Geothermics 65 (2017) 1–9

Contents lists available at ScienceDirect

Geothermics

journal homepage: www.elsevier.com/locate/geothermics

Environmental impact assessment of a ground source heat pump system in Greece

Christopher J. Koroneos, Evanthia A. Nanaki *

University of Western Macedonia, Department of Mechanical Engineering, Bakola and Sialvera, 50 100 Kozani, Greece

ARTICLE INFO

Article history:
Received 7 May 2015
Received in revised form
30 December 2015
Accepted 15 August 2016

Keywords:
Ground source heat pump
Life Cycle Assessment
Geothermal systems

ABSTRACT

The technical and environmental performance of a ground source heat pump system (GSHP) is examined using the method of Life Cycle Assessment (LCA). The present LCA study quantifies the environmental impacts of the installation of a ground heat exchanger based system of the Town Hall of Pylaia in Thessaloniki, Greece. The study examines the manufacturing, transportation as well as the operation stages of the GSHP system and records energy consumption as well as air emissions to the environment. The system boundary includes the production of raw materials such as copper, plastic, steel, aluminium, rubber, the transportation of heat pumps and pipes, drilling, as well as the operation of the GSHP system, and finally the assembly process. The functional unit chosen is 1 kW of installed power. The environmental impacts categories considered in the study are these of greenhouse effect, ozone depletion, acidification, eutrophication, carcinogenesis, winter smog, heavy metals. Analysis of the system indicates that 73% and 14.54% of the assessment are attributed to the categories of acidification and greenhouse effect respectively.

1. Introduction

Shallow geothermal resources (<400 m depth) play a significant role in the production of heating or cooling in domestic applications or in blocks of buildings. Geothermal energy forms include: (a) hot dry rock, which can be exploited for the production of steam (b) high enthalpy geothermal fields, which are mainly exploited for power generation, (c) low enthalpy geothermal fields, which are mainly exploited for heating of buildings, greenhouses and soil and thermal baths, and (d) shallow water bearing horizons and soil exploited for heating and cooling with geothermal heat pumps.

Geothermal energy can be used for heating or cooling either with direct exploitation of groundwater of the substratum (low and medium energy application) or with the use of geothermal pumps (low energy application). Geothermal or ground source heat pumps systems (GSHPs) are the most frequent applications of shallow geothermal energy use and hold the promise of meeting heating and cooling loads much more efficiently than conventional technologies, promising to supply the future societies' energy needs (Turner, 1999) In addition, they are beneficial to low carbon emissions strategic plans both at a regional (e.g. (Yu Xing, 2011; Zhu et al., 2010)) or national level (e.g. (Heiskanen et al., 2011; Hughes and Chaudhry, 2011; Schimschar et al., 2011; US DoE, 2004)). Accordingly, their spread is fostered by grant programs and government incentives (e.g. (Blum et al., 2011; Boait et al., 2011; Caird and Roy, 2010; Curtis et al., 2005; Seyboth et al., 2008)), and special electricity heat pump tariffs. It is worth mentioned that even without extra subsidy funds they present economic and environmental advantages (Blum et al., 2010; Blumsack et al., 2009; Esen et al., 2006; Rafferty, 1995).

During the past years the utilization of geothermal heat pumps for the exploitation of geothermal energy for heating and cooling has increased and the predictions are that this growth will worldwide continue in the next decades (Fridleifsson et al., 2008; Demirbas, 2008; Lund et al., 2011, 2004). Geothermal heat pumps have had an impressive energy use growth, 17.9% compounded annually since 1995 and 7.7% compounded annually since 2010, almost of which occurred in the United States, Europe and China (Lund and Boyd, 2015). The present worldwide installed capacity is estimated at almost 50,000 MWt (thermal) and the annual energy use is about 325,000 TJ (Lund and Boyd, 2015). The size of individual units, range from 5.5 kW for residential buildings, to large units of over 150 kW for commercial installations. In western and central European countries, the direct utilization of geothermal energy to supply heat through district heating to a larger number

* Corresponding author.
E-mail addresses: koroneos@aix.meng.auth.gr (C.J. Koroneos), evananaki@gmail.com (E.A. Nanaki).

http://dx.doi.org/10.1016/j.geothermics.2016.08.005
0375-6505/

of customers is so far limited to regions with specific geological settings.

The main types of direct applications of geothermal energy are space heating 70% (there of 55% using heat pumps), bathing and swimming 15%, horticulture (greenhouses and soil heating) 4.5%, industry 2%, and aquaculture (mainly fish farming) 4% (Lund and Boyd, 2015). The most noticeable recent growth has occurred in China where the areas of space that have been used to heat in 2014 came up to 330 million m^2. At the same time, in the United States, as of 2015, more than 1.4 million units have been installed (Lund and Boyd, 2015). It is also noted that geothermal energy is less dependent on weather than renewable energies such as solar, wind and hydro (Fridleifsson, 2001) and is ideal for providing a base load energy supply. In Iceland geothermal plants run about 8000 h a year giving them a capacity factor of 91%. Geothermal research in Greece has revealed high geothermal potential both of high and low enthalpy in several areas of the country. Greece's existing geothermal potential is very high due to the geological favourable conditions revealing high enthalpy geothermal resources in the islands of the Aegean volcanic arc Milos, Nisyros and Santorini. Low enthalpy fields indicating deeper medium enthalpy geothermal resources are located in the islands of Miocene volcanism Chios, Lesvos and Samothraki (Mendrinos et al., 2008). During the past decade geothermal research and applications were mainly confined to low enthalpy fields (Fytikas et al., 2000).

A GSHP system consists of two parts: the heat source, in most cases a borehole heat exchanger (BHE), and the heat pump. While the heat exchanger makes the energy stored beneath the surface accessible, the heat pump is needed to enable heating, as temperatures in the shallow depths (<400 m) are most often too low for direct use. Heat exchanges with the ground are accomplished by circulating a heat carrier fluid (closed systems) or, if feasible, directly with groundwater (open systems). The heat pump increases or decreases, the incoming temperature from the ground or groundwater to a level suitable for the in-house heating or cooling systems. Thus, auxiliary energy, typically in the form of electricity, is still needed for the operation of the heat pump. There are also other possibilities to provide additional energy needed (e.g. via natural gas). In this study, electricity driven compression heat pumps are taken into consideration (Omer, 2008; Tholen and Walker-Hertkorn, 2008).

Several studies have been carried out, during the past years, regarding the environmental threats or benefits of GSHP systems. These include inter alias the studies of Saner et al. (2010) as well as Bayer et al. (2011) who presented an overview on the last decade of GSHPs in Europe. Lo Russo et al. (2009) calculated significant potential savings in energy use and CO_2 emissions from the use of low-enthalpy geothermal technologies for space heating and air conditioning in Italy, Blum et al. (2010) assessed the total CO_2 savings of GSHP systems in a state of South Germany, Akella and Saini (2009) assessed the social, economic and environmental impacts related to renewable energy systems in India as well as Yasukawa et al. (2010) investigated the long-term prospects of the use of geothermal energy and their environmental effects in Japan; whereas Jenkins et al. (2009) investigated the potential CO_2 savings of closed horizontal-loop GSHP systems in the UK. On the other hand Rybach (2008) emphasizes that the major potential of GSHPs is the avoidance of additional GHG emissions rather than reduction. Finally, Bristow and Kennedy (2010) indicate that alternative heating technologies in Canada, such as GSHPs are beneficial not only with respect to energy efficiency and GHG emission savings, but also with life cycle costs.

Despite the fact that geothermal energy is considered as one clean energy source available, important interactions with the environment are taking place over the whole lifecycle of a GSHP system (materials, manufacturing, transportation, utilization and final disposal). These interactions may result to depletion of natural sources, greenhouse effect, acidification, eutrophication etc. A technique that can be used in order to assess the environmental impacts of a GSHP system over its whole lifecycle is Life Cycle Assessment (LCA). In this study emphasis is given to the environmental impact associated with the production and utilization of geothermal systems and in particular to the atmospheric pollution of a ground source heating system during its life span. So far, to our knowledge no LCA study has been carried out in Greece on shallow geothermal systems. As a representative study case, the vertical ground heat exchanger of parallel connection coupled to a heat pump system for air conditioning and heating in a public building of northern Greece, with a heating and cooling capacity of 321.7 kW and 288.9 kW respectively is considered.

The objective of this study is to investigate the environmental benefits and threads of a GSHP system in Greece, during its whole lifecycle. Special focus is set to the environmental performance of the GSHP design. Given that during the past years, the world transition to a low-carbon economy is an issue of great importance, it is noted that the LCA methodology can help energy policy decision makers to focus uniquely on reducing carbon emissions to the recommended levels by outlining the most carbon-effective approach to climate change mitigation.

2. Life cycle analysis methodology

Life Cycle Assessment has been chosen as the methodology to qualitatively evaluate the environmental loads of the studied GSHP system. Analysis of a system under LCA encompasses the extraction of raw materials and energy resources, the conversion of these resources into the desired product, the utilization of the product by the consumer, and finally the disposal, reuse or recycle of the product after its service life. The technical guidelines for the LCA methodology have been standardized by the International Organization for Standardization (ISO) (ISO, 1997, 2006) and include the following stages:

- Goal definition and scoping, so as to define the product and purpose of the study
- Inventory analysis in which data of the unit processes of the product system are collected, analyzed and finally related to one quantitative output of the same system, the so called functional unit
- Impact assessment, in order to evaluate the significance of the environmental impacts contained in a life cycle inventory and to determine the relative importance of each of these inventory items
- Interpretation, so as to evaluate results and to compare them with the defined goals

In this study, modelling was performed using the LCA software SimaPro 7.1.8 (PReí, 2008) which depends on the incorporated life cycle inventory database of Eco- Indicator 95 (Eco-indicator) covering a variety of manufacturing procedures and impacts. The goal of this study is to assess the life cycle of a low-enthalpy, shallow and vertical GSHP system. The life cycle includes:

- Production of raw materials. It includes the excavation of raw material from the ground, such as the production of steel, copper and aluminium. This stage includes the transportation of raw materials from the excavation point up to the point of their treatment.
- Construction. It is separated in two individual stages: manufacturing of materials and manufacturing of product.