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Indonesian Geothermal Energy: History, Development and the Opportunity to Contribute on GHG Emission Reduction

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Abstract

This paper has provided an overview of Indonesia's geothermal energy development, emphasizing its potential as a long-term solution for clean and sustainable energy amidst increasing electricity demand and concerns about global warming. While geothermal energy alone may not fully address global warming, it can significantly contribute to a cleaner energy future, especially when integrated with other renewable sources and efforts to improve energy efficiency. Despite Indonesia's considerable geothermal resources, only approximately 8% had been tapped as of 2022. Past political and economic challenges are believed to have hindered the country's geothermal development progress.These utilization figures fall short of Indonesia's ambitious emissions reduction targets outlined in its Nationally Determined Contributions (NDC) under the Paris Agreement. Regardless to that, the government has revised its targets, aiming for a higher emission reductions of 31.89% (unconditional) and 43.2% (conditional) by 2030, compared to the previous targets of 29% and 41%, respectively. To optimize its geothermal resources, Indonesia must establish clear and supportive policies and regulations to incentivize development. Additionally, fostering stronger collaboration between the government, private sector, and international partners is essential for maximizing geothermal energy's contribution to Indonesia's sustainable energy goals.

Keywords: Geothermal Energy, Green House Gas Emission, Indonesian geothermal policy, climate and energy policy

1. Introduction

Indonesia is an archipelago located between the Mediterranean volcanic belt and the Circum-Pacific volcanic belt, and so Indonesia is blessed geothermal resources in all classifications. Due to this geographical location, Indonesia is also suffering the impacts of climate vulnerability and change.

In term of geothermal resources, based on data reported by the National Electricity Company (PLN), Indonesia has the potential to generate 28,910 MW electricity from geothermal sources (PLN, 2015). However, these abundant renewable energy sources have not been utilized to generate electricity anywhere close to potential the potential levels.The distribution of 312 individual geothermal sites across Indonesia as of 2015 with total potential power production of 28,910 MWe is roughly shown in Figure 1 and Table 2 (Directorate General for New and Renewable Energy and Energy Conservation, 2015). However, approximately 8,000 MWe of this potential has been categorized as low to medium enthalpy resource (Fauzi, 2015).

Electricity demand growth and raising concerns relating to global warming have led the Indonesian government to shift its energy policy focus from fossil fuel to renewables (Wahjosoedibjo & Hasan, 2012). As part of this shift, the government issued Presidential Regulation No. 5/2006 that set up a road map with specific development targets for geothermal energy; this is reproduced in Figure 2.11. Inspection of the road map indicates that total installed capacity was expected to reach 4.600 MW by 2016 (Nasruddin et al., 2016), but by June 2017 only 1,698.5 MW (or around 37%) of this target had been achieved (Directorate General for New and Renewable Energy and Energy Conservation, 2017).

Figure 1 shows that energy sector contribute to 70% of Green House Gas (GHG) emissions in Indonesia if emission from Land Use and Land Use Change is excluded (Djalante, Jupesta, & Aldrian, 2021).

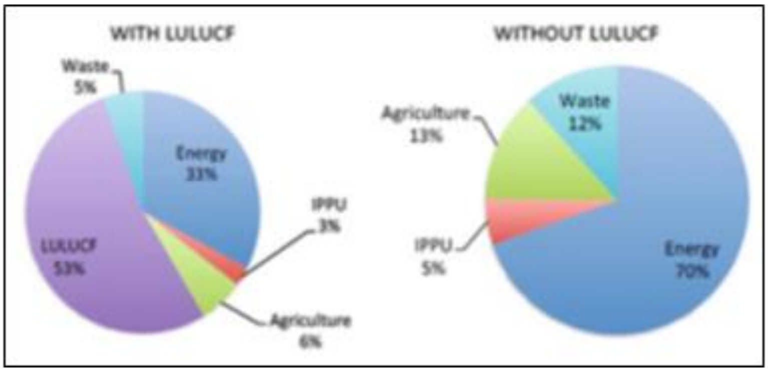

Figure 1. The shares of Indonesian GHG Emission per Sector ((Djalante, Jupesta, & Aldrian, 2021)

While geothermal energy alone may not solve global warming entirely, it can certainly contribute to a cleaner and more sustainable energy future, especially when combined with other renewable energy sources and efforts to increase energy efficiency. y harnessing geothermal energy, countries can reduce their dependency on fossil fuels such as coal, oil, and natural gas, which are the primary contributors to global warming. This reduces carbon emissions from the burning of fossil fuels, thereby slowing down the rate of climate change. Geothermal power plants emit very low levels of greenhouse gases compared to fossil fuel-based power plants. They release about 99% less carbon dioxide than coal-fired power plants, making them a cleaner alternative. By harnessing geothermal energy, countries can reduce their dependency on fossil fuels such as coal, oil, and natural gas, which are the primary contributors to global warming. This reduces carbon emissions from the burning of fossil fuels, thereby slowing down the rate of climate change.

2. Methods

This paper uses literature studies method. A literature review is a critical summary and evaluation of existing research literature on a specific topic or research question. It provides context for the research by summarizing what is already known about the topic and helps to situate the research within the broader scholarly conversation and identify gaps or areas where further investigation is needed.

Researchers analyze and synthesize the findings from the literature, looking for patterns, inconsistencies, or gaps in the existing research. They may use techniques such as thematic analysis, content analysis, or meta-analysis to identify commonalities and differences across studies. Finally, researchers write the literature review, synthesizing the findings from the literature into a coherent narrative that provides context, summarizes key findings.

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3. Results and Discussion

3.1. History of Geothermal Development in Indonesia

Geothermal exploration in Indonesia dates back to the era of Dutch colonial government. In 1926, the Dutch colonial Geological Survey of Indonesia (GSI) conducted initial exploratory drilling of 3 shallow wells at Kawah Kamojang producing steam and a two-phase mixture of steam and hot water, where the third well (KMJ-3) discharged steam continuously for 50 years producing 10 tons/hour of steam with temperature 140 °C while the two other wells stopped discharging after 1928 (Hochstein & Sudarman, 2008).

In 1974, PERTAMINA conducted the first deep well drilling at Kawah Kamojang (KMJ-6), to a depth of 615 m, producing 6.5 tons/hour of steam at a temperature of 239 °C. In total, five shallow exploration wells were drilled in Kamojang between 1974 and 1975 (Sudarman, Boedihardi, Pudyastuti, & Bardan, 1995) with the first electricity production starting in 1978 via a pilot power plant providing capacity of 0.25 MW. Commercial operation of the first unit (with capacity 30 MW) began in 1983 with steam supplied by 26 wells (Suryadarma, Dwikorianto, Zuhro, & Yani, 2010). By 1995 the Kamojang field was confirmed as the fourth largest vapour-dominated system in the world, after Larderello in Italy, the Geyser in the USA, and Matsukawa in Japan

(Hochstein & Sudarman, 2008). In total, 81 wells had been drilled within 14 km2 prospect areas of the Kamojang field, supplying steam for a total generating capacity of 200 MW by 2010 (Suryadarma et al., 2010).

Geothermal exploration continued with the Darajat prospect, about 10 km in south-west of the Kamojang field. In 1976, PERTAMINA drilled the first well with a depth 760 m followed by the second (DRJ-2) with similar depth in 1977 producing 10 tons/hour of dry steam with a maximum (bottom hole) temperature 239 °C (Hochstein & Sudarman, 2008). The third well (DRJ-3) was drilled in 1978, with a depth of 1521 m, a maximum steam temperature of 240 °C and 40 tons/hour of wet steam, equivalent to 6 Mwe (Whittome & Salveson, 1990; (Dobbie, 1991; Hochstein & Sudarman, 2008). The Darajat exploration activities were completed by Amoseas Indonesia Inc (part of the Chevron Group) between 1985 and 1986 under a Joint-Operation-Contract (JOC) with PERTAMINA signed in 1984 (Whittome & Salveson, 1990; Hochstein & Sudarman, 2008). Commercial operations began in 1994 with the commissioning of 55 MW at Unit I, owned and operated by PLN. Unit II and Unit III were commissioned in 2007 and 2008 respectively, adding 271 MW to total capacity.

In 1982, the PERTAMINA signed a JOC with Unocal Geothermal Indonesia (UGI) to develop the Gunung Salak geothermal prospect. The initial drilling at this site was performed in the Awi Bengok field, a water-dominated reservoir system with a depth of 1,370 m and steam output equivalent to 5 MWe. A further four deep wells were drilled with depths of 2 to 2.5 km within the 6 km2 prospect area. In 1984, exploration drilling shifted to another low resistivity area with three wells being drilled. The deepest there was 2470 m with temperatures reaching 307 °C in rock with high acid alteration levels. However, the steam test showed the presence of moderate level of non-condensable gas (NCG) in the steam, potentially reducing performance of the power plant. The drillings therefore were shifted back to the Awi Bengkok field with three new wells drilled in 1985. The first of these (AW-6) was successful, with 1370 m depth and a maximum temperature of 260 °C (equivalent to 20 MW), this became the major production well in Indonesia (Hochstein and Sudarman, 2008), and commercial operations based on this resources began in 1994 with two units operated by PLN with a total capacity of 110 MW. In 1998, a further three units of 55 MW power plants were installed, increasing the capacity to 330 MW (Stimac et al, 2008). By 2002, total capacity had increased to 377 MW with the field is owned by Chevron Geothermal Salak following the acquisition of UGI in 2005. As of 2013, 107 wells had been drilled, 82 production wells and 25 injection wells (Aprilina, Satya, Rejeki, Golla, & Waite, 2015). No further major changes have occurred by the time of writing in term of generating capacity installed (Darma, 2020).

Geothermal exploration activities outside Java were first undertaken in Sumatra in 1972 by VSI, beginning with the Muaralaboh prospect. The Seulawah Agam prospect followed between 1981 and 1984 and the exploration continued by Pertamina in 1990. By 1991, overall 25 prospects had been investigated in Sumatra with geophysical surveys employed for around half of these. Another phase of drilling exploration occurred between 1992 and 1995 with 12 high temperature Sumatran prospects involved (Hochstein and Sudarman, 2008). By 2019, only three prospects in Sumatra had been exploited, Sibayak, Ulubelu and Sarulla with capacities of 12 MW, 220 MW and 330 MW respectively (Darma, 2020).

Sibayak was the first geothermal power plant to operate commercially in Sumatra. The geo-scientific investigation of the prospect began in 1989 with the drilling of 10 wells. Exploration results showed that Sibayak had good potential but involved high acidic hot water and scaling problems (Daud, Sudarman, & Ushijima, 2001). These problems have restricted the development of Sibayak geothermal field to 12 MW, 2 MW in 1990 followed by further units beginning in 1997.

The Ulebelu prospect was the second to be commercially developed in Sumatra, with work undertaken by Pertamina Geothermal Energy (PGE) in 2007. Units I and II, with capacity of 55 MW each, were commissioned in 2012 (Yuniar, Hastuti, & Silaban, 2015), and supplied with steam from 11 production wells producing steam at a rate of 836 tons/hour. PGE drilled a total of 34 exploration and development wells between 2006 and 2015 ((Agani, Patangke, Hartanto, & Silaban, 2015; Yuniar et al., 2015) with Units III and IV proposed for commercial operation in 2017 (Richter, 2016a). Other prospects such as Sorik Merapi, Hululais and Lumut Balai are targeted for commercial operation over the next few years; the first units of Sorik Merap and Lumut Balai fields are now expected to be commercially operated in September 2019 with installed capacities 45 and 55 MW respectively.

Sarulla is the first geothermal project to benefit from Indonesian government support, in the form of a Business Viability Guarantee Letter (BVGL). This involved a 20-year guarantee for PLN's financial obligations via a 30-year energy offtake contract(Rakhmadi, 2015). The prospect exploration started with geo-scientific surveys conducted between 1987 and 1990 by PERTAMINA. In 1993, PERTAMINA signed a JOC with UNOCAL after which drilled 13 deep exploration wells, yielding 330 MW of commercial geothermal resources. In 2002, UNOCAL pulled out of the Sarulla project and sold their rights to PLN for US$ 60 million but in 2006, PLN opened an IPP bidding process for these rights and a consortium led by Medco-Ormat-Itochu won the tender. After a long process of negotiation, the JOC between PGE and Sarulla Operation Limited (SOL) signed in 2013. In March of the following year, the consortium signed a further financial agreement with a syndicate consisting of the Japanese Bank for International Cooperation (JBIC), the Asian Development Bank (ADB) plus six commercial lenders (Ganefianto, et al, 2015). Sarulla began commercially operated in March 2017, with a total capacity 330 MW and overall investment cost of US$ 1.6 billion (Rakhmadi, 2015).

In Sulawesi, major geothermal exploration occurred between 1970 and 1980 with Kotamobagu, Lahendong and Tompaso the three prospects involved. Geological, geochemical and geophysical surveys were conducted in 1976 and the manifestations mapped by VSI between 1977 and 1979. Lahendong is the only prospect in Sulawesi that has been commercially developed to date. The reconnaissance studies in Lahendong were completed in 1981-1982 with three small diameter wells drilled to reach 230, 350 and 650 meters of depth. The first deep exploration well (LHD-1) was drilled in 1983, to a depth of around 2,200 meters and a maximum temperature of close to 300 °C. A further five deep wells were drilled between 1983 and 1986, with depths ranging from 1900 m to 2200 m and temperatures up to 350 °C (Hochstein & Sudarman, 2008). In 2001, the first of four 20 MW units was commissioned with total installed capacity of 80 MW reached in 2012. The 10 steam production wells in this field initially reached 600 tons/hour (with brine production of 500 tons/hour) (Prabowo, et al, 2015). In 2016, PGE expanded the total installed capacity of the field to 120 MW.

3.2. Geothermal Energy Policy of Indonesia

In the World Geothermal Congress of 2010, Darma et al., (2010) suggested the existence of a number of barriers mean that ambitious goals for developing geothermal energy in Indonesia are unlikely to be met. These included; (1) geothermal law (e.g forestry issues); (2) competitiveness of the geothermal energy pricing market; (3) the lack of a government role in risk mitigation; (4) the tendering process for geothermal concessions; (5) power purchase agreement (PPA) issues; (6) a lack of substantive incentives for firms; (7) fossil fuel price subsidies; (8) shortage of competence human resources; and (9) absence of technology and research and development support.

The first action taken by the Indonesian government to support geothermal development involved replacing Geothermal Law No. 27/2003 with Geothermal Law No. 21/2014. One of the main changes in the new act was the easing of conditions relating to the award of licenses for geothermal activity located in conservation and protected forest areas (Dhanisworo, 2014). This change was important as approximately 60% of Indonesian geothermal resources are located in forest areas; 5,935 MWe in conservation forests; 6,623 MWe in protected forests; and 3,670 MWe in production forests (Nasir, 2017).

The new Geothermal Law also reformed the concession tender process. Under the old law, the process could be organized by central government, provincial government or district government, depending on the location of the reserves. Under the new legislation, the tender process has been split between indirect use (e.g for electricity) and direct use (e.g crop drying, hot springs bathing, etc) projects. Central government has the right to tender all concession areas where indirect use is involved, regardless the location. In contrast, local government authorities (provincial and district) are only authorized to tender concessions in direct use cases. Since geothermal activities are not classified as mining activities anymore, the new law changed the name of geothermal permit to Geothermal License (IPB).

Another obstacle for geothermal development in Indonesia, relates to regular government changes to the pricing for geothermal power (Dhanisworo, 2014). Indonesian Government often alter pricing policy to try and find a balance between attractive tariffs and the relative risks borne by PLN and government subsidies. In 2014, via Regulation of Ministry of Energy and Mineral Resources (MEMR) No.17/2014, the government re-implemented the use of a new ceiling tariff. However, this pricing system was itself replaced in 2017 through MEMR Regulation No. 12/2017 which sets tariff based on the Average Generation Cost (BPP) of PLN. The negotiated price in the PPA must not exceed the BPP of the respective area where power plant located; one implication of this new regulation is that geothermal tariffs for areas with low BPP are now less attractive compared to those set under Regulation No. 17/2014. This lacks consistency in policy has caused planning difficulties for the entities involved that may hinder further investment (McCormack & Mandelli, 2017).

3.3. Geothermal Energy Development and GHG Emission Reduction

By 2022, only around 8% of Indonesia's geothermal resources had been utilized. Past political and economic problems suspected have slowed down the development of geothermal energy development in Indonesia (Darma & Wirakusumah, 2015). In particular, inconsistency in the application of rules and laws coupled with lack of business security have threatened investments (Darma & Wirakusumah, 2015). in the end of 2019, therefore total installed capacity reaching 2,138.5 MW (see Table 1). Even with current installed capacity Indonesia is the second biggest producer in the world after the United States jumped from the third position in 2015.

Table 1. Geothermal Power Plant Installed Capacities in Indonesia by 2022

No	Field	Province	Developer/Project owner	MW

1	Sibayak	North Sumatra	Pertamina Geothermal Energy (PGE)	12
2	Ulubelu	Lampung	PGE	220
3	Salak Mt.	West Java	Star Energy	377
4	Wayang Windu	West Java	Star Energy	227
5	Kamojang	West Java	PGE	235
6	Darajat	West Java	Star Energy	270
7	Dieng	Central Java	Geodipa Dieng Energy	60
8	Lahendong-Tompaso	North Sulawesi	PGE	120
9	Ulumbu	East Nusa Tenggara	PT. PLN (Persero)	10
10	Mataloko	East Nusa Tenggara	PT. PLN (Persero)	2.5
11	Patuha	West Java	Geodipa Dieng Energy	55
12	Sarulla	North Sumatra	Sarulla Operation Limited	330
13	Karaha	West Java	PGE	30
14	Lumut Balai	South Sumatra	PGE	55
15	Sokoria	East Nusa Tenggara	PT. Sokoria Geothermal Indonesia	5
16	Sorik Merapi	North Sumatra	PT. Sorik Merapi Geothermal Power	45
17	Muara Laboh	West Sumatra	PT. Supreme Energy Muara Laboh	85
Total				**2,138.5**

These numbers are not optimal to achive the ambitious goal set by Indonesian government to reduce emission by 2030 as set out in Nationally Determined Contributions (NDC) under Paris Agreement. On the other side, government has revised their target in Nationally Determined Contributions (NDC) to cut emissions to 31.89% (unconditional) and 43.2% (conditional) as compared to 29% and 41% respectively in the previous version by 2030 (UNDP, 2024).

Therefore to fully optimize the geothermal resources, Indonesia government should establish clear and supportive policies and regulations to incentivize geothermal development. This includes streamlining permitting processes, providing financial incentives such as tax breaks or subsidies, and setting ambitious targets for geothermal capacity expansion. Regulatory stability is crucial to attract investment and mitigate risks for developers. Furthermore, the collaboration between the government, private sector, and international partners is essential for financing, technical expertise, and project development. PPPs can facilitate funding, risk-sharing, and knowledge transfer, accelerating geothermal projects' implementation. Indonesia can leverage multilateral development banks, international agencies, and private investors to mobilize financing for geothermal development.

4. Conclusion

This paper has presented an overview of the development of geothermal energy in Indonesia, highlighting its potential as a long-term solution for clean and sustainable energy. This aligns with Indonesia's commitment to reduce greenhouse gas emissions by 31.89% (unconditionally) and 43.2% (conditionally) by 2030, as stated in its Nationally Determined Contributions (NDC). Indonesia, as a developing nation, is actively addressing climate change through adaptation and mitigation efforts, but there is still a need for further governance of these actions. Improved coordination across multiple sectors and the establishment of robust legal frameworks for climate action are necessary. Adaptation and mitigation efforts can lead to sustainable development, ultimately addressing poverty, promoting equality, and preserving the environment in the long run. While there is room for improvement in these processes, lessons learned should be integrated into broader development agendas for streamlined progress.

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