Building rooftops photovoltaic potential in mountainous regions: a case study from the Pyrenees

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1. Introduction

Nowadays, buildings account for 40% of total final energy consumption and 36% of CO_2 emissions in the European Union (EU). The EU has set itself a long-term goal of reducing greenhouse gas emissions by 80-95% when compared to 1990 levels by 2050 (European Commission, 2016).

This context points to the need for countries to dedicate greater efforts in implementing effective policies that focus on minimising buildings energy-related CO_2 emissions. Solar energy technologies are expected to contribute to addressing this challenge in a near-future (IRENA, 2016). Solar PV rooftop systems have shown the capacity to convert residential and commercial neighbourhoods into distributed power generation areas (Barrier and Irvine, 2015; James et al., 2011). Urban areas provide a large amount of unused rooftop with an important electricity generation potential. Major cities, such as Barcelona or Boston, have characterized their building rooftops to estimate PV electricity generation potential and show the obtained results in a public webapp to encourage citizens to install generation systems[1].

Many methods of estimating rooftop PV potential have been developed, ranging from simple multipliers of total building space to methods that employ complex geographic information systems (GIS) or three-dimensional (3D) models. Unlike simple methods, GIS-based 3D models are more detail-specific and replicable across multiple regions. On the other hand, these methods are time and computer resource-intensive (Melius et al., 2013).

This paper describes a case study for the assessment of building rooftops PV electricity generation potential in two mountainous areas (Escaldes-Engordany in the Principality of Andorra and Tavascan in Catalunya). Its location, in the middle of the Pyrenees, means that surrounding mountains generate shadows that can reduce significantly PV potential. A GIS-based 3D analysis is conducted to represent accurately urban areas and surrounding topography

2. Aim and approach used

Main objectives of this paper are estimate building rooftops PV potential of two mountainous urban areas (Tavascan and Escaldes-Engordany) and quantify the impact of topography in the availability of incident solar radiation. Tavascan and Escaldes are villages with around 100 and 15000

[1] Interesting example: https://www.mapdwell.com/es/solar/boston

inhabitants, respectively, and can be considered as representative of small and medium-sized urban areas in the Pyrenees.

The estimate of rooftop suitability for PV is conducted using light detection and ranging (LiDAR) data and Solar Analyst, the ArcGis extension for modelling solar radiation (Fu and Rich, 1999).

The methodology employed in this paper is represented in the flowchart in Fig. 2. It consists of five steps which are detailed bellow.

(1) The area of interest is identified using a 5x5 m digital elevation model (DEM) and the *viewshed*[2] tool included in ArcGis 3D Analyst. This tool determines the raster surface locations visible to a set of observer features. In our case, visible locations determine the surrounding topography which is affecting rooftops solar radiation. DEM area needs to be limited to avoid excessive computation time but it must include all areas that could shadow the roofs.

(2) The next step is create a high resolution 3D model to represent buildings accurately. Although 5x5 m DEM is enough to represent the topography, urban areas needs better resolutions. In our model we use LiDAR data with 1 m point spacing, the minimum to reflect accurately characteristics of the rooftop, such as roof slope, roof orientation, and adjacent structures and vegetation (Kodysh et al., 2013).

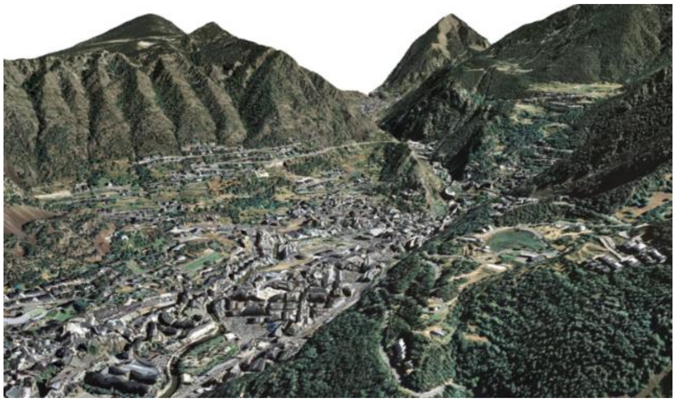

Fig. 1. High resolution 3D model of Escaldes-Engordany and surrounding topography

(3) Global solar radiation is calculated using the Area solar radiation[3], included in ArcGis Spatial Analyst toolbox. This tool derives incoming solar radiation from a raster surface. Table 1 shows the parameters considered in the analysis. It must be emphasized that `Calculation directions` value is set to 32. Typically, a value of 8 or 16 is adequate for areas with gentle topography, whereas a value of 32 is adequate for complex topography. Increasing the number of directions increase accuracy but also increase calculation time.

Day interval	14
Hour interval	1
Calculation directions	32
Zenith divisions	8

[2] http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/viewshed.htm

[3] http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/area-solar-radiation.htm

Azimuth divisions	8
Diffuse model type	UNIFORM_SKY
Diffuse proportion	0.3
Transmitivity	0.5

Table 1. Parameters used in the solar radiation calculation

(4) The next step is the extraction of solar radiation values for each roof. The simplest method consists in using buildings footprints. In both cases, Tavascan[4] and Escaldes-Engordany[5], we use topographic maps included in public databases applying some manual corrections to represent accurately the rooftop outline.

(5) The last step in the methodology is to determine the PV potential of the buildings converting insolation falling in a given area into electricity. In this calculation we use 250 Wp; 1.7 m^2 PV modules, an overall system efficiency of 80% and we have considered a useful area of 75% to exclude architectural and technical elements present in the roofs.

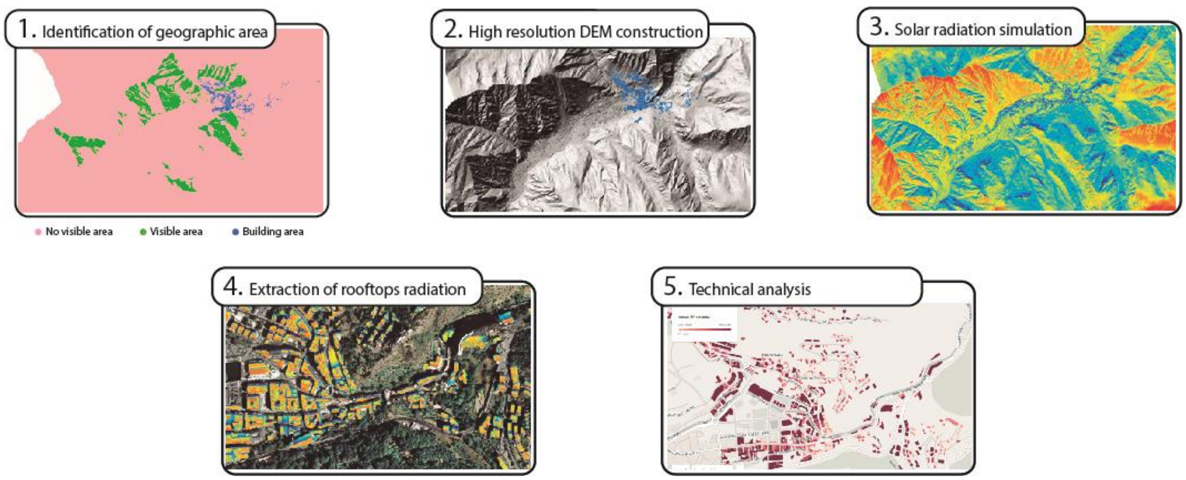

Fig. 2. Flowchart of the methodology to estimate rooftops PV potential

Finally, in order to quantify the impact of the topography we build a DEM (step 2) of the urban area without including surrounding topography. Then we repeat steps 3, 4 and 5 and compare obtained results.

3. Scientific innovation and relevance

Although there is a fair amount of studies analysing rooftop PV potential using LiDAR data (Brito et al., 2012; Kodysh et al., 2013; Redweik et al., 2013), most of them are developed in flat areas where there is no influence of topography. As far as we are aware, only one study (Mavromatidis et al., 2015) is conducted in a mountainous region.

[4] http://www.icgc.cat/en/Public-Administration-and-Enterprises/Downloads/Topographic-cartography

[5] http://www.ideandorra.ad/geodades/

The main innovation of our paper is the numerical quantification of the impact of the topography. Obtained results are specific for two zones in the Pyrenees but can be used as a reference for other mountainous regions without the resources to conduct a GIS-based 3D analysis.

The methodology used in this work is similar as used in other papers (Kodysh et al., 2013) but we introduce the use of viewshed method to determine the geographic area of interest which is fundamental in mountainous areas to include influent topography in the model. This study represents the first rooftop solar PV potential analysis conducted in Andorra and in the Pyrenees using high resolution 3D models.

4. Preliminary results and conclusions

Results obtained in the analysed areas show an overall PV roof potential of 21 GWh/year in Escaldes and 780 MWh/year in Tavascan. Considering the local residents and the average electricity consumption in Andorra and Catalunya, we conclude that covering all roofs with PV technology would satisfy 21% and 127% of the demand in Escaldes and Tavascan, respectively.

As it was expected, the surrounding topography reduces PV potential. The impact of this factor ranges from 3.4% in Escaldes and 12.8% in Tavascan. The location of the latter in a closed valley could be the main reason for this significant reduction.

The next steps in this work involve a GIS-based analysis of roofs architectural characteristics and physical characteristics of surrounding topography. Further work should be focused on expanding the study to other mountainous areas to extend the sample of results.

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