CO_2 emission from Geothermal Plants

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Abstract

Geothermal energy is considered to be a benign energy source as regards environmental impact. One of its impacts is the release of the greenhouse gas, CO_2, to the atmosphere. In a recent survey by the IGA it was shown that in comparison with the burning of fossil fuels there is a considerable advantage to using geothermal energy. Mitigating circumstances for geothermal power plants include the possibility of cascading uses such as industrial production, space heating, greenhouse culture etc. that can be run parallel with the power production and reduce the gas emission per energy unit. The CO_2 emitted from geothermal plants is already part of the CO_2 cycle, no new CO_2 is being produced as is the case in fossil fuel plants. Furthermore this CO_2 is usually removed from the cycle where there is already vigorous degassing from geothermal and volcanic areas and it is possible that the addition to the atmosphere is negligible. Studies already carried out to this effect have in fact suggested that this is the case. Thus it is suggested that background emission from geothermal areas be estimated before the total added from a power plant is estimated. On the basis of the results of such studies Italy has decided not to include geothermal CO_2 emission as part of their anthropogenic greenhouse gas emission reported in connection with international agreements. Recently Iceland has decided to take the same course of action.

Keywords: *Geothermal, environment, cascade, greenhouse gas, anthropogenic, inventory.*

1 Introduction

Environmentally geothermal energy is generally considered a benign energy source. One of the impacts that have been considered is release of the greenhouse gas CO_2 to the environment even though this has been shown to be much less than from fossil fuel power plants (Fig. 1). Further mitigating circumstances are that geothermal power plants are in some cases parts of multiple purpose plants constituting industrial production, space heating, greenhouse industry etc. thus reducing emission per unit production. Furthermore it has been proposed that the CO_2 emission from power plants is just emission that has been transferred from one location to another in the CO_2 cycle and that natural degassing from volcanic and geothermal areas and the emission from a power plant is only an insignificant part of the total emission. In this paper these ideas will be examined with reference to published results from a variety of locations.

2 CO_2 Emission from Geothermal and Volcanic Areas

2.1 International Geothermal Association Survey

The International Geothermal Association (2002) carried out a survey of CO_2 emission from geothermal power plants with the aim of showing the environmental advantage of geothermal energy in mitigating global change. The results were summarised with reference to emission expressed as g/kWh in relation to production in MW_e (Table 1). The total range for all plants was 4-740 g/kWh with weighted average 122 g/kWh.

Figure 1. CO_2 emission from various types of power plants (After Hunt 2000)

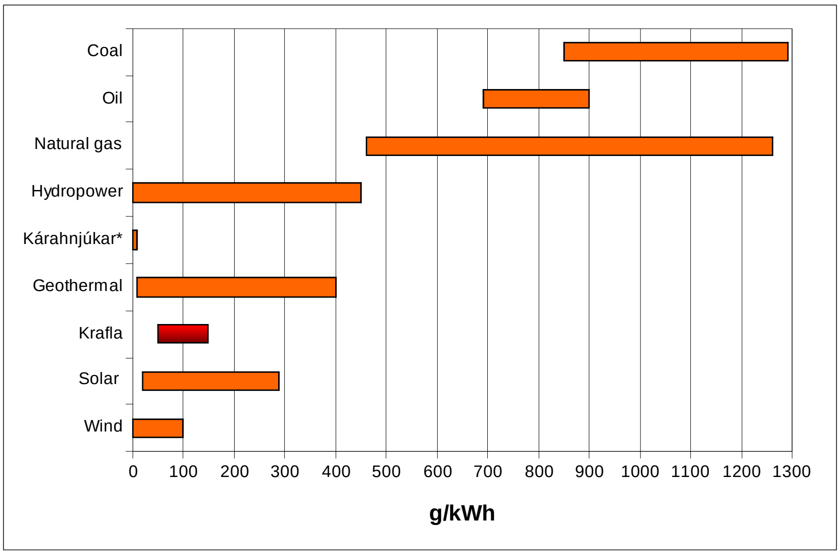

Table 1. CO_2 emission and total running capacity of power plants divided into 9 emission categories (International Geothermal Association (2002)

Emission category g/kWh	Running capacity MW_e	Average g/kWh
>500	197	603
400-499	81	419
300-399	207	330
250-299	782	283
200-249	346	216
150-199	176	159
100-149	658	121
50-99	1867	71
<50	2334	24

In the report it is suggested that the natural emission rate pre development be subtracted from that released from the geothermal operation, citing Larderello as an example of a field where a decrease in natural release of CO_2 has been recorded and shown to be due to development.

2.2 Origin of CO_2 in Geothermal Areas

Geothermal systems are often located in volcanic areas or other areas of high CO_2 flux of magmatic origin but CO_2 may also be derived from depth where it is mainly produced by metamorphism of marine carbonate rocks. There is a large flux through soil but groundwater where present is also often rich in dissolved CO_2. Processes of natural generation are independent of geothermal production. The output is very variable but usually quite substantial. Estimated output from several volcanic and geothermal areas is shown in Table 2. There seems to be no difference between producing and non-producing areas.

The most thorough investigation of the proportion of CO_2 emitted through various conduits was done by Favara et al. (2001), but estimates of fractions emitted through groundwater on the one hand but soil and fumaroles on the other have been made at Mammoth Mountain (Sorey et al. 1998, Evans et al. 2002, Gerlach et al. 2001) and

Furnas (Cruz et al. 1999). The results for these areas are listed in Table 3. Calculations for some of the areas listed in Table 2 and a few others give a mean CO_2 flux in g $m^{-2}day^{-1}$ as 200.

Table 2 CO_2 output from some volcanic and geothermal areas

Area	Megaton/year	Reference
Pantellera Island, Italy	0.39	Favara et al. (2001)
Vulcano, Italy	0.13	Baubron et al. (1991)
Solfatara, Italy	0.048	Chiodini et al. (1998)
Ustica Island, Italy	0.26	Etiope et al. (1999)
Mid-Ocean Volcanic System	30-65	Gerlach (1991)
Popocatepetl, Mexico	14.5-36.5	Delgado et al. (1998)
Mammoth Mountain, USA	0.055-0.2	Sorey et al. (1998), Evans et al. (2002), Gerlach et al. (2001)
White Island, New Zealand	0.95	Wardell and Kyle (1998)
Mt. Erebus, Antarctica	0.66	Wardell and Kyle (1998)
Geothermal systems, New Zealand	0.002-0.048	Seaward and Kerrick (1996)
Furnas, Azores, Portugal	0.01	Cruz et al. (1999)
Total	1000	Delgado et al. (1998)

Table 3. Relative CO2 emission through different conduits from three areas (Favara et al. 2001, Sorey et al. 1998, Evans et al. 2002, Gerlach et al. 2001)

	Pantelleria Island	Furnas Volcano	Mammoth Mountain
Soil %	81	49 [1)]	63-90 [1)]
Focussed degassing %	7		
Fumarole %	0.0004		
Bubbles %	3		
Groundwater %	9	51	10-37

[1)] Total flow directly to atmosphere

2.3 CO_2 Emission from Geothermal Areas in Iceland

The CO_2 emission from geothermal plants in Iceland has been recorded since the early 1980s when it was 48000 tons per year up to now. Last year it was 155000 tons. In the early years power production was extremely low but the relatively high CO_2 emission was due to a gas pulse in Krafla associated with the Krafla fires (Ármannsson et al. 1982). Two attempts at estimating natural flow resulted in 148000 tons/year assuming all flow was through fumaroles (Ármannsson 1991) and 2.1 million tons/year based on estimates of heat flow (Arnórsson 1991). The latter would include flow through soil and water. At the same time Ármannsson (1991) estimated the proportion of CO_2 emitted from producing plants and that emitted naturally, again assuming that all but a negligible portion was emitted through fumaroles and found that most CO_2 is emitted naturally while the reverse was the case for H_2S (Fig. 2).

In 1984 a well in Svartsengi started producing dry steam. This steam contained orders of magnitude more CO_2 than previous steam from that and other wet wells. A steam cap had formed and in 1993 another well specifically drilled to produce from the steam cap was added. Finally two more wells producing from the steam cap were added in 1999 and 2001 respectively. The influence of these wells can be seen in Fig. 3 showing CO_2 emission from Svartsengi (Ólafsson 2003). Other changes are due to variable production from the area.

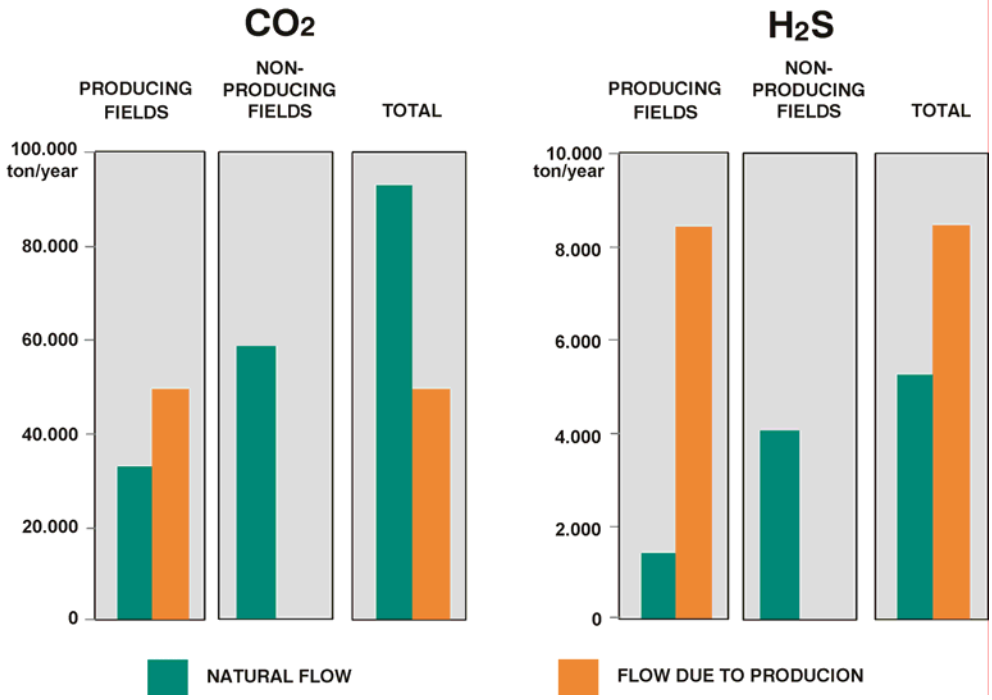

Figure 2 CO_2 and H_2S emission from producing and non-producing fields

The concentration of CO_2 in the steam cap has decreased gradually and is now about half what it was in 1984. Natural fumaroles have been formed and release to the atmosphere has apparently increased. If on the other hand all the brine boils to steam a drastic reduction in natural flow to the surface can be expected corresponding to production. While the brine is boiling down there will be an initial increase, the magnitude of which will gradually diminish.

Of the three main producing areas in Iceland two, Nesjavellir and Svartsengi, are space heating plants as well as power plants whereas the third one; Krafla just produces electricity. In Table 4 there is comparison between CO_2 and S (expressed as SO_2) emission per kWh for the power production and if the space heating is accounted for. Krafla and Svartsengi are a little above the world average for power production but a very small amount of CO_2 is emitted from Nesjavellir. The figure for Svartsengi is much improved when space heating is accounted for.

3 Inventories

Iceland is party to international conventions requiring inventeries of anthropogenic airborne material. The most important ones are:

- FCC: Framework Convention on Climatic Change
- CLRTAP: Convention on Long-Range Transboundary Air Pollution

The first is a UN convention and a panel has issued regulations on how to calculate and present the contents of the inventories. The second which is a European convention has now adopted a comparable set of rules. The Kyoto protocol according to which nations undertake to limit their emissions has not been signed by Iceland. Iceland has signed several protocols associated with CLRTAP but none of those have taken effect yet. Iceland has published inventories since 1990 and the geothermal component of CO_2 emission has increased from about 3.5% to about 5% during this time (Hallsdóttir 2001). Taking into account the large amount of natural emission and the fact that the CO_2 emission can be regarded as being

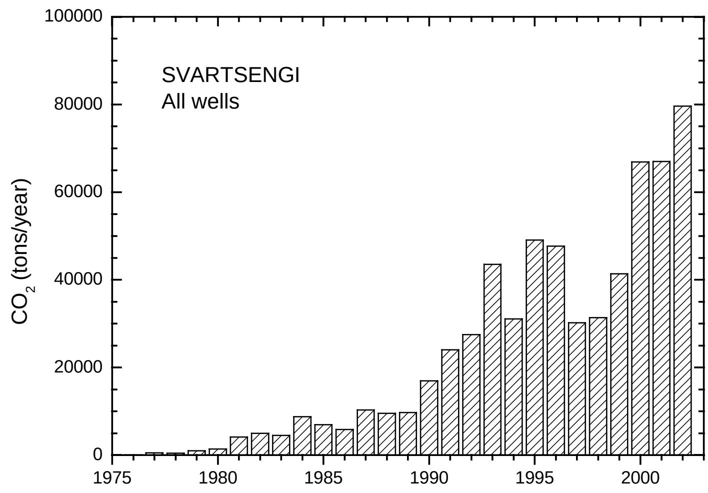

Figure 3 CO_2 emissions from Svartsengi 1976-2002

Table 4 CO_2 and S (expressed as SO_2) emission per kWh from Iceland's major geothermal power plants

Plant	Power production only		Total production	
	CO_2 g/kWh	S as SO_2 g/kWh	CO_2 g/kWh	S as SO_2 g/kWh
Krafla	152	23	152	23
Svartsengi	181	5	74	2
Nesjavellir	26	21	10	8

transferred in its location rather than being an addition to the CO_2 cycle Italy has decided not to consider CO_2 emission from geothermal plants as anthropogenic and does not include it in their inventory (Ruggeri, pers. comm.). Last year Iceland followed suit temporarily (Hallsdóttir, pers. comm.).

No studies have been carried out on CO_2 emission through soil in Iceland. If it is comparable to other parts of the world the Krafla area, which is intensely volcanic and has recently had eruptions with increased gas flow to the surface (Ármannsson et al. 1982), should emit at least the average 200g $m^{-2}day^{-1}$. The geothermal area has been estimated to be about 50 km^2 which means that natural emission could be > 1 million tons CO_2/year if the amount of gas is above average. In 2001 the total CO_2 emission from the power plant was 73000 tons, which is quite small in comparison. The flow through soil might be smaller in other areas but it seems a worthy undertaking to set up a network to estimate it.

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