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Overview of the Potential and Utilization of Geothermal Energy on Flores Island

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Abstract: Geothermal energy on Flores Island is a suitable subject for a contextual approach in physics studies. Research activities, exploration, and the practical application of geothermal energy rely on fundamental physical concepts and principles. Flores Island and the surrounding archipelago are endowed with significant geothermal potential. Consequently, this research endeavor, aimed at assessing the potential and utilization of geothermal energy on Flores Island, serves as an excellent resource for contextual physics learning, particularly in the context of Flores Island. This research uses a literature study approach by reviewing related literature to obtain information about the research object. Flores Island and its neighboring island groups host 24 volcanoes. Specifically, Flores Island boasts 20 locations with geothermal potential, with resources capable of generating up to 739.5 MWe. Notably, by 2023, three Geothermal Power Plants (PLTP) will be operational on Flores Island, including Ulumbu PLTP, Mataloko PLTP, and Sokoria PLTP. These developments have positioned Flores as the first island in Indonesia to surpass the Renewable Energy mix target of 25.38%.

Keywords: Flores Island; Geothermal Energy; Physics

Introduction

Flores is one of the large islands in the Province of East Nusa Tenggara (NTT), apart from the islands of Sumba and Timor. There are small islands around Flores Island, namely Komodo and Rinca Islands at the west end, Palue Island at the north, and Adonara, Solor, Lembata, Pantar, and Alor Islands at the east end. As of October 2022, the electrification ratio on Flores Island has reached 95.67% (Muhammad, 2022), and NTT Province has reached 92.50% (MEMR, 2023). This condition places NTT as the province with the smallest electrification ratio in Indonesia. In contrast to the conditions mentioned above, Flores is the first island to reach and even exceed Indonesia's Renewable Energy mix target, according to Government Regulation No. 79 of 2014 Regarding the National Energy Policy, of 23% in 2025. Flores Island 2022 exceeded the national target with a Renewable Energy (EBT) mix reaching 25.38% (Lewokeda, 2022).

Flores Island has much alternative energy potential, including water, solar, geothermal, and ocean currents (Handoyo & Mychelisda, 2016). Specifically for geothermal energy, NTT Province has the potential to reach 1,223.5 MW (5.15% of national potential) and is spread across 31 regions (MEMR, 2021). Of this number, 30 points are on Flores Island and its small islands. Based on these facts, it is unsurprising that the government designated Flores as a Geothermal Island through the Ministry of Energy and Mineral Resources (MEMR) in 2017. Also, geothermal prospect areas in the cluster of small islands around Flores can be optimized, including Lembata Island (Atadei) and Pantar Island. (Mount Sirung). Geothermal energy has advantages compared to fossil energy and other renewable energy, namely that it can produce energy at a stable level and is not influenced by seasons or weather (Nurwahyudin & Harmoko, 2020), including increases in fossil oil prices (Gunawan et al., 2021).

Renewable energy (including geothermal energy) on Flores Island is a physics study material that is very appropriate to study using a contextual approach. Research activities, exploration, and the practical application of geothermal energy rely on fundamental

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physical concepts and principles. Implementing contextual learning also correlates with increasing student activity to prove the truth of concepts and academic content regarding surrounding phenomena (Haryanto & Arty, 2019; Hidayatullah et al., 2021). It helps train students' problem-solving skills using physics concepts in everyday life (Sari et al., 2023) and contributes to developing students' creative abilities (Sapulete et al., 2023).

Science literature is an inseparable part of the science learning process, primarily contextual science literature. The availability of learning resources can improve students' ability to understand teaching materials (Setiawan et al., 2023). Preliminary studies found that scientific literature and articles relating to geothermal potential and its utilization in Flores and NTT, in general, still need to be improved. Most literature comes from news articles in the mass media or releases or reports from relevant government agencies or ministries. Therefore, this research, which aims to describe the potential and utilization of geothermal energy on Flores Island, can be used as a source of contextual physics learning, especially regarding Flores Island. This article also serves as study material to support the development of the Flores Island Contextual Physics course in the Physics Education Study Program, Faculty of Teacher Training and Education, at Flores University.

Method

This research is qualitative with a literature study approach. Research data was collected from various sources, including academic journals, conference proceedings, official government agency reports, and relevant news articles. Furthermore, the data collected will undergo comprehensive compilation and analysis to answer the research problems, namely: (1) What is the potential for geothermal energy on Flores Island? (2) How is the potential for geothermal energy utilized on Flores Island? Thus, in this research, the final form that will be obtained is a brief review of the potential and utilization of geothermal in the Flores Island area.

Result and Discussion

Geothermal Systems

Geothermal energy is heating energy in certain geological conditions in the earth's crust. Geothermal energy that comes to the surface can be directly utilized in the form of hot water or hot steam (Santoso, 2012). Geothermal heat comes from magma, which propagates heat in the surrounding rocks. The geothermal system has requirements such as the availability of water, caprock, reservoir, and heat source (Larasati et al., 2023). Generally, an area that has geothermal potential has manifestations on the surface. This manifestation is thought to arise due to heat propagation or fractures so that geothermal fluid can break through to the surface (Saptadji, 2012). Some geothermal manifestations include solfatara, fumaroles, hot springs, mud pools, and hydrothermal alteration (Lihayati et al., 2022).

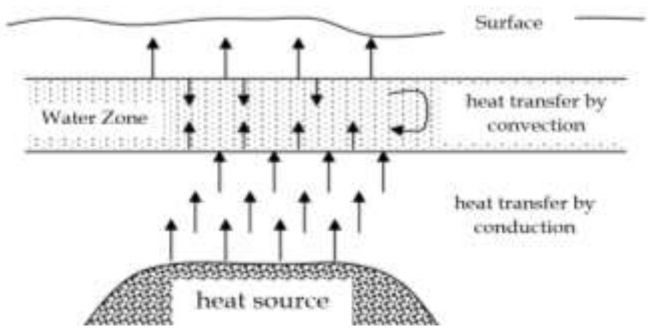

Figure 1. Heat transfer from the Earth's geothermal system (Saptadji, 2012)

Figure 1 shows that heat transfer in a geothermal system occurs through conduction (rocks) and convection (contact between water and the heat source). Hot water that rises to the surface occurs due to buoyant force; water that encounters a heat source causes the temperature to increase and its density to decrease. This condition causes hot water to rise to the surface and colder water to move down to replace the place left by the hot water, giving rise to convection currents (Saptadji, 2012).

Geothermal Power Plants have the same working principle as Steam Power Plants. The difference between these two systems lies in the steam source, where Steam Power Plants come from boiler heating, and Geothermal Power Plants come from geothermal reservoirs (Khasmadin & Harmoko, 2021).

Table 1. Geothermal systems classification based on reservoir temperature (Hawkins & Tester, 2018)

Geothermal temperature system	Muffler & Cataldi (1978)	Rybach (1981)	Hoche-stein (1988)	Cormy (1990)
Low	< 90°C	< 150°C	< 125°C	< 100°C
Intermediate	90°C-150°C	-	125°C-225°C	100°C-200°C
High	> 150°C	> 150°C	> 225°C	> 200°C

Geothermal systems are grouped based on the fluid phase into hot water-dominated and steam-dominated systems (Archer, 2020). Geothermal systems based on the fluid temperature in reservoirs are grouped into high-temperature, medium-temperature, and low-temperature reservoirs (Table 1).

The Potential of Geothermal Energy on Flores Island

Geothermal energy is generally associated with volcanic pathways (Rachmawati et al., 2019), characterized by the presence of volcanoes (Wardani, 2017). Geothermal is one of the most prospective green sources of energy in Indonesia. However, its utilization is minimal as most potential geothermal areas are in conservation (Ekawati et al., 2019). According to MAGMA Indonesia (2021), 29 types of A, B, and C volcanoes exist in the Bali-Nusa Tenggara region. Of this number, 24 volcanoes (including underwater volcanoes) are in the NTT Province, all located on Flores Island and the surrounding island groups. So many volcanoes confirm that Flores is a volcanic island (Arif et al., 2012; Astro et al., 2020). Flores is in third place as the island with the most volcanoes in Indonesia. However, in terms of island size, Flores has Indonesia's highest density of volcanoes. In detail, for the Flores archipelago group, including Adonara, Lembata, Alor, Pantar, and Palu'e, there are 17 type A volcanoes, 2 type B, and 5 type C (MAGMA Indonesia, 2021; Pratomo, 2006). Details of volcanoes in the Flores archipelago are described in the Table 1.

Table 2. Volcanoes in the Flores Region (MAGMA Indonesia, 2021)

Island	Volcano	Type
Flores	Anak Ranakah, Inerie, Inelika, Ebulobo, Iya, Kelimutu, Egon, Lewotobi Perempuan, Lewotobi Laki-Laki, Lereboleng	A
	Ilimuda	B
	Waesano, Poco Leok, Kaldera Sokoria, Ndetu Napi, Riang Kotang	C
Palue	Rokatenda	A
Adonara	Ili Boleng	A
Lembata	Ili Lewotolok, Ili Werung, Hobal	A
	Ili Labalekan	B
Pantar	Sirung	A
Komba	Batutara	A

Volcano-hosted geothermal systems have great potential for power generation (Rahayudin et al., 2020). Specifically, 18 locations on Flores Island have geothermal potential, with resources reaching 741.5 MW (MEMR, 2021). The specific location and magnitude of Flores Island's geothermal potential can be seen in Figure 2.

Figure 2. Flores geothermal prospect area (MEMR, 2021)

Administratively, the Oyang Barang prospect area is part of East Flores Regency but is not located on mainland Flores but on Adonara Island. The geothermal potential areas on Flores Island are spread from West Manggarai Regency to East Flores Regency, with the majority being on the west–central side of the island. Geothermal areas in Flores are characterized by hot springs and fumaroles as manifestations of geothermal heat on the surface. Apart from that, the latest data update found three new prospect areas on Flores Island, namely Marapokot, Randoteno, and Pajoreja, all three of which are in the Nagekeo Regency area (central region of Flores Island) (MEMR, 2021). Thus, there are 20 prospect areas with the potential to reach 739.5 MWe specifically for the Flores mainland. Outside Flores Island, there are also potential areas on several islands, including Atadei, Adum, Roma-Ujelewung (Lembata Island), Gunung Sirung (Pantar Island), East Alor-Maritang and Bukapiting (Alor Island).

The Utilization of Geothermal Energy on Flores Island

Geothermal energy on Flores Island is generally used directly for the tourism sector in the form of hot springs. There are many hot spring tourist locations on Flores Island, including Waebobok and Kolang in West Manggarai, Wetok in Manggarai, Rana Masak, Wae Mapos, and Rana Roko in East Manggarai, Mangeruda and Boba in Ngada, Marapokot in Nagekeo, Ae Oka, Ae Wau, Lia Sembe in Ende, Blidit in Sikka, and Mokantarak in East Flores (Ola, 2022). Until 2023, there will be 3 Geothermal Power Plants (PLTP) operating in NTT Province, and all of them are located on Flores Island, namely the Ulumbu PLTP and Mataloko PLTP, which PLN produces, and the Sokoria PLTP, which has IPP (Independent Power Producer) status (Figure 3). From the economic side, geothermal and wind power plants require the most significant investment and add the highest net Gross Domestic Product (GDP) to the economy (Hartono et al., 2020). Thus, the government has begun to involve the private sector in developing geothermal power plants using the IPP scheme

Figure 3. Location of PLTP Ulumbu, Mataloko, and Sokoria on Flores Island (Sarmiento et al., 2019)

The Flores Islands currently have 8 Geothermal Working Areas (WKP), namely Sokoria, Mataloko, Ulumbu, Oka-Ille Ange, Waesano, Nage, as well as Atadei on Lembata Island and Mount Sirung on Pantar Island. Meanwhile, other prospect areas still have Open Area status. Of the 8 WKPs, 2 WKPs (Ulumbu and Mataloko) have been produced by PLN and 1 WKP (Sokoria) has been produced by the private sector (PT Sokoria Geothermal Indonesia), 3 WKPs are in the exploration stage (Oka-Ile Ange, Atadei, and Gunung Sirung), 1 WKP (Waesano) has Government Drilling status, and 1 WKP (Nage) is in the exploration preparation stage by the Government (MEMR, 2021; Prismono, 2023).

Based on the geothermal powerplan development plan contained in the PLN NTT Business Plan for Providing Electricity (RUPTL) for the 2019-2028 period, it is planned that there will be 13 PLTP units with a target capacity of 115 MW, including Ulumbu (2 units), Mataloko (2 units), Sokoria (5 units), Oka- Ile Ange (1 unit), Atadei (2 units), and Mount Sirung (1 unit). Apart from that, there is potential for developing PLTP for 6 locations/ generating plants with a capacity of up to 120 MW, including Waesano, Waepesi, Mapos, Gou-Inelika, Nage, and Lesugolo (MEMR, 2021).

The Ulumbu geothermal field is in the Manggarai Regency area, more precisely in Wewo village, Satar Mese. The fluid temperature in the Ulumbu reservoir is relatively high, namely between 230°–250°C. Geothermal manifestations in the Ulumbu WKP include hot springs (Wae Cecu, Wae Mantar, Limba, and Wae Gulung) with surface temperatures ranging from 36°–47.5°C, as well as fumaroles (Ulumbu 88.3°C and Anak Ranakah 98.4°C). Ulumbu has estimated geothermal reserves of 187.5 MW, with proven reserves of 12.5 MW (Pambudi, 2018).

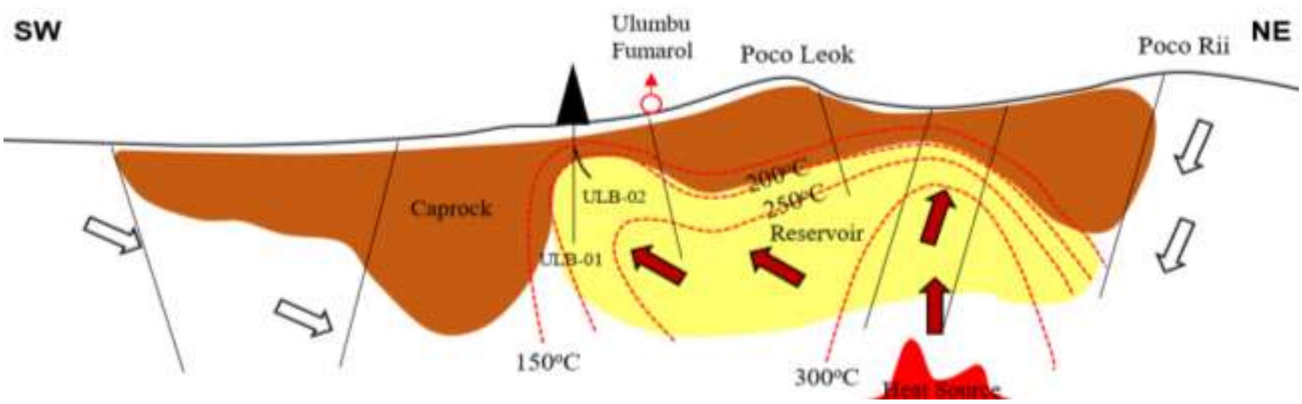

Figure 4. Conceptual model of the Ulumbu geothermal system (Kurniawan et al., 2018)

Surveys and preliminary studies of the Ulumbu geothermal potential area have been carried out since 1972-1982 by the Center for Volcanology, Pertamina, and PLN, covering aspects of geology, geochemistry, geophysics, and geohydrology (Idianto et al., 2021; Mahon et al., 1992). The Ulumbu geothermal system

(Figure 4) is a system dominated by steam at the top (shallow) and water dominated at the bottom (deep) (Kurniawan et al., 2018). The installed capacity at the Ulumbu PLTP managed by PLN in 2016 from 4 operating units was 10 MWe (MEMR, 2017). The capacity expansion of Ulumbu PLTP units 5 and 6 is planned to have a capacity of 2x20 MW.

Another geothermal potential on Flores Island that has been optimized for electricity generation is Mataloko. Mataloko WKP is in Ngada District, not far from Bajawa City, in the volcanic area of the Ebulobo volcano (Nagekeo District) and the Inerie and Inelika volcanoes (Ngada District) at an altitude of around 1,000 meters above sea level (Pradhipta et al., 2019). The Wai Luja fault is the main structure controlling the Mataloko geothermal system. Manifestations on the surface at the Mataloko WKP include hot springs (Soka, Mangeruda, Keli, Tukapela, Watuwuti, Nage, and Mataloko) with surface temperatures ranging from 40.2°C–88.9°C. Mataloko WKP has suspected reserves of 62.5 MWe and proven reserves of 2.5 MWe (MEMR, 2017). The Mataloko geothermal system (Figure 5) consists of a shallow reservoir with a steam-dominated system with a temperature of 210°C and a deep reservoir with a water-dominated system with a temperature of 275°C (Pradhipta et al., 2019).

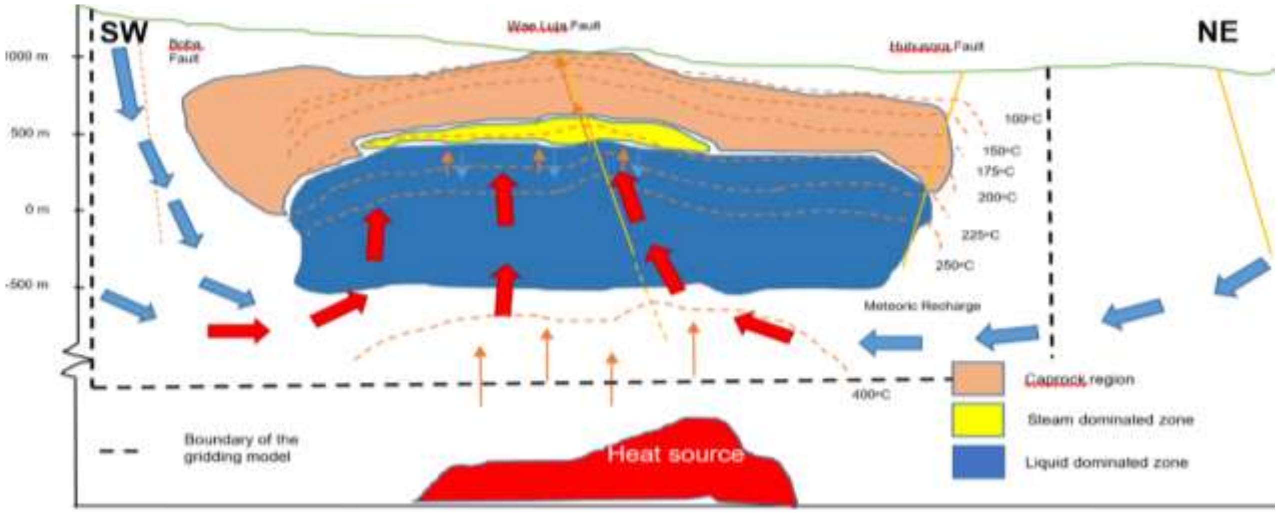

Figure 5. Conceptual model of the Mataloko geothermal system (Pradhipta et al., 2019)

Mataloko is the first geothermal field in eastern Indonesia (Kasbani et al., 2004). Preliminary studies of the Mataloko geothermal field took place in 1997-2002 due to collaboration between Indonesian and Japanese researchers, including remote sensing, geology, geophysics, geochemistry, and reservoir studies (Pambudi, 2018). The initial stages of development, including shallow well exploration (MTL-01 in 1999), well MT-1 (2000), and well MT-2 (2001), failed due to wild steam bursts and an increase in mud temperature. According to Wahyuningsih & Sitorus (2003), after the bilateral cooperation between Indonesia and Japan, the development of the Mataloko PLTP was then carried out by the Indonesian Government, which 2003 excavated the MT-3 and MT-4 wells. The addition of the Mataloko PLTP capacity by PLN developers by two units with a capacity of 2x10 MW is planned for 2024 and 2025, respectively (MEMR, 2021).

The Sokoria geothermal prospect area and several other geothermal potential points, including Kombandaru, Detusoko, and Jopu, are in the Sokoria WKP and administratively in the Ende Regency area. The geothermal manifestations in the Sokoria WKP include hot springs (Detusoko, Wolofeo, Liasembe, Jopu, and Kombandaru) with surface temperatures between 37°C – 61.9°C, warm water (Ae Melo 26.5°C), and Fumarol (Mutubusa) with temperatures reaching 96.8°C. There is a Lowo Ngolopo fault structure, which is thought to control the emergence of the Mutubusa Fumarole. The Sokoria geothermal heat is thought to originate from Kelimutu volcanic activity (Figure 6). Based on analysis of Mutubusa fumarole gas, Sokoria geothermal is classified as a water-dominated system (temperature more than 240°C). The depth of the reservoir is estimated to be between 700-800 meters, with the constituent rocks being pyroclastic and lava (MEMR, 2021). The surface geology of the Sokoria area is dominated by andesite lava and pyroclastic deposits.

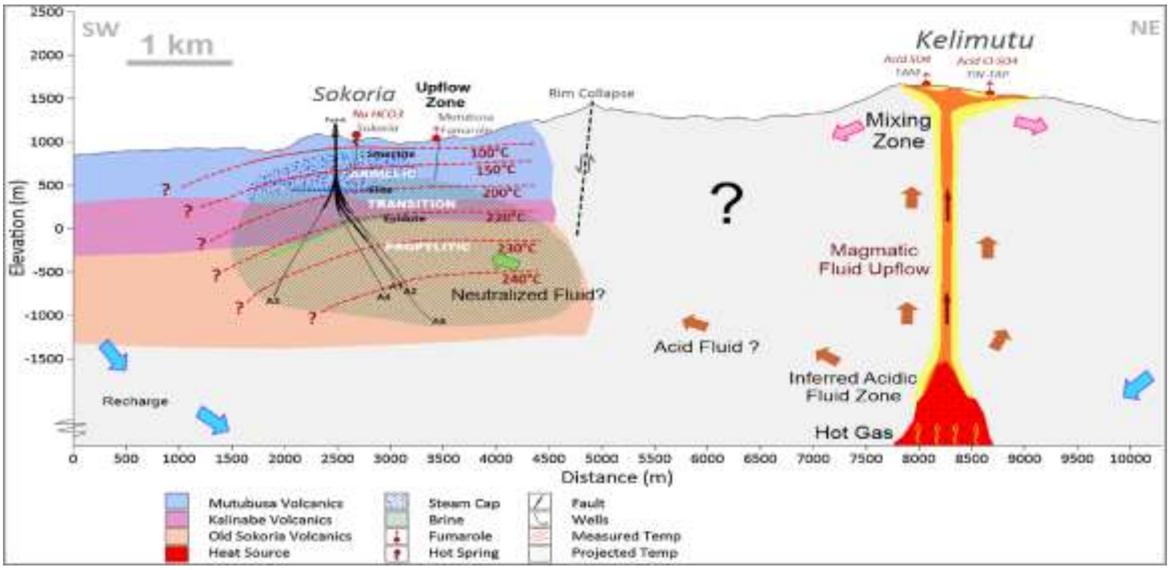

Figure 6. Conceptual model of the Sokoria geothermal system (Sarmiento et al., 2019)

According to Robertus et al. (2007), investigations of the Sokoria geothermal prospect area and its surroundings have been carried out by Chasin in 1974, Suwarna in 1990, PLN in 1995, and Boegis in 2004. Preliminary studies were also carried out through a cooperation scheme between the Governments of Indonesia and New Zealand in 1995, including geological, geochemical, and geophysical analyses (Harvey et al., 1998). This PLTP is managed using an IPP scheme by PT Sokoria Geothermal Indonesia (PT SGI). In the 2017-2018, PT SGI drilled five exploration wells (Sarmiento et al., 2019). In July 2023, unit 2 of the Sokoria PLTP operated with a capacity of 3 MW, after previously, in March 2022, unit 1 operated with a capacity of 5 MW (Prismono, 2023). The Sokoria PLTP will continue to be optimized until it reaches a total capacity of 30 MW (Sarmiento et al., 2019).

Conclusion

Flores Island and the surrounding islands have a significant potential for new renewable energy, especially geothermal energy. The total geothermal potential in East Nusa Tenggara reaches 1,223.5 MW (5.15% of national potential), most of which is in the Flores archipelago. A total of 24 volcanoes in the Flores archipelago are correlated with 20 prospect areas with the potential to reach 739.5 MWe, specifically for mainland Flores. Direct use of geothermal energy is generally in the form of hot spring tourism, while indirect use is used as electrical energy. To date, there are 8 Geothermal Working Areas (WKP) in the Flores Islands region, and 3 of them have reached the production stage. The operation of PLTP Ulumbu (4x2.5 MW), PLTP Mataloko (1x2.5 MW), and PLTP Sokoria (5 MW and 3 MW) also contributed to making Flores the first island to exceed the New and Renewable Energy mix target in Indonesia of 25.38%. It is still possible to exceed this achievement by optimizing the existing PLTP, including developing other geothermal fields still in the exploration stage, government drilling, and exploration preparation.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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