

Visual impact, landscape and renewable energy plants: the case of PV

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SUMMARY

The installation and operation of PV plants, recently promoted in some European countries by new sell-back tariffs, is a relevant transformation of the territory for various reasons (land use, visual impact on the landscape, glare, etc). Besides, concerns of local communities and governments about the environmental, territorial and landscape impacts of this technology are increasing rapidly.

Consequently, the studies concerning the procedures for assessing the territorial and landscape impacts of this type of systems have recently seen a remarkable development. At the Italian level, the guidelines for the authorization of renewable energy plants (DM 10 settembre 2010) contains some new criteria for the landscape integration of PV plants.

If an extensive scientific literature is available in other cases (e.g. wind turbines), there are few studies dealing with the visual impact of photovoltaic plants.

Given this picture, in this work the activity and studies conducted by the authors regarding the territorial impacts of photovoltaic plant are presented. In particular, the assessment of the risk of glare by reflection of direct sunlight from the surfaces of photovoltaic modules and the visual impact analysis based on a quantitative indicators are analyzed and presented. The use of vegetation as a green screen is also discussed and applied.

From the results, it can be derived that such procedures can be effectively used provided that a regulatory framework is set by the local authority that carries out the authorization procedures.

The results of this research may also contribute to the improvement of the know-how that is required to carry out the landscape integration report (Relazione paesaggistica D.P.C.M. 12.12.2005) that is required by the local authorities during the authorization procedures of such plants.

Finally, a discussion on how this procedure may be used and integrated into the administrative requirements of large and small scale PV plants developments is carried out.

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1. INTRODUCTION

The installation and operation of PV plants, recently promoted in some European countries by new sell-back tariffs, is a relevant transformation of the territory for various reasons (land use, visual impact on the landscape, glare, etc). One of the most recent studies on the environmental impacts from the installation and operation of large-scale solar power plant has proved that the is the one of Turney and Fthenakis (2011) that appraise 32 impacts, 22 of which are beneficial, 4 are neutrals and 6 are to be appraised. However, none of the impacts are negative when PV plants are compared to the traditional power generation plants.

However, concerns of local communities and governments about the environmental, territorial and landscape impacts of this technology are increasing rapidly. Consequently, the studies concerning the procedures for assessing the territorial and landscape impacts of this type of plants should be implemented at the authorization level. In fact, if they have recently seen a remarkable development from a theoretical point of view, particularly for the case of wind turbine and other installations, it remains to be studied how those procedures may be implemented into the authorization procedures in order to better understand the impact of an installation and to perform a judgment.

At the Italian level, the guidelines for the authorization of renewable energy plants (DM 10 settembre 2010) contains some new criteria for the landscape integration of PV plants.

2. METHODS

There are basically two different types of landscape impact assessment methodologies that, by extension from other fields, can be applied to the case of photovoltaic systems. These are:

- methodologies based on the analyses of real photographic images or visual simulations;
- methodologies based on the calculation of visibility indexes of the plant over a vast territory.

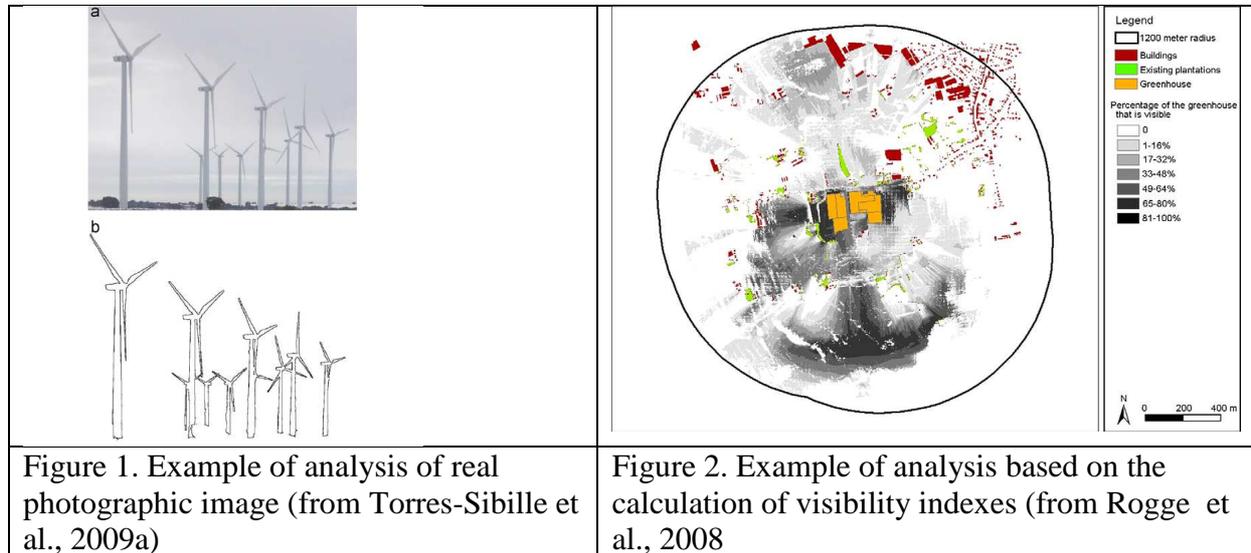
It is evident that the first one is a punctual one, while the second one is of an extensive type. In the first case the scenario settings should be defined before performing the analysis, while in the second case the boundary of the study area should be defined before performing the analysis.

The first type of methodologies takes into account not only the visibility of the plant but also other aspects of the perception that are more difficult to measure, such as the shape and colour of the artefacts. The idea of assessing the visual quality of the landscape by means of photographic images comes under the visual simulation techniques for assessing the compatibility of landscaping projects or the visual quality of the countryside (Arriaza et al., 2004). This type of analysis, even if it is simplified and applicable, for various reasons, to the authorization procedures of a PV plant, it is influenced by the conditions at the moment the picture was taken (weather, focus, etc.).

The second type of analysis, applied by Hurtado et al. (2004), Möller (2006) and Tsoutsos et al. (2009) in the case of wind turbines as well as by Rogge et al. (2008) in the case of

agricultural greenhouses, is based on a discretization of the territory that may potentially be impacted by the artefact and on the determination of indices of impact on the landscape – usually but not exclusively, of vision – for each unit of land, that are weighted as a function of, for example, the population density of each portion of land. These types of assessments are usually conducted through a GIS application, with the related spatial analysis tools.

An example for each approach is reported in figures 1 (from Torres-Sibille et al., 2009a) and 2 (from Rogge et al., 2008).



3. THE AUTHORIZATION PROCEDURE

Within an authorization procedure of a PV plant a number of different studies should be provided; as regards the land carrying capability of a new PV plants the documents that are at least required can be into the following four families:

- a) documents that demonstrate the exclusion from zones under all the applicable planning instruments at all levels and scopes;
- b) documents regarding the type of crop and land use capability (agronomy report);
- c) documents regarding the geological, geomorphological, hydrogeological and seismic surveying of the site (geological report);
- d) documents regarding the impact on the landscape of the plant (landscape report).

The last ensemble of documents may be referred to as a landscape report. This report usually contains a description of the actual landscape conditions (land use, agricultural or forestry characterization, natural resources), of the local landscape planning instruments and regulations, of the proximity to protected areas (SIC, ZPS; SIR, etc.), a large photographic survey, various visual simulations of the plant, the discussion and representation of mitigation measures. The representation of the natural or atrophic visibility barriers is usually done on a orthoimage or by means of cross sections.

On the contrary, visibility analyses based on a 3D model by means of the spatial extension of GIS software tools are not common, especially for the ground mounted PV plants.

In the case of sun-tracking systems, the landscape impact becomes greater. This is due to the fact that the sun-tracking system has a greater high above the ground and may easily be seen from the surroundings, and its position changes during the day to follow the sun position. Also the studies to assess the risk of glare from the reflection of the direct sunlight by means of the clear glass PV panel cover are not commonly developed. They are conducted only in cases where the PV plant is near an infrastructure (highway road, airport) or in steep and hilly territories. A methodology to assess the glare risk can be found on (Chiabrande et al., 2009).



Figure 3. Visual simulation of a ground-mounted PV installation (courtesy of Studio Sintesi Igegneria e Paesaggio)



Figure 4. Visual simulation of a sun-tracking PV installation

The short analysis of the documents that are currently produced during the authorization procedure of a PV plant that was presented before, showed that some visual simulation of the landscape integration of a PV plant is always done. These images are requested by the competent Landscape Authority but there is no uniformity on the way in which these images should be evaluated. This is particularly important in case of proximity to historic sites, protected areas, hilly territory or mountains, where the site of the PV plant can be seen from various different locations and may affect the landscape perception from some of the typical views.

In fact, at a general level, the landscape is still perceived by means of specific viewpoints form or towards certain locations (a hill, a front river, a monument, etc.) (Daniel, 2001).

Scope of this paper is to propose the application of an objective visual impact assessment of the visual simulation images to be used during the authorization of project developments of PV plants. This procedure has the advantage to use the same techniques for the visual simulations that already are to be presented when authorizing a PV plant and may be used also for building integrated PV installations, that are spreading rapidly latterly.

On the contrary, the application of methodologies that are extensive type (see paragraph 2), may not be appropriate for the reasons of costs and competences involved, in case of small and medium size projects

4. PROPOSAL

First, the authority should clearly define a regulatory framework where the viewpoints from which the visual simulation of the PV plant should be taken, the representation rules, focus, etc. This is summarized in the first part of Table 1 where the various steps for the definition of a regulatory framework for the objective visual impact are set out. The steps, that are taken by the Local Community Authorities, are the followings:

- 1.1.definition of the outstanding landscape elements. These may become viewpoints *from which or towards which* a landscape perception should be preserved.
- 1.2.definition of the viewpoints from which the visual simulation should be taken;
- 1.3.definition of the representation rules (focus, distance, size, etc.) of the picture to be taken; a reference picture may be used for each viewpoints; these pictures may represents the landscape that the local community is intended to preserve.
- 1.4.adoption of an appropriate objective visual impact assessment procedure to determine the impact of the plant on the visual simulation images;
- 1.5.adoption of appropriate thresholds values for the analysis of PV plants.

This may seem quite difficult at first, but it should be noted that in many hill or mountain local communities this is feasible and allows better results than the use of GIS tools for each project development. The viewpoints may be determined once, by means of a visibility analysis made by GIS and based on the criteria selected by the authority (population density, historical sites, preservation of identities, etc.). The decision about these criteria cannot be taken by a technician, but is eminently social and political.

Once that the viewpoints are selected, then for each PV plant installation the design simulation should be made and analyzed by means of a procedure such as the OAI_{SSP} tool.

The steps that follow are summarized into the Stage 2 of Table 1.

The specifications for each project development include:

- 2.1. the visual simulation of the project under development following the specifications that are established by the Local Community (steps 1.2 and 1.3) as regards the viewpoints, the representation rules, etc.;
- 2.2. the application of the objective visual impact assessment of the simulation images following the procedure of step 1.4;
- 2.3. the evaluation of the outcomes of the visual analysis by comparing the results with the thresholds limits.

Such a procedure has the advantage of being objective, while frequently in practice the aesthetic and landscape impact assessment is evaluated by means of judgments of the technician on visual simulation.

Table 1. Steps of the evaluation of visual simulations of ground mounted PV plants

Stage 1	Regulatory framework		
	<i>Step</i>	<i>Actor</i>	<i>Time</i>
1.1	Definition of the landscape outstanding elements	Local Community	Once
1.2	Definition of the viewpoints	Local Community	Once
1.3	Definition of the representation rules	Local Community	Once
1.4	Adoption of a procedure for the objective visual impact assessment	Local Community	Once
1.5	Definition of threshold of visual acceptance	Local Community	Once
Stage 2	Analysis of the visual simulations		
	<i>Step</i>	<i>Actor</i>	<i>Time</i>
2.1	Creation of the visual simulation in accordance to steps 1.2 and 1.3	Project developer	At each project development
2.2	Analysis of the visual simulation of step 2.1 following the rules established in step 1.4	Project developer	At each project development, for each visual simulation
2.3	Final evaluation of the results according to the thresholds of step 1.5	Local Community	At each project development, for each visual simulation

5. THE OBJECTIVE ASSESSMENT OF THE VISUAL IMPACT OF PV THROUGH PICTURES

The techniques for the visual quality assessment through the analysis of pictures or photographs have been widely developed in the last 20 years; among the authors that may be cited, Ian Bishop is one of the researcher that most contributed to the development of an objective aesthetic impact of wind turbines and other facilities.

In this work, a study of a Spanish research group (Torres Sibille et al., 2009) on the objective assessment of the aesthetic impact of solar systems through evaluation of photographic images, as later modified by the Authors, is presented and applied in order to demonstrate how it can be used into an authorization procedure.

The indicator to be used is called OAI_{SSP} (Objective Aesthetic Impact Solar System Panels) and is measured by a continuous number that falls between 0 and 1. This indicator is the weighted sum of the following four sub-parameters, which account for various aspects:

- sub-parameter I_v to take into account the visibility of the plant;

- sub-parameter I_{cl} to take into account the color of the plant compared to the color of the immediate surrounding;
- sub-parameter I_f to take into account the shape of the plant;
- sub-parameter I_{CC} to take into account the concurrence of various forms and types of panels in the same plant.

Following (Torres Sibille et al., 2009) the percentage of each of these sub-indicators on the global indicator value is equal, respectively, to 64%, 19%, 9% and 8%. The global equation reads

$$OAI_{SPP} = 0,64I_v + 0,19I_c + 0,09I_f + 0,08I_{cc}$$

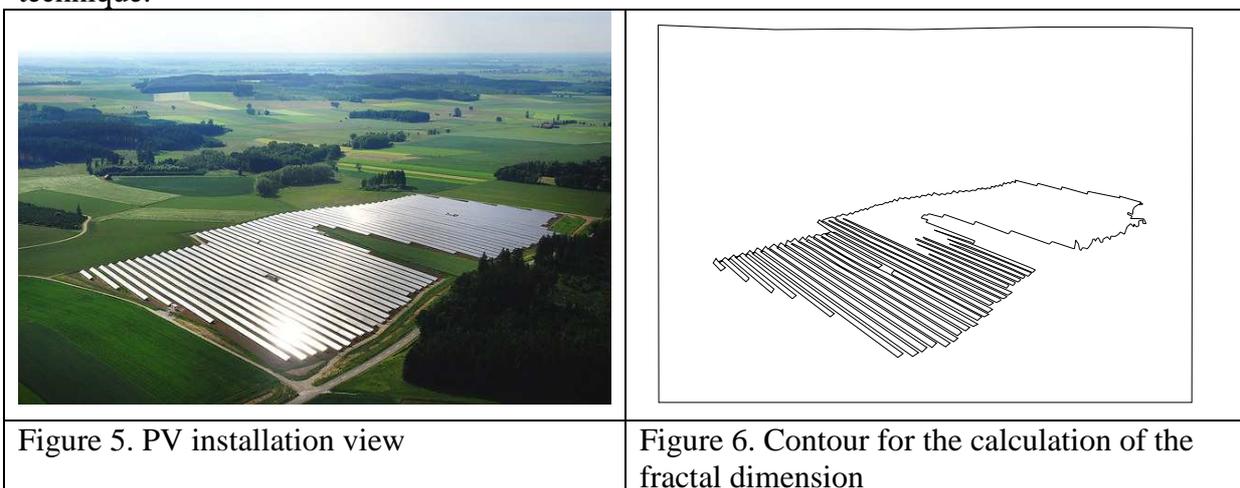
A climate indicator reduces the visibility and color impacts depending on the weather conditions (e.g. good visibility, haze, precipitation, fog). It can be easily seen that most of the aesthetic impact is attributed to the visibility and color of the plant (over 80% of the overall indicator is represented by these sub-parameters) and given that the pictures are usually taken in good visibility conditions, in most of the times the analysis of the visual impact of a plant can be performed by means of the only four sub-parameters.

To determine the sub-parameter I_v the ratio of the total area occupied by the panels and the area of the landscape background A_{pl}/A_{ba} should be calculated and expressed as a percentage. From this quantity, the impact indicator for visibility is calculated through the curve proposed by Torres Sibille et al. (2009b)

$$I_v = \begin{cases} -0,004x^2 + 0,128x & \text{per } x < 13,5 \\ 1 & \text{per } x > 13,5 \end{cases}$$

where x is the A_{pl}/A_{ba} percentage ratio.

The sub-parameter I_f refers to the plant form and is calculate from the fractal dimensions D_f of the figures of the plants (subscript pl) and of the background (subscript ba). It is necessary to extract from the images the contour of the installations (for example, the contour of the picture of Figure 5 is shown in Figure 6) and export them into bitmaps. The fractal dimensions can be calculated by means freeware or commercial software tools based on the box counting technique.



The ratio between the fractal dimension of the plant and the one of the background, which can range from 0 to 2 for the definition of fractal dimension, is minimal for a $D_{f,pl}/D_{f,ba}$ equal to 1,

while it grows for $D_{f,pl}/D_{f,ba}$ that tends to 0 or 2. The curve to calculate the index is the following

$$I_f = \begin{cases} 1 & \text{per } z = 0 \\ 100z & \text{per } 0 < z \leq 0,01 \\ -0,085z + 1 & \text{per } 0,01 < z \leq 0,75 \\ -3,745z + 3,745 & \text{per } 0,75 < z \leq 1 \\ -1,048z^2 + 4,145z - 3,097 & \text{per } 1 < z \leq 1,94 \\ 1 & \text{per } 1,94 < z \leq 2 \end{cases}$$

where z is the ratio $D_{f,pl}/D_{f,ba}$.

The sub-parameter I_{CC} is to be used only if there are significant differences in the forms used in the various modules of the plant.

As for the impact due to the colour of the plant, the CIELab1974 formula for determining the colour difference can be used. It is based on the CIELab colour space triple coordinates hue L^* , saturation a^* and brightness b^* , and the difference between two colours can be expressed as the Euclidean distance between the two points that in the colour space represent the two colours. It becomes

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

The transition from the average colour difference to the sub-parameter I_c is done assuming a maximum value of I_c , which is equal to 1 for the maximum DE^* (equal to 374 giving the fields of variability of the coordinates L^* a^* b^* equal to $0 < L^* < 100$, $-128 < a^* < +127$ and $-128 < b^* < +127$) and a zero I_c for a zero DE^* .

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REFERENCES

Arriaza, M, Canas-Ortega, JF, Canas-Madueno, JA, Ruiz-Aviles, P, 2004, Assessing the visual quality of rural landscapes, *Landscape and Urban Planning*, vol. 69 (1), pp. 115–125.

Chiabrando, R, Fabrizio, E, Garnero, G, 2009, The territorial and landscape impacts of photovoltaic systems: definition of impacts and assessment of the glare risk. *Renewable and Sustainable Energy Reviews*, vol. 13 (8), pp. 2441–2451.

Chiabrando, R, Fabrizio, E, Garnero, G, 2011, On the applicability of the visual impact assessment OAI_{SPP} tool to photovoltaic plants. *Renewable and Sustainable Energy Reviews*, vol. 15 (1), pp. 845–850.

Daniel, TC, 2001, Whither scenic beauty? Visual landscape quality assessment in the 21st century, *Landscape and Urban Planning*, vol. 54, pp. 267-281.

Hurtado, JP, Fernandez, J, Parrondo, JL, Blanco, E, 2004, Spanish method of visual impact evaluation in wind farms, *Renewable and Sustainable Energy Reviews*, vol. 8 (5), pp. 483–491.

Möller, B, 2006, Changing wind-power landscapes: regional assessment of visual impact on land use and population in Northern Jutland, Denmark. *Applied Energy*, vol. 83 (5), pp. 477–494.

Rogge, E, Nevens, F, Gulinck, H, 2008, Reducing the visual impact of ‘greenhouse parks’ in rural landscapes, *Landscape and Urban Planning*, vol. 87 (1), pp. 76–83.

Torres Sibille, A, Cloquell-Ballester, V, Cloquell-Ballester, V, Darton, R, 2009a, Development of a multicriteria indicator for the assessment of objective aesthetic impact of wind farms, *Renewable and Sustainable Energy Reviews*, vol. 13 (1), pp. 40–55.

Torres Sibille, A, Cloquell-Ballester, V, Cloquell-Ballester, V, Ramirez, M, 2009b, Aesthetic impact assessment of solar power plants: an objective and subjective approach, *Renewable and Sustainable Energy Reviews*, vol. 13 (5), pp. 986–999.

Tsoutsos, T, Tsouchlaraki, A, Tsiropoulos, M, Serpetsidakis, M, 2009, Visual impact evaluation of a wind park in a Greek island, *Applied Energy*, vol. 86 (5), pp. 1587–1600.

Turney, D, Fthenakis, V, 2011, Environmental impacts from the installation and operation of large-scale solar power plants, *Renewable and Sustainable Energy Reviews*, vol. 15, pp. 3261–3270.

BIOGRAPHICAL NOTES

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