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Accelerating Geothermal Development in Indonesia: A Case Study in the Underutilization of Geothermal Energy

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Abstract

Geothermal energy is a clean, reliable, and domestic source of energy that offers constant electricity while emitting relatively few emissions of carbon dioxide and other pollutants. Despite these benefits, its development globally has not been as rapid in recent years as that of other renewable energy sources. We examine Indonesia as a case study— while home to over a third of the world's geothermal resources, the country exploits only 5.8% of it. Moreover, as a rapidly developing economy with projected electricity growth of 8.5% per year until 2025, Indonesia must harness its geothermal potential if it is to meet electricity needs without requiring the fossil fuels upon which it has historically been reliant. However, significant roadblocks impede geothermal development in Indonesia, primarily in the geoscientific, financial, and political spheres. Firstly, there is a lack of geologic data crucial to preliminary geothermal potential assessment, rendering it difficult to locate available resources. Financial issues also deter investment in geothermal development by private companies due to the high up-front cost of preliminary resource exploration. Lastly, an uncertain political and regulatory environment create uncertainty for geothermal investors. Cognizant of these problems, we examine solutions and policies effectively implemented by other countries and industries that can be applied to Indonesian geothermal energy development. While specific to Indonesia, our recommendations for collaborations amongst governments, development agencies, and private companies bear implications for accelerating the development of geothermal energy resources worldwide.

Author's Note

Our team finds it startling that the country of Indonesia, although estimated to possess about one-third of the world's geothermal energy resources, utilizes only a negligible amount. In particular, we are motivated by the fact that this underutilization is more than an academic question: two years after the momentous international accord that arose out of the Paris Agreement of 2015, the question of how developing countries will sustainably lift their poor out of the trenches of poverty—without gravely endangering the stability of the global climate system—remains one of the most significant sources of uncertainty in assessing the geopolitical trajectory of the 21st century. In this light, the challenge of geothermal development in Indonesia provides an exemplary case study—Indonesia being a highly populous island and rapidly industrializing nation for which the problems of sustainable electrification, the mitigation of climate change and sea level rise, severe health risks owing from air pollution, and poverty alleviation and marginalization loom large. We are furthermore compelled by a sense of humanitarian urgency: Indonesia's failure to develop its geothermal resources would most likely result in the country's burgeoning electricity demand being instead met by coal power, exacerbating all of these problems.

As senior undergraduates and recent graduates interested in geophysics business and economics, we are also intrigued by the inherent interdisciplinary nature of the problem, which cuts across both the natural and social sciences: from geology, geophysics, and environmental science to renewable energy policy, politics, sustainable electrification and poverty alleviation, finance, and economics. Emboldened by how our different but complementary interests provided us with a holistic perspective on the diversity of subjects constituting geothermal development, we set out to research and evaluate the problems hindering geothermal development in Indonesia, the solutions that had already been researched and attempted, and how particular actors can better collaborate to take advantage of this abundant renewable energy source.

We owe much to the experts we interviewed, ranging from geothermal scientists and consultants to renewable energy specialists and UN sustainability advisors, who have generously shared their insights and experience with geothermal energy development practices, both in Indonesia and around the world.

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Keywords: Geothermal energy, renewable energy policy, Indonesia, sustainable electrification.

I. Introduction

a) The Need for Sustainable Electrification in Indonesia

The world's fourth most populous country, Indonesia has 255 million people and the largest economy in Southeast Asia. Given that it is a nation consisting of 18,000 islands across its expansive archipelago, universal access to electricity—a key driver of poverty alleviation and income inequality reduction—has been a major challenge. Indeed, Indonesia faces an electricity crisis: over 80% of regional electricity systems are prone to frequent or sporadic power outages (PwC, 2016, p. 8). The situation could still worsen. Considering Indonesia's strong population growth, rapid urbanization, industrialization, and rising per capita income, future electricity consumption is projected to grow at the precipitous rate of 8.5% per year until 2025 (PwC, 2016, p. 7).

The benefits of universal electrification are well-documented, as are their correlation with higher levels of human development (Figure 1), providing water and irrigation for enhanced agricultural production, improving educational outcomes via lighting and communication tools, and reducing child/maternal mortality and disease incidence via refrigeration of medication (UNDP, 2013). As recently as 2000, the nationwide electrification ratio was 57%—and though it had increased to 84% by 2014 (ADB, 2015), 50 million people still lack access to electricity. Improvement in this sector therefore offers an opportunity to positively affect tens of millions of Indonesians.

Yet the historical, near-exclusive reliance upon fossil fuels in Indonesia has had substantial, deleterious consequences, disproportionately affecting its most marginalized populations. At present, fossil fuels are responsible for 88% of electricity generation in the country (EIA, 2015). This presents significant health risks because of air pollution: according to Greenpeace (2015), an estimated 6,500 people per year die prematurely due to coal plants, while the National Bureau of Research (2016) estimates that 58% of Jakartans suffer from air pollution-related diseases. Thus, reducing Indonesia's reliance on fossil fuels and strengthening its capacity to produce renewable energy is imperative to improve the health of Indonesians. Moreover, as an island nation, Indonesia is vulnerable to future socio-economic harm from climate change and coastal inundation, particularly because 60% of the population resides in coastal cities such as Jakarta. Likewise, agriculture and fisheries, two economic sectors upon which the poor in Indonesia are heavily reliant, are anticipated to experience substantially lower yields in future decades due to increased extreme weather events such as floods and monsoons (Measey, 2010). Projected climate change therefore stands to exacerbate Indonesia's already large income inequality[1] with a 'perfect storm' of adverse, coupled effects.

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[1] A common statistical measure of the degree of wealth inequality in the distribution of family incomes in a country, Indonesia' Gini Index was 36.8 as of 2009, ranking 79th out of 145 countries (see CIA, The World Factbook, "Country Comparison | Distribution of Family Income - Gini Index"). For the Gini Index, a score of 0 represents maximum income equality, while a score of 100 represents maximum income inequality.

Climate change is also projected to adversely affect Indonesia more directly via the effects of elevated temperatures throughout the 21st century. For instance, defining the signal-to-noise (S/N) ratio as the amplitude of climate change in units of existing climate variability, Frame et al. (2017) expresses the effects of climate change statistically, in terms of the unfamiliarity of future projected climates for specific geographic areas with respect to present conditions. According to this conceptual framework, an S/N value of 3 indicates that a projected new climate is warmer than 99.9% of the base (present) years and is therefore designated with the highest risk moniker of "unknown". The Association of Southeast Asian Nations (ASEAN), including Indonesia, is projected to experience an S/N value of up to approximately 25 by the end of the 21st century, resulting in an unprecedentedly warmer climate. Furthermore, this presents significant potential for global spillover effects in economic, security, and political realms—particularly where climate impacts contribute to security and humanitarian issues in vulnerable countries[2]. Given the magnitude of these challenges, there is thus urgent and substantial impetus for Indonesia to reduce its unsustainable carbon emissions, and their attendant adverse effects on human health, economic longevity, social stability, and the environment. To this end, this paper shall focus on the contributions that renewable energy sources such as geothermal energy can make in terms of providing sustainable alternatives.

[2] Frame et al. 2017, page 1. According to this framework, S/N=1 denotes an "unusual" climate, S/N=2 denotes an "unfamiliar" climate, and S/N≥3 denotes an "unknown" climate. For the latter, an "unknown climate" is unknown in the sense that the overlap between coldest projected years and warmest base period years is only 13%, such that the new mean climate is warmer than 99.9% of base years, and the new climate state would be experienced on average only once every 740 years in the base climate - far beyond what a single human could reasonably expect to experience in their own lifetime. A value of S/N=25, at the upper limits of what is projected for Indonesia by the end of the 21st century, therefore represents extreme climate change in statistical terms.

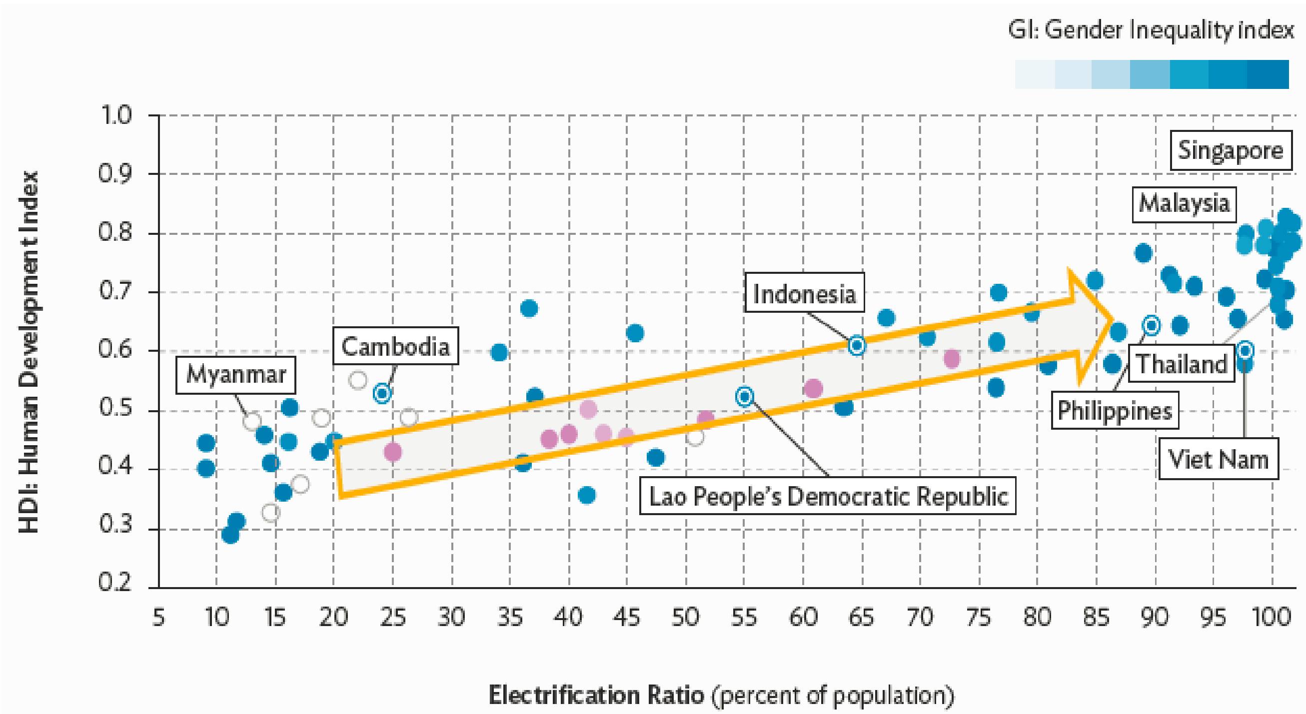

Figure 1: Relationship between Electrification Rate and Human Development Index and Gender Inequality in 2009, with emphasis upon Southeast Asian countries. Note that Indonesia's electrification ratio has increased significantly in recent years, to 84% as of 2014. *Source:* UNDP. (2013). *Human Development Report.*

b) Indonesia's Geothermal Energy Resources

Indonesia owes its abundant geothermal resources to its privileged position in the Pacific Ring of Fire, at which the Indo-Australian Plate and the Pacific Plate are subducted beneath the Eurasian plate. Once these plates reach depths of approximately 100km, temperatures are sufficient for rock to turn into magma, which subsequently rises to the surface at sites of volcanic eruption. This manifested in Indonesia's 76 historically active volcanoes—the largest number of any country (Volcano Discovery). More than 75% of Indonesian residents live within 100km of a volcano that erupted within the last 11,700 years (Smithsonian Institution). Since geologically young volcanoes are typically the areas with the highest underground temperatures (Union of Concerned Scientists), Indonesia possesses an enormous opportunity for energy production, having an abundance of such high-temperature hydrothermal systems. Indeed, geothermal heat flow at the surface is up to 100% greater in some regions of Indonesia than the average heat flow at the surface of Earth's continents (Figure 2), up to 120 milliwatts per square meter (i.e. power per area) as opposed to the more typical value of 60 milliwatts per square meter. Such high heat flow values in the country can be attributed to volcanic and magmatic heat as well as some non-volcanic sources, such as extinct magmatic systems at old subduction zones, tectonic extensional domains, and intra-cratonic basins (Suryantini, 2017).

It because of this favorable geological and thermal environment that Indonesia possesses an abundance of geothermal energy: an estimated 35-40% of the world's global geothermal energy potential (see Appendix I for further discussion of the variability in this estimate).

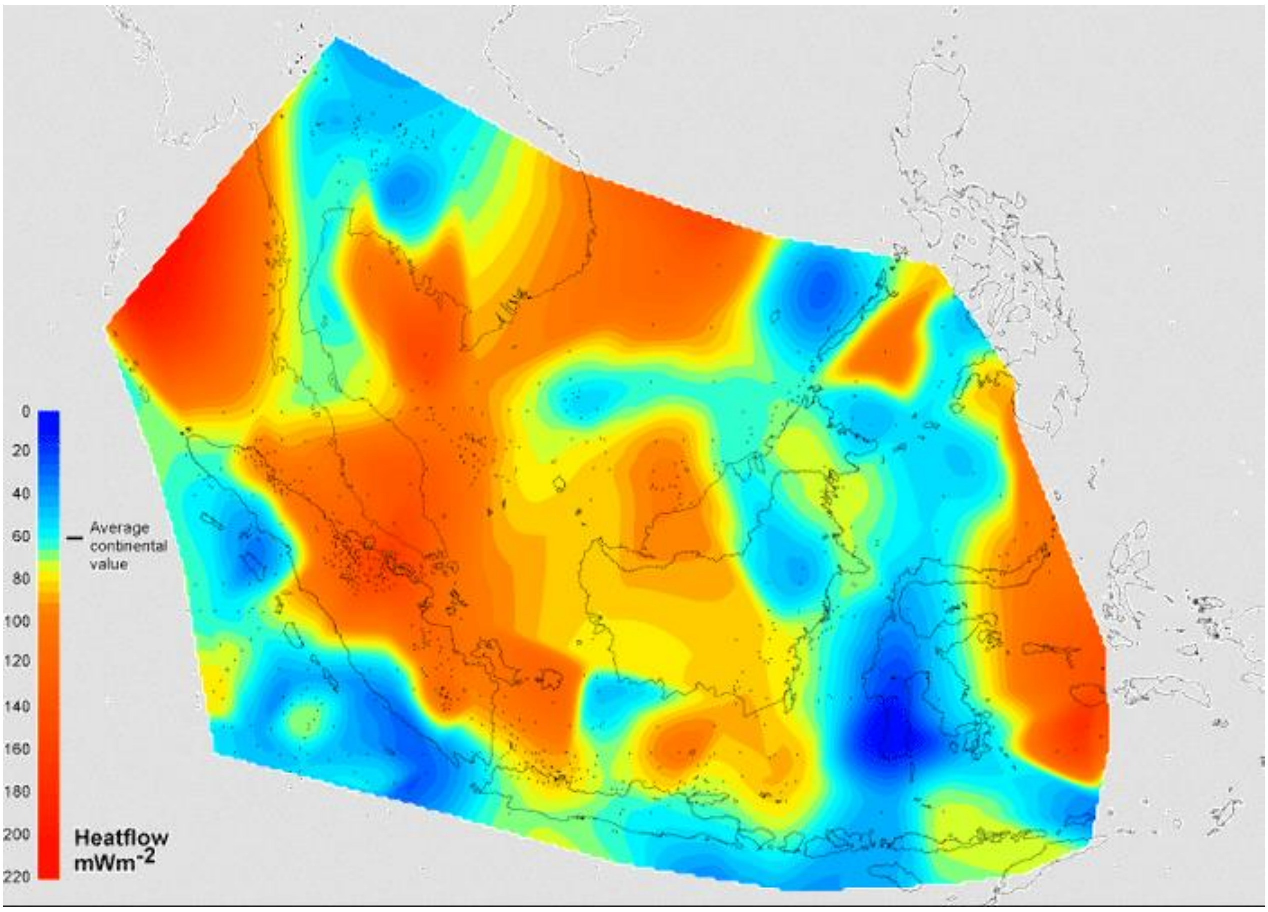

Figure 2: Geothermal heat flow in Indonesia, in units of milliwatts per meter squared. Data has been interpolated (owing from the relatively sparse data coverage in some regions) and smoothed.
Source: SEARG (Southeast Asia Research Group). *Heat Flow | SE Asia Heatflow Database*. Compilation map by Helen Smyth. (http://searg.rhul.ac.uk/current-research/heat-flow/).

Furthermore, many geothermal resources in Indonesia are situated in ideal locations, both near major population centers where electricity demand is high and still increasing, and near impoverished eastern parts of the country where electrification rates are low. For example, the Geothermal Energy Upstream Development Project for Indonesia, initiated in 2016, focuses upon the underdeveloped geothermal power market in Eastern Indonesia — where electrification rates are lowest and poverty rates highest. It is a joint initiative of Pertamina Sarana Multi Infrastruktur (PT SMI), an infrastructure financing company, and the World Bank (Qadir, 2016, page 3).

The Indonesian federal government has repeatedly stated its intention to develop the country's abundant geothermal resources, which are estimated to be 24 GW or 35% (Fauzi, 2015) of the global geothermal potential of 70 GW, where the latter is defined as the total extractable geothermal energy estimated based on current technology (Bertani, 2009). As of December 2012, the Geological Agency (Badan Geologi) of the Ministry of Energy and Mineral Resources has identified 299 geothermal working areas in Indonesia (Smillie, 2015, p. 1). However, installed capacity in 2014 was 1.4 GW, a mere 5.8% of total potential (Fauzi, 2015). In addition, the federal government's stated goal is to increase geothermal capacity more than fourfold by 2020 (Ministry of Energy and Mineral Resources, Indonesia), which seems impractical[3]. Overall, substantial scientific and technical, financial, and political problems keep the situation in stasis.

The stakes loom large. Any shortfall in installed capacity will most likely be met by construction of additional coal power plants (ADB, 2015, p.1), rendering almost impossible Indonesia's COP21 pledge to reduce greenhouse gas emissions by 29% by 2030[4]. In light of the interconnected problems of climate change and sea-level rise, mortality and illness from fossil-fuel air pollution, and sustainable electrification, Indonesia's failure to utilize its geothermal resources has dire implications for the future welfare of its people.

c) Geothermal Energy: Scientific Principles and Environmental Impact

Geothermal energy is derived from the flow of the Earth's internal thermal energy to the surface, which includes both thermal energy from the original formation of the planet and the heat-producing radioactive decay of elements in the Earth's mantle and crust (Berrizbeitia, 2014, p. 1). The exploitation of hydrothermal geothermal systems is a mature technology. It consists of naturally convecting fluid circulation systems, in which hot water and steam are extracted from permeable reservoirs near the surface in areas with high heat flow. They are the most commonly exploited geological setting for geothermal energy production. Figure 3 illustrates the principles relevant to a conventional flash steam geothermal plant in a hydrothermal system. The utilization of hydrothermal systems for electricity is distinct from that of Enhanced Geothermal Systems (EGS), a more recent innovation in which areas with high heat flow but insufficient natural permeability for natural fluid convection are artificially stimulated via the injection of water at high pressures, with the ultimate goal of producing a fracture network with high fluid permeability (Dempsey & Suckale, 2015, p. 2/5). However, the focus in Indonesia thus far has been upon exploiting hydrothermal systems, which tend to be both cheaper and easier to establish.

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[3] Private correspondence with Huong Mai Nguyen, Energy Specialist with focus on geothermal and hydro power in Indonesia, at the World Bank.

[4] This projected reduction is calculated with respect to a business-as-usual scenario in which 2.881 Gigatons of CO2 equivalent is emitted in 2030 (see Republic of Indonesia 2015, "Intended Nationally Determined Contribution").

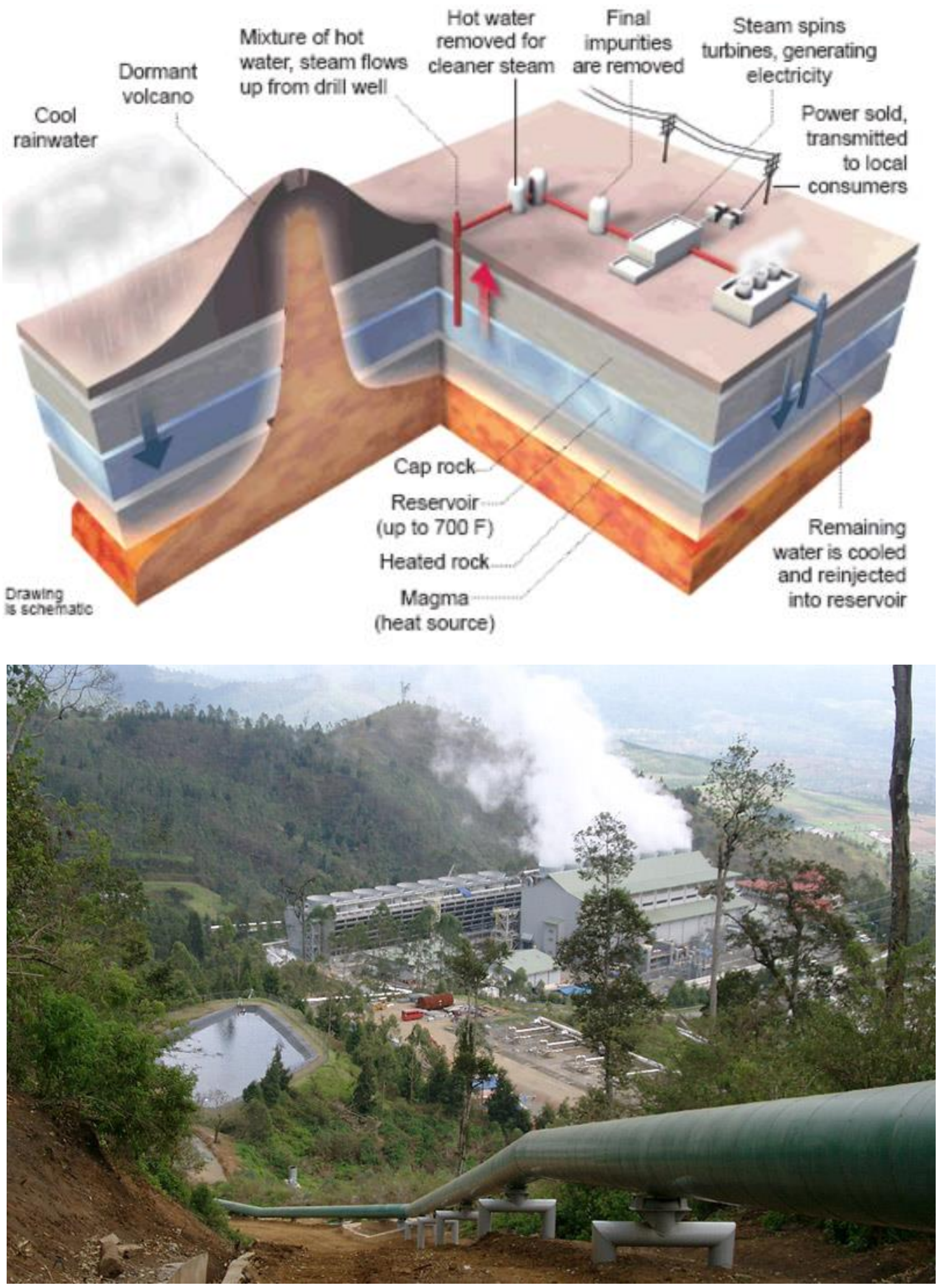

Figure 3: (Top) Schematic illustrating how a Flash Steam Geothermal Power Plant (the most common kind) works. *Source:* McDowell, R. (2006). "Indonesia sitting on geothermal power plant." NBCNEWS.com. (Bottom) Dajarat III Power Station, West Java, possessing 290 MW in capacity, rendering it the world's 10th largest geothermal plant as of 2013.

With the ability to fulfill fast-growing electricity demand, alleviate health risks, and tackle climate change issues, geothermal energy is a continuous, baseload source of power (in contrast to wind and solar) that results in comparatively minimal environmental damage (in contrast to hydroelectric, which adversely impacts fluvial ecosystems) and improves energy security. Geothermal is a relatively clean energy, with flash steam plants emitting 4% of the sulfur dioxide (0.16 kg/MWh), 0% of the nitrous oxide, and 3-5% (27-40 kg/MWh) of the carbon dioxide created by a coal power plant producing an equivalent amount of electricity. Closed-loop binary plants emit zero or near-zero emissions of sulfur dioxide, nitrous oxide, and carbon dioxide (Tester et. al., 2006, p. 8-6). Geothermal plants also require less land (0.4 m^2/MWh) than other energy technologies, from three times less than wind power to nine times less than coal power, while using less than 5% of the water (38 L/MWh) of an equivalent coal power plant (GEA, 2014, Figures 16, 18).

Though potentially harmful environmental effects of geothermal energy have been documented, such impacts can be mitigated. For instance, it has been stated that geothermal waters pose a large potential risk to water quality, soil quality, and local vegetation if released into the environment, due to their high concentrations of toxic elements including antimony, arsenic, lead, and mercury. However, the risk of release can be virtually eliminated by proper design and engineering controls (Clark, Harto, Sullivan, Wang, 2011, p. 49). Examples of such controls include the direction of fluids in surface runoff to impermeable holding ponds, and the injection of all wastewater streams deep underground. Another control against fluid leakage into shallow fresh-water aquifers consists of designing well casings with multiple strings (long sections of pipe lowered into a well and subsequently cemented), in order to provide redundant barriers between the inside of the well and the adjacent formation (Tester et. al., 2006, p. 8-6).

Ecosystem impacts such as wildlife/habitat loss or vegetation disturbance associated with geothermal energy are relatively minor at hydrothermal projects in the United States (Tester et. al., 2006, p. 8-12). Specifically, geothermal field development can involve the removal of trees and brush to facilitate the installation of necessary infrastructure such as the power house, substation, well pads, piping, emergency holding ponds, and otherwise. However, once a plant has been built, reforestation can restore the area to a semblance of its initial appearance, masking the presence of buildings and other structures. While such efforts do not preclude the possibility of long-term ecosystem damage, the small area required for geothermal plant operations relative to most other electricity sources (both non-renewable and renewable) minimizes this concern. Finally, as with other types of power generation facilities, industrial accidents can occur. Those involving well drilling and testing are unique to geothermal. In the early days of geothermal energy production, well blowouts were fairly common; however, at present, the use of fast-acting blowout preventers have essentially eliminated this possibility (Tester et. al., 2006, p. 8-15).

II. Why Is Geothermal Underutilized in Indonesia?

a) Technical Challenges

The two fundamental physical requirements for the generation of economically-viable amounts of geothermal power are high geothermal heat flow and high permeability of the geothermal fluid as it migrates to the surface. Indonesia, however, lacks the borehole heat flow data that would allow for the optimal characterization of its numerous hydrothermal geothermal systems. Even where it does exist, such data is largely limited to areas with a high density of oil wells in which heat flow measurements can be easily taken (Suryantini, Ehara, and Nishijima, 2006), as shown in Figure 4. The absence of such data creates a high degree of uncertainty in any estimates of heat flow or fluid permeability. It should be noted that drilling boreholes is necessary in order to take accurate measurements of heat flow. Moreover, test holes must be drilled sufficiently deep to reduce the effect of climate variations at the surface (Guy Masters, 2017, p. 84). While oil and gas companies often possess such data (collected from oil wells), it is often proprietary. To date, no central database exists for the agglomeration of Indonesian heat flow measurements.

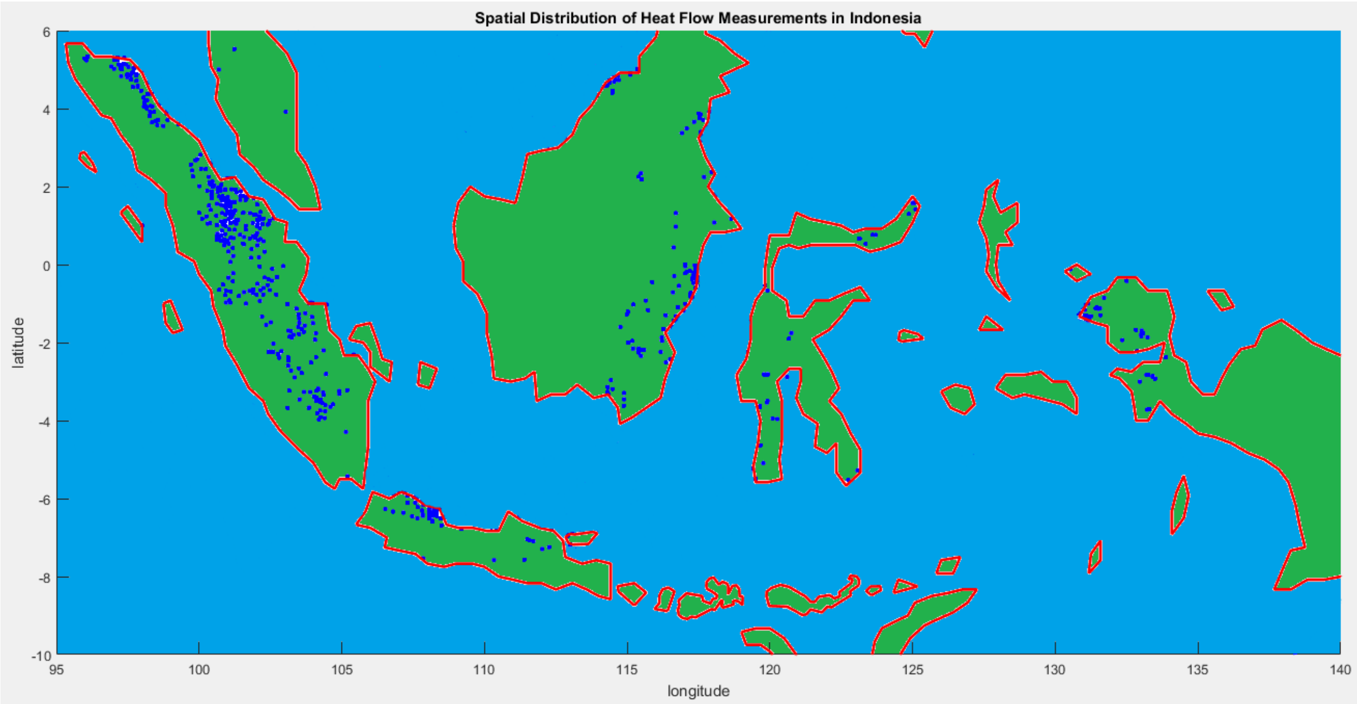

Figure 4: Spatial distribution of geothermal heat flow measurements in Indonesia, in units of power per area (milliwatts per meter squared). *Source:* Map created using South-East Asia heat flow data from SEARG (Southeast Asia Research Group), *Heat Flow | SE Asia Heatflow Database*, with compilation map by Helen Smyth. (http://searg.rhul.ac.uk/current-research/heat-flow/).

In addition to data quantity, geothermal data *quality* has also been of concern. Many developers have complained about the poor quality of data offered during the geothermal resource tendering process (ADB, 2015, p. 108). Indeed, the 2004 revision of the Indonesian geothermal reporting standard does not require explicit disclosure of the assumptions used to develop resource capacity and extraction estimates. This is a substantial impediment, as such assumptions necessarily include specification of the technology pathway, the basis for selecting values for resource parameters (e.g. area, temperature), land tenure, and environmental issues. Without the explicit disclosure of such assumptions in Indonesian reporting standards, it is impossible to perform a verification by an independent authority to replicate the resource estimate and assess its reliability (ADB, 2015, p. 111). Furthermore, the Indonesian standard is not available in an official English version (only in Bahasa Indonesia, the national language) and does not address the use of probabilistic estimates, both of which reduce the international credibility of Indonesian geothermal prospects for investors. It is also essentially one-dimensional, containing only provisions relating to geoscience (ADB, 2015, p. 111-112), and excluding social and environmental considerations.

In contrast, formal geothermal reporting codes now exist in at least two countries: Australia and Canada. These codes embody principles such as transparency and accountability regarding both the presentation of results from geothermal exploration, and the estimates of future geothermal power production (IFC, 2013, p. 3). Furthermore, they have been extensively peer-reviewed, are endorsed by the International Geothermal Energy Association (IGA), and have built up a track record of use and validation (ADB, 2015, p. 108-109). In particular, the Australian code is multidimensional, incorporating not only geoscience concerns (as in the Indonesian code) but also considering the myriad other aspects that affect ultimate project feasibility: economic, marketing, environmental, social, legal, and regulatory factors (ADB, 2015, p. 111). While it may be questioned whether the Australian/Canadian codes are applicable to Indonesia, the fact that they have already been employed in three geothermal feasibility studies at Lumut Balai, Ulubelu, and Tompaso supports the notion of their successful, widespread implementation in the future.

Overall, the lack of high-quality, accessible, country-wide data presents significant uncertainty for private developers and amplifies investor risk, rendering development prohibitively expensive for small companies.

b) Financial Challenges

High quality exploration work prior to drilling maximizes the probability of achieving the required rate of return for prospective financiers (IFC, 2013, p. 27). Unfortunately, geothermal development projects generally suffer from high exploration costs, and thus high initial investment costs and risks (Figure 5). For example, test drilling to confirm the existence of sufficiently large heat flow and geothermal resources costs between US$2-6M per well. Since multiple wells need to be drilled, test drilling costs can total to tens of millions of dollars (ESMAP, 2016). Moreover, after confirming the existence of a geothermal resource, the investment required to develop the power plant is substantial. According to a World Bank geothermal specialist we interviewed[5], the general rule of thumb for the total investment needed for the exploration and development stages in Indonesia is US$8M per MW of capacity (1 MW powers 1,000 U.S. homes, or roughly 7,000 Indonesian homes, according to Brown). Thus, approximately US$400M of investment is required for a mid-sized 50 MW plant. In comparison, only US$2-3M/MW is required for a coal plant, rendering geothermal investment relatively

[5] Private correspondence with Thrainn Fridriksson, Geothermal Specialist, World Bank.

expensive during the exploration and plant construction stages[6], and often risky for the private sector due to the high likelihood of unsuccessful exploration. Given this risk, banks are reluctant to lend to private developers. Even if availability of the resource is confirmed, financial payoff is deferred, as development takes at least 7 years. Given such constraints, financial challenges pose serious obstacles to geothermal development in Indonesia.

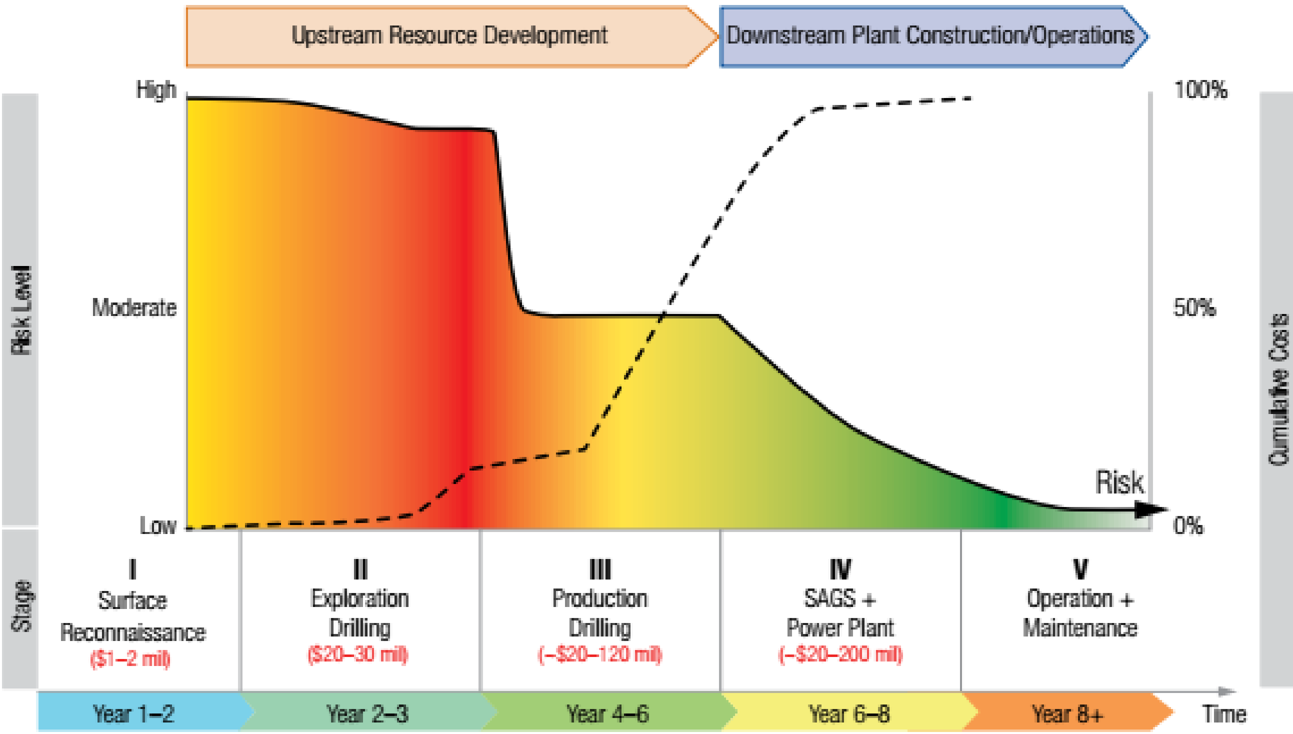

Figure 5: Visualization of the risks and costs at different stages of geothermal development. Adapted from ESMAP (2012), *Geothermal Handbook: Planning and Financing Power Generation*, as cited in ESMAP (2016), *Comparative Analysis of Approaches to Geothermal Resource Risk Mitigation | A Global Survey*, p. 2.

However, once constructed, geothermal plants have competitive operating costs because they do not require purchase of fuels, unlike fossil fuel plants. As of 2015, most Indonesian geothermal plants had operating costs of US¢8.5/kWh or below, while those for coal and gas plants varied from US¢4.2-19.3/kWh (ADB, 2015, p. 8, 27).

c) Political Challenges

Geothermal energy is heavily impacted by Indonesian government policies. One challenge facing geothermal energy is uncertainty resulting from an ever-evolving legal and regulatory framework. The federal government has issued a proliferation of laws and regulations in the past several years. For instance, in the "Regulation of

[6] Private correspondence with Huong Mai Nguyen, Energy Specialist, World Bank.

Minister of Natural Resources No. 17/2014", the ceiling tariff for geothermal power projects was altered for the fourth time. It was revised from a scheme in which tariffs varied based on plant capacity to a geographically-based tariff regime.

Moreover, different federal government ministries, often with diverging interests, have overlapping responsibility for geothermal development. While the Ministry of Energy and Mineral Resources pushes for greater aid for geothermal development, the Ministry of Finance is reluctant to use government funds for such purposes. Meanwhile, the Ministry of State-Owned-Enterprises, which controls Pertamina Geothermal Energy (national geothermal developer) as well as PLN (national energy distributor), requires strong profits from its companies. With relatively high geothermal plant development costs, state-owned-enterprises (hereby abbreviated 'SOE') are disincentivized to increase geothermal investment (ADB, 2015, p. 83).

Given the Indonesian federal government's stated initiative to vastly increase the country's geothermal energy utilization by 2025, future human capital in the geothermal industry has also been cited as a concern, particularly in the geoscientific disciplines of geology, geophysics, and geochemistry necessary to perform exploration. Because geothermal energy has not been consistently developed in Indonesia, conventional market forces to identify and satisfy the demand for technical staff have not been developed, resulting in a depleted human resource pool from which to draw staff for new geothermal plants (Smillie, 2015, p. 1).

III. What Solutions Have Been Attempted Locally and Globally?

a) What actions have already been undertaken in Indonesia?

In the early 1980s, the SOE Pertamina was appointed head of all Indonesian geothermal energy development. In 2007, the federal government took steps to improve its geothermal data coverage by establishing Governmental Regulation No. 59/2007, under which it assumed legal ownership of all data acquired under the Geothermal Mining Business License.

In 2011, the federal government also set up a US$300M Geothermal Support Fund (PwC, 2016); however, the funds, were not allocated until 2017. Initially created to provide loans for exploration, the fund has now been restructured to facilitate government-led exploration and drilling[7], and will include a contribution of US$55M from the World Bank. PT SMI, the infrastructure investment arm of the federal government, will be responsible for managing the fund, while the Ministry of Energy and Mineral Resources and The Ministry of Finance are working to establish a geothermal exploration committee consisting of officials from the Ministry of Energy and Mineral Resources, the Ministry of Finance, and the Geological Agency of Indonesia (Baden Geologi) (JG, 2017). There was also a partnership coordinated in 2012 between private enterprises, SOE, and academic institutions in order to build up human resources and expertise in the geothermal sector (Smillie et. al, 2015).

[7] Private correspondence with Huong Mai Nguyen, Energy Specialist at the World Bank.

In 2014, the maximum electricity paid to private geothermal operators (the ceiling tariff) was increased by the Decree of the Minister of Energy and Mineral Resources via Ministerial Regulation No. 17/2014[8]. This regulation reverted the tariff to a previously employed geographically-based regime and additionally considered the time required for a project to reach commercial operation, to account for inflation (Hasan & Wahjosoedibjo, 2016, p. 6). Regions were classified principally by potential levels of electricity infrastructure development. For instance, Region 1, in which geothermal would primarily replace large coal plants, includes Sumatra, Java, and Bali. In 2017, this region was accorded the lowest geothermal ceiling tariff of US¢12.6/kWh. Region 2, comprising Sulawesi, West Nusa Tenggara, East Nusa Tenggara, and others, was accorded an intermediary ceiling tariff of US¢18.2/kWh. In these areas, geothermal would replace small coal power plants. Region 3, covering other areas for which isolated diesel generation is the primary source of power, received the highest ceiling tariff of US¢26.2/kWh[9] (Hasan & Wahjosoedibjo, 2016, p. 6).

The breakthrough, however, was the "New Geothermal Law" of 2014 (No. 21/2014), under which geothermal activities became permissible in forests after obtaining a permit from the Minister of Forestry. This opened for development the 50% of geothermal resources located in protected forests or national parks (IFC, 2013, p.6). However, some forestry regulations that still classify geothermal development as a mining activity may require further amendment before the provisions of the New Geothermal Law can be effectively implemented within forested areas. The law also re-centralized authority over geothermal power generation, placing the distribution of geothermal licenses and working area tenders under the sole federal jurisdiction of the Ministry of Energy and Mineral Resources instead of under the authority of governors and regents/mayors as had previously been the case (Hadiputranto, Hadinoto & Partners, 2014, p. 1). The law also stipulated a production bonus scheme: local governments near geothermal working areas would receive a portion of the revenues based on a percentage of the Geothermal License Holders' gross income beginning from when the first unit operates commercially. This was important because the old law stated that Geothermal License Holders were to pay state income tax and non-state income tax but did not specify who the actual recipient of the bonus would be, nor how the bonus would be calculated (Hasan & Wahjosoedibjo, 2016, p. 4).

Despite the ostensible benefits of the New Geothermal Law, its tangible impact upon geothermal development is difficult to assess, in particular due to the nature of Indonesia's highly hierarchical legal system. For instance, despite the fact that the law removes the classification of geothermal as a mining activity, other subsidiary laws and regulations must also be implemented (within a span of two years of the initial one) in order for the initial law to have any effect. Indeed, the relevant forestry

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[8] See Baker & McKenzie (2014) for additional commentary regarding the subtleties of this revision to the geothermal ceiling tariff regime.

[9] While all ceiling tariffs quoted are for 2017; note that the tariff for all regions increases by US¢18.2/kWh by 2025.

regulations classifying geothermal as a mining activity need to be updated to reflect this change (Hasan & Wahjosoedibjo, 2016, p. 5).

b) How can examples from other countries help us?

Many countries utilize government-led or sponsored programs (such as through the intermediary of SOEs) to map their geothermal reserves (ADB, 2015, p.74). For instance, Iceland's federal government actively led geothermal mapping within the country until 2003 when it created Iceland GeoSurvey, an entity which receives funding from private Icelandic companies in the geothermal industry and carries out the same tasks as a non-profit organization (Orkustofnun, 2010, p.33). However, to recoup the costs of preliminary geoscientific data surveys, the government can charge fees to private companies that use its information, as was the case for New Zealand (ESMAP, 2016, p. 12). Alternatively, countries such as Japan employ cost-sharing, in which the government shares 40% of exploration drilling costs and 20% of production drilling costs with private developers; this scheme is said to have hastened the development of most of the 536 MW of geothermal power operating in Japan today (ESMAP, 2016, p.7). Another option produced the Geothermal Risk Mitigation Facility in East Africa, which was set up in 2010 with €110M of funding from the EU for geothermal exploration and development (GRMF).

The common theme amongst all countries with significant geothermal development is a highly involved government that catalyzes strong funding initiatives. Once the geothermal industry is built up by preliminary government-led initiatives to reduce exploration risk for the private sector, the geothermal industry can ultimately be privatized, as exemplified by Iceland in 1986 and the Philippines in 2007 (Orkustofnun, 2010, p.19).

IV. Recommendations and Opportunities: Filling The Gaps

a) Improved Geothermal Data Standards, Science, and Technology

Firstly, Indonesia needs to improve the quality and credibility of its geothermal data. To achieve this, the federal government should develop a more systematic and transparent estimation methodology of geothermal potential by adopting an established, peer-reviewed, internationally-recognized geothermal recording code such as those in Australia and Canada (IFC, 2013, p.3). While such an adoption may encounter resistance because of the effort required to change reporting codes, the inadequacies of the present code (highlighted in Section IIa) are sufficient to warrant this effort, and will continue to hamper international investment in Indonesian geothermal development until they are resolved either by improving the code or by adopting another one that explicitly stipulates standards for resource estimation assumptions and uncertainty. Moreover, the Indonesian code does not appear to actually have been used (or if so, then not transparently) in resource capacity estimates on which current tendering and forward planning is based (ADB, 2015, p. 110). Nonetheless, either approach will necessarily require time and the overcoming of institutional resistance to a new/revised code. In addition, geothermal exploration practitioners in Indonesia should adopt the Geothermal Play Fairway Analysis method, a research initiative developed by the United States Department of Energy to improve uncertainty quantification. The method evaluates a range of geologic, technical, and socio-economic factors, which are subsequently integrated in order to narrow a basin or regional-scale area down to smaller areas of interest for further study and prospecting (Garchar, 2016).

Secondly, countries such as Indonesia interested in geothermal development should encourage research into the application of geoscientific techniques to improve preliminary characterization of the subsurface, for example with grants to public universities. Such techniques are important because they can guide and constrain the location of borehole drilling, which is essential given the high cost and inherently uncertain nature of drilling. Used in conjunction, integrated geological, geophysical, and geochemical data deliver better estimates of geothermal potential than can be provided by surface geological data. Surface manifestations of key geothermal parameters (heat flow and fluid permeability)—can be only be inferred (from hydrothermal springs and geologic fault density respectively, for instance) but not definitively known from surface investigations alone. Conversely, it is only through the utilization of subsurface methods, such as geophysical/geochemical surveys and borehole drilling, that these key parameters can be constrained in order to construct accurate models of geothermal reservoir systems.

Geophysical methods can be employed to non-invasively acquire subsurface data and key indicators of geothermal potential, in order to increase the probability that expensive drilling wells discover high-productivity geothermal resources (Gibson et. al., 2015). Geophysical methods include gravity, magnetics, temperature gradient drilling, 2D and 3D seismic, and electromagnetic surveys (such as magnetotellurics). They attempt to identify anomalies in the subsurface physical properties of density, magnetic susceptibility, and electrical conductivity measurements, respectively. These methods have been deemed indispensable as they help constrain the understanding of geothermal heat flow as well as of the geologic structure of geothermal systems (IFC, 2013, p. 20). Meanwhile, geochemical methods such as geothermometry, electrical conductivity, pH, flow rate determination of fluids from active features, and soil sampling can be used to determine the chemical characteristics of underground geothermal fluids at a prospective field site (Juliarka & Niasari, 2016). Surface surveys can include gathering local knowledge, locating active surface manifestations of geothermal activity, and assessing surface geology (IFC, 2013, p. 8). For a comprehensive elaboration of the many and varied types of data that are relevant to exploration for geothermal resources, see "Data Checklist for Project Review and Exploration Risk Insurance Applications" (IFC, 2013, Appendix A3, p. 64).

Generating such geoscientific data can be completed in numerous ways. First, the federal government (such as the Ministry of Energy and Mineral Resources) can collect the data, then charge geothermal companies for the usage of data—a model that has been implemented in New Zealand (ESMAP, 2016, p. 12). Second, the federal government could create a non-profit organization that conducts research and collects data and is funded by private companies, as is the case in Iceland (Orkustofnun, 2010, p.33). Third, the federal government can provide grants to universities and research organizations to collect data. Out of the three, the first option, government-driven data collection and cost recoupment (from fees charged to those using the data), is the most viable. This structure is easier to initially set up and facilitates centralized organization of data with standard methodologies. The second option requires cooperation from geothermal companies across Indonesia with an agreement on who pays what. Such a structure is much more difficult to form in Indonesia than in small, homogenous countries such as Iceland. The third option, on the other hand, may result in data with different methodologies and representations due to the fact that the data is collected by independent institutions. Government-led data collection avoids the challenges faced by the second and third options, while enabling the federal government to recoup a large proportion, if not all, of the data collection cost by charging companies for the usage of the data.

b) Enhanced and Alternative Funding Mechanisms

There exist multiple channels through which geothermal energy resources can be developed. The federal government should first focus on promoting collaboration on rural geothermal exploration between the US$300M Geothermal Support Fund (discussed in Section IIIa) and the Tropical Landscapes Financing Facility (TLFF), a pioneering US$1B fund between the Indonesian federal government and international partners that provides long-term, low-interest financing for social and environmentally beneficial projects in rural areas[10]. These funds should be used to prioritize the expansion of the SOE Pertamina's Geothermal Energy Upstream Development Project. In this venture, over half of the proposed sites for exploration drilling are in largely rural and poorly electrified Eastern Indonesia. This could potentially provide electrification to impoverished, marginalized areas that have historically been difficult to access (PT SMI, 2016, p.10).

Secondly, the federal government should entice geothermal development by implementing tax incentives to make investment more attractive. Such incentives could be modelled, for instance, upon the Philippines' 7-year tax holiday for geothermal developers, or upon Canada's flow-through shares tax provision for investors in the mining industry, through which investors claim tax deductions for exploration costs (NRC, 2017). In Indonesia, inducing private sector investment is critical. The federal government alone cannot provide the estimated US$25B in investment required to increase geothermal power from the current 1,400 MW to their goal of 7,500MW by 2025 (PwC, 2016, p.103).

Thirdly, to offset the risk of exploration, a consortium consisting of the federal government, development banks, and/or the private sector could collectively contribute to an insurance scheme, in which a portion of exploration costs are paid out to private developers in the event that exploration is unsuccessful. The Indonesian government can draw on the expertise from private insurers and development agencies to create its own insurance scheme or make a deal with private

[10]Fan came to learn about this fund while attending a talk held by Satya S. Tripathi, who is the Chief Executive of the TLFF, in addition to being the Senior Advisor to the 2030 Agenda for Sustainable Development (UN Environment Programme).

insurers to ensure geothermal exploration by private developers. In such an arrangement, the government would share the cost of the premium with private developers, thus reducing risk. Mexico, for example, is working with Munich Re and the Inter-American Development Bank to provide insurance for private developers (MunichRe, 2015).

Finally, a public-private partnership should be considered in which the Indonesian government conducts the exploration and then sells or leases out the site to private developers to build and operate the plant. Such a model is used in Turkey (IFC, 2013, p.29). They could also consider mandating utilities to derive a certain percentage of electricity provided from geothermal sources. This program might lead utilities to seek power supplies from geothermal sources, increasing private-sector investment in geothermal development (ESMAP, 2012, p.90).

It is of course important to note that Indonesia should leverage private over public investment for geothermal development to the greatest possible extent. The federal government has a multitude of priorities outside of geothermal development. Large and consistent investments over the coming decades in infrastructure, education systems, health care, and a variety of industries (i.e. manufacturing and agriculture) are critical to develop Indonesia's economy, for which GDP per capita remains below US$4,000 as of 2016. 28 million people live with less than US$26.60 per month (Indonesia Investments, 2017). Geothermal development should not distract the government from this extensive set of daunting challenges that will require innovative policies and government resources to tackle. Hence, Indonesia should focus on creating an environment in which private investors have confidence in the ability of geothermal energy to provide a sufficient financial return, thereby stimulating private investments. Many of the recommendations listed here are focused on precisely this: the provision of tax incentives, introduction of insurance schemes, and creation of public-private partnerships are all policies that require limited government funding but provide strong incentives for companies to invest in geothermal development.

c) Government-driven Political Initiatives

The enabling mechanisms for accelerated preliminary exploration have thus far been absent in Indonesia. To address this inertia, the SOE Pertamina Geothermal Energy should be given authorization to be more extensively involved in drilling, potentially with federal funding. This would help alleviate resource development stasis, which is due to the aforementioned competing interests amongst the Ministry of Energy and Mineral Resources, the Ministry of Finance, and SOEs. Governmental efforts should also be made to provide and disseminate updates to private developers regarding geothermal regulations and laws pertaining to environmental impact assessment, social license, and ceiling tariff schemes.

While the New Geothermal Law (Law Nr. 21/2014) in theory opens up to development the 50% of Indonesian geothermal resources located within protected forest areas and national parks, all government ministries must implement this change to their own regulations in order for it to have any impact. Therefore, the

Ministry of Forestry should prioritize the changing of its regulations to declassify geothermal as a mining activity, given the significantly reduced impact of geothermal energy development upon the environment (as outlined in Section Ic) relative to traditional mining activities. Such regulatory changes should necessarily include the stipulation that award of Geothermal Licenses is conditional upon comprehensive environmental and social impact assessments, emphasizing any potential estimated impacts upon forest ecosystems and indigenous tribes.

Principles applying to international tendering processes should be applied to the Indonesian geothermal project tendering practices. Indeed, the aforementioned poor quality of geothermal data available during the tendering process can be attributed to a corresponding lack of standardization in this regard throughout the country. The Indonesian government should establish a technically qualified central tender committee to conduct tenders on behalf of local governments. While such an entity would require significant technical assistance, it has been stated that bilateral donors would be highly interested to provide such assistance. Meanwhile, a balance would be struck between the interests of the central federal government and local governments by appointing a local government representative to the committee (ADB, 2015, p. 106).

However, if the federal government wishes for Pertamina and Pertamina Geothermal Energy to play a meaningful role in national geothermal development, the demand that they compete with other SOE's in terms of equity returns alone should be removed. Specifically, the Ministry of SOE's should consider setting up a benchmark for the equity returns for geothermal projects separate from that of oil and gas projects so that the former does not compete with the latter, as geothermal cannot compete with oil and gas in such singular terms as SOE equity returns. This would demonstrate the federal government's recognition of the broader, positive socioeconomic returns to the country due to geothermal investment, which are not necessarily apparent in such a narrow measure of profitability (ADB, 2015, p. 107).

Finally, it is crucial for the federal government to rectify the lack of human capital and build institutional expertise in the geothermal sector. One solution would be to renew the Geothermal Capacity Building Program (or implement a program of a similar nature in its place), which was terminated in 2015. A pioneering Indonesian-supported program between Indonesia and the US, the program trained geothermal scientists and engineers and was an international collaboration that strengthened networks amongst federal government agencies, academic institutions, SOEs, and private companies, including The Ministry of Energy and Mineral Resources, the Bandung Institute of Technology (ITB) and other Indonesian universities, the University of Southern California, the United States Agency for International Development (USAID), Star Energy, Pertamina Geothermal Energy, and other private geothermal developers operating in Indonesia (Smillie et. al., 2015, p. 1). The program facilitated the establishment of an advisory board, a scholarship for the Geothermal Master's program at ITB, a geothermal seminar program consisting of 5 seminars in 5 Indonesian cities (with a total of 1300 participants), and a "Train the Trainers" program, which built the capacity of Indonesian university lecturers and local government officials (Smillie et. al., 2015, p. 3-6). The program doubled in the average number of masters students enrolled per year in geothermal-related disciplines from 2012-2015, while the percentage of women increased from 14.0% to 26.4% in what is traditionally a highly male-dominated program and field. Furthermore, improvements were made to the understanding amongst Indonesian practitioners of geothermal systems, exploration, development, and utilization, in addition to resource assessment methodology, environmental analysis, and impact assessment (Smillie et. al., 2015, p. 8). Were the program to be reinstated, the collaboration could be strengthened by developing a research consortium with industry, improving teaching and curriculum guides, and increasing student support in the form of scholarships, industry networking, and employment opportunities (Smillie et. al., 2015, p. 8).

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Appendix I

While Indonesia is typically cited as possessing 40% of global geothermal potential, this estimate relies upon estimates from a 2013 study by the Geological Agency of Indonesia, which arrived upon 29 GW from an assessment of approximately 300 sites (Geological Agency, 2013). This study, however relied upon a flawed methodology, in which estimates of some *reserves* (energy that can be exploitable given current economic conditions) were double-counted as *resources* (energy that may become exploitable, given future economic conditions and/or technological developments). This is problematic because sites were being classified as both reserves *and* resources, after which the total of the 2 categories were summed, resulting in an inflated estimate. Fauzi applies a more realistic methodology and arrives upon the estimate of 24 GW. Considering that the estimated global geothermal potential is 70GW (a conservative figure from Bertani (2009), which precludes the possibility of technological development of enhanced geothermal systems, which could double this figure), Indonesia's estimated proportion of the global geothermal potential then becomes the slightly lower, albeit still substantial figure of 34.3%.