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An open source GIS tool to quantify the visual impact of wind turbines and photovoltaic panels

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ABSTRACT

Although there are clear economic and environmental incentives for producing energy from solar and wind power, there can be local opposition to their installation due to their impact upon the landscape. To date, no international guidelines exist to guide quantitative visual impact assessment of these facilities, making the planning process somewhat subjective. In this paper we demonstrate the development of a method and an Open Source GIS tool to quantitatively assess the visual impact of these facilities using line-of-site techniques. The methods here build upon previous studies by (i) more accurately representing the shape of energy producing facilities, (ii) taking into account the distortion of the perceived shape and size of facilities caused by the location of the observer, (iii) calculating the possible obscuring of facilities caused by terrain morphology and (iv) allowing the combination of various facilities to more accurately represent the landscape. The tool has been applied to real and synthetic case studies and compared to recently published results from other models, and demonstrates an improvement in accuracy of the calculated visual impact of facilities. The tool is named r.wind.sun and is freely available from GRASS GIS AddOns.

Introduction

Over the 21st century, global demand for energy is expected to double, arguably requiring growth in renewable energy production such as solar (photovoltaic panel) and wind turbines to reasonably meet demands (Lewis and Nocera, 2006). Although there are clear benefits to these renewable technologies, uptake does not match potential of renewable energy production for a variety of reasons (Painuly, 2001). At a local scale, one such barrier is the aesthetic impact of renewable energy facilities on the landscape (Wüstenhagen et al., 2007). Hence, there is a clear need to carefully locate wind farms and photovoltaic panels to minimise their visual impact and increase social acceptance.

At present, there is not a unilaterally agreed, standardized method to quantify the visual impact of photovoltaic fields and wind farms. Landscape quality evaluations may rely upon local guidelines (Hurtado et al., 2003; Regione Autonoma della Sardegna, 2008), good practice manuals (Landscape Institute, Environmental Management Assessment, 2002; Scottish Natural Heritage et al., 2006; Vissering et al., 2011), survey-based or index methods (Ladenburg, 2009; Tsoutsos et al., 2009), and/or colour and light based methods (e.g., blending with the landscape) (Bishop and Miller, 2007; Chiabrando et al., 2011; Shang and Bishop, 2000).

Typically, the visual impact of a range of environmental phenomena is assessed through viewshed analysis in a GIS. In this method, a digital elevation model is used to determine which parts of the landscape are visible or not visible from a particular vantage point (Longely et al., 2010). For instance, studies have been carried out on the visibility of *Nuraghes* (De Montis and Caschilli, 2012), native buildings from the Isle of Sardinia in Italy, on the visibility of electric transmission towers (Turnbull and Gourlay, 1987), and on the maximisation of the scenic viewpoints along a touristic road (Chamberlain and Meitner, 2013). Manchado et al. (2013) recently reviewed computer programmes available to perform visibility analysis for a variety of purposes.

Visibility analysis techniques have been applied to evaluate solar panel and wind turbine visibility (e.g. Moeller, 2006 and the references therein). We build upon this work by taking into account how the perceived size and shape of an object become distorted depending on the viewing point. An object's shape distortion as perceived by a human eye can affect the quantification of the area affected by visual impact on landscape perception, as we demonstrate.

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This method is based on the concepts of (i) visibility analysis (Manchado et al., 2013) and visual magnitude (Chamberlain and Meitner, 2013), (ii) human eye perception and its field of view (Costella, 1992; Spector, 1990) and (iii) descriptive geometry (De Rubertis, 1979).

Quantitative analysis of visual impact is performed by (i) computing the field of view of an observer at a specific distance, (ii) evaluating the object shape distortion perceived by a human eye, and (iii) analysing the mutual relation between object, observer and earth morphology. The tool is developed as an add-on module for GRASS GIS, an Open Source GIS software (Neteler and Mitasova, 2008). As the code is completely available, users can freely read, verify, redistribute and modify the code, meaning that the tool is flexible and that the reproducibility of results is guaranteed (Ince et al., 2012).

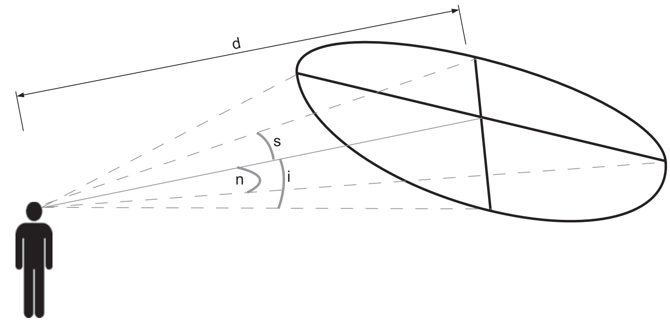

Fig. 2. The static field of view.

Material and methods

The tool developed is named "r.wind.sun". It is coded in the Python programming language (Van Rossum and Drake, 2001) as an add-on module to GRASS GIS, an Open Source GIS software (Neteler and Mitasova, 2008). The tool builds upon the existing GRASS GIS tool "r.viewshed" (Toma et al., 2012) which is based on the concept of line of sight (LOS), the straight line between the observer and object (e.g., Molina-Ruiz et al., 2011).

In the r.wind.sun tool, visual impact is quantified by the proportion of the field of view that is obstructed by the wind turbine or photovoltaic panel. This builds upon previous work by Rodrigues et al. (2010) that measures visual impact as the size of the observed object and half of the full solid angle multiplied by the square of the distance between the object and the observer.

In this section we introduce the key concepts applied to (i) calculate the field of view, (ii) calculate the perceived size of objects within the field of view and (iii) calculate the ratio between the perceived size of object and the field of view and demonstrate that this is independent of distance. In the section Visual impact index, we define the visual impact index and then show the development of the tool to measure this.

The human field of view

In this section we define the shape and size of the region that can be seen by an observer, this is the human field of view (FOV). The "static" FOV is defined by three angles (Fig. 1):

- nasal (n): measuring 85°, starting from the nose of the observer and extending outwards across a horizontal plane (Fig. 1a).
- superior (s): vertical angle, measuring 65°, starting from the nose of the observer and extending upwards (Fig. 1b).
- inferior (i): vertical angle, measuring 70°, starting from the nose of the observer and extending downwards (Fig. 1b).

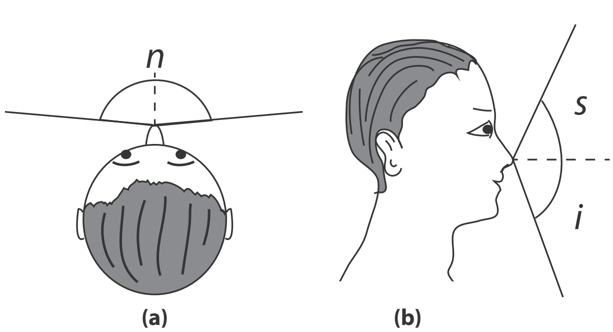

Fig. 1. The angles that define the static human FOV. (a) n is the nasal angle defining a horizontal plane of 170° from the nose. (b) s and i are the superior and inferior angles defining lines extending 65° upwards and 70° downwards respectively from a horizontal line extending from the nose. When combined, these angles form an ellipse that defines the static FOV, shown in Fig. 2.

These angles define the region seen by at least one eye.

The virtual field of view area (A_{fov}) depends on the distance (d) between the observer and the object. The shape of the virtual field of view is an irregular ellipse of which the dimensions can be estimated by simple trigonometric relations.

Different values can be taken for angles s, i and n (e.g., considering only the full binocular part of the field of view, Spector, 1990). However, small changes to the values of these angles would cause only general scaling of the results without altering their meaning and the ratio between them.

If we now take into account the ability of the observer to move about a fixed point, we introduce two types of "dynamic field of view": "cylindrical" and "spherical".

In the first case, the observer can rotate their sight by 360° on the horizontal plane. Consequently, the elliptical shape of the field of view becomes the internal (lateral) area of a cylinder (Fig. 3).

In the second case, we extend this idea by assuming that the observer is able to move their sight in a vertical direction. The area of the field of view then becomes the internal area of a sphere (Fig. 4).

As photovoltaic panels generally have a low/flat profile, the dynamic cylindrical FOV approach is used to calculate their visual impact. Whereas, the vertical dimension of wind turbines is not negligible and thus the dynamic spherical FOV approach is applied to calculate their visual impact.

The perceived shape and size of an object

The *perceived* size and shape of an object will differ from its *true* dimensions depending on the position (distance and angle) between the object and the observer. In the section Perceived size of an object, we demonstrate how the perceived size of an object is calculated. In the section Perceived size as a proportion of area of field of view, we demonstrate that when the perceived size is represented as the proportion of the field of view occupied by an object, this becomes independent of the distance between the observer and the object. This allows us to

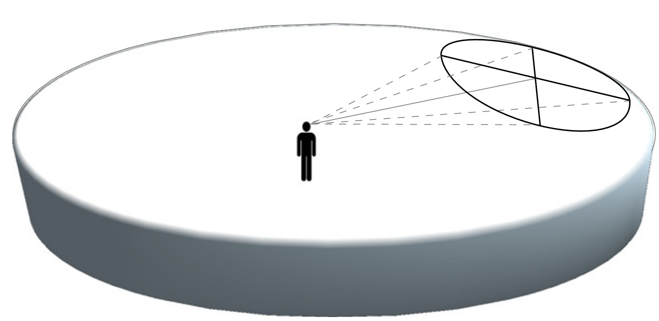

Fig. 3. The dynamic cylindrical field of view.