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Review

Ocean Thermal Energy Conversion and Other Uses of Deep Sea Water: A Review

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Abstract: Research into renewable energy is an active field of research, with photovoltaic and wind being the most representative technologies. A promising renewable energy source is Ocean Thermal Energy Conversion (OTEC), based on the temperature gradient of seawater. This technology has two contradictory features, as its efficiency is relatively low while, on the other hand, its energy source is almost unlimited. OTEC research has focused on optimizing energy extraction, with different techniques having been used for this purpose. This article presents a review of the advances and applications of OTEC technology around the world. Throughout the document, the different uses of deep seawater are analyzed; further, the current systems which generate energy through the marine temperature gradient are reviewed, and the main advantages and disadvantages of each method are highlighted. The technical operations, construction variations, and the projects that have been developed around the world and those which are in the planning phase are also detailed. The two main conclusions are that this technology is still under development, but it is quite promising, especially for regions with little access to drinking water. Second, given the high implementation costs and low conversion efficiency, the development of this technology must be sponsored by governments.

Keywords: OTEC; marine energy; power plant; island; desalinization; deep ocean water

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1. Introduction

Islands contribute negligibly to the global emissions of greenhouse gases (GHG); however, they emit large amounts of GHG per capita. For example, in 2015, 0.4% of GHG emissions worldwide originated from the Caribbean Islands. Similarly, the per capita production of GHG is higher in islands (120 t), compared to the rest of the world (5 t) [1]. These GHG emissions are derived mainly from fossil fuels [2,3].

Renewable energies have been spreading to preserve the environment and human health, with solar and wind being the most common sources [4,5]. Due to their learning curves and increased installation capacity, the efficiency of renewable energies has been improved and their installation costs have been reduced [6]. However, it must also be kept in mind that not all cities have the optimum conditions (e.g., solar irradiation or wind speed) to apply these technologies [7].

Marine energy technologies represent a keen interest for islands and coastal areas, as they allow for the generation of electricity using an abundant resource in these regions; that is, seawater. The primary marine energies are produced by the ocean's thermal energy, tides, marine currents, offshore wind turbines, and waves [8].

Wave power transforms the kinetic energy contained in the movement of the waves into electrical energy. Identifying the areas where more massive waves are generated is extremely important when planning and deploying wave energy equipment. Bearing in mind that wave formation is closely related to surface winds, the places with the most excellent feasibility for wave sites are between 40º and 60º of latitude in both hemispheres [9].

There are two types of designs to capture the energy of waves. On one hand, devices can be located at the bottom of the water, at a shallow depth and crossing the water's surface. On the other hand, floating devices can also capture the kinetic energy of a wave's movement and convert it into electricity through a generator [10,11]. The relative level difference between different points of the machine turns hinges joined to hydraulic systems, which pump fluids that turn electrical generators. The main advantage of this type of device is that it does not need to be fixed to the seabed and only works with the relative water level difference, allowing for its installation in locations at different types of depths and distances from the coast.

Tidal Power is a type of marine energy which is often confused with wave power. In order to clarify these distinctions, it is considered essential to understand their differences. The energy of a wave is only related to the energy from the movement of the waves, while tidal energy takes advantage of the movements of tides: that is, the change in the tide produced by the gravitational forces exerted by the sun and the moon. When the tide rises, the floodgates of a dyke open, allowing the entry of wtaer into a reservoir. When it has been filled, the doors are closed. When the tide descends below the reservoir's level, reaching its minimum height, the gates open and let the water pass through narrow conduits that pass into turbines connected to electric generators [12].

A characteristic that hinders the propagation of tidal energy in the world is that it should be installed in places where the high and low tides have a considerable difference (i.e., of more than five meters) in height. Otherwise, it would not be profitable [13].

Marine current power takes advantage of the kinetic energy of marine currents. Although it is not widely used, it can be used to generate electricity in the future, as tides are more predictable than wind and sunlight. Ocean currents are produced by combining several factors such as temperature, wind, salinity, and the earth's rotation, among others [14,15]. The appropriate water speed is estimated between 2 and 3 m/s. A seawater current at a speed of 2 m/s has, per every square meter of area perpendicular to its flow, the same energy as a wind current at 18 m/s [16].

The main drawback of the devices designed to take advantage of marine current energy at high depths is their high manufacturing, installation, and maintenance costs. It is estimated that around 80% of the energy of marine currents is located in areas more than 40 m deep [17], such that it is necessary to use new designs for devices that can operate in these areas. As such, the cost of a large structure fixed to the seabed makes first-generation solutions unviable. The second-generation systems have anchoring systems, with a fixed base or anchor at the bottom and a series of cables that hold the device to the seabed [18].

Ocean Thermal Energy Conversion (OTEC) is a renewable energy source based on sea temperature change, concerning depth. This temperature gradient can be used to drive a thermal machine that generates useful work, which is then transformed into electricity [19]. The oceans capture the heat generated by solar radiation and cover more than 70% of the earth, making OTEC systems an almost unlimited source of energy, as they only depend on the sun and ocean currents; this effectively makes them the most effective energy storage systems in the world [20]. It has been estimated that the power that can be collected ranges from 3 to 5 TW, without harming the environment [21].

This paper presents a comprehensive overview of OTEC technology, based on its different prototypes, infrastructure, and technological advances in the development of devices, as well as the multiple applications that can be obtained to generate drinking water and food. The comprehensive vision of this paper serves to help governments, private entities, or researchers who intend to develop projects of this type and wish to have a first approach to this technology.

The remainder of the paper is organized as follows: Section 2 explains the differences in sea temperature and the different cycles of OTEC technology, while Section 3 exposes the possibilities of installation. Section 4 discusses other uses of deep seawater. Section 5 provides an overview of OTEC technology. Sections 6 and 7 are, respectively, concerned about the associated environmental impacts and technical limitations. Section 8 analyses the economic viability of OTEC projects, depending on the location. Finally, our main conclusions are given in Section 9.

2. Temperature in the Sea and Otec Cycles

The temperature of tropical seas depends directly on the depth; there is an approximate 20 °C difference between the surface and 1000 m of depth. This difference can be used to build an OTEC power plant [22]. Such regions exist mainly in the Equatorial latitudes, with more considerable temperature differences being observed in the Pacific Ocean's western part. The regions to the east and the west of Central America and some remote areas off the United States are also satisfactory.

The temperature differential strongly determines the efficiency of the cycle. The more significant the temperature difference, the higher the efficiency [23]. In different areas of the world, the water has different temperatures, depending on the depth in which it is found; especially in the tropics, where three thermal layers can be distinguished:

- The surface: From 100 to 200 m deep, which acts as a heat collector, with temperatures range between 25 and 30 °C.
- The intermediate: Between 200 and 400 m deep, with a fast temperature variation and acting as a thermal barrier between the upper and lower layers.
- The deep: The temperature decreases smoothly, reaching 4 °C at 1000 m and 2 °C at 5000 m.

Thus, the surface water could be used to heat a liquid (using a heat exchanger), which would then be transformed into steam to move a turbine generating electricity. Then, this steam would cool in another heat exchanger in contact with the cold water of the depths, restarting the generation cycle. This process presents several challenges, such as the heat transfer losses and pressure drop due to the long path that the fluid has to travel.

The transformation of thermal energy into electrical energy is carried out using the Rankine cycle [24] (a thermodynamic cycle in which the heat consumption is related to the production of work), in which a liquid evaporates to pass through a turbine. The cycle can be open, closed, or hybrid.

2.1. Open-Cycle

An open-cycle OTEC system uses a vacuum for its operation; vacuum is the condition that occurs inside a closed cavity when the pressure of the air or other gases is close to absolute zero. Figure 1 shows the scheme of an open cycle, where the surface water is pumped first into a vacuum chamber that operates between 1 and 3% of the atmospheric pressure [25]; the pressure drop rapidly evaporates the water. It should be noted that the salt and other seawater components remain in the vacuum chamber; therefore, this is a freshwater vapour. This vapour passes through a low-pressure turbine which, in turn, is connected to an electric generator. Apart from producing electricity, this technology also produces desalinated freshwater, which is suitable for drinking water, irrigation, or aquaculture [26].

Low-pressure water vapour has a high specific volume; thus, an open-cycle OTEC must be designed with large flow areas, in order to avoid high vapour velocities [27]. The gases present in seawater (carbon dioxide, oxygen, and nitrogen) are incondensable gases which leave the solution in a vacuum and, thus, must be eliminated [28].

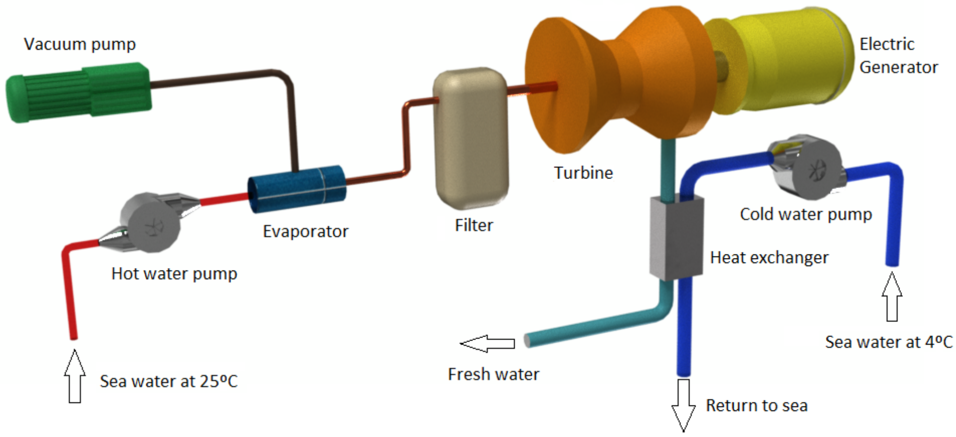

Figure 1. Open-cycle OTEC scheme.

The vacuum chamber walls usually have several gates which are used to install instruments. In medium vacuum applications, rubber O-rings are typically used for sealing. On the other hand, in high vacuum applications, the flanges are welded directly to the chamber [29]. In higher vacuum applications, the flanges have hardened steel blades welded on them, which cut a copper gasket when the flange is bolted. The side channel vacuum pumps are designed to work in both suction and compression modes. The aspirated air is forced to follow a spiral path using a unique impeller and subjected to repeated accelerations, thus increasing the differential pressure of the fluid transported through the blower. The fluid aspirated is kept clean and free of oil traces, as no type of lubrication is necessary for the side channel blowers, which are built entirely of die-cast aluminium [9].

An electrical power generation system for real applications based on this technology requires a large turbine, in order to cope with the large volumes of steam produced [30]. The turbines used in a conventional steam power plant can be used, but their production is limited to 2.5 MW, due to technological limitations. For this reason, an open-cycle OTEC above 2.5 MW is very expensive, as it would require several modules for its operation [31].

A practical example of electricity production using an open-cycle OTEC can be found in [32]. This work stated that an OTEC system's maximum theoretical efficiency is 9.2%, and the real efficiency will generally be less than this. The results achieved show that this technology is feasible; however, a common problem was failure of the grease-lubricated bearings in centrifugal pumps [33]. The use of magnetic bearings was recommended to avoid this problem, reducing energy consumption and increasing the power delivered [34].

2.2. Open-Cycle with Mist Lift System

Another mode to operate an open-cycle OTEC is using a Mist Lift system, which replaces the steam turbine with a hydroelectric turbine, as shown in Figure 2. In Mist Lift systems, a floating concrete container is used, large part of the structure of which is submerged underwater. A hydroelectric turbine located at the base of the structure generates electricity. This turbine is fed by large amounts of warm seawater, which fall by gravity from a height of approximately 100 m [35]. Mist lift systems are so named because of the water lift technique used, consisting of reintegrating the water into the structure's upper part. The hot water on the surface boils due to the partial vacuum inside the container, creating a great magnitude of rising steam. At a height greater than 20 m, cold seawater flows are sprayed within the steam, retracting quickly and creating a lower pressure. This pressure difference between the base and the upper part of the structure generates a mist of multiphase steam, which comes out of the upper part of the structure at high speed [36].

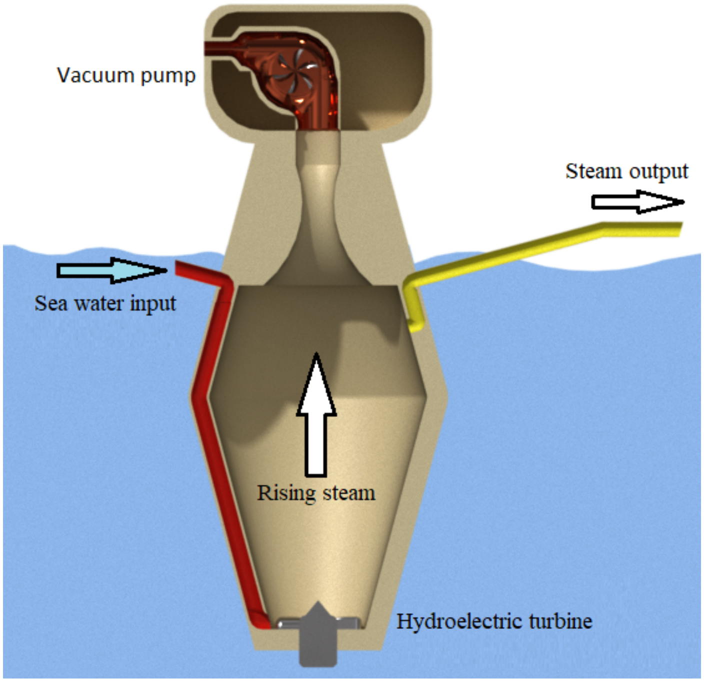

Figure 2. OTEC with Mist Lift System.

A problem that may arise is the generation of microbubbles due to the turbine's late start when the water has already risen, causing large steam cavities in the turbine [37]. In this case, a submerged chamber can be used; however, the project costs would rise more than 40%, due to the resistance and volume necessary for its operation. A chamber with a large volume is necessary to avoid high flow speeds, which generate significant friction. It should be clarified that the structure must be conditioned to withstand pressure at depths of around 100 m [38].

An electric power generation project based on Mist Lift could be between17% and 37% cheaper than a closed-cycle plant, as it does not require large pumps and heat exchangers, as in other types of OTEC systems [39].

2.3. Closed-Cycle

A refrigerant is a substance that acts as a cooling agent, with the special properties of evaporation and condensation point. Through changes in pressure and temperature, they absorb heat in one place and dissipate it in another, through a change from liquid to gas (and vice versa) [40], as can be seen in Figure 3. Low-boiling fluids are used as refrigerants, such as propane or ammonia. In closed-cycle OTEC plants, the surface water's heat is sufficient to evaporate the refrigerant [41]. The steam generated is used to move the turbines and is then cooled using water from the deep layers, and the cycle begins again. This method is cheaper and technically more comfortable than an open cycle, but does not produce desalinated water.

In 1979, a small floating OTEC system was presented in [42]. The system was located 2.4 km off the coast of Hawaii and produced enough energy to operate a ship's lighting and some electronic equipment, becoming the first successful case of a closed-loop OTEC system.

In a closed-loop OTEC system, the highest cost of implementation lies in the heat exchangers. These devices are responsible for transferring heat from one place to another, and are separated by a contact wall.

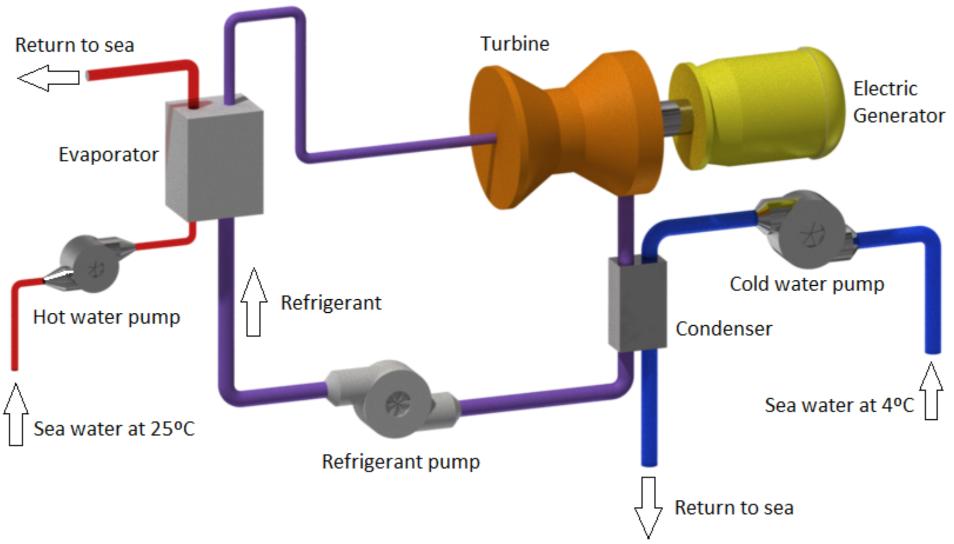

Figure 3. Closed-cycle OTEC scheme.

2.4. Hybrid Cycle

A hybrid cycle OTEC is presented in Figure 4, which combines both closed- and open-cycle characteristics. A vacuum chamber quickly evaporates warm seawater. In this way, water steam causes a working fluid to reach its boiling point. Electricity is generated by expanding the refrigerant in the turbine, followed by the vaporized fluid condensing inside a heat exchanger, thus generating desalinated water [43].

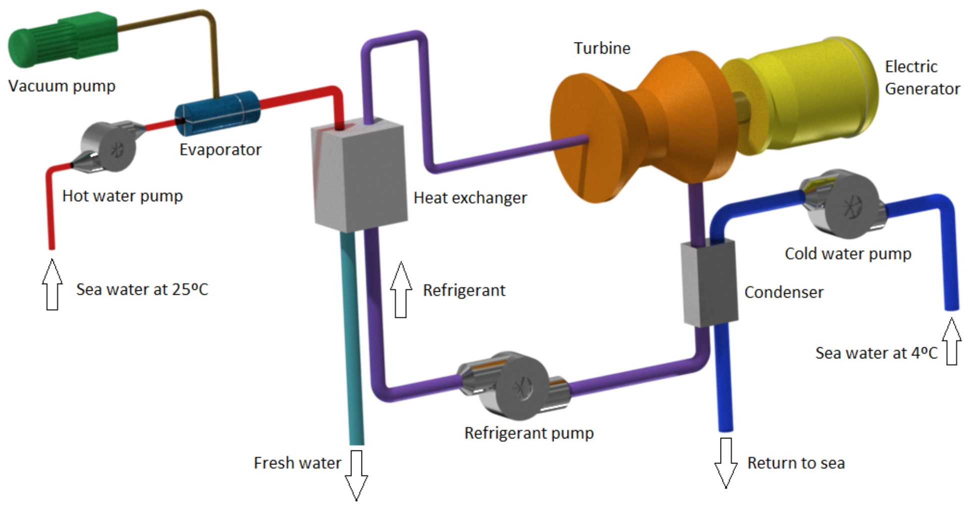

Figure 4. Hybrid cycle OTEC scheme.

The following working fluids can be used: (i) Ammonia, which has excellent transport properties, is easy to obtain, and its cost is low. Unfortunately, it is a toxic and easily flammable fluid. (ii) Fluorinated carbons providee another choice; they have the advantages that they are not toxic or flammable, but they help to weaken the ozone layer [44]. (iii) Hydrocarbons can also be used; however, they have the disadvantage of being flammable [44]. On the other hand, the pressure of the fluid used strongly affects the system's size, as a higher pressure decreases the size of both the turbine and the heat exchangers; in turn, the wall thickness must increase [45].

2.5. Optimizations for OTEC

Thermodynamic optimizations for OTEC systems and design components are presented below.

2.5.1. Thermodynamic Optimizations for OTEC

One of the main problems for OTEC systems is the low energy efficiency of the system. In energy conversion, heat exchangers transfer heat energy to the heat engine, converting it into power. Various studies carried out to evaluate the performance, performed by Ikegami's group in Japan, are described below.

In [46], a multistage heat engine was used to analyze the maximum usable power and to propose an evaluation formula based on the maximum power. The results obtained showed that, for a multi-stage motor (compared to a single-stage motor), the power increased by approximately twice at its maximum and the thermal efficiency of the cycle for maximum power was constant and independent of the number of stages.

On the other hand, the theoretical maximum power production and the relationship between the performance of the heat exchanger have been studied in [47], in which a method for evaluating the total performance of heat exchangers was developed, describing the theoretical relationship between the heat transfer performance of the heat exchangers, including the pressure drop and heat engine power output. Research with a similar goal can be found in [48], where the authors presented the potential energy of heat sources using the dead state as the state of thermal equilibrium of finite heat sources, instead of considering an infinite amount of ambient temperature. It was also proposed that the normalized thermal efficiency of energy conversion should be defined as the ratio of work to potential energy. Another method for performance evaluation has been presented in [49]. In this work, a theoretical model of the maximum work of an ideal thermal engine with finite heat transfer performance of heat exchangers was presented. The evaluation method was applied to evaluate a cross-flow type plate heat exchanger. A simplified method for evaluating the overall performance of heat exchangers, which can be fully and easily applied and considers heat transfer performance and pressure drop, has been presented in [50]. Other recent research performed by Ikegami's group can be found in [51–54]. Similar investigations carried out in China can be found in [55,56].

2.5.2. Designs for OTEC System Components

Based on constructal theory, various investigations have been developed to design both a shell-and-tube evaporator [57] and condenser [58], with the working fluid being ammonia–water. In both cases, the principal objective was to optimize the tube diameter. In the evaporator case, a complex function composed of the heat transfer rate and total pumping power was taken as the optimization objective, while the heat transfer area of the tubes is taken as the constraint. The inlet temperature of hot water has a specific influence on the ammonia–water and hot water optimal mass flow rates, but does not influence the heat transfer rate's optimal external diameter [57]. A complex function formed of the entropy generation rate and total pumping power was minimized for the condenser case, which reflects the trade-off between the entropy generation rate and total pumping power [58]. Other recent research performed in this same line can be found in [59–62].

In [63], based on constructal theory, the optimal design of a dual-pressure turbine for a OTEC system was presented under the condition that the total volume of the turbine was fixed. The turbine's total power output was chosen as the optimization objective. The optimization variables were the volume fraction, the ratio of wheel diameter, and relative flow angle at the rotor outlet. Their significant results were obtaining the dual-pressure turbine's optimal performance and optimal constructs with the same and different structural parameters. The turbine total power output increased with the increase of the inlet pressure of the low-pressure turbine, the mass flow rate ratio of the working fluids, the total volume of the turbines, and the absolute flow angle at rotor inlet; while it decreased with the increase of the reaction degree.

Other relevant works for the design of OTEC system components that combine finite-time thermodynamic optimizations for the thermodynamic cycle with constructal designs and other appropriate design techniques can be found in [64–68].

3. Location of an Otec Power Plant

OTEC systems can be built on land (onshore), on a fixed platform in the sea (offshore), or as floating constructs.

3.1. OTEC Onshore

Onshore locations have three advantages over offshore systems: First, they do not require a robust lashing system and maintenance is more comfortable to carry out [69]. Second, they can be designed in such a way that they are protected from storms. Finally, the products generated—electricity and desalinated water, among others—can be easily distributed. On the other hand, the disadvantages of an onshore installation are several. First, bringing seawater to the plant requires a significant investment in civil works, as it must be ensured that the pipes are fixed in changes in the tide or storms. In this sense, the distance between the plant and an adequate depth, requiring the excessive use of pipes to transport both hot and cold water [70], are crucial. Some of these problems can be solved by building the plant in shallow waters (i.e., between 10 and 30 m deep), reducing the distance to the optimal depth and, therefore, the water loading and unloading pipeline. However, the construction would be subject to a marine environment, thus requiring special maintenance [71].

3.2. OTEC Offshore

OTEC power plants can be installed around 100 m deep. Thus, the turbulent waves generated near the coast can be avoided; additionally, it would be closer to the cold water supply. Carrying out an installation at a greater depth would increase the costs, compared to onshore systems [72]. The problems include stress due to the open sea conditions and the complicated delivery of the product. Strong marine currents and large waves increase the implementation costs. These platforms require massive pillars to ensure their stability, while the distribution of the energy produced requires submarine cables to reach the distribution power lines [73].

3.3. Floating OTEC

A medium- or high-power OTEC device can be settled on a ship, reducing the implementation costs compared to submarine infrastructures. The difficulty in design and construction time also decreases with this type of installation. Floating OTECs are suitable for large systems; however, these systems present several challenges: Anchoring in deep waters is not easy; additionally, the distribution of energy can be affected by the damage of the marine cables, as they are exposed to constant movement, and their repair or maintenance is not easy to carry out [74].

4. Other Uses of Deep Ocean Water

Concerning renewable energies, such as photovoltaic or wind power, OTEC plants have the advantage of generating energy 24 h a day throughout the year. This is their main characteristic, especially in islands located in the tropics, which generally obtain their electrical energy from fossil fuel-based plants. Additionally, OTEC plants can generate other services, which are mentioned below.

4.1. Desalinated Water

Approximately 97% of the water in the world is saline [75]. The most common methods for desalination are lightning evaporation, reverse osmosis, distillation, and freezing. These processes require high energy consumption, which usually results in the consumption of fossil fuels; this is why more efficient methods are actively being sought.

An open-cycle or hybrid OTEC plant produces desalinated water, converting seawater vapour into drinking water. For example, a 1 MW hybrid OTEC could generate around 4500 m^3 of drinking water daily. Its performance, in terms of production cost and the quality of the water produced, is very similar to that of a standard desalination plant [76]. An OTEC system that remarkably desalinates water has been described in [77].

4.2. Refrigerated Soil Agriculture

Temperate climate plants can be grown in the subtropics; for this, it is necessary to cool the soil where the plants are planted. This cultivation technology is known as refrigerated soil agriculture. An OTEC system can be used for cooling by use of the flow of cold seawater, which cools the surrounding soil through which the pipeline passes [78]. An example of this technology has been described in [79], where they showed an example of spinach production throughout the year.

4.3. Aquaculture

An OTEC system pumps large amounts of water from the ocean depth. Considering that the water at high depths is richer in nutrients, this water can be used to feed aquaculture systems [80]. In this way, various species (e.g., oysters, clams, and lobsters, among others) can be raised at a lower cost, as no auxiliary system is required to pump the water with nutrients [81].

5. History and Otec Projects around the World

OTEC systems began to be studied in the late nineteenth century; since then, new developments have emerged to improve their benefits.

5.1. Beginnings of OTEC Technology

In the 1880s, Jacques D'Arsonval, based on the Rankine thermodynamic cycle, first proposed closed-loop OTEC technology [82], for use in tropical oceans. The proposed system uses a stream of ammonia that passes through two heat exchangers (evaporator and condenser). To do this, it uses the difference in temperature between surface water and water found at high depths (i.e., greater than 800 m) as an energy source. The cycle begins by using the first heat exchanger to evaporate the pressurized ammonia. Then, the steam generated is used to drive an electric turbine. The next cycle is achieved with cold seawater and the second heat exchanger, which is responsible for condensing the ammonia vapour.

The open-cycle OTEC concept would take a further 40 years to arrive. Georges Claude proposed the use of ocean water as a working fluid. To do this, he used a vacuum chamber to evaporate the warm water from the surface; the resulting steam was used to drive an electric turbine. The steam that passes through the turbine is condensed using the water at depth, which is lower. This system can produce both electricity and desalinated water [83].

In the 1930s, a 22 kW pilot plant was implemented, using a direct contact condenser but avoiding desalinated water production. Unfortunately, the expected 22 kW was not achieved; however, it operated for several weeks, until a storm destroyed it [84].

5.2. OTEC in Japan

In 1994, the Ocean Energy Institute at Saga University in Japan built a 4.5 kW plant. This institute leads in research related to OTEC systems, focusing on energy production and secondary products or services derived [85].

In 2013, a 100 kW OTEC plant was installed on the island of Kume, Japan. This plant had a double objective: To check the validity of computational models and to verify the real functionality of this technology. The plant is comprised of two functional units, one to generate electricity and the other to carry out on-site tests [86]. In 2015, water desalination functionality was added to the OTEC plant. Japanese researchers have been interested in using nutrients from deep ocean waters [87] and using refrigerated soil agriculture at a large scale [88].

5.3. OTEC in United States

Hawaii is another suitable place for the use of OTEC technology, due to the sea's high surface temperatures and the vast depths that can be reached very close to the coast, where the temperature drops to 5 °C. In 2011, an OTEC pilot plant was installed in Hawaii; this plant was used to design and test heat exchangers. Its ultimate goal was to reduce manufacturing costs, thus increasing the useful life and performance [89].

In 2015, a closed-loop OTEC pilot plant, capable of producing 105 kW and connected to the United States power grid, was installed in Kona, Hawaii [90]. This plant has generated income for the region through aquaculture, and produces around 7000 gallons of fresh water every day [91].

5.4. NEMO Project

New Energy for Martinique and Overseas (NEMO) is an OTEC project (still in the design phase) located on Martinique island in the Caribbean Sea [92], which consists of a moored barge containing four turbogenerators. Each one will be driven by a closed cycle using ammonia and taking advantage of the approximate temperature difference of 20 °C; the depth used is 1.1 km. Each turbine has a generation capacity of 4 MW, obtaining a nominal capacity of 16 MW. The tests have shown a net generation capacity of 10.7 MW [92]. The energy is carried to an electrical substation by a submarine cable [92].

The power generated will be exported to the network through the submarine cable to an electrical substation. This project is part of the collaboration agreement signed in January 2013 between DCNS and Akuo Energy, to combine their respective skills to develop renewable marine energy. DCNS and Akuo Energy plan to have NEMO operational by 2020, which would be the largest OTEC plant to date [93].

5.5. Other OTEC Projects in Development

A project under consideration, studied for the U.S. naval base on Diego García Island in the Indian Ocean, is a 13 MW plant, which would be built to replace fossil fuel-based electric generators and generate 5 million litres of drinking water per day [94].

India has developed an experimental floating OTEC near Tamil Nadu. The plant finally did not succeed, due to a fault in the cold water pipe. Even so, the Indian government continues to sponsor investigations [95].

6. Environmental Impact

OTEC technology is a source of clean energy; although ammonia is used in closed-cycle OTECs, it is never emitted into the environment, avoiding the generation of hazardous waste. On the other hand, in the case of open-cycle OTECs, a negligible amount of carbon dioxide is emitted into the ocean, compared to fossil fuel plants [96].

Analyses obtained from OTEC systems have shown that the water expelled by the systems at depths of 60 m is diluted at a ratio of 1:3; that is, one part of the water expelled by the OTEC system to three portions of seawater [97]. This water return depth also provides vertical separation of the hot water entrance by about 20 m, which is necessary to avoid reingestion by the plant. From the above, it can be deduced that such systems have minimal impact on the seabed.

The environmental risks of OTEC facilities are similar to those presented by any civil work of constructing a marine platform. Under normal conditions, emissions to the environment from the workflow (ammonia) are incipient [98]. It should be clarified that a workflow emission due to a malfunction of the system should be avoided at all costs [99].

OTEC systems must be designed to interact with the environment. There are two effects to take into account. On one hand, fish may be attracted to an OTEC system, as it will emit seawater with nutrients, positively affecting fishing. On the other hand, the eggs and larvae may be affected by said emission. In this sense, the success of an OTEC operation will be directly proportional to the balance between these two effects [100]. Finally, with proper planning, OTEC systems can serve to increase tourist attractions [101].

7. Technical Challenges and Restrictions

A complete safety system must be implemented for the anchorage system and the submarine electric cable, in order to ensure the well-being of workers. In this sense, survival burdens must be available to cope with extreme environmental phenomena. Similarly, there must be loads induced by fatigue which can be used in normal operations [102].

Ensuring the stability of the platform is also a challenge. To face this challenge, traditional offshore mooring systems can be used, or a more sophisticated system which makes use of dynamic positioning propellers [103]. On the other hand, the pipes used to transport the large volumes of water from the depth to the surface is also an active challenge. Researchers hve attempted to address this challenge by using computer-assisted analytical methods, complemented by laboratory and at-sea tests [104]. High-density polyethene pipes can be used for onshore plants, as long as the diameter is less than 1.6 m [105]. In offshore plants, steel or concrete pipes can be used; however, the costs are considerably increased. A promising technology is pressurized tubes made from reinforced elastomeric fabrics [9]; the disadvantage of this technology is that pumps must be used at the cold water inlet, which may operate incorrectly at a depth greater than 800 m over long periods.

The efficiency of OTEC plants can be evaluated using the principles of thermodynamics used in conventional steam power plants. The difference lies in the large volumes of water used for heat transfer, consuming approximately 30% of the energy to operate the pumps [106]. Additionally, various energy losses are generated, due to gravitational energy, friction, and density differences between different fluids [107]. At a temperature difference between 26 °C and 4 °C, the theoretical maximum efficiency is 8%, but losses associated with pumping needs and heat transfer produce actual efficiencies between 3% and 4% [76]. Although this seems to be a reasonably small value, compared to other renewable energies, it is worth noting that the energy source is practically inexhaustible. Approximately 4 m^3/s of warm water and 2 m^3/s of cold water are needed to generate 1 MW of electricity, between which there must be a nominal temperature difference of 20 °C [108]. Closed-loop OTEC technology is limited to less than 100 MW generation, due to suitable pipe sizes. Open-cycle technology is limited to 2.5 MW, due to the difficulty of handling low-pressure steam [109].

8. Economic Viability

The pilot plants implemented at different locations worldwide have demonstrated the technical feasibility of OTEC technology. Due to both infrastructure and implementation costs, the most viable plants are 100 MW for developed countries. In return, for middle-income countries, lower power plants have been recommended [110]. Pilot plants below 300 kW are not commercially viable, at least in developed countries. There is currently enough information for developing OTEC systems up to 10 MW [110]. In this sense, when reviewing the economic viability of an OTEC system, the production of other services apart from electrical energy, such as aquaculture and desalinated water, among others, must be evaluated, as the initial investment for an OTEC system is quite considerable. OTEC systems have low financial viability, due to the current costs and availability of fossil fuels. For this reason, these systems probably have to be developed by government entities [110].

The viability of this type of project is more reasonable for small islands, where they generally obtain electricity from fossil sources and fresh water is scarce. In this sense, a 1 MW plant with desalinated water production would be profitable under the current costs. It should be noted that the number of places that meet these conditions is limited [110]. Another viable market would be middle-income island countries. In these countries, up to 10 MW open-cycle OTEC systems could be installed, and desalinated water could be generated at a competitive price [110]. Finally, industrialized island nations could implement hybrid OTECs of up to 50 MW, produce electricity through a closed cycle, and desalinate water through an evaporator. This scenario would be profitable under high prices for fossil fuels or freshwater [110]—a scenario that is not illogical in the future.

9. Conclusions

There is enormous potential for OTEC technology, thanks to its almost unlimited energy source. Almost all proposals have not made the leap from experimental prototype to commercial plants, due to high infrastructure costs—especially for cables that would lead the sea to the mainland—and the hostile and corrosive environment of marine waters. Many companies have been developing new and efficient solutions, in order to take advantage of the potential of the ocean as an unlimited energy source. The optimization of heat exchangers, condensers, vaporizers, and turbines, among other devices, is an active line of research that must be developed from various points of view, including thermodynamic theory, new materials, and engineering designs.

Over the next few decades, an increase in the research, development, and diffusion of OTEC technology is expected. Currently, 98 locations around the world have been identified as potential markets for this technology. Due to the high implementation costs and low efficiencies, these projects must be developed with a comprehensive vision, including the generation of freshwater, the design of spaces, the generation of food, and correct community appropriation.

Finally, small islands and small cities located in the coastal region of developing countries require small plants that can generate between1 and 10 MW and produce between 1700 and 35,000 cubic meters of desalinated water per day, enough for communities of 4500 to 100,000 inhabitants. Unfortunately, most of these populations are economically poor and the current costs of implementation are beyond their financial capabilities. For this reason, governments must become involved in the development of these initiatives.

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Abbreviations

The following abbreviations are used in this manuscript:

OTEC	Ocean Thermal Energy Conversion
GHG	Global emissions of greenhouse gases
DCNS	Direction des Constructions Navales
NEMO	New Energy for Martinique and Overseas

References

1. Bank, W. *World Development Indicators*; World Bank: Washington, DC, USA, 2019.
2. Meckling, J. The developmental state in global regulation: Economic change and climate policy. *Eur. J. Int. Relations* **2018**, *24*, 58–81. [CrossRef]
3. Seungtaek, L.; Hosaeng, L.; Junghyun, M.; Hyeonju, K. Simulation Data of Regional Economic Analysis of OTEC for Applicable Area. *Processes* **2020**, *8*, 1107. [CrossRef]
4. Ullah, N.; Ali, M.A.; Ibeas, A.; Herrera, J. Adaptive fractional order terminal sliding mode control of a doubly fed induction generator-based wind energy system. *IEEE Access* **2017**, *5*, 21368–21381. [CrossRef]
5. Tobón, A.; Peláez-Restrepo, J.; Villegas-Ceballos, J.P.; Serna-Garcés, S.I.; Herrera, J.; Ibeas, A. Maximum power point tracking of photovoltaic panels by using improved pattern search methods. *Energies* **2017**, *10*, 1316. [CrossRef]
6. Gohar Ali, H.; Vilanova Arbos, R.; Herrera, J.; Tobón, A.; Peláez-Restrepo, J. Non-linear sliding mode controller for photovoltaic panels with maximum power point tracking. *Processes* **2020**, *8*, 108. [CrossRef]

7. Tobón, A.; Peláez-Restrepo, J.; Montano, J.; Durango, M.; Herrera, J.; Ibeas, A. MPPT of a photovoltaic panels array with partial shading using the IPSM with implementation both in simulation as in hardware. *Energies* **2020**, *13*, 815. [CrossRef]
8. Thirugnana, S.T.; Jaafar, A.B.; Yasunaga, T.; Nakaoka, T.; Ikegami, Y.; Su, S. Estimation of Ocean Thermal Energy Conversion Resources in the East of Malaysia. *J. Mar. Sci. Eng.* **2021**, *9*, 22. [CrossRef]
9. Bernardoni, C.; Binotti, M.; Giostri, A. Techno-economic analysis of closed OTEC cycles for power generation. *Renew. Energy* **2019**, *132*, 1018–1033. [CrossRef]
10. Drew, B.; Plummer, A.R.; Sahinkaya, M.N. A review of wave energy converter technology. *Proc. Inst. Mech. Eng. Part J. Power Ene* **2009**, *223*, 887–902. [CrossRef]
11. Alawadhi, K.; Alhouli, Y.; Ashour, A.; Alfalah, A. Design and Optimization of a Radial Turbine to Be Used in a Rankine Cycle Operating with an OTEC System. *J. Mar. Sci. Eng.* **2020**, *8*, 855. [CrossRef]
12. Ishaq, H.; Dincer, I. A comparative evaluation of OTEC, solar and wind energy based systems for clean hydrogen production. *J. Clean. Prod.* **2020**, *246*, 118736. [CrossRef]
13. Chen, W.B.; Liu, W.C.; Hsu, M.H. Modeling evaluation of tidal stream energy and the impacts of energy extraction on hydrodynamics in the Taiwan Strait. *Energies* **2013**, *6*, 2191–2203. [CrossRef]
14. Xu, Q.K.; Liu, H.W.; Lin, Y.G.; Yin, X.X.; Li, W.; Gu, Y.J. Development and experiment of a 60 kW horizontal-axis marine current power system. *Energy* **2015**, *88*, 149–156. [CrossRef]
15. Seungtaek, L.; Hoseang, L.; Hyeonju, K. Dynamic Simulation of System Performance Change by PID Automatic Control of Ocean Thermal Energy Conversion. *J. Mar. Sci. Eng.* **2020**, *8*, 59. [CrossRef]
16. Davila-Vilchis, J.; Mishra, R. Performance of a hydrokinetic energy system using an axial-flux permanent magnet generator. *Energy* **2014**, *65*, 631–638. [CrossRef]
17. Rourke, F.O.; Boyle, F.; Reynolds, A. Marine current energy devices: Current status and possible future applications in Ireland. *Renew. Sustain. Energy Rev.* **2010**, *14*, 1026–1036. [CrossRef]
18. Li, Y.; Calışal, S.M. Modeling of twin-turbine systems with vertical axis tidal current turbines: Part I—Power output. *Ocean Eng.* **2010**, *37*, 627–637. [CrossRef]
19. Jia, Y.; Nihous, G.C.; Rajagopalan, K. An Evaluation of the Large-Scale Implementation of Ocean Thermal Energy Conversion (OTEC) Using an Ocean General Circulation Model with Low-Complexity Atmospheric Feedback Effects. *J. Mar. Sci. Eng.* **2018**, *6*, 12. [CrossRef]
20. Zhao, B.; Wang, S.; Liu, H.; Xu, J.; Fu, K.; Klimont, Z.; Hao, J.; He, K.; Cofala, J.; Amann, M. NO x emissions in China: Historical trends and future perspectives. *Atmos. Chem. Phys.* **2013**, *13*, 9869–9897. [CrossRef]
21. Nihous, G. A preliminary investigation of the effect of ocean thermal energy conversion (OTEC) effluent discharge options on Global OTEC Resources. *J. Mar. Sci. Eng.* **2018**, *6*, 25. [CrossRef]
22. Wang, M.; Jing, R.; Zhang, H.; Meng, C.; Li, N.; Zhao, Y. An innovative Organic Rankine Cycle (ORC) based Ocean Thermal Energy Conversion (OTEC) system with performance simulation and multi-objective optimization. *Appl. Therm. Eng.* **2018**, *145*, 743–754. [CrossRef]
23. Rau, G.H.; Baird, J.R. Negative-CO_2-emissions ocean thermal energy conversion. *Renew. Sustain. Energy Rev.* **2018**, *95*, 265–272. [CrossRef]
24. Yang, M.H.; Yeh, R.H. Analysis of optimization in an OTEC plant using organic Rankine cycle. *Renew. Energy* **2014**, *68*, 25–34. [CrossRef]
25. Eldred, M.; Landherr, A.; Chen, I.C. Comparison of Aluminum Alloys and Manufacturing Processes Based on Corrosion Performance for Use in OTEC Heat Exchangers. In Proceedings of the Offshore Technology Conference, Houston, TX, USA, 3–6 May 2010.
26. Boehlert, G.W.; Gill, A.B. Environmental and ecological effects of ocean renewable energy development: A current synthesis. *Oceanography* **2010**, *23*, 68–81. [CrossRef]
27. Heydt, G.T. An assessment of ocean thermal energy conversion as an advanced electric generation methodology. *Proc. IEEE* **1993**, *81*, 409–418. [CrossRef]
28. Comfort, C.M.; Vega, L. Environmental assessment for ocean thermal energy conversion in Hawaii: Available data and a protocol for baseline monitoring. In Proceedings of the OCEANS'11 MTS/IEEE KONA, Waikoloa, HI, USA, 19–22 September 2011; pp. 1–8.
29. Lee, C.; Ridgway, S. Vapor/droplet coupling and the mist flow (OTEC) cycle. *J. Sol. Energy Eng.* **1983**, *105*, 111–118. [CrossRef]
30. Cavrot, D. Economics of ocean thermal energy conversion (OTEC). *Renew. Energy* **1993**, *3*, 891–896. [CrossRef]
31. Cunningham, J.; Magdol, Z.; Kinner, N. Ocean thermal energy conversion: Assessing potential physical, chemical, and biological impacts and risks. *Report by University of New Hampshire. Report for National Oceanic and Atmospheric Administration (NOAA). New Hampshire, Durham, NH* 2010. Available online: https://tethys.pnnl.gov/publications/ocean-thermal-energy-conversion-assessing-potential-physical-chemical-biological (accessed on 24 March 2021).
32. Cable, B.; Tayler, W.; Tindal, C.; Varley, R.; Brissey, L. The Navy's Ocean Thermal Energy Conversion program. In Proceedings of the OCEANS 2010 MTS/IEEE SEATTLE, Seattle, WA, USA, 20–23 September 2010; pp. 1–8.
33. von Jouanne, A.; Brekken, T.K. Ocean and geothermal renewable energy systems. In *Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications*; Wiley: Hoboken, NJ, USA, 2019; pp. 391–441.

34. Hendrawan, A.; Cilacap, A.M.N. Calculation of power pumps on otec power plant ocean (ocean thermal energy conversion). *ICoSASTE* **2019**, *201*, 14–15.
35. Vyawahare, M. Hawaii first to harness deep-ocean temperatures for power. *Sci. Am.* **2015**, *27*. Available online: https://www.scientificamerican.com/article/hawaii-first-to-harness-deep-ocean-temperatures-for-power/ (accessed on 24 March 2021).
36. Daniel, T. *A Brief History of OTEC Research at Nelha*; Natural Energy Laboratory of Hawaii Authority: Kailua-Kona, HI, USA, 1999.
37. Ng, K.C.; Shahzad, M.W. Sustainable desalination using ocean thermocline energy. *Renew. Sustain. Energy Rev.* **2018**, *82*, 240–246. [CrossRef]
38. Liao, X.; Hall, J.W. Drivers of water use in China's electric power sector from 2000 to 2015. *Environ. Res. Lett.* **2018**, *13*, 094010. [CrossRef]
39. Mckenna, P. Deep oceans may offer "limitless" green energy. *New Sci.* **2008**, *200*, 28–29. [CrossRef]
40. Stene, J. Design and application of ammonia heat pump systems for heating and cooling of non-residential buildings. In Proceedings of the 8th IIR Gustav Lorentzen Conference on Natural Working Fluids, Copenhagen, Denmark, 7–10 September 2008.
41. Yasunaga, T.; Ikegami, Y.; Monde, M. Performance Test of OTEC with Ammonia/water as Working Fluid Using Shell and Plate Type Heat Exchangers, Effects of Heat Source Temperature and Flow Rate. *Trans. JAME B* **2008**, *74*, 445–452.
42. Oahu, H. Aquaculture updates in the Northern Pacific: Hawaii, Federated States of Micronesia, Palau, and Saipan. In *SPC Fisheries Newsletter No. 118*; Produced by the Information Section; Marine Resources Division, SPC: Noumea Cedex, New Caledonia, 2006.
43. Claude, G. Power from the tropical seas. *Mech. Eng.* **1930**, *52*, 1039–1044.
44. Nihous, G.; Vega, L. A review of some semi-empirical OTEC effluent discharge models. In Proceedings of the OCEANS 91: Ocean Technologies and Opportunities in the Pacific for the 90's, Honolulu, HI, USA, 1–3 October 1991.
45. Syed, M.; Nihous, G.; Vega, L. Use of cold seawater for air conditioning. In Proceedings of the OCEANS 91: Ocean Technologies and Opportunities in the Pacific for the 90's, Honolulu, HI, USA, 1–3 October 1991.
46. Yasunaga, T.; Ikegami, Y. Application of finite-time thermodynamics for evaluation method of heat engines. *Energy Procedia* **2017**, *129*, 995–1001. [CrossRef]
47. Yasunaga, T.; Fontaine, K.; Morisaki, T.; Ikegami, Y. *Performance Evaluation of Heat Exchangers for Application to Ocean Thermal Energy Conversion System*; Journal of OTEC (Departmental Bulletin Paper); Institute of Ocean Energy Saga University Japan: Saga, Japan, 2017; Volume 22, pp. 65–75.
48. Yasunaga, T.; Koyama, N.; Noguchi, T.; Morisaki, T.; Ikegami, Y. Thermodynamical optimum heat source mean velocity in heat exchangers on OTEC. In Proceedings of the Grand Renewable Energy, Yokohama, Japan, 17–22 June 2018.
49. Fontaine, K.; Yasunaga, T.; Ikegami, Y. OTEC maximum net power output using Carnot cycle and application to simplify heat exchanger selection. *Entropy* **2019**, *21*, 1143. [CrossRef]
50. Yasunaga, T.; Ikegami, Y. Finite-time thermodynamic model for evaluating heat engines in ocean thermal energy conversion. *Entropy* **2020**, *22*, 211. [CrossRef]
51. Morisaki, T.; Ikegami, Y. Maximum power of a multistage Rankine cycle in low-grade thermal energy conversion. *Appl. Therm. Eng.* **2014**, *69*, 78–85. [CrossRef]
52. Yasunaga, T.; Noguchi, T.; Morisaki, T.; Ikegami, Y. Basic heat exchanger performance evaluation method on OTEC. *J. Mar. Sci. Eng.* **2018**, *6*, 32. [CrossRef]
53. Ikegami, Y.; Yasunaga, T.; Morisaki, T. Ocean Thermal Energy Conversion Using Double-Stage Rankine Cycle. *J. Mar. Sci. Eng.* **2018**, *6*, 21. [CrossRef]
54. Matsuda, Y.; Yoshitake, T.; Sugi, T.; Goto, S.; Morisaki, T.; Yasunaga, T.; Ikegami, Y. Construction of a Static Model for Power Generation of OTEC Plant Using Uehara Cycle Based on Experimental Data. *J. Mar. Sci. Eng.* **2018**, *6*, 18. [CrossRef]
55. Feng, H.; Chen, W.; Chen, L.; Tang, W. Power and efficiency optimizations of an irreversible regenerative organic Rankine cycle. *Energy Convers. Manag.* **2020**, *220*, 113079. [CrossRef]
56. Feng, H.; Qin, W.; Chen, L.; Cai, C.; Ge, Y.; Xia, S. Power output, thermal efficiency and exergy-based ecological performance optimizations of an irreversible KCS-34 coupled to variable temperature heat reservoirs. *Energy Convers. Manag.* **2020**, *205*, 112424. [CrossRef]
57. Feng, H.; Chen, L.; Wu, Z.; Xie, Z. Constructal design of a shell-and-tube heat exchanger for organic fluid evaporation process. *Int. J. Heat Mass Transf.* **2019**, *131*, 750–756. [CrossRef]
58. Feng, H.; Chen, L.; Wu, Z.; Xie, Z.; Xia, S. Constructal optimization for an organic fluid shell-and-tube heat exchanger based on entransy theory. *Sci. Sin. Technol.* **2020**, *50*, 1577–1587. [CrossRef]
59. Cai, C.; Feng, H.; Chen, L.; Wu, Z.; Xie, Z. Constructal design of a shell-and-tube evaporator with ammonia-water working fluid. *Int. J. Heat Mass Transf.* **2019**, *135*, 541–547. [CrossRef]
60. Wu, Z.; Feng, H.; Chen, L.; Xie, Z.; Cai, C. Pumping power minimization of an evaporator in ocean thermal energy conversion system based on constructal theory. *Energy* **2019**, *181*, 974–984. [CrossRef]
61. Feng, H.; Cai, C.; Chen, L.; Wu, Z.; Lorenzini, G. Constructal design of a shell-and-tube condenser with ammonia-water working fluid. *Int. Commun. Heat Mass Transf.* **2020**, *118*, 104867. [CrossRef]
62. Wu, Z.; Feng, H.; Chen, L.; Ge, Y. Performance Optimization of a Condenser in Ocean Thermal Energy Conversion (OTEC) System Based on Constructal Theory and a Multi-Objective Genetic Algorithm. *Entropy* **2020**, *22*, 641. [CrossRef]

63. Wu, Z.; Feng, H.; Chen, L.; Xie, Z.; Cai, C.; Xia, S. Optimal design of dual-pressure turbine in OTEC system based on constructal theory. *Energy Convers. Manag.* **2019**, *201*, 112179. [CrossRef]
64. Wu, Z.; Feng, H.; Chen, L.; Tang, W.; Shi, J.; Ge, Y. Constructal thermodynamic optimization for ocean thermal energy conversion system with dual-pressure organic Rankine cycle. *Energy Convers. Manag.* **2020**, *210*, 112727. [CrossRef]
65. You, J.; Feng, H.; Chen, L.; Xie, Z.; Xia, S. Constructal design and experimental validation of a non-uniform heat generating body with rectangular cross-section and parallel circular cooling channels. *Int. J. Heat Mass Transf.* **2020**, *148*, 119028. [CrossRef]
66. Troina, G.; Cunha, M.; Pinto, V.; Rocha, L.; Santos, E.D.; Fragassa, C.; Isoldi, L. Computational Modeling and Constructal Design Theory Applied to the Geometric Optimization of Thin Steel Plates with Stiffeners Subjected to Uniform Transverse Load. *Metals* **2020**, *10*, 220. [CrossRef]
67. Hazarika, S.A.; Bhanja, D.; Nath, S. Fork-shaped constructal fin array design a better alternative for heat and mass transfer augmentation under dry, partially wet and fully wet conditions. *Int. J. Therm. Sci.* **2020**, *152*, 106329. [CrossRef]
68. Feng, H.; Wu, Z.; Chen, L.; Ge, Y. Constructal thermodynamic optimization for dual-pressure organic Rankine cycle in waste heat utilization system. *Energy Convers. Manag.* **2021**, *227*, 113585. [CrossRef]
69. Vega, L.; Nihous, G. At-sea test of the structural response of a large-diameter pipe attached to a surface vessel. In Proceedings of the Offshore Technology Conference, Houston, TX, USA, 2–5 May 1988.
70. Sverdrup, H.U.; Johnson, M.W.; Fleming, R.H. *The Oceans: Their Physics, Chemistry, and General Biology*; Prentice-Hall: New York, NY, USA, 1942; Volume 7.
71. Thomas, A.; Hillis, D. *Biofouling and Corrosion Research for Marine Heat Exchangers*; Technical Report; Argonne National Laboratory: Lemont, IL, USA, 1989.
72. Hubbard, H.M. The real cost of energy. *Sci. Am.* **1991**, *264*, 36–43. [CrossRef]
73. Quinby-Hunt, M.S.; Wilde, P.; Dengler, A. Potential environmental impacts of open-cycle thermal energy. *Environ. Impact Assess. Rev.* **1986**, *6*, 77–93. [CrossRef]
74. Quinby-Hunt, M.; Sloan, D.; Wilde, P. Potential environmental impacts of closed-cycle ocean thermal energy conversion. *Environ. Impact Assess. Rev.* **1987**, *7*, 169–198. [CrossRef]
75. Al-Ismaili, A.M.; Jayasuriya, H. Seawater greenhouse in Oman: A sustainable technique for freshwater conservation and production. *Renew. Sustain. Energy Rev.* **2016**, *54*, 653–664. [CrossRef]
76. War, J.C. Seawater Air Conditioning (SWAC) a renewable energy alternative. In Proceedings of the OCEANS'11 MTS/IEEE KONA, Waikoloa, HI, USA, 19–22 September 2011; pp. 1–9. Available online: https://es.overleaf.com/project/605c2011767e932529cf3534 (accessed on 24 March 2021).
77. Nakasone, T.; Akeda, S. The application of deep sea water in Japan. In Proceedings of the 28th UJNR Aquac Panel Symp, UJNR Technical Report, Kihei, HI, USA, 10–12 November 1999; Volume 28, pp. 69–75.
78. Lindman, Å.; Söderholm, P. Wind power learning rates: A conceptual review and meta-analysis. *Energy Econ.* **2012**, *34*, 754–761. [CrossRef]
79. Martin, B.; Okamura, S.; Nakamura, Y.; Yasunaga, T.; Ikegami, Y. Status of the "Kumejima Model" for advanced deep seawater utilization. In Proceedings of the 2016 Techno-Ocean, Kobe, Japan, 6–8 October 2016; pp. 211–216.
80. Takahashi, M. *DOW: Deep Ocean Water as Our Next Natural Resource*; Terra Scientific Publishing Company: Tokyo, Japan, 2000.
81. Mofor, L.; Goldsmith, J.; Jones, F. *Ocean Energy: Technology Readiness, Patents, Deployment Status and Outlook*. Report; International Renewable Energy Agency: Abu Dhabi, United Arab Emirates, 2014.
82. Liu, T.K.; Hwung, H.H.; Yu, J.L.; Kao, R.C. Managing deep ocean water development in Taiwan: Experiences and future challenges. *Ocean Coast. Manag.* **2008**, *51*, 126–140. [CrossRef]
83. Looney, C.M.; Oney, S.K. Seawater district cooling and lake source district cooling. *Energy Eng.* **2007**, *104*, 34–45. [CrossRef]
84. Yoon, J.I.; Son, C.H.; Baek, S.M.; Ye, B.H.; Kim, H.J.; Lee, H.S. Performance characteristics of a high-efficiency R717 OTEC power cycle. *Appl. Therm. Eng.* **2014**, *72*, 304–308. [CrossRef]
85. Kalina, A.I. Generation of Energy by Means of a Working Fluid, and Regeneration of a Working Fluid. U.S. Patent 4,346,561, 31 August 1982.
86. Lilley, J.; Konan, D.E.; Lerner, D.T. Cool as a (sea) cucumber? Exploring public attitudes toward seawater air conditioning in Hawaii. *Energy Res. Soc. Sci.* **2015**, *8*, 173–183. [CrossRef]
87. Greenlee, L.F.; Lawler, D.F.; Freeman, B.D.; Marrot, B.; Moulin, P. Reverse osmosis desalination: Water sources, technology, and today's challenges. *Water Res.* **2009**, *43*, 2317–2348. [CrossRef] [PubMed]
88. Takahashi, P.K.; Trenka, A. *Ocean Thermal Energy Conversion*; Wiley: New York, NY, USA, 1996.
89. Avery, W.H.; Wu, C. *Renewable Energy from the Ocean: A Guide to OTEC*; Oxford University Press: Oxford, UK, 1994.
90. Leraand, T.; Van Ryzin, J. Air conditioning with deep seawater: A cost-effective alternative for West Beach, Oahu, Hawaii. In Proceedings of the 'Challenges of Our Changing Global Environment', Conference Proceedings, OCEANS'95 MTS/IEEE, San Diego, CA, USA, 9–12 October 1995; Volume 2, pp. 1100–1109.
91. Daniel, T.H. Ocean thermal energy conversion: An extensive, environmentally benign source of energy for the future. *Sustain. Dev. Int.* **2000**, *3*, 121–125.
92. Udayakumar, K.; Anandakrishnan, M. *Renewable Energy Technologies: Ocean Thermal Energy Conversion and Other Sustainable Energy Options*; Narosa: Donegal, Ireland, 1997.

93. Magagna, D.; Uihlein, A. Ocean energy development in Europe: Current status and future perspectives. *Int. J. Mar. Energy* **2015**, *11*, 84–104. [CrossRef]
94. Commission, E. *Action Needed to Deliver on the Potential of Ocean Energy in European Seas and Oceans by 2020 and Beyond*; European Commission: Brussels, Belgium, 2014.
95. MacGillivray, A.; Jeffrey, H.; Hanmer, C.; Magagna, D.; Raventos, A.; Badcock-Broe, A. *Ocean Energy Technology: Gaps and Barriers*; *SI Ocean* 2013. Available online: http://www.policyandinnovationedinburgh.org/ocean-energy-technology-gaps-and-barriers.html (accessed on 24 March 2021).
96. Carlsson, J.; Fortes, M.; de Marco, G.; Giuntoli, J.; Jakubcionis, M.; Jäger-Waldau, A.; Lacal-Arantegui, R.; Lazarou, S.; Magagna, D.; Moles, C.; et al. *ETRI 2014-Energy Technology Reference Indicator Projections for 2010–2050*; European Commission, Joint Research Centre, Institute for Energy and Transport, Publications Office of the European Union: Luxembourg, 2014. [CrossRef]
97. Del Río, P.; Mir-Artigues, P. Combinations of support instruments for renewable electricity in Europe: A review. *Renew. Sustain. Energy Rev.* **2014**, *40*, 287–295. [CrossRef]
98. Simas, T.; O'Hagan, A.M.; O'Callaghan, J.; Hamawi, S.; Magagna, D.; Bailey, I.; Greaves, D.; Saulnier, J.B.; Marina, D.; Bald, J.; et al. Review of consenting processes for ocean energy in selected European Union Member States. *Int. J. Mar. Energy* **2015**, *9*, 41–59. [CrossRef]
99. Owens, W.; Trimble, L. Mini-OTEC operational results. *J. Sol. Energy Eng.* **1981**, *103*, 233–240. [CrossRef]
100. Scott, N. *European Practices with Grid Connection, Reinforcement, Constraint and Charging of Renewable Energy Projects*; Highlands and Islands Enterprise: Kirkwall, UK, 2007.
101. Allan, G.; Lecca, P.; McGregor, P.; Swales, J. The economic impacts of marine energy developments: A case study from Scotland. *Mar. Policy* **2014**, *43*, 122–131. [CrossRef]
102. Yamada, N.; Hoshi, A.; Ikegami, Y. Performance simulation of solar-boosted ocean thermal energy conversion plant. *Renew. Energy* **2009**, *34*, 1752–1758. [CrossRef]
103. Yoza, B.A.; Nihous, G.C.; Takahashi, P.; Golmen, L.G.; War, J.C.; Otsuka, K.; Ouchi, K.; Masutani, S.M. Deep ocean water resources in the 21st century. *Mar. Technol. Soc. J.* **2010**, *44*, 80–87. [CrossRef]
104. Mitsui, T.; Ito, F.; Seya, Y.; Nakamoto, Y. Outline of the 100 kw Otec Pilot Plant in The Republic of Naure. *IEEE Trans. Power Appar. Syst.* **1983**, *PAS-102*, 3167–3171. [CrossRef]
105. Zak, G.M.; Ghobeity, A.; Sharqawy, M.H.; Mitsos, A. A review of hybrid desalination systems for co-production of power and water: Analyses, methods, and considerations. *Desalin. Water Treat.* **2013**, *51*, 5381–5401. [CrossRef]
106. Rabas, T. Design and cost of near-term otec plants for the production of desalinated water and electric power. *ASME Sol. Energy. Div.* **1990**, *10*, 89–97.
107. Arias Gaviria, J. Adoption of Deep Ocean Water Technologies and Their Contribution to Sustainable Development in the Caribbean. Ph.D. Thesis, Universidad Nacional de Colombia-Sede Medellín, Medellín, Colombia, 2018.
108. Weisser, D. On the economics of electricity consumption in small island developing states: A role for renewable energy technologies? *Energy Policy* **2004**, *32*, 127–140. [CrossRef]
109. Sinama, F.; Martins, M.; Journoud, A.; Marc, O.; Lucas, F. Thermodynamic analysis and optimization of a 10 MW OTEC Rankine cycle in Reunion Island with the equivalent Gibbs system method and generic optimization program GenOpt. *Appl. Ocean Res.* **2015**, *53*, 54–66. [CrossRef]
110. Chen, Y.; Li, Y.R.; Hsieh, P.F.; Lee, C.S. Strategies of Developing Deep Ocean Water Industry-Cluster and Value Network Views. In Proceedings of the PICMET'07-2007 Portland International Conference on Management of Engineering & Technology, Portland, OR, USA, 5–9 August 2007; pp. 351–357.