SOLAR PANEL SUITABILITY MAP AND ASSESSMENT OF THE LOCATION OF INSTALLED PANELS IN ROOFS IN THE MUNICIPALITY OF VITORIA-GASTEIZ (ALAVA, SPAIN)

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Abstract

Dependency on unsustainable energy sources like fossil fuels is at the stake due to their contribution to global warming and climate change. The pursue of development and exploitation of alternative, cost-effective and environmentally friendly energy sources like renewables energies is vital for the reduction of greenhouse emissions to the atmosphere. Solar energy is a freely available renewable energy with great potential and comparatively free of CO2 emissions. This work focuses on the installed solar capacity in Vitoria-Gasteiz, a medium-sized city of about 250,000 inhabitants in the Basque Country, north of Spain. A roof suitability map has been produced using a potential solar radiation algorithm together with a highly resolved 1m Digital Surface Model (DSM) derived from LiDAR data. Location and orientation of solar panels on roofs of city buildings have been manually digitized from ortophotos, which resulted in 1,349 photovoltaic solar panels polygons on 183 buildings and a total horizontally projected surface of 22,253 m2. By comparing the radiation impinged on the area covered by the PV panels with the potential energy of the whole roof area, a usability rate was calculated and 49 installations found to be located in unsuitable locations. The findings identify a considerable number of installations for which the efficiency of the installation is low but could be easily improved by simply relocating the panels in a more suitable fashion in the same building.

Keywords: solar panels, suitability map, solar radiation, LiDAR

1. Introduction

According to Intergovernmental Panel on Climate Change (IPCC), the harmful impact of current energy model, globally based in 86% in fossil fuel and nuclear sources, in climate change is undeniable [1]**]**. In order to mitigate the climate change effects and not to surpass the limit of two degrees established by the IPCC, director of NASA stated, it is not sufficient to set limits for CO_2 produced by burning fossils fuels but "we must identify a portion of the fossil fuels that will be left in the ground" [2]. A recent study confirms this theory: "a third of oil reserves, half of gas reserves and over 80 per cent of current coal reserves should remain unused from 2010 to 2050 in order to meet the target of 2°C" [3]. Furthermore, the run out speed of the world oil reserves seems to be imminent; the Association for the Study of Peak Oil and Gas (ASPO) "[…] world oil production might be down by 50% around 2030." [4]**.** Lastly, fossil fuel based energy model has not only climate change or resource depletion limits but also international social conflicts. Given the lack of global homogeneity in the distribution of fossil fuels and the need for high-cost technologies for their extraction, socio-political conflicts derive from the supply of fossil fuels are becoming more frequent [5].
Consequently, the shift towards a more sustainable energy model requires that a significant fraction of this energy demand can be fulfilled with local, clean and democratic sources of energy. Solar power is an unavoidable piece of the fabric of sustainable cities; solar power is plentiful in most regions of the globe, it is a renewable source of energy and CO_2 emissions free [6].

In Spain, three distinct stages can be defined for the installation of renewable energy systems (RES) during the last 30 years. The first stage lasted from 1997 to 2007 and was triggered by Royal Decree 54/1997 [7] and the corresponding governmental incentives, so-called Special Regime, that set generous feed-in tariffs that made solar PV generation rather profitable

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particularly during the second half of the period. The second period, from 2008 to 2015 started with Royal Decree 1578/2008 [8] and was followed by a third Royal Decree 1/2012 [9], which reduced feed-in tariffs drastically, making many RES installations not viable. The third period, from 2015 to date, was marked by Royal Decree 900/2015, which established a tax on self-consumption from PV installations, thus penalizing the democratic use of a source of great potential but also making solar energy installations not viable.

Spain, one of the European countries with the most hours of sunshine has defined in the Code of Technical Building [10] that all new buildings are required to install solar thermal energy systems. This law has supposed a definitive impulse to this technology, because the minimum of the total hot water demand must be 70% from solar thermal systems. In recent years, there has been a notable increase in solar thermal installations due, on the one hand, to the greater social and political sensitivity towards environmental issues and, on the other hand, to the continuous improvement and reduction of costs of solar thermal systems [11].

This paper aims to be a technical contribution towards the optimization of the installation capacity of solar PV in buildings. Similarly, several recent works have been conducted to assess the solar potential in roofs and facades using Light Detection and Ranging (LiDAR) data (for example, [12], [13], [14]). Nowadays the cost of LiDAR data is comparatively low and the data is often provided by state or local governments. That is the case of the Basque Autonomous Community, where LiDAR data is freely available from the Basque Country Spatial Data Warehouse [15].

At the onset, this research work set three main objectives: the first two were so to provide generate information required by local authorities and government managers to improve energy policies;

i) To produce a roof suitability map in Vitoria-Gasteiz for the suitable location of solar panels (thermal and PV)
ii) To quantify the total surface area of solar panels already installed in Vitoria-Gasteiz.
iii) To assess the percentage of the panels installed suitably located maximizing the available solar radiation.

2. Methods

2.1. Study Areas

This research work has been conducted in Vitoria-Gasteiz, the seat of government and the capital city of the Basque Autonomous Community and of the province of Araba, in northern Spain (Figure 1). The municipality — which comprises not only the city but also the mainly agricultural lands of 63 villages around — is the largest in the Basque Autonomous Community, with a total area of 276.81 km^2 and it has a population of 242,082 people (2014). The total primary energy supply (TPES) per capita of the Basque Country has reach the historical maximum in 2008 42.76 kWh/year, 21% more than the average Spanish state consumption in the same year. Nevertheless a new tendency of de-growth has occur during the last years, specially due to the economic crisis, the relocation of good and services production in more profitable countries and limits of fossil fuels based energy model, has reduce in 23% the regional average TPES, with an average consumption of 33.28 kWh per capita and year, still 15% higher than the national average [16].

This research work has been conducted in Vitoria-Gasteiz, the seat of government and the capital city of the Basque Autonomous Community and of the province of Araba, in northern Spain (Figure 1). The municipality, which comprises the city itself plus the main agricultural lands of 63 villages surrounding it, is the largest in extension of the Basque Autonomous Community, with a total area of 276.8 km2 and a population of 242,082 (2014). The total primary energy supply (TPES) per capita of the Basque Country has reached a historical maximum of 42.76 kWh/year in 2008, 21% more than the overall average in Spain. Remarkably, a de-growth trend has been observed during the past few years, due to the acute economic crisis, the progressively increasing relocation of the production of goods and services in foreign countries, and limits on the energy model based on fossil fuels. This has resulted in a reduction of 23% of the regional average TPES, with an average consumption of 33.28 kWh per capita and year, still 15% higher than the national average [16].

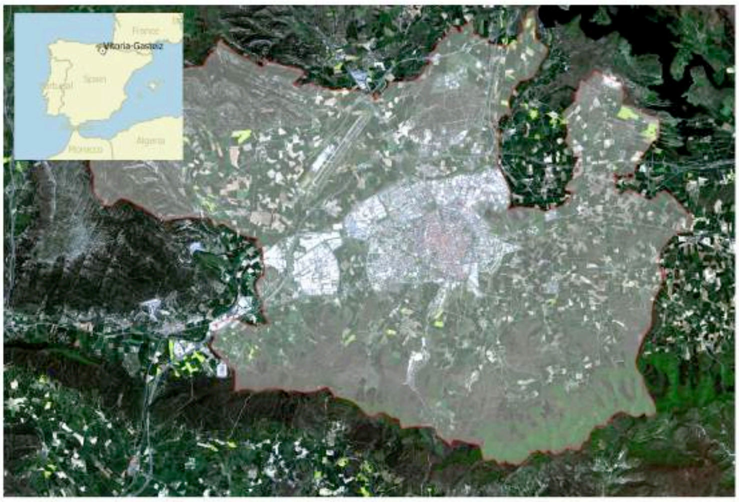

***Figure 1**. Location of the municipality of Vitoria-Gasteiz, where the research study has been carried out*

2.2. Data

Three main geospatial sources have been employed, all freely available by the Basque Government Spatial Data Warehouse, GeoEuskadi (http://www.geo.euskadi.eus).

i) The Digital Surface Model (DSM) derived from a LiDAR flight in 2012, a 1 x 1 m^2 spatial resolution product that captures the elevation of natural and man-made features on the Earth's surface. This data has been used to compute the solar radiation for each pixel.
ii) The ortophoto derived from the flight done during the summer of 2012 by the Basque Government, a cartographic document adjusted for topographic relief, lens distortion, and camera tilt. This ortophoto has a spatial resolution of 25 x 25 cm^2 and has been used for digitizing the extent of the solar panels.
iii) The 1:5000 buildings scale vectorial cartography, obtained by restitution of photogrammetric techniques

2.3. Digitizing the solar panels

Solar panels on building roofs are clearly distinguishable in ortophotos, as they consist of rectangular-shaped panels of characteristic dark color and high contrast against the roof background. Panels have been digitized in groups, that is, one polygon for each group of contiguous panels. When digitizing over a conventional ortophoto the main problem is the distortion of position and shape for elements elevated from the ground, because the images are corrected at ground level. Generally, solar panels are located in elevated locations from the ground and their location appear shifted due to heights hat have not been removed. An example of these spatial inconsistencies is shown in Figure 2a, where the digitized panels are unrealistically shown outside of the building perimeter (the blue line shows the correct position of the building, as correctly mapped by restitution). To get around this inconvenience, all the digitized locations of the panels have been manually adjusted so that they fit within the building perimeter as shown in Figure 2b. As a result, all the solar panels were correctly located within the building perimeters and showing their real location.

a) **b)**

***Figure 2**. a) Original digitized solar panels b) Displaced digitized solar panels*

2.4. Solar Radiation computation methodology

The Open Source System for Automated Geoscientific Analyses (SAGA http://www.saga-gis.org) software has been used to compute the potential incoming solar radiation, specifically the "Potential Incoming Solar Radiation" module in particular and its algorithm described in [17]. This package can compute both the direct and diffuse solar insolation considering the Digital Surface Model (DSM) provided. To obtain a solar insolation time series, a period has been defined from 1st January to 31st of December 2012, with a temporal resolution of 30 minutes so that the accumulated solar irradiation through the day is computed. A solar constant of 1,367 W/m^2, a sky view factor based on local slope has been used, together with the standard default parameters (lumped atmospheric transmittance of 70%, height of atmosphere 12,000 m, barometric pressure 1,300 mbar, average water content of a vertical slice of atmosphere 1.68 cm and dust factor 100 ppm). The Total Incoming Solar Radiation raster is obtained adding the Direct and Diffuse Radiation.

2.5. GIS/Statistical Analysis

The following methodology has been used to achieve each of the partial objectives:

i) The Total Incoming Solar Radiation raster has been segmented into vector polygons using the Meanshift algorithm (firstly proposed in [18]) in the Orfeo Toolbox Implementation (https://www.orfeo-toolbox.org/Applications/Segmentation) with default parameters and a minimum polygon size that has been set to 10 pixels (10 m^2). Only the polygon calculated that intersect the buildings have been selected, and the mean value of Total Radiation for each polygon has been calculated. Subsequently a statistics analysis has been done to set the solar radiation shown in Table 1 set to obtain the suitability map.

Table 1. *Roof areas suitability to locate panels*

Criteria (Total Radiation Segments)	Suitability
< 25^{th} Percentile	Very inadequate
25^{th} – 50^{th} Percentile	Inadequate
50^{th} – 75^{th} Percentile	Adequate
> 75^{th} Percentile	Optimum

ii) The panels located in the roofs of Vitoria-Gasteiz are directly obtained from the manually digitized panel polygons. The real panel surface is higher than the projected one digitized, but the 1 m DSM is not enough to compute the value of the slope with confidence. For communications with one of the company that installs panels on the Basque Country [19] three values have been considered: 20º (some installations use the roof slope), 35º (the usual installation tilt angle for those roofs that are horizontal) and 45º (for those panels that are thermal).

$$\text{Inclined surface} = \text{Projected surface} \ / \cos(\text{tilt\_angle})$$

iii) To assess if those panels already working on the roofs are located in the best possible location, the radiation recorded in the roof of the building and that obtained in each panel are compared. Specifically, the 90^{th} percentile recorded in each panel is compared to 50^{th} percentiles of the building.

3. Results

The statistical analysis (see boxplot at Figure 3a) of the radiation received on roofs, after the segmentation of the Total Solar Radiation, has been defined as "adequate" when the mean radiation of the segments is higher than 1,053 kWh/m^2 year (50^{th} percentile) and "optimal" when is higher than 1390 kWh/m^2 year (75^{th} percentile). These thresholds are directly applicable to the segmentation to obtain the roof suitability map (Figure 3b).

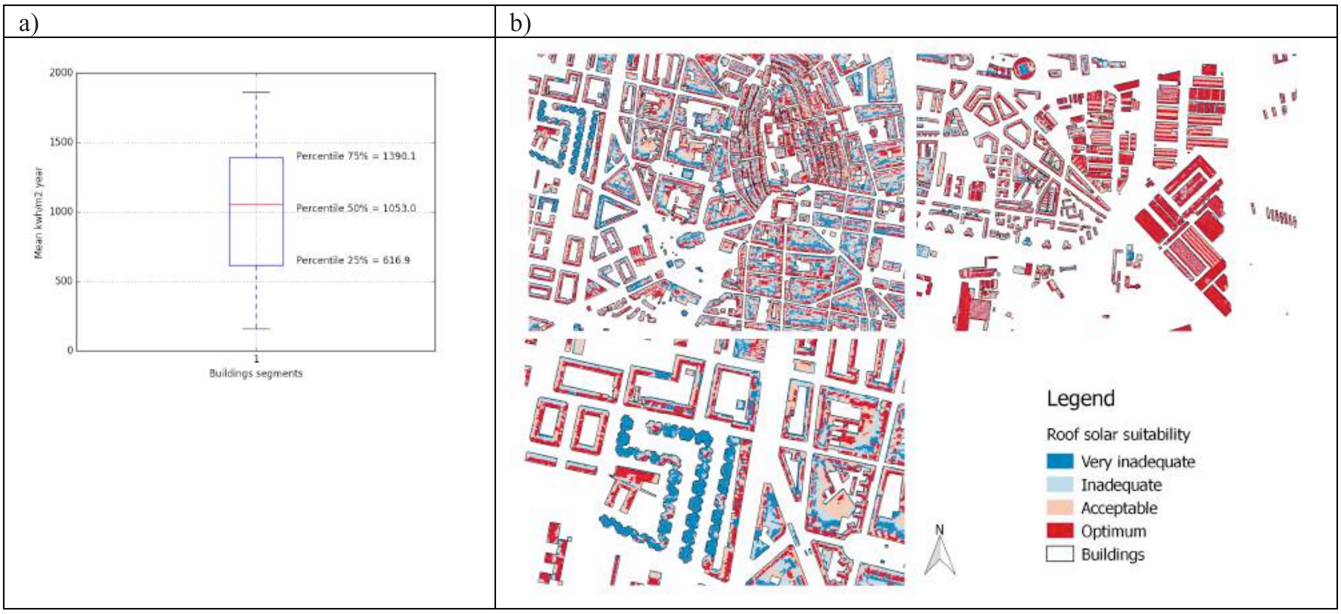

***Figure 3**. a) Boxplot of the segments obtained using the Total Solar Radiation located in roofs (the sum of Direct and Diffuse radiation) b) Roof solar suitability on the roofs of Vitoria-Gasteiz, three detail maps*

As part of the work done towards the second objective, 1,349 solar panel polygons have been digitized, with 22,253.178 m^2 of projected surface. Assuming that the real varies from 20 to 45º, a range of surface area from 29002 m2 and 38541 m2 has been mapped. Note that thermal and photovoltaic panels have not been able to be differentiated in the ortophoto. This surface of solar panels are located in 183 buildings (less than the 2% of the buildings of Vitoria-Gasteiz), most of them on residential buildings (85% approximate) and the rest on industrial buildings (15%). Recently build neighborhoods are the areas with a higher solar panel existence (basically Zabalgana neighborhood on the West side and Salburua neighborhood on the East side; figure 4), related to the Code of Technical Building that was introduced in 2007 that makes compulsory the use of solar thermal panels to have a minimum of the total hot water of at least 70% from renewable energy sources (Figure 4).

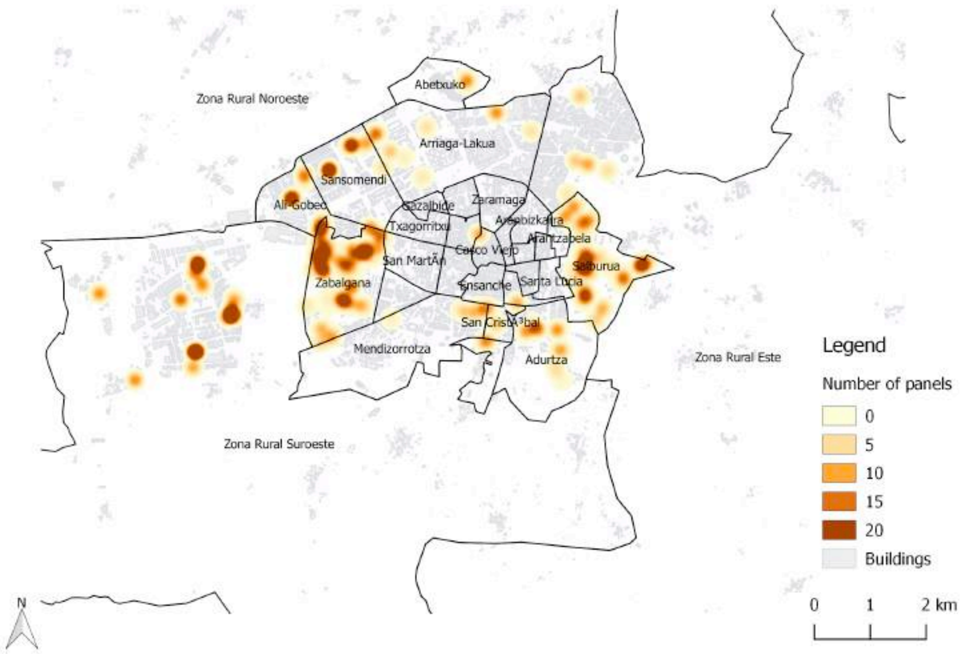

***Figure 4**. Heatmap of location of solar panels in Vitoria-Gasteiz*

The radiation recorded on the panels and that recorded on the buildings where these are located shows that 49 solar panels (3.6% of them) are located in areas where the radiation received is lower that the 50th percentile of the building. This means that there is a high likelihood to establish a better location of those panels.

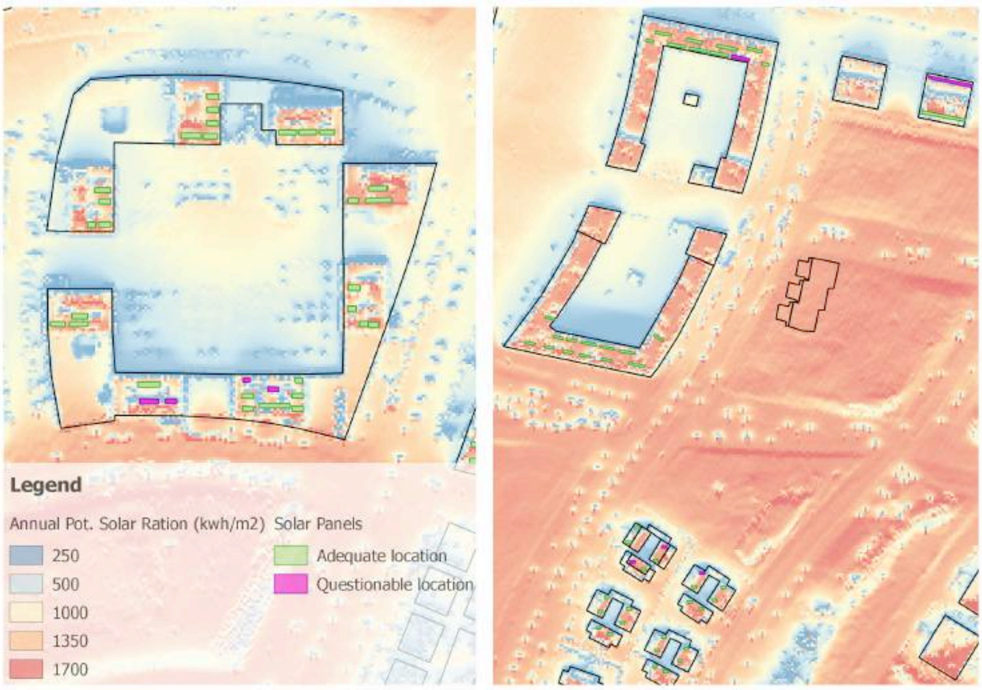

***Figure5** . Adequate (in green) and questionable (dark pink) location of panels. The questionable panels are located in buildings that have a 50^{th} percentile of total radiation higher that the 90^{th} panel, showing that a better location at the same roof is highly likely.*

4. Conclusions

This study includes some useful information both for local government that we believe will benefit of information of the roof solar panel suitability map to invest more effectively the public money on clean energy sources. Also the information about the total solar panels surface installed may be very useful for municipal regulations. Finally, the analysis of the location of individual panels may be useful for the particulars intending to improve the efficiency of their installation by relocating panels with very limited cost.

5. References

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