rodrigues et al., 2021), government tax privileges, or annual discount rates. Segura et al. (2019) tested the Economic Feasibility of Automated Maneuvers on Tidal Energy Farms. They inferred that the proposed tidal energy project is technically viable based on their findings obtained using this technical indicator and considering the commercialization of the tidal energy project. Using real-time wave and tidal current data, Bricker et al. (2017) investigate the economic potential of this resource. The findings suggest that marine energy technology can provide consistent and predictable electricity to the energy-generating mix in several places around Japan. SeaGen and Verdant-type tidal turbines have been demonstrated to run significantly below the country's current energy price when installed in straits with substantial tidal flows near major population areas in western Japan (Bricker et al., 2017). Li et al. (2022) performed TRNSYS (Transient System) simulation to demonstrate a proposed community that comprises 8 high-rise residential buildings and 2 mid-rise office buildings with a 9.86 MW community peak power demand. With the current price settings, they have found that tidal stream energy generation is less profitable than offshore wind energy generation. However, studies suggested that plants/sites with a maximum flow speed greater than 2.5 m/s are economically feasible for tidal energy (Bryden and Macfarlane, 2000; Bryden and Couch, 2006; Batten et al., 2007; O Rourke et al., 2010).

Wave energy

To extract energy from ocean waves, wave energy converters (WEC) devices are used. Though it is not economically feasible in Europe (Segura et al., 2019), wave energy economic competitiveness will continue to rise as energy-gathering equipment technology advances, indicating that it has much potential for growth and use (Zhang et al., 2009; Pérez-Collazo et al., 2015). Wave energy can efficiently supply flexible and low-cost power assurances for offshore projects with significant power grid development requirements, such as marine farms, surveillance equipment, and drilling platforms (Chen et al., 2022). Although Wave energy is considered one of the most promising types of MREs, existing models for estimating the costs of a wave energy project are frequently oversimplified. The ensuing dispersion in economic estimates undermines potential investors' trust posing a barrier to wave energy development [23]. Leijon et al. (2003) think the degree of utilization, such as the ratio of annual produced energy in the installation to installed power, should be included because it has a major impact on the investment's present value. Like other MRE sources, economic viability, location selection (Iglesias et al., 2009; Muliawan et al., 2013), and various associated parameters are key factors for wave energy generation. The usage of the €/MWh measure for expressing O/M and operational expenditure (OPEX) for wave energy can be misinterpreted if not adequately described as location-specific (O'Connor et al., 2013).

A 75 MW wave energy plant was simulated on the west coast of Ireland and the north coast of Portugal. Their findings show that factors such as access and resultant availability substantially influence case study outcomes, lowering energy output and, correspondingly, financial returns (O'Connor et al., 2013). Thus, Feed-in tariffs will need to be adjusted to the region in question and the device's technological maturity level, with case study simulations showing that high FIT will be necessary to sustain early-stage WEC projects due to the influence of 'availability' on project profit returns. De Oliveira et al. (2021) tested the economic feasibility study of ocean wave electricity. Their findings reveal that a high-capacity factor impacts LCOE values most, putting ocean wave energy on the level of solar photovoltaic energy in Brazil. The study emphasizes the need to invest in ocean wave energy technology and development to realize bigger results, making this project production more feasible. In addition, with its limited variance in wave height (and thus restricted average wave height), wave power from the Baltic Sea indicates that smaller units have the highest economic potential (Leijon et al., 2003).

The Aquabuoy, Pelamis, WaveDragon, and Guarda-type Oscillating Water Column Wave Energy Converters (WEC) in northern Japan have comparable costs to current energy prices. Although Aquabuoy and Pelamis are no longer in operation, new generation wave energy converters are projected to produce electricity at even lower prices, enhancing the feasibility of growing wave power in northern Japan (Bricker et al., 2017). In addition, using a similar WEC, Castro-Santos et al. (2018) developed a method to test the economic feasibility (net present value, internal rate of return, Levelized energy cost) of floating offshore wave energy firms in Portugal. They have concluded that the best location for economic feasibility should consider the waves' significant height, the waves' period, the bathymetry, and the distance from farm to shore, farm to shipyard, and farm to port. Among the WECs, With 316.90 €/MWh, the Wave Dragon has the best LCOE, followed by Pelamis (735.94 €/MWh) and AquaBuOY (2967.85 €/MWh) (Castro-Santos et al., 2018).

Ocean thermal energy

Despite a theoretical worldwide capacity of up to 30 TW, the energy that can be deployed economically is uncertain for Ocean thermal energy conversion (OTEC) (Langer et al., 2021). Many large-scale ocean current systems exist globally, such as the cold currents located on the eastern edge of ocean basins, although they have slower flow rates than western boundary currents. The actual flow velocity is moderate, even in the western boundary currents. Most of the world's tidal flows have the same problem: the speeds are usually too low to operate a turbine of commercial size (Manasseh et al., 2017b). As ocean current energy power systems are mostly turbines in concept, Kinetic Turbines (KTs) must move to generate economically efficient power. The process requires high investment and efficient technology. KTs, most appropriate for the Agulhas Current, are proposed and trailed in Japan and Taiwan (Murali and Sundar, 2017).

Roberts investigated OTEC's engineering and economic potentiality. To assess the economic feasibility, the author developed a conventional LCOE model integrated with the thermal fluid system model of a 20 MW OTEC plant. His analysis suggests that OTEC is practical from an engineering viewpoint, but a 20 MW plant's economic viability would be confined to tiny or remote island populations (Upshaw, 2012). Due to OTEC's relatively high capital expenditures, small island developing states (SIDS) may need to integrate energy, food, and water production security to increase cost-effectiveness (Fujita et al., 2012). OTEC is a technology that is most cost-effective in large system sizes, and Langer et al. (2022) discovered that the adage "bigger is better" also holds true at the component level, supporting the above findings of Roberts (Upshaw, 2012). They demonstrated their model in operation for a 136 MWgross plant in Ende, Indonesia, with an LCOE of 15.12 US (2021)/kWh vs. a local electricity pricing of 15.77 US (2021)/kWh. They also suggested that large-scale OTEC may benefit at least eleven other countries economically.

Langer et al. (2022) evaluated 100 MWe OTEC on a provincial and national level in Indonesia. The national economic potential is 0–2 GWe with an LCOE as low as 15.6 US$ct.(2018)/kWh against a regionally variable electricity tariff of 6.67–18.14 US$ct.(2018)/kWh. They believe capital expenses, capital factors, and discount rates are the most sensitive variables of the LCOE. Oko and Obeneme (2018) conducted a thermo-economic analysis of Nigeria's ammonia closed-cycle OTEC 100 MW. Estimated 12 years break-even threshold, the plant's unit energy cost was determined to be 0.11US$/kWh, compared to 0.1US$/kWh for municipal energy supply. Only big organizations could invest in this project because of the high initial installation cost of 7954.37US$/kW and life cycle cost of 1.30bUS$ (Oko and Obeneme, 2018).

In contrast, Bernardoni et al. (2019) conducted a Techno-economic analysis of closed OTEC cycles for power generation. The obtained LCOE (269 €/MWhe) confirms how OTEC technology is not ready to compete in the energy market. Jung et al. (2016) also performed a 20-kW OTEC plant's thermo-economic analysis using the modified productive structure analysis method. The OTEC pilot plant's unit energy cost with a thermal efficiency of 0.66 percent is around $0.363/kWh. However, The OTEC system was shown to be economically viable in areas where warm sea water temperatures remain constant at 25°C or moderate (Langer et al., 2022) and power plant condenser effluent is available (Jung et al., 2016).

Combined (Hybrid) energy plants

Many renewable resources are discontinuous or fluctuating by nature, providing electricity irregularly and abruptly, whereas customers require power variably but predictably throughout the day. Thus, the concept of combining several ocean renewable resources in one offshore installation is gaining traction (Lund, 2006; Fusco et al., 2010; Stoutenburg and Jacobson, 2010; Muliawan et al., 2013; Caballero et al., 2013) as a method to make better use of the marine resource (Hoste et al., 2009; Taniguchi et al., 2013) and make this renewable a cost-competitive choice (Caraiman et al., 2011). As wave energy cost is still a bit higher, deploying WECs may diminish the overall project's economic value. On the other hand, Tidal stream energy generation is regarded as less economical than offshore wind energy generating at the present pricing levels (Li et al., 2022). Saheli et al. (2022) examine the feasibility of a hybrid wave-photovoltaic (PV) system using MATLAB/Simulink in the Caspian sea, Iran. Oscillating water column (OWC) converters are deployed to harvest the wave energy in the site. Their study suggests that the system is not economically viable in Iran. A hybrid notion incorporating a mix of Spar-type floating wind turbines (FWT)s and axis-symmetric two-body WECs is discussed by Muliawan et al. (2013). Compared to separate deployments of FWTs and WECs, this integrated approach would result in lower overall project capital expenditures since the number of power cables, mooring lines, and structural bulk of the WECs would be decreased (Muliawan et al., 2013). In addition, Blechinger et al. (2016) discovered that about 7.5 GW of solar and 14 GW of wind power hybrid systems could be constructed and managed cost-effectively on small islands (geographic information system-GIS based), resulting in a 50% reduction in GHG emissions and fuel usage. By preventing the combustion of 7.8 billion liters of diesel yearly, more than 20 million tons of GHG emissions might be avoided.

When these capacities are paired with 5.8 GWh of battery storage, cost reductions of roughly 9 USD ct/kWh are achieved on average (Blechinger et al., 2016).

Countries like Ireland have a significant and enviable wave resources and outstanding wind potential (Yue et al., 2020). Both resources can arise at various times, and combining them in a combination farm allows for more consistent, less unpredictable, and predictable electrical power generation (Fusco et al., 2010). In addition, the benefits of merging offshore wind and wave energy into a single farm include fewer hours of zero power generation and less inter-hour fluctuation. Stoutenburg et al. (2010) investigated the optimization of the transmission capacity for various wind and wave generation mixes. Their results show that the optimal transmission capacity for a 1000 MW combined farm is approximately 80 MW less than either a 100% wind or 100% wave energy farm.

Adaramola et al. (2012) investigated the technical and economic assessment of using hybrid energy (wind + solar) systems for electricity generation in rural communities in southwest Nigeria. The study revealed that a Wind-PV-Generator-Battery hybrid system is the best alternative for a stand-alone power-producing system in Ibadan. The LCOE for this hybrid energy system ranges between $0.437/kWh and $0.606/kWh, depending on the diesel price. These expenses are much lower than the price of running a diesel generator alone (without a battery), which ranges from $0.607 to $0.940 per kWh (Adaramola et al., 2012). Stoutenburg et al. (2010) investigated co-located WECs and Wind turbines along the California coast. Co-located offshore wind and wave energy farms provide less variable power production than a wind or wave farm operating alone. The minimal temporal connection of the resources decreases variability across all periods (Stoutenburg et al., 2010). Taniguchi et al. (2013) conducted a feasibility study on hybrid (wave and wind) energy around the Japanese coast. The authors used a correlation coefficient between wave and wind power to determine a suitable marine region. According to their assumptions, the Pacific Ocean side has a better chance of combining wave and wind energy (Taniguchi et al., 2013).

Previous research shows how the surplus output grows when the RES input for wind, photovoltaic, and wave electricity increases (Lund, 2006). Al Katsaprakakis et al. (2019) investigated perspectives of two wind/photovoltaic parks and pumped hydro storage in the Faroe Islands. Employing RES data and real demand, they have shown that RES annual penetration is higher than 90% can be approached with RES- storage power plants are absolutely feasible both technically and economically. Meanwhile, a combination of RES can help reduce surplus output growth. For example, an ideal combination of 20–40% photovoltaic and, as a result, 60–80% wind power has been determined to have less surplus output than either photovoltaic or wind power at 100%. Denault et al. (2009) findings show that any degree of wind up to 30% improves the production shortfall risk profile of an all-hydro system for all scenarios taken into account. In addition, Silva and Estanqueiro (2022) designed a utility-scale wind for the hybrid power plant. The obtained results unequivocally demonstrate the added value of hybrid power plants, as they promote: (i) a higher installed capacity and yearly capacity factor (up to 50%); (ii) increased efficiency of existing electric infrastructures; and (iii) a positive contribution to a sustainable energy system capable of generating economic value. The notion of a conversion system based on a real-time simulation of hybrid offshore wind and the tidal current system is discussed by Caraiman et al. (2011). They offered a simulation research apparatus comprising two real-time emulators to deliver dependable, environmentally friendly, and cost-effective electrical energy. However, among these are the usage of diesel group generators, typically viewed as cost-effective and reliable, but given their influence on the environment, there is a need to consider other resources at this time (Caraiman et al., 2011). In addition, Li et al. (2022) also realized coastal zero-energy communities through hybrid wind-tidal energy systems.

Country-based discussion

Five major continents are at different development stages of implementing MREs commercialization; Europe is in the most advanced, while Africa is at the initial stage. Developed economies like the UK, Germany, Portugal, and Ireland are in the most advanced stage in Europe, whereas the USA and Canada are also trying to commercialize the MRE technologies PoRtMaN (2010); Krohn (2013). In Asia, China, Korea, Japan, and Taiwan are among the top users of MREs (Lim et al., 2015). The previous research studies and statistics show that advanced economies are in the leading position in implementing and commercializing MRE technologies. Different country's Cost-effective analyses among various MRE types are demonstrated in Table 1 (ranking 1-4).

China

Marine renewable energy (tidal energy, marine current energy, wave energy, ocean thermal energy, and salinity gradient energy) is currently being researched but is rarely used for commercial power generation due to high costs, low efficiency, poor reliability, poor stability, and small scale in China (Zhang et al., 2009; Liu et al., 2011). The overall reserve of usable maritime energy resources in China is expected to be 1000 GW, with enormous potential for development (Wang et al., 2011). The northern South China Sea (NSCS) nearshore region sees much global commercial activity and is a hotspot for marine resource development and usage (Chen et al., 2022). The Bohai Sea, Yellow Sea, East China Sea, and the South China Sea coastal waters, as well as 426 prospective tidal energy dam sites

TABLE 1 Cost-effective analysis among various MRE types (ranking 1-4).

Country	Wind Energy	Tidal Energy	Wave Energy	OTEC	Combined
Australia	1	4	3	2	–
China	1	4	3	–	2
India	–	3	2	–	1
Germany					
U.K.	1	–	2	–	–
USA.	2	3	1	–	Wave+WInd
Japan	1	2	3	–	Solar+ Hydro
Scotland	1	–	2	–	–
Portugal	–	–	1 (wave dragon)	–	–
Ireland	1	2	Location-specific	–	Wind + wave
Denmark	–	–	1	2	Wind + wave
Thailand	1	2	–	–	3
Nigeria	1	10% Discount rate	3	Not feasible	2
Turkey	1	–	–	–	Solar+ Hydro
Pakistan	–	–	1	–	–
Iran	5% interest rate>	2	1	3	Wave+Wind

Source: authors elaboration based on previous literature

along China's coast with a total installed capacity of 21.8 GW and an annual energy production of 6.24 104 GWh (Shi and Guo, 2012). Many Tidal power plants are not economical for electricity generation (Zhang et al., 2014). However, Hou et al. (2019) conducted a PEST-SWOT analysis and found the maritime renewable energy power industry has a promising future against the backdrop of China's electricity market reform and modification to its energy structure.

Japan

In Japan, where resources are scarce, the country aims to reduce greenhouse gas emissions. There are growing expectations for renewable energy sources. This is because the Fukushima Daiichi nuclear power plant accident in 2011 created a need for alternative energy sources to replace nuclear power, which was responsible for 25% of Japan's electricity supply in 2010. Japan's increasing reliance on thermal power has a high potential for MRE from the perspective of energy efficiency and greenhouse gas reduction since Japan is surrounded by the sea and has territorial waters as large as its land area. According to Day et al. (2015), the government has initiated a technical demonstration study on offshore wind power generation has been initiated. For example, there is a spar-type offshore wind turbine (2.0 MW) in the Goto Islands of Nagasaki Prefecture and a vertical-axis FOWT as the SKWID hybrid wind-current device in Saga Prefecture. Waldman et al. (2017)[96]predict the effects of tidal energy extraction in the Goto Islands by using numerical modeling with tidal energy converters (TECs). The results reveal that, depending on the level of development, between 24 MW and 79 MW of electricity could be available from offshore power generation zones. This MRE will contribute to the establishment of a 100% renewable energy system in Japan. Esteban et al. (2018) perform a simulation analysis based on four GDP and electricity consumption scenarios and the feasibility of combining various renewable energy. It mentions that MRE plays a certain role there.

India

Between April 2015 and February 2021, India built 117.9 GW of electrical production capacity, comprising 53.4 GW of renewable energy and 64.5 GW of fossil fuels. Solar supplied 49,347 MW, wind contributed 40,083 MW, small hydro contributed 10,610 MW, and biomass contributed 4839 MW to India's total renewable power output of 104,879 MW in 2021 (Executive Summary on Power Sector (2022)). Wind energy is used not just as a great source of generating electricity but also to offer power at a lower cost for India (Singh et al., 2022). Mentis et al. (2016) estimated that certain states, such as Rajasthan, Andhra Pradesh, and Gujarat, have significant annual wind energy production, but Goa and other states have little or no wind power potential. Wind power is competitive in the Indian energy market since its Levelized cost ranges between 57 and 100 USD/MWh. But in India, including other types of MREs, Ocean Energy technologies are still expensive compared to biomass, solar and other sources (Dhingra et al., 2014). However, The National Institute of Ocean Technology (NIOT) has focused on wave energy and marine current hydrokinetic devices (Manasseh et al., 2017b).

Turkey

No offshore wind farm (OWF) in operation in Turkey till 2018, but It is demonstrated that the planned OWF projects are only economically viable if specific techno-economic prerequisites are met. The most cost-effective choice has been proven to be the radial electrical design. With an LCOE of $81.85–109.55 per MWh, the Bozcaada OWF looks to be the greatest investment choice, while the Bandirma OWF appears to be the least economically feasible, with an LCOE of $100.73–135.97 per MWh (Cali et al., 2018). But another study by Ünlü examined if profitable use of Turkey's offshore wind power potential is conceivable under present support systems and, if so, how much of it is. The results reveal that none of the wind classes can yield a positive net present value. A sensitivity analysis of capital costs reveals that wind class 7 (with a total capacity of 142.7 MW) may provide a positive net present value (NPV) even at the lowest level of 1.9 M USD (Ünlü, 2012). On the other side, even though wave energy is cheap and clean, environmentally friendly, and has great potential in Turkey, Nonetheless, there are no plans to use and/or invest in wave energy in Turkey until 2023 (Yeşilyurt et al., 2017). However, technically, the available resource is estimated at around 10 TWh/year between 4 and 17 kW/m wave power per year, economically 7.8% of the current Turkish hydroelectric energy potential. The western Black Sea region north of the Bosphorus and the areas between Marmaris and Finike on the southwestern shores of the Aegean Sea have been suggested as the best locations for harnessing wave energy (Sağlam et al., 2010).

USA

There is a difference between the theoretical resource and the practical energy potential for MREs in the USA. Other difficulties are related to marine energy's value streams not being clearly described and not being reflected by conventional energy comparison metrics like the Levelized cost of energy. High costs relative to wind and solar continue to be a major concern in the USA (Bhatnagar et al., 2021). Florida has a particularly attractive alternative because of the flow. Ocean current energy (49 TWh/yr) could provide clean reliable power to the Atlantic southeastern states in the USA (Kilcher et al., 2021). The theoretical resource wave energy is 898-1229 TWh/year, whereas the technical resource is 378–472 TWh/year in the US (Jacobson et al., 2011; Board et al., 2013). The technological resource with a power density of at least 8 kW/m is 899 TWh/yr, or 22.2 percent of US Annual Energy Production (AEP), but the highest practical resource is 522 TWh/yr, or 12.9 percent of US AEP (DOE, 2015). Extracting 5% of the resource might provide enough wave energy to power up to 6-8 million (5%-7%) US households (Board et al., 2013). However, after reviewing the proposals, New York Power Authority (NYPA) announced in 2011 that it was not economically feasible to move forward with the offshore wind on New York's portion of the Great Lakes. In addition, Yang et al. (2014) used simulation to assess the potential effects of tidal energy extraction on the marine ecology at Washington. An unstructured-grid coastal ocean model was used to simulate the tidal energy extracted by various turbine array configurations and the potential implications of the extraction at local and system-wide scales. According to model studies, it seems unlikely that hydrodynamic or water quality issues will be the limiting factor for the construction of large commercial-scale tidal farms. The Gulf of Mexico, on the other hand, appears to be in an advantageous position for companies considering deploying such multi-purpose hybrid (wind & wave) platforms (Weeks et al., 2020). Ocean waves are more predictable with higher density than solar and wind resources. An extensive review of ocean wave energy conversion technologies and the current state of these in the United States has been detailed (Lehmann et al., 2017). Bhattacharya et al. (2021) presented the applicability of the time value of MRE for potential grid applications in the PacWave site in Oregon. They noted that tidal, wave and ocean current resources are all more persistent when compared to wind and solar at hourly time scales.

Germany

Economic analysis of different operation scenarios indicates that the break-even threshold is determined by the market price and the yearly settling success of young mussels for offshore wind energy in Germany (Buck et al., 2008). Germany has set a goal of providing more than 80% of its electricity consumption from renewable energy sources by 2050. In particular, the country is pursuing a grand plan to supply 25 GW of electricity from MREs by 2030. Technological change to MRE is essential for this realization: between 1993 and 2013, offshore wind power in Germany developed through a dynamic interdependence of policy mix and technological innovation systems (Reichardt and Rogge, 2016). Reichardt et al. (2016) point out that the feed-in tariff level and the perceived consistency and credibility of the offshore wind policy mix in Germany further encourage this technological change. In Germany, according to Fornahl et al. (2012), offshore wind industry development is expected to provide new industrial development opportunities for the shipbuilding industry in northern Germany and create jobs through MRE. Ederer (2015), who performs a simulation analysis, finds that offshore wind power has lower price volatility in the spot market, even compared to on-shore wind power; appropriate incentives for technology development related to MRE and institutional design of electricity markets with lower price volatility will be key to Germany's energy sustainability.

UK

In the Liverpool City Region of the U. K., a socio-economic impact assessment for the Mersey Tidal Power project (which explored the feasibility of a tidal barrage, tidal fence, and tidal power gate devices) found that little is known about the tidal power supply chain (Howell and Drake, 2012). Voke et al. (2013) assessed the recreational value of the maritime environment near St. David's, Pembrokeshire, UK, where a tidal stream turbine demonstration project is ongoing, and a bigger array of developments, both wave and tidal, are planned in the coming years. Their findings demonstrated that visitors' disclosed average choice value of £148 per person assigned to the region was more significant than their stated preferred average valuation of £6.70 per person allocated to the area based on willingness to pay (Voke et al., 2013). Allan et al. (2008) used Scotland's regional computable general equilibrium (CGE) model. They showed that, given the encouragement of indigenous solid inter-industry linkages, the development of a marine energy sector could have substantial and beneficial impacts on GDP, employment, and the environment over the lifetime of the MRE devices. However, there has been discussion on Scotland's wave and tidal resources in the increasing control decision and accommodating those for commercial purposes (Johnson et al., 2012; Neill et al., 2017; Baston et al., 2017). Complementary resources to 23.4 GWe of wind power also included solar photovoltaics (10.1 GWe), tidal power (1.5 GWe), and wave power (0.3 GWe) would be possible and Complete defossilization of the Scottish energy system appears feasible by 2050 (Child et al., 2019).

Australia

The tropical northeast of Australia's seawater temperatures may allow for economically feasible OTCE technology (Manasseh et al., 2017a). Behrens et al. (2012) analyzed and forecasted the LCOE of wave energy and Tidal energy for Australia. He found that Wave energy is comparatively cheaper than Tidal energy in Australia. In addition, Vega (2002) calculated wave energy and tidal energy. He found that wave energy cost is a bit higher as he used different assumptions (Manasseh et al., 2017a). However, Behrens et al. (2012) estimated the cost of wind energy to be AUD 60–170 per MW/h, while a more recent estimate of AUD 80–90 per MW/h. by McConnell (AWEA, 1995). Even though many regions are still uninhabited, the finest locations are near the South-West Integrated System, off the coast of Western Australia (grid). Off the shores of New South Wales, Victoria, Queensland, and South Australia, various economically viable site regions exist for offshore wind energy (Messali and Diedorf, 2009). The political power of the coal & nuclear industries (Diedorf, 2006), Education and Awareness; Technology Development; Policy and Regulation; and Finance and Investment are the four main challenges for Australia in developing MRE technologies (Hemer et al., 2018).

Nigeria

Tidal power remains yet to be fully exploited in Nigeria. However, Amoo has assessed tidal stream energy production potential for the most suitable sites, Apapa Lagos (latitude 6° 27.0′N, longitude 3°23.0′E), Lagos Bar (latitude 6°24.0′N, longitude 3°23.9′E), and Bakana New Calabar River (latitude 4°44.0′N, longitude 6°58.0′E) of the country. The capital expenditure rate employed in this analysis is roughly equivalent to t = USD 5.6 m/MW, while operating and maintenance expenses are assumed to be t = USD $0.08 m/MW. The discount rate most commonly utilized in LCOE calculations is 10% for economically feasible sites (Amoo, 2018). Ahaotu et al. (2018) analyzed OTEC's economic feasibility in the Bonga offshore area. According to their study, the plant's installed capital, life cycle, and unit cost are around ₦152 billion, ₦171.95 billion, and ₦86.24/KWh, respectively. The break-even threshold was determined to be 7.854 years at this unit cost. The project's unit cost is significantly higher than Nigeria's average unit cost of power, which is at ₦32/KWh, rendering the planned facility uneconomical.

Recent trends in marine energy system

According to the above discussion, lots of work is all ready to be done in the field of marine energy systems. Now it is necessary to apply the recent technology to assess marine energy systems. In the present scenario, artificial intelligence, the internet of things, blockchain, cloud computing, and game theory are going forward and adopted by the different renewable energy power plants to enhance performance and create an efficient energy management system. These techniques work by integrating advanced information and communication systems that have transformed traditional systems into a smart working environment. Figure 2 shows recent technology in the field of marine energy systems.

There is growing literature on the usage of the internet of things in the marine energy system and marine environmental monitoring (Wang et al., 2014; Xu et al., 2019). An interesting review of IoT in marine environmental monitoring and its applications, along with common IOT-based system architects,

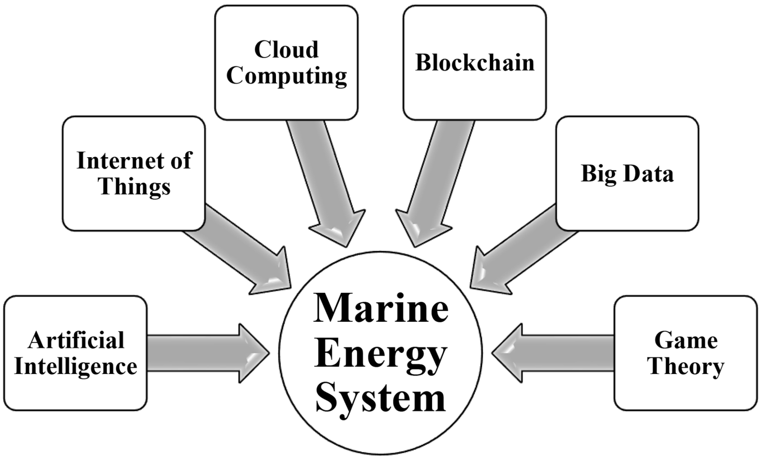

FIGURE 2
Recent technology in the field of Marine energy system.

suggested the growing usage of these two in the literature (Xu et al., 2019). Sreeni et al. (2017) analyzed machine erudition-based extreme point tracking of marine energy conversion systems. Sea temperature, tidal height, tidal range, and tidal turbine hub height are the input parameters in the machine learning test and training data set. It is found that machine learning-based hill climb search has considerably faster conjunction to the maximum power point than regular Hill Climb Search. Zhang et al. (2018) developed an artificial neural network-based real-time tidal prediction model. The final prediction result was obtained by merging the estimation outputs of the harmony analysis model and the Grey-GMDH model. The testing database is made up of measured tide-level data from the San Diego tidal station. According to simulation and experimental data, the suggested approach may accomplish real-time tidal level forecasts with high accuracy, excellent convergence, and stability. Janssen et al. (2015) analyzed potential sites for tidal energy systems through different decision support tools.

Local knowledge is combined with regional attributes in a value mapping tool. These value maps are being used to negotiate assistance to help stakeholders find suitable sites for tidal energy devices. Interactive value mapping was proven to help fill in data gaps and increase map trust. The negotiating tool-assisted parties in balancing the goals of numerous stakeholders. Figure 3 shows the Application of Recent Trends in the Tidal Energy System. Table 2 shows the different purposes of a tidal energy system with artificial intelligence.

In the recent trend of increasing societal development, there is a mismatch in the energy supply globally. Game theory has been used extensively in integrated energy systems to overcome the energy supply shortage. He et al. (2020) presented an extensive review of the usage of game theory and its application in integrative energy systems considering the demand and supply side of energy, distribution network, and planning and dispatching issues. Price elasticity for smart grids has been an important aspect of the literature. Wang et al. (2015) used a game theory-based energy management system to solve smart grids through price elasticity, where the models comprise game theory-based loss allocation reduction and load feedback control with the usage of price elasticity.

Artificial intelligence is the key technology to enhancing the performance of marine energy systems. Lots of work has already been done in the field of marine energy systems with the concept of artificial intelligence; further followings are some possibilities and future scope of this technology in the area of tidal energy systems.

- Develop a drone-based system for finding a suitable location where sufficient amounts of tidal current and tidal height exist for the marine power plant.
- Develop a robotic automation system for the maintenance of marine power plants.
- Develop a machine learning-based reliability measurement system for the marine energy system.
- Develop an artificial intelligence-based control mechanism for the marine energy system. The tide and wave height are the input parameters for supervised and unsupervised learning for artificial intelligence systems.

It's at the heart of a burgeoning ecosystem of big data technologies, largely used to support advanced analytics projects like predictive analytics, data mining, and machine learning. Following is the possibility through big data analysis in marine energy systems.

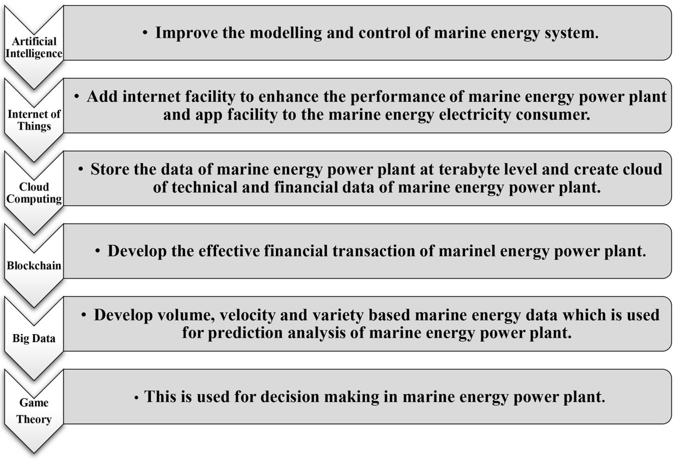

FIGURE 3
Application of Recent Trends in Marine Energy System.

- Create a Hadoop Distributed File System (HDFS) for marine energy power plant data, also used for predictive analysis of marine power plants.
- Create a basket model of reliability analysis of marine power plants.
- A blockchain is a decentralized public record of data collected *via* a network that sits on top of the internet. Blockchain's revolutionary potential is based on how this information is recorded. Several future scopes of blockchain are possible in marine energy systems.

TABLE 2 Objectives on tidal energy system with the application of artificial intelligence.

Bulk energy consumption control and management
Energy modeling of a Tidal Turbine
Estimation of Tidal Current
Estimation of Tidal Height
Forecasting and optimization of Marine model
Load frequency control
Marine energy system optimization
The marine farm decision system
Marine farm density forecasting model
Maximum power point tracking in tidal energy
Modeling of a Barrage system
Optimization for cleaner production of tidal energy
Prediction model of technical properties of tidal energy
Prediction of full-scale thrust for floating wind turbine
Short-term tides speed forecasting
Targeted energy storage solution
Thermodynamic analysis of Tidal Turbine
Tidal power forecast

- Create a financial system for the marine power plants through blockchain technology.
- Create a system in which the process of the electricity bill of the consumer is to be done through blockchain technology.

Conclusion

MRE suits effectively address energy security, socioeconomic development, energy access, climate change mitigation, and. Statistics show that in 2009, 1.4 billion people worldwide lacked access to electricity, with 85% of them residing in rural areas (International Energy Agency, 2009). However, as alternate energy sources emerge, RE may not completely displace fossil fuels. These alternate uses of RE should be categorized as "additions" instead of "transitions." MRE can be critical in changing the perception as energy addition to transition. MRE (Marine Energy) promises a new power source and inspiration for utilizing the "Blue Economy" despite confronting numerous obstacles (economic, financial, technical, and social). The offshore blue economy has the potential to produce 32 PWh/y according to cautious forecasts of global marine energy development. Despite the potential, only a small percentage of this capacity has been used; in 2016, the total amount of marine energy produced worldwide was only 536 MW. MRE construction can be expensive, harm wildlife, take up much space, and be challenging for shipping, yet it may be great for island nations, gathering energy that would not otherwise be captured.

Offshore wind technologies are not yet commercially viable, and wind MRE is still pricey. It is advised to invest more in R&D on offshore wind MREs and expand the market share in light of the higher wind resource quality in the sea, land scarcity, and larger accessible areas in the ocean. Offshore wind energy costs more since it requires more engineering and permissions, uses more advanced equipment, and has a rougher sea surface, yet it is still economically sustainable for the duration of the asset's life cycle. Offshore wind MREs still need more technological advancement, financial support from the government, and FiTs to become commercially feasible in the near future. Hydrodynamics, engineering, and operational R&D advancements would make it practical in the ensuing years.

Wave energy conversion (WEC) systems are currently in the pre-commercial stage in the majority of developing nations. Various experimental projects have shown the capability to convert wave energy into electrical energy but lack the operational records required to advance with commercialization. Pilot or pre-commercial operations of the proper magnitude must be conducted to collect this long-term operational data. To receive commercial clearance, certain WECs must also be evaluated for performance and durability in challenging maritime conditions.

Ocean thermal resources may theoretically provide the majority of the necessary energy. The requirement to find funding for a capital-intensive technology with no track record is a key hurdle for OTEC deployment. The next stage is to determine the costs and possible worldwide environmental effects of OTEC plants in a realistic manner, which can only be done by installing and monitoring operations with first-generation plants. The OTEC thermal resource is accessible throughout the 200-nautical-mile EEZ of 98 nations and territories. Additionally, there is a market for countries that can produce and supply the OTEC plant's machinery. Building each 100 MW plant will run about $750 million. As a result, the market value will be in the billions in a few decades. The economic evaluation of OTEC plants suggests that for industrialized countries, floating plants with a capacity of about 100 MW and smaller plants for tiny island developing states are their commercial futures.

The lack of precise statistics, statistical data, and knowledge of MRE's efficiency compared to energy from fossil fuels, among other things, is one of the biggest barriers to its development. Another challenge is the lack of qualified workers with specialized training in renewable energy. A qualified operator is required to make the best use of MRE technology, hardware, or machinery related to renewable energy, which is still a significant issue for developing nations. Social acceptance, the monopoly of an established business, powerful private investors, corruption and bureaucracy, institutional hurdles, policy and regulation, and other factors can all be barriers.

The MRE sector can benefit the local community's economy and socioeconomics both directly and indirectly. One major concern for MREs is cost savings, which can be achieved through effective energy storage, sector integration, and flexible generation from dispatchable renewable energy resources. However, it is advised to cut deployment, operation, and maintenance costs, invest in environmentally friendly technologies and develop supportive policies. In particular, enlisting the private sector, government financial aid, liberalized market regulations, and investment-friendly laws can help accelerate the development of renewable energy technology. The government must provide financial, political, legislative, technological, and environmental assistance to advance MRE technology. Governmental organizations are more likely than private businesses to support the development of MRE technology due to the low price of crude oil and fossil fuels in general. While these technologies are being developed, the ocean environment must be conserved since MREs have the potential to help reduce the threat of global climate change. Ocean-based renewable energy sources can be used without harming the marine ecology if projects are appropriately sited, scaled, and adhere to environmental standards.

We have not considered other types of REs for combined energy plants (such as solar + Wave/PV+ Wind). Yet some studies referred to combined energy plant types (MREs+ REs). Hybrid model plants of various REs (including MREs) should be studied to check the economic feasibility among different REs. As there is an economic and environmental concern for MREs, future studies should concern the common and systematic application of MREs in the circular economy. Additionally, due to the paucity of credible sources of datasets, most of the existing literature used traditional metrics and advancements that could be incorporated into future studies.

Author contributions

MAB- Draft; PH- Draft; VK- Draft; YM- Draft, Revise; BKT-Revise, MKR- Revise article and approved the submitted version.

Funding

This work was supported by the Japan Society for the Promotion of Science (JSPS KAKENHI Grant Number JP19K13706, JP22K13409).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

Publisher's note

References

Abolhosseini, S., Heshmati, A., and Altmann, J. (2014). *A Review of Renewable Energy Supply and Energy Efficiency Technologies, IZA Discussion Papers, No. 8145*, Bonn Institute for the Study of Labor (IZA). doi: 10.2139/ssrn.2432429

Adaramola, M., Oyewola, O., and Paul, S. (2012). Technical and economic assessment of hybrid energy systems in south-West Nigeria. *Energy Explor. Exploitation* 30, 533–551. doi: 10.1260/0144-5987.30.4.533

Ahaotu, J. O., Nkoi, B., and Lebele-Alawa, B. T. (2018). Thermodynamic design and economic analysis of ocean thermal energy conversion for coastal Nigeria. *Am. J. Eng. Res.* 7, 120–128.

Al Katsaprakakis, D., Thomsen, B., Dakanali, I., and Tzirakis, K. (2019). Faroe islands: towards 100% RES penetration. *Renewable Energy* 135, 473–484. doi: 10.1016/j.renene.2018.12.042

Allan, G. J., Bryden, I., McGregor, P. G., Stallard, T., Kim Swales, J., and Turner, K. (2008). Concurrent and legacy economic and environmental impacts from establishing a marine energy sector in Scotland. *Energy Policy* 36, 2734–2753. doi: 10.1016/j.enpol.2008.02.020

Alvarez-Farizo, B., and Hanley, N. (2002). Using conjoint analysis to quantify public preferences over the environmental impacts of wind farms. *example Spain. Energy Policy* 30, 107–116. doi: 10.1016/S0301-4215(01)00063-5

Amirinia, G., Mafi, S., and Mazaheri, S. (2017). Offshore wind resource assessment of Persian gulf using uncertainty analysis and GIS. *Renewable Energy* 113, 915–929. doi: 10.1016/j.renene.06.070

Amoo, L. (2018). Techno-economic assessment of energy production potential from tidal streams in Nigeria. *Int. J. Energy Environ. Eng.* 9, 81–98. doi: 10.1007/s40095-017-0256-2

Astariz, S., and Iglesias, G. (2015). The economics of wave energy: A review. *Renewable Sustain. Energy Rev.* 45, 397–408. doi: 10.1016/j.rser.2015.01.061

AWEA (1995). *American Wind energy association. how much does wind energy cost?* (AWEA).

Baston, S., Waldman, S., and Woolf, D. K. (2017). The wave and tidal resource of Scotland. *Renewable Energy* 114, 3–17. doi: 10.1016/j.renene.2017.03.027

Batten, W. M. J., Bahaj, A. S., Molland, A. F., and Chaplin, J. R. (2007). Experimentally validated numerical method for the hydrodynamic design of horizontal axis tidal turbines. *Ocean Eng.* 34, 1013–1020. doi: 10.1016/j.oceaneng.2006.04.008

Behrens, S., Griffin, D., Hayward, J., Hemer, M., Knight, C., and McGarry, S. (2012). Ocean renewable energy: 2015–2050. an analysis of ocean energy in Australia. *North Ryde CSIRO* 1–212. doi: 10.4225/08/584af1865b172

Bernardoni, C., Binotti, M., and Giostri, A. (2019). Techno-economic analysis of closed OTEC cycles for power generation. *Renewable Energy* 132, 1018–1033. doi: 10.1016/j.renene.2018.08.007

Bhatnagar, D., Bhattacharya, S., Preziuso, D. C., Hanif, S., O'Neil, R. S., Alam, M. J. E., et al. (2021). *Grid value proposition of marine energy (No. PNNL-31123)* (Richland, WA (United States: Pacific Northwest National Lab.(PNNL).

Bhattacharya, S., Pennock, S., Robertson, B., Hanif, S., Alam, M. J. E., Bhatnagar, D., et al. (2021). Timing value of marine renewable energy resources for potential grid applications. *Appl. Energy* 299, 117281. doi: 10.1016/j.apenergy.2021.117281

Bhuiyan, M. A., Zhang, Q., Khare, V., Mikhaylov, A., Pinter, G., and Huang, X. (2022). Renewable energy consumption and economic growth nexus–a systematic literature review. *Front. Environ. Sci.* 10. doi: 10.3389/fenvs.2022.878394

Blechinger, P., Cader, C., Bertheau, P., Huyskens, H., Seguin, R., and Breyer, C. (2016). Global analysis of the techno-economic potential of renewable energy hybrid systems on small islands. *Energy Policy* 98, 674–687. doi: 10.1016/j.enpol.2016.03.043

Board, O. S.National Research Council and Marine and Hydrokinetic Energy Technology Assessment Committee (2013). *An evaluation of the US department of energy's marine and hydrokinetic resource assessments* (Washington D.C.: National Academies Press).

Bonar, P. A., Bryden, I. G., and Borthwick, A. G. (2015). Social and ecological impacts of marine energy development. *Renewable Sustain. Energy Rev.* 47, 486–495. doi: 10.1016/j.rser.2015.03.068

Breeze, P. (2008). *The future of wind power: increasing economic competitiveness as the technology matures*. Business Insights Limited. pp. 20–38.

Bricker, J. D., Esteban, M., Takagi, H., and Roeber, V. (2017). Economic feasibility of tidal stream and wave power in post-fukushima Japan. *Renewable Energy* 114, 32–45. doi: 10.1016/j.renene.2016.06.049

Bryden, I. G., and Couch, S. J. (2006). ME1–marine energy extraction: tidal resource analysis. *Renew. Energy* 31, 133–139. doi: 10.1016/j.renene.2005.08.012

Bryden, I. G., and Macfarlane, D. M. (2000). The utilisation of short term energy storage with tidal current generation systems. *Energy* 25, 893–907. doi: 10.1016/S0360-5442(00)00020-7

Buck, B. H., Krause, G., Michler-Cieluch, T., Brenner, M., Buchholz, C., and Busch, J. (2008). Meeting the quest for spatial efficiency: progress and prospects of extensive aquaculture within offshore wind farms. *Helgoland Mar. Res.* 62, 269–281. doi: 10.1007/s10152-008-0115-x

Caballero, F., Sauma, E., and Yanine, F. (2013). Business optimal design of a grid-connected hybrid PV (photovoltaic)-wind energy system without energy storage for an Easter island's block. *Energy* 61, 248–261. doi: 10.1016/j.energy.2013.08.030

Cali, U., Erdogan, N., Kucuksari, S., and Argin, M. (2018). Techno-economic analysis of high potential offshore wind farm locations in Turkey. *Energy Strategy Rev.* 22, 325–336. doi: 10.1016/j.esr.2018.10.007

Caraiman, G., Nichita, C., Mînzu, V., Dakyio, B., and Jo, C. (2011). "Concept study of offshore wind and tidal hybrid conversion based on real time simulation". In: *International Conference on Renewable Energies and Power Quality (ICREPQ'11)* Las Palmas de Gran Canaria (Spain), 13th to 15th April. doi: 10.24084/repqj09.459

Castro-Santos, L., Silva, D., Bento, A. R., Salvação, N., and Guedes Soares, C. (2018). Economic feasibility of wave energy farms in Portugal. *Energies* 11, 3149. doi: 10.3390/en11113149

Chen, W., Liu, J., Li, J., Sun, L., Li, B., and Xing, H. (2022). Wave energy assessment for the nearshore region of the northern south China Sea based on *in situ* observations. *Energy Rep.* 8, 149–158. doi: 10.1016/j.egyr.2022.03.068

Child, M., Ilonen, R., Vavilov, M., Kolehmainen, M., and Breyer, C. (2019). Scenarios for sustainable energy in Scotland. *Wind Energy* 22 (5), 666–684. doi: 10.1002/we.2314

Choo, F. (2017). *Renewable energy integration demonstrator. technical report* (Singapore: Nanyang Technological University).

Copping, A. E., Hemery, L. G., Overhus, D. M., Garavelli, L., Freeman, M. C., and Whiting, J. M. (2020). Potential environmental effects of marine renewable energy development–the state of the science. *J. Mar. Sci. Eng.* 8, 879. doi: 10.3390/jmse8110879

Dalton, G., Allan, G., Beaumont, N., Georgakaki, A., Hacking, N., and Hooper, T. (2015). Economic and socio-economic assessment methods for ocean renewable energy: Public and private perspectives. *Renewable Sustain. Energy Rev.* 45, 850–878. doi: 10.1016/j.rser.2015.01.068

Day, A., Babarit, A., Fontaine, A., He, Y.-P., Kraskowski, M., and Murai, M. (2015). Hydrodynamic modelling of marine renewable energy devices: A state of the art review. *Ocean Eng.* 108, 46–69. doi: 10.1016/j.oceaneng.2015.05.036

Denault, M., Dupuis, D., and Couture-Cardinal, S. (2009). Complementarity of hydro and wind power: Improving the risk profile of energy inflows. *Energy Policy* 37 (12), 5376–5384. doi: 10.1016/j.enpol.2009.07.064

Denny, E. (2009). The economics of tidal energy. *Energy Policy* 37, 1914–1924. doi: 10.1016/j.enpol.2009.01.009

De Oliveira, L., dos Santos, I. F. S., Schmidt, N. L., Tiago Filho, G. L., Camacho, R. G. R., and Barros, R. M. (2021). Economic feasibility study of ocean wave electricity generation in Brazil. *Renewable Energy* 178, 1279–1290. doi: 10.1016/j.renene.2021.07.009

Dhingra, R., Jain, A., Pandey, A., and Mahajan, S. (2014). Assessment of renewable energy in India. *Int. J. Environ. Sci. Dev.* 5, 459–462. doi: 10.7763/IJESD.2014.V5.527

Diedorf, M. (2006). Wind power in Australia. *Int. J. Environ. Stud.* 63, 765–776. doi: 10.1080/00207230601047099

DOE (2015). *Quadrennial technology review 2015* (Washington, DC: US Department of Energy).

Ederer, N. (2015). The market value and impact of offshore wind on the electricity spot market: Evidence from Germany. *Appl. Energy* 154, 805–814. doi: 10.1016/j.apenergy.2015.05.033

Ek, K. (2002). *Valuing the environmental impacts of wind power: a choice experiment approach* (Sweden: Doctoral dissertation, Luleå tekniska universitet). Available at: http://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Altu%3Adiva-17107

Ellabban, O., Abu-Rub, H., and Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. *Renewable Sustain. Energy Rev.* 39, 748–764. doi: 10.1016/j.rser.2014.07.113

Esteban, M. D., Diez, J. J., López, J. S., and Negro, V. (2011). Why offshore wind energy? *Renewable Energy* 36, 444–450. doi: 10.1016/j.renene.2010.07.009

Esteban, M., Portugal-Pereira, J., Mclellan, B. C., Bricker, J., Farzaneh, H., Djalilova, N., et al. (2018). 100% renewable energy system in Japan: Smoothening and ancillary services. *Appl. Energy* 224, 698–707. doi: 10.1016/j.apenergy.2018.04.067

Executive Summary on Power Sector (2022). *Central electricity authority, ministry of power, government of India*. New Delhi, India.

Ferreira, R., and Estefen, S. (2011). *Ocean power conversion for electricity generation and desalinated water production* (Linköping, Sweden: Linköping University Electronic Press). 2198–2205.

Fornahl, D., Hassink, R., Klaerding, C., Mossig, I., and Schröder, H. (2012). From the old path of shipbuilding onto the new path of offshore wind energy? the case of northern Germany. *Eur. Plann. Stud.* 20, 835–855. doi: 10.1080/09654313.2012.667928

Fujita, R., Markham, A. C., Diaz Diaz, J. E., Rosa Martinez Garcia, J., Scarborough, C., and Greenfield, P. (2012). Revisiting ocean thermal energy conversion. *Mar. Policy* 36, 463–465. doi: 10.1016/j.marpol.2011.05.008

Fusco, F., Nolan, G., and Ringwood, J. V. (2010). Variability reduction through optimal combination of wind/wave resources–an Irish case study. *Energy* 35, 314–325. doi: 10.1016/j.energy.2009.09.023

Harper, P., Hallett, S., Fleming, A., and Dawson, M. (2016). Advanced fibre-reinforced composites for marine renewable energy devices. *Mar. Appl. Advanced Fibre-Reinforced Composites Elsevier* p, 217–232. doi: 10.1016/B978-1-78242-250-1.00009-0

Haughton, J. H., Giuffre, D., and Barrett, J. (2003). *Blowing in the wind: Offshore wind and the cape cod economy* (Boston MA: Beacon Hill Institute at Suffolk University).

He, J., Li, Y., Li, H., Tong, H., Yuan, Z., Yang, X., et al. (2020). Application of game theory in integrated energy system systems: a review. *IEEE Access* 8, 93380–93397. doi: 10.1109/ACCESS.2020.2994133

Hemer, M. A., Manasseh, R., McInnes, K. L., Penesis, I., and Pitman, T. (2018). Perspectives on a way forward for ocean renewable energy in Australia. *Renewable Energy* 127, 733–745. doi: 10.1016/j.renene.2018.05.036

Hemer, M. A., Zieger, S., Durrant, T., O'Grady, J., Hoeke, R. K., and McInnes, K. L. (2017). A revised assessment of australia's national wave energy resource. *Renewable Energy* 114, 85–107. doi: 10.1016/j.renene.2016.08.039

Hoste, G., Dvorak, M., and Jacobson, M. Z. (2009). *Matching hourly and peak demand by combining different renewable energy sources* (USA: Sanford University, Department of Civil and Environmental Engineering).

Hou, J., Zhu, X., and Liu, P. (2019). Current situation and future projection of marine renewable energy in China. *Int. J. Energy Res.* 43, 662–680. doi: 10.1002/er.4218

Howell, A., and Drake, C. (2012). *Scoping study on socio-economic impacts of tidal energy development in Nova Scotia: A research synthesis & priorities for future action* (Wolfville, Canada: Fundy Energy Research Network).

Iglesias, G., López, M., Carballo, R., Castro, A., Fraguela, J. A., and Frigaard, P. (2009). Wave energy potential in Galicia (NW Spain). *Renewable Energy* 34, 2323–2333. doi: 10.1016/j.renene.2009.03.030

International Energy Agency (2009). *World energy outlook* (France: OECD/IEA Paris).

Jacobson, P. T., Hagerman, G., and Scott, G. (2011). Mapping and assessment of the united states ocean wave energy resource. *Electric Power Res. Institute* 1–176. doi: 10.2172/1060943

Jang, D., Kim, K., Kim, K. H., and Kang, S. (2022). Techno-economic analysis and Monte Carlo simulation for green hydrogen production using offshore wind power plant. *Energy Conversion Manage.* 263, 115695. doi: 10.1016/j.enconman.2022.115695

Janssen, R., Arciniegas, G., and Alexander, K. A. (2015). Decision support tools for collaborative marine spatial planning: identifying potential sites for tidal energy devices around the mull of kintyre, Scotland. *J. Environ. Plann. Manage.* 58, 719–737. doi: 10.1080/09640568.2014.887561

Jeffrey, H., Jay, B., and Winskel, M. (2013). Accelerating the development of marine energy: Exploring the prospects, benefits and challenges. *Technological Forecasting Soc. Change* 80, 1306–1316. doi: 10.1016/j.techfore.2012.03.004

Jenniches, S. (2018). Assessing the regional economic impacts of renewable energy sources – a literature review. *Renewable Sustain. Energy Rev.* 93, 35–51. doi: 10.1016/j.rser.2018.05.008

Johnson, K., Kerr, S., and Side, J. (2012). Accommodating wave and tidal energy–control and decision in Scotland. *Ocean Coast. Manage.* 65, 26–33. doi: 10.1016/j.ocecoaman.2012.04.018

Jung, J.-Y., Lee, H. S., Kim, H.-J., Yoo, Y., Choi, W.-Y., and Kwak, H.-Y. (2016). Thermoeconomic analysis of an ocean thermal energy conversion plant. *Renewable Energy* 86, 1086–1094. doi: 10.1016/j.renene.2015.09.031

Kåberger, T. (2018). Progress of renewable electricity replacing fossil fuels. *Global Energy Interconnection.* 1, 48–52. doi: 10.14171/j.2096-5117.gei.2018.01.006

Kilcher, L., Fogarty, M., and Lawson, M. (2021). *Marine energy in the united states: An overview of opportunities*. (United States: Golden CO).

Kougias, I., Aggidis, G., Avellan, F., Deniz, S., Lundin, U., Moro, A., et al. (2019). Analysis of emerging technologies in the hydropower sector. *Renewable Sustain. Energy Rev.* 113, 109257. doi: 10.1016/j.rser.2019.109257

Krohn, D. (2013) *Wave and tidal energy in the UK: Conquering challenges, generating growth.* Available at: https://www.renewableuk.com/.

Kulkarni, S. S., and Edwards, D. J. (2022). A bibliometric review on the implications of renewable offshore marine energy development on marine species. *Aquaculture Fisheries* 7, 211–222. doi: 10.1016/j.aaf.2021.10.005

Ladenburg, J., and Dubgaard, A. (2007). Willingness to pay for reduced visual disamenities from offshore wind farms in Denmark. *Energy Policy* 35, 4059–4071. doi: 10.1016/j.enpol.2007.01.023

Lago, L. I., Ponta, F. L., and Chen, L. (2010). Advances and trends in hydrokinetic turbine systems. *Energy Sustain. Dev.* 14, 287–296. doi: 10.1016/j.esd.2010.09.004

Langer, J., Cahyaningwidi, A. A., Chalkiadakis, C., Quist, J., Hoes, O., and Blok, K. (2021). Plant siting and economic potential of ocean thermal energy conversion in Indonesia a novel GIS-based methodology. *Energy* 224, 120121. doi: 10.1016/j.energy.2021.120121

Langer, J., Infante Ferreira, C., and Quist, J. (2022). Is bigger always better? designing economically feasible ocean thermal energy conversion systems using spatiotemporal resource data. *Appl. Energy* 309, 118414. doi: 10.1016/j.apenergy.2021.118414

Lehmann, M., Karimpour, F., Goudey, C. A., Jacobson, P. T., and Alam, M. R. (2017). Ocean wave energy in the united states: Current status and future perspectives. *Renewable Sustain. Energy Rev.* 74, 1300–1313. doi: 10.1016/j.rser.2016.11.101

Leijon, M., Bernhoff, H., Berg, M., and Ågren, O. (2003). Economical considerations of renewable electric energy production–especially development of wave energy. *Renewable Energy* 28, 1201–1209. doi: 10.1016/S0960-1481(02)00157-X

Leijon, J., and Boström, C. (2018). Freshwater production from the motion of ocean waves–a review. *Desalination* 435, 161–171. doi: 10.1016/j.desal.2017.10.049

Lewis, M., O'Hara Murray, R., Fredriksson, S., Maskell, J., de Fockert, A., Neill, S. P., et al. (2021). A standardised tidal-stream power curve, optimised for the global resource. *Renewable Energy* 170, 1308–1323. doi: 10.1016/j.renene.2021.02.032

Li, M., Cao, S., Zhu, X., and Xu, Y. (2022). Techno-economic analysis of the transition towards the large-scale hybrid wind-tidal supported coastal zero-energy communities. *Appl. Energy* 316, 119118. doi: 10.1016/j.apenergy.2022.119118

Lim, X.-L., Lam, W.-H., and Hashim, R. (2015). Feasibility of marine renewable energy to the feed-in tariff system in Malaysia. *Renewable Sustain. Energy Rev.* 49, 708–719. doi: 10.1016/j.rser.2015.04.074

Liu, T., Xu, G., Cai, P., Tian, L., and Huang, Q. (2011). Development forecast of renewable energy power generation in China and its influence on the GHG control strategy of the country. *Renewable Energy* 36, 1284–1292. doi: 10.1016/j.renene.2010.09.020

LiVecchi, A., Copping, A., Jenne, D., Gorton, A., Preus, R., Gill, G., et al. (2019). *Powering the Blue Economy; Exploring Opportunities for Marine Renewable Energy in Maritime Markets*. Washington, D.C.: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Available at: https://www.energy.gov/sites/prod/files/2019/03/f61/73355.pdf.

Lund, H. (2006). Large-Scale integration of optimal combinations of PV, wind and wave power into the electricity supply. *Renewable Energy* 31, 503–515. doi: 10.1016/j.renene.2005.04.008

Maandal, G. L. D., Tamayao-Kieke, M.-A. M., and Danao, L. A. M. (2021). Techno-economic assessment of offshore wind energy in the Philippines. *J. Mar. Sci. Eng.* 9, 758. doi: 10.3390/jmse9070758

Mabee, W. E., Mannion, J., and Carpenter, T. (2012). Comparing the feed-in tariff incentives for renewable electricity in Ontario and Germany. *Energy Policy* 40, 480–489. doi: 10.1016/j.enpol.2011.10.052

Magagna, D., and Uihlein, A. (2015). Ocean energy development in Europe: Current status and future perspectives. *Int. J. Mar. Energy* 11, 84–104. doi: 10.1016/j.ijome.2015.05.001

Manasseh, R., McInnes, K. L., and Hemer, M. A. (2017a). Pioneering developments of marine renewable energy in Australia. *Int. J. Ocean Climate Syst.* 8, 50–67. doi: 10.1177/1759313116684525

Manasseh, R., Sannasiraj, S., McInnes, K. L., Sundar, V., and Jalihal, P. (2017b). Integration of wave energy and other marine renewable energy sources with the needs of coastal societies. *Int. J. Ocean Climate Syst.* 8, 19–36. doi: 10.1177/1759313116683962

Mattar, C., and Guzmán-Ibarra, M. C. (2017). A techno-economic assessment of offshore wind energy in Chile. *Energy* 133, 191–205. doi: 10.1016/j.energy.2017.05.099

Mentis, D., Siyal, S. H., Korkovelos, A., and Howells, M. (2016). A geospatial assessment of the techno-economic wind power potential in India using geographical restrictions. *Renewable Energy* 97, 77–88. doi: 10.1016/j.renene.2016.05.057

Messali, E., and Diesendorf, M. (2009). Potential sites for offshore wind power in Australia. *Wind Eng.* 33, 335–348. doi: 10.1260/030952409789685744

Muliawan, M. J., Karimirad, M., and Moan, T. (2013). Dynamic response and power performance of a combined spar-type floating wind turbine and coaxial floating wave energy converter. *Renewable Energy* 50, 47–57. doi: 10.1016/j.renene.2012.05.025

Murali, K., and Sundar, V. (2017). Reassessment of tidal energy potential in India and a decision-making tool for tidal energy technology selection. *Int. J. Ocean Climate Syst.* 8, 85–97. doi: 10.1177/1759313117694629

Navrud, S. (2004). *Miljøkostnader av vindkraft i norge [Environmental costs from wind power]. sammendragsrapport til SAMRAM-programmet. norges forskningsrad. notat. institutt for Økonomi og ressursforvaltning, universitetet for miljø-og biovitenskap (UMB)(in Norwegian)* Norway.

Neill, S. P., Vögler, A., Goward-Brown, A. J., Baston, S., Lewis, M. J., Gillibrand, P. A., et al. (2017). The wave and tidal resource of Scotland. *Renewable Energy* 114, 3–17. doi: 10.1016/j.renene.2017.03.027

Nolan, G., and Ringwood, J. (2006). *Control of a heaving buoy wave energy converter for potable water production.* Kildare, Ireland

O'Connor, M., Lewis, T., and Dalton, G. (2013). Operational expenditure costs for wave energy projects and impacts on financial returns. *Renewable Energy* 50, 1119–1131. doi: 10.1016/j.renene.2012.08.059

OES *Ocean energy systems - an IEA technology collaboration programme n.d.* Available at: https://www.ocean-energy-systems.org (Accessed June 1, 2022).

OES (2018). *International levelised cost of energy (LCOE) for ocean energy technologies* (Lisbon, Portugal: International Energy Agency for Ocean Energy Systems (IEA OES), 03–10.

Oko, C., and Obeneme, W. (2018). Thermo-economic analysis of an ocean thermal power plant for a Nigerian coastal region. *Int. J. Ambient Energy* 39, 562–572. doi: 10.1080/01430750.2017.1318789

O Rourke, F., Boyle, F., and Reynolds, A. (2010). Tidal energy update 2009. *Appl. Energy* 87, 398–409. doi: 10.1016/j.apenergy.2009.08.014

Pérez-Collazo, C., Greaves, D., and Iglesias, G. (2015). A review of combined wave and offshore wind energy. *Renewable Sustain. Energy Rev.* 42, 141–153. doi: 10.1016/j.rser.2014.09.032

PoRtMaN, M. E. (2010). Marine renewable energy policy: some US and international perspectives compared. *Oceanography* 23 (2), 98–105. doi: 10.5670/oceanog.2010.49

Qu, Y., Hooper, T., Swales, J. K., Papathanasopoulou, E., Austen, M. C., and Yan, X. (2021). Energy-food nexus in the marine environment: A macroeconomic analysis on offshore wind energy and seafood production in Scotland. *Energy Policy* 149, 112027. doi: 10.1016/j.enpol.2020.112027

Quirapas, M., and Srikanth, N. (2017). *Ocean energy in insular conditions–a workshop report prepared on behalf of the IEA technology collaboration programme for ocean energy systems (OES)* (Singapore: OES).

Quirapas, M. A. J. R., and Taeihagh, A. (2021). Ocean renewable energy development in southeast Asia: Opportunities, risks and unintended consequences. *Renewable Sustain. Energy Rev.* 137, 110403. doi: 10.1016/j.rser.2020.110403

Ranthodsang, M., Waewsak, J., Kongruang, C., and Gagnon, Y. (2020). Offshore wind power assessment on the western coast of Thailand. *Energy Rep.* 6, 1135–1146. doi: 10.1016/j.egyr.2020.04.036

Reichardt, K., Negro, S. O., Rogge, K. S., and Hekkert, M. P. (2016). Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany. *Technological Forecasting Soc. Change* 106, 11–21. doi: 10.1016/j.techfore.2016.01.029

Reichardt, K., and Rogge, K. (2016). How the policy mix impacts innovation: Findings from company case studies on offshore wind in Germany. *Environ. Innovation Societal Transitions* 18, 62–81. doi: 10.1016/j.eist.2015.08.001

Rodrigues, N., Pintassilgo, P., Calhau, F., González-Gorbeña, E., and Pacheco, A. (2021). Cost-benefit analysis of tidal energy production in a coastal lagoon: The case of ria Formosa – Portugal. *Energy* 229, 120812. doi: 10.1016/j.energy.2021.120812

Sağlam, M., Sulukan, E., and Uyar, Ts. (2010). Wave energy and technical potential of Turkey. *J. Naval Sci. Eng.* 6, 34–50. https://dergipark.org.tr/en/pub/jnse/issue/9992/123479?publisher=msu

Saheli, M. A., Lari, K., Salehi, G., and Azad, M. T. (2022). Techno-economic assessment of a hybrid on grid PV-wave system: A case study in Caspian Sea. *Renewable Energy* 186, 596–608. doi: 10.1016/j.renene.2021.12.146

Salim, R. A., and Rafiq, S. (2012). Why do some emerging economies proactively accelerate the adoption of renewable energy? *Energy Economics* 34, 1051–1057. doi: 10.1016/j.eneco.2011.08.015

Segura, E., Morales, R., and Somolinos, J. A. (2018). Economic-financial modeling for marine current harnessing projects. *Energy* 158, 859–880. doi: 10.1016/j.energy.2018.06.035

Segura, E., Morales, R., and Somolinos, J. A. (2019). Influence of automated maneuvers on the economic feasibility of tidal energy farms. *Sustainability* 11, 5965. doi: 10.3390/su11215965

Shi, H., and Guo, P. (2012). Prospects of tidal energy development and utilisation in China. *Costal Eng.* 31, 72–80. doi: 10.3969/j.issn.1002-3682.2012.01.011

Silva, A. R., and Estanqueiro, A. (2022). From wind to hybrid: A contribution to the optimal design of utility-scale hybrid power plants. *Energies* 15, 2560. doi: 10.3390/en15072560

Sims, R. E. H., Rogner, H.-H., and Gregory, K. (2003). Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. *Energy Policy.* 31, 1315–1326. doi: 10.1016/S0301-4215(02)00192-1

Singh, U., Rizwan, M., Malik, H., and García Márquez, F. P. (2022). Wind energy scenario, success and initiatives towards renewable energy in India–a review. *Energies* 15, 2291. doi: 10.3390/en15062291

Snyder, B., and Kaiser, M. J. (2009). Ecological and economic cost-benefit analysis of offshore wind energy. *Renewable Energy* 34, 1567–1578. doi: 10.1016/j.renene.2008.11.015

Sovacool, B. K. (2009). The importance of comprehensiveness in renewable electricity and energy-efficiency policy. *Energy Policy* 37, 1529–1541. doi: 10.1016/j.enpol.2008.12.016

Sreeni, S., Tahiliani, S., and Gothankar, T. (2017). Machine learning based maximum power point tracking in Tidal/Ocean energy conversion system. *Int. J. Of Electrical Electron. And Data Communication* 5, 36–40. Available at: http://iraj.doionline.org/dx/IJEEDC-IRAJ-DOIONLINE-7660

Stebbings, E., Papathanasopoulou, E., Hooper, T., Austen, M. C., and Yan, X. (2020). The marine economy of the united kingdom. *Mar. Policy* 116, 103905. doi: 10.1016/j.marpol.2020.103905

Stoutenburg, E. D., and Jacobson, M. Z. (2010). "Optimizing offshore transmission links for marine renewable energy farms," in *OCEANS 2010 MTS/IEEE SEATTLE* (seattle, USA: IEEE), 1–9. doi: 10.1109/OCEANS.2010.5664506

Stoutenburg, E. D., Jenkins, N., and Jacobson, M. Z. (2010). Power output variations of co-located offshore wind turbines and wave energy converters in California. *Renewable Energy* 35, 2781–2791. doi: 10.1016/j.renene.2010.04.033

Taniguchi, T., Ishida, S., and Minami, Y. (2013). A feasibility study on hybrid use of ocean renewable energy resources around Japan. *Am. Soc. Mechanical Engineers* 55423, V008T09A065. doi: 10.1115/OMAE2013-11040

UN (2010). *Trends in sustainable development small island developing states (SIDS).* New York, USA.

UN (2015). *General Assembly. Resolution adopted by the General Assembly on 11 September 2015.* (New York., USA).

Ünlü, M. A. (2012). *Offshore wind power economics: analysis on the economic utilization of turkey's offshore wind power potential under the current support mechanisms.* Bergen, Norway. Available at: http://hdl.handle.net/11250/169795.

Upshaw, C. R. (2012). *Thermodynamic and economic feasibility analysis of a 20 MW ocean thermal energy conversion (OTEC) power plant.* Texas, Austin. Available at: http://hdl.handle.net/2152/ETD-UT-2012-05-5637.

Vega, L. A. (2002). Ocean thermal energy conversion primer. *Mar. Technol. Soc. J.* 36, 25–35. doi: 10.4031/002533202787908626

Voke, M., Fairley, I., Willis, M., and Masters, I. (2013). Economic evaluation of the recreational value of the coastal environment in a marine renewables deployment area. *Ocean Coast. Manage.* 78, 77–87. doi: 10.1016/j.ocecoaman.2013.03.013

W20 project *Wave power for clean drinking water | results in brief | H2020* (CORDIS | European Commission n.d) (Accessed). Available at: https://cordis.europa.eu/article/id/241187-wave-power-for-clean-drinking-water (Accessed June 1, 2022).

Waldman, S., Yamaguchi, S., Murray, R., and Woolf, D. (2017). Tidal resource and interactions between multiple channels in the goto islands, Japan. *Int. J. Mar. Energy* 19, 332–344. doi: 10.1016/j.ijome.2017.09.002

Wang, C., Bi, Z., and Da Xu, L. (2014). IoT and cloud computing in automation of assembly modeling systems. *IEEE Trans. Ind. Inform.* 10, 1426–1434. doi: 10.1109/TII.2014.2300346

Wang, K., Ouyang, Z., Krishnan, R., Shu, L., and He, L. (2015). A game theory-based energy management system using price elasticity for smart grids. *IEEE Trans. Ind. Inf.* 11 (6), 1607–1616. doi: 10.1109/TII.2015.2426015

Wang, Y., Qin, Y., Wang, K., Liu, J., Fu, S., Zou, J., et al. (2022). Where and green wind energy? evidence from high-resolution potential mapping in China. *J. Cleaner Production* 134287. doi: 10.1016/j.jclepro.2022.134287

Wang, S., Yuan, P., Li, D., and Jiao, Y. (2011). An overview of ocean renewable energy in China. *Renewable Sustain. Energy Rev.* 15, 91–111. doi: 10.1016/j.rser.2010.09.040

Wang, H., Zhao, X., Zhang, K., and Wang, W. (2022). Economic assessment of a renewable energy-electricity-hydrogen system considering environmental benefits. *Sustain. Production Consumption* 33, 903–920. doi: 10.1016/j.spc.2022.08.010

Weeks, K., Safa, M., Kenyon, G., and Levius, S. (2020). Offshore multi-purpose platform efficacy by US coastal areas. *Renewable Energy* 152, 1451–1464. doi: 10.1016/j.renene.2020.02.079

Xu, G., Shi, Y., Sun, X., and Shen, W. (2019). Internet Of things in marine environment monitoring: A review. *Sensors* 19 (7), 1711. doi: 10.3390/s19071711

Yang, Z., Wang, T., Copping, A., and Geerlofs, S. (2014). Modeling of in-stream tidal energy development and its potential effects in Tacoma narrows, Washington, USA. *Ocean Coast. Manage.* 99, 52–62. doi: 10.1016/j.ocecoaman.2014.02.010

Yeşilyurt, M. K., Öner, İV, Ömeroğlu, G., and Yılmaz, E. (2017). A scrutiny study on wave energy potential and policy in TURKEY. *Period Eng. Nat. Sci.* 5, 286–297. doi: 10.21533/pen.v5i3.108

Yue, X., Patankar, N., Decarolis, J., Chiodi, A., Rogan, F., Deane, J. P., et al. (2020). Least cost energy system pathways towards 100% renewable energy in Ireland by 2050. *Energy* 207, 118264. doi: 10.1016/j.energy.2020.118264

Zhang, D., Li, W., and Lin, Y. (2009). Wave energy in China: Current status and perspectives. *Renewable Energy* 34, 2089–2092. doi: 10.1016/j.renene.2009.03.014

Zhang, Y., Lin, Z., and Liu, Q. (2014). Marine renewable energy in China: Current status and perspectives. *Water Sci. Eng.* 7, 288–305. doi: 10.3882/j.issn.1674-2370.2014.03.005

Zhang, Z.-G., Yin, J.-C., and Liu, C. (2018). A modular real-time tidal prediction model based on grey-GMDH neural network. *Appl. Artif. Intell.* 32, 165–185. doi: 10.1080/08839514.2018.1451220