Life Cycle Assessment and Comparison of Various Ground Source Heat Pump Systems and Coefficient of Performance Calculations Based on a Wisconsin Case Study

***Ayse Ozdogan Dolcek*[1]; *Saurabh Ghanekar*[2]; *James M. Tinjum*[3], *PhD, PE, M.ASCE*;**
[1]Ph.D. Candidate, Geological Engineering Program, University of Wisconsin-Madison, Madison, WI, U.S.A., email: aozdogan@wisc.edu

[2]MS Student, Geological Engineering Program, University of Wisconsin-Madison, Madison, WI, U.S.A., email: ghanekar@wisc.edu

[3]Associate Professor, Department of Engineering Professional Development, University of Wisconsin-Madison, Madison, WI, U.S.A., email: jmtinjum@wisc.edu

Within the heating, ventilation, and air conditioning (HVAC) sectors, ground source heat pumps (GSHPs) offer a potentially economical, low-carbon solution to the impending global energy problem. This study investigates the performance of a conventional vertical GSHP configuration with three boreholes (VERT), a conventional horizontal GSHP (HORZ), an unconventional deep (300 m) insulated single hole GSHP (DISH) system, and a conventional split natural gas air conditioning unit (NGAC). This study also compares their potential for reduced greenhouse gas (GHG) emissions in Wisconsin, USA, using a comprehensive "cradle-to-grave" life cycle analysis (LCA), which is implemented using SimaPro. The stages and main inputs for LCA are shown in Fig. 1. The DISH system is designed as a base scenario to which all other GSHP scenarios are compared. Assuming that the current Wisconsin electrical grid has 5.5% renewables, heating and cooling loads of a 186 m^2 residence, a coefficient of performance (COP) of 4, and a 25-year lifetime, an average of 272 metric ton CO_2 equivalent emissions is calculated for DISH. Top contributors are heat-exchanger operation (93.3%), borehole drilling (2.4%), and circulation pump operation (1.5%). This amounts to GHG savings of 10% and 19% over vertical and horizontal GSHPs, respectively, and 27% over natural gas systems (Fig. 2). Sensitivity analyses determine that a grid with renewables penetration of 50% could save 68% GHG emissions over natural gas (Fig. 3). As the use of fossil fuel decreases and the grid becomes cleaner, GSHP systems become even more beneficial from the perspective of lifetime GHG emissions. A COP of 5 could further reduce GHG emissions by 38%, as seen in Fig. 4, indicating that the COP is a significant factor of GSHP environmental impacts. Performance and assessment of the VERT system is validated based on measured, operational GSHP data from an instrumented Wisconsin case study.

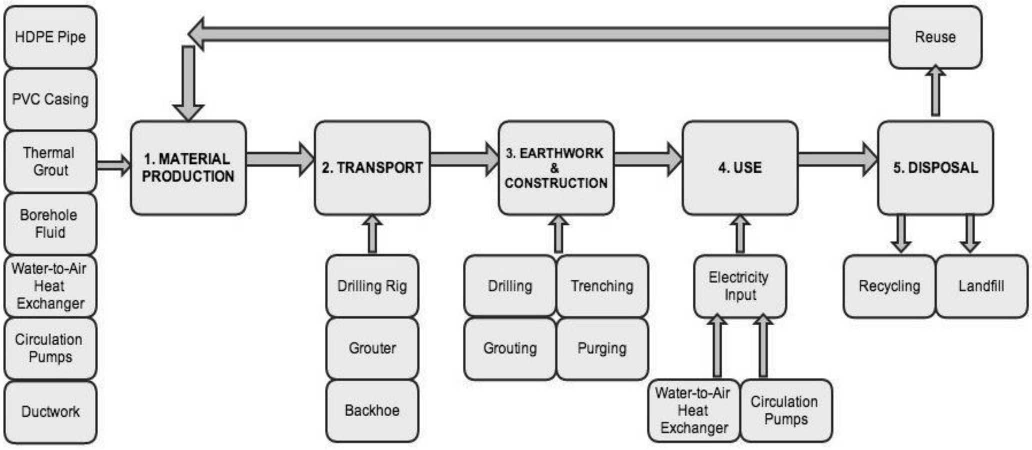

Figure 1: Life-cycle stages of a GSHP system from material inputs to disposal and main flows of each unit process.

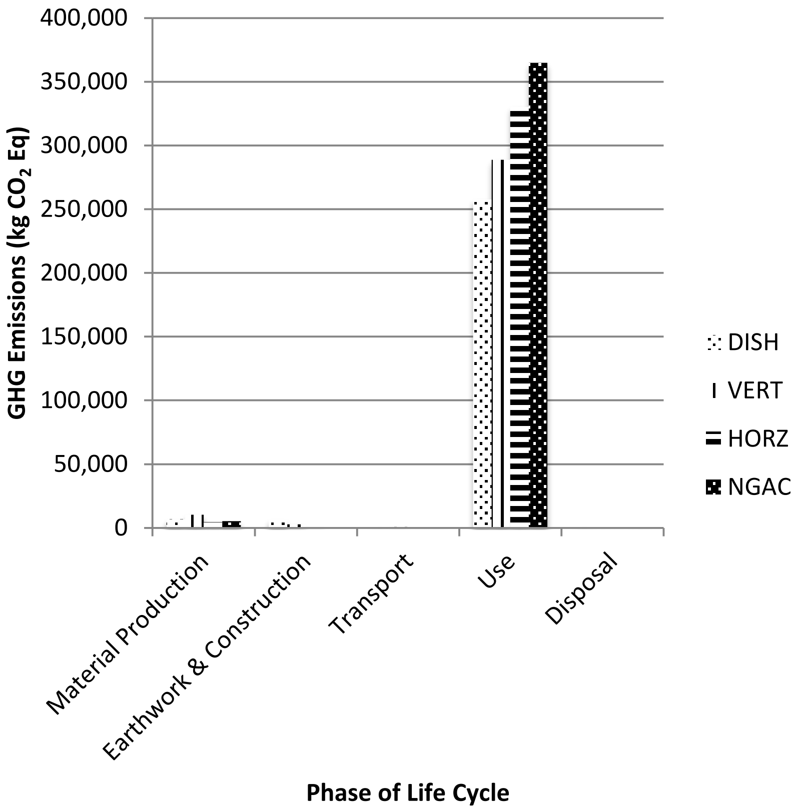

Figure 2: Comparison of greenhouse gas emissions during each phase of a 25-year life cycle for VERT, HORZ, DISH, and NGAC scenarios.

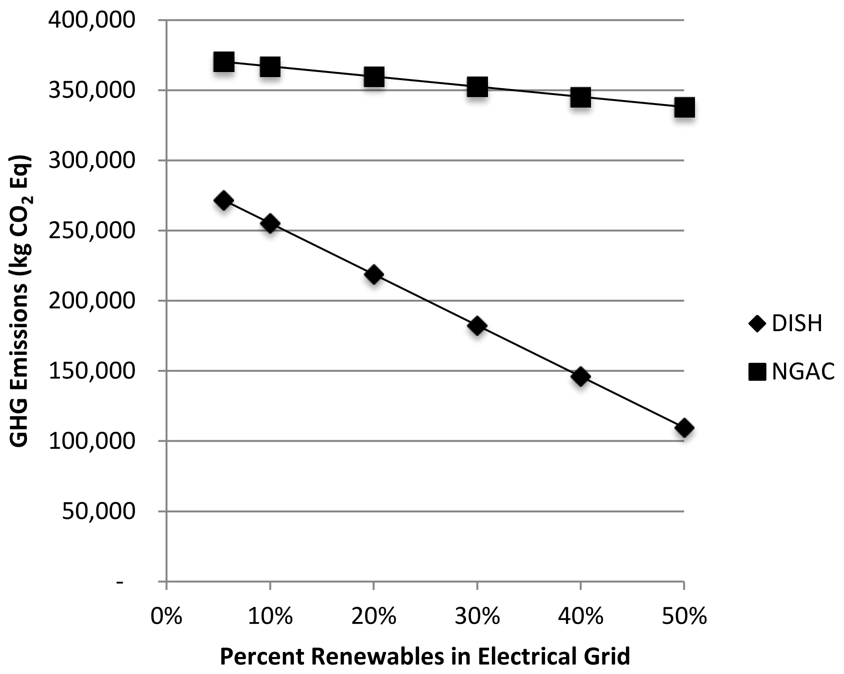

Figure 3: Sensitivity analysis of GHG emissions from DISH system for hypothetical grids in which energy generated from coal is replaced with energy generated from wind.

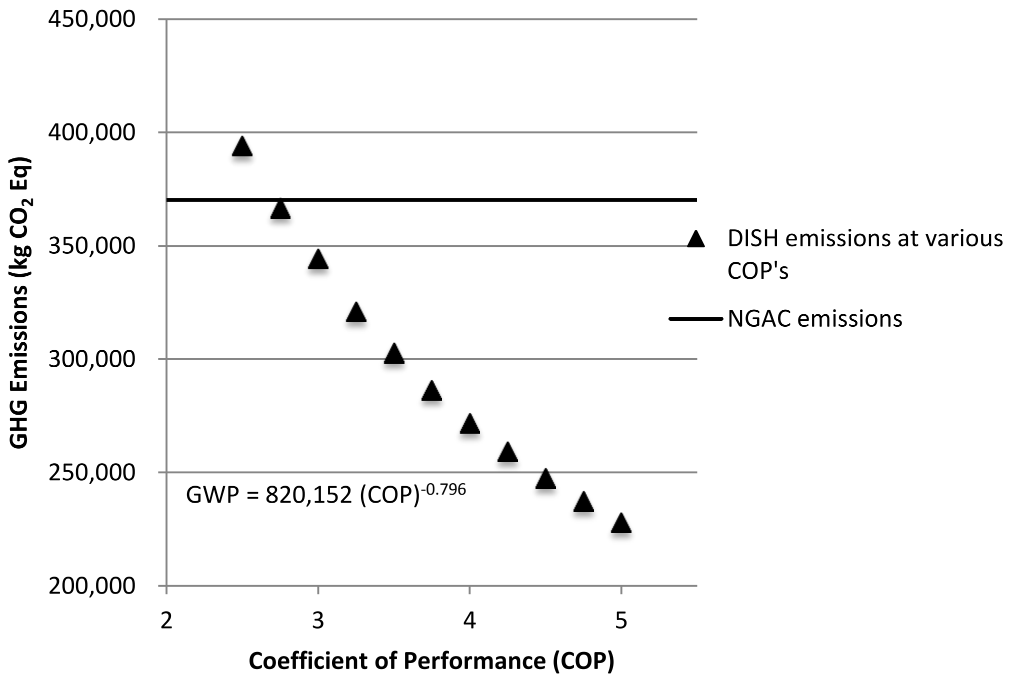

Figure 4: Sensitivity analysis of GHG emissions from the DISH system for various coefficients of performance (COP) values between 2.5 and 5 plotted against the emissions due to a NGAC system.