Solar Potential Analysis in Lisbon Using LiDAR Data

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Abstract. In this work, the goal is to evaluate the roof-top area suitable for installation of solar energy systems in the city of Lisbon, Portugal. The experiment is applied in an area located in heart of the city. A brief technical analysis, considering the optimal location for solar Photovoltaic (PV) systems is performed, but no economic or social parameters are addressed. The data set includes planimetric and altimetric data. The planimetric data that represents the buildings footprints is the Building’s layer of the Municipal Cartography. To characterize the altimetry, the Digital Surface Model (DSM) and the normalized DSM (nDSM) from 2006 were produced based on a LiDAR flight from 2006 and on a Digital Terrain Model (DTM). From this analysis, the building with the highest potential in the study area is a High School, with an estimated production of 142.58 MWh, if the optimal roof area is all covered with PV panels (681 m²).

Keywords. LiDAR, solar, photovoltaic systems, Lisbon.

1. Introduction

The case study presented in this work consists in a methodology for evaluating the solar potential of a city’s neighborhood, based on altimetric data. The motivation for this study is the fact that incorporating solar systems into buildings, offers a mean to locally generate power, based in a renewable source of energy, the Sun. In this context, the use of LiDAR data can play an important role when analyzing the buildings capability for receiving the solar systems.

Identifying buildings that are suitable for solar panel installation requires modeling two variables: 1) the solar radiation incident in each location and, 2) the optimal location for the panels on the roof.

Solar radiation, incident to the Earth’s surface, is a result of complex interactions of energy between the atmosphere and surface. These interactions are determined by three groups of factors: 1) the Earth’s geometry, revolution and rotation, 2) terrain and, 3) atmospheric attenuation. The incident solar radiation can be measured by ground-based meteorological stations or meteorological satellites, 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 and Photovoltaic Geographical Information System (PVGIS) are two examples of solar radiation models.

The Solar Analyst module in ArcGIS can be used to calculate Watt-Hours/meter² at the surface and at the local scale [1]. Inputs to this process are a digital elevation model, the latitude of the scene centre, the sky size, and the date and time one wishes to accumulate insolation and radiation parameters such as Transmisivity and Diffuse proportion. Therefore, the model accounts for atmospheric effects, as well as site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the Sun angle, and effects of shadows cast by surrounding topo-
The PVGIS, developed by the JRC, allows users to estimate solar energy performance at any given location. PVGIS developed a GIS-based methodology for computation of solar irradiance/irradiation at a given surface inclination for any geographical region and for any time moment or interval. This approach has been implemented in the GIS software GRASS and it is based on use of the solar radiation model r.Sun, and the spatial interpolation techniques s.surf.rst and s.vol.rst. For each time step during the day the computation accounts for sky obstruction (shadowing) by local terrain features (hills or mountains), calculated from the digital elevation model. This model is a grid with 1 km resolution, derived from the USGS Shuttle Radar Topography Mission (STRM) data. PVGIS provides a solar radiation database for the European Subcontinent, the Mediterranean Basin, Africa and South-West Asia.

Regarding the panels’ optimal location stage, manipulating LiDAR data within a GIS is a straightforward way of identifying appropriate roof areas. Applying algorithms to automatically classify and segment LiDAR data, enables analyzing buildings’ roofs according to their slope, azimuth, and shaded areas.

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., [2], [3], [4], [5]). The potential can be evaluated regarding electricity production (photovoltaic solar panels), or water heating capabilities (thermal solar panels). The knowledge of solar accessibility on urban surfaces, allows investigating the energy-performance of cities, namely the environment and the economic impact of using solar energy. On the environmental side, factors like absence of pollution or generation of greenhouse gases can be evaluated [6] [7]. On the economic potential of solar panels, analyzing factors like the payback period based on current prices, gives the expected cost of the energy produced by the solar energy system, averaged over the lifetime of the system (e.g., [8]).

### 2. Study area and data set

The experiment is applied in an area located in heart of the city of Lisbon – Avenidas Novas – that occupies 625 ha (2.5 X 2.5 km). The street network is dense and most of the area is built-up, including three major avenues, green areas, multi-family housing, commercial areas and two university campus (Fig. 1).

The spatial database used in this case study included planimetric and altimetric data. The planimetric information was the Building’s layer of the 1:1000 scale Municipal Cartography from 1998. The altimetric data was derived from a LiDAR point cloud. From a flight with a LiDAR camera performed in 2006, a surface image was produced based on the 2nd return, with 1 m resolution. This image represents the DSM of the area (Fig. 2).

All files were geometrically corrected to attribute a common coordinate system (PT-TM06/ETRS89).
Figure 1: Study area for Solar Potential Analysis in Lisbon.

Figure 2: Digital Surface Model of the study area
3. Methodology

Identifying the solar income at the buildings’ level requires modelling the solar radiation incident in each location. Two inputs are required: a DSM and the buildings’ footprints. With these data, modelling the solar radiation can be done in a GIS environment. A four-step methodology is proposed: calculating the solar energy for the whole surface, assessing it at the roof-tops, locate the best sites for PV panels’ installation, and assessing the energy produced.

3.1. Solar energy at the surface

The first methodological step for evaluating the solar potential of the study area, is obtaining the solar energy at the surface level. This is accomplished with the Area Solar Radiation tool, available in ArcGIS, that derives the total amount of incoming solar radiation (direct + diffuse) calculated for each location of the input raster surface. The model accounts for site latitude and elevation, surface orientation, shadows cast by surrounding topography, daily and seasonal shifts in solar angle, and atmospheric attenuation [1]. Therefore, by inputting the local DSM, the tool, after parameterization, produces a solar map that accounts for local topographic influences on solar radiation over the study area. This aspect is particularly important in urban areas, where shadowing effects are very common.

The procedure was applied in a monthly basis, producing a solar map for each month. Then, all 12 maps were summed up and the annual solar radiation at the surface, in Wh/m², was calculated (SolarSurf).

3.2. Solar energy on the roof-tops

After calculating the irradiation at the surface level, the next step is detailing the amount that reaches each roof-top, using the buildings’ footprints.

Due to DSM imprecision along the buildings’ limits indicated on the Buildings layer, only pixels with values lower or equal to 45° in the slope map were selected for roof-top analysis. This value was empirically obtained with the intent of eliminating pixels with elevation values that corresponded to facades. Therefore, in the next step, when combining the SolarSurf with the Building layer, roof-top pixels were correctly identified. The number of buildings evaluated in the next analysis was then 12344. Furthermore, based on the DSM, the projected area of each pixel was calculated. The SolarSurf, corrected for the pixel’s projected area, was then combined with the Buildings’ layer. This operation produced the map with annual solar radiation available at each pixel of the roof. Averaging the energy of all pixels of each roof, created the map with the mean annual solar radiation available at each roof-top (SolarRoof).

3.3. Best roof-top locations for solar photovoltaic systems

After assessing the radiation at the roof-top, the selection of the best locations to install Photovoltaic (PV) panels was addressed. Two assumptions were considered: only pixels with annual radiation equal or higher than 1.68 MWh/m² were considered for PV installation and, due to the minimum requirements for solar system sizing, only the contiguous areas in each roof that were equal or higher than 10 m² were considered. Applying these constraints in the layer with the annual solar radiation available at each roof-top, the map with the location of each PV panel is calculated. As expected, the amount of buildings suitable for solar energy systems was lower than the original number investigated. In fact, from the initial 12344 buildings, only 6075 (49%) had good solar conditions and appropriate size to install PV panels, considering the solar and area limitations selected in this study.
3.4. Energy produced at the best roof-top locations

At this stage, a brief technical analysis of photovoltaic panels is made. Only conversion efficiency is considered. This variable stands for the capability of solar cells for converting the energy of incoming light into electrical energy. Considering now that PV modules have a typical efficiency of 15%, and that of those 25% are lost in conversion [9], the final efficiency of the PV system is 12%. Applying this value to the solar energy reaching the PV panels, an estimation of the annual photovoltaic energy produced at each roof-top was assessed.

4. Results and discussion

Fig. 3 shows the energy produced annually by solar PV systems installed at the best suitable roof. From this analysis, the building with the highest potential in the study area is the D. Luisa de Gusmão High School (area 2 in Fig. 3), with an estimated production of 142.58 MWh, if the optimal roof area is all covered with PV panels (681 m²).

Note that artifacts like roof overhangs, chimneys, dormers, antenna, were not considered by our methodology. To be integrated in this analysis, such identification requires more precise laser intensity values or additional spectral information.

To set up solar technologies, detailed solar suitability information on every building in a community should be available for urban planners. An efficient tool to address community energy objectives are interactive web-based urban solar maps. Such maps take advantage of GIS and visualization technologies, offering a solid knowledge base on available solar resources and best practices in solar energy technologies, providing a unique guide to the solar industry and the general public. Furthermore, solar maps also offer a comprehensive planning tool to the municipalities, allowing evaluating energy reduction opportunities for new and already existing buildings, plan the future energy consumption and supply, or monitor the compliance with energy and greenhouse gas goals.

Based on these premises, a map with the solar potential of rooftops located in a study area, in the city of Lisbon, was produced. This LiDAR-based solar resource map helps rate buildings and houses by solar resource available and provides unique information on which parts of the buildings’ roof are more suitable for solar applications when all critical factors are considered. Using this information, detailed solar generation potential maps can be developed.

Future developments include making this solar analysis map available in widespread visualization software like Google Earth.

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Figure 3: Energy produced annually by solar photovoltaic systems installed in roofs best suitable
References


