Optimizing Micro Renewable Generation for Smart Cities by Combining Solar and Geothermal Energy Potentials

A Case Study of the Hannover Region

Claudia Palmas[1], Holger Jensen[2], Christina von Haaren[1] and Robert Schöner[2]
[1]*Department of Environmental Planning, Leibniz University of Hannover, Herrenhäuserstr. 2, Hannover, Germany*
[2]*State Authority for Mining, Energy and Geology, Stilleweg 2, Hannover, Germany*

Keywords: Micro Solar Energy Potential, Micro Geothermal Energy Potential, Smart Cities, Renewable Energies.

Abstract: In recent years there has been an increasing interest on small renewable energy production systems to supply energy consumption of buildings. In Europe, cities face the challenge of combining energy efficiency and sustainable urban development. This challenge is likely to have an impact on grid infrastructures by implementing intelligent networks and storage facilities in order to secure energy supply. This paper presents an approach for integrating solar and geothermal energy generation on the basis of a spatially explicit assessment of potentials for both energy sources. The results should be applicable for spatial planning. The case study area is the Hannover region. The results demonstrate that with data available in blanked coverage in Lower Saxony the assessment of both renewables energy potentials could be performed. The generated place based information meets the specific demands of regional as well as municipal land use planning. It can be used for allocation and prioritisation of housing development with micro-renewables and for proposing areas with the combination of both.

1 INTRODUCTION

Europe is facing the challenge to reach the so called 20/20/20 objective. This objective includes reducing greenhouse gas emissions by at least 20% compared to 1990, increasing the share of renewable energy sources in final energy consumption to 20%; and improving 20% energy efficiency (European Commission, 2010). To this end a redefinition of strategies may be necessary as several factors like increasing of energy demand, fossil fuel energy scarcity and high environmental impacts are hampering target compliance. An important part of such strategies could be to more efficiently activate the potential of existing and new buildings for producing their own energy. To that end we need innovative strategies and approaches for integrating energy concepts in regional and municipal land use planning. In this context smart cities play a crucial role. Countries in Europe are at different stages of technological, political and administrative development. However, in all cases the development of smart cities depends significantly on smart grids, intelligent grids to leverage energy consumption between the different producers and consumers. The successful combination of smart technologies can help by improving energy efficiency and savings in planning residential development and by adopting measures for existing buildings. Smart technologies need infrastructural changes of energy distribution grids in an optimized way and are seen as a major opportunity to merge energy and ICT industries and technologies (Net!Works European Technology Platform, 2011). Because of the intermittency associated with the most renewable energy production, it is necessary to combine renewable energy technologies and to add some storage mechanism in order to ensure the energy supply. However, energy-saving measures in buildings are either conventional (thermal insulation, energy-efficient air conditioners and appliances) or based on automatic intelligent systems (Wicaksono et al., 2012). The deficits in practice correspond with knowledge deficits about appropriate methods of calculating energy potentials for supporting spatial planning. In this context the *micro renewable heat potential, is especially important because it covers the major part in urban energy consumption. The common sources of micro renewable heat energy production are solar thermal geothermal energy.*

Palmas C., Jensen H., von Haaren C. and Schöner R..
Optimizing Micro Renewable Generation for Smart Cities by Combining Solar and Geothermal Energy Potentials - A Case Study of the Hannover Region.
DOI: 10.5220/0004860602830288
In *Proceedings of the 3rd International Conference on Smart Grids and Green IT Systems* (SMARTGREENS-2014), pages 283-288
ISBN: 978-989-758-025-3

Against this background, the objective of this paper is to present an innovative planning approach which according to energy potentials identifies the best locations for combining solar and geothermal energy. The approach is based on the research conducted in the context of the Project Smart Nord of Lower Saxony, where all renewable energy sources (solar, wind, biomass, hydro and geothermal energy) are taken into account. Here we focus on solar and geothermal energy in order to lead the way for activating the synergies of combining both technologies. In this case, synergies may occur for the following reasons (Tepe, 2011):

- Reduction of borehole depth or number of boreholes in new systems
- Improvement of deficits existing systems to achieve better performance.

The main research questions are:

- How to estimate micro renewable energy potentials? Which methods are needed?
- How to combine solar and geothermal energy systems?

For answering these questions we present in section 2 methods for estimating the geographical distribution of the solar energy potential. In section 3 an application on geothermal energy developed by the LBEG about is presented and integrated with solar energy combinations. Finally we discuss data availability and transferability to other regions as well as possible planning application (section 4) and conclude with recommendations for regional and municipal planning (section 5).

2 METHODS

2.1 General Methodological Approach

To calculate the solar energy potential we have estimated the global irradiation annual average for a horizontal surface, which can be converted according optimized angle for solar panels and solar thermal collectors.

To calculate the geothermal energy potential we have focused on typical shallow geothermal systems for northern Europe. The energy abstraction is achieved by vertical closed loop heat exchangers with a vertical depth of around 100 m. The subsurface model is a three layer model covering the depth of ground surface to 100 m below surface. The horizontal resolution is given by a 50 m by 50 m cell size raster grid.

2.2 Data

In Table 1 datasets used for the calculation of solar and geothermal energy potential maps for the Hannover region, Lower Saxony, northern Germany are shown:

Table 1.

Layer name	Scale/unit	Source
DEM (Digital Elevation Model)	DGM50, 50 m raster grid	Landesamt Bergbau Energie und Geologie Niedersachsen (LBEG) http://nibis.lbeg.de/cardomap3/
Water level in unconsolidated rocks in Lower Saxony	1:200000 only applicable for unconsidated rocks	LBEG (HUEK 200 “Grundwasser-oberfläche”) http://nibis.lbeg.de/cardomap3/
Basal plane of quaternary unconsolidated rocks in Hannover, Lower Saxony	1:500000 edited by detailed point and vector line data	LBEG (GSKH 1:25000) Rohde, P. & Becker-Platen, J. D. Geologische Stadtkarte Hannover 1:25000 NLFB 1998
Geological map 1:500000 Lower Saxony	1:200000	LBEG (GUEK 500) http://nibis.lbeg.de/cardomap3/
Geo-tectonic Atlas 3D	Only uppermost layer from the 3D model was used	Bombien et al. (2012), based on Baldschuhn et al. (2001)
PK OG 2008 “Geothermal Data Catalogue”	Thermal conductivity table of typical rock types in Germany	http://www.infogeo.de/dokumente/download_pool/PKOG_Abschlussbericht_1.3_08-04-25.pdf

2.3 Methodology for the Estimation of the Micro Solar Energy Potential

The solar energy potential is calculated using the r.sun solar radiation model implemented in GRASS GIS (6.4.2) and the PVGIS CM-SAF estimation utility, derived from the Photovoltaic Geographical Information System Interactive Maps (Joint Research Center of the European Commission, 2010). The r.sun model calculates the global solar radiation (beam, diffuse and reflected), for both clear sky and overcast atmospheric conditions from the digital elevation model (DEM) (Šuri et al., 2007). An important factor in producing reliable maps of solar irradiation was the estimation of sky cloud coverage, as the total amount of cloud cover significantly affects ground irradiation. For this reason, the data was validated using PVGIS. The output of this model is a raster map of the global irradiation annual average for a horizontal surface.

The PVGIS calculation of PV potential for a specific site is based on spatial data automatically taken from the PVGIS database. Generally, the overall error for the whole year is quite small (approximately 5%) (ibid.). The database is based on climatic data from 566 meteorological stations covering the 1981–1990 periods and includes monthly averages of daily sums of global and diffuse irradiation and Linke atmospheric turbidity. Elevations and terrain features are represented by a 1-km digital elevation model. More details about the European solar database implemented in the PVGIS estimation utility can be found on its website (ibid.).

2.4 Methodology for the Estimation of the Micro Geothermal Energy Potential

All calculations were done in ArcGIS (ESRI) version 10.0 and Microsoft Access 2007. Input data as described in 3.2 are vector data (polygons) or raster data (DEM). The raster layer was converted to a point vector dataset. The data belonging to each point consist of x,y-coordinates and the elevation. Additional data from the polygon layers were attached to the point layer. For the calculation of the geothermal energy potential a three layer model was used. The first layer consists of the distance from the ground surface to the water table in the quaternary porous rocks (dry unconsolidated rock). The second layer consists of the thickness of the water saturated porous quaternary rocks (saturated unconsolidated rock). The third layer consists of the thickness and type of the “hard rock” up to 100 m below ground which were defined as the pre-quaternary rocks (hard rock base).

Using the thickness and the thermal conductivity for unsaturated and saturated unconsolidated rocks as well as for each hard rock type an average thermal conductivity up to 100 m could be computed for each 50 m raster point. For the estimation of the specific heat extraction values the transformation from thermal conductivity to specific heat extraction was performed following Pannike et al. (2006). Here, the simplified geological stratification from surface to 100 m depth is derived from the data described above, and the specific heat extraction is obtained from the following equation:

$$P_{EWS} = -0{,}85\,\lambda^2 + 13{,}62\,\lambda + 18{,}8$$

where P_{EWS} = specific heat extraction capacity, and λ = average heat conductivity of the rock.

The raster points were converted to a raster layer with a cell size of 50 m. A continuous raster layer set is the result, expressing the specific heat extraction in each cell with 100 m heat exchangers.

For the solid rocks, there were some data limitations due to the decreasing geological information with the increasing depth. Therefore, the rock type sometimes could only be estimated. The data for unconsolidated rocks were taken from geological maps on a scale of 1:25:000. The information regarding the groundwater flow component was not considered according to the VDI 4640 German directive.

2.5 Integration of the Energy Potentials

A first integration can be performed by an overlay of the two energy potentials, because we assumed that all the micro-energy potential maps are of the same weight. The maps obtained show the best locations for the integration of solar and geothermal energy with vertical loops (40 m and 100 m).

3 RESULTS

3.1 Micro Solar Energy Potential Map

The latitude was computed directly from the DEM raster, while the albedo and the Linke turbidity were believed constant over the entire region, as a first approximation. The clear sky indexes were not available. After validation of the date, the output raster map representing the annual average of global irradiation daily sums estimated on optimally inclined plane (Figure 1).

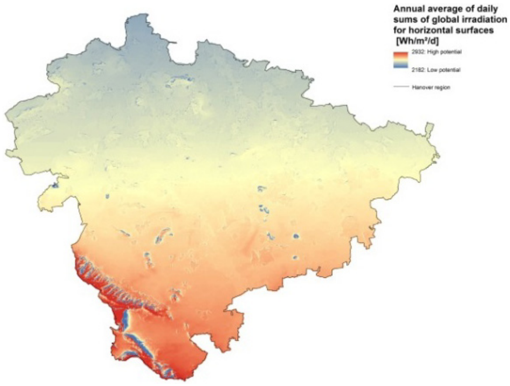

Figure 1: Annual average of daily sums of global irradiation on optimally inclined plane [Wh/m^2/d].

The output units are [Wh/m^2/day].

3.2 Micro Geothermal Energy Potential Maps

As an example, we present here the geothermal energy potential for vertical loops (100 m) (see Figure 2). We calculated for further residential appliance the energy potential for vertical loops (40 m).

3.2.1 Geothermal Vertical Loops (100 M)

The evaluated specific heat extraction capacities, which were calculated from thickness and thermal conductivity of geological strata, has been used to evaluate the geothermal energy potential for the Hannover region. The resulting map was classified into three categories. Class 1 represents very high geothermal energy potential with average specific heat abstraction values of > 45 W/mK, class 2 represents high geothermal energy potential with average specific heat abstraction values of 40-45 W/mK, and class 3 represents standard geothermal energy potential with average specific heat abstraction values of <40 W/mK. Areas not suitable for geothermal energy use because of drilling restriction reasons, e.g. drinking water protection zones, lakes etc., were classified separately as prohibited areas.

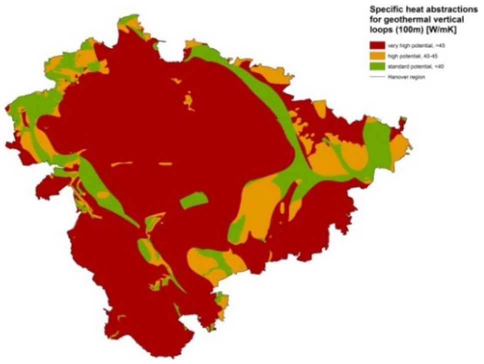

Figure 2: Specific heat abstractios for geothermal vertical loops (100 m) [W/mK]

The GIS overlay results x categories of areas are shown in Figure 3.

The map of the geo-solar combinations demonstrate that the Hannover region is characterized almost by good-high potential for the whole case study area. Nevertheless, areas where the potential is relatively low (areas in green), because of the terrain aspect and slope and rocks characteristics should be integrated with others renewables.

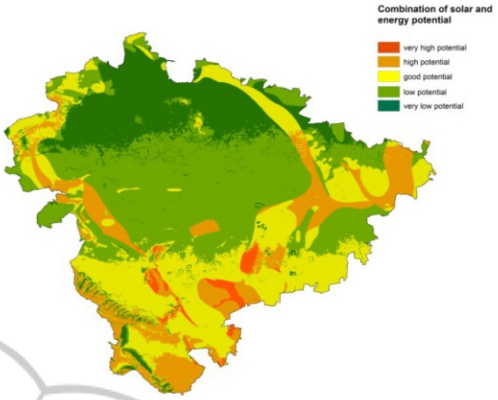

Figure 3: Energy potentials by combining solar and geothermal energy (vertical loops 100 m).

4 APPLICATIONS

The specific heat extraction/geothermal energy potential maps are used for online applications ("Geothermie geht das bei mir?", LBEG 2012) which allow to calculate the required dimension of the closed loop system as subsurface part of a geothermal space heating. With limited input data of a conventional home (area to be heated, energy consumption per area and location of the house) the dimension and costs of the subsurface part can be estimated. This is a powerful tool for architects, planning engineers, and house owners to estimate costs of different heating supply systems.

Furthermore the maps can be used in local and regional planning in various ways: In combination with other spatial information in particular about environmental vulnerability the maps can be used for the allocation of urban development into areas with high potential for a combined micro renewable used. On the regional level this can be prepared by rating and prioritizing areas with reference to the regional or state wide average and by pointing out their potential contribution to regional energy targets. Regional energy targets as to the share of different energy sources will rely on such information. The implementation of such regional planning information may be realized by designations in the mandatory regional plan. On local level, the information can be used in order to allocate housing development as well as to include regulations about adding respective RE facilities in every legally binding development plan. For the technical upgrading of exiting housing areas incentive programs can be set up, which differentiate payments according to the expected results.

5 DISCUSSION

Both methods produce results that are differentiated enough to serve as information basis for regional and local planning as well as for individual house owners. In our estimation the solar energy potential estimation depends on the application of the *r.sun* model and on the *pvgis* data, therefore it can be applied in every region. However, the accuracy depends on input data (DEM) and on *pvgis* data availability.

For the geothermal energy potential maps we can consider the typical amount of vertical heat exchanger per area, which depends on the urban settlement structure. The necessary input data for this advanced model are land use maps and average density of heat exchangers per land use type. With this approach a comparison based on raster layers with an energy value per cell would be possible. For the geothermal energy potential the output energy for space heating is higher than the energy abstracted from the ground due to the input of a heat pump. The seasonal performance factor (spf) of the heat pump is the dimension of surplus from output energy dependent of the input energy. The energy which is available for space heating should be based on a typical spf factor.

Research projects like Geo-Solar (Pärisch et al., 2012) and first pilot products from the geothermal market are focusing of the combination of solarthermal and geothermal systems. The advantage of solarthermal systems is the high effectiveness of collecting energy, the advantage of the geothermal system is the independent availability of energy 24 hours 365 days a year. Combining both systems provides a constantly available effective heating system driven by renewable energy. However, the potentials of combining both energy sources need further research. In the future, for a better integration of both energy sources and the comparison to other energy forms, all potential maps should be all transformed to the same ordinal scaling and best presented on cardinal scales which quantify kilowatt-hour.

6 CONCLUSION

In many regions geodata already allows the spatially concrete estimation of solar and geothermal energies potentials. Our methodologies allow not only for representing the separate potentials but also give a first insight into the added value of combining both sources. The results should be used in regional and local land use planning as a contribution for allocating housing development specifically designed for micro generation of RES. It also can be used for a targeted and results oriented approach to allocating incentives to house owners for upgrading existing houses by RE installation. Last not least the maps could be made accessible to the public and used by architects and house owners for calculating the efficiency of planned solar or geothermal installations.

ACKNOWLEDGEMENTS

The Lower Saxony research network "Smart Nord" acknowledges the support of the Lower Saxony Ministry of Science and Culture through the "Niedersächsisches Vorab" grant program (grant ZN 2764).

REFERENCES

Baldschuhn, R., Binot, F., Fleig, S. & Kockel, F., 2001. Geotektonischer Atlas von Nordwestdeutschland und dem deutschen Nordsee-Sektor: Strukturen, Strukturentwicklung, Paläogeographie - *Geol. Jb.,* A153: 88 p.

Bombien, H., Hoffers, B., Breuckmann, S., Helms, M., Lademann, K., Lange, M., Oelrich, A., Reimann, R., Rienäcker, J., Schmidt, C., Slaby, M. F. & Ziesch, J., 2012. Der Geotektonische Atlas von Niedersachsen und dem deutschen Nordseesektor als geologisches 3D-Modell.- *GMIT*, 48: 6-13.

EU Joint Research Centre (JRC), 2010. *Solar model r.sun*. http://re.jrc.ec.europa.eu/pvgis/solres/solmod3.htm.

LBEG, 2012. *Geothermie geht das bei mir*.- Online application, http://nibis.lbeg.de/geothermie/

LBEG, 2013. *map server*, http://nibis.lbeg.de/cardomap3/

Net!Works European Technology Platform, 2011. *Smart Cities Applications and Requirements*, http://www.networks-etp.eu/fileadmin/user_upload/Publications/Position_White_Papers/White_Paper_Smart_Cities_Applications.pdf.

Pannike, S., Kölling, M., Panteleit, B., Reichling, J., Scheps, V. & Schulz, H.D., 2006. Auswirkung hydrogeologischer Kenngrößen auf die Kältefahnen von Erdwärmesondenanlagen in Lockersedimenten.- *Grundwasser,* 1/2006: 6-18.

Pärisch, P., Warmuth, J., Bertram, E., Tepe, R., 2012. Experiments for combined solar and heat pump systems. *Proceedings of the Eurosun 2012*, Rijeka, Kroatien, 18.-20.09. 2012, Croatian Solar Energy Association & International Solar Energy Society, ISBN: 978-953-6886-20-3.

Šuri M., Huld T. A., Dunlop E. D., Ossenbrink

H. A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. *Solar Energy 81* (2007) 1295–1305.

Tepe, R., 2011. High-efficient heat pump systems with geothermal and solar thermal energy sources, http://www.isfh.de/institut_solarforschung/files/110131_geosolarwp_en.pdf.

VDI 2001. Thermal use of the underground: Ground source heat pump systems.- VDI 4640 Part 2, 43 p., Berlin, Beuth Verlag.

Wicaksono H., Aleksandrov K. and Rogalski S., 2012. An Intelligent System for Improving Energy Efficiency in Building Using Ontology and Building Automation Systems. http://www.intechopen.com/download/pdf/38012