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A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations

Salvador Izquierdo, Marcos Rodrigues, Norberto Fueyo *

Fluid Mechanics Group (University of Zaragoza) and LITEC (CSIC), María de Luna 3, 50018 Zaragoza, Spain

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Abstract

A rigorously founded assessment of the potential of renewable energies is essential for the development of energy policies and regulations. Usually, a hierarchy of potentials are calculated which gradually include restrictions for the use of a specific renewable resource. This paper deals with the estimation of the technical potential of roof-integrated photovoltaic systems. The most restrictive step when estimating this potential for large-scale territories is the estimation of the roof available area in existing buildings, for which no direct data exists. The methodology proposed in this paper allows to estimate the roof area available for solar applications and also quantify the error made in this estimation. It is based on easily accessible data (such as land uses and population and building densities) and on a statistically representative stratified-sample of vectorial GIS maps of urban areas. The main point in this sampling process is that the stratification is done based on a finite set of average building typologies which comprises every urban area in the region of study. An interesting characteristic emerging from the proposed methodology is its scalability and the possibility of being used from regional to continental scales. This methodology is applied in this work to Spain and a mean available area for photovoltaic equipment on roofs of $14.0 \pm 4.5\ \mathrm{m}^2/\mathrm{ca.}$ with a confidence level of 95% is obtained. Additionally, results are given for the technical limit of production of roof-integrated photovoltaic energy.

Keywords: Photovoltaic; BIPV; Representative sample; Renewable energy; GIS

1. Introduction

Policy-making for the successful development of renewable-energy markets relies heavily on the assessment of the implementable potential and of its economically-feasible bounds. An interesting segment of these markets is the one corresponding to building-integrated applications (such as photovoltaic and solar thermal energies), which require an estimate of the surface area available (roof and façades) for equipment installation to accurately assess their potential. The solar-energy and building sectors, and energy policy makers, use this information to evaluate opportunities, applications and new equipment developments.

This work addresses roof photovoltaic applications, but the roof area estimation is also a fundamental input for the knowledge of the solar thermal potential in buildings (Castro et al., 2005) and for evaluating the potential use of rainfall-water (Ghisi et al., 2006). Several considerations

Abbreviations: RBT, Representative Building Topology; ca., capita; GIS, Geographic Information System; HVAC, Heating, ventilating, and air conditioning; H, high; L, low; M, medium; n.a., not applicable; PV, photovoltaic; VH, very high; VL, very low.

* Corresponding author. Tel.: +34 976762153; fax: +34 976761882.
E-mail addresses: Salvador.Izquierdo@unizar.es (S. Izquierdo), Norberto.Fueyo@unizar.es (N. Fueyo).

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Nomenclature

$\mathbb{A}$	unit work area (dimensionless)
A	area (km^2)
C	coefficient (dimensionless)
CV	coefficient of variation (dimensionless)
D_x	density (number of x over A_u in km^2)
e	relative error (dimensionless)
E	absolute total error
n_0	first approximation to the number of total samples ($\mathbb{A}$)
n_k	number of samples in each stratum (RBT) ($\mathbb{A}$)
N_k	number of individuals (municipalities) in each stratum (RBT) ($\mathbb{A}$)
N	number of individuals (municipalities) in the population of study (Spain) $\mathbb{A}$
NOCT	normal operating cell temperature (°C)
p	proportion (dimensionless)
t_α	cutoff point for a cumulative value of the normal distribution equal to the confidence level α
α	confidence level (dimensionless)
β_p	temperature coefficient of power (%°C)
Π	potential ($kWh/year$)

Subscripts

a	available
b	building
c	coefficient
f	facility
i	generic index for RBT's
k	specific index for RBT's
nc	not covered (by Corine)
p	population
r	roof
s	shadow
u	urban
v	void

must be made in order to compute the roof area available. The number and height of the buildings, the population density and the construction typologies influence the built-up surface area. Additionally, limitations such us orientation, inclination, location, shading, historical considerations, and other competing uses (such as HVAC installations, elevators, roof terraces or penthouses) determine the relation between built-up and roof-top available area.

In several studies on building-integrated solar-energy applications, the amount of available area is an input data (Castro et al., 2005; Sorensen, 2001). Because no immediate statistical information is available, a method must be developed to estimate these areas. Ideally, a method (or model) to calculate the available roof surface should: (a) be accurate; (b) be reliable, with the possibility of computing or bounding the error of the roof area estimation; (c) be inexpensive (low cost); (d) be efficient (low calculation times); (e) require few, global, available and standard input data; (f) produce geo-referenced results; (g) be scalable from local to global scales; and (h) be structured and flexible, so that new or unforseen aspects can be introduced, and that the method can be used for the estimation of the long-term evolution of available roof surfaces.

One of the most important aspects to be considered is the size of the area being studied. Very often the same techniques cannot be applied at local and regional or world scales. For instance, it may be possible to quantify the shadowing effects among buildings with a digital three-dimensional model of a city (Robinson, 2006), but this is not a practical option when the scope of a study is a whole continent. For similar reasons, homogeneous or average data is usually considered as first approach (Sorensen, 2001) for large-scale studies, which is obviously inaccurate but inexpensive indeed. More complex approaches appear to have been followed by the International Energy Agency (IEA) IEA (2002) or Greenpeace (2005). The IEA estimates average roof areas for members states; albeit their procedure is not described in detail, their results are often used as a reference given the lack of other data sources. On the other hand, GreenPeace uses actual data for the number of buildings in Spain to estimate the amount of total available area for roofing and façade solar applications; but the whole procedure is neither detailed.

This paper attempts to redress the apparent lack of a methodology to compute an estimation of the available roof area surface for solar applications. Façades are not considered in this work but their estimation can also be straightforwardly integrated in the process in several ways. The methodology is applied to Spain and results for the technical potential of roof-top solar energy are presented. The work is confined to buildings within urban areas (whichever its use: residential, agriculture, commercial and utilities), and excludes those within urban industrial land uses as defined by Corine (2000). The methodology developed is intended to fulfil most of the ideal requirements enumerated above.

The data are processed with the aid of a Geographical Information System and a host of specifically written Linux-shell scripts to process the data. A plug-in by the Spanish cadastre (Catastro, 2006) for Google Earth™ [1] is used to obtain urban maps.

The remaining sections in this paper are organized as follows: first the hierarchical methodology used to systematically compute the physical, geographical and technical limits of photovoltaic solar energy in roofs is presented.

[1] Google Earth is a trademark of Google Inc.