POTENTIAL OF RENEWABLE ENERGY FROM HYDROTHERMAL VENTS FOR NATIONAL ENERGY RESILIENCE IN INDONESIA

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Abstract
Renewable energy has become a primary focus in addressing climate change and reducing dependence on fossil fuels. In Indonesia, hydrothermal vents in the Pacific Ring of Fire present significant potential as an energy source. However, their development faces challenges, including technological limitations, potential environmental impacts, and the need for supportive regulations. This study utilizes a comprehensive literature review and descriptive analysis to evaluate the feasibility of using hydrothermal vents as a sustainable energy source in Indonesia. The key findings emphasize the necessity for technological advancements, careful environmental management, and a supportive regulatory framework to harness this potential effectively. This research contributes to the discussion on renewable energy solutions that align with Indonesia's sustainability goals and global initiatives to combat climate change.

Keywords: Renewable Energy, Hydrothermal Vents, Sustainability, Climate Change

1. INTRODUCTION

Renewable energy has become one of the main focuses in the global effort to reduce dependence on fossil fuels and address climate change. Among various renewable energy sources, hydrothermal vents offer significant potential, especially for countries with high geothermal activity like Indonesia. Hydrothermal vents are openings on the ocean floor that release hot water and minerals from within the Earth to the sea surface, creating a unique ecosystem rich in life. As of 2009, more than 250 hydrothermal vents had been visually documented, and this number was later confirmed using trackers in the deep-sea column (Beaulieu et al., 2013).

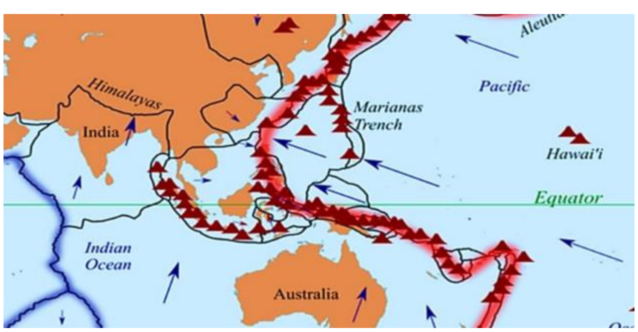

Fig. 1: Distribution of Volcanic and Seismic Activity in Indonesia (Sitepu et al., 2023).

Hydrothermal vents' energy potential is important for marine biodiversity and can be harnessed as a sustainable energy source. Indonesia, located in the Pacific Ring of Fire, has over 400 volcanoes and is one of the countries with the most extensive geothermal potential in the world. Fig. 1 shows the distribution of volcanic and seismic activity in Indonesia, which supports the potential of hydrothermal vents as a renewable energy source. According to data from the Ministry of Energy and Mineral Resources (ESDM), Indonesia's geothermal energy potential is estimated to reach 29,000 megawatts (MW), equivalent to nearly the entire current national electricity supply (Ministry of ESDM, 2020). With favorable geological conditions, hydrothermal vents could become an alternative renewable energy source that is optimally utilized. The question is: How can Indonesia effectively harness the energy potential from hydrothermal vents to enhance renewable energy capacity while ensuring environmental sustainability and compliance with regulations?

2. METHODOLOGY

The research methodology is designed to explore the potential of renewable energy from hydrothermal vents in Indonesia. We employ a literature study and descriptive analysis approach as the foundation of our research. Data sources are drawn from various scientific journals, books, and relevant reports (Moleong, 2007). The literature study process involves collecting and reviewing various literature related to hydrothermal vents and renewable energy potential in Indonesia. This step includes identifying, evaluating, and synthesizing information from existing literature to gain a comprehensive understanding of the research topic. We strive to ensure that all information comes from reliable, up-to-date sources.

Data is collected from various trustworthy sources, including scientific journals, government publications, and industry reports. Our primary focus is on data related to geothermal potential, the distribution of hydrothermal vents, and renewable energy policies in Indonesia. Data analysis is conducted descriptively to illustrate the potential and challenges of utilizing hydrothermal vents as a renewable energy source. The analysis process involves steps such as data classification, source quality evaluation, information synthesis, and result interpretation. Through this approach, we aim to answer the research questions and provide practical and sustainable recommendations.

3. WHAT ARE HYDROTHERMAL VENTS?

A hydrothermal vent is a natural phenomenon that occurs when seawater seeps through cracks in the oceanic crust, particularly around subduction zones, which are areas where two tectonic plates move apart. In this process, cold seawater is heated by hot magma within the Earth. As this water rises back to the surface, it carries various elements from the surrounding rocks, such as copper, zinc, iron, lead, sulfur, and silica. The water temperature at hydrothermal vents can reach over 340°C (or 700°F). Despite the extremely high temperature, the water does not boil due to the extreme pressure at ocean depths that prevents it from doing so (NOAA, 2013).

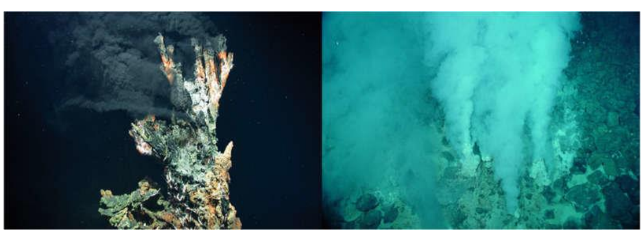

Fig. 2: Types of Hydrothermal Vents
(Omran et al., 2020).

Fig. 2 shows the two main types of hydrothermal vents based on their chemical composition: Black Smokers and White Smokers. Black Smokers emit dark-colored sulfide particles, which are minerals containing sulfur. These vents form in deep ocean environments due to the circulation and heating of seawater at depths of 2-8 km in the oceanic crust. The formation process occurs when the temperature around the vent is lower, as seen in the Eastern Pacific Rise. On the other hand, White Smokers emit white smoke due to sulfide minerals that precipitate into mounds before the fluid exits through the vent (Kelley, 2001). The fluid temperature in White Smokers is cooler, ranging from 250-300°C, and its flow is slower compared to Black Smokers. Generally, the chimneys of White Smokers are smaller. The white color comes from minerals formed when hydrothermal fluid mixes with seawater. In White Smokers, hydrothermal fluid mixes with seawater beneath the seafloor, causing black minerals to form first before the fluid exits. Other chemical reactions produce a white mineral called anhydrite, which changes the color of the fluid to white as it exits through the chimney. With this understanding, we can better appreciate the complexity and uniqueness of hydrothermal vent ecosystems, as well as their potential as significant natural resources.

4. WHAT IS THE DIFFERENCE BETWEEN HYDROTHERMAL AND GEOTHERMAL?

Hydrothermal and geothermal are two terms frequently encountered in discussions about energy and geology, but they have important differences. Hydrothermal refers to processes involving hot water originating from within the Earth, typically occurring in areas with volcanic activity. Here, water trapped in rocks is heated by magma, carrying minerals and other elements that can cause changes in the surrounding rocks, known as hydrothermal alteration.

On the other hand, geothermal encompasses all aspects of energy derived from the Earth's heat. This includes using heat from within the Earth for various purposes, such as electricity power plants, space heating, and industrial applications. Geothermal energy can originate from volcanic activity, heat stored in the Earth's layers, or heat generated by radioactive decay.

A concrete example of hydrothermal alteration can be found in geothermal systems like Cerro Pabellón in Chile, where volcanic activity affects the mineral composition of rocks (Vidal et al., 2023). Meanwhile, geothermal energy can be observed in geothermal power plants that utilize steam or hot water from within the Earth to generate electricity, such as at The Geysers in California (Kraal et al., 2023).

Thus, hydrothermal heat is one phenomenon that results from geothermal heat. All hydrothermal systems utilize geothermal heat, but not all geothermal heat creates hydrothermal systems. While hydrothermal is a part of geothermal phenomena, they have different focuses and applications. Hydrothermal is more specific to the interaction between hot water and minerals, while geothermal encompasses a broader utilization of Earth's heat.

5. UTILIZATION OF HYDROTHERMAL VENTS FOR ELECTRICITY WORLDWIDE

The utilization of hydrothermal vents as a source of electrical energy has become a focus of research and development in various parts of the world. Although it is still in the early stages compared to other geothermal energy sources, technology that harnesses energy from hydrothermal vents shows significant and promising potential.

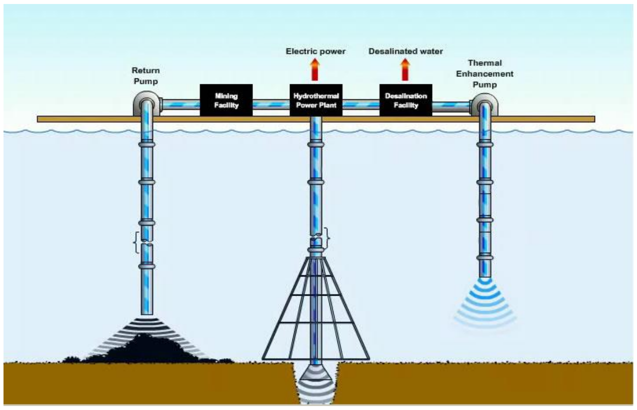

Fig. 3: Complete view of the Marshall Hydrothermal Recovery System showing the power plant, water desalination, and mining facilities operating together (Marshall Hydrothermal, 2011).

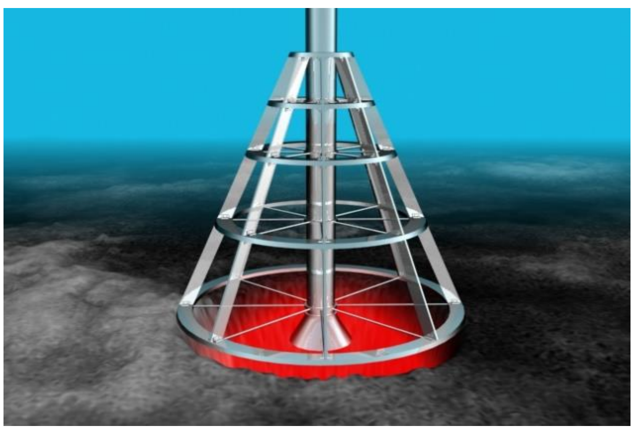

Fig. 4: The Marshall System's base (Marshall Hydrothermal, 2011).

Examples of utilizing hydrothermal vents can be found in the United States, particularly in California. Research in this area shows significant potential for generating electricity from these sources. Several exploration projects are underway to assess their commercial viability. One notable innovation is the implementation of the Marshall Hydrothermal Recovery System, as illustrated in Fig. 3 and 4. This system represents an innovative example of utilizing geothermal energy derived from hydrothermal vents, integrating power generation, water desalination, and mining facilities into one efficient unit. Fig. 3 displays the complete Marshall system, where the Thermal Enhancement Pipe plays a crucial role. This pipe serves as an open channel that extends down to the cold-water layer at ocean depths. By drawing this cold water and using it in thermal reactions, the system can extract more energy than if it solely relied on warmer surface water.

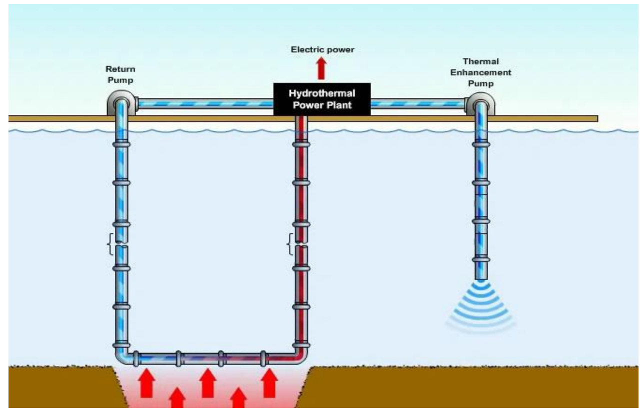

Fig. 5: The Marshall Hydrothermal Recovery System Closed Loop (Marshall Hydrothermal, 2011).

Another interesting system is the Closed Loop variant, as shown in Fig. 5. In this system, instead of bringing hydrothermal fluid to the surface, a clean working fluid circulates in a closed loop and is heated through a heat exchanger. The heat from the vents is transferred to this fluid to drive turbines at the surface. After being cooled, the fluid is returned to the system to be reheated, creating an efficient and sustainable cycle. With this approach, hydrothermal fluids remain at depth, preserving the balance of the marine ecosystem. This innovative approach demonstrates how hydrothermal vents can be effectively utilized to meet future energy needs while maintaining environmental sustainability.

6. ENERGY OUTPUT FROM HYDROTHERMAL VENTS

Based on collaborative studies, the energy output produced by hydrothermal vents can be seen in Fig. 6 (Ilham, 2024). The graph depicts the predicted energy output in megawatts (MW) from hydrothermal vents, as well as the capacities of various ventilation fields to generate renewable energy.

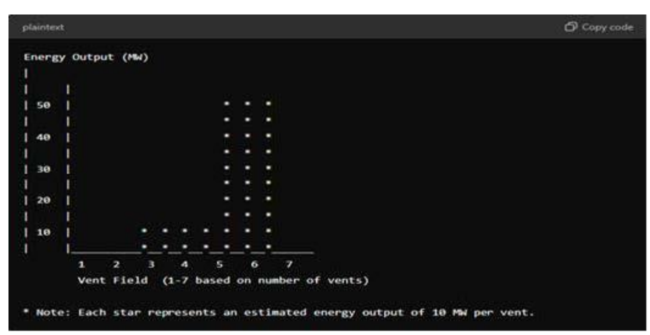

Fig. 6: Energy Output from Hydrothermal Vents (Ilham, 2024).

The graph in Fig. 6 shows varying levels of energy output ranging from 10 MW to 50 MW per ventilation field. This variability depends on the number of active vents and specific geological conditions at each location. Each star in the graph represents an approximate output of 10 MW, making it easier to visualize cumulative energy potentials across multiple ventilation fields. As we progress from one ventilation field to another (labeled 1 through 7), it becomes evident that the potential energy output increases. This additive effect suggests that combining multiple ventilation systems enhances total energy production significantly (Ilham, 2024).

This approach opens opportunities to maximize hydrothermal vent potential efficiently, contributing meaningfully towards future renewable energy demands. With proper strategies, we can optimize and sustainably exploit these natural resources.

7. DISTRIBUTION OF HYDROTHERMAL VENTS IN INDONESIA

Indonesia, with its active geological pathways, has many hydrothermal vent locations, particularly in areas with high volcanic activity. One prominent location is Kawio Barat in the Sangihe-Talaud Waters, North Sulawesi.

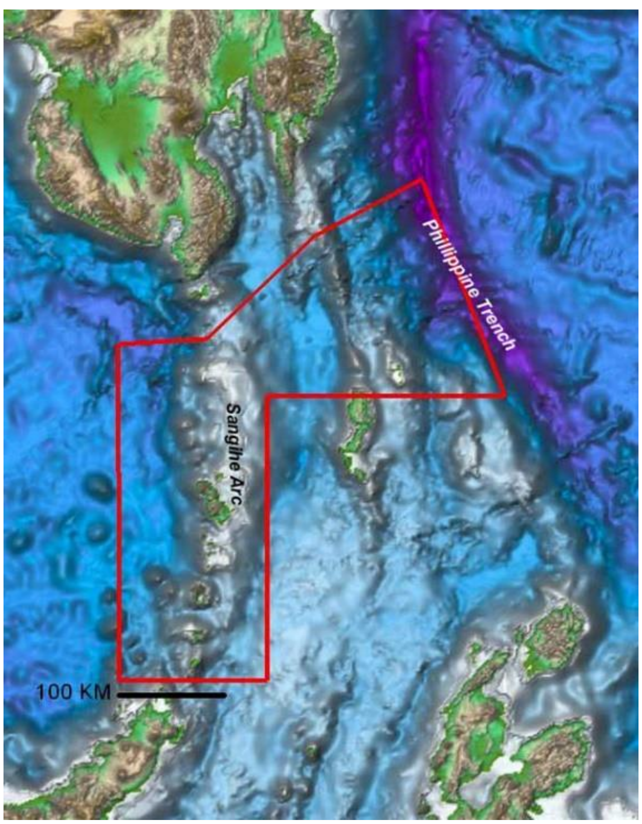

Fig. 7: Map of the INDEX-SATAL 2010 Expedition (NOAA Office of Ocean Exploration and Research, 2010).

In 2010, the INDEX-SATAL Expedition successfully revealed hydrothermal activity at the Kawio Barat underwater volcano. This volcano has a summit at a depth of approximately 1860 meters and a base reaching 5400 meters (Troa et al., 2016). Diving with the ROV Little Hercules on the northwest side of the Kawio Barat underwater volcano revealed chunks of cracked lava covered in bright gray sediment. On the southeast side, pillow lava dominates, while to the southwest, a deep valley shows plumes of smoke from the lower slopes. At a depth of about 1890 meters, the first recorded hydrothermal activity in Indonesian underwater waters was discovered. This activity includes "smokers" emitting white, yellow, and bright gray smoke, indicating differences in the chemical composition of the hydrothermal fluids. Also, hot liquid bubbles and hydrothermal chimneys formed in the plate convergence zone were found (Troa et al., 2016).

Besides Kawio Barat, Komba Waters in Flores and East Nusa Tenggara (NTT) also show potential for hydrothermal vents. Although inactive, the underwater volcano Abang Komba is located along the transitional volcanic arc between the Sunda and Banda Arc (Sarmili et al., 2003). In 2021, three students from ITS Surabaya won second place at the Marine Innovation Festival Indonesia with their innovation of a Hydrothermal Vents Submerged Power Plant in Komba Waters, NTT, demonstrating significant potential for addressing the electricity crisis in the region.

Moreover, the complex Banda Arc area, with its 180-degree curved subduction direction, is known to have active hydrothermal systems due to surrounding volcanic activity. The vents contribute to marine biodiversity and could be a renewable energy source. The Makassar Strait also shows indications of hydrothermal vents, which could be a focus for further research.

With numerous potential locations, Indonesia has excellent opportunities to develop renewable energy from hydrothermal vents. Further exploration will be highly beneficial to maximize this potential, support national energy needs, and preserve the environment.

8. POTENTIAL OF HYDROTHERMAL VENTS AS A RENEWABLE ENERGY POWER SOURCE IN INDONESIA

Indonesia has significant potential to harness hydrothermal vents as a renewable energy source. Several factors support this development:

1. Sustainable Heat Energy Source: Hydrothermal vents generate heat from within the Earth that can be utilized for electricity power plants. This process is similar to traditional geothermal power plants but focuses on utilizing heat from active vents on the seafloor.

2. Environmentally Friendly: Energy from hydrothermal vents does not produce greenhouse gas emissions, making it an environmentally friendly alternative compared to fossil fuels.
3. Diversity of Natural Resources: With numerous hydrothermal vent locations in Indonesia, there is an opportunity to develop power generation projects in various regions, reducing dependence on a single energy source.
4. Support for Marine Ecosystems: Energy from hydrothermal vents can help maintain the sustainability of marine ecosystems by providing habitats for various microorganisms and other marine fauna.
5. Technological Innovation: The development of new technologies to explore and harness energy from hydrothermal vents can make a significant contribution to the renewable energy sector in Indonesia.

Table 1: Analysis of Hydrothermal Vent Potential (Ilham, 2024).

Factor	Description	Potential Impact
Location	Mid-Atlantic Ridge and other offshore areas	Access to vent systems
Energy Output	Estimated energy potential (MW)	10-50 MW per vent field
Technology	Current methods (e.g., hydrothermal plants)	Innovative energy extraction
Environmental Impact	Effects on marine ecosystems	Minimal if managed responsibly
Economic Viability	Initial investment vs. long-term benefits	High potential ROI
Regulatory Framework	Policies supporting marine energy development	Need for supportive legislation
Research and Development	Ongoing studies and technological advancements	Essential for feasibility

The research conducted by Ilham (2024) confirms that energy from hydrothermal vents has excellent potential as a renewable energy source in the future. Table 1 outlines the potential impacts of implementing this energy, ranging from economic to environmental aspects, showing very positive results worth considering.

With Indonesia's commitment to achieving Net Zero Emission (NZE) by 2060, the utilization of hydrothermal vents could be a tangible step towards a more sustainable future. Innovations and developments in this field will support national energy needs and help preserve our environment.

9. HYDROTHERMAL VENT POWER PLANT PROTOTYPE IN INDONESIA

In 2021, a group of students from the Institut Teknologi Sepuluh Nopember (ITS) successfully developed a prototype power plant based on hydrothermal vents in East Nusa Tenggara (NTT). This initiative arose from concerns over the low electrification ratio in the region. The team, consisting of students from the Department of Geomatics Engineering at ITS Surabaya, designed an environmentally friendly underwater electricity system utilizing heat energy from hydrothermal vents.

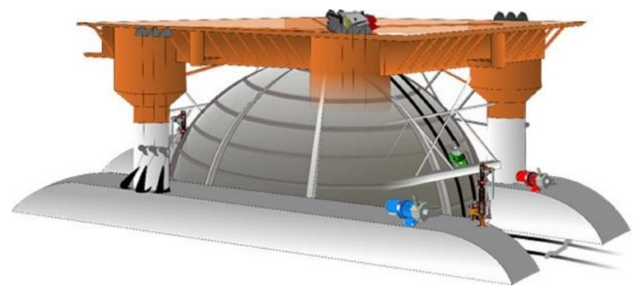

Fig. 8: Prototype Hydrothermal Vents Submerged Power Plant (Institut Teknologi Sepuluh Nopember, 2021).

The prototype depicted in Fig. 8 focuses on exploiting the discharge of hot fluid from hydrothermal vents in the Komba Sea, NTT Region. This area is renowned for having a high concentration of hydrothermal vents, enabling more outstanding energy production.

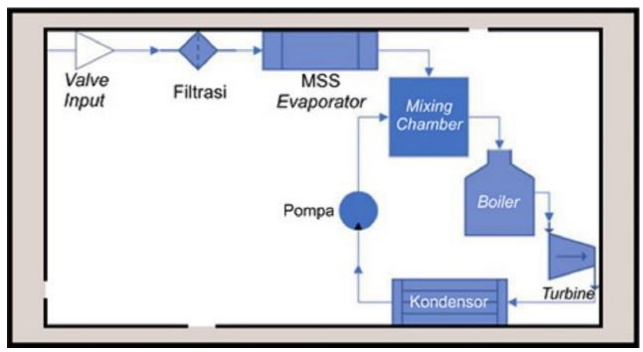

Fig. 9: Process Flow Diagram of Hydrothermal Vents Submerged Power Plant (Institut Teknologi Sepuluh Nopember, 2021).

The operation of this power plant is explained in Fig. 9, starting with capturing hot fluid using massive domes. This rich-in-minerals fluid is then filtered to remove residues before undergoing further processing. Following filtration, the fluid is directed to a Multi-Stage Flash (MSF) evaporator, where the hot fluid is neutralized to pure fluid, enhancing turbine efficiency. The purified fluid enters mixing chambers and flows into boilers, where it is converted into high-pressure steam. This steam powers connected turbines linked to generators, producing electricity.

This innovation strengthens the potential application of hydrothermal vent-based electric power technology as a solution for renewable energy in Indonesia, especially in areas with limited access to electricity. With low environmental impact, this innovation adds significant value given Indonesia’s urgent need to reduce carbon emissions and replace coal-fired power plants with more eco-friendly alternatives.

Through this approach, we address energy challenges in remote areas while contributing to a cleaner and more sustainable future. This local innovation provides real solutions to global challenges.

10. POLICY AND BUDGET SUPPORT FOR RENEWABLE ENERGY FROM HYDROTHERMAL VENTS

The development of renewable energy from hydrothermal vents in Indonesia requires strong policy support and budget allocation to ensure its sustainable and effective implementation. Appropriate policies can create a conducive environment for research, development, and the application of new technologies to harness the potential of hydrothermal vents.

The Indonesian government has established various national energy policies that support the development of new and renewable energy, including geothermal energy. In the National Energy General Plan (RUEN), the government targets an increase in the contribution of new and renewable energy to the national energy mix to 23% by 2025. This policy provides a strong foundation for developing hydrothermal vent projects as part of a strategy to diversify energy sources. It is also designed to address various barriers to adopting new and renewable energy, such as technological challenges, financial constraints, and complex regulations (Solikah & Bramastia, 2024).

The government's role is crucial in supporting this process through mechanisms such as feed-in tariffs, tax incentives, Renewable Energy Certificates (REC), and direct subsidies. These mechanisms aim to reduce financial risks and attract interest from investors and consumers (Mufatdhal et al., 2024). Additionally, regulations such as Renewable Portfolio Standards (RPS) and net metering encourage utilities to integrate new and renewable energy into the national energy mix, creating a market for green energy and accelerating its adoption (Eze et al., 2023; Sobrosa Neto et al., 2020).

Although hydrothermal power plants have minimal environmental impact, especially on marine ecosystems, strict regulations regarding environmental protection must still be enforced. The goal is to ensure that the exploitation of hydrothermal vents does not harm sensitive marine ecosystems. These policies should include comprehensive Environmental Impact Assessments (AMDAL) before projects commence and ongoing monitoring of the ecological impacts of exploitation activities.

Furthermore, policies supporting renewable energy should involve local community engagement in decision-making processes related to new and renewable energy projects. Involving local communities not only enhances social acceptance of these projects but also provides direct benefits to communities through job creation and improved access to energy. This should be a fundamental consideration in policy-making, in accordance with Law No. 30 of 2007 on Energy. This law emphasizes that energy management should be based on principles of utility, rationality, equitable efficiency, value-added enhancement, sustainability, community welfare, environmental function preservation, national resilience, and integration, prioritizing national capabilities (Afif et al., 2023).

With the right approach, Indonesia can optimally harness the potential of hydrothermal vents, supporting national energy needs and resilience while preserving environmental sustainability.

11. CONCLUSION

The distribution of hydrothermal vents in Indonesia, located within the Pacific Ring of Fire, offers significant potential as a renewable energy source. With strategic locations such as the Sulawesi Islands, Nusa Tenggara, the Maluku Islands, and the Banda Sea, Indonesia has vast opportunities to explore and utilize these resources. Hydrothermal vents not only provide opportunities to become a source of renewable energy but also hold significant economic potential.

However, the development of this potential is not without challenges. Limitations in exploration technology, potential environmental impacts from exploitation activities, and the need for supportive regulations and policies are some of the issues that need to be addressed. Therefore, collaboration among the government, researchers, and local communities is crucial. This cooperation will ensure that energy development from hydrothermal vents is carried out sustainably and responsibly.

With the right approach to research and technology development, along with strong policy support, Indonesia can harness the potential of hydrothermal vents to improve electrification ratios and diversify national energy sources. This step will not only strengthen national energy resilience but also support efforts to mitigate climate change and promote sustainable economic development across the country.

Through synergy and joint commitment, we can pave the way toward a cleaner and more sustainable energy future, positioning Indonesia as a pioneer in the innovative and responsible utilization of natural resources.

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