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Review

Applying LIDAR datasets and GIS based model to evaluate solar potential over roofs: a review

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Abstract: The precise knowledge of the capacity to produce energy from renewable resources requires an adequate study to determine the spatial dimension of the territory. The aim of this paper is to present diverse procedures for the solar potential analysis in urban environments. Models and tools, based on the implementation of geo-information technologies and airborne remote sensing data, have been developed considering a certain level of complexity, where urban structure is composed of different areas characterized by their morphology and function. Before any analysis, establish the available information and define the three-dimensional modeling of the urban environment are the first actions. In addition, techniques for the treatment of data and assess the parameters needed to define the optimal location of solar systems for energy generation, are taken into account. Besides, there is a description of some web services developed to show the results and finally, the advances which may improve the precision and increase the detail degree in these studies.

Keywords: LIDAR; GIS; solar irradiation; photovoltaic potential

1. Introduction

The need to mitigate the effects of climate change caused by the emission of greenhouse gases such as carbon dioxide and rising energy costs [1] requires take on new strategies in the supply electricity sector. A main priority in energy policies of all countries should be to promote the transition to a new energy model based on the rational use of electricity, the improving of efficiency in facilities and the use of renewable energy sources. In order to adapt it to this situation, the

European Union (EU) has proposed the transformation of the energy system, and, according to Directive 2009/28/EC, the EU should reach a minimum share of 20% of energy from renewable sources by 2020 [2,3].

Consequently, there are increased efforts in research of renewable energy as a sustainable and clean alternative way of power generation. This type of energy is playing an important role in the diversification of energy resources to ensure the future supply [4,5]. In this sense, the solar photovoltaic (PV) technology is an available and easy access option for on-site power generation.

According with this problem, we should take into account that nowadays, about half of the world population lives in urban areas and the UN's projections estimate that is will become 66% by 2050 [6]. In consequence, a higher challenge should be to develop urban plans that ensure their own sustainable expansion [7]. This policy, should consider that cities concentrate a significant fraction of the energy consumption but they can also produce it. Along these lines, it has lately tried to expose methods for integrating solar energy into urban areas [8].

European Union directive on energy efficiency in buildings (2010/31/EU) [9] shows that they are responsible for consuming about 40% of the energy. This situation has led the European authorities to promote the development of photovoltaic energy. The program aims that all new buildings and, if it is possible the largest number of existing ones, reach an almost zero energy consumption [10]. It is claimed that the installation of PV systems in buildings, has the advantage of not requiring additional space for them to be mounted in areas like roofs or facades [11]. Furthermore, it helps to decrease the required ground area by power plants and, due to the electricity production is located near consumers, to reduce losses by transport energy.

The assessment of the solar potential is a valuable tool to develop strategies to use this source of energy, design facilities and set up appropriate policies for better urban planning [12]. When it is trying to implement plans to install PV systems in urban areas, it is essential a deep knowledge of the urban structure. It is significant to identify available areas on roofs and assess their potential to generate electricity establishing processes that perform a quick and easy analysis [13].

Depending on the complexity of the urban area, more or less precise variables are required in the study. Remote sensing technologies are increasingly used for obtaining high-resolution data that let develop urban model with different levels of detail. These models, joining the ability of Geographic Information Systems (GIS) to associate alphanumeric information and spatial data, have become an essential instrument for understanding the territory [14] and contribute, in this way, to the development of real "smart cities".

In this sense, we will present different methodologies to date to apply LIDAR (Light Detection and Ranging) data and GIS based models to evaluate solar potential in urban environments. This paper focuses on the next steps: (i) describe the wide range of data source consulted; (ii) define an accurate representation of the urban morphology; (iii) show several methods for the assessment the solar radiation; (iv) strategies to perform a detailed estimation of photovoltaic potential; (vi) analyze of solar mapping tools; (vi) proposed methodology to calculate the photovoltaic potential on roofs in urban areas; and, (vii) what works may be develop in the future.

2. Study Area and Data Source

Many studies have investigated the relationship between energy production and the configuration of urban environment. It is required for a proper analysis not only the definition of the geographical unit and territorial structure but also the variety of scales to work. Taking into account the size of the studied area, the available data cannot always be applied at the same way to local or regional analysis [15]. In addition, an important aspect to consider is that the extent of the studied area is sometimes limited by the available data [16]. Considering different levels of complexity, there have been done some local studies (cities, districts and blocks) [17,18] and others more general (national and regional) [19,20].

Previously established the study area, an important step is the initial collection of data. It is not a simple task, information has often an heterogeneous origin with various levels of detail or scale. Sometimes, it is incomplete, does not cover the same extent and it is needed to consult different sources of information [21,22]. A further aspect to be considered is the updating data and how to use it. Information is not always updated with the same periodicity and the latest one is often not available or its cost is high. In these cases, a previous review to identify areas that have changed, it may be necessary to consider this divergence in the final results. These features will influence on both the number of factors that can be analyzed and the accuracy of the final results.

Vector cartographic maps [23], digital cadastral services [24,25] and state geographic information systems [26] are reference sources used in evaluating potential candidates buildings for the installation of PV systems. These resources provide information about the buildings footprint and some useful data such as height or classification of the buildings types (residential, commercial, industrial, etc.). In some cases, all these data are used together with digital surface models (raster format) of the urban areas [27]. Moreover, the aerial images are a good complement for checking the objects which form the urban model [28,29].

Although these data provide information about the buildings layout, it is not possible to determine exactly their structure. When solar potential is calculated, not only the situation of each building influences over the results, but also the size and typology of the roof (flat or tilted). In this sense, these data are quite adequate to provide an overview of the study area. Considering the general characteristics of the buildings, it can be estimated the number of roofs for different types, approaching the parameters which are needed in the determination of the solar potential.

However, the requirement of more accurate three-dimensional city models, has increased the application of LIDAR point clouds [30,31,12]. LIDAR is a remote sensing technology, based on active sensors, to characterize surfaces with a suitable detail [32]. This kind of data more and more can be found available for urban areas (Figure 1). If the quality and density of data is appropriate, it can provide precise information about elements in an area such as buildings, trees or any surrounding object that is necessary to define [33].

As we will see later, models are usually used to estimate the solar radiation reaching the ground, but data from meteorological stations in the study area [15,31] and maps of solar radiation are applied too. There are several web services that provide access to a set of information related to solar radiation, from a map-based interface can display a specific location. They are public access sites, for example: PVGIS is a data inventory for the evaluation of solar energy and power generation from PV systems [34,35]; SoDa (Solar Energy Services for Professionals) is a web service that offers links to resources from solar radiation distributed by different countries [36].

Sometimes, other subjects are analyzed and are used, such as series of statistical data on population, economic factors, power consumption, etc. The information available in the statistical services is useful for relating population data and area of PV systems [37] or the number and type of buildings in municipalities [25].

Once selected and treated the information layers, they are integrated into geographical databases with those other attributes that influence the use of solar energy.

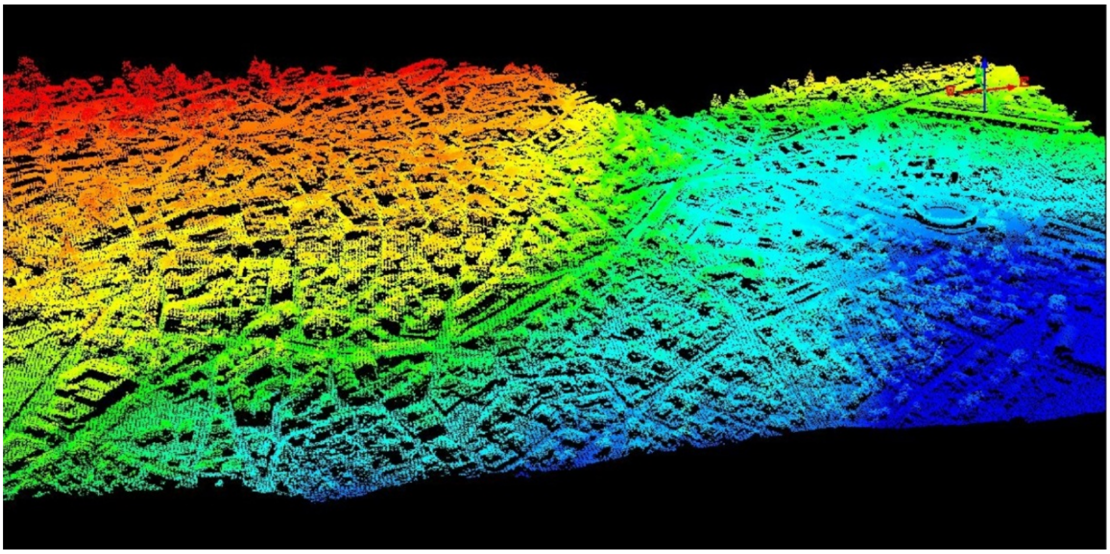

Figure 1. LIDAR point clouds provided by the National Geographic Institute (IGN) from Spain [38] (Miraflores de la Sierra, Madrid).

3. Urban Morphology

In order to quantify photovoltaic potential at cities scale, it is fundamental to have a 3D urban model [39]. For the identification of suitable roofs where install solar panels, it is necessary to have a better representation of the buildings geometry and any other object in the studied area [35]. Some roofs can be quite complex and the ability to provide accurate data to identify them properly is essential [40].

This type of analysis has increased the demand for more detailed urban models and data acquisition of high-resolution remote sensing technologies, such as airborne LIDAR, have shown great potential. These data can be used to determine the available roof area because they define the planes that form the roofs as well as their slope and orientation. But depending on the purpose of the study, other elements can be classified like walls, infrastructures, trees and even vehicles [41]. If a high density LIDAR point clouds is available, besides to establish more accurately the structure of the roofs and their surroundings, it is possible identify chimneys, aerials or another elements on the roofs that can affect the availability of useful surface.

In recent years, there have been done several works with point clouds in order to make models of the urban environment (Figure 2). Procedures have been developed that extract and reconstruct buildings automatically [42,43,44] even create algorithms for the detection of flat roofs and their segmentation [45,46,47]. Polygons with the outline of the buildings are used for integrating planes roofs extracted from point clouds with each individual building [48,49]. Moreover, due to the different levels of complexity that roofs may have, also LIDAR data has been combined with aerial images [50,51].

When trying to establish the structure of the buildings with urban models, one aspect to consider is the presence around of other elements. For example, if there are trees located near buildings, they can hinder the delimitation of roofs because there is no difference between the points corresponding to one or another area [52]. The urban areas characterization, not only makes easier to determine the position and shape of the roofs as well a more realistic study of other parameters like shadow areas or solar radiation are developed [53].

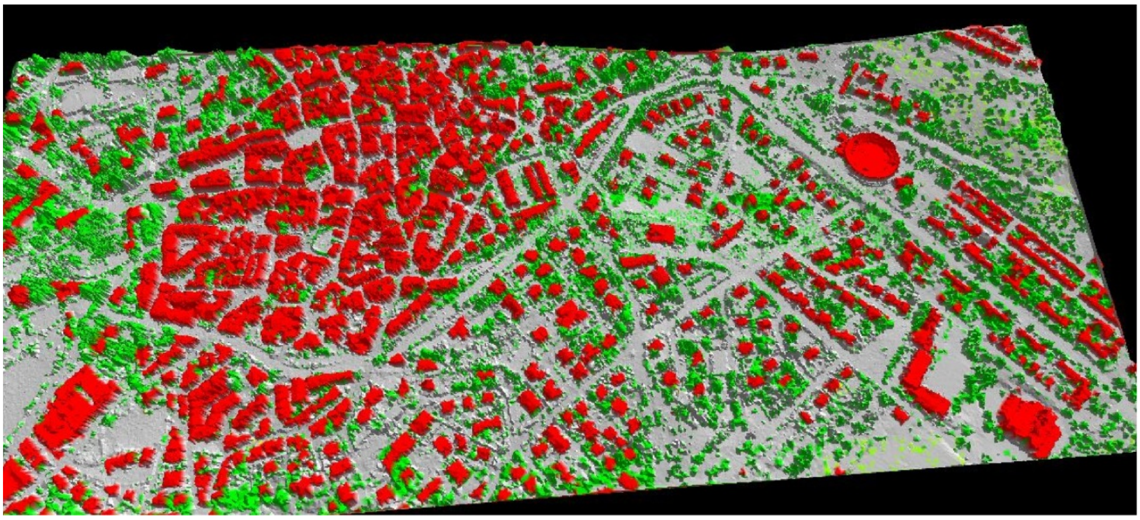

Figure 2. Digital Surface Model (DSM) from LIDAR (source: CIEMAT).

When urban 3D models are created, the LIDAR data processing is not described in most of the works. Important issues are the review and classification of the point clouds to get a proper model of the urban area. It is necessary to debug errors (duplicate or redundant points) and check the relevant elements allocation for the analysis such as buildings, vegetation or ground. The procedure should be done preserving the roofs shape, keeping as much as possible the boundary of surfaces without changing the accuracy of the results.

4. Assessment of the Solar Tadiation

Solar radiation is one of the biggest energy sources and estimate, the amount and how it displays, is the purpose of radiation models. The global radiation incident on a surface is formed by three components (direct, diffuse and reflected), depending on how reaches the objects on the earth surface [54]. There are different factors that can influence over the distribution of radiation and limit the final production of electricity. Not all the solar radiation reaching the atmosphere comes to the surface because the variation of weather conditions, topography, and the characteristics of the ground surface affect it. Even though, latitude, the time and seasons changes solar radiation [55].

Sometimes urban environments have a complex structure. The distribution of solar radiation is modified due to the topography and the presence of obstacles, such as buildings or trees that block it and cast shadows [56]. Quantified these factors is essential to evaluate its influence on the availability of radiation and consequently on the potential use of solar energy. It is necessary to establish an appropriate distribution of the urban structure for each level of detail required.

Notable progress has been made towards the estimation of solar radiation with the application of some software tools. The *r.sun* model from GRASS GIS has been used as a tool to develop, among others, the solar radiation database PVGIS [57]. This model produces raster maps of irradiation and irradiance, reflectance and shadows for horizontal or inclined surfaces considering the weather (it is suitable for clear sky and cloudy) [55,23]. Another widely used tool is ArcGIS 'Solar Analyst' extension that calculates the global radiation (direct + diffuse) for a given area, latitude and a specific time [58,59,60]. The analysis takes into account changes in the sun position and the effect of buildings or other topographic feature defined in elevation model of the area, applying their slope and orientation (Figure 3).

In addition to this, RADIANCE is a simulation software that has been developed for the analysis of urban radiation and the study of daylight for determining the solar potential on roofs and facades [61]. This software employs an algorithm that computes radiation tracing several rays from a set of points, on a volumetric 3D city model. Based on RADIANCE and all weather sky model of Perez et al. (1993) [62], the Daysem software also performs simulations of daylight around buildings, tracking each segment of the sky and the sun position. It considers additional information about weather and shading based on a three-dimensional geometric model of buildings [63,30].

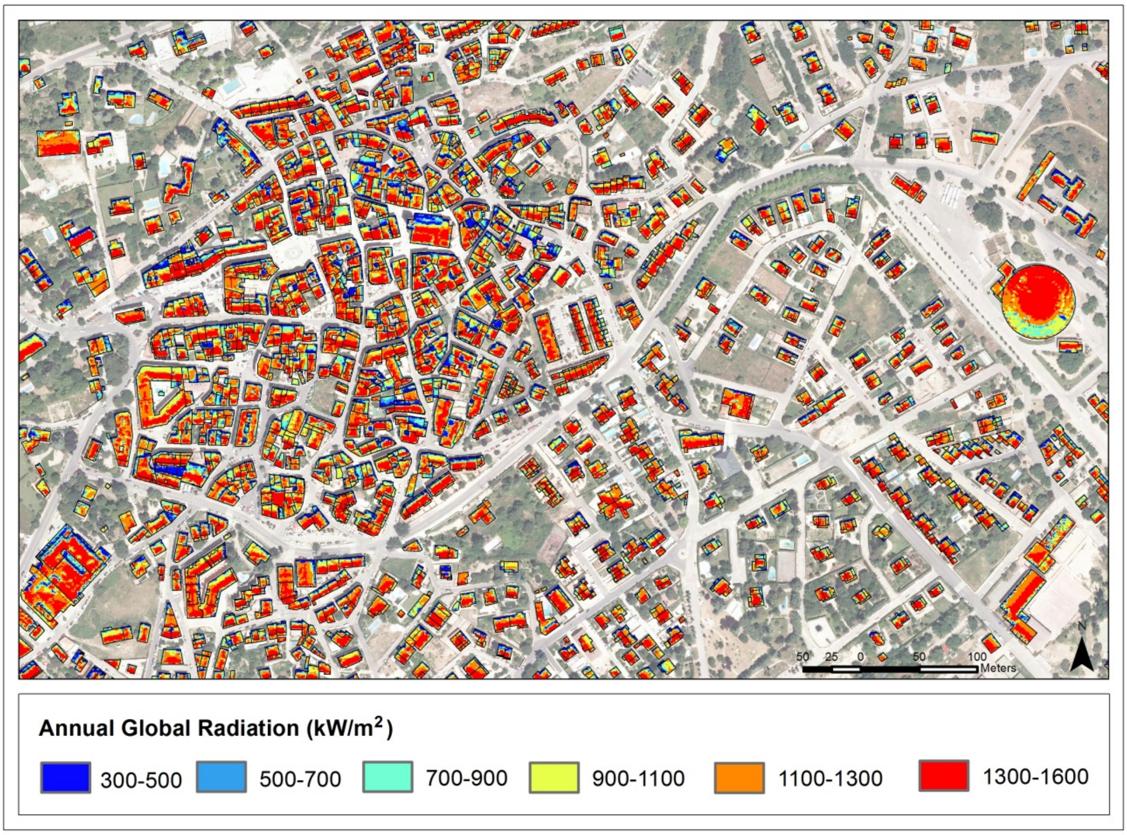

Figure 3. Annual global radiation on roofs calculated using ArcGIS. Town of Miraflores de la Sierra (Madrid) (source: CIEMAT).

Furthermore, models and algorithms have been developed to include the effect of shadows in their analysis. Melo et al. (2013) [64] estimate the energy losses of photovoltaic systems because of shadows caused by buildings or other elements present in the environment. Redweik et al. (2013) [65]

use irradiation values from weather observations for calculating radiation in an area employing the sky view factor (SVF is the relationship between the visible area of the sky and the one hidden by obstacles in a specific point of observation). In another work, Erdélyi et al. (2014) [66] evaluate direct radiation with SORAM model and, as an improved of Pérez model, add the calculation of diffuse radiation. Although, the created algorithm calculates the 3D shadows of obstacles in urban areas, does not consider the reflected radiation.

Related with shadowing, there are also studies that apply urban models generated from LIDAR data. Verso et al. (2014) [67] determine the shadows, slope and orientation of the roofs with this data. They calculate the radiation that incidents on the PV panels using a geometric method. The horizontal radiation is decomposed into the direct and diffuse components. Furthermore, about shadows, Tooke et al. (2012) [68] make a distinction. Instead of treating all elements in the urban environment that cast shadows as solid, they consider trees as semitransparent. They examine the fraction of radiation that can be transmitted through the vegetation cover, according to the state of vegetation cover at the time of taking LIDAR data.

In general, procedures to analyze solar radiation should focus on establishing an adequate characterization of the radiation components, the effect of the shadows and changing atmospheric conditions. Nevertheless, taking into account different procedures, a subject for future works would establish whether these models are applicable in the analysis of large urban areas. These studies include parameters that require complex calculations that need too much runtime.

5. Estimation of Photovoltaic Potential

Estimating the photovoltaic potential of urban environments can be a complex matter. It requires taking into account a variety of parameters that depend on the distribution and morphology of the urban area [3,17]. Although common elements, there is no standard methodology to estimate the potential. The proposed objectives are usually different but complementary, because of the project needs, the developed phases of the proceedings or even the available data in each case. The studies establish the potential on different ways that mainly require: determine the solar radiation incident on a surface considering the factors that influence it (physical potential); identify available roof surface to place the appropriate PV systems (geographic potential); estimate the potential power generation of a given technology in view of the technical limitations and efficiency (technical potential); and finally, the measurement of costs associated with the installations and the energy generation (economic potential).

5.1. Physical potential

In some studies, the suitability of the roofs to install PV systems has been set using the potential radiation in the area. Araya-Muñoz et al. (2014) [28] evaluate the solar radiation with local weather data. The model considers the roofs geometry made of topography and combined with the observation from aerial photographs of the buildings. Nevertheless, as already mentioned above, the use of remote sensing (LIDAR data) to establish the structure of urban areas is becoming more common. These data make easier the characterization of the composing and shape of the roofs (orientation, slope, etc.), improving the evaluation of solar radiation available for potential operating of PV systems. Borfecchia et al. (2014) [35] obtain a map of monthly global radiation, evaluating the reflected component, the distribution of atmospheric turbidity and albedo (acquired from Landsat satellite imagery).

The layout of the urban area with LIDAR data can also be completed with measurements of global and diffuse radiation from pyranometers as shown Lukač et al. (2013) [31]. This analysis also includes the effect on the roofs of the shadows from trees, buildings and surrounding elements. Furthermore, Redweik et al. (2013) [65] create shadow models to integrate roof potential and the facades. They lay down that although the received radiation by the facades is lower, when there is a considerable surface, it has to be taken into account due to its influence on global potential of the area.

5.2. Geographical potential

The roof surface, where PV systems can be installed for energy production, has been investigated in different procedures based on the use of GIS technology and 3D mapping. In the quantification of roof surface is essential a three-dimensional distribution of the urban layout and a proper definition on the morphological characteristics of buildings [14].

Analyzing large-scale areas, reduction factors are needed to estimate the useful surface on roofs, because the characteristics that define the roof shape (slope, orientation or shadows) are not estimated by the urban model [3,15]. Karteris et al. (2013) [69] present a methodology for the evaluation of blocks of flats with horizontal roofs on a statistical model calculation. In this model, the morphological and functional characteristics of the dwellings have been classified according to their orientation. The results have been validated with real measurements on buildings in the city of Thessaloniki (Greece). In another procedure, Bergamasco et al. (2011) [29] calculate the available roof area for PV panels with an algorithm based on the analysis of aerial images. The algorithm, which has been developed in MATLAB software, checks the roofs and is able to consider the shadows and objects that are located on roof.

However, more detailed models generated with LIDAR data, can define the planes that constitute the rooftop and allow managing without reduction factors [49]. Chaves et al. (2010) [70] have designed a model with ArcGIS to analyze the most suitable location on roofs using a Boolean multicriteria system. This model generates a DSM derived from LIDAR point clouds and calculates the slope, inclination and radiation.

The complex areas of roofs and elements such as antennas, chimneys and air conditioning systems are difficult to identify. Jacques et al. (2014) [8] have developed an algorithm to classify the roof profiles using LIDAR data available. This work analyzes small and large buildings separately. The small roofs segmentation algorithm assigns a roof profile to each building from a catalog. On the other hand, the slope and inclination is calculated for large roofs because they are better delineated. Moreover, shadows and the presence of objects on roofs are estimated with a reduction factor of the surface.

However, other works calculate the roof area affected by shadows. Kassner et al. (2008) [5] analyze the surfaces according to the slope, orientation and calculate shadows applying the ArcGIS tool “Hillshade” [71]. Besides, the study of Nguyen et al. (2012) [72] provide an algorithm that incorporates the ground and nearby elements, creates shadows and uses the model *r.sun* GRASS GIS software for modeling the radiation.

5.3. Technical potential

After the examination of suitable roof surfaces for PV systems, their capacity for energy production is determined by analyzing their characteristics of efficiency. Bergamasco et al. (2011) [3] propose some possibilities for the exploitation of solar energy at regional level. They have evaluated different technologies available in the market (monocrystalline, polycrystalline and thin film), considering their efficiency values and the optimal inclination of the panels. Wiginton et al. (2010) [37] also make a basic analysis of photovoltaic potential, dividing the studied area into smaller geographic units. They determine the relationship between the roof surfaces with population, and calculate an approximation of the photovoltaic potential and the energy generated for different types of panels.

There are studies that show the results of the solar potential for different uses of buildings. Hofierka et al. (2009) [23] calculate the potential electricity production using PVGIS. They establish some types of buildings: residential blocks, industrial and other facilities (schools, garage, sport and entertainment halls, etc.). Another example, Ordoñez et al. (2011) [73] investigate the potential for PV systems connected to the network of residential buildings in Andalusia (Spain). Defining the characteristics of buildings and the technical parameters of PV systems, they estimate the amount of electricity that could be generated annually by solar panels.

Although, factors that affect facilities are common, not always they are analyzed in the same way. Hong et al. (2014) [74] make GIS model based on optimizing the generation of electricity, analyzing the parameters related with the PV system (location, temperature, number of panels, etc.) that affect their generation. Additionally, Ko et al. (2015) [75] investigate the effects of shadows on the installed potential of PV systems in Taiwan. They have the objective of determining the capacity of the installed potential to generate photovoltaic energy and what regions or cities are priorities for photovoltaic development.

Nowadays, published papers tend to focus on analyzing the rooftops. Esclapés et al. (2014) [76] present a method to define the potential of solar PV also on urban facades. They generate 3D solar maps from cadastral cartography and solar radiation data got by the Spanish Meteorological Agency (AEMET). The method has provided results such as floor space for PV systems, generated energy and avoided CO_2 emissions.

5.4. Economic potential

Different studies have included other parameters about the amount of electricity demand that would be covered with photovoltaic panels. Brito et al. (2012) [60], based on LIDAR data, calculate the photovoltaic potential taking into account the population and the average electricity consumption. Another model, develop by Mainzer et al. (2014) [25], compares the technical potential calculated for an available roof surface with power consumption of municipalities in Germany. It checks the amount of local demand that can be supplied with photovoltaic energy. Also, the socio-economic influence has been analyzed with the objective of presenting a tool for decision support to manage solar energy. In their study, Gooding et al. (2013) [27] chose factors such as income, education, environmental consciousness, building stock and ownership.

According to economic viability, Sun et al. (2013) [20] have a regional model that considers the geographic distribution of energy production and establishes what is the cost of generation. They show the payback period of the investment and its effect on potential emissions. Finally, Kucuksari et al.

(2014) [13] try to maximize long-term profits of photovoltaic installations and add investment costs, operation and maintenance, payback period of investment and energy saving benefit.

6. Solar Mapping Tools

The availability of solar energy data is becoming greater and gradually the number of cities that allow access to this information is increasing. In order to have querying platforms for people and also a useful tool for administrators and companies to support the decision making [78], there have been developed web applications. These services display a specific area of the urban environment to calculate the solar potential in the selected location.

What roofs are the most suitable for solar installations?, what kind of solar installation is convenient?, how much energy could produce a particular installation?, or what is the necessary investment?, are some of the issues that have being solved. The amount of available information varies considerably in different services. The level of detail changes from solar maps that only provide information about solar irradiance to solar maps that determine the photovoltaic and thermal potential. Some services can provide a catalog of existing facilities and even be part of larger programs that offer additional economic information [79].

Lisbon Solar Potential Map [80] is an online application through Google Maps for all buildings in the city. It displays information about the incident radiation and the estimated thermal and photovoltaic solar productivity per square meter.

Solar roof cadastre webs are tools that have considerable advantages to establish the suitability of roofs for solar systems in cities. *Bologna Solar City* [81] uses ArcGIS tools for calculations which evaluate the solar panels location and map publishing is done by ArcGIS Server [16,54]. In other case, the city of Paris [82] reports the solar potential of buildings and identifies places for installing solar panels through a color code. It indicates the radiation exposure, calculated from the simulation of the annual average of solar radiation and taking into account the shadows of buildings or trees.

Some projects, such as SUN-AREA from aircraft scanner data, determine the solar potential considering parameters like the slope of roof, orientation and shading [83]. This methodology has been applied in some municipalities in Germany [84,85,86] and in Bristol (England) [87]. The results are published in an interactive map that shows the produced potential energy, the useful surface, the CO_2 savings and the investment grade for each roof surface.

For Berlin have also designed a solar atlas [88,89] which presents the solar potential of each building, analyzing whether the investment is viable. It presents an individual report that evaluates the area of modules, their duration and cost, showing the buildings in 2D and 3D.

In USA, the city of San Diego has a website which can be included in Google Maps [90]. It has information about where solar systems have been installed, determines the feasibility of building rooftops and eases to find panel installer companies. Some cities have systems that let people estimate costs, payback period of investment, saving in energy bills or cost after all incentives and taxes. Los Angeles [91], New York [92] and San Francisco [93] provide this type of data, the same as Mapdwell project [94] where can be looked up information of multiple cities. The online application designs nearly your own installation, delimiting the roof area that would occupy.

In addition to the studies for cities, online tools have been developed to large-scale studies. The Noord-Brabant province (Netherland) [95] and Braunschweig region (Germany) [96] analyze solar potential, displaying information about the planning and building of the solar system for a resident.

The *Zonatlas* web from Netherland [97] shows the suitability of roofs for solar power generation of a municipality or province and adjusts the standard calculations to a concrete situation.

All these online tools, which map the allocation of solar energy technologies, can increase environmental awareness of population, helping in the future to a better consideration of their possible use in cities. However, these web sites need to properly define their target audience, adapting the content to the end user, but without losing or hide the quality of the information served. In this sense, the incorporation of metadata and all the information concerning to the origin and quality of the data, as well as the models and calculations applied, is essential. To this we must add, the convenience of using ranges of values appropriate to the scale and the ultimate goal of the web map. This should help improve the usability of the solar maps through internet.

7. Proposed Methodology

In this research field, the main objective of *gSolarRoof* project, developed by Geographic Information Technology and Renewable Energy team of CIEMAT, is developing a geographic model for evaluating the photovoltaic potential in urban areas. The study is based on performing a 3D urban model of the town of Miraflores de la Sierra (Madrid) [59,67]. The urban model is generated from LIDAR data, previously processed and classified. This is integrated into the ArcGIS model in order to determine the possibility of installing PV systems on roofs for energy generation. The methodology consists on three main steps:

- To calculate the total surface available on the for PV systems and select the most suitable locations that consider the following factors: (i) energy losses caused by the tilt and orientation of the roof according to the criteria established by the Spanish ‘Regulation Technical Building’ [77]; (ii) shadow areas on the roofs throughout the year, applying the ArcGIS tool 'Hillshade'; (iii) perimeter space of the roof that provides an access for the PV systems maintenance, and; (iv) identify those specific buildings and monuments that are not appropriate for installing PV systems due to cultural or architectonical reasons.
- To determine the global annual radiation received on rooftops in the study area with ArcGIS “Solar Analyst”. The analysis considers the shape of the buildings, the trees in the neighborhood and other urban elements defined in MDS that may affect the distribution of the radiation (for small areas, an specific equation has been developed [67], but due to the intensive calculation needs it couldn’t be applied to the whole area by the moment).
- To estimate the power potential and the energy production considering the most common types of PV modules on the market (Si-monocrystalline, Si-multicrystalline, CIS, TeCd and amorphous SI). For its determination, it has been designed two ArcGIS tools in Python that allow selecting the type of PV module for performing the analysis.

The model not only makes global calculations for the study area, but also provides the individual data of all buildings, assigning to each one the results that have been obtained in implementing the model.

8. Future Works

Improve the accuracy of the obtained results and add other possible factors that may influence the determination of the PV potential, different studies have proposed various alternatives. Although some papers have already included these type of improvements, they may be generalized as the procedures to estimate the economic potential [17,74] with statistics population data [98], energy demand [99,100] or calculate the required period of time to get back the investment made [4]. However, it is necessary to have more detailed statistics about buildings. For example, energy consumption information is too general and it is difficult to analyze the parameters corresponding to the variety of buildings [101].

The current LIDAR data resolution limits the definition of the roofs and the acquisition of more dense cloud of points, it will make easier to build better 3D urban model [40]. Border roofs delineation improves and may be included other elements such as chimneys, skylights or air conditioning systems which are usually generalized [23]. But the roofs are not the only areas in buildings where install PV systems. When facades are analyzed, they have often been defined as vertical elements without balconies, windows and other architectural elements. Refine LIDAR data will transform the DSM to determine more precisely the area available on the facades of buildings [25,33].

On the other hand, a higher density of LIDAR data may provide a better characterization of the surrounding elements of buildings like vegetation. Trees structure is determinant in radiation captured by photovoltaic panels on roofs and a proper species selection is useful for reducing energy consumption [52]. It would be interesting to know how the trees morphology changes depending on the seasons by using LIDAR and the phenological stage of the different species, analyzing other data as the images.

Around the buildings there are other objects, whether large or small, such as posts or aerials that may be considered in the analysis of the shadows. Develop algorithms for identifying small shadows and indirect radiation would help to approach the actual shape of the shaded areas [53].

Although the characterization in-depth of the urban environment is a key objective in the study of photovoltaic potential, there are several factors that have been included in previous analyzes, but that may be defined better. Have climatic data with a higher spatial resolution [57], analyze the influence of temperature variations and the effect of air masses [32], would complete the study of radiation. It may be included losses in energy production that take place in solar panels due to shadows, position or the presence of dust [102].

Finally, an issue to consider is that when the amount of information that has been managed is increased, the procedures are more complex and require extra runtime. Improve preprocessing LIDAR data [5], automating their treatment and minimizing manual intervention in the characterization of the complexes roofs [16], should also be considered a target objective.

9. Conclusion

It is a fact that there is the increasing number of studies that have investigated the potential capacity of solar systems to generate energy in cities and its potential benefits. The development of GIS applications and the use of remote sensing like LIDAR have come out as a necessary tool with very promising results.

It is widely accepted that in determining the spatial distribution of solar resources, are required adequate 3D city models, adapted to different types of buildings. Several studies focus on that a higher density of data may be needed to assess these complex environments because of the elements definition that compose them would be improve. For the study of the suitability of roofs to install PV systems, parameters related to the position, shape of the roofs and shadows, as well as radiation and generation technology used, each one with different levels of importance.

Although taking common elements, this diversity on the analyzed parameters, has provided varying degrees of detail over the results that has been obtained. As it is shown in solar web services, they offer different levels of detail. However, a general objective is the aspiration of incorporating progressively, precise information to enable accurate results, whenever the availability of data makes it possible.

In these sense, free access web-based has become an opportunity for public administrations to carry out actions that stimulate renewable energy growth. When there is a tendency to create more sustainable cities, these services may help to integrate solar potential into the design and planning of "smart cities".

Conflict of Interest

All authors declare no conflicts of interest in this paper.

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