Geothermal Energy and the Climate Bond Standard (Version 1.0)

Background & Sector Specific Eligibility Criteria

Geothermal Technical Working Group

1. Purpose of this document

The Climate Bonds Initiative (CBI) is an international, investor-focused not-for-profit organization aiming to develop tools to mobilize the bond market for climate change solutions. The Climate Bonds Standard is a screening tool for investors and governments which allows them to easily prioritize climate and green bonds with confidence that the funds are being used to adapt to and/or mitigate climate change on an ambitious decarbonisation trajectory.

The Green Bond market is developing rapidly and in advance of widely accepted standards for use of proceeds, project evaluation and ongoing reporting. Correspondingly, there have already been calls for green bonds to be issued in relation to geothermal projects. CBI is seeking to develop a standard for bonds linked to geothermal projects in response to current, and in anticipation of future, demand.

This document sets out:

- Our understanding of the issues surrounding certification of geothermal projects, gained from discussion with industry experts and a review of relevant literature available to date
- A set of proposed criteria for certifying geothermal power generation projects

Certification of geothermal projects is less straightforward than for other renewables (see below). We emphasize that the criteria may be adapted either due to feedback or future developments in the geothermal sector**.** To our knowledge, detailed low-carbon criteria specific to geothermal projects have not been previously attempted. Therefore, this standard should be recognized as a starting point.

While the Technical Working Group (TWG) has done its best to present a comprehensive first version of the Standard, additions and revisions are welcomed and encouraged as the Standard evolves. We recommend that the Standard be reviewed periodically in order to make it as robust, credible and practical as possible.

The proposed criteria are highlighted in grey boxes.

Development of low carbon standards for geothermal is an emerging area which has not previously received much attention.

2. Geothermal energy's contribution to climate change mitigation

Geothermal has conventionally been constrained to settings where water is heated from naturally fractured rock, creating steam or hot water that flows to the surface when a well is drilled. This has allowed it to form a significant proportion of energy supply in geothermally-active regions, but otherwise has limited its contribution to decarbonizing the world energy supply. Nevertheless, it has been estimated that current global geothermal technical potential could be somewhere in the region of 10% of world primary energy consumption[1].

Enhanced geothermal systems (EGS) technologies are currently being developed that create an artificial geothermal reservoir from which heat can be extracted where there is hot rock but little natural permeability or fluid saturation [16]. The elimination of some geologic limitations creates the potential to greatly expand geothermal's geographical range. EGS has various technical, economic and practical barriers to overcome before it could be widely commercially deployed. The technology is in the demonstration phase and could be commercial within a decade or two. If

[1] Based on [9].
[2] Emissions due to soil degassing, while acknowledged, are little understood and ignored here for practical purposes.

successful, the IPCC estimates that EGS could increase global geothermal technical potential by an order of magnitude [10].

It is therefore conceivable that geothermal energy will play a much greater role in climate change mitigation efforts than it has to date. Investment in geothermal energy should be supported and incentivized to accomplish this. Standards and certification for investment products linked to geothermal projects could play a clear role in directing funds towards them. The range of assets which this would cover would likely include geothermal power stations, direct heat applications (such as district heating), and dedicated transmission lines.

The low carbon policy and investment communities should anticipate the much greater contribution to climate change mitigation that geothermal could make in future.

3. Geothermal emissions

Direct emissions

However, with this aspiration must come awareness that geothermal power plants can be responsible for greenhouse gas emissions. Direct emissions of carbon dioxide (and to a lesser extent methane) result from the release of naturally occurring non-condensable gases (NCGs) from the geothermal fluid during the energy extraction process[2]. Concentrations of NCGs in the fluid vary based on the geology of the geothermal field.

Geothermal power plants are located in areas of natural geological activity with naturally high CO_2 fluxes released through different conduits [2]. Nevertheless, the existence of a facility will affect the rate at which these naturally occurring gases are released to the atmosphere [2,5,8]. Any quantity of greenhouse gases, which would not have been released in the absence of the facility, can be considered additional and therefore anthropogenic[3] [7]. Our understanding is that it is on this basis that geothermal emissions estimates are presented in the literature. Any emissions figures used in this document should be similarly interpreted as anthropogenic *in the sense that they contribute to the stock of greenhouse gases in the atmosphere resulting from human activity* in addition to any natural releases. Carbon emissions from soil degassing and other natural conduits in the setting would not be considered within the scope of these emissions.

Geothermal plants *can* have virtually no direct emissions resulting from operational production. However, the potential range of direct geothermal emissions is vast; according to the literature we have surveyed, 4-1300 gCO_2/kWh (see Annex 1).

Historically, about two-thirds of global geothermal capacity has released direct emissions of less than 100 gCO_2/kWh, while a third has been above this figure [1]. Very high-emitting examples are rare, but, there are examples in the USA, New Zealand and Turkey [4,5,11]. In order to develop criteria that are robust to all eventualities, it is important to exhibit reasonable caution and be aware of such cases.

Lifecycle emissions

A lifecycle estimate would include both direct emissions resulting from plant operation as well as all other relevant 'cradle-to-grave' emissions attributable to the facility, including construction, decommissioning, and energy used for operation.

[2] Emissions due to soil degassing, while acknowledged, are little understood and ignored here for practical purposes.
[3] For example, it has been estimated that 8-16% of the CO_2 emissions from geothermal systems in Iceland are attributable to the operation of geothermal power plants [2].

Geothermal plants can be understood as belonging to one of three lifecycle emissions categories, in comparison with other technologies:

1. **Low**: less than 100 gCO_2/kWh; comparable to other low carbon alternatives, in the best cases negligible
2. **Moderate:** 100-365 gCO_2/kWh; higher emitting than other renewables, but still an improvement on fossil fuel power plant alternatives
3. **High:** over 365 gCO2/kWh[4]; comparable to a fossil fuel power station; may however still be an improvement on fossil fuel carbon intensity within a given country.

With respect to the other components of lifecycle emissions – emissions resulting from construction, energy use, etc. – there is very little information or transparency in the literature (see review in [5]). The few studies which do present details on these components suggest that they can be *up to* (but not necessarily typically) 24% of overall lifecycle emissions, or in absolute terms *up to* (again, not typically) 58 gCO_2/kWh [17,18].

Implications for criteria

There are two main implications for the criteria. Firstly, given the potentially wide range of emissions, **it is key that a standard would be able to distinguish those facilities that have, as the IPCC put it, "*significant environmental advantages relative to a reference electricity mix dominated by fossil fuel sources*"** [8]. This means certifying geothermal plants that are a big improvement on fossil fuel alternatives. But also there is a need to avoid certifying moderate-to-high emitting geothermal facilities that would be likely to displace lower-emitting renewables. The aim is to certify geothermal investments suitable for a portfolio of *ambitious* low carbon investments, consistent with meeting a radical decarbonisation trajectory which limits global temperature rises to 2° Celsius.

This requires establishing a counterfactual against which to compare geothermal emissions which: (i) takes the possibility of displacement into account; but also (ii) compares geothermal fairly with alternatives by including other non-combustion emissions. In practice, the latter means incorporating an estimate of greenhouse gas emissions due to decomposition of biomass from hydroelectric reservoirs.

The lack of information on lifecycle emissions from geothermal in the literature implies two things. Firstly, that methodologies to assess lifecycle emissions as a whole from geothermal are underdeveloped and unlikely to be practicable for the purposes of the Standard. Secondly, that it is infeasible to compare geothermal directly to a counterfactual in terms of lifecycle emissions. We therefore propose to base the criteria on direct emissions only. Direct emissions represent a *lower bound estimate* of lifecycle emissions. While acknowledging this, for want of relevant information to adjust estimates, we define a low-emitting geothermal facility as one with direct emissions of less than 100 gCO_2/kWh.

The challenge is to develop criteria for certifying geothermal projects that are robust, yet limit transaction costs by being simple and transparent. We are not aware of any pre-existing standards for low carbon certification specific to geothermal. In fact it is fair to say that scientific understanding of geothermal emissions is, with respect to some issues, limited and still evolving. We therefore wish to emphasize that this document and these criteria are part of a broader learning process and may be subject to revision as the evidence base develops. Further, we hope that facilities certified under this standard can contribute to this evidence base, reflected in the requirements for measuring emissions (see Criterion 1).

[4] This figure represents the lowest possible lifecycle emissions of a fossil fuel power station, that of a very efficient combined-cycle gas turbine power station [15].

The two key determinants of a geothermal project's potential to reduce emissions compared to the counterfactual are: its specific geological setting and the carbon intensity of the technology it will be replacing.

4. Other social and environmental issues associated with geothermal

Geothermal projects can have a number of other environmental impacts including [10,12]:

- Other air emissions, e.g. ammonia and hydrogen sulphide
- Some degree of surface water extraction which may be returned to water bodies with increased heat content
- Potential to contaminate groundwater by the presence of hazardous chemicals, e.g. arsenic, in geothermal fluid
- Reinjection or disposal of condensate which is more chemically concentrated than the original fluid
- Contaminants from drilling activities

All of these impacts are generally considered manageable with proper procedures and regulation.

In addition, EGS raises concerns regarding contamination of surface waters or soil; and noticeable earthquakes which, very occasionally, damage property (induced seismicity). Experts believe that earthquake damage can be avoided with proper monitoring. There are also concerns that EGS has high water requirements and may be unsuitable in water-stressed areas.

A standard would need to ensure that other potential environmental impacts and concerns over induced seismicity are being addressed according to internationally recognized best practice.

5. Proposed eligibility criteria for geothermal power generation

Overview

The emissions of geothermal power plants are generally better-documented and understood than direct heat applications. For this reason, the criteria below apply only to power generation, with the aspiration to develop standards for direct heat projects at a later date (see Section 7).

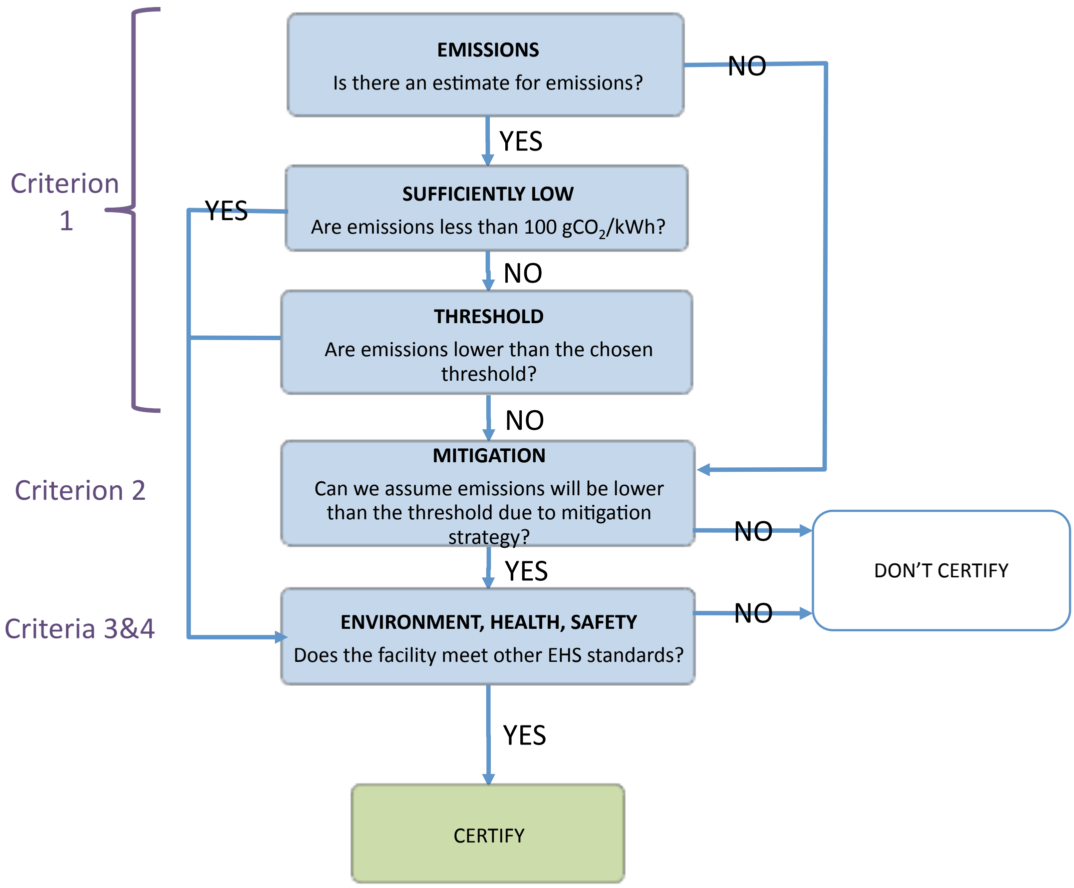
The objectives of the numbered criteria are to:

1. • Distinguish low emitting from high-emitting geothermal applications and ensure emissions are well below acceptable levels
   • Ensure moderate-to-high emitting geothermal which is likely to displace lower-emitting renewables is not certified
   • Ensure geothermal can still be certified in a country with a negligible fossil fuel alternative.
2. Where emissions are too high, or unknown, give credit to mitigation technologies which will reduce them to acceptable levels.

3. & 4. Exclude projects that do not meet acceptable standards in terms of environmental impact, health, safety and induced seismicity.

Figure 1 summarizes the decision tree represented by the criteria.

Figure 1: Decision tree structure of the criteria



Criterion 1: Emissions threshold

Criterion 1 requires the **direct operational carbon intensity** of the geothermal power plant to be lower than a threshold. Carbon intensity is measured in gCO_2 per kilowatt-hour. For ease of estimation and verification, as explained in Section 3, only direct emissions are included, that is, non-condensable CO_2 released from the geothermal fluid due to the operation of an electricity-generating or co-generating plant, determined by geological setting.

The appropriate threshold is based on the 'combined margin' metric used by the UNFCCC and IFC for assessing the emission factor of an electricity system. The metric acts as a counterfactual emission intensity for comparison with renewable projects (i.e. indicates what emission intensity would be in the absence of the renewable project). The metric combines estimates of the carbon intensity of the existing grid (the 'operating margin') and its future intensity given recent trends (the 'build margin'). We propose a simplified version with lighter information requirements based on publicly available data. This is justified by the fact that, while the UNFCCC and IFC need very detailed calculations because they may be assigning monetary payments (for example, via the Clean Development Mechanism) to quantified carbon savings, our purpose is to simply make a binary 'yes/no' decision on whether a facility can be considered a low carbon asset.

Use of the combined margin addresses the potential issue of displacement of other renewables by moderate or high emitting geothermal through the build maring component. The aim of the criterion is to encourage geothermal wherever it is low-emitting or a significant improvement on fossil fuel alternatives (which it will be in the majority of cases), while screening out cases where it is higher emitting than alternatives or an insufficient improvement to be deemed a low carbon investment.

Facilities with direct emissions of less than 100gCO_2/kWh are deemed to be low emitting, which is comparable with other low carbon options (renewables or nuclear) on a lifecycle basis.

The combined margin calculation is set out in Annex 2, which also contains worked examples of facilities in contexts, which would, and would not, pass Criterion 1.

Criterion 1
Exclude the project if:

direct operational carbon intensity of the geothermal facility > nationally-specific threshold (gCO_2/kWh)

where

$$\text{carbon intensity} = \frac{\text{annual direct } CO_2 \text{ emissions}}{\text{nameplate capacity}^{5} \times \text{capacity factor}^{6}}$$

and

nationally-specific threshold = combined margin of national grid (see Annex 2) – ambition margin

or 100 gCO_2/kWh, whichever is higher

In the case of a co-generating plant, the denominator of the carbon intensity formula should also include a term for end use energy in heat applications.

Applicants must also undertake to measure field emissions before and after the construction of a new facility, or the realization of any other project that could alter the rate of release of NCGs.

The ambition margin is likely to be determined through an iterative process, and be country-specific based on available information on what is typical, and what ambitious, for geothermal plants in the relevant country. It may be zero in countries where the combined margin is already low – geothermal power stations would simply need to outperform the combined margin. In countries where the combined margin is high, investors will need reassurance that the facility *significantly* outperforms probable fossil fuel equivalents, therefore it will be greater than zero. See Annex 2 worked examples for further discussion.

Facilities with negligible or low direct emissions, that is less than 100 gCO_2/kWh, are deemed to be comparable with other low carbon options (renewables or nuclear) in lifecycle terms and need not be compared with the threshold. This allows geothermal facilities in countries with very low fossil fuel capacity and a resulting very low combined margin, such as Iceland, to still be certified.

Estimating direct emissions

In terms of the practicalities of estimating carbon intensity, gas and fluid chemistry sampling are routine as part of the site research and exploration necessary for plant design. An initial estimate of emissions could be made at the point in the exploration process at which full-size production wells have been successfully drilled and are producing at a sufficient flow rate for power generation.

[5] Nameplate capacity and all other quantities should indicate the net output of the plant, that is overall output less any electricity used to power the plant.
[6] Typically 85-90% for geothermal plants.

Technical advice on estimation of direct emissions, which we have received from geothermal industry experts, is presented in Annex 3.

The extent to which a geothermal facility accelerates or increases the release of NCGs, thus causing anthropogenic emissions, may not in all cases be conclusively settled. We accept the possibility that estimates may be refined. For this reason, it is a requirement of certification that field emissions are measured both before and after the construction of a new facility, or the realization of any other project that could alter the rate of release of NCGs. In the event that a peer-reviewed study shows that anthropogenic emissions can be deemed to be zero or to have changed, materially affecting the decision to certify or not certify an investment, certification will be reviewed It is hoped that this requirement will also add to the currently limited scientific evidence base on this issue.

Criterion 2: Emissions mitigation technology and/or plant design

Apart from a site's geological characteristics, technology and/or plant design can also influence the degree to which non-condensable gases are released to the atmosphere.

For example, in the case of a *binary* system, a second working fluid is used to drive the turbine with the result that the geothermal fluid can be returned to the reservoir in (in most cases) a fully closed loop, which prevents release. However, in rare cases in a binary system NCGs may be vented rather than re-injected with the rest of the fluid[7]. Therefore, at present we state Criterion 2 as requiring the total reinjection of the geothermal fluid into the reservoir, either via a binary system or some other plant design. This criterion may be updated to include further suitable technologies in the light of later technical advice.

Criterion 2
(Only applies to cases which have not passed Criterion 1)

Include the project (subject to further criteria) if mitigation technologies will be deployed at the facility such that releases of NCGs to the atmosphere are rendered negligible.

At the current time, this is taken to mean any plant design (binary, combined cycle or other) that incorporates total fluid reinjection[8]. The list of technologies that are assumed to reduce emissions to negligible may be expanded as the Standard matures.

Criteria 3 & 4: Environmental, health, safety and social criteria

All projects associated with Climate Bonds must comply with the environmental regulations of the host country. In addition to this requirement we propose additional criteria to enhance EHS and social performance for all projects, and specifically for EGS projects. The IFC has detailed guidelines[9] for managing effluents, air emissions, solid wastes and water extraction which projects would be required to follow. This would provide extra assurances where national regulation is lacking or insufficient.

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[7] For example, this is the case at the Ngawha plant in New Zealand [6].
[8] It has been suggested that processes which capture the CO_2 for industrial use should also be considered under this criterion to result in zero emissions. However, CO_2 captured for, for example, the soft drink industry, will still be released to the atmosphere, and this practice would most likely not result in any net reduction in emissions overall.
[9] As set out in *IFC environmental, health and safety guidelines for geothermal power generation* available on the IFC website: www.ifc.org/EHSGuidelines.

Criterion 3

• Projects are required to comply with best practice international guidelines / standards on environmental, health and safety (EHS) for geothermal power generation (e.g. IFC/World Bank). As these detailed EHS guidelines contain guidance on air emissions, note that compliance with them is a necessary but not sufficient requirement for certification, as the emissions performance required for Climate Bonds certification is more stringent. In addition, the IFC have advised us that the applicability of EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-specific variables are taken into account.
• Meeting IFC Performance Standards on Environmental and Social Sustainability[10] are strongly recommended (e.g. IFC PS5 Land Acquisition and Involuntary Resettlement, or IFC PS6 Biodiversity Conservation and Sustainable Management of Living Natural Resources).

We acknowledge the great potential of EGS as a mitigation technology. The standard should aspire to include EGS projects if possible while addressing the additional concerns it raises. We note that significant monitoring and safety guidelines have been developed alongside experience of EGS in the USA.

Criterion 4

Any Enhanced Geothermal Systems project must comply with US Department of Energy Protocol for Addressing Induced Seismicity Associated with Enhanced Geothermal Systems[11].

Tightening and incorporating experience in monitoring and addressing the EHS and social impacts of geothermal would provide further assurances over the environmental impacts of certified projects.

6. Potential use of CDM appraisals

Projects that are accredited under the Clean Development Mechanisms by definition undergo a process of defining and estimating the emissions likely to be due to both the project and the counterfactual, using a method very similar to the one proposed in this document. A criterion automatically accepting such projects could at a stroke relieve the burden of estimation and verification procedures outlined for Criteria 1 & 2.

Criterion 5
(Where applicable supersedes Criteria 1&2)

If a Project Design Document (PDD) relating to the geothermal project has been reviewed and registered under the Clean Development Mechanism, the project will be accepted without need to comply with Criteria 1&2, subject to scrutiny of the PDD, and unless any serious concerns have been raised subsequent to registration.

[10] See www.ifc.org/sustainabilityframework.
[11] https://www1.eere.energy.gov/geothermal/pdfs/geothermal_seismicity_protocol_012012.pdf

This criterion will need to be modified to apply to any new mechanism(s) replacing the CDM in the wake of the Paris Agreement. In addition, because only projects in Non-Annex I countries have been eligible under the CDM, the geographical scope of this criterion is limited. Criteria 1& 2 would still need to be deployed for projects in other cases.

7. Pure direct heat geothermal projects

Developing criteria for direct heat projects is more difficult given that the established protocols described above and in Annex 2 for estimating counterfactual emissions may lack equivalents. Direct heat projects and emissions are less documented in the literature, and in particular operational emissions. The evidence suggests *lifecycle* GHG emissions for pure direct heat projects in the range of 14-202 gCO_2e/kWh [10]. This compares with around 180 gCO_2e/kWh for combustion of natural gas[12]. Reasons why direct heat project emissions may be more difficult to estimate may include:

- Less necessity to understand the chemical properties of the geothermal fluid for engineering reasons
- Need to factor in indirect emissions from electricity for geothermal heat pumps

Criteria for pure direct heat projects are not included in this document but could be developed at a later stage with better understanding of these issues.

8. Summary

Geothermal energy could potentially play a much greater role in decarbonizing the world's energy supply compared to past experience. However, there is a need to balance efforts to promote it with a recognition that some plants in some locations can have high greenhouse gas emissions.

The criteria seek to filter out those plants that would have higher emissions than likely alternatives, through a combination of:

- Estimating emissions via a simple methodology which aims to minimize workload and cost over what is already routine in project development;
- Allowing for the effect which mitigation technology can have on emissions;
- Using a metric, which will flag up when moderate-to-high emitting geothermal projects would be likely to displace renewable capacity, in order to encourage the lowest-carbon feasible technological option for a given context to be pursued.

Additional criteria are proposed to limit environmental, health, safety and social impacts.

Criterion 5 describes a possible approach to include projects that have successfully registered under the Clean Development Mechanism. However, standard criteria would need to be retained to assess projects in Annex 1 countries.

[12] UK Department for Environment, Food and Rural Affairs conversion factor http://www.ukconversionfactorscarbonsmart.co.uk/

Annexes

1. Overview of estimates of geothermal power station emissions from the literature

The last global overview of carbon emissions from geothermal power stations seems to have been Bertani and Thain (2002) [1], which provided information on 85% of global geothermal capacity. While it is not ideal to refer to a study that is so old, there does not appear to be a more recent, updated comparable study. Table 1 shows the proportion of global geothermal capacity in various emissions brackets according to this study.

Table 1: Overview of the proportions of global geothermal capacity in various emissions brackets according to [1]

Direct emissions (gCO2/kWh)	% global capacity	Comments
0-50	35%	comparable with the best low carbon alternatives
50-99	28%	comparable with, or slightly higher[1] than, less good low carbon alternatives (e.g. nuclear)
100-199	13%	not as good as other low carbon alternatives, high end comparable with direct combustion of natural gas (~180 gCO2/kWh)
200-499	21%	higher emitting than direct combustion of natural gas, upper half comparable with CCGT power station
500+	3%	comparable with higher-emitting fossil fuel power station

*Note: [1] As described in Section 3, direct emissions represent a **lower bound estimate** of total lifecycle emissions. A full lifecycle estimate for direct comparison with other technologies would be higher than the direct emissions shown here.*

These figures indicate that, at least historically, up to around two-thirds of geothermal capacity is comparable to other renewables. But they also indicate that investors should be aware that geothermal power has the potential to be higher emitting than other renewables, or even comparable to fossil fuel power stations.

Table 2 presents further estimates from the literature, for comparison and geographical breakdown.

Table 2: Summary of estimates from the literature of direct CO_2 emissions from geothermal power plants

Country and/or plant	Quantity	Estimates (gCO_2/kWh)	Ref
International	weighted average	122	1
	range	4-740	1
USA	average: binary dry steam flash	 negligible 27 180	3
California[1]	weighted average	98	4
	range	11-370	4
New Zealand	weighted average	80-100	5,6
	range	30-570	5
Iceland	range	26-181	2
Kizildere plant, Turkey	emissions if plant were not used to produce industrial grade CO_2	1300	5

Note: as described in Section 3, direct emissions represent a ***lower bound estimate*** *of total lifecycle emissions. A full lifecycle estimate for direct comparison with other technologies would be higher than the direct emissions shown here. Methane is not included in most studies, but has been estimated at around 15-18 gCO_2e/kWh [5].* [1]*This covers about 83% of US geothermal electricity.*

2. Calculation of Combined Margin (used in Criterion 1) and worked examples

We adopt the approach taken by the UNFCCC and IFC [19,20] in using the **combined margin** emission factor as the baseline carbon intensity of the national electricity system against which the carbon intensity of geothermal facilities should be compared. The combined margin is used by UNFCCC in assessing Clean Development Mechanisms proposals. It is defined as follows:

$$CM = weight_{OM} \times OM + weight_{BM} \times BM$$

where:
CM is the combined margin;
OM is the operating margin, the direct emission factor of existing power plants;
BM is the build margin, a projected direct emission factor of the most likely forthcoming additional capacity; and
$weight_{OM}$, $weight_{BM}$ are weights summing to 1 reflecting the relative importance of these two factors.

We propose the following modifications to the OM and BM:

- In the CDM methodology [20], there are different options for calculating the operating and build margins. The information requirements are quite high, and the formula relatively complicated for some of these. We recognize the importance of precise information in calculating these quantities when monetary payments will be attached to estimated carbon savings, as with the CDM. However, the purpose of the Climate Bonds Standard is to act as a simple screening tool, and it is important that information requirements are kept relatively light. We propose using the simplest option (4) for estimating CO_2 from combustion.
- Non-combustion direct greenhouse gas emissions from renewables are not included in the OM and BM calculations in [19] and [20]; that is CO_2 and methane emissions from decomposition of biomass in hydroelectric reservoirs, as well as geothermal emissions. In order to compare like with like, we propose to include estimates of these in our modified calculation. However, data is lacking on these emissions for many locations, and where this is the case, the methodology suggests reasonable proxies based on the available data.
- The CDM Methodology bases the build margin on a sample of the five most recent power units to have started to supply the grid, as representative of ongoing trends in capacity. In order to make the methodology as transparent and accessible as possible, we use EIA data to derive the average annual increase in generation of different plant types as representative of ongoing trends.

The formulae for the OM, BM and CM are then as follows.

$$OM = share_{FF} \times EF_{FF} + share_H \times EF_H + share_G \times EF_G + share_O \times EF_O$$

where:
EF_{FF} is the emissions factor (in gCO_2/kWh) of fossil fuel plants in the country, taken from the International Energy Administration *CO_2 Emissions from Fuel Combustion* series;
EF_H is the estimated emissions factor of hydroelectric plants in the country, i.e. direct emissions from decomposition in hydroelectric reservoirs, based on the most comprehensive international assessment of these emissions to date [23];

EF_G is the estimated emissions factor of geothermal plants in the country, based on any available relevant literature on these plants; if none is available, the international average of 122 gCO_2/kWh (see Table 2) is used;
EF_O is the emissions factor of all other renewables and nuclear, assumed to be zero;
$share_{FF}$, $share_H$, $share_G$, $share_O$ are the shares of annual electricity generation from each source, calculated from US Energy Information Administration International Energy Statistics.

$$BM = \frac{growth_{FF}}{growth_{TOT}} \times EF_{FF} + \frac{growth_H}{growth_{TOT}} \times EF_H + \frac{growth_G}{growth_{TOT}} \times EF_G + \frac{growth_O}{growth_{TOT}} \times EF_O$$

where:
$growth_{FF}$, $growth_H$, $growth_G$, $growth_O$, $growth_{TOT}$ are the average annual increase of fossil fuel, hydroelectric, geothermal, 'other' and total generation over the most recent five years for which data is available, in TWh.

Finally:
$$CM = 0.5 \times OM + 0.5 \times BM$$

where the weight values for non-intermittent renewable projects recommended in the CDM methodology are used.

Worked examples

Tables 3 and 4 below show some worked examples. Table 3 shows the step-by-step calculation of the combined margin for Indonesia. Table 4 shows **for illustrative purposes** whether facilities would pass Criterion 1 in a variety of scenarios. Five countries are shown with varying levels of geothermal, hydroelectric and fossil fuel capacity, hence varying combined margins. The tables show whether four separate facilities, with direct emissions of 25 gCO_2/kWh (negligible), 75 gCO_2/kWh (low), 180 gCO_2/kWh (moderate) and 400 gCO_2/kWh (high) respectively, would pass Criterion 1. The examples assume that the ambition margin is context-specific and that Criterion 2 is not (for simplicity) applicable.

The scenarios show that low-emitting facilities will be certified under all conceivable circumstances. However, moderate and high-emitting facilities may not be certified under the following circumstances:

- If the country already has high levels of renewables;
- If renewable capacity has recently been increasing much more rapidly than fossil fuel capacity, or fossil fuel capacity has been declining;
- If the ambition margin is set relatively high, based on an assessment of what is typical and what ambitious for a given country and its geology.

Table 3. Illustrative worked example of the calculation of the operating, build and combined margins for Indonesia

Indonesia	Quantity	Source
% electricity generation		
fossil fuels	88.0%	[21]
hydroelectric	6.8%	[21]
geothermal	5.1%	[21]
other	0.1%	[21]
GHG intensity		
Grid, CO_2 from combustion only	761 gCO_2/kWh	[22]
fossil fuels	$\frac{761}{0.88}$ = 865 gCO_2/kWh	Combining information from [21] with [22]
hydroelectric	24 gCO_2/kWh	Derived from average CO_2 and CH_4 fluxes for a low latitude non-Amazonian hydroelectric reservoir presented in [23]; combined with data on capacity and reservoir size of a sample of Indonesian hydroelectric reservoirs in [24]
geothermal	63 gCO_2/kWh	Weighted average from three Indonesian geothermal plants presented in [25]
other	assume direct emissions are zero	
Operating margin	OM = 0.88 × 865 + 0.07 × 24 + 0.05 × 63 = 765 gCO_2e/kWh	Option 4 in [20]
Average annual increase in generation, 2008-2012		
fossil fuels	10.1 TWh/yr	[21]
hydroelectric	0.3 TWh/yr	[21]
geothermal	0.3 TWh/yr	[21]
other	0.03 TWh/yr	[21]
total	10.7 TWh/yr	[21]
Build margin	BM = $\frac{10.1}{10.7}$ × 865 + $\frac{0.3}{10.7}$ × 24 + $\frac{0.3}{10.7}$ × 63 BM = 817 gCO_2/kWh	Similar methodology suggested in [20] adapted to use most accessible publicly-available information
Combined margin	CM = 0.5 × OM + 0.55 × BM = 0.5 × 765 + 0.5 × 817 CM = 791 gCO_2/kWh	Formula in [20]

Table 4. Examples of application of Criterion 1 with respect to illustrative 25 gCO_2/kWh, 75 gCO_2/kWh, 180 gCO_2/kWh and 400 gCO_2/kWh geothermal power plants in different countries with differing illustrative combined margin estimates

<table>
<tr><th rowspan="2">Case</th><th rowspan="2">Country</th><th rowspan="2">Estimated Combined Margin (illustrative)</th><th colspan="4">Does a geothermal facility with these emissions pass Criterion 1?</th></tr>
<tr><th>25 gCO_2/kWh</th><th>75 gCO_2/kWh</th><th>180 gCO_2/kWh</th><th>400 gCO_2/kWh</th></tr>
<tr><td>Carbon-intensive grid</td><td>Indonesia</td><td>791 gCO_2/kWh</td><td rowspan="5">Yes, below combined margin in all cases and also less than100 gCO_2/kWh.</td><td rowspan="4">Yes, below combined margin in all cases and also less than 100 gCO_2/kWh.</td><td>Yes, well below combined margin; ambition margin unlikely to be set high enough to exclude this facility.

Fossil fuel capacity has been very rapidly increasing in Indonesia, therefore the facility represents a significant improvement on the likely alternative.</td><td>Depends on context-specific information and ambition margin. Though high, still represents a significant improvement on the likely alternative, so possible that it may pass.</td></tr>
<tr><td rowspan="2">Carbon-intensive fossil fuel plants, but large share of renewables</td><td>Kenya</td><td>262 gCO_2/kWh</td><td>Depends on context-specific information on what is typical for geothermal in Kenya and resulting ambition margin.</td><td>No, exceeds threshold.

Kenya has a high share of hydroelectric which has recently been increasing, while fossil fuel capacity has not.</td></tr>
<tr><td>Guatemala</td><td>185 gCO_2/kWh</td><td>Probably. Combined margin is low, so ambition margin could be zero, in which case the facility is beneath the threshold.</td><td>No, exceeds threshold.

Fossil fuel capacity only accounts for 32% of generation in Guatemala and has been declining, while hydroelectric has been increasing.</td></tr>
<tr><td>Efficient fossil fuels, but large share of renewables</td><td>New Zealand</td><td>119 gCO_2/kWh</td><td colspan="2">No, exceeds threshold.

Fossil fuel capacity only accounts for 27% of generation in New Zealand and has been declining, while all renewables have been increasing.</td></tr>
<tr><td>No fossil fuels (almost)</td><td>Iceland</td><td>46 gCO_2/kWh</td><td>Yes, below 100 gCO_2/kWh.</td><td colspan="2">No, exceeds threshold.

There is almost no fossil fuel capacity in Iceland compared with which the facility would be an improvement. The combined margin results from estimates of high-latitude hydroelectric reservoir emissions and existing geothermal emissions.</td></tr>
</table>

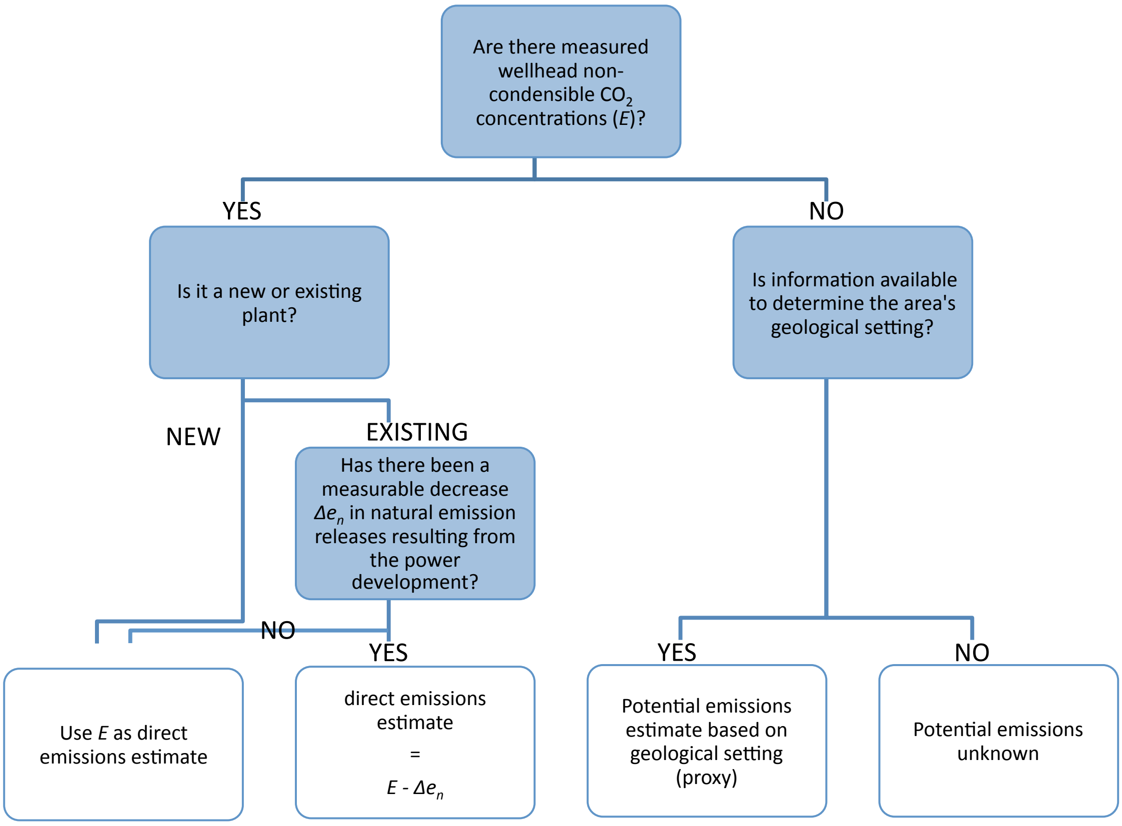
Notes: Combined margin estimates are illustrative, but have been arrived at through the same calculation steps as in Table 3. They should not be taken as the definitive estimates which would apply in these countries. In particular, significant data gaps remain for estimates of hydroelectric and geothermal emissions.

Note that the calculation would result in a very low combined margin in the world's predominant geothermal country, Iceland, where the fossil fuel alternative is negligible. However, facilities which are below the 100 gCO_2/kWh threshold, or which mitigate their emissions as described under Criterion 2, will still be eligible for certification, The proposed criteria therefore still envisage plenty of opportunity for geothermal in countries which already have a low share of fossil fuels.

3. Proposed method for estimating emissions

Figure 2 summarizes the recommended process for estimating direct emissions under Criterion 1.

Figure 2: decision tree for estimating direct emissions



This process acknowledges the following practical considerations in determining direct emissions:

- Wellhead non-condensible gas estimates may not be available, and a proxy measure based on potential emissions determined from geological setting may be the only viable option
- The release of direct CO_2 emissions due to the operation of the power station may result in lower natural releases. This should be taken into account when these can be estimated. This can only be achieved once the power station is in operation. It is proposed that this could be used in the case of retrofit of existing stations, or for re-applications for certification of facilities that were initially rejected.

References

[1] Bertani, R., & Thain, I. (2002, July). Geothermal Power Generating Plant C02 Emissions Survey. IGA News, (49), 1–3.

[2] Armannsson, H., Fridriksson, T., & Bjarni Reyr Kristjansson. (2005). CO2 emissions from geothermal power plants and natural geothermal activity in Iceland. Geothermics, (35), 286–296.

[3] GEA (2013), 'Promoting Geothermal Energy: Air Emissions Comparison and Externality Analysis', report by the US Geothermal Energy Association

[4] Sullivan et al. (2012), 'Geothermal Life-Cycle Assessment - Part 3', report for Argonne National Laboratory

[5] Bayer et al. (2013), 'Review on life cycle environmental effects of geothermal power g eneration', Renewable and Sustainable Energy Reviews 26 (2013) 446–463

[6] NZGA (2009), New Zealand Geothermal Association website: http://www.nzgeothermal.org.nz/emissions.html

[7] Aksoy et al. (2015), 'CO2 Emission from Geothermal Power Plants in Turkey', presented to the Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19-25 April 2015

[8] Goldstein, B. et al. (2011), 'Geothermal Energy' in IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[9] Stefansson, V. (2005). World geothermal assessment. In: Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005, available at: www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/0001.pdf

[10] IPCC, 2011: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[11] Kaplan and Serpen (2010) 'Developing Geothermal Power Plant for Geothermal Fields in Western Turkey', Proceedings World Geothermal Congress 2010, Bali, Indonesia 25-29 April 2010

[12] IFC (2007), 'Environmental, health and safety guidelines for geothermal power generation', International Finance Corporation

[13] Strand and Rosendahl (2012), 'Global emissions effects of CDM projects with relative baselines', Resource and Energy Economics 34 (2012) 533– 548

[14] Jacobson (2009), 'Review of solutions to global warming, air pollution, and energy security', Energy and Environmental Science 2009, 2, 148-173

[15] UK Parliament (2011), 'Carbon Footprint of Electricity Generation', POSTnote 383, available at: http://www.parliament.uk/documents/post/postpn_383-carbon-footprint-electricity-generation.pdf

[16] US Department of Energy (undated), 'What is a Enhanced Geothermal System (EGS)?', https://www1.eere.energy.gov/geothermal/pdfs/egs_factsheet.pdf

[17] Clark C., Sullivan, J., Harto, C., Han, J., Wang M. (2012), 'Lifecycle environmental impacts of geothermal systems' in Proceedings, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 30 - February 1, 2012

[18] Karlsdottir, M.R., Palsson, O.P. and Palsson, H. (2010), 'Factors for Primary Energy Efficiency and CO2 Emission of Geothermal Power Production', Proceedings World Geothermal Congress 2010, Bali, Indonesia, 25-29 April 2010

[19] IFC (2013), 'IFC Greenhouse Gas Reduction Accounting Guidance For Climate-Related Projects', IFC Climate Business Department, International Finance Corporation

[20] UNFCCC (2015), 'Tool to calculate the emission factor for an electricity system: Version 05.0', United National Framework Convention on Climate Change,

https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v5.0.pdf accessed January 2016
[21] US Energy Information Administration International Energy Statistics: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm, accessed January 2016
[22] IEA (2015), 'CO_2 Emissions from Fossil Fuel Combustion, 2015 Edition', International Energy Agency
[23] Barros et al. (2011), 'Carbon emission from hydroelectric reservoirs linked to reservoir age and latitude', *Nature Geoscience* 4:593-596, September 2011
[24] GEO (undated), Global Energy Observatory power plant database, http://globalenergyobservatory.org/, accessed January 2016
[25] Yuniarto et al. (2015), 'Geothermal Power Plant Emissions in Indonesia', Proceedings World Geothermal Congress 2015, Melbourne, Australia, 19-25 April 2015