International Congress on Environmental Modelling and Software

9th International Congress on Environmental Modelling and Software - Ft. Collins, Colorado, USA - June 2018

Jun 26th, 10:40 AM - 12:00 PM

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iEMSs International Congress on Environmental Modelling and Software

9th International Congress on Environmental Modelling and Software
Fort Collins, Colorado, USA, Mazdak Arabi, Olaf David, Jack Carlson, Daniel P. Ames (Eds.)
https://scholarsarchive.byu.edu/iemssconference/2018/

A SDSS to Integrate Ground Source Heat Pump into Regional Energy Strategies

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Abstract: Reaching the ambitious European energy and climate goals asks the heating and cooling (H&C) sector for a drastic reduction in energy consumption and a significant increase of production from renewable energy sources (RES). Nowadays in Europe half of the energy consumption is used for H&C, and 84% of this energy is still generated from fossil fuels while only 16% is generated from RES. The Ground Source Heat Pump (GSHP) technology can play a strategic role, increasing the efficiency of H&C systems and strengthening the flexibility of the whole energy system. This study presents a Spatial Decision Support System (SDSS) designed to include the GSHP into the energy strategy and spatial planning process. The model integrates legal, technical, environmental, and economic constraints at the local/regional scale. The SDSS allows to compare scenarios with different technological solutions, also relating them to different energy, environmental and financial targets. The proposed SDSS is applied in a case study i.e. Valle d'Aosta, a small Italian alpine region. The spatial unit of analysis is the single building; where the information at the building level was not available, data from the Italian National Statistics Institute at the census tract scale has been integrated for filling the knowledge gap. The aim of this model is to support decision-makers in fostering sustainable energy plans targeted to improve both energy production from RES and energy renovation of the existing building stock. The research output can have a key impact in the H&C field helping to increase the knowledge of the GSHP technology and to enhance its integration into energy plans and strategies. In addition, it can contribute to reduce CO_2 emissions in the energy production sector. Finally, the research aims to develop a broader approach towards the energy transition of cities and regions starting from local settings.

***Keywords**:* Ground source heat pumps; spatial decision support system; renewable energy sources; regional energy planning.

1 INTRODUCTION

In European households, heating and domestic hot water alone accounts for almost 80% of total final energy use. Cooling accounts for a smaller share, but the demand from households and businesses is rising during summer. Moreover, only 16% of heating and cooling (H&C) demand is covered by renewable energy sources (RES) (European Commission n.d.). Under the pressure of climate change, the EU has set ambitious targets related to the reduction of greenhouse gas (GHG) emissions and energy consumption across all sectors. As a result, the implementation of both technical solutions for energy saving and energy systems based on RES is now a paramount concern in the building sector.

Ground Source Heat Pump (GSHP) is one of the least carbon-intensive technologies for the H&C of buildings (Nejat et al. 2015). It exploits the heat stored within the ground, a local RES that is widely available across territories and less dependent from changes in time and space (as most of RES). Global CO_2 emissions deriving from the exploitation of GSHP are related to the electricity production mix. Instead at local level, the GSHP impact is very limited in terms of air pollution (NO_x, PM, etc.),

depending upon the backup system. This gives GSHP a competitive advantage in relation not only to fossil fuel systems but also to the use of other renewable sources, such as biomass. Furthermore, GSHP (and heat pumps in general) have the advantage of shifting the heat demand from a thermal demand to an electrical one. Since there are several peaks in the energy production from RES (particularly due to photovoltaic and wind production), heat pumps are even more interesting because they allow the exploitation of surplus production by allowing to store the thermal energy in the buildings while mitigating the peaks (Finck et al. 2017).
As a result, GSHP technology can play a strategic role in increasing the efficiency of H&C systems, strengthening the flexibility of the whole energy system and reducing local and global CO_2 emissions. Despite this features, GSHP has been scarcely considered in European, regional and local energy policies. Its growth is limited mainly by factors such as the scarce knowledge of this technology, the complicated and fragmented legislation, and high installation costs (Casasso et al. 2017). Hence, it is necessary to increase the awareness of its advantages among policy- and decision-makers. To this end, a Spatial Decision Support System (SDSS) has been developed which provides decision- and policy-makers with insight and information on if and how to include GSHP systems into local energy strategies and spatial planning policies.
The SDSS is based on the technical, economic, legislative evaluation of a multiplicity of single GSHP plants in different points in space. The dimensioning of the single plants and the appraisal of the produced energy depend on: the geophysical characteristics of the terrain, the legislative and geological constraints, the specific thermal energy demand and the position and power of others installed GSHP plants. All these variables are spatial dependent. For this reason, the estimation of the energy potential from GSHP within a municipality or a region should be conducted using a spatialized approach. In this study, a specific open source software using GRASS GIS, Python and R is developed. The software is part of a set of tools developed for the analysis of the potential energy production from renewable sources (Garegnani et al. 2018), (Sacchelli et al. 2016), (Zambelli et al. 2012). For the calculation, the software needs as input the maps of the geo-physical characteristics of the ground, which have been provided by the Regional Environmental Agency of Valle d'Aosta (ARPA VdA), and the map of the thermal energy demand. For the elaboration of the latter, a GIS-based method designed to estimate the thermal energy demand of residential buildings has also been developed. This method requires the classification and characterization of the building stock by considering the physical features and the time of construction (Exner et al. 2017), (Tooke et al. 2014). In this study, the attention is focused on the residential share of the building stock.
Altogether, the SDSS integrates spatial data and information into a computational framework that assesses, when possible at the buildings level, the economic feasibility of GSHP by considering the correlated technical, legal and environmental constraints (GRETA project 2018).
The SDSS compares also GSHP financial figures with other technologies, such as gas or biomass boiler, to assess the economic feasibility. The model allows estimating the share of thermal energy demand of the buildings that can be covered with geothermal energy in a certain area or in the entire region. The spatial representation of these potentials, together with the overall aggregated scalar values, are meant to support decisions- and policy-makers in including this technology into energy plans. This study is performed within the EU-funded project GRETA (near-surface Geothermal REsources in the Territory of the Alpine space[1]) and applied to the Italian region of Valle d'Aosta.

2 METHODOLOGY

The methodology matches the energy potential of the GSHP with the energy demand, building by building, and calculate the main financial figures to assess the feasibility of the GSHP system. The method consists in four main steps: (i) identify all the areas that must be excluded to respect environmental, legal and technical constraints, (ii) assessment of the energy demand; (ii) dimensioning the main components of the GSHP system; (iii) estimation of the main financial figures.
In the first step, all the area with environmental (e.g. contaminated areas), legal (e.g. minimum distance from water wells) and technical (e.g. presence of landslide) issues are excluded from the analysis.
As second step, the thermal energy demand of the building stock is assessed computing a simplified energy balance between the energy losses due to climatic condition and building features, on one

1 http://www.alpine-space.eu/projects/greta/en/home

side, and the internal and solar energy gains, on the other side.
Based on the annual energy demand of buildings, several load-curves resulting from dynamic simulations of a residential building with good or bad insulation are used. These normalised load-curves are applied to estimate the main power peaks of the plant and then the dimensioning of the Borehole Heat Exchanger (BHE). All simulations were performed in TRNSYS. Considering the geo-physical characteristics of the ground (conductivity and diffusivity provided by ARPA VdA) and using the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers[2]) method, the model estimates the total area needed to create a BHE field for each building.
Once the main GSHP components are defined, the fix (investment and installation) and the variable (operative and maintenance) costs can be appraised. Similarly, fix and variable costs of alternative heating systems (e.g. methane and gasoline boilers, air source HP, combined RES systems) are assessed and compared with the GSHP solution, also considering their CO_2 and air pollutant emissions. The comparison, based on economic KPI (Lu et al. 2017), allows to evaluate the economic viability of a GSHP system in a given location and to assess the share of thermal energy demand that can be covered with the geothermal source.

3 PRELIMINARY RESULTS

The methodology has been applied in the Valle d'Aosta region (NW Italy). The main outputs - obtained both at the building and at the census tract level - include: (i) the appraisal of the thermal energy demand of the residential building stock given by the calculation of the energy performance of each building; (ii) the evaluation of the technical and financial suitability of GSHP solutions for covering the energy demand of the housing sector and replacing, as much as possible, fossil energy sources within H&C systems. The detailed information of the energy demand can be used to rank and prioritize the area for possible building renovation interventions. The information regarding the suitability of the GSHP in the area can be used to identify possible energy target and for the definitions of local energy policies. Two different scenarios are built: one considering only the economic aspects, and the other minimizing the the CO_2 emissions.
Furthermore, the SDSS highlights all the census tracts suitable for a mini-district due to an energy demand density greater than a user-defined threshold (e.g. 150MWh/ha per year) (Hausladen & Hamacher 2011),
All the different modules of the SDSS for the integration of GSHP into the energy plans and strategies developed within this work will be available as open source tools and publish as GRASS GIS addons.

4 CONCLUSION AND LIMITATIONS

This study presents a Spatial Decision Support System that aims at including Ground Source Heat Pump systems into the energy strategy and planning process at regional scale. The model integrates the thermal energy demand of the residential buildings, the local geothermal potential and the technical and financial feasibility of GSHP systems. In the case study area, i.e. an Italian alpine region, it allows to compare scenarios with different technological solutions to cover the energy demand of the building stock. This will support local decision-makers in developing sustainable energy plans targeted to improve both the energy production from GSHP and the energy renovation of the existing building stock.
Since the H&C sector has to drastically reduce its energy consumption and increase the share of RES to reach the EU energy goals, this model can play a strategic role in the field helping to expand the knowledge of the GSHP technology and foster its integration into energy plans and strategies. The GSHP systems are also one of the least carbon-intensive technologies for the H&C of buildings and can contribute to the reduction of CO_2 emissions in the energy production sector.
The main limitation of the presented study concerns the homogeneity and availability of data. For instance, the scale of analysis of the data gathered from the Italian National Statistics Institute (Census, year 2011) is the census tract while the geometrical features are calculated at the building level. In addition, it would be useful to acquire measured data on the thermal consumption of the building stock in order to better validate the estimated values of the energy demand; or to get information at the building level regarding the occupancy and the intended use of the buildings (here

2 https://www.ashrae.org/

again the source is the Census). Unfortunately, these data are often difficult to gather because of privacy issues or because the different public administrations do not collect them at the same detail level. Nevertheless, the presented model estimates the required values at building level, forcing the results to be consistent with the data available at census tract level. Moreover, the model allows to achieve a trade-off between the number of inputs, the detail level required by the decision- and policy-makers and a reliable estimation of the main financial and environmental indicators.
As next steps, the research intends to develop a broader approach towards the energy transition starting from the local point of view. This would be done integrating the output of the model within the urban and regional planning process, thus creating fruitful synergies between sustainable energy and spatial planning disciplines.

ACKNOWLEDGMENTS

GRETA project is co-financed by the European Regional Development Fund through the INTERREG Alpine Space programme.

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