Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Rapid Environmental and Social Assessment of Geothermal Power Development in Conservation Forest Areas of Indonesia

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Keywords: environmental and social impacts, conservation forest, risk assessment

ABSTRACT

Geothermal energy is an important form of renewable energy, contributing to reducing greenhouse gas emissions and related global warming. In Indonesia, however, the fact that the majority of geothermal potential is located in or close to forest areas has raised societal concerns about environmental and social impacts. In Indonesia, geothermal potential often occurs in mountainous forest areas that play an important role in supplying fresh water, harbor endangered wildlife, or have high cultural or religious values. This paper provides an innovative approach to assessing risk associated with potential and existing geothermal project locations in Indonesia. Through a micro-level assessment of 16 existing Indonesian geothermal projects, an improved insight into the key impacts and risks typically associated with geothermal power development in forest areas was developed. Key findings include that for each 100 MW of geothermal power generated per year, about 10 km of project roads and 30 ha of forest clearing is needed, while about 10 km^2 of forest is indirectly impacted through the effects of road-facilitated hunting, illegal logging, use of fire, and other detrimental activities. Through a macro-level assessment of the officially published 330 geothermal area potential points for Indonesia, the environmental and social risk rankings for every individual point was determined. Each of these was characterized according to weighted environmental and social variables, including forest use status (conservation area type etc.); land cover; claims for social forestry; presence of indigenous people, traditional land claims, recent deforestation history; international biodiversity values (World Heritage site, Key Biodiversity Area, Important Bird Area); size of conservation area; and location of geothermal point in relation to conservation area boundary. Based on the cumulative weighted scores of these variables, they were categorized as Low, Medium, and High-risk sites. The resulting risk assessment provides a simple tool for the Government of Indonesia and other key stakeholders to guide geothermal power projects towards the areas with the least environmental costs and lowest likelihood of societal concerns about these costs. This tool also helps the government, banks, other finance institutions and geothermal energy companies to avoid material and reputational risks that can be associated with geothermal energy development in high-risk areas.

1. INTRODUCTION

Geothermal resources are one of Indonesia's largest potential sources of renewable energy with an estimated potential of 29 GW, a potential which would support Indonesia's target of achieving the production of 23% of its energy mix through new and renewable energy production by 2025. Furthermore, the production of geothermal energy comes with relatively low greenhouse gas (GHG) emissions and airborne particulate matter and would curb the country's dependence on fossil fuels for electricity generation. The development of the geothermal power sector provides a significant opportunity to address Indonesia's power shortages and increase its electrification ratio, especially in remote parts of the country, whilst meeting international commitments towards reducing GHG emissions.

Unlocking Indonesia's geothermal power potential, however, has been hampered by a lack of capital investment in exploration and project development as well as by policy restrictions. One of the reasons includes the Geothermal Law No. 27/2003 which defined geothermal development as a mining activity, only allowing its development in Protection and Production Forest and non-forest areas. Furthermore, a prolonged permitting process and complex compliance requirements associated with working in forest areas have delayed or cancelled many proposed geothermal power developments. In order to stimulate the industry, a major revision of the law in 2014 (Geothermal Law No. 21) removed substantial barriers whereby geothermal energy development was no longer defined as a mining activity and allowed geothermal energy development in certain conservation areas not previously available for development.

The fact that the majority of geothermal potential is located in or close to forest areas has raised societal concerns about environmental and social impacts, especially in forests that play an important role in supplying fresh water, harbor endangered wildlife, or have high cultural or religious values. The degree to which these social and environmental risks and impacts vary between geothermal power projects is not well understood, and thus a key focus of this study. Based on the study "Rapid Environmental and Social Assessment of Geothermal Development in Conservation and Forest Areas" under the World Bank's GeoFor - Indonesia Technical Assistance, risk avoidance and mitigation based on the identified risks and impacts are recommended. The ultimate objective is to further stimulate the development of a clean energy source in Indonesia by de-risking through up-front avoidance of high-risk areas and effectively mitigating social and environmental impacts through good operational management practice.

2. APPROACH AND METHODS

The first step in this analytical process was to conduct a desktop review of existing (installed capacity) and planned geothermal power projects in Indonesia and a selection of global geothermal power projects in operation, as well as rapid site visits to selected geothermal power development projects in Java and Sumatra. The desktop review used a non-systematic search approach, starting with general internet searches for environmental and social impacts of geothermal projects, and more specific searches in the scientific literature using Google Scholar.

A micro-level risk assessment was conducted on selected on-the-ground and desktop studies of existing geothermal projects to determine common practices in the industry, and how these relate to social and environmental threat mitigation. A macro-level risk assessment at the Indonesian national level was developed, assessing how the geothermal potential overlaps with environmental and social values, and land use allocation, and provide a tool to Indonesian government institutions and investors which distinguishes between high and low risk project areas.

2.1 Micro-level Assessment of Impact and Risk

An analysis of the social and environmental impacts of existing geothermal projects in Indonesian forest areas was conducted for 16 active (operating or in construction) Indonesian geothermal projects. The visible infrastructure and related land clearing footprint viewed on Google Earth Pro imagery were manually digitized on screen. Whenever it was unclear whether particular infrastructure elements seen on the imagery were part of geothermal developments or related to other developments (e.g., village roads) historic imagery were used (available in Google Earth Pro) as well as uploaded site photos from the project location were used to determine whether particular features should be included as part of the project infrastructure. The resulting digitized project infrastructure lines and polygons were imported into the GIS and converted to ArcGIS shapefiles.

From the ArcGIS files, we calculated the total road length per project. We estimated the average road width in each project area by measuring width across road clearings (from forest edge to forest edge) on Google Earth on 10 points at 250 m intervals along project roads. To estimate total deforestation from project development, the total area of cleared polygons was added to the area cleared along roads (total road length * average road width).

The next part of the analysis was to create a 1,000 m buffer around combined roads and other project-related infrastructure to determine approximate areas of indirect impacts around project infrastructure. The 1,000 m buffer was selected on the basis that published research shows that it represents an indication of indirect impacts such as hunting and unauthorized forest clearance which decline linearly with distance from forest camps and roads (Blom et al. 2005; Clayton et al. 1997; Laurance et al. 2006), but which can still be detected at 1,000 m from the road (depending on local terrain). The 1,000 m buffer is a conservative measure of indirect impacts and could extend as far as 5,000 m from roads, as was found in Sumatra for bird trapping (Harris et al. 2017).

These analyses provided data on the direct impacts in terms of the amount of forest that had been opened up to facilitate the development of the geothermal projects, and the larger potential area of indirect impact from these projects on forests and forest wildlife. These impact estimates were compared to the projects' installed capacity to investigate the relationship between energy capacity and impact on forest and forest wildlife. This was expressed as 1) deforested area per MW capacity; 2) length of road development per MW capacity; and 3) indirectly impacted forest area per MW capacity.

Where available, the analysis was augmented with very recent (late 2016 or 2017) Landsat 8 OLI 30m multispectral imagery downloaded from the USGS website. In several cases, especially where projects are still under development, certain project features (e.g., new roads), not yet visible on Google Earth imagery were revealed through use of more recent imagery.

To ground-truth the findings from the image analysis of project footprints, field assessments were made at Darajat project (located in a Natural Reserve or *Cagar Alam*), Salak project (located in a National Park), and Sarulla project (located in a Protection Forest or *Hutan Lindung*) to discuss how environmental and social risks were managed, and to see on the ground what those impacts typically look like. To assess the effectiveness of mitigation strategies and the actual impacts, the authors observed and noted aspects such as road width, quality of forest along road sides (e.g., replanted, degraded natural forest, burnt forest), signs of non-project use (e.g., farming along roads), signs of hunting (e.g., people on roads carrying hunting equipment), road use (e.g., car speed, use of roads by non-project vehicles), security (e.g., presence of guarded road portals), and signage (e.g., prohibitions on hunting, burning etc., depending on local forest status). Where available, we used biodiversity monitoring reports and survey reports to assess the effectiveness of mitigation strategies.

2.2 Macro-level Risk Assessment of Impact and Risk

Using the insights from the micro-assessment, we developed a methodology to produce a "macro" risk assessment based on a spatial analysis of the environmental and social risks associated with the development of geothermal resources across Indonesia. We used the geothermal potential point data produced by the Geological Agency (*Badan Geologi*) as the basic unit of analysis and the overlap of these points was assessed with nine environmental and social parameters. We recognize that these geothermal potential points are only an approximation of the actual location of the geothermal field and the likely location of the eventual project location. The current macro-analysis is a first step in starting to qualify and quantify development risks, and more detailed spatial data on likely locations and size of project developments are required to increase the accuracy of the analysis. We selected the parameters on the basis of a) a possible impact of geothermal power development on these environmental and social values; and b) availability in spatially-referenced format for the entire geography of Indonesia. The analysis has more bias towards environmental values as these are more readily available as secondary data compared to social values.

The analysis was initially focused, similar to such assessments by government agencies, on the overlap of existing and potential developments with state designated forest land, namely conservation areas (*Kawasan Konservasi*), Protection Forest (*Hutan Lindung*), but also Production Forests (*Hutan Produksi*) and land outside the Forest Estate (*Areal Penggunaan Lain*). In addition to confirming the respective overlap with conservation areas and various forest use designations, we also identified where geothermal potential and existing projects overlapped with internationally recognised areas of high biodiversity value (equivalent to Critical Habitat), high socio-cultural value, and also identified where overlaps existed with areas of high deforestation or with stable landcover.

We assessed a list of geothermal projects that were included in the 2016 – 2017 Ministry of Energy & Mineral Resources' plan for concession tender using this approach. The outcome of the macro-level assessment was a ranking per geothermal potential point of the possible environmental and social risks associated with development.

2.2.1 General Overview of Typical Environmental Impacts in Indonesian Geothermal Projects

We conducted the analysis using the Geographical Information System software ArcGIS incorporating a variety of secondary data sources which were publicly available or made available by the World Bank. One of the key datasets was the geothermal potential point locations from the Geological Agency, which was unavailable as digital point data. We manually generated the digital points by using a combination of the published list (ESDM 2012) and a scanned Indonesia-wide map of the points. We manually digitized all of the 330 point-locations and associated attributes (ID, name, administrative region, speculative, hypothetical, possible, probable, proven, and/or installed MW capacity values) and entered them into the GIS, as it was not possible to obtain the native data.

The forest land use status data produced by the Indonesian Ministry of Environment and Forestry (MoEF) was a key dataset in this assessment and enabled the identification of the official forest use status at each of the 330 geothermal potential points. The conservation area categories included different types of conservation areas from National Parks to Strict Nature Reserves but for the overall assessment all types of conservation area were grouped into one with a weighting of 4 as this was considered the class with the highest potential to experience negative impacts as a result of development due to a reduction in conservation values which would result. The Production Forest category consisted of Production Forest, Limited Production Forest and Conversion Forest and was weighted as 2. Protection Forest was weighted as 3 as it was assumed that environmental values are high in this forest use category as its function is watershed protection and therefore disturbance would result in a loss or reduction in this function. Protection Forests are generally located in hilly or mountainous terrain, another reason why environmental impact is potentially weighted as 3. The non-forest category (*Areal Penggunaan Lain*) was weighted as 1 as environmental impact would potentially be relatively low compared to the other forest use classes.

We derived the land cover categories from the official forest and land cover data for 2015 published by MoEF which consisted of 50 classes. For the purposes of the assessment only three classes were used in the analysis, primary forest (3 points) which equated to dense canopy cover forest, secondary forest (2 points) which equated to degraded forest and non-forest (0) which was everything but forest. These weightings conveyed the relatively high environmental values of primary forest compared to non-forest and therefore the higher environmental risks associated with developing a geothermal power project.

The third spatial dataset from MoEF was the Indicative Map of the Social Forestry Areas (PIAPS, 2016) which identifies areas that can be managed by communities under the Social Forestry scheme, namely the management of Village Forest, Community Forest, Community Plantation Forest, Partnership and Forest Rights. The PIAPS dataset was used as a social risk factor indicating areas where communities have rights to manage forests or could potentially have rights in the future. Based on our collective experience and on consultation with the World Bank Team supervising the assessment, a weighting system for environmental and social factors was developed (Table 1).

Table 1: Weighting system of environmental (shaded green) and social factors (shaded orange) that indicate the risk of developing geothermal projects in particular areas.

Weighting factor	Categories and weighting of category between brackets			
Forest land use status of geothermal point (MoEF, 2015)	Conservation area (4)	Protection Forest (3)	Production forest (2)	Non-forest use (1)
Land cover (MoEF, 2015)	Dense canopy cover forest (3)	Degraded forest (2)	Non-forest (0)	
Deforestation history (Hansen et al., 2013)	High forest loss (2)	Moderate forest loss (1)	No or limited recent forest loss, stable landscape (0)	
International values (UNESCO website, Birdlife International website)	UNESCO World Heritage or Cultural Landscape (2)	Birdlife International Important Bird Area (1), Key Biodiversity Area (1)	No other category (0)	
Size of conservation area	Planned geothermal impacts > 10% of conservation area (2)	Planned geothermal impacts < 10% of conservation area (1)		
Location of geothermal point in relation to area boundary	Geothermal point is deep inside conservation area (3)	Geothermal point is on the boundary of conservation area (1)	Geothermal point is outside conservation area (0)	
Presence of Isolated Indigenous People (IP Screening World Bank 2010)	Present (2)	Not present (0)		
Indicative social forestry areas (PIAPS, MoEF, 2016)	Existing claim (2)	No existing claim (0)		
Customary Land (Wilayah Adat) based on Badan Registrasi Wilayah Adat data	Certified (4)	Verified (3)	Registered (2)	Newly recorded (1)

A World Bank dataset was provided which identified the presence/non-presence of isolated indigenous people ("isolated customary communities") at the village level across Indonesia. The development of a geothermal project was considered to potentially increase negative social impacts in areas where indigenous people lived as well as increasing the reputational risk faced by operators developing projects in these areas. The presence of indigenous people received a weighting of 2. In addition to the presence of indigenous people, the presence of customary land was also included as a social risk factor. The weighting used the four classes of customary land areas displayed on the BRWA GIS; certified customary land (4), verified customary land (3), registered customary land (2), and newly recorded (1).

One point of uncertainty is the weighting system used in the current macro-analysis (see Table 1). This weighting system is subjective and more detailed study of individual geothermal projects is required to assess whether the current weighting system correlates well with actual social and environmental risks. For example, in the dissemination workshops it was argued that certification and verification of customary land, which was judged in the current analysis to entail high risk for project developers, could in fact be low risk because communities would be much more aware of their rights and in a better position to negotiate a fair deal with the geothermal company.

For each of the mapped geothermal projects, we determined, using GIS analysis, whether these were located in forest or non-forest areas, the land use status of the project centre point (non-state forest land, Production or Protection Forest or conservation area), and the installed capacity in MW. It was also determined whether any of these points were located in areas of particular biodiversity importance (e.g., Key Biodiversity Areas, Important Bird Areas, UNESCO World Heritage sites).

To assess general deforestation threats in areas targeted for geothermal development, a 2000 – 2015 global deforestation dataset was used (Hansen et al. 2013). A spatial buffer area was generated with a radius of 2.5 km around each geothermal potential point (area of circle is 19.6 km^2) to approximate the average area of indirect impact around geothermal sites. This size was based on the average 20 km^2 of indirect impacts estimated for 12 existing projects in Indonesia. This estimated average for each potential point had to be used as a proxy because reliable data on the potential geothermal capacity for each potential project location was not available. Within these polygon circles, the number of deforestation pixels was automatically counted. The distribution of the points is strongly left skewed, with 50% of the points having between 1 and 523 deforestation pixels per circle and the remaining 50% between 525 and 21,399 deforestation pixels. Cut-off points were used for the first tertile, i.e., 33% of the points, ("low deforestation") between 0 and 269 pixels per circle, the second tertile "moderate deforestation" between 270 and 1062 pixels per circle, and the third tertile "high deforestation" 1063 or higher pixels per circle.

Next, the weighting system was applied to each of the 330 potential geothermal points, and the sum of the scores was calculated to determine in which risk category a potential geothermal power project falls. The weighting system can result in maximum 24 points and minimum 1 point. Cut-off boundaries were used for low, medium, and high risks, 1–3 points, 4–6 points, and 7–18 points, respectively. Points which were categorized a low risk (1 – 3) were generally found in non-forest status land areas with no forest cover and none of the three social risk factors present. Points in the medium risk category (4 – 6) were generally not in conservation areas but in non-forest, Production or Protection Forest with no international conservation values but potentially close to a conservation area, or with one social aspect present. High risk points (7 – 18) were predominantly in conservation areas, or Protection Forests with high weighted environmental and social values such as social forestry, customary land or presence of indigenous peoples.

A project identified as high risk would not necessarily mean that it should not be developed, although financial institutions may be wary about financing such projects. It would certainly require specific regulatory arrangements that guarantee that only high-quality operators capable of implementing high environmental and community management standards and practices on the ground would be allowed to work in the area, and that these would be monitored more strictly in terms of adherence to environmental, conservation and community management practices in their working area.

The aim of this assessment was to predict for each of the geothermal potential points in Indonesia what their potential footprint would be if a project was implemented. This would allow various government institutions and geothermal companies and investors to predict impact on each conservation area in Indonesia, and use this to assess risks. Such assessments could also assist in the development of new regulations for geothermal developments in conservation areas, similar to those that exist for mining (underground only) allowed in Protection Forest (*Hutan Lindung*) and open pit mining allowed in Production Forests (i.e., any forest unit can never have more than 10% of the total forest area and/or concessions allocated to borrow-lease permits (*pinjam pakai*) for mining).

2.2.2 Roads, Forest Access and Fragmentation

Building on the insights from the micro-assessment regarding the relationship between installed capacity and the environmental footprint (deforested area, road length and indirectly impacted area), the potential impacts were predicted for the 330 geothermal potential areas across Indonesia. It was found to be somewhat problematic to estimate potential capacity on the basis of available data. The correlation between speculative, hypothetical, possible, or probable capacities, with installed capacity as provided by MEMR was poor (r^2 = 0.02, i.e., 2% of the variation in installed capacity is explained by the data on speculative, hypothetical, possible, or probable capacities). This means that it is very difficult to predict potential installed capacity on the basis of data currently available, and current Indonesian production capacity estimates have been referred to as essentially meaningless (ADB & The World Bank 2015). Only at the proven resource level does the predictive value of the final installed capacity increase, with a coefficient of determination (r^2) of 0.73. Few of the 330 geothermal potential points in Indonesia (existing and potential) have proven resource estimates: speculative (n = 115); hypothetical (n = 70); possible (n = 110); probable (n =11); proven (n = 15); and installed (n = 18). This basically means that future installed capacity cannot reliably be predicted on the basis of available resource estimate data.

Because of the above-mentioned uncertainties in resource estimates, the following approach was used to predict potential impacts of future geothermal projects in Indonesia. Minima, maxima, and means of the road length and area of indirect impact of existing Indonesian geothermal projects (Table 2) were calculated and applied to all potential geothermal points in Indonesian conservation areas. Next, the team calculated for each of these conservation areas whether geothermal development would likely affect > 10% of a particular conservation area, based on the size of that conservation area.

Table 2: Road length and area of indirect impact for 15 active geothermal projects in Indonesia.

	N	Minimum	Maximum	Mean	Std. Deviation
Road length (km)	15	0.11	39.82	15.3	11.28
Area of indirect impact (km^2)	15	4.09	40.00	23.4	10.96

3. OUTCOMES OF THE STUDY

All forms of electricity power generation have environmental and social impacts but it is the relatively small magnitude of these impacts that make geothermal energy power generation highly appealing compared to fossil fuels. In general, although minimal compared to the footprint from fossil fuels, the main environmental impacts of geothermal energy are air emissions, noise pollution, water usage, land usage, waste disposal, subsidence, induced seismicity, and impacts on wildlife and vegetation. Geothermal energy whether utilized in a binary, steam, or flash power plant, cooled by air or water systems is by most considered to be a clean, reliable source of energy, with only minimal environmental impacts, even when compared with other renewable energy sources. One source of impacts, however, remains relatively understudied and underreported. This is the impact of geothermal development on forest environments, and especially high biodiversity tropical forest areas. Overall, public perceptions about geothermal energy are relatively positive compared to other energy sources, but knowledge about impacts is low as the technology is not widely used and therefore not well known (Carr-Cornish & Romanach 2014). Such situations of insufficient public understanding of impacts from geothermal development have frequently led to conflicts in many parts of the world.

3.1 Micro-level Assessment

3.1.1 General Overview of Typical Environmental Impacts in Indonesian Geothermal Projects

The key Indonesian government guidebook on geothermal development in conservation areas (Sugiharta 2016) discusses the typical environmental impacts of different stages of geothermal project development in forest areas. These focus on noise, air pollution, water pollution and other environmental impacts, fragmentation of ecosystems, disturbance of wildlife; interruption of animal dispersal; and release of $H2S$. It also mentions increased access to conservation areas through new roads, although there is no specific mention of human factors (illegal settlement, hunters, bird poachers etc.). As in most other countries, a typical environmental impact management approach is recommended that focuses on monitoring environmental changes and trends in indicator species.

The potential impacts of geothermal developments in Indonesian protected forest areas need to be seen against the baseline of what is happening without such developments. Indonesia's conservation areas are currently not sufficiently well managed to prevent deforestation and loss of biodiversity. For example, Indonesia's terrestrial conservation areas lost approximately 0.37 million hectares (Mha), or 2.6% of their 2000 forest cover by 2010 (Fuller et al. 2013). Mean annualized deforestation rate for National Parks were 0.22% and for Nature Reserve and Wildlife Reserves were 0.35% (Fuller et al. 2013). This is lower than the average annual forest loss for the entire country (Abood et al. 2015; FAO 2009), but it indicates that conservation areas are not effectively protected from forest loss. Unsustainable hunting is also affecting wildlife populations in conservation areas in Indonesia (Corlett 2007; Lee et al. 2005; Natusch & Lyons 2012; Nijman 2005), indicating insufficient levels of patrolling and law enforcement.

3.1.2 Roads, Forest Access and Fragmentation

Indonesian conservation area management is not yet optimal, with, for example, illegal deforestation occurring in many sites (Fuller et al. 2013; Gaveau et al. 2009), undermining the objectives of protecting forest biodiversity. This means that additional care is needed when projects such as geothermal power developments are allowed within these areas. Key concerns are that road infrastructure associated with geothermal projects provides access to core parts of conservation areas. The 16 active Indonesian geothermal projects analysed in this study had an average length of road network of 15.3 km (minimum 0.11 km and maximum 39.8 km), with total road length correlating well with installed capacity (Figure 1). The two steam-dominated projects in Indonesia (Kamojang and Darajat) appear to have shorter road lengths relative to installed capacity (Figure 5), which is to be expected as they need fewer injection wells. We note that Wayang Windu, Dieng and Sibayak have had exploration drilling for a significantly larger capacity than is currently installed, which does to some extent show up in the graph (J. Lawless in litt. 18 October 2017).

Road clearing width in forest areas as measured from Google Earth satellite imagery varied considerably between Indonesian geothermal power project sites. The widest road clearings were measured in the Rantau Dedap project (which was under construction at the time of writing), where land clearings from forest edge to forest edge across roads were sometimes as wide as 100 m. Average road clearing width across the Indonesian geothermal projects was 14 m (Figure 1), with average maximum road clearing width 31 m. If we take the average road length for Indonesian projects (15.3 km) and multiply this with the average road clearing width (14 m), an average deforestation area for infrastructure development results of 21 ha (note this does not yet include clearings for buildings and other project infrastructure). There was no clear correlation between installed capacity and road width ($r^2 = 0.04$), indicating that road width and length is determined by terrain (possibly steep terrain requiring wider road clearings), or operator (different operators using different standards for road construction). Difficult terrain will tend to mean longer roads as well as wider. With regard to road width, as a generalisation the terrain could be classed as follows: Easy: Lahendong, Sibayak; Medium: Wayang Windu, Darajat, Ulubelu, Sarulla, Kamojang, Darajat, Patuha; and Difficult: Rantau Dedap, Lumut Balai, Hulu Lais, Salak (J. Lawless in litt. 18 October 2017). This to some extent seems to explain the variation in both road length and width (Figure 5), although there are obvious exceptions, such as the narrow roads in Salak, despite the difficult terrain.

Road widths are important for determining the degree of fragmentation caused by roads. For example, our field surveys in the Salak geothermal project showed canopy connectivity across roads in many places. This allows arboreal species to safely cross road clearings. Similarly, narrow roads are much less of a barrier to terrestrial species than wide road clearings. A gibbon (*Hylobates* sp.), for example, may come to the ground to cross a narrow road but may not do that when the road is too wide, and would certainly prefer to use the arboreal route. If geothermal roads extend deeply into forest areas, wide roads may effectively cut the forest area into isolated forest blocks for species unable to cross road clearings. This affects the likelihood of survival of individual populations.

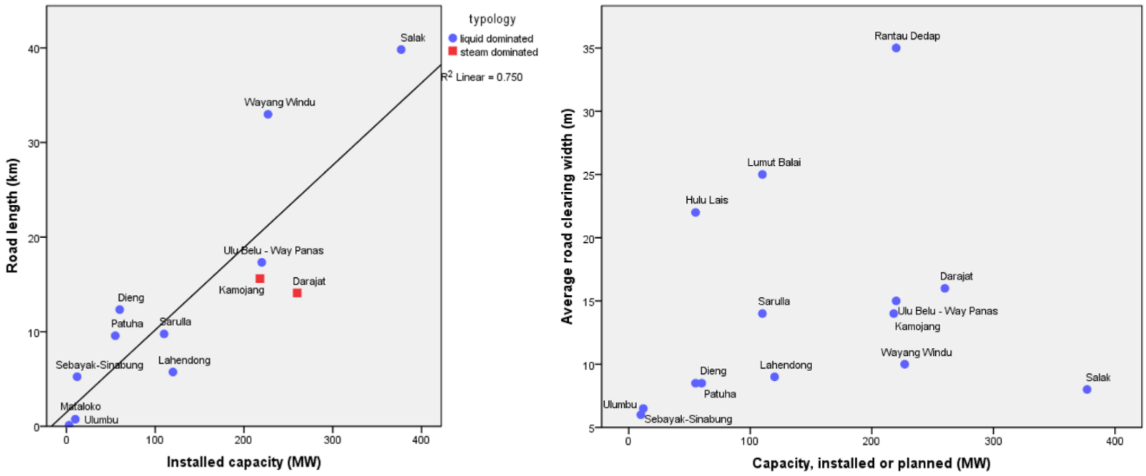

Figure 1 (Left): Graph of installed geothermal capacity in 12 Indonesian projects versus total road length of projects. Blue projects are liquid dominated, red projects are steam dominated. R2 of linear fit = 0.75. (Right): Average road clearing width in Indonesian geothermal projects. Installed capacity for the projects currently under development in Hulu Lais, Rantau Dedap, and Lumut Balai projects was estimated at 55, 220, and 110 MW respectively.

As noted in the Indonesian guidebook on geothermal projects in conservation areas (Sugiharta 2016), roads also provide access to previously remote forest areas. This aspect of geothermal development remains under studied, but our field observations indicate that this is a cause for concern. In one of the visited sites in this assessment, for example, project staff showed us a location where people had come in to open up forest areas for agricultural use alongside the project road, despite a prohibition on forest clearing.

One of the concerns raised by NGOs that were interviewed during the assessment is that geothermal projects in conservation areas require the development of road infrastructure, often going into areas that were previously much less accessible. The current study indicates that for every 10 MW of installed capacity, 1 km of roads need to be built. Unless access to such roads is carefully controlled, people can use them to settle in conservation areas, or harvest trees or wildlife, making it more difficult to implement effective conservation management. The examples highlighted here indicate that control of road access varies. In the Salak geothermal project, very few people apparently entered through the road network, although people reportedly entered the geothermal area through forest paths to bypass the road gates. In Darajat, people commonly used the roads through the Protection Forest part of the concession, but less so to access the Nature Reserve. In Sarulla, which was still under development at the time of our visit, road access appeared to be more difficult to control with people using roads to access forest areas where they had informal land use claims.

3.1.3 Indirect Impacts

While the direct impacts of geothermal development are relatively small, the indirect impacts may be more significant. These indirect impacts refer to increased threats that are associated with but not directly caused by the geothermal power developments. This includes factors such as increased hunting and collecting pressure through improved access to forests areas, increased fire risk through drying out of forest edges along roads and project infrastructure, and increased likelihood of people using the project infrastructure to move into previously inaccessible forest areas (also see above on section on road impacts).

Figure 2 indicates that indirect impacts increase with increasing installed capacity. Every additional 100 MW adds about 10 km^2 of indirectly impacted forest area. The average indirectly impacted area of 15 project areas in Indonesia (including several projects under development) is 23.4 km^2. These estimates of indirect impact could help government authorities to determine the relative impact a proposed geothermal project could have on a particular forest or conservation area. For example, a 200 MW project with an indirect impact area of 20 km^2 in a small conservation area of 40 km^2 would potentially negatively impact half of that conservation area, and government authorities may decide that this is too much.

As with the linear road features, the two steam-dominated projects, Kamojang and Darajat both fall under the linear regression line, which may indicate that steam-dominated projects have smaller environmental footprints in terms of forest impacts. A sample size of two is, however, too small to draw definitive conclusions on this issue.

It is noted that the linear regression coefficient of 0.43 is low, but that a power function has a much better fit (r^2 = 0.76), which indicates that larger project capacities have relatively small increments in areas impacted. One outlier in Figure 2 is Hulu Lais, which has a very long access road of some 8 km with few side roads. Such linearly-shaped project areas, much longer than they are wide, have relatively larger areas of impact than more compact, rounded project areas.

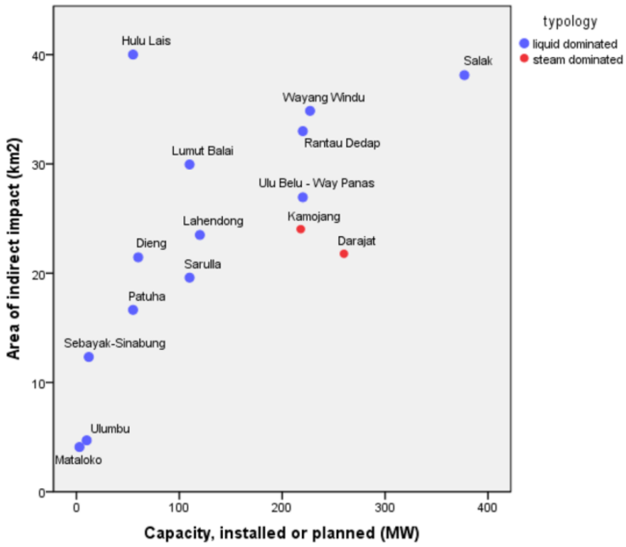

Figure 2: Graph of installed geothermal capacity in 12 Indonesian projects versus total area of indirect impact of project. Blue projects are liquid dominated, red projects are steam dominated. R2 of linear fit = 0.43.

3.1.4 Deforestation by Geothermal Projects

Geothermal projects are generally considered to have low environmental impacts because their ecological footprint on forest areas is relatively small compared to, for example, an open-cast coal mine or hydro-electric dam. Surprisingly though there appear to be no quantitative studies of what the deforestation impacts actually are. The mapping of geothermal infrastructure in Indonesia in the current study indicates the following deforestation associated with geothermal development (Table 3). As generally thought, the actual direct footprint is small, although there is quite a degree of variation between projects. It should be noted that these deforestation estimates are based on measurements taken from imagery on Google Earth, or Landsat imagery, and may underestimate the actual area cleared on the ground. These deforestation estimates are not official figures reported by the individual projects.

Table 3: Deforestation estimates for geothermal projects in Indonesia. Deforestation for roads was estimated by multiplying average road width in each project with measured road length. Deforestation from clearings was measured from project infrastructure digitized on Google Earth in 2017.

WKP (Project Name)	Status	Installed capacity (MW)	Location relative to forest	Deforestation for roads (ha)	Deforestation from other clearings (ha) - well pads, buildings etc.	Total deforestation (ha)
Sibayak-Sinabung	Inactive	12	Mainly outside	1.2	3.4	4.6
Sarulla	Operating	110	Mainly within	12	78	90
Hulu Lais 1	Operation	55	Mainly outside	10.6	7.9	18.5
Rantau Dedap	Construction	220	Mainly within	30	25	55
Lumut Balai	Construction	110	Mainly within	62	74	136
Ulu Belu - Way Panas	Operating	220	Not within	0	0	0
Salak	Operating	377	Mainly within	32	69	101
Kamojang	Operating	218	Partially within	5.7	9.5	15.2
Darajat	Operating	260	Partially within	10	7.5	17.5
Wayang Windu	Operating	227	Mainly outside	1.0	2.0	3.0
Patuha	Operating	55	Mainly outside	1.75	3.6	5.35
Dieng	Operating	60	Not within	0	0	0
Lahendong	Operating	120	Not within	0	0	0
Ulumbu	Operating	10	Partially within	0	0.6	0.6

3.1.5 Comparing the Footprint of Indonesian Versus Other Geothermal Projects

A comparison of road length and indirect project area impacted by development for 15 Indonesian projects and 9 projects in the Philippines, Central America and Japan indicated that Indonesian projects require relatively more road construction and impact larger areas than non-Indonesian projects. As discussed above, Indonesian projects require ca. 10 km of roads and impact 10 km^2 for every 100 MW produced, whereas the international projects that were analysed required ca. 5 km of roads and impacted between 6 and 7 km^2 for every 100MW produced. The slopes of the regression lines for Indonesian and international project differ significantly for both road length and area of indirect impact (Figure 3). All four regression lines in the figures were statistically significant ($p < 0.01$).

Table 4: Nine international geothermal projects and their project footprint as established in the current study.

Project Name - country	Installed capacity (MW)	Road length (km)	1km Buffer Area (km²)
Mount Apo - Philippines	106	12.8	17.6
Mount Talinis - Philippines	**223**	**22.9**	**23.37**
Northern Negros - Philippines	49	8.56	14.09
Makban - Philippines	**458**	**23.5**	**27.78**
Las Pailas - Costa Rica		17.01	21.2
Momotombo - Nicaragua	**43**	**9.58**	**10.46**
San Jacinto - Tizate Nicaragua	77	6.01	15.99
Kakkonda - Japan	**80**	**6.63**	**11.29**
Mori - Japan	50	2.75	8.27

It is not immediately clear what causes the differences between Indonesian and international projects and whether these differences are indeed meaningful. Firstly, the dataset is small and analysis of a larger number of projects would be needed to confirm that there are significant differences in project infrastructure in Indonesia compared to other countries. Overall it appears that Indonesian projects often have long access roads, which might relate to the generally low density of existing roads in Indonesia, especially in forest areas which thus requires development of new infrastructure. The average number of well pads was lower for Indonesia (10 per project for an average project capacity of 137.1 MW) versus international projects (14.8 well pads per project for an average project capacity of 137.7 MW). This indicates that Indonesian projects take up larger areas than average international projects, but with fewer well pads.

Certainly, quite a few Indonesian projects are in remote areas and hence need longer roads to actually get into the development area, although these may not be within conservation forest areas. The topography in Indonesia is challenging in many resource areas with little pre-existing infrastructure and this will also increase the length of road to actually move the same direct distance. Rantau Dedap is a case in point, with particularly long access roads. The developer constructed a more direct road between two sectors of the resource, but the road is reportedly in very steep terrain and there are concerns potential slippage. The two Nicaraguan projects (Momotombo and San Jacinto) in our analysis are in less steep terrain and are accessed by quite short spurs directly off existing national roads.

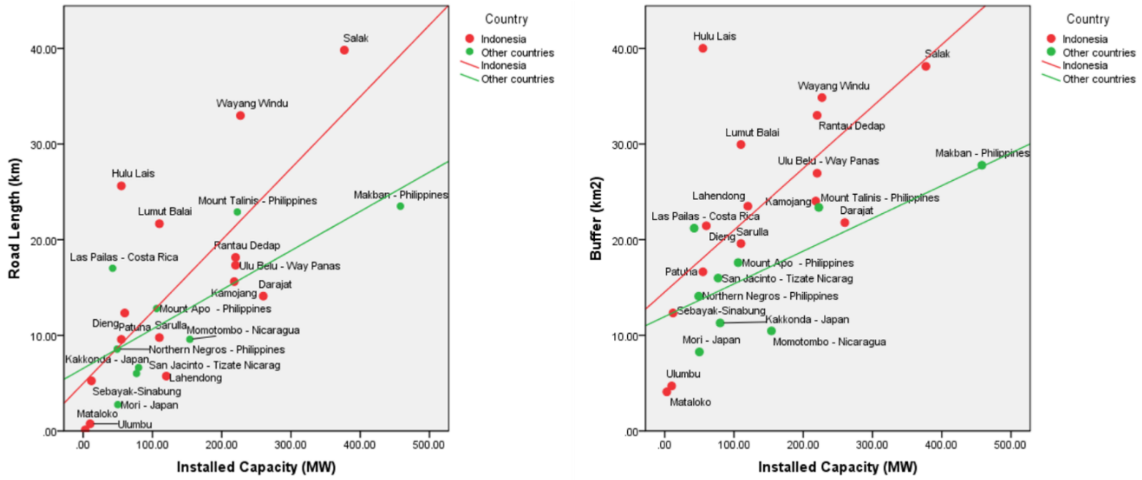

Figure 3 (Left): Installed capacity versus road length for 15 Indonesian and 9 international geothermal projects. Lines show the linear regression for each subgroup. (Right): Installed capacity versus area of indirect impact for 15 Indonesian and 9 international geothermal projects. Lines show the linear regression for each subgroup.

One other possible explanation for the differences between Indonesian and other projects is geology. As a general rule, geothermal projects in island-arc settings such as Indonesia tend to be in mountainous areas associated with andesitic volcanoes, whereas geothermal projects in countries like New Zealand tend to be in flat-lying basins associated with rhyolitic volcanism, so the access is easier. The Philippines is similar to Indonesia, but Japan and some of Central America are in intermediate geological settings, so there is a mixture of mountains and basins (Lawless 1993).

The issue of greater impact on forests in Indonesia compared to similar projects elsewhere is real however and requires further consideration. Special geological setting, the concentration of high biodiversity in remaining forest areas with highest geothermal potential, and the relatively low density of Indonesia's rural road network, means that Indonesian geothermal power developments in forest areas are highly likely to have higher environmental and biodiversity impacts than projects elsewhere. This in turn requires that greater precaution is taken in developing the Indonesian geothermal sector, also justifying the macro-risk assessments developed in this report.

3.2 Macro-level Assessment

3.2.1 Geothermal Energy Development Risk Mapping in Indonesia

Most of the geothermal potential points in Indonesia are on the islands of Sumatra, Java, Sulawesi, and Flores (Figure 4). The other large islands of Kalimantan and Papua have far fewer geothermal potential points. The islands where high biodiversity and high geothermal potential intersect are Sumatra, Java, Maluku and Sulawesi. The highest number of high-risk geothermal potential points are found on Sumatra (30 points) which has some of the highest geothermal potential and also very high biodiversity values, social values were lower but this may be a result of the lack of data relating to social factors mapped.

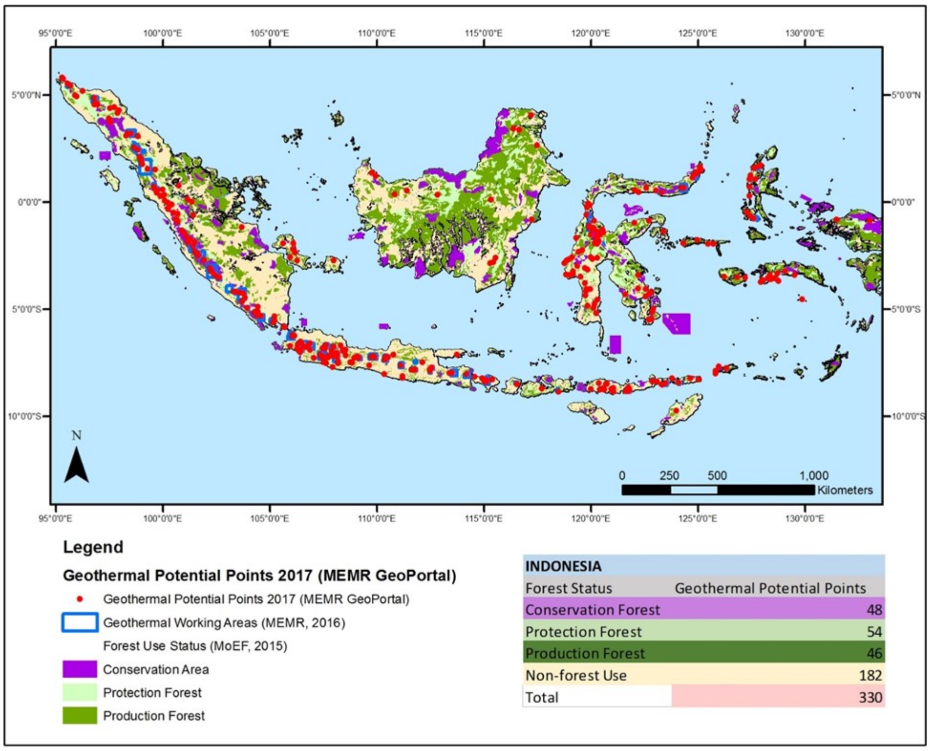

Figure 4: Geothermal potential in Indonesia in relation to land use (based on current analysis).

Out of a total of 330 potential geothermal points, 148 are ranked low risk (0 – 3 points), 89 are ranked medium risk (4 – 6 points), and 93 are ranked high risk (7 – 17 points). The macro-level risk analysis found that twenty of the geothermal potential points were clearly within a national park boundary and nine were likely in or were on the edge or just inside a national park. Four points were within a Nature Recreation Park (Taman Wisata) and four in Grand Forest Park (Tahura). Nine points were found to be within Strict Nature Reserves (Cagar Alam), two points within a Wildlife Reserve (Suaka Margasatwa). The relative values per island show that 21% of geothermal potential points in Sumatra are located in conservation areas, for Java and Bali this dropped to 18% and 13% for Sulawesi.

The current assessment determined the potential geothermal capacity that was located in forest areas, degraded forest areas and on cleared land based using data from Badan Geologi on the speculative, hypothetical, possible, probable or proven reserves. For this assessment, the most reliable resource estimate for each potential geothermal point was used, with "speculative" being the lowest reliability and "proven" the highest. This differs from the approach of the Directorate of Geothermal (2016, p. 34 and onward) where the resource capacity is calculated by summing the estimates for speculative, hypothetical, possible, probable or proven reserves for each geothermal point. This allows a comparison of the resource capacity of each potential project location and its individual risk level. This assessment indicates that the higher capacity projects (> 200 MW) are primarily located in high and medium risk locations, with most low risk location having < 200 MW capacity estimates.

Taking the current approach indicates that 66% of Indonesia's estimated geothermal capacity is on cleared land (in 218 geothermal locations), and 34% in degraded and primary forest (in 112 locations). Taking the government approach indicates a higher percentage of total capacity on non-forested land (73%) (Table 5).

The same approach as above was used to estimate the geothermal potential in different land use categories. Most geothermal potential is in non-forest use land (APL), i.e., 38% of total capacity in 154 geothermal points. Protection Forest has the second highest potential capacity, i.e., 27% of total in 55 points. The remainder of the potential capacity is in Production Forest areas (11%) and in conservation areas (23%).

Table 5: Overview of potential capacity in 314 geothermal points for which resource estimates were available in relation to land cover. Potential capacity is estimated by using the most reliable resource estimate for each geothermal point. The Sum of resource estimate uses the approach by the Geothermal Directorate (Directorate of Geothermal 2016).

Land cover	Potential capacity (MW)	Sum resource estimates (MW)
Cleared land	14,832	20,285
Degraded forest	5,173	6,418
Primary forest	1,076	1,076
Total	21,081	27,779

Table 6: Overview of potential capacity in 314 geothermal points for which resource estimates were available in relation to land use. Potential capacity is estimated by using the most reliable resource estimate for each geothermal point. The Sum of resource estimate uses the approach by the Geothermal Directorate (Directorate of Geothermal 2016).

Land use status	Potential capacity (MW)	Sum resource estimates (MW)
Non-forest use (APL)	8,056	12,240
Production Forest	2,416	2,758
Protection Forest	5,736	7,125
Conservation Areas	4,873	5,656
Total	21,081	27,779

4. RECOMMENDATIONS

4.1 The need to consider environmental and social trade-offs in clean energy development

From a global environmental perspective, the benefits of geothermal energy development are beyond dispute. In Indonesia, however, the fact that most of the geothermal potential is located in environmentally sensitive areas means that it is critical that the geothermal energy sector adheres to high operational standards whereby environmental and social impacts and risks are assessed early in the project cycle. Such impacts need to be avoided, if possible, or mitigated and managed. Affected communities need to be consulted throughout project preparation and development.

Sustainable development of Indonesia's geothermal energy rests firstly, on a strong regulatory framework which is consistently enforced and effectively monitored to ensure environmental protection and social inclusion (community engagement and consultation, grievance redress and fair benefit sharing), and, secondly, on the implementation of high operating standards in sensitive areas and avoidance of development in very sensitive areas, such as core zones of national parks. Here in lies the major challenge for geothermal energy development in Indonesia.

There are trade-offs between the costs and benefits of geothermal development in forest areas. In certain cases where the geothermal potential is very high and the potential for environmental and social impacts low, it seems an obvious choice to support geothermal development. In the opposite case of high environmental and social impacts and low geothermal potential the opposite is true and many people may agree that the project should not be developed. This is all seems simple, but the reality is often a lot more complex. Opinions may differ on how one defines high environmental values and the extent to which these are affected by geothermal developments. Furthermore, environmental and social impacts can be much reduced by high quality operational management and impact avoidance and mitigation. A well-managed project with good security that stops people from using company roads to go hunting will obviously have lower environmental impacts than one without such high standards. A project which plans road construction in such a way that roads are kept to a minimum width and length with well managed run-off and sediment control will obviously have much lower environmental and social impacts. Government decision-makers therefore need clear and objective guidelines that facilitate decision-making about geothermal (yes/no decision), but also about the conditions under which this would happen.

4.2 Recommendation for Environmental and Social Screening of Project Risk

From an investor and developer standpoint geothermal projects are risky with geological exploration risk (or resource risk) often considered the greatest challenge and capital intensive (ESMAP 2012). Significant investment is required before knowing whether the geothermal resource has enough potential to recover the costs. This report has demonstrated, with a number of examples, that environmental and social risk has the potential to cause significant delays or cancellations of geothermal projects.

One of the key outputs of this study has been the rapid desktop evaluation tool for environmental and social risk screening of geothermal potential points. This screening method is relatively quick and affordable, and could be feasibly institutionalized in MEMR and MoEF, to help the government (and investors) identify areas which should be avoided due to very high environmental and social risks, or it could be used to inform design and to the scope of subsequent environmental and social assessments. Specific recommendations are made in Table 7.

Table 7: Recommendations based on the environmental and social screening approach

Key issues	Recommendations
1. Risk level of geothermal power development in Indonesian forest areas varies greatly depending on a range of social and environmental factors. Ignoring these risks significantly raises the costs of geothermal power development. According to government data, most high potential capacity projects are also high risk projects.	• Institutionalisation of the environmental and social project screening tool. Government institutions, project developers, and financiers should use the World Bank risk assessment in the allocation of areas for exploration and development, focusing first on project sites with low risks and high potential capacity. Risk avoidance might require targeting of lower capacity projects (below 250MW). Extra risk mitigation measures are needed when higher risk locations are developed.
2. Most geothermal capacity is located in areas already deforested and on non-state-forest land. Geothermal capacity in forested areas makes up about 27% of the total capacity in Indonesia according to government data.	• In order to avoid social and environmental impacts, exploration investments should preferably target the significant geothermal capacity in non-forest areas and on APL land with the caveat that these areas are likely to be more populated which comes with possible land acquisition challenges. In addition many of these resources are of lower-medium enthalpy.
3. Risk assessment is determined on the basis of variables and values for environmental and social risk and geothermal capacity that will change with better data and changing conditions.	• MEMR and MoEF jointly use the risk assessment tool in their planning for geothermal development and regularly update it as new data become available. Government institutions should share accurate data to ensure that the risk tool is as accurate as possible.

5. CONCLUSION

Despite the clean nature of geothermal energy and other renewables, their development and implementation are not without environmental and social impacts. In areas where such impacts are high, the costs and efforts of mitigating environmental and social costs can be prohibitive, potentially endangering the financial viability projects. Early scanning for such risks is therefore important to the geothermal sector in Indonesia and elsewhere. Our analyses have quantified common environmental impacts of geothermal in Indonesia, and based on this developed a macro-risk assessment that allows government and investors to guide geothermal investments to areas with the highest benefit/costs ratios (high geothermal potential and low social and environmental risks). We show that this can be done using relatively simple methods and publicly available data. These methods could be used in other contexts, for example, the risk assessment of hydropower developments, or similar projects requiring early evaluation of the trade-offs between national-level clean energy benefits and local-level environmental and social costs.

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