The Future Of Marine Renewable Energy: The Role Of Marine Energy Technology In Climate Change Mitigation

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Abstract

Human life cannot be separated from the use of energy. Energy is needed for many things like cooking, traveling, and working. Currently, electrical energy is the main need. To produce electrical energy, power plants that utilize renewable and non-renewable energy sources are needed. Technology in the field of renewable energy continues to experience rapid development. The use of renewable energy aims to reduce the impact of global climate change and reduce dependence on fossil fuels. A variety of natural resources are available as renewable energy alternatives, one of which is marine power technology. Marine energy technology is a technology that utilizes various properties and movements of the ocean to generateelectrical energy. Energy sources from the sea can be utilized by using marine technology such as ocean current technology,ocean wave technology, and ocean thermal energy conversion. This technology makes it easy to adapt to the characteristics of the exploited sea.

Keywords: Ocean Energy, Conversion Technology, Eco-friendly, Renewable Energy

INTRODUCTION

Today, the world is taking aggressive steps to combat global climate change, which is driven by high concentrations of greenhouse gases (GHGs). Carbon dioxide and methane are major contributors to increasing greenhouse gas emissions (Hari, 2019). The main sources of these emissions are the energy, industrial, agricultural, construction, and transportation sectors. One example is the use of electric vehicles when the electricity they consume is generated using fossil fuels or coal [1].

To address climate change, the international community adopted the Paris Agreement in 2015, which was ratified by 195 countries. Indonesia also participated by ratifying the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) (Windyswara,2018). This represents a step taken by countries that is internationally recognized. The aim is to limit the increase in global temperature to below 2 degrees Celsius and to pursue efforts to limit it to 1,5 degrees Celsius above pre-industrial levels. Indonesia has committed to reducing greenhouse gas emissions by 29% or the equivalent of 834 million tons of carbon dioxide [2].

The energy sector is a primary focus, with a target of reducing carbon emissions by 7,28% or 314 million tons of carbon dioxide (by 2020). The main strategy is to shift from fossil energy to new and renewable energy (EBT). EBT is divided into two categories: new energy, which involves technologies that are relatively new in Indonesia, and renewable energy, which is generally free of pollution and greenhouse gases. Renewable energy is considered a "sustainable and environmentally friendly natural process" [2].

However, there are several issues associated with these environmental considerations. One is that renewable energy availability can be sporadic, making it difficult to meet peak energy demand because energy sources change from year to year as a result of seasonal variations. Renewable energy comes in various forms, and Indonesia has diverse renewable energy sources, including geothermal energy (PLTP), wind energy (PLTB), and hydropower (PLTA), among others. Given the range of available technologies, the Indonesian government needs to evaluate and select the most promising renewable-energy options. As an archipelagic country with a marine area of 3.257.356 square meters, Indonesia has substantial opportunities to develop ocean-based power generation. Marine power-generation technologies that can be used include wave power, ocean-current power, and ocean thermal energy conversion (OTEC). Therefore, this article focuses on power-generation technologies that harness energy from the sea [3].

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METHOD

The aim of this study is to explore the energy potential of Indonesian seas. This study uses library research, and the analysis is supported by various sources with theoretical relevance. Quality criteria are also discussed in another book that focuses on developing substantive theory based on concepts emerging from empirical data. This means that the study does not directly examine the subject through field research, but instead seeks relevant theories [3].

The research focuses on the use of technology to harvest energy from Indonesian seas. This is because Indonesia, as an archipelagic country, has energy potential in its marine environment, including wave energy, tidal energy, ocean-current energy, and ocean thermal energy, which can be used as an energy source for the public [3].

RESULTS AND DISCUSSION

Ocean Energy Potential

Energy from the sea, particularly tidal energy, is a form of renewable energy that harnesses seawater movement caused by natural tidal phenomena. Tidal energy can be converted into electricity by using the difference in sea level between high and low tide. Systems such as water turbines or tidal barrages can be used to generate energy from this phenomenon [16].

To explain the calculation of ocean energy potential in greater detail, several related basic concepts can be discussed:

1. Power and Energy

Power is the rate of energy conversion or the rate at which energy is used per unit of time, usually measured in watts (W) or megawatts (MW). 1 MW = 1.000.000 watts. Energy is the total amount of power used or generated over a specific period, usually measured in watt-hours (Wh) or megawatt-hours (MWh). Energy can be calculated as the product of power and time [16].

2. Tidal Energy

In the context of tidal energy, we can estimate how much energy is generated based on the power available from the tides over a specific period. If a tidal-energy system generates 12 MW (12 megawatts) from seawater movement over 1 hour, the energy generated in 1 hour is: E = 12 MW x 1 Hour = 12 MWh

3. A Longer Time Period

If the tidal-energy system operates for more than 1 hour, we simply multiply by the duration (in hours) to determine the total energy generated. For example, if the system operates for 24 hours: E = 12 MW x 24 Hours = 288 MWh. This means that the energy generated by the system in 24 hours is 288 megawatt-hours. The longer the system operates, the more energy it generates.

4. Capacity and Efficiency

Other important factors in a tidal-energy system are its capacity and efficiency. Capacity is the maximum amount of power that the system can generate. Efficiency determines how much of the potential energy from water movement can be converted into electricity. In practice, a system may not operate at maximum capacity all the time, and energy-conversion efficiency also varies; therefore, the total energy generated may be lower than estimated [16].

Types of Technologies That Can Be Used to Harvest Ocean Energy

Based on the literature collected, several technologies can be used to harvest energy from the sea, including the following:

1. Wave Energy Technology (Wave Power Energy)

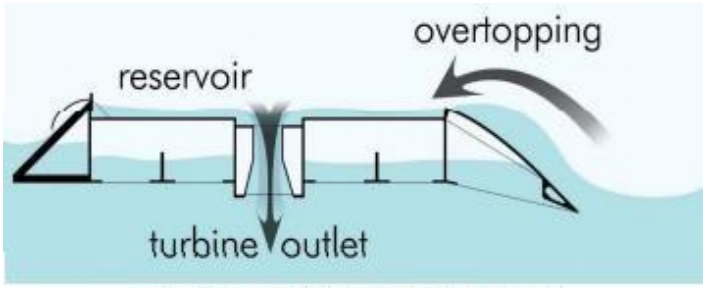
Wave power technology, also known as ocean-wave energy, generates energy from the vertical and horizontal movement of ocean waves. Ocean waves are primarily caused by wind blowing across the sea surface, making wave power a renewable energy source. Although this concept was discussed and patented as early as the 18th century,

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recent research into wave-energy use expanded rapidly after the oil crisis of the 1970s. Today, growing concern about climate change and high carbon dioxide concentrations has further strengthened interest in generating energy from ocean waves [4].

Electricity generated from renewable energy has once again become a significant research topic. Ocean-wave energy, as a renewable source, has advantages because its production can be predicted well in advance, it is available consistently during the day and night, and it can produce more energy than wind or solar power. Various methods used to harness ocean-wave energy include overtopping, absorbers, attenuators, and oscillating water columns.

An overtopping device is a long structure that allows ocean waves to fill a reservoir to a level higher than the surrounding sea surface. The pressure difference between the water in the reservoir and the surrounding seawater causes water to flow through a low-pressure turbine connected to a generator, thereby producing electricity. Overtopping technology can be deployed both on land (along the coast) and offshore [5].



Gambar 1. Teknologi Overtopping Di Laut
Sumber: ourworldofenergy

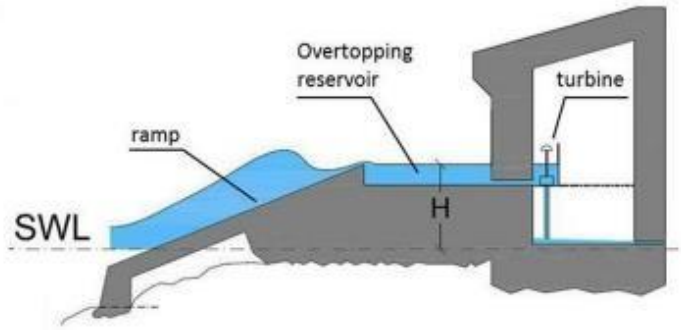


Figure 1. Schematic illustration of an overtopping wave-energy device. Incoming waves flow over a ramp into an elevated reservoir, and the stored water passes through a turbine to generate electricity

Wave-energy absorbers are a promising method for generating substantial amounts of electricity using relatively compact equipment. Although designs vary, the basic operating principle is similar. These absorber devices float on the sea surface and use buoys that move up and down with the waves. This vertical movement is then used to compress a gas or liquid, which is subsequently converted into rotational motion in a generator to produce electricity [6].

Floating electricity-generating technology consists of floating devices that operate parallel to the direction of wave propagation and move along with the waves. The devices are installed at selected locations with good wave potential and anchored to the seabed. They capture energy from the relative movement of two arms as waves pass [6].

Oscillating water column (OWC) technology uses a hollow structure that is partially submerged in water. When ocean waves cause the water column to rise and fall, the air pressure inside the structure also changes. The trapped air is then forced out through a turbine, causing the turbine to rotate and generate electricity [6].

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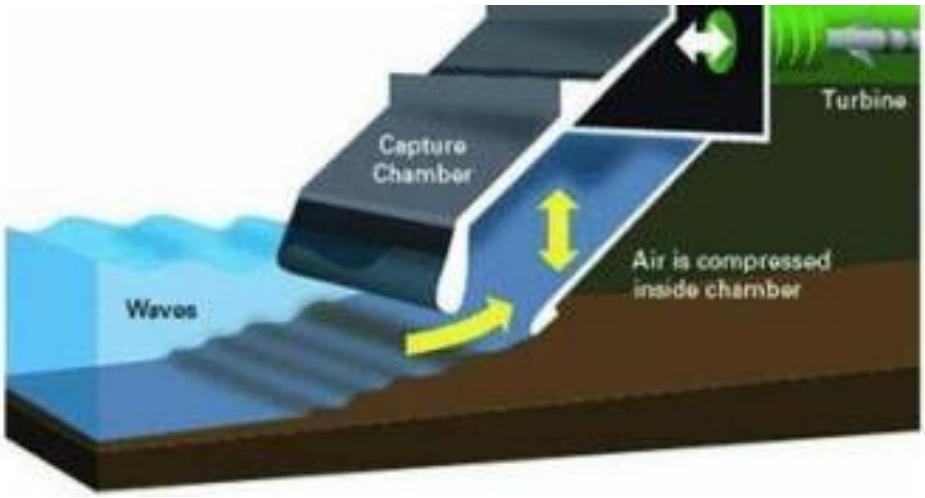


Figure 2. Schematic illustration of an oscillating water column (OWC) device. Wave-driven changes in water level compress and release air inside the chamber, driving a turbine to generate electricity.

The main challenges, however, are high initial costs and the ability of devices to withstand extreme marine conditions. Although still under development, wave-power technology has considerable potential, particularly for archipelagic countries such as Indonesia, which has a long coastline [6].

2. Ocean Current Technology

Ocean-wave power generation is a technology that harnesses energy from the movement of waves at sea. Its advantage lies in the continuous movement of ocean waves. Waves are formed through complex interactions among wind, the Moon's gravity, coastal topography, water depth, and Earth's rotation [7].

The operating principle of this power-generation technology is similar to that of conventional hydropower plants, but it uses the rise and fall of waves as its energy source. Wave-energy harvesting devices convert the vertical or horizontal movement of waves into electrical energy. Although wave strength varies, its energy potential is substantial. For example, a wave 3 meters high can produce energy equivalent to wind travelling at 100 km/hour [7].

Ocean-wave power-generation technology involves various types of devices, such as oscillating water columns, buoys, or mechanical arms that move up and down with the waves. Each device is connected to a generator that converts mechanical movement into electricity. Installations may be located offshore or near the coast, depending on the system design and local wave conditions [7].

An advantage of current-energy technology is its ability to provide a consistent energy supply because ocean currents are more stable than other renewable sources, such as wind or solar energy. In addition, ocean and river currents occur continuously, offering the potential for a more reliable electricity supply [8].

The best locations for applying ocean-current technology are between islands, particularly in straits. In general, currents in straits are stronger than those in the open ocean. Indonesia, with its long coastline and numerous straits and waters rich in ocean currents, has considerable potential to use current-energy technology. With strong currents in several areas, such as the Sunda Strait and Lombok Strait, this technology could become a sustainable energy source and be well suited to meeting electricity needs in coastal areas or small islands that are difficult to reach through conventional electricity networks. This technology offers a promising solution for countries with access to waters that have strong currents [8].

3. Ocean Thermal Energy Conversion (OTEC)

Indonesia, described as the world's second-largest archipelagic country after Canada, has a territory consisting largely of ocean. Indonesia's marine natural resources have been extensively exploited, particularly in fisheries, mining, and industry. However, Indonesian seas also have considerable potential as a source of renewable electricity.

Sunlight reaching the sea surface is effectively absorbed by the water, storing energy in the upper ocean layer at depths of 35 to 100 meters. In this layer, temperature and salinity mix under the influence of wind and waves. In tropical ocean regions between latitudes 15°N and 15°S, solar energy warms the mixed layer of seawater to approximately 28°C (82°F), which remains stable throughout the day and night [9].

Below this mixed layer, seawater temperature begins to decrease with depth, reaching depths of 800 to 1000

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meters, where the temperature is approximately 4,4°C (40°F). At depths greater than 900 meters, a very large reservoir of cold water exists, formed from water and ice from polar regions. This creates a temperature difference between warm surface water and cold deep water, reaching 22°C to 25°C. This temperature difference is relatively stable throughout the year, although it may fluctuate by several degrees due to weather and seasonal changes; the temperature change between day and night is only about 1 degree. OTEC operation is similar to the water cycle on earth. During the day, the Sun causes water molecules to evaporate and form clouds, after which wind carries them over land, leading to condensation in the clouds. Water droplets that were previously vapour become liquid again and fall to the ground. OTEC imitates this process by pumping warm surface seawater, evaporating it in a turbine system to generate electricity, condensing it again with cold deep seawater, and repeating the cycle [10].

In a closed-cycle OTEC system, warm seawater vaporizes a low-boiling-point working fluid, such as ammonia or propane, in a heat exchanger. The resulting vapour drives a turbine connected to an electric generator. After passing through the turbine, the vapour is cooled by cold seawater from the deep ocean and returns to liquid form for reuse in the cycle. An open-cycle OTEC system uses seawater itself as the working fluid. Warm seawater is evaporated in a vacuum chamber to produce vapour, which then drives a turbine. After passing through the turbine, the vapour is cooled by deep seawater and returned to liquid water, which can be used as freshwater [11].

Ocean thermal power plants use the temperature difference between the upper and lower ocean layers to generate electricity. Sunlight warms the sea surface, while water at depth remains cold. In tropical regions such as Indonesia, this temperature contrast is substantial.

Ocean Thermal Energy Conversion (OTEC) technology uses this minimum temperature difference of 25°C to drive an electricity generator. The working fluid is heated by warm surface water until it evaporates, and the vapour is then used to turn a turbine. The vapour is subsequently cooled using cold water from the deep ocean. In addition to generating electricity, this process can also be used for desalination, or converting seawater into freshwater. This technology offers considerable potential as a renewable energy source, particularly for archipelagic countries such as Indonesia, which is surrounded by extensive ocean areas [11].

As an archipelagic country located in the tropics and surrounded by extensive ocean areas, Indonesia has substantial potential to develop OTEC technology. The significant temperature difference between surface and deep water in Indonesia's tropical waters makes the country suitable for OTEC applications. OTEC could not only provide environmentally friendly electricity but also help address freshwater availability in coastal areas and small islands. Through this technology, Indonesia could maximize its marine resources to support the transition to renewable energy [11].

Warm surface water is conveyed through an evaporator together with the working fluid. OTEC technology uses the temperature difference in seawater: warmer surface water is pumped and evaporated to drive a turbine that generates electricity. The vapour is then condensed using cold seawater from depth. This cycle repeats continuously. Indonesia has considerable potential to develop OTEC technology. According to research, South Kalimantan and North Sulawesi are the two areas with the greatest potential, with ocean depths reaching 500 meters. With technological advances, it is hoped that OTEC research and development will become more efficient and can be optimized to meet the public's electricity needs [12].

4. Tidal Current Energy

Fluctuations in sea level caused by tides can be used as an energy source. Tidal energy is not only renewable but also non-polluting (environmentally friendly), like hydropower. Given that Indonesia's hydrocarbon energy resources will continue to decline and eventually be depleted, it is important to recognize that Indonesia is surrounded by seas with substantial tidal-energy potential. Therefore, studies and research into its utilization are needed [13].

Tidal power-generation facilities have been established at La Ranche, France, and subsequently at Murmanche, Lamboy, Te Menzo Boi, and the Tite Sea in Russia. In Australia, not far from Indonesia, this technology is used in Kimberley. At present, the tidal-energy potential across the world's oceans is 3106 MW.

Indonesia is an archipelagic country surrounded by the sea. Its location on the equator, between two major oceans—the Indonesian Sea and the Pacific Ocean—results in strong tidal, wind, wave, and ocean-current conditions. Measurements of tidal heights in Indonesian waters indicate that significant storm waves occur in several offshore coastal areas of Indonesia [13].

Indonesia consists of many islands. There are several narrow straits between islands and bays around each island. These features allow tidal energy to be utilized. Whether sea levels are high or low, water currents can drive turbines to generate electricity. In Indonesia, potential areas include Sumatra, Sulawesi, West Nusa Tenggara, West Kalimantan, Papua, and parts of the southern coast of Java, where tidal heights can exceed 5 meters [14].

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More than 100 locations worldwide are considered suitable for the construction of tidal-energy facilities. Tidal-energy utilization systems are generally divided into two types: single-basin and double-basin systems. In the first system, tidal energy is used only during either the ebb (falling tide) or flood (rising tide). The second system uses a double basin and both tidal periods, allowing energy to be used during both high and low tides. Waterwheels and water channels are located in a dam separating the basin from the sea. At high tide, the water level in the basin is equal to the sea level. As the tide begins to fall, a difference in height (head) develops between the basin and the sea, and water begins to flow toward the sea, causing the turbine to rotate [14].

In a dual-basin system, turbines operate with flow in two directions. The two basins are separated by a dam fitted with bidirectional turbines. The dam is located at the boundary between the sea and a river estuary. Although the waterwheel operates continuously, its speed varies according to the difference between the water level in the basin and the sea surface. In locations with tidal energy, the height difference between the basin water level and the sea surface can range from several meters to 13 meters. One disadvantage of tidal energy is that it requires a sufficiently large area (reservoir) to hold seawater. Its advantage is that the generator is environmentally friendly and does not release toxic pollutants into the water or air [13].

Current Issues, Challenges, and Future Prospects

The use of renewable energy has become one of the most important issues in the world today, from environmental-policy, economic, and social perspectives. This issue is developing rapidly because of the increasingly urgent need to reduce dependence on fossil energy, lower carbon emissions, and protect the environment. The following are several current issues and future prospects related to the use of renewable energy [15]:

1. Climate Change and International Commitments:
   a. Paris Agreement: Many countries have committed to reducing carbon emissions and keeping the increase in global temperature below 2°C. Renewable energy is key to achieving this target.
   b. COP (Conference of the Parties): Every year, countries meet to update their emissions-reduction targets. Renewable energy is one of the main topics discussed.

2. Energy Transition:
   a. Energy Market Deregulation: Many countries have begun adopting policies to deregulate the energy sector in order to increase investment in renewable energy.
   b. Removal of Fossil-Fuel Subsidies: In some countries, subsidies for fossil energy are being reduced to create room for the development of renewable energy.

3. Technology and Innovation:
   a. Improved Technological Efficiency: Technologies such as solar panels, wind turbines, and energy-storage batteries continue to develop, with increasing efficiency and decreasing costs.
   b. Hybrid Renewable Energy: Combining renewable energy with energy-storage batteries to address intermittency (the variable availability of energy).

4. Infrastructure Barriers:
   a. Integration into the Electricity Grid: One of the main challenges is integrating renewable energy into existing electricity grids without disrupting the stability of energy supply.
   b. Development of Supporting Infrastructure: Building infrastructure for renewable energy, such as transmission networks, is an important issue, especially in developing countries.

5. Economics and Employment:
   a. Renewable-Energy Costs: Over the past several decades, the cost of generating energy from renewable sources has fallen sharply, particularly for solar and wind power.
   b. Job Creation: The renewable-energy sector creates new jobs in construction, technology development, and project management.

6. Energy Security:
   a. Reducing Dependence on Imports: By developing local renewable-energy sources, countries can reduce their

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dependence on energy imports from other countries.

b. Diversification of Energy Sources: Renewable energy helps countries avoid dependence on a single energy source, thereby improving overall energy security.

Development and Utilization of Marine Technology as a Source of Electricity

Indonesia is the world's largest archipelagic country and has an extensive marine area. Approximately 70% of Indonesia's territory consists of ocean. In addition, Indonesia has the fourth-longest coastline in the world, after Canada, Norway, and Russia. These geographical conditions give Indonesia substantial potential to develop marine-based renewable energy [15]. Marine energy resources that can be utilized in Indonesia include:

1. Ocean-current energy: Many straits in Indonesia have strong and constant ocean currents.
2. Wave energy: The southern regions of Indonesia bordering the Indian Ocean have large ocean waves with potential for utilization.
3. Tidal energy: Several areas in eastern Indonesia, such as Papua, have significant tidal differences.
4. Ocean thermal energy: Indonesia's tropical waters have a vertical temperature gradient suitable for ocean thermal power generation.

Indonesia has many islands and straits that could be potential locations for marine power plants. For example, the Lombok Strait and Bali Strait are known to have strong ocean currents. Meanwhile, areas such as East Nusa Tenggara and Maluku often experience large ocean waves that could potentially be harnessed as an energy source [15].

Therefore, the development and use of marine technology as a source of electricity is receiving increasing attention amid global efforts to reduce dependence on fossil fuels and transition to renewable energy. These marine technologies harness the energy available in the sea, including wave power, ocean currents, tides, and differences in seawater temperature. Each technology operates according to a different principle, but all share the same goal: converting energy stored in the ocean into sustainable electricity. Using marine technology for electricity generation also supports the global agenda of climate change mitigation. These technologies not only provide an environmentally friendly energy source but also make use of naturally available and abundant resources. With appropriate investment in research, development, and infrastructure, these technologies can play an important role in the transition to a low-carbon economy and in achieving future renewable-energy targets [15].

CONCLUSION

The utilization of renewable energy, particularly marine technology, is a strategic solution to the challenges of global climate change. Technologies such as ocean-wave energy, ocean-current energy, and ocean thermal energy conversion (OTEC) offer substantial potential. As an archipelagic country with an extensive marine area, Indonesia has considerable potential to develop these technologies. With further development, they could provide an environmentally friendly and sustainable energy source and contribute to reducing greenhouse gas emissions. Although challenges remain in terms of initial costs, equipment durability, and supporting infrastructure, the development of marine technology should be a priority in the transition to renewable energy. Indonesia is strategically positioned to utilize its marine resources, which, if managed properly, could positively affect national energy security, job creation, and dependence on fossil energy. Through sustained research and investment in marine technology, Indonesia could become a leader in renewable-energy innovation in Southeast Asia and contribute to global efforts to reduce the impacts of climate change. These efforts have significant implications not only for the present but also for creating a more environmentally friendly and sustainable future for generations to come.

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