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An assessment of photovoltaic potential in shopping centres

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ABSTRACT

The solar photovoltaic is a renewable energy source which allows nowadays, in many places, the generation of electricity at a cost comparable with the conventional thermal generation methods. However, ending 2014, with a worldwide power capacity installed of 177 GW, the integration level in the electricity generation mix was still far from the targets set up for this technology in the global warming mitigation strategies.

Technical, financial and regulatory barriers slow down a massive penetration of photovoltaic generation facilities, hence practical and innovative measures are necessary to facilitate a wider deployment.

The building integration of solar photovoltaic facilities offers an efficient solution because the electricity is generated near the consumption point and gives a new economic value to roofs and facades. In this paper we develop a scientist methodology for determining the potential in shopping centres, to establish that, in terms of photovoltaic integration, these present important competitive advantages over other alternatives, i.e. the residential buildings. The power capacity potential obtained making use of this methodology in the countries selected is 16,8 GW, that means 10% of the worldwide capacity installed at the end of 2014, with a yearly electricity generation of 22,7 TW h equivalent to 14% of the worldwide generation in 2014.

1. Introduction

Global warming experienced in the earth in the last decades is a reality with proved grave consequences. With a high degree of probability, the key reason behind this global warming is the anthropogenic greenhouse gasses (GHG hereinafter) emissions, fundamentally caused by the global population growth rate and the economic development since the beginning of the industrial era (Intergovernmental Panel on Climate Change, 2014).

To face this situation, the international community has adopted the commitment to limit the earth global warming to 2 °C above pre-industrial levels (European Climate Foundation, 2010; The White House. President of the US, 2013). The fulfilment of this commitment requires of global and important measures sustained over time to achieve a significant reduction of the GHG emissions. Many governments and international institutions have established future scenarios and designed strategies to reach this achievement that include necessarily interventions to mitigate the present emission levels.

According to the majority of the analysis carried out in this field, one of the main sources of GHG emissions is the power sector; therefore, important efforts should be done here to contribute as it should be, towards the achievement of the mitigation targets. The use of renewable energy sources (RES hereinafter) in the electricity generation is the base to support this contribution. Presently it has been reached a significant share of penetration of RES in the electric generation mix; but this rate should be increased massively to attain the transition from the present electricity generation scheme, fundamentally based on the use of hydrocarbons (Intergovernmental Panel on Climate Change, 2011), to a near-zero emissions power sector.

Among the RES, the solar photovoltaic source (PV hereinafter) has an essential characteristic that favours its massive penetration: the dispersion degree. The solar radiation is received worldwide with an intensity level that, depending on the specific location latitude, makes possible the production of electricity almost everywhere. Besides, the PV technology presents nowadays a technical and economical maturity that allows high efficiency generation at such a low cost comparable with the traditional generation based on conventional thermal methods (Colmenar-Santos et al., 2012; Feldman et al., 2014; Hernández-Moro and Martínez-Duart, 2013; Lazard, 2014; Ondraczek et al., 2015; Ossenbrink et al., 2013; Philipps et al., 2014).

The integration of a massive share of RES in the electric power grid implies technical barriers and problems with an impact on the operation and stability of the whole system. The facilities must

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Nomenclature

General		*Greeks*	
A_{SP}	area of the solar panel	α_s	solar altitude angle
A_{PV}	PV area	β	panel slope. It is the angle between the solar panel surface and the horizontal
CR	covering ratio	P_P	PV peak power
DOE	US Department of Energy	P_{SP}	maximum power of the solar panel at STC conditions
DSO	distribution system operator	PR	performance ratio of the PV facility
EU28	European Union 28 countries	PV	photovoltaic electricity source or facility
GLA	gross leverage area	RES	renewable energy source
GHG	greenhouse gases	SC	shopping centre
G_T	yearly solar irradiation (insolation) in kW h/m^2/year incident on an optimally-tilted solar panel	US	United States of America
		γ_s	Azimuth solar angle
		ε	solar panel efficiency
		φ	latitude angle

implement specific systems to favour the integration of the electricity generated, including eventually elements to storage the surplus generation to be used in deficit times (Barth et al., 2014; Luthander et al., 2015; Mai et al., 2012). This is a handicap for small facilities in residential buildings or single family houses, even for small commercial buildings, because all of these auxiliary systems can turn the facility more complex and with needs of professional assistance and likely their users will not have an adequate technical profile and will have to contract a utility company to do it.

In the previous technical literature, several studies have been carried out to determine roof area availability or solar PV potential in buildings. Most of them are focused only on residential buildings: (Karteris et al., 2013) analysed the suitable roof areas in multifamily buildings in cities based on statistical calculation obtaining that the solar roof factor of utilization in this type of residential buildings is only between 25% and 50%. (Li et al., 2015) investigated the annual solar yield per floor space in urban residential buildings at different levels of site density. (Ordóñez et al., 2010) developed a methodology to determine the solar PV generation potential on residential rooftops using statistical data to characterize the building stock.

Other previous research did not differentiate the use of the buildings under analysis and, therefore or do not detail the PV potential of every of them: (Defaix et al., 2012) estimated the technical potential in integrated PV for residential and non-residential buildings in the EU-27 countries, (Izquierdo et al., 2008) defined a methodology, based on statistics available data and GIS maps, for estimating roof surface area for large-scale PV potential evaluations in all type of existing buildings and applied this methodology to Spain to obtain an estimate of energy generation, (Peng and Lu, 2013) carried out an investigation about the PV potential of hotels and commercial buildings in the city of Hong Kong. (Pillai and Banerjee, 2007) developed a methodology to for potential estimation of solar water heating that applied to a synthetic area of 2 sq. km in India considering residential houses, hospital, nursing homes and hotels. (Schallenberg-Rodriguez, 2013) investigated about the solar PV potential on roofs for several type of buildings in regions and islands and applied their research for obtaining an estimate of the PV potential in the Canary Islands, (Singh and Banerjee, 2015) carried out a methodology for estimating solar photovoltaic potential in a city for all type of buildings and (Wiginton et al., 2010) defined a method to estimate total rooftop PV potential based in GIS and object-specific image recognition city of Ontario (Canada).

Generally, the pre-existing literature has considered any type of buildings with similar features to host PV facilities independently of its use. However, from a constructive point of view, the availability of residential building roofs is generally lower to commercial building ones.

All of the aforementioned features, as well as other analysed in more detail below, point to shopping centres as best-fitting buildings for the purpose of installing PV facilities and therefore they should be the target of a detailed assessment about their PV potential.

As a consequence, the likelihood of taking advantage more efficiently of the roof space and the better technical adaptability for the integration of PV generation contributes to maximize the effect in the building energy performance because it is possible to achieve a larger level of self-generation.

This paper is aimed firstly at analysing the particular advantages of shopping centre buildings to install PV facilities, including technical comparatives versus the residential buildings that represent the predominant type widely used to estimate the PV potential. Secondly, the article focuses the research on determining the shopping centres potential in terms of power capacity and electricity generation as well as the possible contribution to achieve the penetration targets set up for this technology. The research has been developed for a large area including all the countries in the 2014 PV power capacity top ten list.

Below in Section 2 we review the world present situation in terms of photovoltaic penetration and will be determined the reference targets used in this article. In Section 3, we specify the reasons for considering shopping centres as buildings with important advantages for PV facilities. In Section 4 we define the methodology developed to obtain the power capacity and generation potential in shopping centres located in different countries and in we carry out the determination of this potential. In Section 5 the methodology is applied to a real shopping centre located in Madrid (Spain) to obtain the capacity and share potential. Finally, in Section 6 the conclusions of the results obtained in the study are presented.

2. Present situation and targets

2.1. Present world situation

Ending 2014, the world PV power capacity installed was 177 GW. As shown in Fig. 1 the distribution of the capacity presents a high concentration degree, so that the top ten countries host 149 GW, what means 84% of total (Fig. 2).

The countries included in this article are those in the top ten list: the 28 countries members of the European Union (EU28