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Assessing visibility in multi-scale urban planning: A contribution to a method enhancing social acceptability of solar energy in cities

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ABSTRACT

Urban areas are facing a growing deployment of solar photovoltaic and thermal technologies on building envelopes, both on roofs and on façades. An effective solar energy planning process considers social acceptance, in relation to the landscape alteration induced by the solar modules. “Visual impact” is often considered as a major component of social acceptance but comprehensive visibility assessment models are lacking at the scale of the city. This paper presents a scale-dependent methodology to assess the visibility of building envelope surfaces exposed to solar radiation, which could host solar modules, in urban areas. A match between annual solar radiation, visibility and socio-cultural sensitivity of the built environment are proposed in a multi-criteria decision framework.

Results are illustrated for the city of Geneva (Switzerland), as a case study: a partial overlap between highly sensitive urban areas and high visual interest is identified at the broad, strategic planning scale. In a second more detailed phase, a frequency breakdown of buildings is provided, according to the (non-) visible share of useful roof area for solar energy production. Less visible roofs are more likely to be situated in courtyards, far from the streets, in deep urban canyons or on low-pitched roofs. The outcomes indicate that stakeholders can reasonably expect to harvest a serious amount of solar energy by means of building integrated solar systems without crucially affecting public perception. In Geneva, more than 50 m^2/building of non-visible roof surface receiving sufficient solar radiation for an economically viable solar refurbishment is available over half of the buildings.

This method is valuable for large districts or cities (i) to spot more/less visible building sets and to estimate adapted precinct refurbishment strategies; (ii) to compare visibility on a common conventional basis and to detect zones deserving further investigations at the finer scale.

1. Introduction

In most developed countries, urban areas are already consolidated: the largest share of energy consumptions due to the building sector is accounted to the existing stock (Nolte and Strong, 2011). With the greater benefits in addressing energy savings in existing buildings, a bigger effort is requested in modifying the built infrastructure. Currently, most of the attention is devoted to the mitigation of energy demand, but in the future, comprehensive refurbishments involving localized energy production are envisioned. Solar energy qualifies as one of the most widespread renewable sources: the conversion efficiency increase, coupled with the reduction of installation costs (Zhang et al., 2014), makes it attractive even for small applications on less exposed buildings.

A recent report highlights how the solar power production potential from photovoltaic roofs and façades could cover between 15% and 60% of the electricity demand in IEA countries (International Energy Agency IEA, 2002). It is foreseen that more than half of the global PV capacity from now to 2050 will be installed on buildings, producing a little less than half of the total PV electricity needed (International Energy Agency IEA, 2014). Such a massive deployment requires a rational arrangement of the solar modules according to the site characteristics, this task implying a concertation between heritage protection, energy and spatial planning. A match between building energy needs, solar energy potential and site identity should be found. Therefore, a complex decision platform is needed, as well as a precise qualification of the

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site identity.

On the one hand, Multi Criteria Decision Making (MCDM) techniques provide solutions to problems involving conflicting and multiple objectives. Several methods based on weighted averages, priority setting, outranking, fuzzy principles and their combinations are employed for energy planning decisions.

This paper focuses on the assessment of site identity in relation to solar refurbishment, to be included as a parameter in the decision model. This identity feature has been named "criticity" in a recent publication, a combination of the socio-cultural value of the urban context (viz., sensitivity) and the visibility from the public space of the building envelope component that will potentially host the solar power plant (viz., visibility) (Munari Probst and Roecker, 2015).

To map the "criticity" of city surfaces, it is essential to systematize the visibility assessment of building envelopes and to combine the relative outcome with urban sensitivity, available from other sources. This work proposes a quantitative methodology to assess visibility, according to the spatial planning scale in an urban context. An exemplifying framework to classify sensitivity zones is also provided. After a short state of the art of visibility assessment in sustainable energy planning, the methodology is presented: the urban area of Geneva (Switzerland) is used as a case study, a few districts being analyzed into detail.

2. Visibility in sustainable energy planning

The use of solar technologies in existing urban environments has been sometimes assessed as impacting negatively, in absolute, on social acceptance (Dall'O' et al., 2013). In spite of this, established research states that a high architectural integration quality can be even a driving force for solar development, when coherent refurbishment strategies are put in place by setting appropriate requirements within homogeneous zones of intervention (Munari Probst and Roecker, 2012.). Established literature is available around the concept of architectural integration, which will not be discussed further in this paper (Munari Probst and Roecker, 2012; Munari Probst, 2009; Hestnes, 1999). The characterization of the zones of intervention is expressed by the abovementioned concept of "criticity" (Munari Probst and Roecker, 2015) (Fig. 1): a historical city center, rich in cultural heritage (high sensitivity), will require a much higher architectural integration quality, compared to a medium sensitivity residential development area or a low sensitivity industrial district. In combination with sensitivity, the more a building is visible from the public space, the more impact a solar power plant applied on its envelope would have on social acceptance, determining an increased need for integration quality.

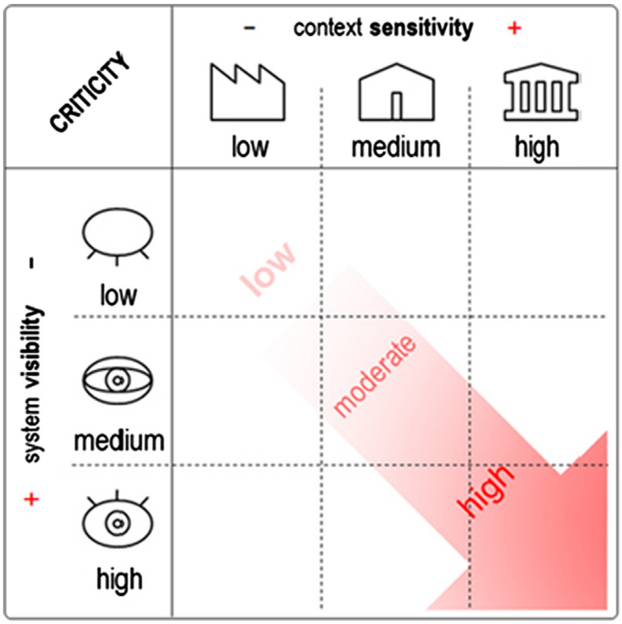

Fig. 1. "Criticity" matrix as a function of visibility and sensitivity (Credits: Munari Probst and Roecker (2015).

According to a recent census (Strantzali and Aravossis, 2016), 28% of multi-criteria studies in renewable energy investments across the last 20 years considered "social acceptability"; only the exact half (14%) though, is concerned with the "visual impact" of the project. Renewable energy generation plants in a broad sense (i.e.: wind and solar farms) can be arranged in large arrays that affect visual perception. Sometimes visual impact is estimated separately from social acceptability, according to the distance from the nearest observer, the type and the size of the equipment (Cavallaro and Ciraolo, 2005). In other occasions, especially in landscape or archaeological sites as specific high sensitivity zones, visual impact is explicitly linked with social acceptability (Wüstenhagen et al., 2007): an interesting study focusing on the Corsica landscape took into account the reciprocal position of the potential observers and the proposed photovoltaic power plants (geometric factor). The relevance of viewpoints was sorted based on their location on significant roads, homes or villages, thus setting a sort of viewpoints hierarchy (Haurant et al., 2011). Moreover, land uses were assigned a score based on the touristic interest, the cultural value and the agricultural productivity, approaching the concept of sensitivity.

Beyond MCDM, visibility models have been developed to address renewable energy plants specifically. Most of these studies define visibility as "visual impact", subtending a negative meaning, consequently trying to minimize it. Some of them include the "mass effect" generated by the number of possible viewpoints in the model, e.g. the amount of permanent inhabitants in a zone (Hurtado et al., 2004), or the quantity of traffic along a road section (Fernandez-Jimenez et al., 2015). The large majority provides a geometric method to assess visibility of targets from a set of viewpoints based on their reciprocal position (Fernandez-Jimenez et al., 2015), often supported by Geographic Information System - GIS tools: "viewshed" or "visibility tools" are the most commonly used. Some researchers took the size of the target into account (Minelli et al., 2014); others examined as well the relation with the surrounding landscape and the resulting perception (Torres-Sibille et al., 2009; Chiabrando et al., 2011). A very interesting study assessed the visual impact of wind farms through a "visually affected-area" index, as the fraction of the surface area in the analyzed region from which a renewable facility can be observed (Rodrigues et al., 2010); the same work introduced the concept of solid angles for visual perception estimation.

All the previous studies were conducted in large territorial areas: in urban areas, though, visibility assessment is mostly neglected for small-scale renewable energy plants, such as Building Added Photovoltaics and Solar Thermal (BAPV - BAST) or Building Integrated Photovoltaics and Solar Thermal (BIPV - BIST).

Few methods can identify target objects that are more prominently seen in an urban context, mostly involving visual angles or solid angles (Albrecht et al., 2013; Lin et al., 2015) or even 3D isovists in voxel spaces (Morello and Ratti, 2009). An interesting proposal relies on Virtual Geographic Environments (videogame renderers): a realistic 3D reconstruction of the urban area is reproduced, to easily compute the visual field of a set of viewpoints by exploiting the graphic processor (Lin et al., 2013), and then track their contribution back on target objects. Some experiences on spot buildings and districts have been successfully carried out (Koltsova et al., 2013; Dessi, 2013). Worth to mention is the use of saliency models, currently limited to the architectural scale (Xu and Wittkopf, 2014).

3. Methodological framework

This state of research demonstrates the crucial need for MCDM tools to pursue an effective deployment of renewable energy plants,