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Marine Renewable Energy Integration in Offshore Infrastructure

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***Abstract-** The global shift towards low-carbon energy systems has generated significant interest in the use of marine renewable energy as a viable solution towards the peaceful use of the ocean and the decarbonization of infrastructure systems in the sea. Offshore infrastructure systems such as oil and gas platforms, ports, islands, and coastal industrial systems have generated significant interest in the use of various renewable sources of energy to combat the impacts of global climate change. Therefore, this paper discusses the integration of various versions of marine renewable energy technologies into offshore infrastructure systems.The research study employs a qualitative analytical methodology based on the results obtained from a critical review of the most recent innovations in the field of technology, system architecture, operation, and various aspects of energy integration. Some of the most significant dimensions of energy integration evaluated are energy generation potential, grid connection, hybrid systems of power, energy storage, reliability of operation in a harsh marine environment, etc. Various aspects of environment, technology, and regulation evaluated are the viability of marine-based renewable energy.Moreover, hybrid energy system analysis, as presented, focuses on the potential of such a system comprising marine renewables, traditional power production, and energy storage to reduce fuel, emission, and operational cost through increased system reliability. In addition, timely integration of renewable energy technologies during the design of offshore infrastructures has potential benefits towards optimized efficiency and sustainability. Overall, the paper contributes to relevant literature on offshore energy transitions and strategic information useful for policymakers, strategists, and planners of marine renewable energy uptake.*

I. INTRODUCTION

However, the continuing trend of changes towards a more sustainable and a low carbon-based energy future has led to a critical need to increase the use of renewable energy across all facets of the global economy. Marine environments, which have historically been associated with the production of fossil fuels and other energy-intensive industrial activities, are being recognized as one critical area for the promotion and integration of renewable energy. The offshore infrastructure that comprises oil, gas, industries, ports, and islands presents a formidable opportunity for the integration of renewable energy.The conventional source of power used in these structures, such as diesel generators, gas turbines, and grid supply, has led to higher levels of emissions and increased operating costs due to the transport of these fuels to the particular site. The regulations on climate change have emphasized the need for clean and appropriate power for the infrastructure developed in the offshore location. The conventional source of power for these sites has a higher impact on the environment. This is because there are higher fuel supply challenges involved in these infrastructure developments in these locations, which also varies depending on the location.Marine renewable energy offers an opportunity to face these problems from a different perspective. Marine renewable energy sources include offshore wind farms, solar photovoltaic floating systems, wave energy converters, tidal energy conversion systems, and others. Marine renewable energy sources receive an abundant and reliable source of energy from our ocean. Additionally, the last decade has seen remarkable advancements in the field of Marine Engineering and Material Science, making Marine Renewable Energies highly competitive in their engineering and economic aspects. Marine Renewable Energies have started being considered in the designs of Off-Shore Infrastructure Energy Systems.The addition of marine renewable energy in such infrastructures has the advantage of providing various technical benefits as well as the benefits of the feasibility of hybrid energy systems, which include conventional sources of energy as well as other sources of energy that are renewable. The location of such infrastructures has the advantage of ensuring that they are near good sources of wind, tide, and waves, making it possible for the infrastructure to use these as sources of energy that

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are renewable. Besides that, it is possible for the infrastructures and foundations to use these structures as a way of cutting costs and as a way of ensuring that the ecosystem is not significantly affected. Nevertheless, despite these opportunities and challenges, merging marine energy resources with infrastructure faces challenges as a systems engineering problem. Various offshore infrastructures are, in many cases, subjected to adverse weather conditions, composition of seawater, poor accessibility, and high safety considerations. The ocean environment in which marine energy resources can be set up should demonstrate their reliability, survival ability, and compatibility with existing offshore infrastructures.Intermittency, grid issues, and storage issues are some of the technical challenges faced in developing infrastructures involving sea energy.Environmental concerns play an important role in the integration of ORE. Although it may seem obvious that the benefits of the ocean as it relates to protection against climate change by utilizing marine renewable energy sources, there is a need to ensure that in the implementation thereof, all factors are considered with regard to the environment to ensure that there is no significant damage. There are cases when, in the integration of ORE while contemplating existing structures, there would be fewer environmental concerns than building a brand new structure.Energy Systems at Sea: From the policy and regulatory perspective, it can be stated that the energy system at sea creates a link among the different regulatory regimes, such as maritime regulations, energy regulations, environmental regulations, and occupational safety regulations. The integration of different forms of renewable energy in the maritime landscape requires the formulation of new regulatory streams that enable the promotion of hybrid models in the field of energy systems, electrification of such models, and decarbonization in the maritime industry. One of the challenges comes from the presence of regulatory risks or governance risks.

Academic activities concerning research on the field of marine renewable energy have shown a rapid increase of studies in the past few years on the field of marine energy technology development, energy resource assessment, as well as grid-connected energy systems. Nevertheless, little emphasis has been placed on the integration of marine-based energy systems with the existing infrastructures used for the development of hybrid and autonomous energy systems. Most academic research on the field of energy system implementation has concentrated on isolated system implementation, failing to consider the interoperation, limits of operation, as well as the durability of the system. The present paper attempts to bridge the said gap by approaching the subject of the integration of renewable energy from the perspective of systems integration. Specifically, the objective of the present paper is to successfully address the possibilities of integration of various types of renewable energy forms with various types of structures, energy storage units, and various traditional power plants to enable the development of stronger and purer forms of energy. In the process, it also aspires to develop the subject matter regarding the technical, environmental, and jurisdiction-related issues of the subject of renewable energy, as far as the related subject of offshore energy integration is concerned. As far as the rest of the paper is concerned, it can be outlined as follows: the next section of the paper entails a discussion of past literature and related works with regard to marine renewable technologies and marine offshore energy systems. After that section of the paper, the analysis of the architectures, operations, and environment aspects will be undertaken. Then, the policy and research direction aspect of the paper will be discussed. Finally, the conclusion and strategic plans of the paper will be highlighted.

II. LITERATURE REVIEW

The use of Renewable energy in the infrastructure of the Marine environment has been gaining significant attention in the the aim of addressing the importance of the Marine infrastructure as a catalyst in the process of the global energy transition process. The Marine environment has presented a challenge to unlock the enormous potential in the unexplored sources of Renewable energy such as Wind energy, Wave energy, Tidal energy, and Solar energy. The topic has been addressed and explored in the existing body of literature with regard to potential and availability.Offshore wind energy can be defined as the major type of marine renewable energy, and this type of energy is in the advanced phase of commercial development. Various research studies have been done to demonstrate the potential of wind farms located offshore, citing the high benefits of offshore wind energy due to the high volume of energy harnessed per wind farm. Moreover, the research indicates that there is the possibility of integrating wind energy with structures located offshore based on the space available and the demand. Nevertheless, despite the above issues, the problems that affect the strategy of offshore structures include those related to wind.In addition, the energy density of wave energy as well as its predictability has been widely researched. Most of the tests undertaken within the field have been with regard to the design of wave energy converters, the type of power take-off mechanism that is integrated into these systems, as well as the ability of these systems to withstand extreme sea states. Although the field has not advanced as far as offshore wind power, the hybrid aspect of offshore energies indicates that the place of wave technology, as far as hybrid energy systems are concerned, is the facilitation of wind patterns.Tidal energy, which encompasses tidal streams as well as tidal ranges, presents an interesting research topic owing to the high degree of predictability associated with these kinds of energy types. Literature is on the side of tidal energy, focusing on leveraging structures erected on the sea bed due to the high predictability level when it comes to the cycles of this particular type of energy. There is an indication that tidal energy integration is good for cutting down on fossil fuels due to high potential levels. However, limitations hinder the use of tidal energy for offshore structures.Another recently added name in the list of maritime renewable energies, the concept of floating solar photovoltaics has started to gain some interest in the field. All the research related to the concept of solar photovoltaics has been conducted in the context of an inland environment, with several possibilities being explored related to the installation of the solar photovoltaics in an offshore environment. One of the main advantages of solar photovoltaics is said to be the modularity of the concept and the option of easy installation along with the potential of integration with the related devices of energy storage. Besides these technologies, another area of significant importance in the field of hybrid technology is hybrid energy technologies. Hybrid energy technology, as the name implies, is another extension or a hybrid form of incorporating wind, wave, tidal, and solar power together with storage and other conventional power sources, which is gradually being accepted and recognized as a potential way towards increasing the reliability and lowering the emissions; thus, the results obtained from the research indicate the positive role of hybrid technology in reducing the intermittency observed in the above sources and increasing their reliability. But the majority of the existing research has been restricted to the theoretical aspects only. Energy storage is always included as an enabler for the integration of offshore REs. Besides, research has identified the significance of batteries and hydrogen to address the supply/demand balance, power quality, as well as the autonomous operation that is required. Nonetheless, there are still some challenges related to the storage process, which are significant hurdles to address. Considering the environmental as well as the regulation dimensions of the literature, there is significance placed on the planning as well as assessment realities of the MAR systems. As emphasized in the literature, despite the significant contributions to the mitigation of the effects of climate change brought by the marine RE systems, there is a realization that the systems can still pose a threat to the environment as well as the sea. Thus, the discussion of the integration of RE systems to the existing infrastructure for the mitigation of the environmental impacts to decarbonize the planet further is an interesting finding of the literature. Overall, the existing literature on marine energy demonstrates that there is a strong technical potential to deploy the energy resources. Nevertheless, there is a recognized issue of the consideration of system-based frameworks for the integration with the offshore infrastructures. All the research studies reviewed were based on the evaluation of the stand-alone type of technology instead of the system-based perspective of the marine energy system applied to the concerned offshore infrastructures. This research is an extension of the existing literature with the inclusion of the combined perspective of the concerned dimensions with regard to the deployment of the marine energy resources.

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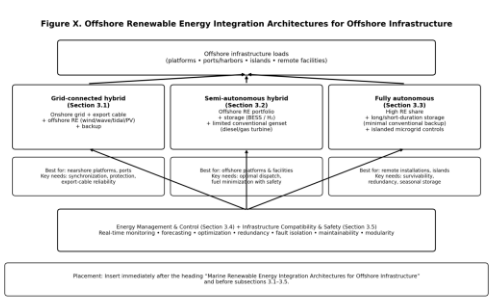
Table 1. Comparison of Marine Renewable Energy Technologies for Offshore Infrastructure Integration

Technology	Key Advantages	Main Limitations	Integration Potential
Offshore wind	High maturity, large energy output	Intermittency, maintenance complexity	High
Wave energy	High energy density, complementary to wind	Technological immaturity, cost	Medium
Tidal energy	Predictable and reliable output	Site-specific constraints	Medium
Floating solar	Modular, flexible deployment	Offshore durability challenges	Emerging
Hybrid systems	Enhanced reliability, reduced emissions	System complexity	Very High

Marine Renewable Energy Integration Architectures For Offshore Infrastructure



For effective integration of marine renewable energy systems with existing infrastructures, there must be effective system architecture that addresses different issues, focusing on variability, reliability, safety, and environmental considerations. The infrastructures that are inherent in offshore sites include platforms utilized for oil and gas wells, industries, harbors, and independent energy systems, usually far away and not necessarily connected naturally to the grid due to their remote locations. This makes it important to look at the importance of offshore integration compared to alternatives to conventional energy systems. Typically speaking, there are three classes of marine renewable energy systems with regard to the conceivable potential of the grid support system hybridization. These are the grid-connected hybrid systems, the semi-autonomous hybrid systems, and the autonomous offshore systems.

3.1 Grid Connected Hybrid Off-Shore

Usually, the systems that are connected to the grid supply electrical energy to shore-based facilities that are either near the coastal electrical grids or those that can be accessed by means of submarine transmission lines. Therefore, marine electrical energy resources such as offshore wind electrical energy, as well as electrical energy from the grid and the electrical energy from the sources of backup electric power, are usually a combination of electric energy normally found or traditionally used and electric energy of the renewable type generated by the sources of such energies.This kind of structure also provides for the stability and the flexibility of a grid, wherein excess power is provided to the grid for the deficient power. However, in considering the issue concerning the connection of a grid, the power electronics, synchronization, and protection are fundamental in handling the issue concerning the dynamism of the power received from the source of renewable energy. Regarding the cables for the offshore, the availability is dependent on reliability.

3.2 Semi-Autonomous Hybrid Offshore Systems

One of the most examined types of architecture for the infrastructure that is situated off the shore is that of the semi-autonomous system. Within the framework of the system of architecture, the traditional sources of generation, which comprise diesel generators receiving their energy from the gas turbines, and the sources of energy storage, which include batteries and hydrogen containers, respectively, integrate with the sources of the marine energy of the renewable type. It is observed that one of the significant components used in such a semi-autonomous design is the role of the energy storage system. It is thus observed that the variation in the power supply can be managed with the help of the utilization of the battery energy storage system, while the use of various methods such as the hydrogen storage system helps in the achievement of autonomy in the long run. This type of architecture is thus seen to be in a state of balance in relation to issues such as reliability and decarbonization, and the design can be thus used in areas such as offshore platforms/industries where the power supply is stable. The significant issue that comes up in the design is the optimization in such a way that fuel usage is reduced without compromising the level of safety.

3.3 Fully Autonomous Offshore Renewable Energy Systems

Fully autonomous systems are those systems that have the least amount of conventional generation, making use of MRE and energy storage. The fully autonomous systems have the greatest applicability to small offshore platforms, remote monitors, and island energy systems that have a low power demand. Fully autonomous architecture is given the highest priority for renewable energy penetration and reduction of emissions, but energy management systems are needed to achieve reliability.Some of the major challenges include storing energy over extended periods of time, provision of redundant plans, and ensuring the survival of these systems in extreme weather conditions. Since the process of purely autonomous systems in large-scale offshore infrastructure is still limited in development, improvements in storage and electronic control systems make more and more projects viable.

3.4 Energy Management and Control Strategies

Energy management systems are an essential component of the performance of various schemes of offshore renewable energy system integration architectures. Thus, the platforms of EMS use real-time data, prediction tools, and optimization tools to strike a balance between renewable sources of energy, energy storage, and backup sources of energy. The predictive techniques facilitate the decision-making process through weather forecasts and loads.

A simple energy balance relationship used in designing a system is:

Total demand for power = renewable generation + storage discharging + conventional generation - storage chargingThis will be the pattern that will dictate system sizing and optimization for optimal utilization of renewables without compromising reliability.

3.5 Infrastructure Compatibility and Safety Considerations

Norms pertaining to safety and reliability have to be adhered to stringently in the integration of the infrastructures. The renewable systems have to be structurally compatible with the offshore platform and capable of withstanding hostile environmental conditions. The electrical systems have to incorporate redundancy, fault tolerance and isolation capabilities for the safe operation of the system under faulty conditions.In addition to this, maintenance access and system modularity are thought to be important. The components of renewable energy and storage are helpful in ensuring maintenance access. This minimizes possible downtime, especially considering that there is limited access offshore.

Table 2. Offshore Renewable Energy Integration Architectures

Architecture Type	Renewable Share	Reliability Level	Typical Applications
Grid-connected hybrid	Medium	High	Nearshore platforms, ports
Semi-autonomous hybrid	High	Very High	Offshore platforms, facilities
Fully autonomous	Very High	Medium	Remote installations, islands

Environmental And Operational Challenges in The Integration of Offshore Renewable Energy

While the application of marine renewable energy systems has huge potential to support reducing the carbon footprint for offshore structures, it poses special challenges to the environment and operations, which have to be dealt with from a design and planning viewpoint. The environments are classified as hard due to the weather conditions, corrosion aspects, and accessibility issues, impacting efficiency and life cost for renewable energy systems and the offshore structures they will serve in concert with.One of the most significant environmental challenges facing renewable energy systems includes exposure to heavy wind and ocean currents, including extreme weather phenomena. In essence, this means that the renewable systems deployed at sea, both wind turbines and ocean currents, are set to experience cyclic loading, thus likely to affect the whole structure of these devices. Considering the critical role played by renewable energy in dispensing to various systems, there is a looming danger if the systems were to shut down due to exposure to weather patterns.This is yet another serious problem that has to be considered: material corrosion and degradation. Any corrosive effects that contact with sea water can bring upon metals, connections, and supporting structures will immediately increase much more than it would happen in a normal, inland power plant. Such renewable power equipment installed in these structures needs to be designed under consideration of portraying much greater resistance to corrosive effects. Prevention of corrosion protection represents a major problem, especially when structures originally designed for conventional power production are being fitted out with renewable power equipment.Another relevant operational issue is biofouling. In fact, it might very easily degrade the performance of tidal stream turbines and wave energy converters, besides floating solar panel installations. Biofouling enhances the drag resistance experienced on the device and enhances process efficiency. Thus, biofouling management techniques that are most friendly to the environment have to be employed to ensure long-term performance while ensuring ecological effects.From the point of view of the energy system, variability and intermittency of renewable energy sources are a particular concern in operational terms. For instance, wind and wave energy exhibit variability given weather or sea state, while solar power depends on diurnal and seasonal variability. For an offshore situation, there are constant and steady energy requirements, and hence variability in power will affect quality and reliability if not adequately managed through adequate energy storage and intelligent energy management strategies. One relationship commonly used which involves operational reliability, as applied in system planning is given by:

System Reliability = Renewable Availability + Storage Capacity + Backup Generation Capability

This interrelationship underlines the fact that considering higher penetration of renewable power alone is not appropriate to secure higher reliability; appropriate storages are as important as backup. It is of vital importance that appropriate optimization be achieved in relation to these three components.Environmental impact considerations not only incorporate the performance of the system but also environmental impact that the system has on the marine ecosystem and the other users of the ocean. The impacts of the offshore system with the integrated renewable energy system can incorporate the hydrodynamics, the level of noise within the system, as well as the structures within the environment. A number of studies show that the impacts of the offshore system with the integrated renewable energy system can be managed; incorporation with other offshore infrastructure adds complexity to the system.Further, operational logistics add to the difficulty in offshore renewable energy systems. For installing, inspecting, and maintaining these systems, very limited access is available at the offshore locations. These renewable energy systems, requiring frequent maintenance, may result in increased vessel activities, more operational expenses, and safety concerns. Therefore, design strategies that emphasize the ability of the system to withstand are highly preferred.Finally, some operational issues in offshore energy systems could be said to be overarching safety and regulatory issues. This is considering the fact that the electrical systems, fire safety, structural integrity, and personnel in these systems have to meet rigid safety regulations. While the integration of renewable technologies with the existing systems can be very challenging regarding safety considerations, not taking the necessary consideration at the design phase of the installation may also be rather risky.In sum, these environmental and operational factors underline that there is a need for an integrated approach to renewable energy resources' deployment, resting on a systems approach. It has to cope with structural resilience, corrosion protection, variability in energy, environmental protection, and operational aspects all at once for the success of its outcome.

Table 3. Key Environmental and Operational Challenges and Mitigation Strategies

Challenge	Impact on Offshore Infrastructure	Mitigation Strategy
Extreme weather	Structural fatigue and downtime	Conservative design margins and redundancy
Corrosion	Reduced lifespan and reliability	Corrosion-resistant materials and coatings
Biofouling	Efficiency loss and maintenance burden	Environmentally friendly fouling control
Energy variability	Power instability	Energy storage and smart energy management
Limited accessibility	High maintenance cost	Modular design and remote monitoring
Environmental impact	Ecosystem disturbance	Monitoring and adaptive management

Environmental And Operational Issues In The Integration Of Marine Renewable Energies

Although MRE holds considerable potential to contribute to decarbonized infrastructure, integration into the marine environment encompasses a lot of issues that are challenging, with unique environmental and operational concerns that make way for their effective management. The respective offshore infrastructure faces a most inhospitable environment with extreme conditions in terms of weather, corrosiveness of seawater, and accessibility with respect to restrictions. Depending on how factors such as extreme weather, corrosiveness of seawater, and restricted accessibility are taken into consideration, the sustainability of the systems pertaining to renewable energy and the infrastructure in question is affected.Other significant environmental challenges to be addressed include extreme meteorological and oceanographic phenomena. The systems that make up the offshore renewable energy infrastructure must be kept in mind to ensure that they can persist in extreme wind conditions, large waves, and strong currents. In this regard, weather-related malfunctions causing downtime of the system owing to cyclic loading in relation to wind turbines or wave energy converters will present impacts on structural integrity over time. These effects may be critical in relation to offshore infrastructure, which requires an uninterrupted supply. Essentially, integration methods must incorporate conservative design margins.Another important challenge that has to be addressed is that of the corrosion of the material. Seawater has the effect of accelerating corrosion phenomena in metallic parts for renewable energy systems to be integrated with the offshore platforms built for conventional energy production. Thus, corrosion-resistant products and coatings of high quality, as well as electrical connections and structures, need to be fully sealed against the effects of seawater. Such a lack of adequate protection against corrosion might result in a higher rate of maintenance, as well as a decrease in the overall availability of such systems and, hence, higher costs. These problems are present particularly with hybrid systems, where integration of several of the components of the renewable energy system takes place with those of the platforms created for the production of conventional energy.Biofouling also presents a major operational problem whereby the biofouling constituents settle and grow on a submerged surface. In general, biofouling plays a role in the overall degradation of the operating performance of tidal turbines, wave energy converters, and floating solar platforms. It raises the hydrodynamic drag force associated with these devices, lowers the efficiency of the device while converting the energy it harvests from the sea, and complicates maintenance. Any countermeasures to biofouling that are taken along the way should be ecologically friendly to make sure that proper system performance is achieved with minimal ecological impact.From the perspective of the energy system, variability and intermittency are considered some of the main challenges that face the modes of energy generation. For example, wind energy depends on wind, solar energy depends on sun conditions, and wave energy depends on waves, whereas in an offshore infrastructure that is constantly in need of energy, all these factors will definitely have an impact on the quality of power supply if not well managed. Energy storage would, therefore, be important in matching supply with demand for efficiency in the supply of power.A simplified form of the relation for operational reliability used in system planning is:

System Reliability = Renewable Availability + Storage Capacity + Backup Generation Capability

This again reveals that high levels of renewable power may not be adequate to ensure reliability; indeed, storage and backup levels also need to be good. Thus, system designers will have to balance many such factors. These environmental impact statements extend beyond system performance to contemplate the probable impacts on the marine environment as well as on other marine users. The probable impacts of these offshore renewable energy systems exist on marine ecosystems. While various studies claim that the impacts can be controlled or minimized, the integration with the already existing offshore infrastructure is likely to add a degree of complexity. Environmental impacts will be an essential issue to address to ensure that the integration of offshore renewable energy systems does not negatively affect the environment. However, further complications are found in the integration of offshore renewable energy, based on operational logistical issues. Sometimes, access to the offshore site for installation, inspection, and maintenance purposes is restricted based on weather conditions. A renewable technology that requires maintenance operations on a recurrent basis may increase vessel movements as well as operational and safety risks; therefore, it is more favorable to make use of design techniques that provide durability, modularity, and remote observation for onshore purposes. Finally, safety and regulatory compliance issues are also a key issue in safety operations, which are essential in operations and managing offshore installations. Safety issues must be directed towards making sure that offshore energy installations, be it of renewable or non-renewable sources, meet appropriate safety standards in relation to safety in electrical installations, safety against fire, safety in structure, safety in personnel, amongst others. All these environmental and operational challenges cumulatively serve to highlight the increasing need for effective integrated systems-based solutions to be adopted towards the implementation of offshore renewable energy. However, it is worth pointing out that any solution provided to structural resiliency, corrosion protection, energy variability, environmental protection, or operational logistics challenges would have to be considered in an integrated manner.

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III. DISCUSSION AND FUTURE OUTLOOK

Within the above framework of thought, it can thus be noted that the analysis offered within the above study indicates that in relation to the overall context of its integration with the offshore infrastructure, the term "marserenew" represents not an evolutionary trend in the technologies used in the broader context of engineering design but a paradigm shift within the entire context of the design and operation of the offshore energy system as a whole. As has been highlighted within the above framework of thought, within a more holistic context of thought, there remains a significant degree of scope with regard to improving the sustainability of the infrastructure by the application of the term "marserenew."The significant achievement of this paper is that hybrid energy systems offer great potential in the deployment of offshore renewable energy sources in the near-medium term. Although independent and purely dependent on renewable energy sources face challenges in meeting energy storage demand in achieving reliability, especially in energy-consuming offshore facilities since there is an ongoing demand for electrical energy at all times, the hybrid concept that balances marine renewables, energy storage, and conventional energy supply is set to offer advantages in ensuring that the highest utilization of RE results is in line with safety and reliability of operations, as attained in conventional offshore operations.From the above discussion, another thing which is also emphasized is the need to develop context-specific system design. In other words, this means that renewable offshore technology does not actually operate in isolation, but rather to a very large extent, it is affected by its environment, as well as specific demands and constraints. For instance, the effectiveness of the integrated wind-wave offshore energy system is also affected not only by external resources but also by maintenance, corrosion, and relative demands.From an environmental perspective, the integration of the existing infrastructure with a source of renewable energy has the potential to result in considerable benefits to the environment. Thus, the collocation of various systems has the ability to ensure the mitigation of the level of disturbance to the seabed as well as the rate of the generation of conflicts while promoting the rate of decarbonization while minimally developing infrastructure. Thus, based on the dialogue that has been created, the precise benefits to the environment are not guaranteed, depending on the system's design. Cumulative impacts constitute an essential theme to explore further.Both these variables appear as enablers as well as inhibitors. As already mentioned above, the presence of strong enabling regulations and policy frameworks reduces the investment risks and spurs innovation. On the other hand, the issue of regulatory fragmentation and regulatory uncertainty acts as an inhibitor. It has already been concluded above that the quest for better cooperation between those dealing with the regulations of the maritime business and those dealing with the regulations related to the energy and environment sectors is key to making the regulatory regime easier and developing an integrated offshore energy system.If we consider the future, we will see that technological advancements are sure to increase the feasibility of MRE integration in our energy landscape. In this aspect, there are several technological advancements in energy storage, digital management of energy, and materials that can assist in the increase of MRE integration in an efficient manner. The digitalization of MRE is expected to revolutionize the future of integrating MRE into our energy landscape.Hence, it may be essential that further research validates different integration structures through empirical verification, and techno-economic assessments in different varied offshore environments to support decision-making for the operators of such infrastructure and lawmakers.It must, however, be highlighted that an important aspect of further research would be an interdisciplinary approach that would incorporate various disciplines, including engineering, environmental, and policy disciplines.

IV. CONCLUSION AND RECOMMENDATIONS

Therefore, the current paper sought to explore the concept of the integration of marine renewable energy systems in infrastructures on or off the shore as an effective strategy that can move forward the development of sustainable or green energy systems. Of course, based on the different discussions and exploration of the concept of marine renewable energy systems, the findings of the study conclusively prove that the concept is technically feasible and technologically necessary. Also from the above analysis, it is evident that the application of hybrid systems of offshore energy provides the best means for the integration of renewable energies into infrastructures located in the sea. Integration means the combination of marine renewable energies with storage and conventional energies, so that the reduction of the needs for fossil fuels can be achieved without compromising the reliability of infrastructures located in the sea. The paper also emphasizes the need for integration at early stages of development. In this case, an integration design for systems like renewable energy sources may be targeted for optimization at development stages to make the infrastructure economically efficient when developed by infrastructure developers.Infrastructures also have to comply with certain climatic conditions around a certain region, such as extreme weather conditions and corrosion conditions. The policy/governance dimension in the study points out the need to develop an appropriate policy to encourage the integration of offshore sources of renewable energy in an effective manner. There is also the need to develop mechanisms for the promotion of policy clarity structures in hybrid offshore sources of energy. Based on the suggestions drawn from the findings, appropriate recommendations can be drawn from the concepts identified in the finding section. For example, the different operators in the infrastructure located in the offshore location should invest in hybrid sources of renewable energy, including extensive sources of storage and technology platforms. After analyzing the findings, it is evident that the integration of marine renewable energy is a significant enabler in the transformation and transition towards the use of offshore energy sources in the world today. Through the synergetic engagement of the industry, government, and academia, it is possible to transition the offshore structure from being carbon-based to being a low-carbon structure that can effectively contribute to sustainability criteria in the world today.

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