SUN-AREA
TOWARDS LOCATION-BASED ANALYSIS FOR SOLAR PANELS BY HIGH RESOLUTION REMOTE SENSORS (LIDAR)

Dorothea Ludwig [2], Sandra Lanig [1] ,Martina Klärle [1]
[1] Steinbeis-Transfer Center Geoinformation and Landmanagement
Würzburger Straße 9, 97990 Weikersheim, Germany
lanig@klaerle.de
klaerle@klaerle.de

[2] University of Applied Sciences Osnabrück
Department of Agricultural Sciences and Landscape Architecture
Oldenburger Landstraße 24, 49090 Osnabrück, Germany
d.ludwig@fh-osnabrueck.de

Abstract

In the course of the discussion about climate change, there is an urgent need for action. The expansion of renewable forms of energy is a way to make a sustainable energy supply possible. Solar energy is a rapidly growing branch for the future. In Germany, for almost two years, an increasing number of municipalities nationwide have created solar potential maps of roof surfaces and have made the results available to the public. This allows a method, developed at the University Of Applied Sciences Of Osnabrück (Germany) as part of a research project, to automatically assess each building in a large region for suitability as a solar energy collector, and to calculate the solar potential of roof surfaces. Many cities in Germany have mapping of this kind available, which has led to a massively increased share of electricity generated from solar power. The basis for these methods of application is high-resolution LiDAR (Light Detection And Ranging) data. Chile, a country with the world's highest solar radiation values is urgently looking for alternatives to central power generation. Chile is also increasingly applying LiDAR data. In cooperation with the Santiago de Chile-based company Digimapas Chile, the SUN-AREA method was adapted to Chile's situation and a first test region was calculated. The potential of roof areas for the production of solar energy in Chile is immense.

1. Introduction

"A stable climate is of fundamental importance for the natural resource base and our whole life as we know it today" (BMU 2006). According to the UN Report on Climate Change (IPCC 2007), 1.3 degrees of global warming since the beginning of the industrial era is to be expected. If no climate protection measures are taken, the critical threshold of 2 degrees could be exceeded. This would mean that all climate zones shift. The biggest polluter is the burning of fossil fuels such as coal, gas and oil and the consequent release of CO_2. A sustainable energy policy is essential to address climate change. Energy consumption worldwide has to be massively reduced; energy efficiency must be greatly increased and the expansion of renewable energies must be rigorously pursued. At the University Of Applied Sciences Of Osnabrück, Germany, a method was developed within the context of the research project SUN-AREA, that allows fully automatic solar potential mapping of roofs on each building in a large region targeted for examination. Additionally, the determination of site suitability for solar panels on the roof is required. For appropriate roof areas, the second step is to calculate the solar potential. Based on high-resolution laser scanner data, with accuracy in position and height of approximately 15 cm, the smallest structures on the roof such as chimneys or roof dormers can be captured. The SUN-AREA method is already applied to many cities in

Germany, for example Osnabrück (www.osnabrueck.de/sun-area), Braunschweig (www.braunschweig.de/sun-area), Gelsenkirchen (www.solar-gedacht.de) or Wiesbaden (http://geopm-kom4.de/geoapp/frames/index.php?&gui_id=WiesbadenPhoto), and the proportion of solar use in thus massively strengthened. In the spring of 2009 the SUN-AREA method was adapted to the Chilean situation, and a test calculation performed.

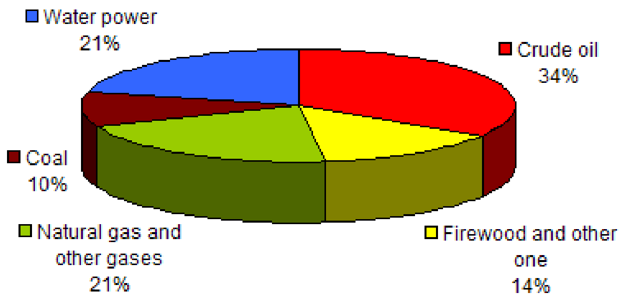

Figure 1. Primary energy consumption in Chile in the year 2002 (CNE, 2009)

In addition to the global problem of climate change, Chile also has local energy problems. Chile is a country without fossil energy reserves with the exception of some small gas storage facilities. For this reason the dependence on energy imports is relatively high. Hydropower offers Chile its own primary energy production. Chile possesses hydro power plants, but their disadvantage lies in the great expense of transporting the energy. Due to the poorly developed infrastructure in Chile, energy supply is not considered secure. A central power supply to the scattered population distribution is therefore very difficult. The largest proportion of primary energy production in Chile is derived from oil in addition to hydropower and natural gas (Figure 1. Primary energy consumption in Chile). An inexhaustible source of energy in Chile is solar energy. Chile has the world's highest insolation values. The use of solar energy would enable a decentralized energy supply and could be used in combination with other renewable energy sources to cover a high proportion of annual energy requirements.

These paper presents a method that allows on the one hand a fully automatic solar potential mapping, and furthermore, the determination of site suitability for solar panels on the roofs on each building in a large investigation area. Based on high-resolution LiDAR data the solar potential for appropriate roof areas were calculated. In the following we give a short overview to the solar technology and favoured locations for solar energy (section 2). Section 3 represents the developed SUN-AREA method and the necessary adaptions to the Chilean situation. In section 4 we show our results for the test area Los Angeles in Chile and finally we sum up and give a short outlook to future works.

2. Solar Energy

The basis of solar technology is the modality of the use of solar energy. The strength of solar radiation determines the energy efficiency of a solar energy collection system. A distinction is made between the photovoltaic and solar thermal technology. The use of photovoltaic modules enables solar radiation to be directly converted into electricity. Solar thermal technology harnesses the inherent thermal energy of solar radiation. Solar thermal systems are primarily used for heating domestic water and for central heating. Power generation through CSP (Concentrating solar power) is becoming common in many countries- USA, Spain, the Sahara desert.

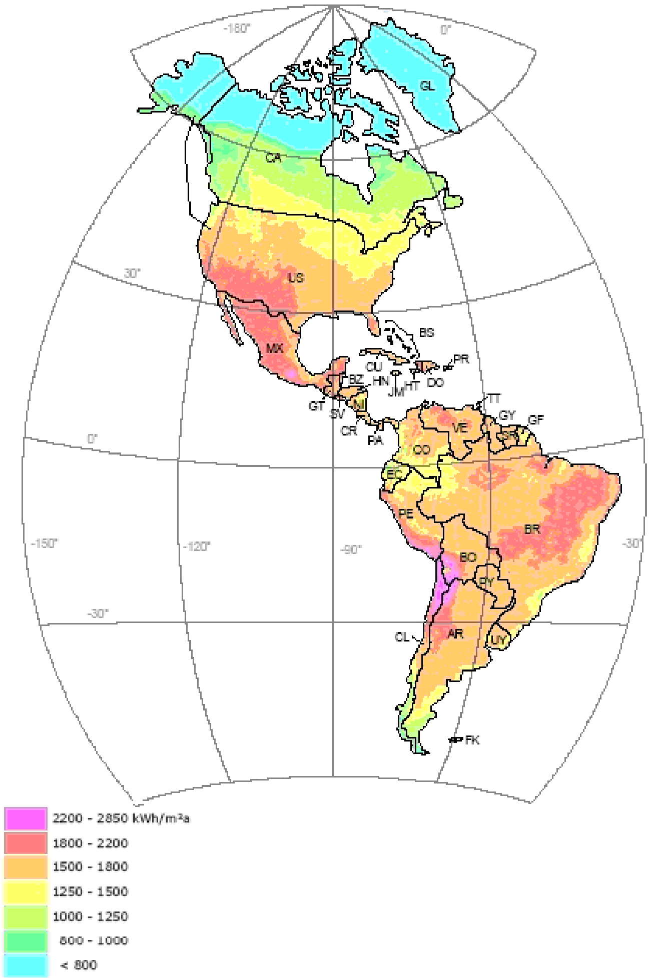

Figure 2. Annual solar radiation in North and South America (Blatter 2008)

Global radiation is defined as the sum of direct, diffuse and reflected radiation. The total solar radiation is therefore the radiation energy received on the earth on a horizontal surface (see Malberg 2007). Germany has global radiation values of 850 to 1100 kWh/a*m². In Chile, values from 1400 to over 2800 kWh /a*m² have been measured (Figure 2. Annual solar radiation in North and South America). The highest solar radiation in the world is reached between the region of Arica, Coquimbo and Parinacota in the north of Chile. Solar technology to date is used primarily in those regions of the country (CNEa 2009**).** In the south, the insolation falls to about 1400 kWh /a*m².

3. Development of methods for calculating solar potential

The method developed for the calculation of solar potential on roofs within the research project SUN-AREA has been applied to a test area in the Chilean city of *Santa Maria de Los Ángeles*, capital of the province Bio Bio. Chile has high-resolution LiDAR data for large parts of the country. The company Digimapas Chile, a local flying company has already covered more than 54.000 km² of the country with LiDAR data and digital aerial Images. These have been provided for the calculation of the test area. Application of the SUN-AREA method in Chile requires some methodology adjustments to be made on which I would like to explain in the following.

3.1.Study area and data base

The small town Los Angeles, with a population of 117.972 (as of 2002, INE 2009) is located about 600 km south of Santiago de Chile. The power supply of the region is primarily produced by several hydroelectric power plants using the water from the Bio Bio rivers and their tributaries (Wikipedia, 2009). Los Angeles has rather low global radiation values by Chilean standards, but still 60% higher than those in Germany. Los Angeles has a maximum insolation of approximately 1.600 kWh/a*m². The sun's zenith on 21st December is at 80° above the horizon and falls to a maximum of 30° in June.

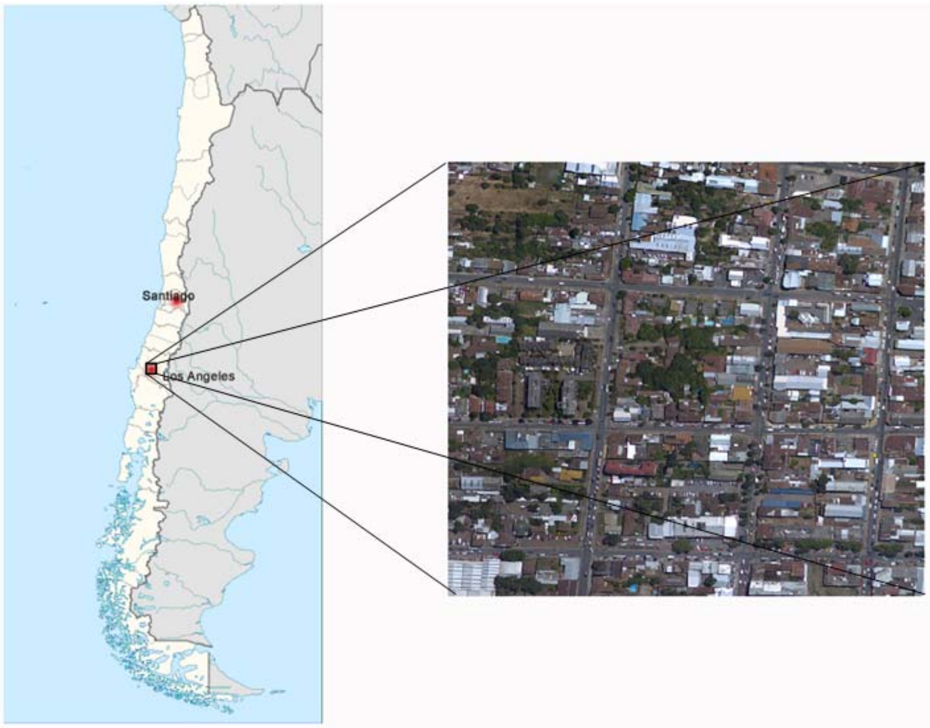

Figure 3. Location of Los Angeles within Chile

LiDAR data has been recorded for Los Angeles. Through Airborne Laser Scanner Data (LiDAR) it is possible to generate high-precision Digital Surface Models (DSM) for grouping analysis and derivation of the roof surface. Together with the LiDAR data, the building outlines are used (Klärle and Ludwig 2006). The basis of the calculation method is the first pulse of the LiDAR data. The data preparation starts with the interpolation of the unevenly distributed point clouds. The resulting Digital Surface Model (DSM) is stored as on a 1 meter grid. The data for Los Angeles was recorded using a Harrier 56 Dual-Cam system, consisting of a bar scanner Riegl LMS-Q560, an Applanix PosAV 410 IMU / GPS navigation system and two cameras; Applanix DSS 422 (RGB and NIR). The flight altitude took place at 650 meters above ground; the point density was required 2 – 3 Points/ m². The data were taken up in winter 2006/2007.

A second set of data using building outlines will be used to locate the position of the roofs. Germany has extensive records of this type of data in the ALK (Automated Land Register Map). In Chile, the only comparable maps are to be found in capital city Santiago de Chile. Los Angeles regrettably does not yet have this information. For the calculation of the test area, building outlines were digitized from the high-resolution orthophotos.

3.2. Methodological Implementation

To calculate the suitability of a roof for a solar installation five factors must be taken into consideration. In addition to the roof orientation and slope, the radiation energy, the shadow situation and the appropriate size of the roof need to be identified.

Many approaches to automatic building extraction from LiDAR data and the generation of 3D city models have so far not shown the desired results. The procedures differ primarily in the data base to be used and the methods. In addition to the procedures of e.g. Schwalbe 2004, Hofmann 2004 or Steinle 2005, whose data-driven approach was developed exclusively based on LiDAR data, Rottensteiner et al (2003) for example, also used aerial imagery for the automatic generation of building models. The method developed under the research project SUN-AREA pursues a totally different approach. From the experience of the 3D city model development, which does not have a fully automatic method for generating Level of Detail 2 (LOD2) models with detailed roof superstructures, the roof situation is not generated through roof side levels, but calculated on a grid model. For the solar potential analysis, it is essential that even the smallest structures such as dormers or chimneys, which interrupt the homogeneous roof, be taken into account and calculated out of the area to be installed. The results are homogeneous non clouded roof areas. Figure 4 shows the simplified workflow of the SUN-AREA method.

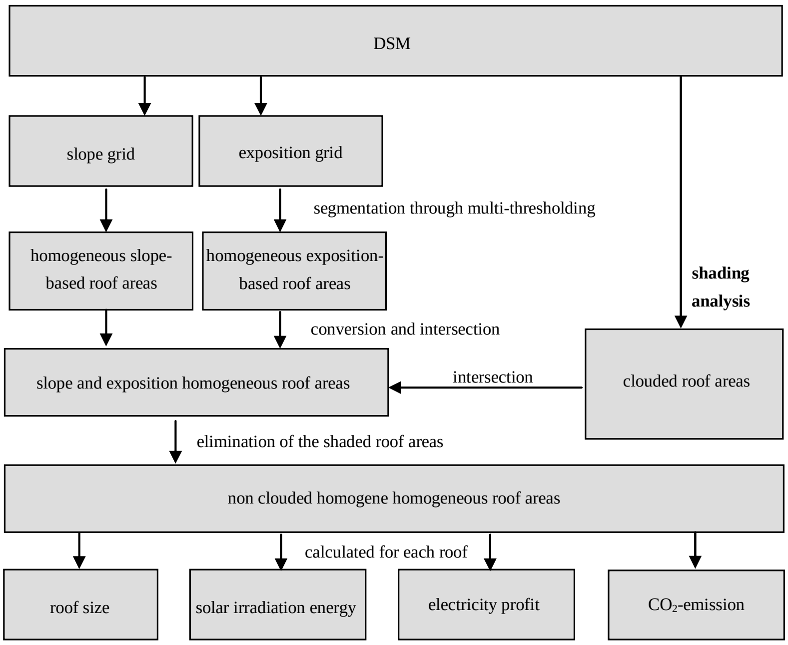

Figure 4. Generalized Method Workflow (Ludwig et al. 2008)

3.3. Selection of homogeneous roof areas

The installation of solar panels on roof surfaces necessitates sufficiently large homogeneous roof areas. Homogeneous roof areas can be defined into uniform slope and orientation surfaces. The basis of the procedure for selection of homogeneous roof areas is an interpolated 1 meter grid from the first pulse raw LiDAR data. A deterministic interpolation is used, which is based on the Sibson algorithm (Sibson 1981). The interpolated grid forms the foundation for the tilt and orientation calculation which runs in parallel. Within the slope grids, homogeneous areas are selected through multiple thresholding (image processing) runs. By adjusting the limits and re-running the thresholding, further grid cells can be combined into homogeneous surfaces. Each thresholding operation is assigned to the calculation of the absolute gradient value for the aggregated segment. The multiple thresholding operation with changed limits is applied to the exposure grid. As a result of this process, two separate partial result grids are available as shown in Figure 3. A conversion and blending of the partial results generates polygons, which represent homogeneous areas of the roof, both in slope and exposure (Ludwig et al. 2008).

3.4. Shadow analysis

Shadows cast by vertical objects onto the solar panels can cause significantly greater power reductions than a sub-optimal orientation of the generator. Therefore, even partial shading of a module can diminish the overall performance of the installation. Any shading of the solar generator should therefore be avoided (Sander 2006). The shadow modelling is based on a grid analysis. The input parameters are the 1m DSM, the site, slope, orientation, and the daily and seasonal change of sun angle. The theoretical background for the widely used radiation calculation is based on work by McKenney et al (1999), by Page et al. (2001) and by Hofi-Erka et al. (2002). The shadow modelling includes a line-of-sight analysis of each DSM-pixel to the sun. The radiation tracking algorithm determines for each time of day and season the patency of incident solar radiation on the roof. If an obstruction cuts the beam, then that roof pixel is classified as shadow (Lanig et al. 2009). Each shaded area of roof within the period of observation is deemed unsuitable for photovoltaic (PV) use and is not considered in further calculations (Figure 4. Generalized Method workflow).

3.5. Calculation of the solar energy potential

For homogeneous roof areas, the solar energy potential is calculated using six parameters:

- Insolation,
- Roof size
- Potential electricity generation
- Potential CO_2 savings
- Power in KW
- Investment volume.

Appropriate roof areas for using PV technology in Chile have access to 65% - 100% of the maximum possible local radiation energy, are not affected by shadow and are at least 15 m² (pitched roofs) and 45 m² (flat roofs) . It is meaningfully to install solar panels on flat roof with some slope. In this case a smaller surface area is to be used (about 40% of roof area). The solar thermal technology uses smaller surface area, smaller 15/45 m². These surfaces were not determined within the test calculation in Los Angeles.

4. Results of Los Angeles - Chile

1229 buildings within the 37 ha test area in Los Angeles were examined for site's suitability for solar use. The 1229 buildings have a combined footprint of 129964 square meters. Homogeneous roof areas were selected for each building. The absolute gradient and orientation of the partial roof areas were calculated. The analysis of the gradient and orientation first testifies to the building culture in the Chilean test area. The statistical analysis of the slope value of all suitable roof areas in the zone shows that flat roofs are predominately to be found, the mean gradient of all appropriate areas is 19° (Figure 5. Slope in degrees). Looking at the orientation of the appropriate roof areas, the uniform distribution over four high peaks is noticeable. Most roofs are north-south or east-west oriented (Figure 5. Aspect in degrees). This is a planned, symmetrical urban structure, straight from planning board (Figure 3. Location of Los Angeles within Chile, the aerial Images).
The solar potential calculation according to SUN-AREA judged 672 buildings from 1229 to be suitable for photovoltaic use. The 672 buildings have 46.100 m² of suitable roof area. This would mean that 35% of the buildings' footprint is acceptable for solar use. If these were to be fitted with photovoltaic systems working at an efficiency of 15%, 6916 MWh/a of electricity could be produced. The calculation of the potential electricity production includes abatement (Performance ratio) of 0.75.

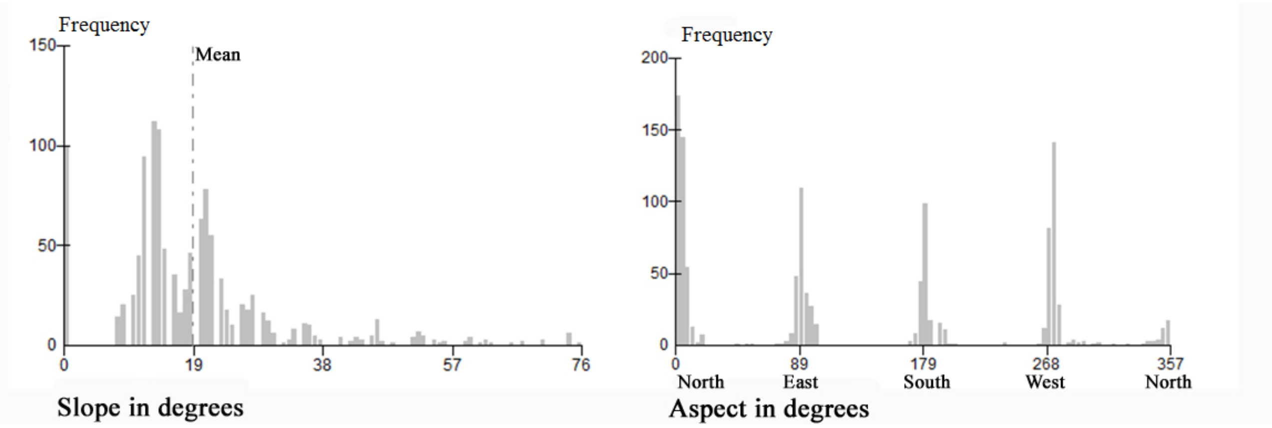

Figure 5. Statistical analysis of results data, slope and aspect

In the test area, radiation levels on the roof areas can be expected to be between 1024 and 1600 kWh/a*m². Due to the very high position of the sun in December at 80° above the horizon, the highest radiation levels in the year can be reached on roofs with minimal fall of approximately 10-20°. On horizontal surfaces 96% of the maximum possible radiation in the test area was measured and therefore also on flat roofs. The test area has over 100 suitable flat roofs. The building shown in figure 6 has a very good suited roof with a northern aspect. 441 m² could be able to generate 75799 kWh/a yield (Table 1 Solar potential values of the very good and partly suitable roof).

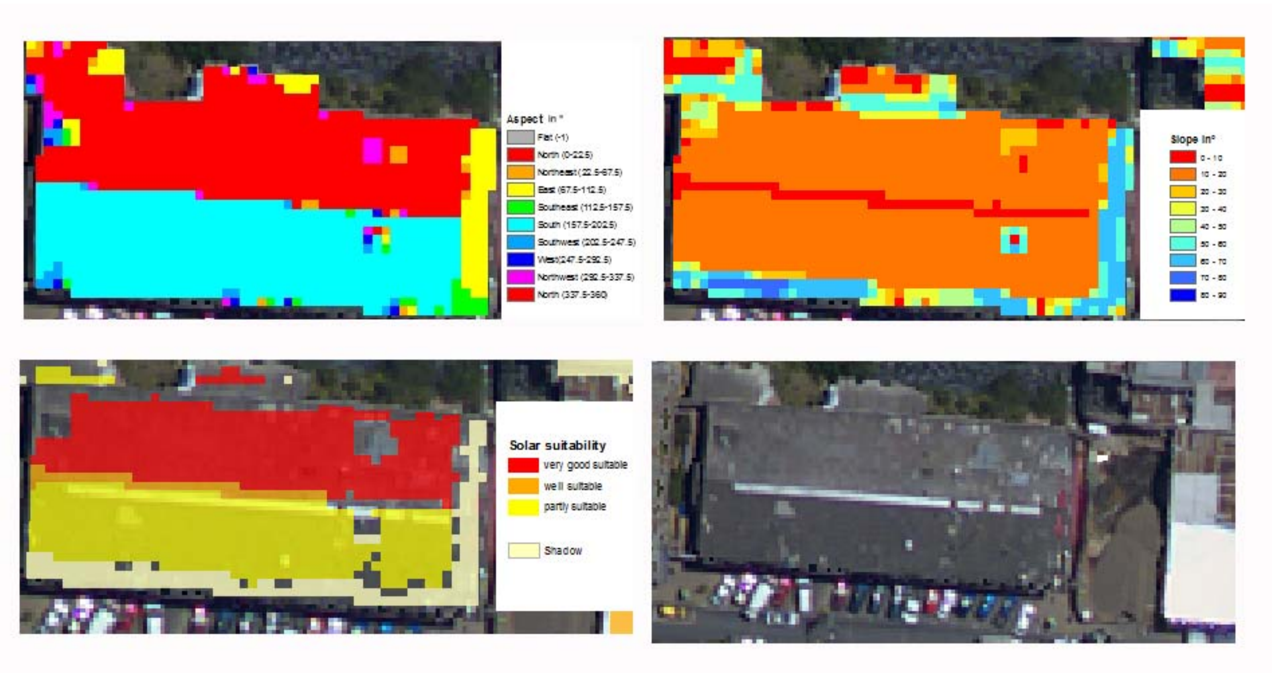

Figure 6. Example of a very good suitable area: aspect, slope, solar suitability and the aerial image

	Very good suitable Area; northern aspect	**Partly suitable area; southern aspect**
Slope	16 °	16°
Aspect	5°	181°
Roof Area	441 m²	440 m²
Current Yield (15% Efficiency)	75799 kWh/a	57994 kWh/a
KWp	55	55

Table 1. Solar potential values of the very good and partly suitable roof surfaces of the example building in Figure 6.

The solar potential in Chile is tremendous due to very high insolation. The roof space in the city of Los Angeles could be well adapted for solar usage, although the insolation levels are rather low by Chilean conditions. The SUN-AREA method does not give statements as to the quality or structural strength of the roofs.

5. Summary and Outlook

In this paper a complete methodology from the location analysis for solar plants which is fully automatic applicable for large data sets by standard GIS functions based on LiDAR data was introduced. The challenge exists between the high computation accuracy and the automated application. The SUN-AREA methodology was tested for example for the German cities Osnabrück (www.osnabrueck.de/sun-area) were computed already. The sustainability of SUN AREA is secured by the fact that the method is transferable to other regions without problems. The method was adapted to South-American terms and in particular the Chilean condition. The solar potential in Chile is tremendous due to very high insolation. The roof space in the city of Los Angeles could be well adapted for solar usage.

Acknowledgment

The project financed by AGIP (working group of innovative projects of the Ministry for science and culture of the state of Lower Saxony). The project SUN AREA was completed during one period by 26 months at the University of Applied Sciences, Osnabrück, faculty agrarian sciences and landscape architecture, under the direction of Professor Dr. Martina Klärle, with the cooperation partners IGF (Institute for geo computer science and remote sensing, University of Osnabrück, Germany) and the company TopScan (Rheine, Germany). The Company Digimapas Chile have been provided LIDAR data and digital aerial Images for the calculation of the test area.

References

BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) 2006, ENVIRONMENTAL REPORT 2006, the environment - innovation - employment, self-Verlag Berlin

Blatter , M. 2008, Fachbuch "Geografie der erneuerbaren Energien" Energie-Atlas GmbH, Biel/Bienne, CH

CNE (Comisión Nacional de Energía) 2009, Consumo de Energías Primarias / Total País; URL: http://www.cne.cl/cnewww/opencms/03_Energias/Otros_Niveles/fuentes_energeticas_primarias/Energia_Primaria/consumo_energias_primarias.html (last accessed 25.06.2009)

CNEa (Comisión Nacional de Energía) 2009 , Energia Solar, URL: http://www.cne.cl/cnewww/opencms/03_Energias/Otros_Niveles/renovables_noconvencionales/Tipos_Energia/energia_solar.html (last accessed 25.06.2009)

Hofierka, J., Suri, M. 2000, The solar radiation model for Open source GIS: implementation and applications, Proceedings of the Open source GIS - GRASS users conference 2002 - Trento, Italy, 11-13.

Hofmann, A.D., Schwalbe, E. 2004, Evaluation automatisch rekonstruierter Gebäudemodelle aus Flugzeuglaserscannerdaten, Tagungsband der 24. Wissenschaftlich- Technische Jahrestagung der DGPF, Band 13, pp. 51-58

INE (Instituto Nacional de Estadísticas) 2009, DEMOGRAFÍA, Ciudades Pueblos Aldeas y Caserios; URL: http://www.ine.cl/canales/chile_estadistico/demografia_y_vitales/demografia/demografia.php (last accessed 25.06.2009)

IPCC (Intergovernmental Panel on Climate Change) 2007: Climate Change 2007, Summary for Policy Makers, URL: www.ipcc.de (last accessed 01.07.2009)

Wikipedia, 2009: VIII Región del Biobío; URL: http://es.wikipedia.org/wiki/Bio-B% C3% ADO (last accessed 25.06.2009)

Klärle, M., Ludwig, D. 2006, SUN-AREA location analysis for photovoltaic plants through high-resolution sensors in remote sensing - A research project at the Fachhochschule Osnabrück. In: GI @ IGF-reports, publication of the AK-Remote Sensing - 5 / 2006.

Lanig, S.; Ludwig, D.; Klaerle, M . 2009 submitted, Modeling Shading for the Automated Solar Potential Analysis on Urban Roof Areas based on LiDAR, InviroInfo09, Berlin.

Ludwig, D., Klärle, M., Lanig, S. 2008, Automated location analysis for solar use on roof surfaces on high-resolution laser scanning data. In: Strobl, J., Blaschke, T., Ebner Gries, G. (Eds.): Applied Geoinformatics 2008 - Contributions to the 20th AGIT-Symposium Salzburg, 466 - 475 . Wichmann, Heidelberg.

Malberg, H. 2007, Meteorologie und Klimatologie Eine Einführung, Springer-Verlag Berlin Heidelberg.

McKenney, DW, Mackey, BG, Zavitz, BL. 1999, Calibration and sensitivity analysis of a spatially-distributed solar radiation model. International Journal of Geographical Information Science, 13, 1: 49-65.

Page, JK, Albuisson, M., Wald, L. 2001, The European solar radiation atlas: a valuable digital tool. Solar Energy, 71: 81-83.

Rottensteiner F., Briese, Ch 2003, Automatic generation of building models from LIDAR data and the integration of aerial images. Paper to Conference: ISPRS, Vol XXXIV, Dresden.

Sander, T. 2006, grid photovoltaic systems, Hüthig & Pflaum Verlag, Munich / Heidelberg.

Schwalbe, E. 2004, 3D building model generation from airborne laserscanner data by straight line detection in specific orthogonal projections, IAPRS International Archives of Photogrammetry and Remote Sensing and Spatial Information Sciences Vol.34, Part 3 B3, pp.249-254.

Sibson, R. 1981, A Brief Description of Natural Neighbor Interpolation, Chapter 2 in Interpolating Multivariate Data, John Wiley & Sons, New York, pp 21-36.

Steinle, E. 2005, Gebäudemodellierung und –änderungserkennung aus multitemporalen Laserscanningdaten Dissertation, DRK Reihe C, 594; URL: http://129.187.165.2/typo3_dgk/docs/c-594.pdf, (last accessed 30.10.2006)