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Applications of solar mapping in the urban environment

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ABSTRACT

Promoting the use of solar energy in urban environments requires knowing the geographical distribution and characteristics of the best places to implement solar systems. In this context, buildings can be used to locally generate electricity. Based on remote sensing data, the city's surface can be modeled and the solar income at each location can be estimated. The present study assesses photovoltaic (PV) potential of residential buildings. Two variables are modeled, the income of solar energy at the roof tops, and the population at the building level. The model is tested in Lisbon, Portugal, using Geographic Information Systems (GIS) based solar models and Light Detection and Ranging (LiDAR) data. The total PV potential is assessed and compared with the local electricity demand. The results constitute an initial assessment of the city's solar potential that can be used to support management decisions regarding investments in solar systems.

Introduction

Local governments are responsible for applying, in their cities, strategic guidelines to improve energy efficiency based on renewable sources. In order to make informed policy decisions, officials need a higher level of detail than the standard numerical analysis (Lamie, Campbell, & Molnar, 2012). Geographic-based approaches are necessary to determine the most suitable locations, to estimate revenues and expenses. In this context, remote sensing technologies can be an effective source of updated geo-information about the urban environment. Through the generation of energy demand and supply scenarios for the city, urban planners and city officials can obtain accurate assessments and decide upon realistic sustainable goals.

Solar energy is one of the best renewable energy sources, having the least negative impacts on the environment (Solangi, Islam, Saidur, Rahim, & Fayaz, 2011). Assessing the city's solar energy potential through solar mapping, constitutes a valuable analytical tool that permits quantifying local capabilities for energy production and use those findings for designing and implementing urban planning energy strategies, in line with sustainable development goals and aims.

Furthermore, solar maps can be updated on a regular basis and thus used for monitoring effects of policy application. Energy production and replacement of fossil fuels by renewable sources, along with energy savings on the demanding side (Lund, 2007), constitute the basis for sustainable energy policies that are concerned with reducing dependence on those fuels, thus gaining in environmental benefits. Such policies can include new legislation and incentives to investment. Knowing the installed capacity for solar energy generation, as well as the geographical distribution and characteristics of the best places for implementing solar systems, can lead to effective expansion of distributed generation of renewable energy in the city.

The residential sector plays an important role in cities' electricity consumption. In Lisbon, capital city of Portugal, about a third of the electric intake is absorbed by the residential sector (Ferreira & Pinheiro, 2011). Solar technology in Portugal is already being valued via the implementation of European Union Directives (Directive 2002/91/EC). This new awareness, associated with the fact that Portugal is one of the European countries with the highest levels of annual solar irradiation (Šúri, Huld, Dunlop, & Ossenbrink, 2007), contributes to a growing interest in the quantification of energy-based indicators at the city and building's scale, in order to assess photovoltaic (PV) conversion and thermal solar potential. In order to propose technical and financial solutions, data on the solar power generating potential of the city is required.

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Planning for energy investments on solar systems requires information on 1) the electric power demand, and 2) on the generation capabilities. Methodologies for energy planning have been addressed in the literature (Cellura, Di Gangi, Longo, & Orioli, 2012; Gadsden, Rylatt, Lomas, & Robinson, 2003; Izquierdo, Rodrigues, & Fueyo, 2008; Mourmouris & Potolias, 2013; Ordóñez, Jadraque, Alegre, & Martínez, 2010; Wiginton, Nguyen, & Pearce, 2010). These studies deal with energy consumption models and the contribution of solar systems for fulfilling that demand. However, either the built structure was not modeled in detail (e.g., Izquierdo et al., 2008; Mourmouris & Potolias, 2013; Wiginton et al., 2010), or it was made through the use of statistical data, or 2D maps obtained from imagery analysis (e.g., Cellura et al., 2012; Ordóñez et al., 2010). Consequently, the incoming solar irradiation at the rooftop was not very accurately estimated.

As far as the generation capabilities of the solar systems, it is important to highlight that to adopt solar technologies, detailed solar suitability information on every building in a community should be available for urban planners (Santos et al., 2011). Identifying buildings that are suitable for solar panel installation requires modeling 1) the built environment, 2) the solar irradiation and, 3) the available area at the rooftops for panels' installation. In the following paragraphs each of these issues is discussed in detail.

The accuracy of urban solar mapping depends, among others, on the quality of the 3D city model. Modeling urban environments can be a difficult task, and constitutes one of the active research topics in Geography. In the last decades, photogrammetric techniques allowed the production of precise 2D maps. But the ability to obtain 3D information over large areas was limited. However, in order to perform accurate estimations of solar radiation, information on roof structure is essential. Several methods for data acquisition are commonly used in this context, such as image matching algorithms, image segmentation or integration of different data sources (e.g., Bergamasco & Asinari, 2011; Izquierdo et al., 2008; Wiginton et al., 2010). Aerial LiDAR currently offers the possibility of producing detailed and accurate 3D city models (Haala & Kada, 2010; Kaartinen et al., 2005; Moreira, Nex, Agugiaro, Remondinoc, & Lima, 2013; Ruiz-Arias, Tovar-Pescador, Pozo-Vázquez, & Alsamamra, 2009). Consequently, airborne LiDAR has become an accurate, cost-effective alternative to conventional technologies for the creation of altimetric data at vertical accuracies that range from 0.15 to 1 m (Gamba & Houshmand, 2002; Hill et al., 2000; Kaartinen & Hyyppä, 2006). There are several approaches to interpolate and construct a 3D urban surface model (incorporating the relief), based on LiDAR and GIS buildings data (e.g., Brédif, Tournaire, Vallet, & Champion, 2013; Carneiro, Morello, & Desthieux, 2009; Rottensteiner, Trinder, Clode, & Kubik, 2003; Santos et al., 2011; Tack, Buyuksalih, & Goossens, 2012; Vögtle, Steinle, & Tóvári, 2005).

The incident solar radiation can be measured by ground-based meteorological stations or meteorological satellites and/or be estimated through models. There are several solar models available in the literature. They vary in the detail of the input parameters and, consequently, in the output map. Solar Analyst (Fu & Rich, 1999) and Photovoltaic Geographical Information System (PVGIS) (Šúri, Huld, & Dunlop, 2005) are two examples of solar radiation models.

Manipulating the solar resources at the building level within a GIS is a straightforward way of identifying appropriate roof areas for panel installation. Applying algorithms to automatically classify and segment data, enables analyzing buildings' roofs according to their slope, azimuth, and shaded areas (Santos, 2011). Knowing the amount of incident solar radiance and the optimal roof areas for capturing that energy, the solar potential of any roof plane can be easily calculated (e.g., Brito, Gomes, Santos, & Tenedório, 2012; Hofierka & Kaňuk, 2009; Jochem, Hofle, Hollaus, & Rutzinger, 2009; Kassner, Koppe, Schüttenberg, & Bareth, 2008; Kodysh, Omitaomu, Bhaduri, & Neish, 2013; Rottensteiner, Trinder, Clode, & Kubik, 2005). This analysis has also been extended to include solar potential of facades and other vertical surfaces (Redweik, Catita, & Brito, 2013).

In the present study, we analyze the rooftops' solar potential contribution for the residential electricity demand at the building level, thus linking technical solar capabilities with user needs. The roofs' PV generation capability is tested using a 3D model of the buildings based on LiDAR data. This approach allows for a detailed estimation of the energy generation through PV since the shadows cast by surrounding buildings and topography, are calculated for each building in the area. Furthermore, the methodology is based on the projected roof area (retrieved from LiDAR data) and local atmospheric effects (obtained from PVGIS). The results are presented in two rooftop exploration scenarios - considering the investment in PV panels for fulfilling electricity demand at the building level and, alternatively, by renting the roof space to third parties and receiving benefits from it.

It is pertinent to clarify that, according to the literature (e.g., Izquierdo et al., 2008), solar potential may be characterized in different hierarchal classes: the total amount of energy received from the sun is the physical potential, while the geographic potential is restricted to the locations where this energy can be captured; the technical solar potential takes into account the technical characteristics of the equipment, including its performance and losses in order to determine the power generated by the PV modules. This work mainly focus on the technical solar potential since it takes into account the effect of the mutual shades between buildings as well as the performance of the modules themselves, via PV conversion efficiency, including the minimum area restriction for viable roof top PV systems.

Methodology

The methodology is a two-stage process. Firstly, PV generation potential of the rooftops is calculated based on the solar incidence on each roof and the available area. Then, the resident population in each building is estimated. Based on the combination of these outputs, two models of rooftop PV exploitation, for energy planning purposes, are analyzed in a study area.

Study area and data set

The methodology is implemented in Alvalade, a parish located in the city of Lisbon, the capital of Portugal (Fig. 1). The parish includes part of the Alvalade neighborhood, a planned zone from the 1940s–50s, characterized by a modern morphology, with residential areas, avenues, squares and school facilities, designed to promote pedestrian movement. The area includes mainly residential five-story buildings with commercial services in the lower floors, green areas (in the web version) and public buildings. According to the 2001 Census (INE, 2001), 9620 people live in this parish.

Within the area, a total of 811 buildings were identified in the municipal cartography. The average footprint is 221.6 m^2.

For solar mapping, a spatial database including planimetric and altimetric data was used (Fig. 2). The planimetric information comprises three sets: the building footprints, the census block groups, and the land use map. The building footprints were obtained from the Lisbon's Municipal Cartography from 1998, at 1:1000 scale, and updated for the year of the LiDAR flight. The census block groups in Portugal are supported by cartography and are available in vector format for every decade. The block group is the finest spatial unit for which the decadal Census reports population and housing data. Land use information was provided by the Urban Atlas, which maps land use for selected European cities,