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Environmental impact of electricity from selected geothermal power plants in Italy

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ABSTRACT

Geothermal plants supply a significant contribution to the electricity balance from renewable sources in Tuscany. However, this electricity conversion is not exempt from environmental drawbacks.

In our study, the electricity production phases of four geothermal electricity plants are analyzed by means of a careful airborne emissions assessment carried out over the entire LCA of the plants. The impact categories considered are global warming (GWP), acidification (ACP) and human toxicology (HTP). The functional unit used is 1 MWh of electric energy produced from geothermal power plants in Mount Amiata area.

For the environmental impact categories considered, the impact potentials are evaluated for each of the four geothermal power plants as follows: 380–1045 kg CO_2 eq/MWh for GWP, 0.1–44.8 kg SO_2 eq/MWh for ACP and 1.1–31.6 kg, 1.4-DB eq/MWh for HTP. The main contributions to the impact are associated with the high content of NH_3, H_2S, CH_4 and CO_2 gases present in the effluents of each plant. The impact change in relation to the geothermal site has a strong correlation to the basin of fluid withdrawal and is related to the technologies used for pollutants depletion. In some cases the impact is higher than that found for production of electricity from fossil fuels (for example, a coal plant of comparable power).

1. Introduction

The production of geothermal energy in Italy began (by the beginning of the twentieth century) with the exploitation of the geothermal field of Larderello, Italy (Barbier, 2002). Currently in Italy 882.5 MWe (772 MWe net power) geothermal plants are installed (Terna, 2010) with a production of 1.8% of the electricity generated at national level. In Tuscany, geothermal power accounts for about 25% of total annual electricity production (Cappetti et al., 2010). In 2011, the production of geothermal power plants located in the Province of Siena (with a total capacity of 180 MW) was 1325 GWh which represented more than 100% of the 1316 GWh, the total annual consumption of the Siena province.

The objectives of geothermal development in Italy, and, in particular, in the Tuscany region, are related to the development of thermal use and to the increase of the production of electricity from renewable sources, in order to lessen dependence on fossil fuels and to reduce CO_2 emissions. These objectives are in agreement with international Protocols such as the Kyoto Protocol and the EU Directive 2009/28/EC on renewable energy sources. Electricity is one of the vectors that is more advantageous and versatile due to its easy transportation and the fact that it has an impact only where is produced and not where it is used.

Therefore, as a precondition for the intensification of exploitation, it is important to understand the environmental characteristics of geothermal power generation and to find solutions to minimize the impact. The geothermal resource is site specific (like all mineral resources), since its location is determined by geo mineralogical phenomena that have allowed the formation, accumulation and storage. Mount Amiata is a dormant volcano, located in the provinces of Siena and Grosseto in the southern part of the Tuscany region. The exploitation of geothermal resources there began in 1960. In the 1990's, a high enthalpy geothermal well was discovered at a depth of about 2.5–4 km with temperatures of

List of abbreviations: GWP, Global Warming Potential; ACP, Acidification Potential; HTP, Human Toxicity Potential; BG3, Bagnore 3 geothermal power plant; PC (3, 4 and 5), Piancastagnaio geothermal power plants.

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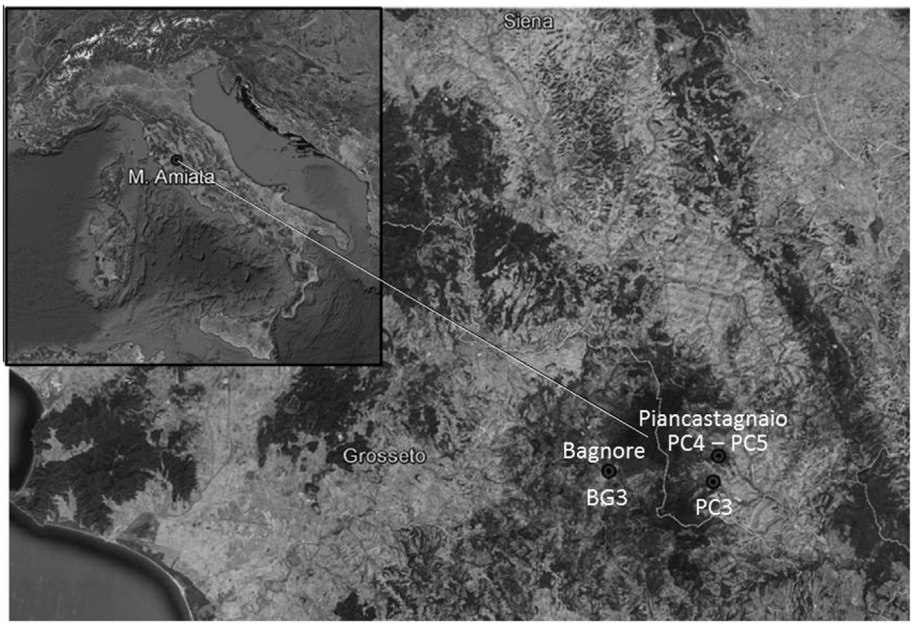

Fig. 1. Map of Monte Amiata area including all locality names and power plant locations mentioned in the study.

300–350 °C and pressures around 20 MPa which had high potential for electricity production (Bertani, 2012).

Many studies in literature deal with the environmental impact associated with the production of geothermal electricity. Hagedoorn (2006) provides a general overview of these. Other studies have focused on the sustainable production of geothermal resources and suggest the use of models for the management of geothermal fields (Axelsson and Stefansson (2003)). Bertani and Thain (2002) and Bloomfield et al. (2003) argued that the natural discharge of CO_2 from geothermal fields is probably higher than that of CO_2 emissions from energy use in the same field. Furthermore Bertani and Thain (2002) concluded that CO_2 emissions from geothermal plants are balanced by a reduction in natural release of CO_2 from geothermal fields. Following this line of thought, the European community does not include Greenhouse gas emissions produced from geothermal power plants in the burden shares allocated to countries. Consequently, in Italy and the rest of Europe, greenhouse gas inventories do not take into account CO_2 emissions from geothermal plants.

The life cycle inventories of electricity production in different networks have been carefully reviewed by Itten utilizing for geothermal (and tidal) electricity production the model and data set for wind power (Itten et al., 2012). More recently a comprehensive review on life cycle environmental effects of geothermal power generation has been published by Bayer et al. (2013) concluding that it is crucial the influence of site-specific characteristics.

Armannsson, referring to Iceland where natural phenomena are more visible than in Italy, doubts that CO_2 emissions from electricity plants are negligible (Ármannsson et al., 2005).

Frondini et al. (2009) argue that it is likely that natural emissions in Mount Amiata area due to volcanic degassing are much lower than those due to the exploitation of geothermal fluids at a considerable depth (as the wells feeding the plants considered in this study). In the past, most studies have focused mainly on liquid emissions (where the greatest progress has been made) and which are the most malodorous and for which the need for urgent removal was considered (Bacci, 1998). At the end of twentieth century the mercury emission rates ranged from 3 to 4 g/MWh of electric energy production in the Amiata area. These emissions were coupled with a release of 7–8 kg/MWh of hydrogen sulphide (Bacci et al., 2000).

In our study, we developed an impact potential analysis, based primarily on non-condensable gases emitted from geothermal power plants in the area.

Table 1
The description of the four geothermal power plants.

Description of the study site	Bagnore 3	Piancastagnaio 3	Piancastagnaio 4	Piancastagnaio 5
Geographic coordinates WGS84	42.842/11.558	42.833/11.700	42.857/11.705	42.856/11.702
Province	Grosseto	Siena	Siena	Siena
Acronym	BG3	PC3	PC4	PC5
Installed capacity, MWe	20	20	20	20
Starting date	17/12/1998	04/05/1990	28/11/1991	02/02/1996
Abatement technologies	AMIS (Abatement of mercury and hydrogen sulphide)	AMIS	None (AMIS was installed in late 2008)	AMIS
Type of unit	Single Flash	Steam with entrained water separated at wellhead		
Well Depth, km	From 2 to 4			
Temperature, °C	Between 300 and 350			
Pressure, MPa	Around 20			
Annual Energy Produced 2008, GWh/y	169.7	160.4	139.1	145.3