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Review

A Review of Offshore Wind and Wave Installations in Some Areas with an Eye towards Generating Economic Benefits and Offering Commercial Inspiration

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Abstract: Wind and wave energy have gained significant attention in recent years as high-quality renewable energy sources. Commercial applications of these technologies are still in their infancy and do not offer significant benefits to the general public due to their low economic efficiency. The main objective of this paper is to contribute to the commercialization of wind and wave energy. The first step toward achieving this goal is to review equation models related to the economic benefits of wind and wave energy. A case study approach is then used to examine several successful offshore wind and wave energy conversion devices. As a result of this examination, we identify limitations and difficulties in commercializing and developing wind and wave energy. Finally, we propose various measures to address these challenges, including technological innovation, policy support, and market regulation. Research and decision-makers interested in the promotion of renewable energy sources will gain valuable insights from this study, which will ultimately lead to the adoption of sustainable energy practices for the benefit of society and the environment.

Keywords: application; commercialization; case study; developing; economic efficiency; renewable energy; wind and wave energy

Citation: Zhang, Y.; Zhang, D.; Jiang, H. A Review of Offshore Wind and Wave Installations in Some Areas with an Eye towards Generating Economic Benefits and Offering Commercial Inspiration. *Sustainability* **2023**, *15*, 8429. https://doi.org/10.3390/su15108429

Academic Editors: Wei Shi, Qihu Sheng, Fengmei Jing, Dahai Zhang, Puyang Zhang and Antonio Caggiano

Received: 16 April 2023
Revised: 13 May 2023
Accepted: 19 May 2023
Published: 22 May 2023

1. Introduction

Over the past few years, as pollution has continued to occur, a growing awareness has been developed regarding the importance of protecting the environment. In addition, some regions are experiencing an energy crisis, and the need for energy is increasing. There has been an increase in the development and utilization of clean energy. By using wind and wave energy, we can reduce our dependence on fossil fuels, reduce our carbon dioxide emissions, and increase employment opportunities in the energy sector and related industries [1]. Thus, it is gradually gaining attention. Figure 1 illustrates this. It is also noted that the share of wind and wave energy in all energy sources is increasing year by year, indicating a great deal of potential for the future. Figures 2 and 3 illustrate this. A number of issues have emerged as the industry has developed, such as the low intensity of related equipment, low economic efficiency, unpredictable natural environments, and more. In the process of developing wind and wave energy, these issues are challenging tasks. They must be overcome.

The development of technology has resulted in the development of a wide range of wind and wave energy conversion devices. However, commercial development of wind and wave energy is still in its infancy. As a result of the numerous challenges it has encountered along the road to commercialization, its economic benefits have been difficult to demonstrate in support of its commercialization. As examples of these challenges, we can mention the efficiency of the device's energy conversion, its environmental impact, the risk of collision with offshore traffic, the maintenance costs, as well as its impact on other marine industries [2]. It is therefore imperative to overcome the limitations and challenges associated with commercializing wind and wave energy, as illustrated in Figure 4.

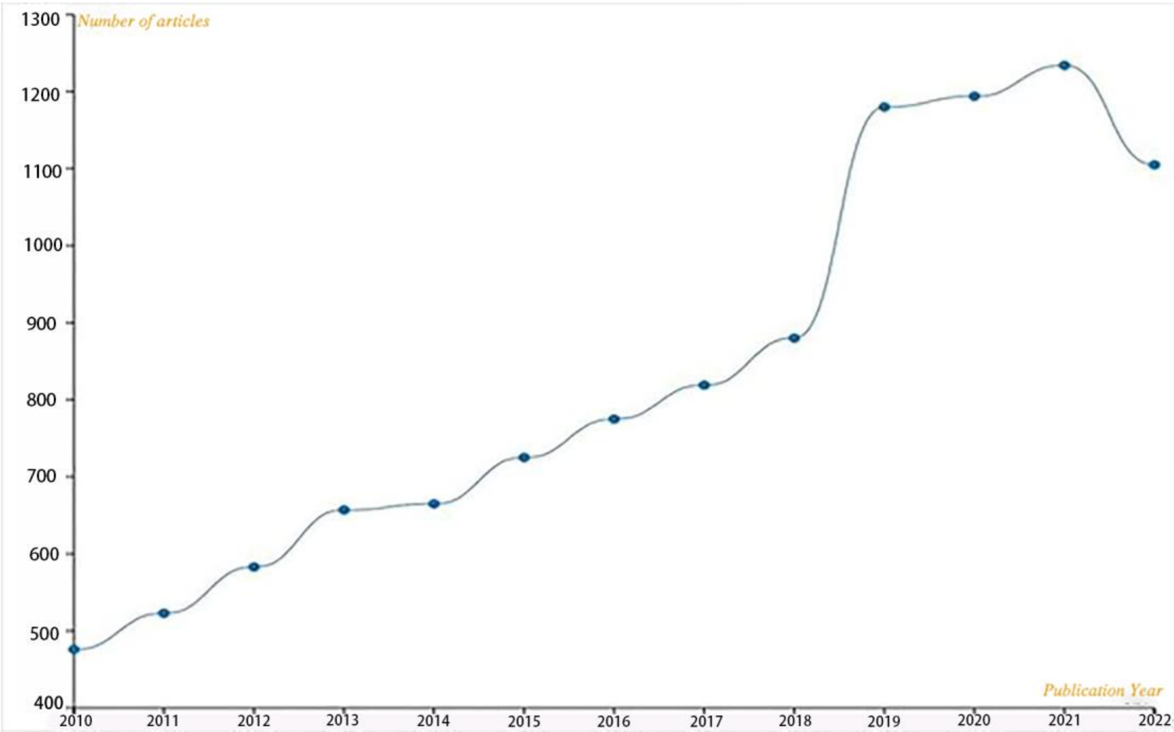

Figure 1. The number of published results about wind and wave energy in the Web of Science.

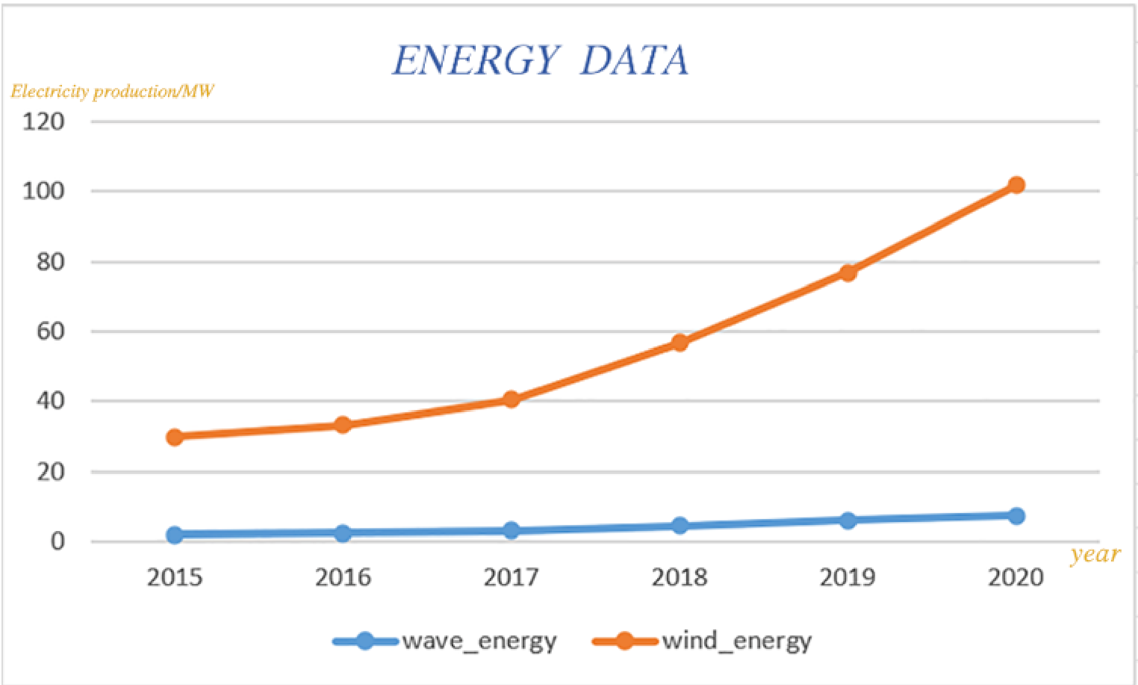

Figure 2. Wind and wave power generation production data (in MW) from https://www.nrel.gov/index.html, accesses on 10 January 2023.

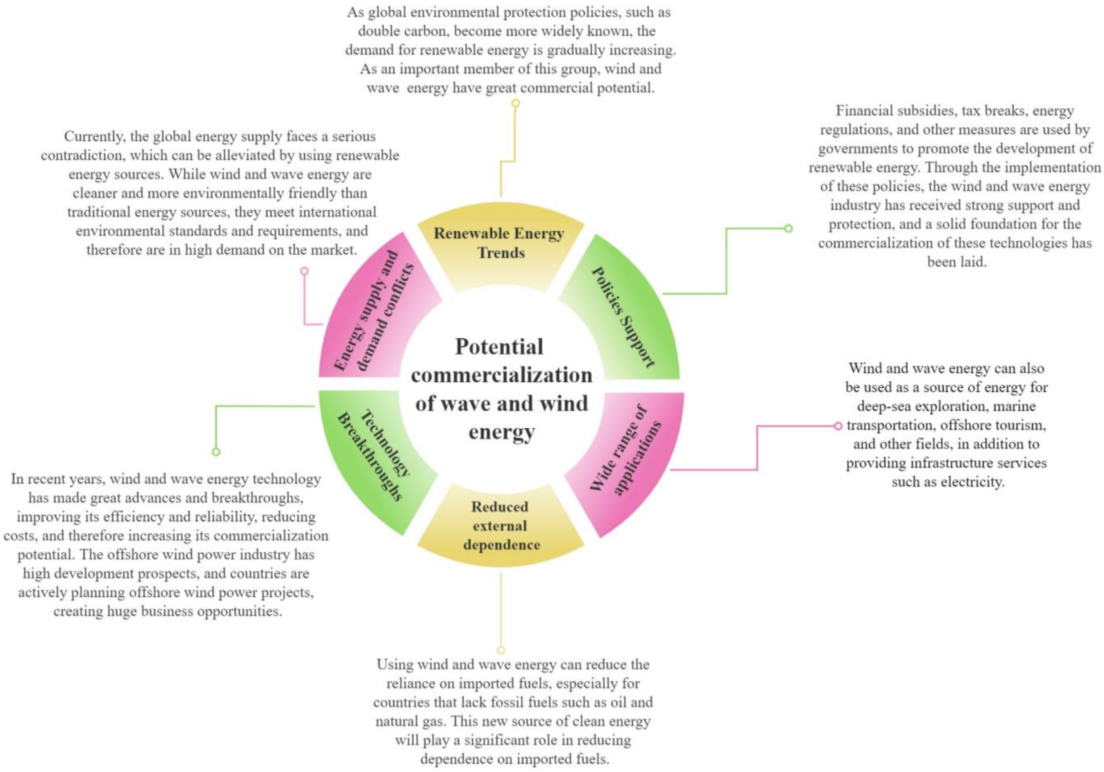

Figure 3. The factors that make wind and wave energy potentially commercially viable.

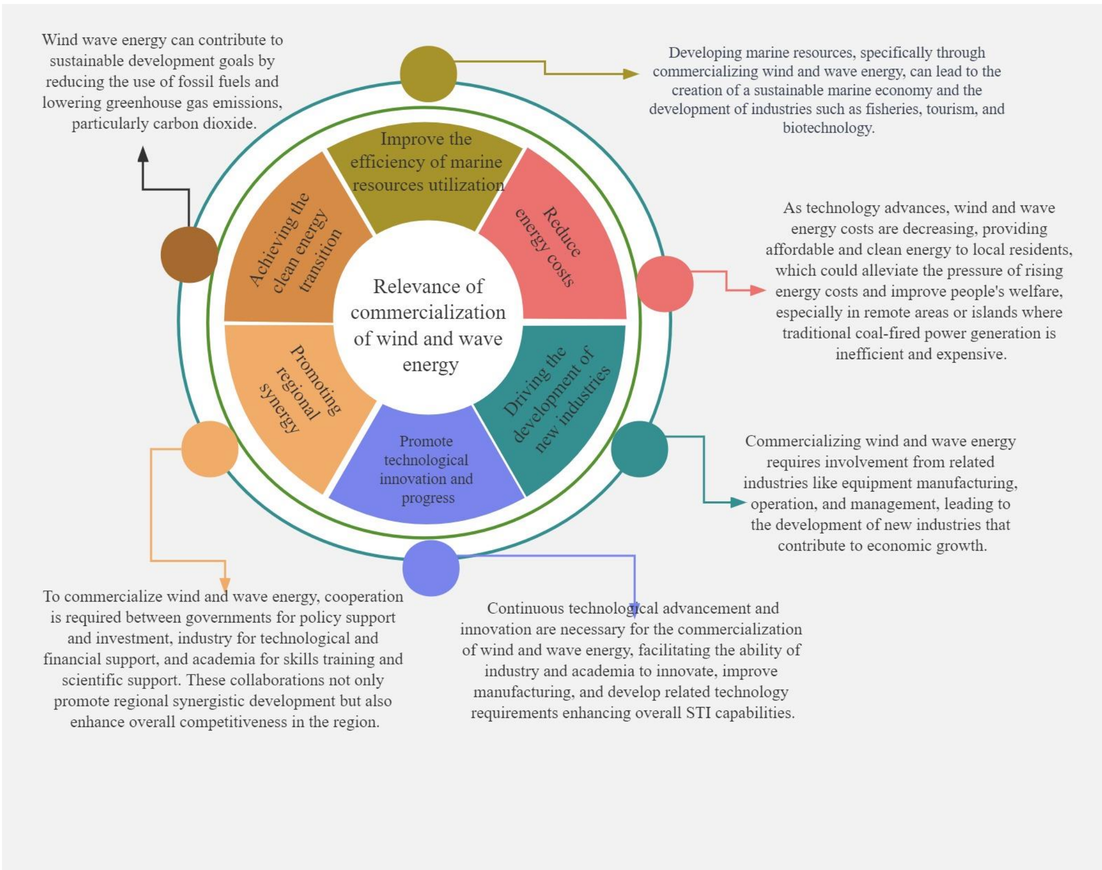

Figure 4. The relevance of commercializing wind and wave energy.

The purpose of this paper is to contribute to the further development of commercial applications of wind and wave energy. The method of this article is to make an overview of relevant papers on the economic benefits generated by wind and wave energy, as well as examples of installations that have been successfully deployed. An examination of the difficulties and limitations associated with the commercialization of wind and wave energy is provided through a general discussion encompassing both practical and theoretical aspects. A combination of theoretical and practical approaches is used in this article to analyze models related to economic efficiency. Using the elements of the model, real-life cases are analyzed in order to identify challenges and limitations, and then recommendations are provided. Figure 5 illustrates the research flow for this paper. It can be used as a reference for the development of wind and wave energy commercialization to some extent. This paper has the following specific research implications:

- As a result of the study and analysis of the economic benefit equation model, people are now better able to evaluate and study the investment value of wind and wave energy projects;
- A series of case studies summarizes the experience of successful offshore wind and wave energy conversion equipment, providing references for research and development in related industries, as well as ideas and directions for future improvements;
- This study analyses and discusses the limitations and difficulties of the wind and wave energy industries in order to assist researchers and policymakers in identifying the bottlenecks and developing appropriate solutions;
- In this study, we propose a strategy for promoting wind and wave energy commercialization, including policy support, technology improvement, and market promotion. This study assists in guiding the development of the industry as well as accelerating the adoption and diffusion of renewable energy in the energy industry.

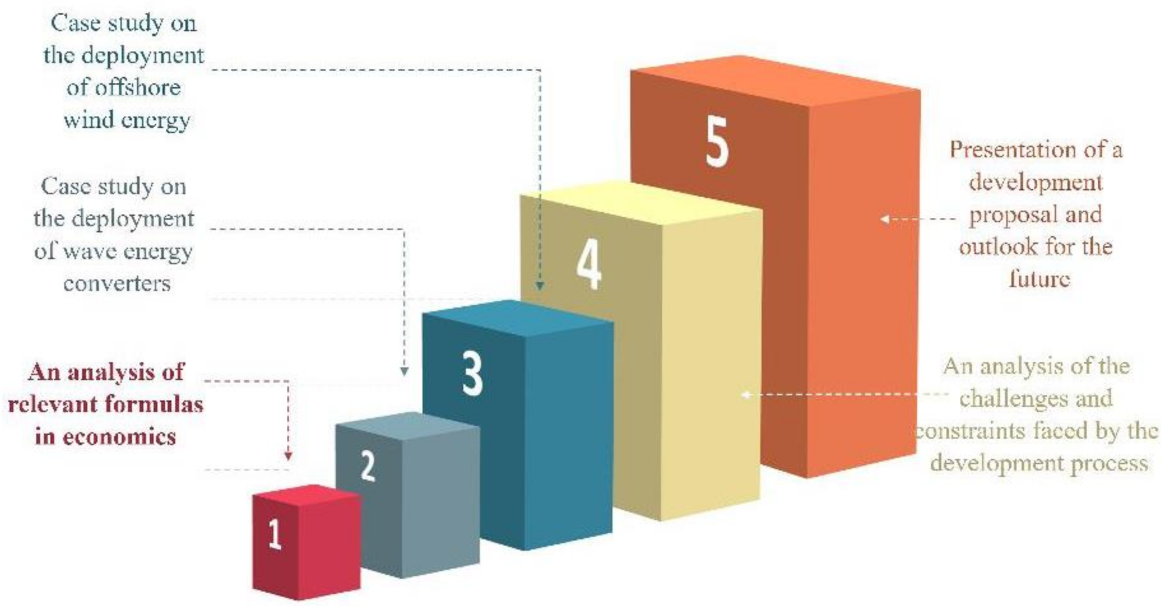

Figure 5. An overview of the study of this article is provided in the following flow chart.

Figure 2 illustrates that offshore wind power is much more commercialized than wave energy. As a result, this paper will primarily discuss offshore wave power generation.

2. Literature Review

2.1. Economic Efficiency Equation

Economic efficiency is typically improved through research on ways to reduce costs and increase returns. Here are five examples of cost equations that can be calculated by summing the costs associated with various aspects of wind and waves.

Choupin et al. divided the cost into several factors with their own weights and parameters. Equation (1) illustrates the mathematical expression. The total factor is calculated by multiplying the weights and parameters of each factor together. All factors are summed (represented by the variable "i") and all instances of each factor are summed (represented by the variables "j" and "ni"). By decomposing construction and operation into different components and tasks, the cost of each component and task is estimated. The purpose of this process is to assist in selecting the best configuration and site based on cost considerations [3].

$$Total\_factor = \sum_{i=1}^{nf} Factor_i = \sum_{i=1}^{nf} Weight_i Paramrter_i. \tag{1}$$

Choupin et al. developed an equation to calculate the string base cost of a wave energy converter (WEC). In accordance with Equations (2) and (3), string base cost is the sum of several components, including SW (structural engineering), SP (pickup system), SC (control system), MC (mooring and connection system), BU (buoyancy system), SOP (start-up and operating procedures), and SAM (site assessment and management). Each of these components constitutes the total cost of the WEC, and this equation provides a method for calculating the total cost based on the individual costs of each component [4].

$$\text{String}_{Total\_\cos t} = String_{Base\_\cos t} + String_{Total\_factor}; \tag{2}$$

$$\begin{aligned} String_{Base\_\cos t} = SW_{Total\_\cos t} + SP_{Total\_\cos t} + SC_{Total\_\cos t} + MC_{Total\_\cos t} \\ + Bu_{Total\_\cos t} + SOP_{Total\_\cos t} + SAM_{Total\_\cos t} \end{aligned}. \tag{3}$$

The study by Connor et al. focuses on the operation-related costs of the equipment, including operation and maintenance costs (O/M), average annual overhaul costs (AOC), and average replacement costs (ARC). Based on Equations (4)–(6). It is possible to estimate the total cost of maintenance and replacement using these three equations [5].

$$Total\_O/M = sum(O/M_{wec} + O/M_{mooring} + O/M_{cable}); \tag{4}$$

$$AOC = \frac{\sum (total\_overhaul\_\cos ts)}{project\_years}; \tag{5}$$

$$ARC = \frac{\sum (total\_replacement\_\cos ts)}{project\_years}. \tag{6}$$

Clark et al. developed a cost model. Co-located wind and wave energy arrays are included in the model along with their associated costs. Costs associated with preinstallation, implementation, operation, and maintenance (OPEX), and decommissioning are included in this category. In accordance with Equation (7). Using the model, we will be able to quantify the synergies of co-location and identify opportunities for cost savings [6].

$$C_t = C_{\text{Pre}-installation} + C_{\text{Im}plementation} + C_{OPEX} + C_{Decommissioning}. \tag{7}$$

Shafiee et al. provided Equation (8) as a cost breakdown structure (CBS) for the predevelopment and consent (P&C) phase of an offshore wind project. CBS is composed of five components: project management costs (C_{projm}), legal costs (C_{legal}), investigation costs ($C_{surveys}$), engineering costs (C_{eng}), and contingency costs ($C_{resount}$). Adding these costs together yields the total cost of the P&C phase (CP&C). The CBS is a tool used to identify and categorize all project costs. It allows the project manager to identify areas where costs can be reduced or optimized by breaking down the project's costs into components. In addition, it helps to ensure that all costs are taken into account and that no unexpected surprises arise during the course of the project [7].

$$C_{P\&A} = C_{projM} + C_{legal} + C_{surveys} + C_{eng} + C_{contingency}. \tag{8}$$

This equation provides a good assessment of the project costs of wind and wave energy and can be used to analyze the economics of the installations. For the commercialization of the wind and wave industries, however, good methods for estimating costs are necessary. A number of factors are used to analyze and predict the cost of wind energy projects, including the levelized cost of electricity (LCOE), net present value (NPV), return on investment (ROI), and marginal cost. The purpose of this section of the paper is to analyze these different evaluation metrics in order to identify their shortcomings and prepare the ground for the recommendations to follow.

2.1.1. Levelized Cost of Electricity

The levelized cost of electricity (LCOE) measures the cost and economic efficiency of renewable and non-renewable energy projects. The LCOE is a critical metric for wind and wave energy projects since it assists investors and decision-makers in evaluating and comparing the economic benefits of different types of energy projects. In the case of wind wave energy projects with a lower LCOE than other competing projects, the project will be more attractive since it is more likely to offer more competitive electricity rates. In addition to the costs and benefits of the wind wave energy project itself, the LCOE takes into account other factors, such as fees, taxes, and loan rates, making it a comprehensive metric that can assist investors and decision-makers in better understanding the economics and risks of a project.

Andres et al. proposed Equation (9), which illustrates how the net present value (NPV) of the capital and operating expenditures (CAPEX and OPEX) of a wave energy converter (WEC) project are related to the cost of energy (LCOE) and the average energy production (AEP) in megawatt hours per year (mwah/year) of the project. As a result of this formula, the total cost of the project is proportional to the cost of energy and the amount of energy produced. With the help of this formula, the authors of the paper were able to calculate the upper-cost limits for the different technical parameters of the WEC [8].

$$NPV \times (CAPEX \times OPEX) = LCOE \times AEP. \tag{9}$$

Kluger et al. developed an equation to represent the Levelized cost of energy (LCOE) for renewable energy projects. In accordance with Equation (10), the initial capital cost (ICC) refers to the total cost of building and installing a renewable energy project. The fixed cost rate (FCR) represents the annualized cost of capital, including borrowing costs and return on investment. Operational expenses are the costs associated with the operation and maintenance of a project over its lifetime. The annual energy production (AEP) of a project is the amount of electricity it is expected to generate each year. This formula can be used to compare the LCOE of different renewable energy projects and determine which are the most cost-effective [9].

$$LCOE = \frac{ICC \times FCR \times AOE}{AEP}. \tag{10}$$

An equation that can be used to calculate the levelized cost of energy (LCOE) for a wave energy converter (WEC) project has been provided by Andres et al. As shown in Equation (11), there are three main components of this equation: capital expenditures (CAPEX), operating expenditures (OPEX), and WEC production. This equation includes the sum over time, denoted by the variable "t", which ranges from 1 to "n", and the total project life cycle. As a result of the time value of money, the discount rate, denoted by "r", is used to reflect the fact that money earned or spent in the future is worth less than money earned or spent today. In the equation, the LCOE is calculated by adding capital expenditures to the present value of operating expenditures over the project's lifetime and dividing the sum by the present value of WEC production. The result is a measure of the cost per unit of energy produced by the WEC project [10].

$$LCOE = \frac{CAPEX + \sum_{t=1}^{n} \frac{OPEX_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{WEC\_Production_t}{(1+r)^t}}. \tag{11}$$

Têtu et al. provided an equation for calculating the levelized cost of energy (LCOE) for the wave energy concept. In accordance with Equation (12), A_f is the capital expenditure and the operating expenditure, and NAEP is the net annual energy production. As a result of this equation, both the initial investment and ongoing operating costs of a wave energy converter can be calculated. It is possible to assess the economic viability of a wave energy concept at an early stage of development by setting LCOE targets. By doing so, it is possible to identify potential improvements or modifications that could make the concept more economically viable [11].

$$LCoE = \frac{A_f \cdot CAPEX + OPEX}{NAEP}. \tag{12}$$

An equation for calculating the levelized cost of energy (LCOE) of a wave energy converter (WEC) plant is provided by Dallman et al. In Equation (13), the LCOE is used to compare the cost of energy production from different sources. This approach considers the cost of building and operating a power plant over the course of its life cycle as well as the amount of energy it produces. Capital expenditures (CAPEX), operating expenditures (OPEX), and annual energy production (AEP) are included in the equation. During the construction of WEC equipment, CAPEX refers to the initial cost, while OPEX includes ongoing costs, such as maintenance and repairs. FCRs are indicated by an asterisk, which indicates that they are fixed values determined by the terms of the financing [12].

$$LCOE = \frac{(FCR \times CapEx) + OpEx}{AEP}. \tag{13}$$

As shown in Equation (14), Farrell et al. provided an equation for calculating the levelized cost of energy (LCOE). This represents the total cost of the project, i.e., the sum of all costs incurred over the life of the project, discounted to its present value using a discount rate (r). In the denominator, the total energy generated over the life of the project is discounted to its current value using the same discount rate. The summation symbol (σ) indicates that the equation represents the sum of all the costs or energy generated over the project's life from year 0 (n = 0) to year N. C_n and Y_n represent the costs and energy generated in year N, respectively [13].

$$LCOE = \frac{\sum_{n=0}^{N} \left(C_n/(1+r)^n\right)}{\sum_{n=0}^{N} \left(Y_n/(1+r)^n\right)}. \tag{14}$$

For the design of wind farms, Feng et al. provided an equation for calculating the levelized cost of energy (LCOE). Equation (15) illustrates this. AEP is calculated based on the total capital expenditures (CAPEX) and annual operating expenditures (OPEX) of the wind farm. OPEX consists of maintenance, insurance, and other operating expenses, while CAPEX refers to the cost of the wind turbine and the rest of the power plant. A capital recovery factor (CRF) is also included in the equation, which represents the cost of financing the project. In this equation, OpexRef represents the reference operating expenditure, which represents the cost of operating and maintaining a wind farm of a certain capacity. CF is the capacity factor of the wind farm under consideration, which is the ratio between the wind farm's actual energy output and its maximum potential output. Equation (16) illustrates this. A wind farm's annual operating expenses (OPEX) are calculated using Equation (17). In this equation, the OPEX value ($Opex_{ref}$) is based on the capacity of the wind farm as well as a reference OPEX value. To determine the impact on operating expenses, the capacity factor is compared to a reference capacity factor (CF_{ref}). Using this equation, it is assumed that the OPEX increases by 0.5% for every 1% increase in capacity factor over the reference value. In contrast, a 1 percent decrease in capacity factor results in a 0.5 percent reduction in operating expenses [14].

$$LCOE = \frac{CAPEX_{\text{total}} \times CRF + OPEX_{\text{annual}}}{AEP}; \tag{15}$$

$$CF = \frac{P_{total}}{Capacity}; \tag{16}$$

$$OPEX_{annual} = opex_{ref} \times Capacity \times [1 + 0.5 \times (CF - CF_{REF})]. \tag{17}$$

It is acknowledged that the LCOE plays an important role in assessing the economic benefits of wind and wave energy; however, the following drawbacks have been identified from the above review:

i. The LCOE fails to adequately consider the social and environmental impacts of energy projects. As an example, even if an energy project has a low levelized cost of energy, its environmental and public health impacts may add other costs to the project;
ii. The LCOE can only be used to make a rough comparison between different types of energy projects, but cannot be used to compare different energy projects of the same type. Various types of energy projects have different generation methods, risks, and market conditions;
iii. Market and policy changes, including fluctuations in electricity demand and changes in policy, cannot be predicted by the LCOE;
iv. Assumptions and estimates are used in the calculation of LCOE, such as maintenance costs, project life, etc., which can affect its accuracy;
v. There may be differences in LCOEs between countries and regions due to market conditions and policy differences, which may result in different LCOEs for the same energy project.

2.1.2. Net Present Value

A net present value calculation is used to evaluate the economic benefits of an investment project. By converting all future cash flows to their present value, it determines the value of a project. The NPV can be used to predict the economics of wind and wave energy projects and to assess their feasibility. In order to calculate the net present value of a wind wave energy project, various possible benefits and costs need to be modeled. Investors can make better investment decisions by understanding the risks and potential rewards of wind wave energy projects by utilizing the NPV model.

Guanche et al. provided the formula for calculating the net present value (NPV) of wave energy projects. As shown in Equation (18), in finance, the net present value (NPV) represents the present value of future cash inflows and outflows of a project, discounted at a particular rate of return (r). According to the formula, the NPV is equal to the sum of all future cash inflows (FV) minus the initial investment (I_0). Divide the present value of each cash inflow by (1 + r) multiplied by the number of years between now (t) and the receipt of the inflow. This sum of all current values is then calculated for the entire project life cycle (n_y). This formula is used to analyze the financial uncertainty associated with wave energy projects. As a result of climate variability, there was an increase in uncertainty [15].

$$NPV = \sum_{t=1}^{n_y} \frac{FV}{(1+r)^t} = -I_0 + \sum_{t=1}^{n_y} \frac{Annual\_\text{Revenue} - Operation\_\text{Cost}}{(1+r)^t}. \tag{18}$$

Teillant et al. provide a mathematical equation for calculating the net present value (NPV) of a wave energy project. According to Equation (19), there are two other terms used in this equation: FCF (free cash flow) and DCF (discounted cash flow). The equation is expressed as a sum, where y represents the cash flow year and y represents the last year of the project. For each year of the project, the equation calculates the sum of discounted cash flows. As a percentage, Rd represents the discount rate used in the equation. A project's economic value can be evaluated using this equation [16].

$$NPV = \sum_{y=0}^{Y} \frac{FCF(y)}{\left(1 + \frac{R_d}{100}\right)^y} = \sum_{y=0}^{Y} DCF(y). \tag{19}$$

Based on the above review, it is concluded that the calculation of the NPV should be based on accurate cash flow forecasts; however, the cash flow of re-wind energy projects is affected by a variety of factors, such as weather changes, market demand, and policy changes, which makes it difficult to forecast, and if the forecast is incorrect, this affects the accuracy of the NPV calculation results. Furthermore, re-wind energy projects usually require large-scale engineering construction, requiring a considerable amount of capital and time. The NPV calculation may be affected as a result of the lengthy capital payback period and the need for long-term financial support, such as government subsidies. Finally, re-wind wave energy projects also need to face challenges from social factors, including equipment maintenance and renewal costs, and local residents' opposition to wind turbine airport construction, which may have an impact on the NPV calculation results and project feasibility.

2.1.3. Return on Investment

The return on investment (ROI) is a measure of the rate of return on an investment project that is often used to determine the economic benefits of an investment. When predicting the economic benefits of a wind and wave energy project, the ROI can aid investors in predicting the project's return rate and level of risk. By calculating the ROI, investors can determine whether or not the wind and wave energy project they are investing in will generate sufficient profitability to justify the investment.

Walmsley et al. studied the calculation of energy return on investment (EROI), defined as the ratio between the energy produced by a wind farm (e_{gen}) and the energy input needed to build and operate the wind farm (e_{input}). Equation (20) illustrates this. It is important to note that the numerator of the equation represents the energy generated by the system (E_{gen}), while the denominator represents the sum of all energy inputs required to build and operate the system (E_{foad}, E_{cable}, E_{earth}, $E_{materials}$, E_{trans}, and E_{op}). Consequently, the ratio represents the system's energy production efficiency [17].

$$EROI = \frac{E_{gen}}{E_{road} + E_{\mathrm{cable}} + E_{materials} + E_{trans} + E_{op}}. \tag{20}$$

Abdullah et al. presented case studies on the use of renewable energy technologies to promote economic development in rural areas. For some of the case studies presented, we calculated the return on investment (ROI). According to the study, this method can help determine whether an investment is profitable and whether it is a worthwhile investment. Additionally, it facilitates the comparison of different investment options and the selection of the one with the highest return on investment [18].

Kittner et al. compared the EROI of microhydroelectricity and solar power. In accordance with Equation (21), an energy return on investment is defined as the EROI. A system's efficiency can be expressed in terms of the $E_{materials}$, $E_{Lifetime\_output}$, $E_{Manufacturing}$, $E_{Transport}$, $E_{install}$, the $E_{end\text{-}of\text{-}Life}$, which represent the energy required for material, total energy output through its life cycle, manufacturing, transportation, installation, and disposal at the end of its life cycle, respectively. According to the study, distributed mini-grids with solar PV penetration rates of up to 50% can outperform some conventional centralized grid systems that use fossil fuels. The results of the study indicate that small hydro plants have a higher return on investment than solar PV plants [19].

$$EROI = \frac{\frac{E_{lifetime\_output}}{\eta}}{E_{materials} + E_{manufacturing} + E_{transport} + E_{install} + E_{end-of-life}}. \tag{21}$$

According to the review above, the ROI calculation does not include the inflation factor. Inflation may increase the investment cost of wind and wave energy projects, but the ROI only measures the relationship between investment return and investment cost. In addition, the ROI does not take into account the time value of cash flows. The ROI does not reflect the impact of timing differences between investment returns and investment costs, while the time value of cash flows may cause the ROI to understate or overstate actual returns. Furthermore, the ROI does not reflect the project's long-term benefits. While wind and wave energy projects may have long-term profit potential, the ROI only considers returns on investment and investment costs in the short term, and does not consider long-term returns.

2.1.4. Marginal Cost

In the economic evaluation of wind and wave energy projects, marginal cost plays an important role. It is possible to measure and control production costs by calculating marginal cost, which determines the additional cost of each additional unit of electricity generated. A marginal cost calculation can also assist companies in determining the output that maximizes economic efficiency. In order to achieve optimal economic efficiency, marginal costs must be compared with market prices. Additionally, marginal costs play an important role in determining the cost of flexibility in wind and wave energy projects. The marginal cost calculations and analysis can assist companies in reducing costs and improving efficiency to ensure maximum economic efficiency at any level of production if production volumes are required to be adjusted in response to changes in market demand.

Zhao et al. utilized the rotor inertia of a wind turbine as a short-term energy storage device to smooth the marginal cost in the context of fluctuating power from the wave industry that sometimes reduces the efficiency of wind energy capture. At different wind speeds, the proposed overall compensating control allows the turbine speed to oscillate around its optimum point, thereby smoothing the total power output of the wind farm [20].

Stoutenburg et al. discussed the marginal cost of a transmission system for a farm located 60 km offshore near buoy 46030 and how distance increases the marginal cost box for levelization vertically as distance increases cable supply and installation costs. The paper explains how distance increases the marginal cost box for levelization by raising the cost of cable supply and installation vertically [21].

In the review above, it was found that the initial investment costs for wind and wave energy are typically high and that marginal costs do not fully reflect these costs. The impact of initial investment costs on the economic benefits of wind and wave energy projects also needs to be taken into account when assessing the economic benefits of wind and wave energy projects.

2.2. Energy Conversion Capacity

As can be seen from a review of some of the equations above, the energy conversion capacity of wind and wave energy devices has a significant impact on the economic efficiency of the wind and wave energy industry. Such problems are currently being studied using mathematical methods and computer simulations.

2.2.1. Simulation and Modeling

In order to develop offshore wind and wave power generation devices, the insights provided by Komori et al. on the turbulent structure and scalar transfer mechanism of wind-driven turbulence with wind waves and ripples are of great importance. The reason for this is the presence of shear at the interface between liquid and gas in offshore wind and wave power generation devices as well as the complexity of the turbulent structure created by waves and wind. Thus, by gaining a better understanding of the turbulence structure and scalar transfer mechanisms, offshore wind and wave power generation devices can be improved to improve their performance and efficiency as well as reduce the cost of energy generation [22].

Li et al. examined the dynamics of water waves generated by the main phases of Miles-Phillips mechanism. To capture multistage water waves generated by turbulent winds over initially calm water, the authors conducted high-resolution direct numerical simulations. They introduce the stochastic sweeping assumption of barometric fluctuations into Phillips' theory in order to propose a stochastic sweeping turbulent pressure-wave interaction model. Wind and wave energy can be commercialized to some extent as a result of this research. This study further explores and validates Phillips' theory of wind-wave generation. Using high-resolution numerical simulations, the researchers obtained more refined data on the wind-wave generation process, which contributes to the understanding and study of the mechanism for wind-wave generation. Additionally, the stochastic swept turbulent pressure-wave interaction model proposed in this study provides new ideas and methods for the development of wind-wave energy. By assuming a stochastic sweep for the pressure fluctuations, it is possible to better simulate the complex wind-wave interaction process, improving the efficiency of wind-wave energy collection. The model will require further experimental validation and engineering applications before it can be applied to commercial development [23].

A fully coupled analysis of an integrated floating wind and wave power platform was conducted by Chen et al. under a variety of sea conditions. An analysis of the dynamics characteristics of the platform and the energy conversion efficiency of the wind-wave power generation system is presented in the paper. Furthermore, sensitivity analysis and optimized design are carried out in order to verify the accuracy of the mathematical model. The results of this study will be of great assistance to the commercialization of wind and wave energy. Using the fully coupled analysis of the integrated floating wind and wave power platform under a variety of sea conditions, it becomes possible to evaluate the platform's performance and energy capture capabilities more accurately, which provides a scientific basis for its commercial application. In addition to sensitivity analysis and optimization design, the paper provides references for further improvements and performance enhancements of the platform [24].

2.2.2. Mathematical Equations

A mathematical model is constructed in order to be able to quantify the object of study accurately. In order to estimate the energy conversion capacity of wind and wave projects, a good equation construction is very important.

It is essential to accurately assess the power generation of an installation in order to develop and plan related technologies and projects. An accurate assessment of power can assist in evaluating new technologies and optimizing specific projects. The inaccuracy of power assessments can result in errors in the design and operation of installations, which can result in lower efficiency and higher costs, negatively affecting the economics of the equipment. As a result, accurate power assessments are crucial to studying the economics of wind and wave installations and to enabling their commercialization [25,26].

A renewable power factor (RPF) can be calculated using Equation (22) by Stefek et al. A renewable power factor (RPF) is a measure of the variability of the power output of a renewable energy system, such as a solar panel or a wind turbine. *Max (P)* represents the maximum power output of the system, *Min (P)* represents the minimum power output, and *Pavg* represents the average power output. The numerator of the equation calculates the difference between maximum and minimum power output, while the denominator calculates average power output. The RPF value can be obtained by dividing the numerator by the denominator. This value provides an indication of how much the power output fluctuates over time and is useful for evaluating the performance of renewable energy systems [27].

$$R_{PF} = \frac{Max(P) - Min(p)}{P_{avg}}. \tag{22}$$

The following Equation (23) was developed by Yu et al. The oscillating surge wave energy converter (OSWEC) generates hydraulic power (*HP*). There are three variables that are taken into account in the equation: power (*P*), flow rate (*Q*), and efficiency ($\alpha 1$). OSWEC performance and economic viability are greatly influenced by the hydraulic power generated by the device. Based on the flow rate of the water and the efficiency of the power conversion system, this equation is used to estimate the power that can be generated by the equipment [28].

$$HP = \frac{P \times Q \times \eta_1}{1714}. \tag{23}$$

According to Biyela et al., the power output of a WEC is proportional to the number of waves passing through it and the frequency of these waves. Equation (24) was proposed. As a result, the power output (*P*) of the wave energy converter (WEC) is expressed in terms of the number of waves (*N*) and the frequency of the waves (*f*) during a given period of time (*t*). As the number of waves increases, the power output return decreases. This phenomenon can be explained by using the natural logarithm. In order to convert the frequency of waves from cycles per second to periods per wave, the constant value 2 is used. This model provides a means of estimating the potential power output of different WEC technologies. The researchers can determine which technology is more economically viable by comparing the power output of different technologies [29].

$$P = N \exp(\ln(tf)/\ln(2)). \tag{24}$$

Castro-Santo et al. provided a computational equation that represents the power generated by a wave energy converter (WEC). As shown in Equation (25), this equation includes the power generated by the WEC (P_{WEC}), the number of wave periods considered (n_t), the probability of occurrence of a wave of height *i* and period *j*, and the power generated by the WEC for a wave of height *i* and period *j*. As part of the energy phase of the method developed in the paper, this equation is used to determine the amount of energy generated by each WEC. In the economic phase, the generated energy is used to calculate the WEC's economic parameters [30].

$$P_{WEC} = \frac{1}{100} \times \sum_{i=1}^{\mathrm{n}_T} \sum_{j=1}^{n_H} p_{ij} \times P_{ij}. \tag{25}$$

A mathematical equation was developed by Sirigu et al. in order to represent the unit mass of the peWEC (pendulum wave energy converter). Equation (26) illustrates this. There are several components in this equation, including the mass of the unit peWEC (M_{unit}), the buoyancy coefficient constant (β_U), the total mass of the peWEC (M_{tot}), the mass of the hull ($\mathrm{M_h}$), and the number of pendulums in the peWEC (N_p). It is important to consider the unit mass when designing the peWEC since it has a significant impact on the device's overall performance and efficiency. In order to maximize efficiency and cost-effectiveness, this equation calculates the optimal unit mass of the peWEC. It is possible for the device to produce more energy while minimizing the cost of electricity by minimizing the unit mass [31].

$$M_{\mathrm{unit}} = \frac{\beta_u (M_{tot} - M_h)}{N_p}. \tag{26}$$

As described by Lavidas et al., Equation (27) is a mathematical expression that represents the wave energy device index (WEDI). The WEDI measures the efficiency of a wave energy converter (WEC) in converting the power of waves into electrical energy. A power output average over a given time period is represented by the numerator of the equation, *Pwave*. WEC power output is determined by the wave energy flux, WEC efficiency, and WEC characteristics. A wave energy flux at the site of the WEC is represented by the denominator of the equation, *Jwave*. As a result of integrating the wave energy flux over time and dividing by the duration of the integration period, this value is obtained. In financial analysis and project planning, the WEDI can be used to estimate the potential energy output of the WEC at particular locations based on wave height, wave period, and water density [32].

$$WEDI = \frac{\overline{P_{wave}}}{\overline{J_{wave}}}. \tag{27}$$

Chen et al. provided a formula for calculating the average power output of a point absorber wave energy converter. As can be seen in Equation (28), P_{ave} is the average power generated, T_p is the wave period, B_{pto} is the damping factor for the takeoff (PTO), $\dot{x}_3^2$ is the float's velocity in lift direction, and τ is the time variable. The equation is derived from a time-domain model based on the Cummins equation, which describes the motion of the float under wave excitation. It is modeled as a linear spring-damper system that behaves similarly to a trilinear damper system that limits the motion of a float. According to the equation, the average power generation is proportional to the PTO damping factor and the square of the float's velocity. In a wave cycle, the integral represents the average time during which power is generated. As a result of this equation, a point absorber wave energy converter can be measured quantitatively for its efficiency in generating power. Using this method, it is possible to optimize the design of the power output device system and the end point mechanism so that the power generation efficiency can be improved under different sea states where the wave cycle prevails [33].

$$P_{\mathrm{ave}} = \frac{1}{t_p} \int_0^{t_p} B_{pto} \dot{x}_3^2(\tau) d\tau. \tag{28}$$

In Sheng et al., an equation was presented that represents the calculation of the power matrix of the BBDB OWC device. Equation (29) illustrates the equation. In this equation, p_{irr} represents the power matrix of the device in an irregular wave. In the limits of integration, the integer ω represents the sum of all values of the function. A function being integrated is the product of two other functions; the first is denoted by the symbol p_{rag} (Ω) and the second by the symbol S (Ω). This function represents the power response curve of the BBDB OWC device in a regular waveform. The graph shows the relationship between the wave frequency and the power output of the device. The function S (Ω) represents the wave spectrum, which is a measure of the distribution of wave energy in relation to frequency. The wave spectrum represents the wave climate at a particular location. The integral of the product of these two functions over all frequencies represents the power matrix of the device in the irregular wave. As a measure of the power performance of the device, this value represents the amount of energy that can be extracted from waves during a given period of time [34].

$$P_{\mathrm{irr}} = 2\int_0^{\infty} \overline{P}_{reg}(\omega) S(\omega) d\omega. \tag{29}$$

Sirigu et al. provided an equation to represent the mechanical power produced by the ISWEC (inertial wave energy converter). Equation (30) illustrates the equation. P_{Mech} is the mechanical force generated, φ is the angular velocity of the flywheel, and a_1 and a_2 are coefficients that depend on the design of the ISWEC. The importance of this equation lies in the fact that it enables the designers of the ISWEC to optimize the design of the system in order to maximize the mechanical power generated while minimizing the cost. Designers can test different configurations and parameters using a mathematical model to simulate the behavior of the system [35].

$$P_{Mech} = a_1 \varphi + a_3 \varphi^3. \tag{30}$$

2.2.3. Limitations

Based on the review in this section, it is evident that both the mathematical approach and the simulation approach require specific cases and, therefore, specific analyses. In reality, the situation is much more complex and variable. In order to estimate the economic benefits of wind and wave energy, a systematic approach is necessary.

2.3. Wave Energy Converter

According to their location, conventional wave energy converters can be classified into three general types. The equipment that is designed for onshore use is usually installed at or near the shoreline, the equipment that is designed for offshore use is generally installed in deep water (water depths greater than 40 m), and the equipment that is designed for nearshore use is generally deployed in shallow water (water depths less than 20 m) [36].

As a result of these similarities and differences, the analysis is focused on wave energy conversion devices deployed in the Mediterranean Sea, Indonesia, Eastern Pacific Ocean, Indian Ocean Area, and North Sea.

The similarities:

- There is a high energy demand in these areas due to their large populations;
- These areas have developed fisheries and are rich in species, and these success stories can be used to study the prevention of conflicts between wave energy devices and fisheries and the environment.
- The differences:
- In each region, the climate varies and the wave energy is different;
- The salinity and depth of seawater varies from region to region;
- Regions of the world have very different marine ecosystems and species of organisms.

All of these similarities and differences lead to different constraints on the wave energy contained in these areas and on the deployment of wave energy converters. As a result, these areas are representative to some extent.

2.3.1. Mediterranean Region

In the Mediterranean, wave energy converters have provided clean energy to some small islands. In addition to providing sufficient energy for economic development, it is a renewable resource.

The Resonant Wave Energy Converter 3 (REWEC3) is a wave energy converter that belongs to the oscillating water column (OWC) family of wave energy converters. Similarly to conventional OWCs, it consists of an oscillating water column and an air cavity connected to the turbine. Moreover, it contains a small vertical U-shaped pipe that connects the water column to the open wave field. It is an important feature of the REWEC3 that the natural period of the water column can be adjusted to match the desired wave period by adjusting the size of the U-shaped pipe. The RWECS3 is characterized by its resonant design, which allows it to efficiently capture the energy of ocean waves across a wide frequency range. It is capable of operating in waves as small as one meter in height and can withstand extreme weather conditions, such as hurricanes and typhoons. Furthermore, the REWEC3 is also suitable for small wind farms located in shallow waters. Consequently, it may not be suitable for larger projects in deeper water, where larger turbines and foundations may be required. There is a power plant currently operating in the port of Civitavecchia (Rome, Italy) that relies on a REWEC3 for electricity generation. A total of 17 caissons, each with eight chambers, make up the REWEC3 infrastructure [37]. As shown in Figure 6. Dielectric elastomer generators (DEGs) convert mechanical energy into electrical energy by deforming an elastic membrane to large amounts. To improve the efficiency of power generation, Moretti et al. initially designed a full-size U-OWC with a DEG-PTO. According to research, the DEG is a promising solution for U-OWC, as it may perform as well as or better than an air turbine, despite its simpler structure. Figure 7 illustrates this [38].

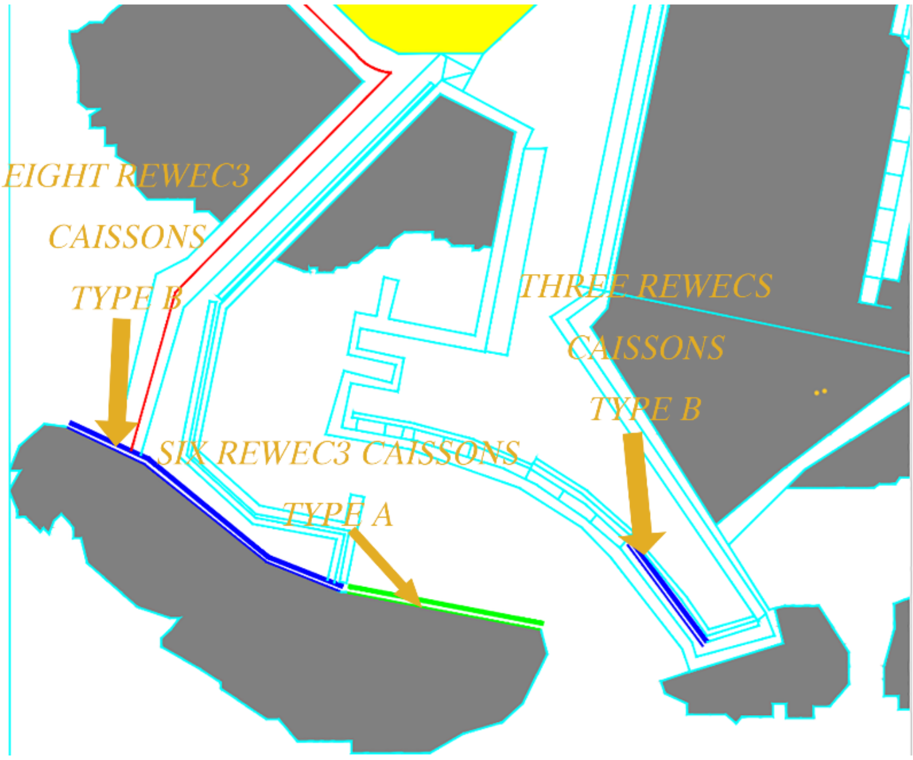

Figure 6. Location of the REWEC3 caissons in the new dock, from [37].

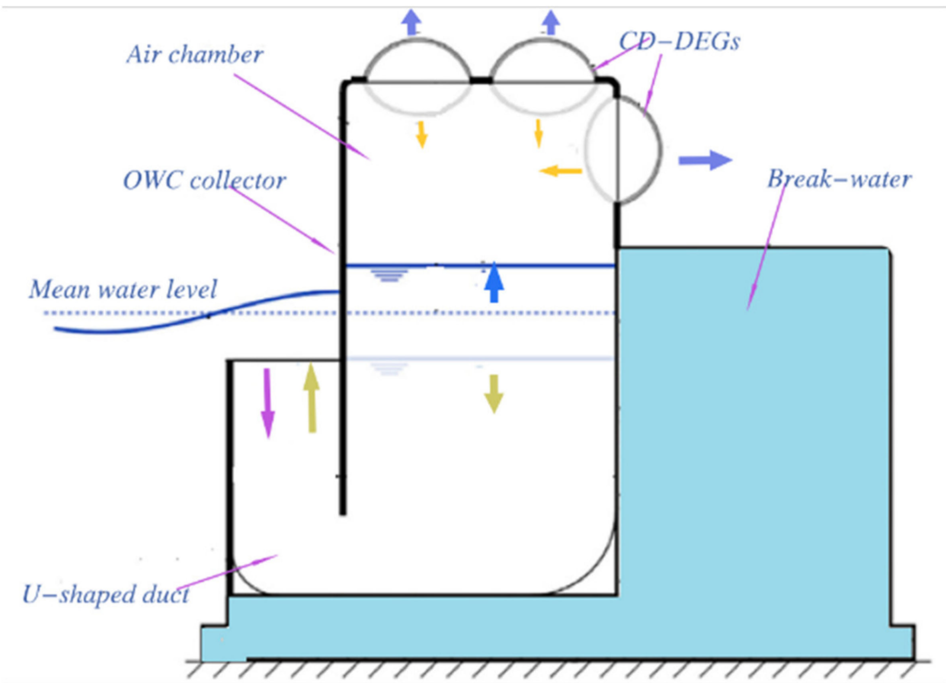

Figure 7. Breakwater integrating a U-OWC with CD-DEGs, from [38].

In order to overcome the low economic efficiency caused by the high construction costs, the Port of Naples built the world's first wave energy converter fully integrated within a breakwater structure. The device is called OREC (overtop breakwater for energy conversion) [39]. As the device is fully integrated into the breakwater structure, it is protected from wear and tear and damage from the marine environment, thereby increasing its reliability and longevity. Although the equipment requires large-scale civil works and marine operations, its construction process is complicated and time-consuming. In Figure 8, a cross-section of the prototype OBREC is shown in the port of Naples.

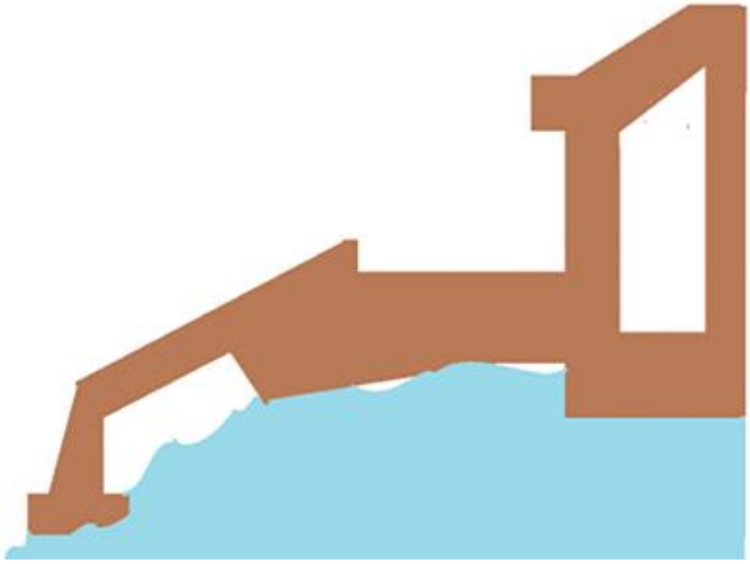

Figure 8. Cross-sections of the OBREC prototype in the Naples harbor, from [39].

Since the Mediterranean Sea has shorter waves with higher frequencies, Pozzi et al. developed a pendulum converter (PeWEC: pendulum wave energy converter). It consists primarily of a floating hull attached to the seabed and a pendulum, which is integral to the structure of the hull [40]. Even though PeWEC is capable of being deployed in waters other than shallow waters, it requires a certain amount of ocean space, which may be a limiting factor in some waters where vessel traffic or other activities are required.

As with the PeWEC, the inertial wave energy converter (ISWEC) is a power generation device enclosed inside a hull. It has the advantage of increasing equipment's durability. The ISWEC works by the following mechanism: first the waves force the hull to pitch, then the pitch is transmitted to the gyroscope system located on the internal platform of the buoy. Due to the gyroscopic force exerted by the rotating flywheel, torque is generated on the main shaft, and finally the power transmission converts the torque into electrical energy. The ISWEC is easy to maintain and highly adaptable to the aquatic environment. Due to its installation requirement, its deployment is subject to a high upfront cost due to the high cost of installation. On the island of Pantelleria, ISWEC was launched in August 2015 [41].

2.3.2. Indonesia

Increasing demand for energy has accompanied Indonesia's economic growth as the 16th largest economy in the world. Being the largest archipelagic nation in the world, harnessing its abundant marine resources can be an important component of solving the energy crisis.

There are several species of fish that are attracted to fish aggregation devices (FADs), which are environmentally sustainable artificial marine infrastructures. A small tidal turbine with FAD was appropriately designed by Mutsuda et al. by studying the tidal characteristics of the Indonesian archipelago. The purpose is to supply power to the archipelago independently [42]. Small tidal turbines equipped with FAD are not required to be fixed to the seabed since they can float on the surface, eliminating the need for drilling and other costly activities. A FAD may also be fixed to the seabed by means of coupling devices, such as ropes or chains, thereby maintaining some stability. In addition to its modular design, the turbine is low-cost, easy to deploy, and reusable. The small tidal turbine with FAD does, however, have some limitations. As a result of its small size, it generates less power.

An oscillating water column array system consisting of oscillating water column conversion devices has been constructed in South Java waters. It is possible to obtain renewable and clean energy by converting wave potential energy into kinetic energy. In Figure 9, you can see the structure of the oscillating water column converter [43].

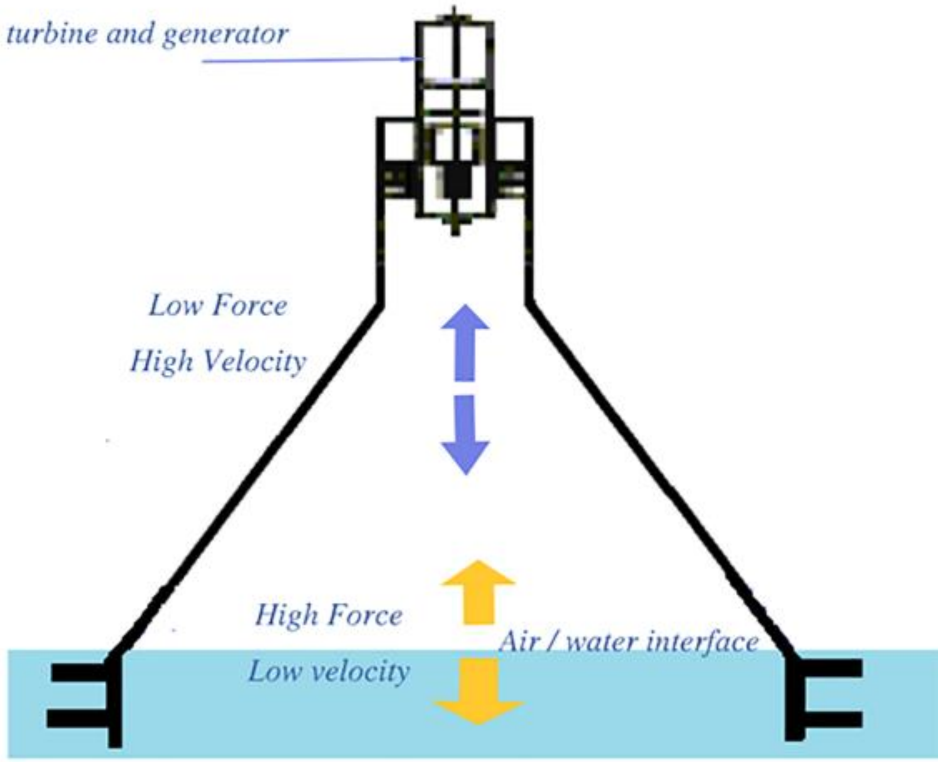

Figure 9. A sketch of floating oscillating water column wave energy converter, from [43].

Hantoro et al. developed an easy-to-operate and maintain oscillating wave transition pendulum system (OWC-PS). It consists of a cylindrical float as the main hull and two reaching arms on one side. This can be seen in Figure 10. The whole train system was found to be more efficient and effective at obtaining wave energy than a single unit [44]. By using the most advanced power electronics and control systems, OWC-PS units are more reliable and stable. To generate sufficient power, OWC-PS units must be installed in waters with relatively high wave energy, making the choice of waters more challenging.

2.3.3. Eastern Pacific Region

Menco et al. have designed a one-wave power system that comprises a buoy with mechanical devices and a linear generator. This device is called a floating linear generator wave energy converter (FLGWC). The device was designed to operate in the Colombian Pacific. The device may be placed on the sea surface (in shallow water), in a breakwater, in a dam, or fixed to a cliff. In most cases, the location of the converter is accessible, which makes maintenance and installation easy [45].

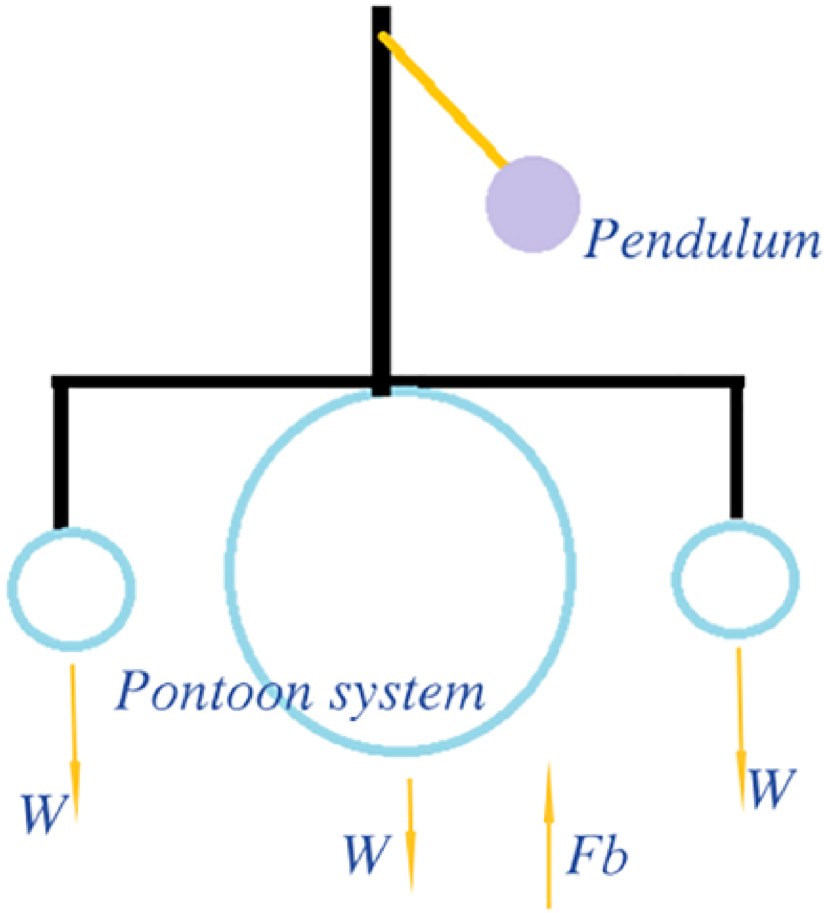

Figure 10. Schematic of WEC-PS, from [44].

The west coast of the United States is bordered by the eastern Pacific Ocean and is rich in marine resources. Recently, some energy agencies have been focusing more and more attention on the development of wave energy converters as the US government pays increasing attention to the development of wave energy. Columbia Power developed a hydroelectric device called StingRAY. Ultimately, StingRAY is intended to be able to operate in deep water. StingRAY is classified as a wave-activated body that captures wave and surge forces. A composite hull is used as well as a direct-drive rotating generator [46]. With its own rudder and depth control system, StingRAY is capable of autonomous navigation and position adjustment. It is capable of working at a variety of depths on the seabed, even in harsh marine environments. Due to the fact that StingRAY must be installed and maintained in deeper areas of the ocean, this presents certain challenges for both personnel and equipment. The safety of maintenance personnel is at risk in harsh marine weather conditions, for example.

A device called WaveCarpet is being developed by California Wave Power Technology. This device is classified as an underwater pressure differential WEC [47]. A WEC called Centipod is being investigated by Ecoli Technologies. With Centipod, power is extracted from wave lift and sink by five-point absorbers that use a common, stable floating reference structure [48]. Among the major advantages of Centipod is its wide range of applications and its ability to operate in a variety of water flow conditions; however, it is highly dependent on the weather. The construction of Centipod equipment may have irreversible effects on the ecology of the aquatic environment, such as affecting fish migration and spawning.

Northwest Energy Innovations Corporation (NWEI) has developed a WEC called Azura, which is a wave-activated device that is capable of operating in both lift and pitch. In Oregon, the company has successfully deployed the device. As a result of funding from the US Department of Energy, the team has now placed its Azura device on the water. It is connected to the Hawaii power grid [49]. Azura can be used in a wide range of tidal conditions for a variety of applications. Due to the marine environment, Azura equipment is more complex and relatively more difficult to maintain and repair.

2.3.4. Indian Ocean Area

TheM4 machine is a wave energy generation unit used in Obani, Western Australia,. There are three floats in this M4 machine, each of which is a vertical circular cylinder with a hemispherical lower end. The two smaller floats are rigidly connected by a beam above the water, and the largest float is connected to the middle float by a second beam; this beam is rigidly connected at the third and largest float, but hinged at the middle float. By rotating the hinge above the middle float, the machine's power converter generates power [50]. Designed with a simple and reliable structure, the M4 wave energy converter reduces operating costs and maintenance expenses. Although the construction cost of the M4 wave energy converter is high, it requires a significant amount of capital and human resources. Additionally, the construction and operation of the M4 wave energy converter may have an impact on the marine ecology, including the flora and fauna of the seafloor.

According to Sricharan et al., a floating wave energy converter (BFWEC) with multiple "bean-shaped" floats and a hydraulic power output system has been proposed. As a whole, the device consists of a central buoy (CB) connected to a set of buoys around a lever arm and positioned using a tension mooring system. In Indian waters, the device is intended for deployment in shallow to medium depths [51]. In comparison with conventional wave energy converters, the BFEWC has a simplified structural design without the complex mechanical systems, which results in lower operating and maintenance costs. The BFEWC with a flexible flip-flop structure, however, is prone to instability, which should be optimized and improved.

2.3.5. North Sea (Atlantic)

The overflow device (OD) consists of three chambers located at varying heights. There is an opening in the upper part of each chamber. The system has an external ramp-like shape that increases water level height and fills the internal chambers with water. In order to convert the potential energy of the water within each chamber into electrical energy, a multi-stage low-head turbine is used. Off the coast of Norway, the equipment is deployed [52]. A sophisticated electronic control system and a precise mechanical structure are utilized in the overflow device, which provides high reliability and safety. Installation and use of overflow devices, however, have some impact on the marine environment. When overflow devices are installed in storage tanks, pollutants, such as wastewater and exhaust gases, may be generated. In addition, in the marine environment, overflow devices can negatively impact the marine ecosystem, so it is necessary to establish scientific environmental monitoring and management systems in order to minimize this impact.

There are five horizontally stacked cylinders in the bottom hinge system, which consists primarily of a barrier. As the barrier is held in place by horizontal hinges, the braking wave creates rotation, which activates the high-pressure pump. A pipe transports the pressurized water to the shoreline, where a turbine and alternator are installed in order to generate electricity [53]. This device is called a bottom-hinged device (BHD). On the Finnish coast, the device is being used to harness wave energy [54]. The bottom hinge system is simpler and easier to maintain and operate than other wave energy conversion technologies. On the other hand, the initial construction costs are high since the device must be fixed to the seabed and facilities, such as turbines and generators, must be built on shore.

2.3.6. Limitations

According to the equations described in Section 2.1, several important factors affecting wave energy generation have been selected to create Tables 1 and 2 for the purpose of analyzing the case more effectively. According to Table 1, most of the wave energy converters are more expensive to manufacture. This is due to the high cost of the materials used in the manufacture of these devices. However, most of the high installation and maintenance costs can be attributed to the design of the installation, the structure, and the human resources. From Table 2, it can be seen that most of the devices are less stable, which is partly due to the variable climate and complex sea conditions at sea. A large deployment area reveals a lack of development in related areas, such as equipment stability and cable transmission technology. By combining the two tables, it is apparent that large power generation devices have a greater impact on the environment. Despite the fact that individual small devices have less environmental impact, they are less powerful and require a large number of them in order to meet the energy demand. It should be noted, however, that the large number of deployments has a significant impact on the environment. In Section 3, these shortcomings will be discussed in more detail.

Table 1. The characteristics of different wave energy converters (1).

Device Name	Maintenance Costs	Installation Cost	Manufacturing Costs	Single Device Power
REWC3	Medium	High	High	High
OREC	Low	High	High	High
PeWEC	Medium	High	High	High
ISWEC	High	Low	High	High
FAD	Low	Low	Low	Low
OWC-PS	High	High	High	High
FLGWC	High	High	High	Medium
StingRAY	Low	Low	Low	Low
Centipod	High	High	High	Medium
Azura	High	Medium	High	High
M4	High	High	High	High
BFWEC	Medium	Low	Low	High
OD	High	High	High	Medium
BHD	Low	High	High	Low

Table 2. The characteristics of different wave energy converters (2).

Device Name	Reliability	Deployment SCOPE	Impacts of the Marine Environment
REWC3	High	Shallow water areas	High
OREC	High	Shoreline	High
PeWEC	Medium	Wide deployment scope	High
ISWEC	Medium	Wide deployment scope	Low
FAD	High	Wide deployment scope	High
OWC-PS	High	Smaller deployment scope	Medium
FLGWC	Low	Medium deployment scope	Medium
StingRAY	High	Smaller deployment scope	High
Centipod	Medium	Medium deployment scope	High
Azura	Medium	Medium deployment scope	High
M4	Low	Wide deployment scope	High
BFWEC	High	Wide deployment scope	Medium
OD	Medium	Smaller deployment scope	Low
BHD	Low	Shoreline	High

2.4. Offshore Wind Energy

There are two types of offshore wind turbines, namely land-supported and floating. Offshore wind turbines with fixed foundations are fixed to the seafloor, while offshore wind turbines with floating foundations are connected to the seafloor by mooring cables. An additional classification of offshore wind turbines is illustrated in Figure 11. The monopile and jacketed offshore fixed-base turbines are two types of commercially operated floating fixed-base turbines. In contrast, a jacketed support is a lattice structure with three or four legs embedded in the bottom by suction and gravity. It is only possible to install fixed-support offshore wind turbines in water depths of up to 60 m [55].

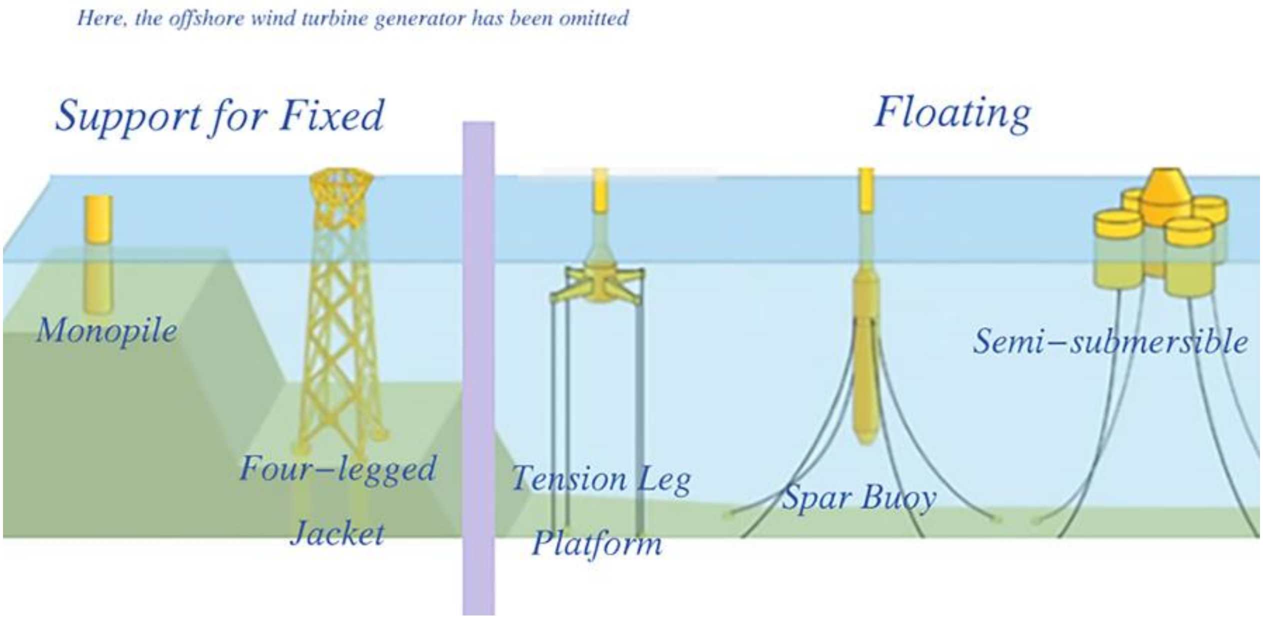

Figure 11. Support structures for offshore wind turbines, from [55].

Based on the following similarities and differences, this paper examines the Japanese sea area, the Indian Ocean area, the European area, and the Chinese coast.

The Similarties:

- At the intersection of the Oceanic Interplate and the Eurasian Continental Plate, these coastal areas are characterized by relatively stable geological formations and tortuous and variable coastlines;
- It is important to note that all of these coastal areas are located near the oceans or seas and are subject to seasonal or cyclical climatic variations;
- The fisheries resources in these coastal areas are relatively rich. As a result, offshore wind power plants can be studied with respect to their impact on fisheries;
- As a result of the development of port facilities and maritime transportation systems, these coastal areas are important hubs for international trade and shipping. It is possible to observe the impact of offshore wind power generation on maritime traffic.
- The differences:
- It is important to note that the coastal areas of Japan are more frequently affected by typhoons and seasonal storms, and offshore winds are strong; the wind is more stable in the coastal areas of Europe, while the wind size varies due to the influence of climate in the coastal areas of China and the Indian Ocean;
- Due to the influence of the warm North Atlantic current, the European coast is relatively mild when it comes to sea conditions, and the currents are relatively stable as well. Due to monsoons, seawater temperatures, current speeds, and salinities fluctuate

greatly along the Chinese coast and Indian Ocean; however, the Japanese coast is highly variable due to the influence of typhoons and seasonal storms.

Offshore wind power deployment is influenced by the factors listed above. As a result, these areas are somewhat representative.

2.4.1. Japan's Surrounding Seas

Diffuse wind turbines (DAWT) have a funnel-shaped diffuser structure that collects and concentrates approaching wind. An exit point rim and an inlet cover were added to the diffuser by Ohya et al. at Kyushu University in Japan to create a lensing effect. As a result of this modification, the energy conversion efficiency can be greatly increased and, therefore, the economic efficiency can be improved [56]. As a result of the high speed and small diameter of the DAWT, high frequency noise is generated during power generation. In Japan, DAWT equipment is currently in the semi-commercial stage of development [57].

2.4.2. Indian Ocean Region

The PN-14 airborne wind energy system, developed by SkySails Power from Germany, will be deployed on the east coast of the island of Mauritius in 2021 [58]. Alternatively, airborne wind energy (AWE) refers to the concept of converting wind energy into electricity, with characteristics that are common to both autonomous kites and unmanned aircrafts. Compared to conventional wind turbines, AWE systems offer a number of potential advantages. In comparison with tower turbines, they require less material, can be manufactured at lower costs, can be deployed more quickly, and can harness stronger and more stable winds due to their higher altitude [59]. Although the device requires high meteorological conditions (such as wind speed and direction), too high or too low wind speeds will affect its ability to generate electricity. Birds may be affected by the design of wind turbines or kites.

India is the third largest emitter of carbon dioxide in the world. Due to an increase in domestic electricity demand, the country has actively explored the potential of offshore wind power [60]. Several offshore wind farms consisting of conventional turbine generators have been installed in the northwest of the country [61].

2.4.3. Europe Region

A wind farm located approximately 11 km off the north coast of Kent, UK, in water depths approaching 25 m, is known as the London Array wind farm. It is equipped with 175 Siemens Gomez SWT-3.6-120 wind turbines and two offshore substations. Monopile foundations support each wind turbine and offshore substation [62].

The Walney Wind Farm is a group of offshore wind farms located off the coast of Cumbria in the Irish Sea, England. The Walney Wind Farm is equipped with horizontal-axis wind turbines. In this type of turbine, a set of blades is attached to an axle that is parallel to the ground. As a result of strong global winds, the blades rotate, resulting in the axle spinning, generating electricity [63].

The Hornsea offshore wind farm is located approximately 120 km off the coast of Yorkshire, UK. Each section of the wind farm has an installed capacity of approximately 400 MW. Wind turbines are connected to HVAC collector substations, which in turn are linked to HVAC reactive power compensation stations located offshore. A UK National Grid substation is then connected to an onshore HVAC substation [64].

The Kriegers Flak offshore wind farm is located in the Arkona basin in Danish waters in the southern Baltic Sea. Kriegers Flak's joint grid solution, which connects offshore wind farms in series to the grids of two different countries, is a world first. Depending on the connection capacity, the electricity generated by the wind farm can be transmitted to the country with the highest demand and price, thus improving its economics. In addition, the connection between Denmark and Germany may serve as an interconnector. This allows electricity to be transmitted between the two countries, even when no electricity is produced by the wind farms themselves. It improves the overall reliability of the power grids in both countries, as well as reducing the overall cost of electricity. The disadvantage of this solution is that it requires a very high level of resistance to submarine cables [65].

The Borssele 1 and 2 offshore wind farm is the largest offshore wind farm in the Netherlands, with a total installed capacity of 752 MW. It also has 94 Siemens Gomersa 8 MW wind turbines. By the beginning of September 2020, all turbines will have been installed, and the wind farm will be fully commissioned by November 2020 [66].

2.4.4. China

The province of Guangdong is located on the eastern coast of China and has extensive offshore wind energy resources. Meanwhile, it is the center of economic development in South China. In order to achieve the new goal of reshaping Guangdong, Hong Kong, Macao, and the Great Bay Area, a vigorous development of offshore wind power has been undertaken by the Chinese government. This has resulted in a more effective adjustment of coastal resources and a more prosperous economy [67].

The Yangjiang Shaba II offshore wind farm, for example, will be fully operational by 2021. As part of the 400 MW project, 62 6.45 MW offshore wind turbines will be installed in the sea west of Shaba, Yangjiang City, Guangdong Province. The Guangdong–Hong Kong–Macao Greater Bay Area receives clean electricity from the wind farm.

2.4.5. Limitations

In comparison to wave power generation, wind power is more commercially viable. In spite of this, wind power plants still have limitations, such as high transportation costs, high manufacturing costs, and a high environmental impact.

2.5. Some Developments in Wind and Wave Hybrid Technology

Most waves are generated by wind on the sea surface. Due to its inefficiency, wind-wave hybrid energy has become a viable solution to the low economic efficiency of wind energy.

It has been decided that we conduct a small-scale offshore hybrid energy farm experiment in Hakata Bay, Fukuoka, Japan, as our first step toward realizing the next generation of medium-sized distributed offshore renewable energy farms. In this experiment, one of the main objectives was to demonstrate the advantages of wind power generation at a location with typical annual average wind speeds in Japan. This was done even at a relatively short distance from the adjacent coast. A floating platform equipped with two 3 kW wind turbines and two 2 kW photovoltaic panels was constructed [68].

Wang et al. proposed a combined concept consisting of a 5 MW semi-submersible floating offshore wind turbine (FOWT) and an annular wave energy converter (WEC). In addition, four different shapes of WEC are examined. Based on the hydrodynamic coefficients, the hydrodynamic performance and dynamic response of the concept are compared in the frequency domain [69].

It is proposed to develop a hybrid system that integrates an oscillating water column (OWC) wave energy converter (WEC) with an offshore wind turbine on a monopile structure. The WEC subsystem of this hybrid energy converter was primarily defined and tested in a simplified form. To characterize the hydrodynamic response of 1:37, an experimental campaign was conducted [70].

In their study, Perez-Collazo et al. developed a hybrid system for monopile substructures, which are the most common types of substructures used in offshore wind turbines. They focused specifically on the wave energy converter subsystem in the oscillating water column. Towards this end, an in-depth experimental campaign was conducted using a 1:40 scale model of the wave energy converter subsystem and the monopile substructure, taking both regular and irregular waves into account. An in-depth analysis of the device's performance and interaction with the wave field was conducted based on the experimental results. This is a fundamental step toward understanding the advantages and limitations of this hybrid wind-wave system, laying the foundation for its future development [71].

According to Hu et al., numerical optimization of the size and layout of WECs within a hybrid system is investigated for a given sea state. Based on frequency-domain viscosity-corrected potential flow theory, a numerical model is developed to investigate the hydrodynamic performance of a hybrid system consisting of a floating platform and multiple undulating WECs. We propose a dimensionless method for determining the radius, draft, and layout of cylindrical WECs at typical wave frequencies [72].

A floating platform for offshore wind turbines is designed to minimize pitch motion. This would otherwise result in high accelerations and loads on the turbines, nacelles, and blades, shortening their service lives. The effects of pitch motion are amplified when wind turbines are upgraded to more powerful versions due to the higher height and mass of the turbine. It is therefore imperative to develop innovative solutions to control pitching motion. Kamarlouei et al. proposed a solution that utilizes concentric arrays of wave energy converters whose original purpose was to generate wave energy on floating platforms. Additionally, the concept was found to provide a greater recovery moment to the platform, which is amplified by its levered arm, which helps control the pitching motion [73].

According to Zhang et al., a novel integrated wind and wave power platform combines a semi-submersible floating wind turbine foundation and a point absorption wave energy converter (WEC). This study focused on the optimization of the WEC's dimensions [74].

The Wavestar wave energy converter (WEC) with multi-point absorbers around the DeepCwind semi-submersible floating platform was numerically analyzed by Ghafari et al. A Wavestar point absorber was selected as a suitable point absorber for conduction with a floating wind turbine supported by a DeepCwind semi-immersion vessel. ANSYS/AQWA software has been used to investigate the effect of the Wavestar mechanism on the power extraction and motion of the DeepCwind semi-submersible using the potential flow-based boundary element method (BEM) in the time domain. Wavestar WEC with multi-point absorbers is proposed as a new arrangement [75].

3. Discussion and Conclusions

As a result of the study above about the relevant factors of economic cost, deployment, and a review of some technological developments. This paper will analyze various perspectives, such as economics, environment, and conflict with other industries.

3.1. Difficulties and Limitations

3.1.1. Economic-Related Issues

According to the research and analysis presented in Section 2.1 of this article, the majority of the relevant economic equations are subject to certain conditions. Conditions that affect wind and waves include cost differences between different types of installations, mooring system costs, seafloor conditions, installation and maintenance costs, and variations in local climate. There is no highly detailed equation that can accurately calculate costs and profits and predict the economic benefits of a project [76–80]. Secondly, the relationship between various assessment metrics is not clearly defined, for example, the relationship between LCOE and NPV. The reliability of assessment indicators requires a large amount of data, such as accurate measurements and predictions of factors, such as marine environment, equipment wear and tear rate, and maintenance costs.

3.1.2. Limitations of Mathematical Modeling and Simulation Methods

In light of the review above, several limitations of the use of mathematical models and simulation software in the evaluation of wind and wave energy projects have been identified as follows:

- Limitations of model assumptions: Mathematical models and simulation software build models based on certain assumptions, and these assumptions may not accurately reflect reality. Water depth, wind speed, and other parameters in the model, for example, will be affected by measurement errors;

- The results of mathematical models and simulation software assessments are based on predictions or simulations rather than actual data. As opposed to the actual operation of the system, there are deviations between the data obtained by the shark and the predicted results. The accuracy and reliability of the assessment can be affected by these deviations;
- It is sometimes difficult for mathematical models and simulation software to keep up with the rapid development of science and technology as a result of technological development. In the case of wind and wave energy devices, it is difficult to apply it. In addition, it is difficult to make a comprehensive assessment of the future configuration of wind and wave energy equipment;
- An evaluation of mathematical models or simulation software requires the input of a variety of parameters and conditions, which can be subjective, as well as human error. This can affect the outcome of the evaluation.

3.1.3. Issues Related to Device Deployment

According to the deployment cases in Sections 2.2 and 2.3, most of the installations are located at the shore or within a short distance of the shore. Most of the installations are deployed in small numbers. It is particularly evident in the deployment of wave energy converters. Due to these phenomena, wind and wave energy cannot demonstrate good commercial value even in the absence of alternative energy sources. According to further research and analysis, there are several main factors contributing to this phenomenon:

1. Energy storage issues: Batteries, or supercapacitor storage, are required for offshore wind and wave converters to store electrical energy, but the density of stored energy is limited. In addition, environmental factors and their lifetime should be taken into account. It is the distance from the shore that determines the speed of power transfer and the amount of power lost during the transfer process. As a result of the limited energy storage capacity of the equipment manufactured by current technology, it is not possible to deploy the equipment too far from the shore [81–83];
2. The harsh conditions of the marine environment result in high construction and maintenance costs for the equipment. In the marine environment, parameters such as pH, salinity, waves, and wind speed are much more complex than on land. It is currently not possible to implement efficient maintenance systems, and equipment that is deployed too far away can increase the number of maintenance tasks and, therefore, the cost of maintenance [84,85];
3. Immature technology: Offshore wind and wave converters are still in the R&D and testing stage, and the technology is not yet mature. As a result, the equipment operation can be subject to greater uncertainty and maintenance costs. It has resulted in a limited number and variety of equipment deployments;
4. The impact of government policies: Uncertainty in government policy can negatively impact the development of ocean energy, including delaying investments, increasing costs, and limiting innovation. Additionally, this has resulted in a low number of wind and wave energy devices [86–98].

3.1.4. Issues Related to Law and Regulation

In order to develop and operate offshore wind and wave converters, environmental impact assessments are required, as is compliance with relevant laws and regulations, such as the Law of the Sea and Aquatic Law. This increases the complexity and costs involved [89].

3.1.5. Inadequacy of International Standards

As offshore wind and wave converters are emerging technologies, their related databases are not well developed. As a result, there are no international standards or specifications for this type of equipment. As a result, equipment development and commercial application are made more difficult [90,91].

3.2. Some Inspiration Found in the Review

The above review contains a number of worthwhile solutions. The grid connection solution for the Kriegers Flak wind farm makes efficient use of the energy generated by the plant. In order to reduce production costs, some sites have adopted solutions, such as the integration of existing buildings with wave barriers. Considering geographical factors, such as uneven wave and wind energy and the problems associated with marine equipment and ecology, it seems that a combination of multiple types of equipment is the most appropriate solution at this time. As an example, offshore wind power projects are combined with aquaculture [92] and desalination plants [93]. Alternatively, wind and wave energy could be commercialized by generating electricity from offshore oil rigs [94]. Additionally, the integration of wind and wave energy technologies [95,96] maximize capacity by utilizing superior control technology [97]. Depending on the marine environment and climate conditions, different types of wind power generation equipment need to be selected. In order to ensure the efficiency of wind resource utilization and the operational performance of the wind farm as a whole, the power, height, and blade length of the wind turbines need to be considered during the design and layout process. Additionally, coordination and mutual cooperation among the equipment should be monitored in order to avoid affecting the overall performance of the wind farm. The following recommendations have also been made in addition to these.

3.2.1. Technological Innovation

There is a need for further improve the technical level of offshore wind and wave converters, reduce construction and maintenance costs, improve power generation per unit area, and promote the development of equipment that is more large-scale, intelligent, modular, reliable and long-lasting, particularly in:

1. The development of materials that are more resistant to high temperatures, high pressures, and high strength can improve the efficiency and service life of the equipment. Additionally, it can increase the capacity of the equipment to store energy. Two good examples can be found in [98,99];
2. The simulations of fluid dynamics and computational mechanics that are used to simulate and optimize the flow state and thermal characteristics of turbines, which can improve design efficiency and reduce testing costs;
3. The application of fine operational adjustment and maintenance techniques can significantly extend the life of equipment, reduce breakdowns and repair costs, and reduce conflicts between parallel circuits, as shown in [100–102];
4. The design and optimization of organizational structures to reduce flow resistance and power consumption, thereby improving turbine efficiency [103];
5. The uncertainty factors that exist in wind and wave energy project forecasting; uncertainty analysis methods can be used to provide confidence intervals for the assessment results to provide a more comprehensive assessment of project feasibility;
6. The data quality management techniques that should also be strengthened under the premise of data sharing. For data to be authentic and reliable, it is necessary to establish data quality standards, improve data collection and processing processes, and strengthen data security and confidentiality.

3.2.2. Government Support

It is important for governments to provide incentives to promote offshore wave and wind energy development and deployment, and the following recommendations may be helpful:

1. Relief from taxation: The government may provide relevant preferential taxation policies, such as tax relief for companies using offshore wave and wind energy generation equipment;
2. Subsidies and grants: The government may provide subsidies and grants to encourage large companies, small- and medium-sized enterprises, and individuals to invest in

and develop offshore wave and wind energy resources. In addition to subsidizing electricity prices, the government can also implement relevant policies;

3. Developing regulations: Governments may develop a series of policies and regulations to govern the development and deployment of offshore wave and wind energy in order to maximize policy consistency and feasibility and to ensure the long-term success of the industry [104–106];
4. Investment and financing support: Governments can increase the competitiveness of the offshore wave and wind energy sector by providing investment and financing support;
5. Public relations and promotion: The government can also use various channels and platforms to publicize and promote the benefits and characteristics of offshore wave and wind energy.

3.2.3. How can Companies or R&D Institutions Take Advantage of Government Support?

1. Understand government policies and regulations regarding wave and offshore wind energy development and deployment, including incentives, tax breaks, subsidies, allowances, etc.;
2. Consider how to use the various support programs provided by the government to expand market share and improve competitiveness. In this regard, technological innovation, product development, production costs, and so on can be considered;
3. Actively apply for government support, such as financial assistance, technical assistance, information exchange, etc., and submit relevant materials in accordance with policy guidelines;
4. Participate actively in industry organizations and associations, as well as other social organizations, promote information sharing and experience exchange, actively provide feedback to the government about the industry's situation and needs, and assist the government in formulating policies and plans more effectively.

3.2.4. Strengthen International Cooperation

With the growing process of globalization, international cooperation in science and technology is becoming increasingly common. As a result of the experience of [107–111], the following recommendations are made:

1. The government can assist wind and wave energy technology firms and institutions in establishing joint R&D projects in order to jointly overcome key technical problems and improve wind and wave energy technology;
2. By sharing patent technical information, the government can encourage China's wind and wave energy technology enterprises to avoid duplication of research and development costs and improve the efficiency of technology development;
3. Establish joint ventures: The government can encourage Chinese wind and wave energy technology companies to establish joint ventures with foreign companies to promote cooperation and integration between the two countries by sharing resources, optimizing management, and reducing costs;
4. International standard-setting: In order to strengthen international coordination and cooperation, as well as promote the standardization process for wind and wave energy technology, the government can actively participate in international organizations and standard-setting efforts related to wind and wave energy technologies;
5. Establish a high-quality database: Through the use of data platforms and Internet technologies, promote the sharing of data across regions and fields. Utilize artificial intelligence and other technologies for data mining and analysis. Thus, a more accurate, credible and comprehensive database of wind and wave energy resources can be compiled. Improve the value of mathematical models and simulation software as well.

3.2.5. Related Education and Training Programs

1. Establish laboratories and research centers: In order to educate and train human resources, governments should establish research centers and laboratories for wind and wave energy technologies. Using these centers and laboratories, students and researchers can acquire knowledge and skills related to wind and wave energy in a real-world setting;
2. Programs for undergraduates and graduates: Several universities offer undergraduate and graduate courses in wind and wave energy technology, covering knowledge and skills related to wind and wave energy resources, components of wind and wave energy systems, technologies for producing wind and wave energy, technologies for harvesting wind and wave energy, and equipment for converting wind and wave energy. It is possible to promote innovation and application of wind and wave energy technologies through the training of professionals;
3. Workshops and training programs: The government can organize various training programs and workshops to provide training services on wind and wave energy technologies, offering professional knowledge and skills training to research institutions, businesses, and individuals. By listening to lectures and participating in hands-on activities, participants can gain knowledge and experience related to wind and wave energy. Besides providing training programs and workshops, professional services can also be provided, such as data collection, analysis, and processing for migration regulations;
4. Thesis and internship programs: In order to facilitate the understanding and application of wind and wave energy technologies in a practical environment, the government can encourage wind and wave energy companies to offer internships to college students. Furthermore, universities may also encourage students to carry out theses in the field of wind and wave energy to acquire more in-depth technical knowledge, as well as to promote further development of these technologies;
5. Continuing education and vocational training: The government can assist wind and wave energy companies and institutions in providing continuous learning opportunities to their employees in order to keep them abreast of the latest technological advances and industry developments. The wind and wave energy sector requires talented people to continuously improve their professional skills through vocational training and continuous learning.

Author Contributions: Conceptualization, Y.Z. and D.Z.; methodology, Y.Z. and D.Z.; software, D.Z.; validation, D.Z. and Y.Z.; formal analysis, Y.Z. and D.Z.; investigation, H.J. and D.Z.; resources, D.Z.; data curation, Y.Z.; writing—original draft preparation, Y.Z.; writing—review and editing, D.Z.; visualization, Y.Z.; supervision, D.Z.; funding acquisition, D.Z. and H.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Program for Scientific Research Start-up Funds of Guangdong Ocean University, grant number 060302072101; the Zhanjiang Marine Youth Talent Project- Comparative Study and Optimization of Horizontal Lifting of Subsea Pipeline, grant number 2021E5011; and the National Natural Science Foundation of China, grant number 62272109.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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