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Geothermal Green Bond Certification: Challenges in Investment Screen Criteria Development Using Global Geothermal Carbon Dioxide Emissions Rates

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ABSTRACT

Geothermal project development is often hampered by the availability of funding, particularly at stages of exploration prior to confirmation drilling. However, the increasing investor appetite for sustainability-related financial instruments has introduced demand for "green bonds." If geothermal projects can sufficiently meet sustainability-related investment criteria, geothermal developers may have increased access to funding in the bond market – including large financiers.

Geothermal projects are often touted as climate-friendly because the greenhouse gas (GHG) emissions are low relative to many fossil fuel fired power plants, and the gases released from the stack are the naturally-occurring non-condensable gases contained in geothermal reservoir fluids. However, these emissions are often categorized as anthropogenic under international GHG accounting standards. As a result, the "greenness" of a geothermal project may hinge on the ability to accurately estimate a reservoir's emissions rate – and the power plant technology appropriate for the project.

This work briefly reviews current and upcoming attempts to define criteria that would enable a project to qualify for a green bond using a process that enables standard and transparent disclosures for investors. This work begins by providing a discussion of the challenges to developing a multi-stage "green" screen for geothermal projects, and continues with a review of the distribution of carbon dioxide (CO_2) emissions from operational geothermal power plants around the world to characterize the potential variance in project emissions that developers may face. Future work will include advancing the understanding of emissions variability by categorizing reservoir GHG signatures by geothermal system type.

1. THE DEMAND FOR GEOTHERMAL GREEN BONDS

Funding for activities at the early development stages of a geothermal project is typically provided by the following: 1) the developer's internal balance sheet; 2) private equity investment (sometimes involving a portfolio of projects); 3) other forms of corporate equity; and 4) support from governments and multi-lateral financing institutions. Resource supply (*i.e.*, drilling and well field development) for conventional hydrothermal has been estimated between 32-48% of the total capital costs (Hance, 2005). And, higher risk projects (including Enhanced Geothermal Systems) are likely to have even higher proportions of their cost embedded in resource development. While later stages of development have qualified for mezzanine debt (a combination of debt and equity), debt financing is rarely offered until the resource is proven and the project is moving into the power plant construction and operation stages (Figure 1 below, Salmon et al., 2011). Although credit markets have improved overall since the depths of the recession that began in 2008, recent analysis of U.S. projects in development suggests that access to financing and overall capital budgeting (i.e. funding priority decisions between available projects) continue to hamper geothermal deployment (Wall and Young, 2016).

Since debt may comprise 45-70% of project's total financing when a project is without access to grants (Figure 2 below, Salmon et al., 2011; Olafsson 2014), the cost of interest may be significant over the lifetime of the project. It is estimated that over half of geothermal power costs can be related to covering interest and repaying capital (Hance, 2005). As a result, reductions in interest rates through refinancing of this capital and access to lower-interest bonds may be beneficial to improving geothermal operators' bottom lines. In the U.S., developers have used tax equity to repay construction loans because rates were priced similarly to debt (Salmon et al., 2011).

Not only would the geothermal market potentially benefit from additional access to bonds, but "green bond" issuances targeted for renewable energy or energy-efficient projects are a rapidly increasing proportion of the debt markets. In 2014, earmarked green bonds were 38 billion USD issued for clean energy investments, up from 15% of debt issuances in 2013, and were projected to be nearly 42 billion USD in 2015 for clean energy (Suki 2015). Corporate, project, and asset-backed securities facilitate this growth – and all could be appropriate for geothermal projects given the appropriate qualifying criteria (Figure 3, Suki 2015).

1.1 Existing Green Bond Standards

Standards for the issuance of "green bonds" are not yet codified in regulations. Given the market interest for these products, the investment community has begun development of voluntary standards and verification processes to provide investor transparency. The Green Bond Principles (ICMA 2015) is a set of voluntary criteria that designate whether a project promotes environmentally sustainable activities. While no criteria specific to geothermal projects has been published at the time of this paper, the Climate Bonds Initiative (CBI) is currently in the final stages of developing project finance criteria for its green bond verification process. Separately, the World

Bank is finalizing a technical note on how to address greenhouse gas emissions from geothermal power projects in the context of the Bank´s GHG accounting scheme, which has the potential for supporting green bond criteria development.

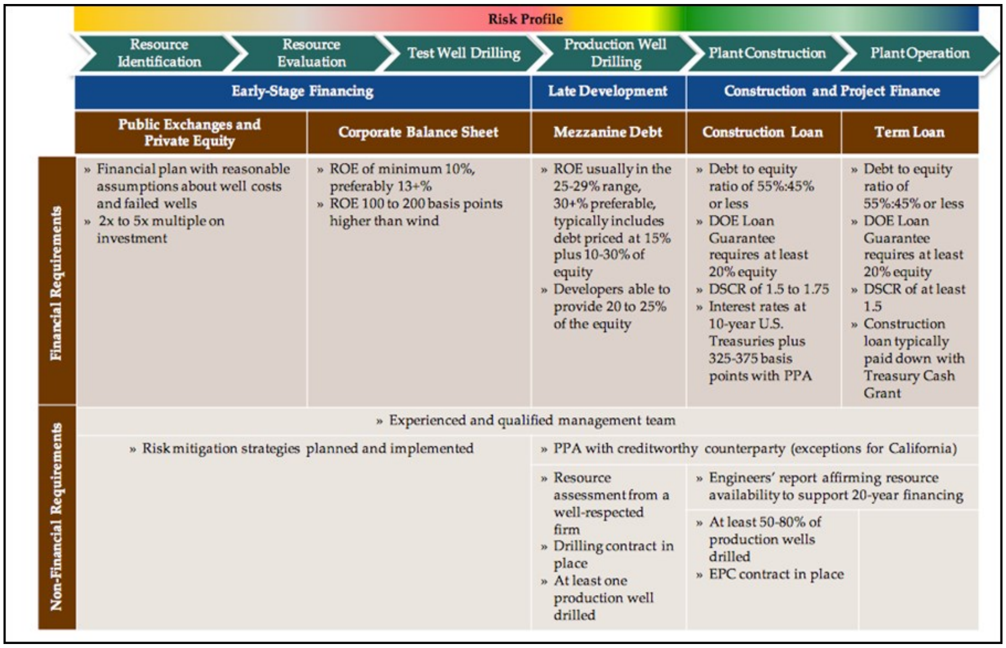

Figure 1: Summary of the types of financing available to U.S. geothermal projects at each development stage (Salmon et al. 2011)

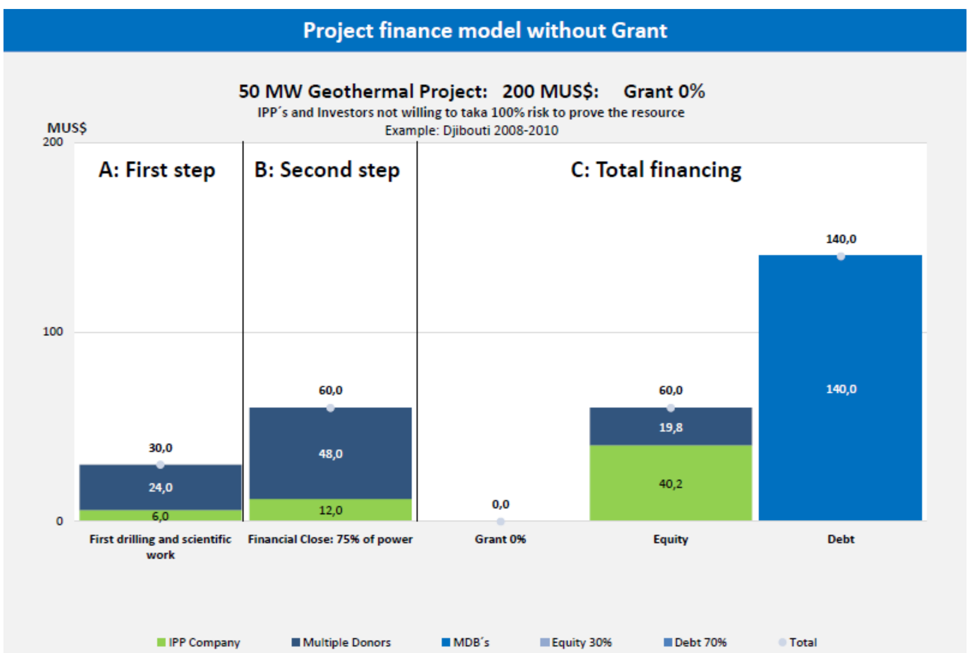

Figure 2: Example of geothermal project finance structure (at 70% debt) when no grants are available for upfront exploration costs. (Olafsson, 2014)

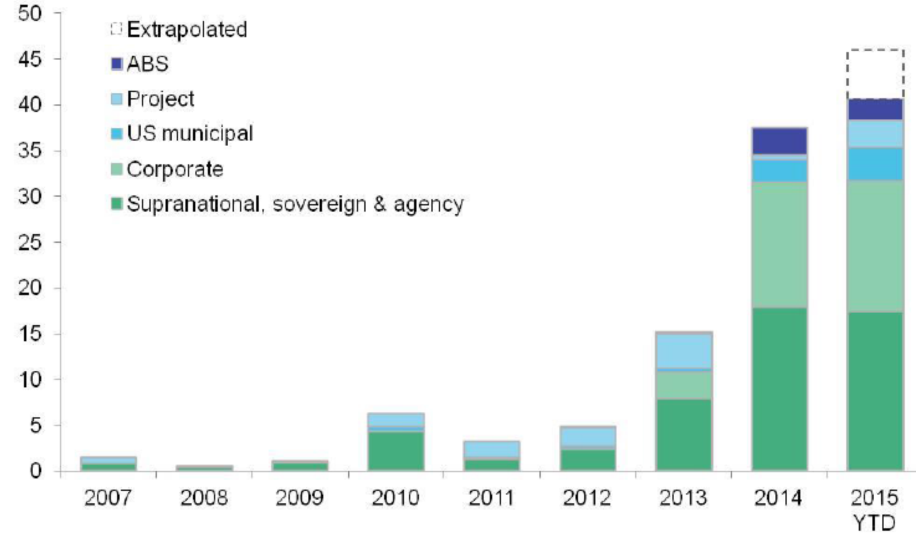

Figure 3: Categories of debt issued as green bonds, in billions USD (Suki 2015).

1.2 Green Bond Criteria

The Green Bond Principles allow issuers to define their own criteria and process for screening projects to fit environmental sustainability objectives. As a result, no standard currently exists to compare the environmental impact of different projects across different issuers. CBI seeks to issue globally applicable criteria for each renewable technology to allow investors a basis to compare projects in their portfolios. Since GHG accounting has become an acceptable standard to indicate climate impacts, CBI focuses its primary screen on the emissions of the project. For geothermal project criteria, the following types of emissions screens have been considered:

- ***Threshold:*** The project qualifies for green certification if the emissions of the project are measured (or estimated) to be less than a predetermined level of environmental sustainability.
- ***Technology:*** The project qualifies for green certification if the emissions of the project use emissions-reducing or mitigation technologies.
- ***Country***: The project qualifies for green certification if the emissions of the project are less than the country's average emissions rate for all power plants connected to the grid.

All of the above screens require an understanding of the project's likely GHG emissions. GHG emissions of a geothermal area are related to the release of non-condensable gases in the fluid – whether through soil degassing or the production of geothermal fluids. Since the ability to accurately estimate an area's emissions indirectly determines whether or not a project qualifies according to CBI's criteria, an understanding of the variance in geothermal emissions is critical to a robust geothermal green bond market. Therefore, we now present a review of geothermal project emissions to assess this variability for geothermal projects in different countries.

2. ASSESSMENT OF GEOTHERMAL EMISSIONS VARIABILITY

A better understanding of the most likely and range of GHG emissions possibly emitted by a geothermal project in a given country is both useful and necessary in order to meet green bond criteria based on national grid emissions rates. This work does not attempt to provide a comprehensive catalog of plant GHG emissions. Instead, the following analysis investigates the distribution of a sample of global installed geothermal capacity to evaluate whether average GHG emissions rates by country provide reasonable estimates for criteria setting.

2.1 Method

A better understanding of the most likely level and range of GHG emissions possibly emitted by a geothermal project in a given country is both useful and necessary in order to meet green bond criteria based on national grid emissions rates. This work does not attempt to provide a comprehensive catalog of plant GHG emissions. Instead, we investigate the distribution of a sample of global installed geothermal capacity to evaluate if average GHG emissions rates by country provide reasonable estimates for criteria setting.

2.1 Method

This analysis combines both peer-reviewed literature values, measured emissions data reported from operators, and calculated emissions estimates from publically available sources. Information in peer-reviewed literature and actual measurements published by a company or government agency comprise nearly 43% of the plant data analyzed. Calculations of emissions comprising the other 57% of this analysis were used only when other data sources were not available. Based on the literature and discussions with operators, the following assumptions were used when measurements were not available:

- Released non-condensable gases (NCGs) contain 95% carbon dioxide (CO_2) (DiPippo, 2012)
- Geothermal power plants are typically available 96% of the time of an 8,766 hour year.
- Annual generation, if not reported, was calculated as net capacity x 8,766 operating hours/year. If net capacity was not available, annual generation was calculated as gross capacity x 8,766 operating hours/year. In some cases generation in kWh was available for a given facility and this calculation was not necessary.
- Emissions leaks during gas separation or fluid transport in the plant are negligible; all CO_2 released from produced NCGs are either discharged at the cooling tower or otherwise mitigated by the technology (i.e. *e.g.*, binary cycle power plants in which the geothermal fluid remains in a closed loop).

To calculate estimate total CO_2 emitted annually when published rates or totals were not available, the following formula was used:

Annual emissions rate (g/kWh) = [Gas Content (% wt.) * Steam Consumption (t/h) * (95% CO_2 content) * Plant availability]/ Annual Plant Generation (kWh)

To remove variability in emissions rates due to changes in reservoir chemistry over time, only the most recent available annual data for each plant is represented in this analysis. Overall, the sample dataset comprises:

Number of Plants: 143

Number of Countries: 16

Total Installed Capacity: 7,958 MW

Percent of Total Operating Nameplate Capacity Represented (GEA 2016): 61%

2.1 Statistics

Figure 4 illustrates the heavily skewed distribution of emissions rates in this sample dataset. The mean global emissions rate of 175 g CO_2 / kWh carries a standard deviation of 255 g CO_2 / kWh; three quarters of this dataset has emissions rates of 188 g CO_2 / kWh or less. The median emissions rate of all projects is only 73 g CO_2 / kWh. Only 20% of projects emit at rates greater than 250 g CO2/kWh while 20% of projects emit less than 8.5 CO_2/kWh. Simply put, it is very unusual for a geothermal plant to emit more carbon dioxide than the average natural gas powered facility emitting 548 g CO_2 / kWh (*i.e.*, 1.21 lbs CO_2 / kWh EIA 2016).

These results are similar to the findings of Bertani and Thain in their 2002 survey of 85 plants operating in 11 countries, comprising 6,648 MW of operating capacity (representing 85% of the world's operating geothermal power plant capacity at that time). This study's results ranged from 4 g CO_2/kWh to 740 g CO_2/kWh with the weighted average of 122 g CO_2/kWh.

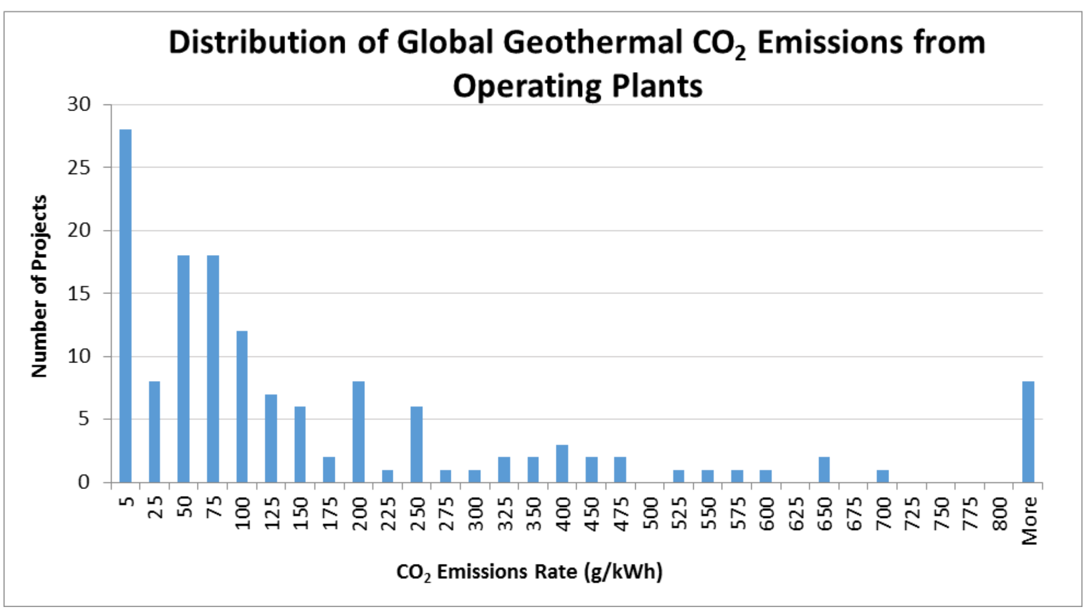

Figure 4: Histogram of annual CO_2 emissions rates from the most recent geothermal operating plant data in this sample dataset. Emissions rates range from 0 to 1,300 g CO_2 /kWh. 95% of projects emit less than 900 g CO_2 /kWh.

However, the shape of the emissions distribution also varies by technology employed – a choice dictated by the underlying resource. Figure 5 shows differences in the frequency of plants with given emissions rates when grouped by the power plant technology in use. As seen below, dry steam plants are highly variable (with emissions ranging 50 to 700 g CO2/ kWh/ yr) and emissions from binary plants exhibit a bifurcated distribution (either near zero/very low or very high). Single and double flash plants both show a left-skewed distribution, indicating it is more likely to have plants with lower emissions values but some high-emitting facilities will occur.

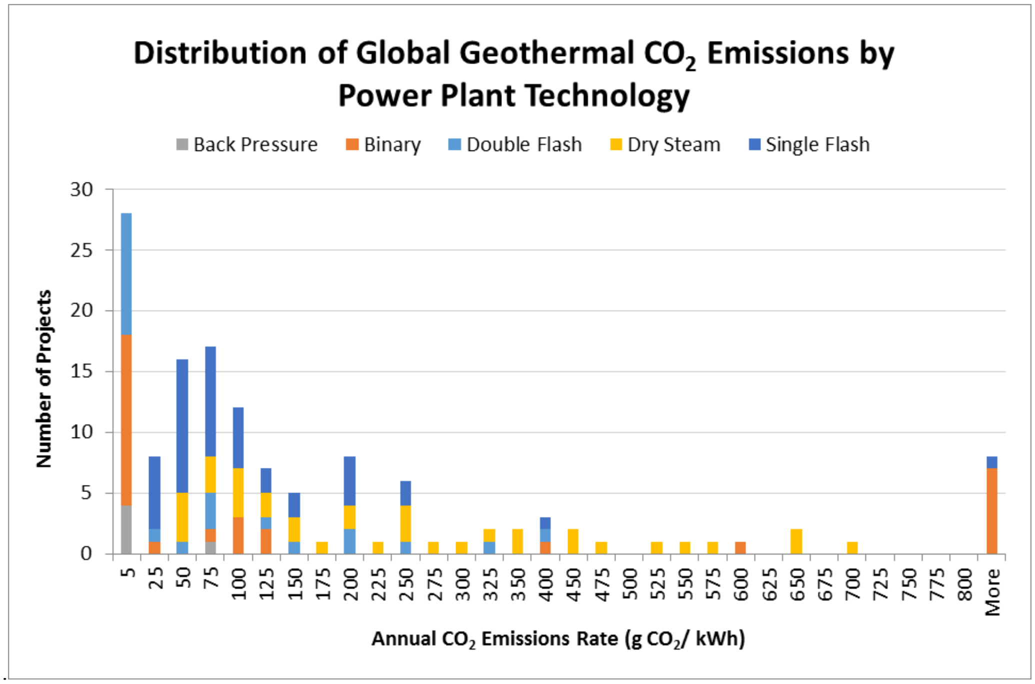

Figure 5: Histogram of annual CO_2 emissions rates for projects globally, grouped by power plant technology installed.

The variability of geothermal emissions within each country may also be significant – particularly when technology is considered. As seen in Figure 6 below, the highest emissions rates recorded in the United States are still less than the lowest emissions rates found at plants in Turkey. And, these highly variable emissions appear to be occurring at binary plants (Figure 7). While this dataset's current size limits meaningful statistical tests (*e.g.*, Iceland contains a sample size of only 6 plants), this work illustrates the potential for an average emissions estimate to either over or underestimate a plant's emissions by an order of magnitude, or more.

3. APPLICATION

With the understanding of emissions variability developed in the section above, this work turns to a hypothetical application of emissions criteria to demonstrate a screen's potential uses – and pitfalls.

Example 1: Project A is a closed loop binary plant located in the U.S, looking to use green bonds to refinance its construction loans. Measurements show the fluid would emit 150 g CO_2/kWh if released, but emits negligible gas from the closed loop. The threshold criterion for a geothermal plant is that it cannot emit more than the average emissions rate from all power projects on the grid (*e.g.* 522 g CO_2/kWh). Project A would pass all three screens to qualify for green certification:

- ***Threshold:*** The project qualifies for green certification because it is below the threshold of 150 g CO_2/kWh< 522 g CO_2/kWh.
- ***Technology:*** The project qualifies for green certification because the project uses emissions-reducing or mitigation technologies to emit 0 g/kWh of carbon dioxide
- ***Country***: The project qualifies for green certification because the plant's negligible emissions are below that of the national US grid (*i.e.* 0 g CO_2/kWh < 522 g CO_2/kWh).

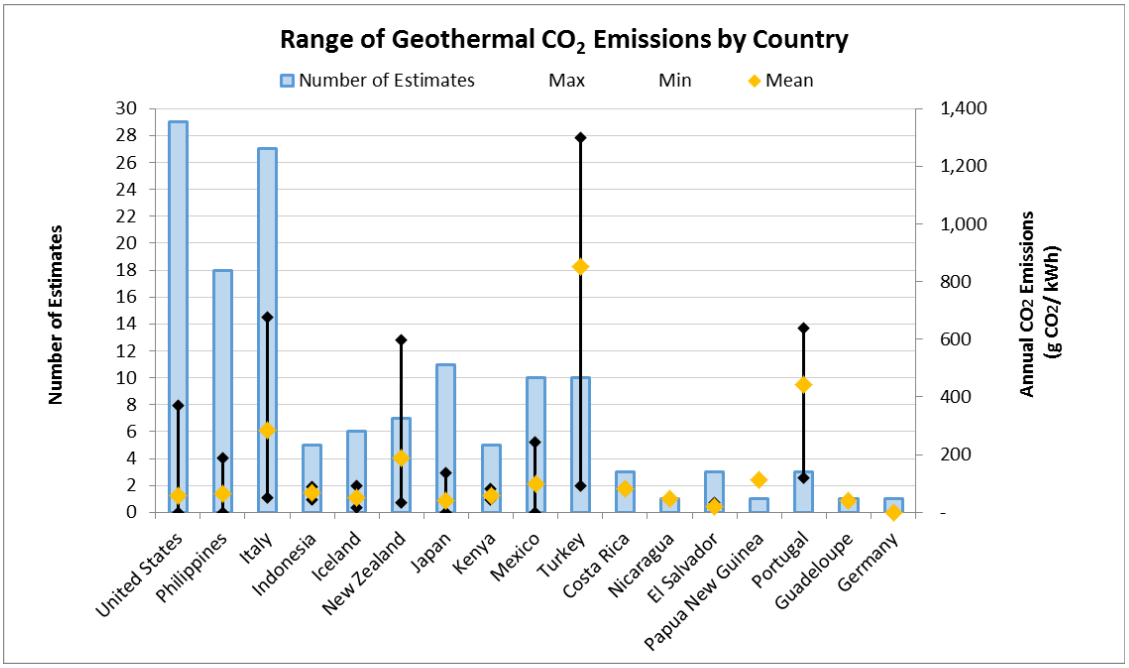

Figure 6: Range and mean CO_2 emissions rate by country. Emissions rates from the United States, the Philippines, and New Zealand, among others, are skewed toward lower emissions rates. Emissions rates from Turkey are distinct in that average emissions rates are skewed toward higher emissions rates.

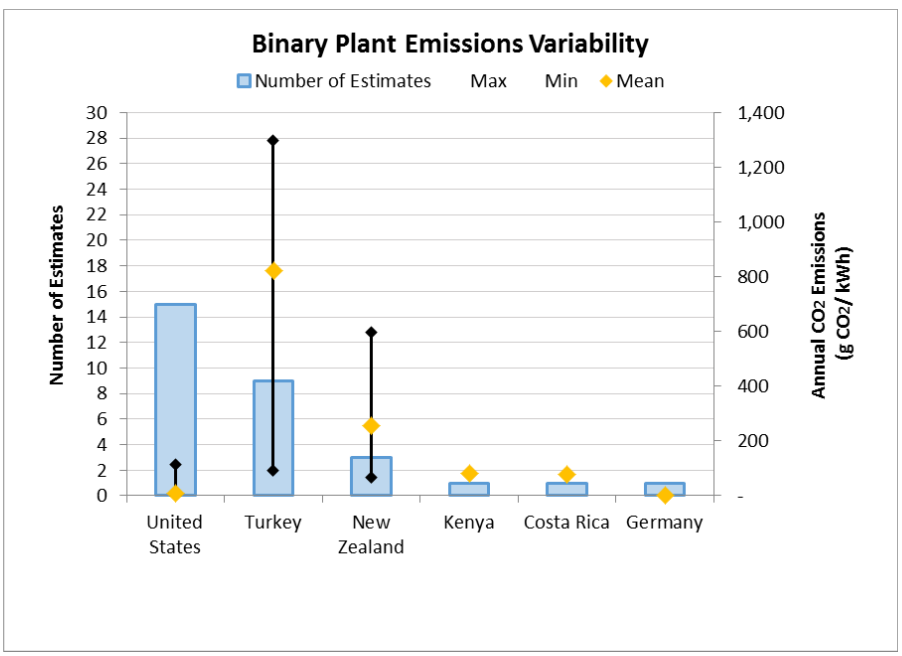

Figure 7: Range and mean CO_2 emissions rate for installed binary plants by country. Note the variability in emissions at binary plants accounts for much of the variability in country-wide emissions in Turkey and New Zealand.

Example 2: Project B is an early stage prospect in the Philippines, looking to use green bonds to fund exploration research. No measurements of emissions are available. Other plants in this type of geology in the Philippines are double flash and emit 8.5 g CO_2/kWh of anthropogenic emissions, while all geothermal plants in the Philippines emit on average 64 g CO_2/kWh. The threshold criterion for a geothermal plant is that it cannot emit more than the lowest-emitting fossil fuel energy alternative (e.g. fuel oil, 757 g CO_2/kWh), and the weighted average of emissions on the grid is 377 g CO_2/kWh). Project B would pass two of the three screens to qualify for green certification because:

- ***Threshold:*** The project assumes the most likely emissions for the geology (8.5 g CO_2/kWh) until better information is available. The project then qualifies for green certification because the likely emissions are lower than the threshold fossil fuel emissions (*i.e.* 8.5 < 757 g CO_2/kWh)

- ***Technology:*** Since projects in similar settings are double flash, this technology is assumed to be likely until better information is available. Thus, this project would not qualify for green certification because dry steam plants alone do not mitigate emissions. However, this project could qualify if the developer installed technology to mitigate these emissions.

- ***Country***: The project assumes the average emissions rate of all geothermal plants in the Philippines until better information is available. The project would then qualify for green certification because the likely project emissions are lower than the national grid (*i.e.* 8.5 < 377 g CO_2/kWh)

For projects with measured emissions, a threshold-based screen is straightforward: compare the project emissions to the threshold and reject or accept the project for certification. However, applying a technology screen alone does not capture the potential impact of projects without mitigation technologies. The most likely combination of these criteria may then be a downselect process or decision tree, such as Figure 8 below.

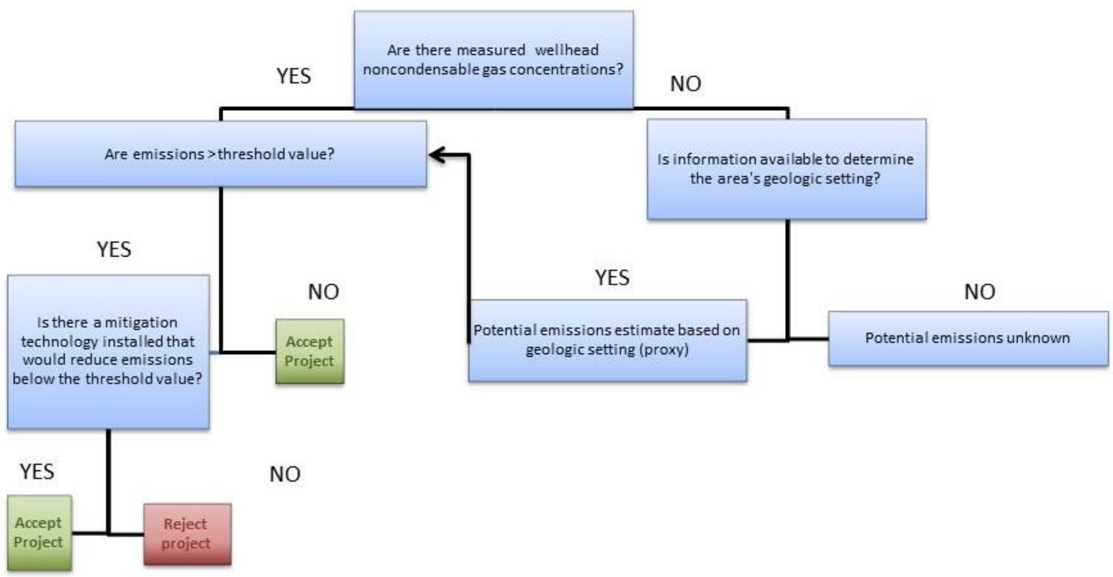

Figure 8: Example of a possible decision tree using emissions-driven screening criteria for green project certification.

4. DISCUSSION

GHG emissions are primarily related to the production of fluids themselves, as reactions with the host rock or from reactions with gas influxes. As a result, variability in geothermal NCG emissions are largely due to differences in the geologic setting of the geothermal system. Characterizing emissions by geothermal setting is an important missing link to understanding and estimating emissions variability. Initial efforts have begun to create an extension of this study that includes geological settings and geochemistry. Green bond criteria development would benefit from this work by not only providing better comparability in setting reasonable emissions thresholds, but by providing emissions proxies for early-stage projects prior to drilling.

This work does not attempt to designate whether the emissions of these plants are anthropogenic or non-anthropogenic. This distinction is problematic for geothermal because geothermal systems naturally emit NCGs through fumaroles, vents, and soil degassing (Bertani and Thain, 2002; McLin et al., 2004; Werner et al., 2014). However, the operation of a geothermal power plant may cause emissions to be released during a human lifetime at rates potentially faster than they would have escaped naturally (Óladóttir and Fridriksson, 2015; Frondini et al., 2009).

In the scenario that geothermal plant operations release emissions at a faster rate than natural venting, these plants are likely to qualify geothermal emissions as anthropogenic per international GHG accounting standards (IPCC 2011, WRI 2004). Without information on both the natural emissions seepage prior to a plant's operation and the emissions at the plant, green bond criteria will continue to classify released emissions at a geothermal plant as anthropogenic. Future refinements of this work would be to investigate information available on natural rates of CO_2 seepage. As a result, developers seeking financing with green debt may benefit from actively measuring emissions in early stages of project exploration; if they determine plant operations would increase emissions over the background rate, developers may then have the time to design appropriate carbon dioxide mitigation technologies to allow the project to pass green debt screening criteria.

3. CONCLUSION

The development of a robust market for geothermal green bonds will depend on the transparency into and understanding of geothermal emissions sources and variability. This work primarily highlights challenges in public access to transparent, reliable data of operating geothermal power plants that provide the full range and frequency of emissions. Globally, geothermal plants are likely to emit 7.5 times less CO_2 per kWh than a natural gas plant; only the 91st percentile of this sample would contain the emissions greater than or equivalent to natural gas combustion. Further research is needed to validate that these emissions trends hold over time.

This analysis also points out the dangers of choosing simple averages as screening criteria due to the highly skewed emissions distributions, both within individual countries and globally. In early stage project finance, issuers will be interested in knowing both the "most likely" and "worst case" emissions to decide whether the project meets sustainability thresholds. To protect the credibility of the certification from the black eye of incorrectly certifying a high-emissions project as green, bond issuers might wish to use the upper range of emissions estimates in these cases, until better information is known. In turn, a better understanding of the variance in geothermal project emissions will help to tailor bond criteria to different issuer risk appetite. A better understanding of the natural range in geothermal project emissions then has the opportunity to directly help the investment community make better decisions on geothermal project financing.

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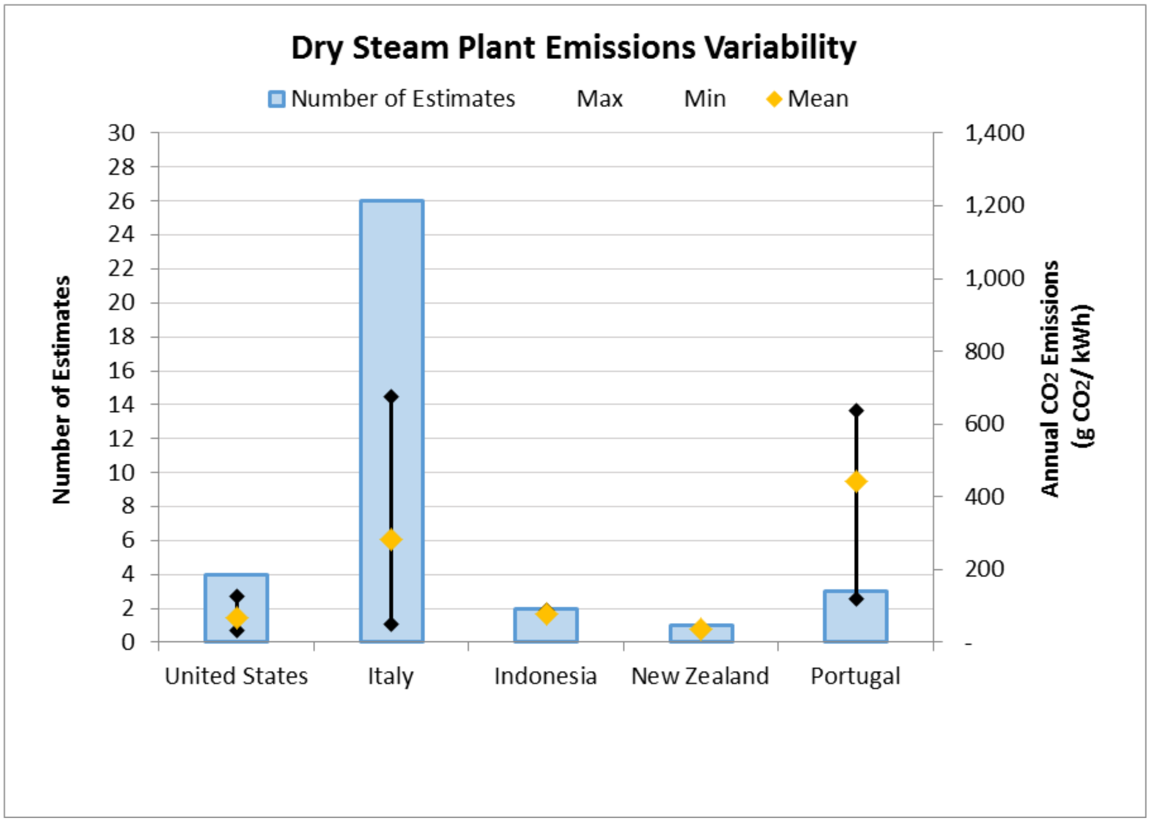
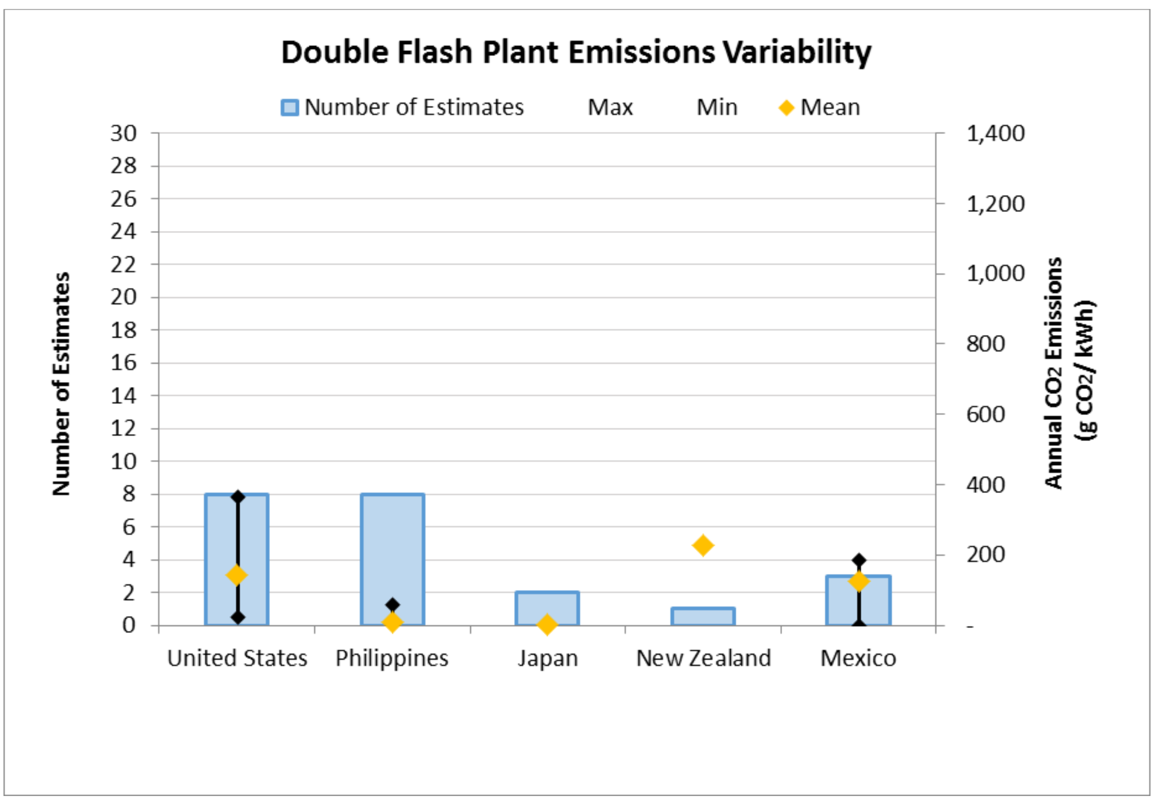
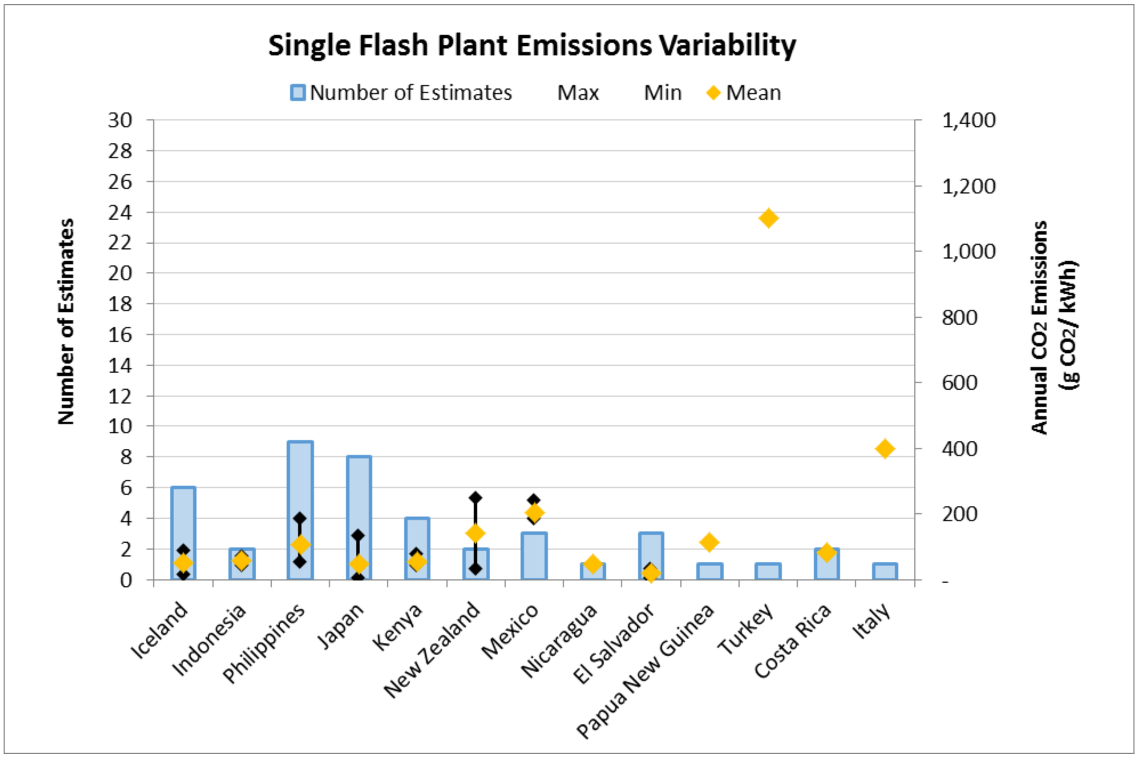
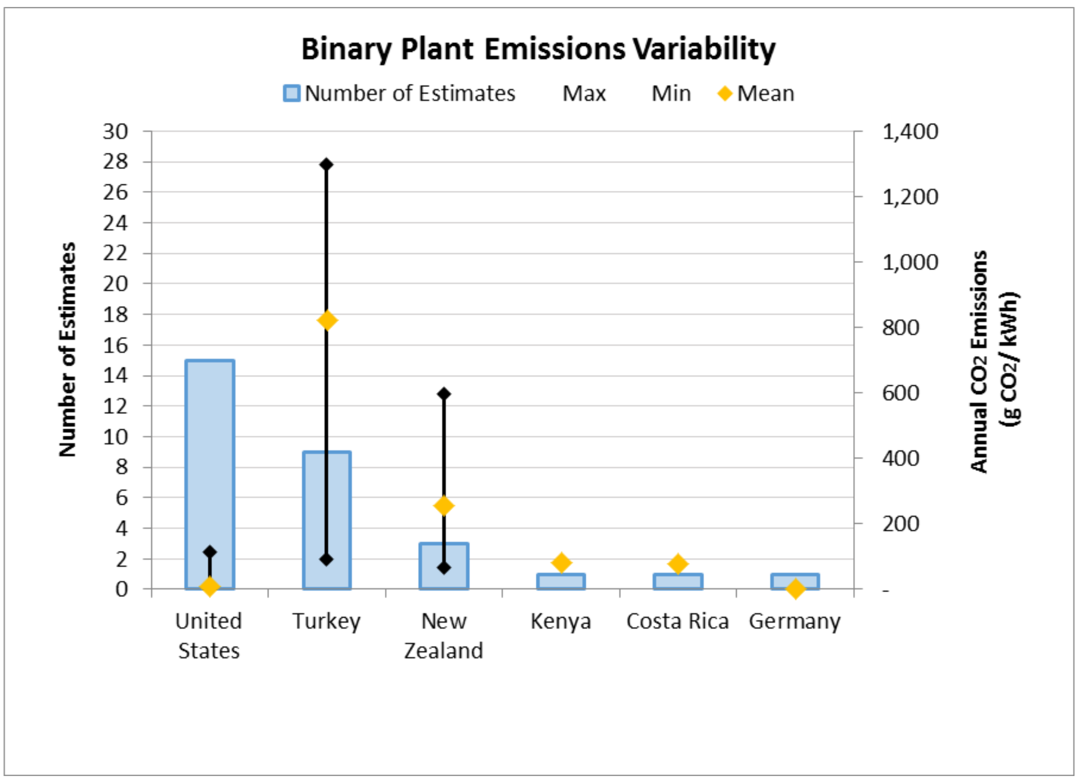
APPENDIX B: Country CO_2 emissions ranges by technology type.






Single Flash Plant Emissions Variability
Number of Estimates
Max
Min
Mean
Number of Estimates
Annual CO2 Emissions (g CO2/ kWh)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1,400
1,200
1,000
800
600
400
200
-
Iceland
Indonesia
Philippines
Japan
Kenya
New Zealand
Mexico
Nicaragua
El Salvador
Papua New Guinea
Turkey
Costa Rica
Italy


Binary Plant Emissions Variability
Number of Estimates
Max
Min
Mean
Number of Estimates
Annual CO2 Emissions (g CO2/ kWh)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1,400
1,200
1,000
800
600
400
200
-
United States
Turkey
New Zealand
Kenya
Costa Rica
Germany