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Aesthetic impact of solar energy systems

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ABSTRACT

The presence of solar energy systems has increased significantly in recent years both in rural areas –in the form of solar farms–, and in urban areas as part of building installations. This transformation of the landscape, in spite of the good social acceptance of solar energy, causes an aesthetic impact whose interest has been growing in literature in recent years. This study aimed to review prior literature in order to establish the objective factors, aesthetic perception and methods that are most relevant when assessing the aesthetic impact. As a result of the lack of consensus, a new qualitative methodological framework is proposed that can serve as a basis for future research in the field of the integration of solar energy and its aesthetic impact. The framework comprises three sub-impacts: land use, solar system energy and glare. The results are discussed for future research and innovation in building photovoltaic integration and for SES site location and its environmental impact assessments.

1. Introduction

Solar energy has been promoted in recent decades as an alternative to fight against climate change, and its use has increased significantly. Photovoltaic and solar thermal energy systems (SES) have therefore been in a continuous process of improvement and the energy sector continues to strive to implement them as efficiently as possible. Nowadays, more and more, we find SES in the form of solar farms in rural landscapes, but also SES integrated into the envelope of buildings as part of the urban landscape. The installation of solar thermal systems is more limited in form and design since, for efficiency reasons, they are accompanied by the water facility they serve. However, in the case of photovoltaic systems, the features of their components allow greater freedom in design, being used in the field of architecture where the formal aspect is of great importance. Thus, the photovoltaic installations in buildings are classified in BIPV (building-integrated photovoltaics) when the system is fully integrated into the building envelope as an additional building material, or BAPV (building-applied photovoltaics) when the system is simply located on the roof with a metallic support structure.

Whether in urban or rural environments, several studies support the environmental benefits obtained by using SES [2–4]. Moreover, there is a general positive perception of SES as a clean and renewable source, although the importance of the user's environmental concern must be taken into account [4–6]. On the other hand, we also find studies that reveal certain negative aspects to be taken into account [7–13]. However, even accepting that SES implementation causes environmental impacts such as water usage, wildlife impacts, land use intensity, noise, or hazardous emissions among others, this technology in general is much environment-friendly than traditional energetic sources, even considering wildlife and land use impacts [3].

The aesthetic perception of the landscape has been the subject of numerous studies for decades [14–17], including rural and urban landscape. From an architectural point of view, aesthetic aspects are fundamental, because it is not enough to be functional, as function does not necessarily determine form [18].

Aesthetic perception of SES implementation has also been considered a relevant question regarding its environmental impacts [1,10,19–26]. In fact, if we aspire to normalize and promote the exploitation of solar energy, it would be fundamental to increase the acceptance of society, transferring indeed this awareness to everyday life [27]. In this sense, we must bear in mind that, in urban environments,

Abbreviations: SES, Solar Energy System; BIPV, Building Integrated Photovoltaics; BAPV, Building Applied Photovoltaics; GIS, Geographical Information System; FD, Fractal Dimension; Cl, Colour; Vi, Visibility; SP, Surface Patterns; F, Frame; Cc, Concurrence; Sh, Shape; PoV, Point of View; ID, Integration Degree; Gl, Glare; VS, Visual Saliency; Tr, Transparency; Fr, Fragmentation of the installation; TA, Topographic Alterations; Pa, Pattern; CSP, Computer Simulation Pictures; Ph, Photos; KE, Kind of Environment assessed; R, Rural landscapes; U, Urban landscapes; PV, Photovoltaic; OAISSP, Indicator of Objective Aesthetic Impact developed in [1]; SAM, Self-Assessment Manikin; AHP, Analytical Hierarchy Process; WTA, Willingness to Accept; WTP, Willingness to Pay; CNN, Convolutional neural networks; LSC, luminescent solar concentrators; EIA, Environmental impact assessment

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the visual appearance of the installation plays a very important role in the end user's preferences [5,28]. Additionally, in rural settings, the perception of the photovoltaic plants has been shown to depend on the visual relationships established by the observers with its environment [10,23]. Consequently, the requirement to consider visual impacts becomes imperative.

Precisely, the aim of this study was to conduct a review of the literature about aesthetic impact of SES in both rural and urban landscapes. Three relevant features are identified: objective factors, subjective perception and methods. Objective factors refer to those taken into account, or for which its influence on aesthetic perception has been analysed, such as colour, visibility, fractality, etc. Methods include the relationship processes within objective factors and subjective perceptions (such as weighted sum of objective factors).

Based on the literature review, a new qualitative and methodological framework is proposed to serve as a starting point for future research on the aesthetic perception of SES impact. The literature review and the framework proposed here are discussed, considering the limitations of the study, and their application in different areas such as photovoltaic integration assessment or site location.

2. Landscape aesthetics

According to [29]: "The history of landscape studies can been traced in two broad fields of inquiry: (1) geographical research and (2) art and landscape painting, which make the landscape itself an object worthy of aesthetic admiration. […] In the twentieth century, new tools and concepts enriched and diverted this approach into a wide array of disciplines. On the one hand, a broader geographical and anthropological branch of landscape studies has considered land and the interactions between human activities and physical geography. On the other hand, cultural geography has incorporated aesthetic and symbolic readings of the landscape with the geographical and art traditions. More recently, social geography has filled the gap between regional studies, i.e., landscape assessment, and cultural geography, i.e. landscape perception, by exploring the question of social and individual well-being. […] The art tradition was joined with garden architecture and the cultural component of geographical analysis resulting in landscape architecture and landscape planning."

The field of research on society-ecosystem interactions in the context of sustainability is highly complex and a landscape-based approach can be very useful [30]. Ecosystem services [31] and the related Landscape character [32] have become general concepts for the expression of values assigned by people to different landscapes.

Ecosystem services are the benefits that humans obtain from ecosystems, and they are produced by interactions within the ecosystem. Four broad types of service have been recognized: (1) those that cover the material or provisioning services (e.g. food, water, wood, etc.); (2) those that cover the way ecosystems regulate other environmental media or processes (e.g. climate and flood regulation); (3) those related to the cultural or spiritual needs of people (e.g. aesthetic, spiritual, educational, etc.); and finally, (4) the supporting services that underpin these other three categories (e.g. nutrient cycling, soil formation, etc.).

Changes in the landscape affect the human well-being [33]. Land use intentionally and unintentionally influences the biodiversity as well as the structure and functions of ecosystems. Two types of land use interventions are usually considered in impact assessments: land transformation (or land use change), besides land occupation [34]. In accordance with the ecosystem services of the Millennium Ecosystem Assessment [31], life cycle assessment covers two main impacts [35]: the biodiversity damage potential and the ecosystem services damage potential. The former includes the protection of global species diversity, as well as the functional diversity of species in ecosystems. The latter includes the impact on the production of biomass, the impact on climate by influencing the carbon sequestration in the top soil and land cover, the impacts on water quantity and quality, as well as the impacts on soil quantity and quality. Moreover, landscapes exhibit diversified and interconnected types of values, not all them with objective measures of the impact, such as visual-aesthetic, recreational and touristic values.

"Visual impact assessment often uses the term unity as the degree to which all visual elements combine to form a coherent, harmonious pattern" [36], being therefore usually directly related to physical features. From this perspective, aesthetic impact can be related visual disturbance due to perceived landscape interventions as a result of human-made elements that have a *disruptive effect* because of their size, incongruent style or unintegration with the surroundings and original settings [37].

The concept of aesthetic derives from the design theories, linking the descriptors related to landscape with terms developed in other different fields, such as philosophy, psychology and art, posteriorly transferred to landscape contexts [16].

Several theories explain landscape aesthetics in terms of perception and preferences, which are usually "divided into evolutionary theories and cultural preference theories. The evolutionary theories explain landscape perception and preference as […] a dimension of human fitness and survival, where landscape preferences reflect landscape qualities satisfying human biological needs to survive and thrive as a species" [16]. The latter theoretical models argue that perception and experience of landscapes predominantly depend on the cultural background and personal attributes of the observer, emphasizing that aesthetic appreciation differs over time and across regions, as well as individuals. These theories usually focus more on affective responses and "personal attributes, such as age, gender, occupation, hobbies, academic background and familiarity" in order to explain the landscape preference (for a review [16],). In this context, the ecological aesthetic models link preferences for landscape and ethics, suggesting a predisposition for ecologically sound landscapes [38].

More recently, several approaches to landscape aesthetics have tried to recognize the influence of both cultural (learned) and biological (innate) factors in order to explain landscape preferences [36]. According to this new perspective, genetically based preferences are challenged by experience and cultural influences and a synthesis of both points of view is more appropriate for further research concerning the aspects of the visual landscape that most humans respond to. In addition, as the capacity to unfold aesthetic appreciation seems to manifest universally, so this sensitivity should be an intrinsic part of the human biology that has developed throughout the evolution of our species [39].

One interesting approach that relates landscape architecture with art is the Aesthetic Creation Theory [40]. This theory states that art function is to have aesthetic properties in virtue of having certain non-aesthetic properties. Thus, aesthetic properties, which must be delineated with reference to beauty and ugliness as the central aesthetic properties, would depend on non-aesthetic ones [41].

3. Objective factors

Bishop theory divided the visual impact aspects that we can quantify into three groups: factors related to objects (size, colour), factors related to the environment (visual quality, visual absorption capacity), and factors related to the observer (activity, exposed population). Nevertheless, his research concluded that the greatest interest resides precisely in the relationship between the object and the environment [42,43]. This relationship should be analysed by means of objective factors from the scene itself that can also be easily quantified. However, from a subjective point of view, the influence of the observers themselves should not be underestimated, since several studies have reported a clear influence of the individual´s type of professional training on their aesthetic perception [44,45].

A review of the literature focused on the objective or physical factors influencing on the impact and perception of SES has been carried