Which Locations in a Solar Energy Project Contribute the Greatest Visual Impact?

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Abstract: Current visual impact assessment for permit approval is (has?) to include a viewshed that shows the number of sampled project points seen from locations in a study area. These analyses typically do not weight the impact of points closer to the viewer higher than points further away. Perhaps more important, the analysis does not represent the portions of a project that have the greatest visual prominence. This paper develops a method to conduct these analyses and applies it to a photovoltaic solar energy project in Maryland, USA.

Keywords: GIS, visibility analysis, distance zones

1 Introduction

GIS visibility analysis is one of the standard methods used for visual impact assessment (VIA) (FELLEMAN 1979). Typically, the VIA prepared as part of a permit application includes a cumulative viewshed map that displays the number of turbines, or other project elements that are visible from locations within the study area. This analysis answers the question: Where in the landscape is the project visible?

ERVIN & STEINITZ (2003) pointed out that visibility is a two-way phenomenon. The analysis can also be adapted to answer the question: Which locations within a project are most visible to the surrounding landscape? This second application of visibility analysis would seem to be of particular interest to permitting agencies, since it has obvious uses for identifying areas that require mitigation or removal from the project. PALMER (in review) reviewed the viewshed maps in wind energy VIAs prepared by 25 different firms and did not find any examples that analyzed which turbines had the greatest visual impact.

It is known that visual impact decreases as the distance between the project and viewer increases. Often VIAs discuss distance zones that are used to characterize this shift in perceived visual prominence (LITTON 1968, USFS 1995) and include buffer-lines at the zones' threshold distances surrounding the project elements. PALMER (in review) review of wind energy VIAs found that none of the VIAs systematically incorporated distance to evaluate the extent of visual impact. All of the cumulative viewshed maps sum all visible turbines into a single count without reference to distance.

PALMER (in review) demonstrates a method that evaluates visual prominence by incorporating distance zone weights into the visibility analysis. This approach provides more useful information about how individual locations in the study area that are impacted. It can also be applied to answering the question about which project features have the greatest impact on the surrounding area. The answer to this question is critical for identifying optimal wind project configuration when developers seek approval for more turbine sites than the project's permitted energy production requires – an increasingly common situation.

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Wind turbines are discrete visual targets, highly suited to demonstrating the method of evaluating which parts of a project that are most visible. It is less obvious how to adapt the method to a project that occupies a large area but is not very tall, such as a photovoltaic solar project. This paper demonstrates how to do that.

2 Methods

2.1 Photovoltaic Solar Energy Project Case Study

The energy company Constellation partnered with Mount Saint Mary's University, the second oldest Catholic college in America to develop Mount Solar, a 16.1 megawatt (MW) photovoltaic solar energy project in Emmitsburg, Maryland, USA. Mount Solar was the largest solar energy project in the state when it became operational in 2012. The project is arranged into three discrete sections: Papa is the largest occupying 208,631 sq m and accounts for approximately 10.5 MW, the Mama is 102,058 sq m for 5.2 MW, and the Baby is 8,168.75 sq m for 0.4 MW. The Mama and Baby sections are enclosed by a single security fence; Papa is enclosed by a separate security fence. Figure 1 shows the study area with a 4 mi (6,437 m) radius from the solar panels.

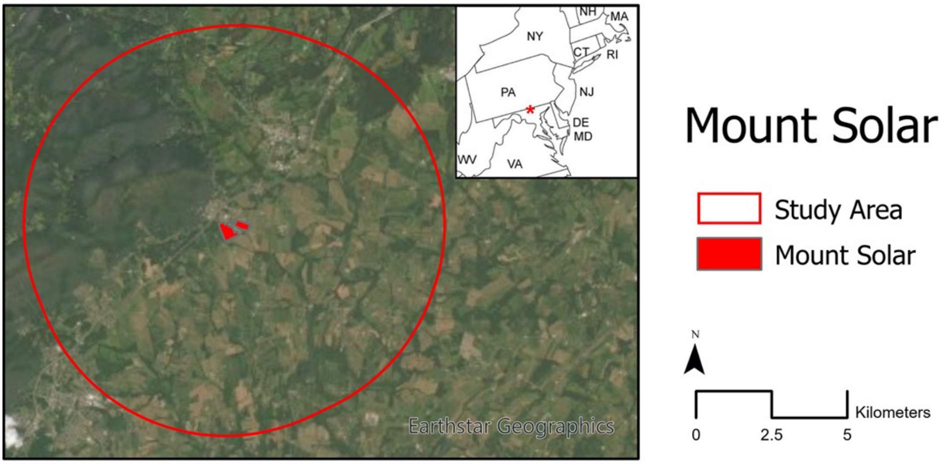

Fig. 1: Mount Solar study area

2.2 GIS Data

Plans for the project were not available, so the three sections occupied by the solar panels were digitized by hand. A 40 m grid was located over the project area, and the intersections of the grid lines within the area of solar panels was saved as a point shapefile. In addition, a point was located every 40 m around the perimeter of the three solar panel areas. LiDAR-derived digital terrain model (DTM) and digital surface model (DSM) with 1 m resolution were used to calculate visibility from each of the project-points.

2.3 GIS Analysis

The approach used here assigns visual prominence weights to distance zone. It is possible to calculate the decay of visual dominance as a function of distance and avoid the use of distance zones. For instance, TARA et al. (2021) recently calculated the decay in visual dominance for buildings using visual magnitude and distance measures. In a review of the literature, he found general agreement that the decay generally follows a negative power function, though the specific parameters vary among studies. However, this approach is purely geometric and does not account for perceptual meaning and interpretation. PALMER (in review) reviews the literature relating distance to visual prominence of wind turbines observed in the field and the results also generally follow a negative power function. However, a similar literature does not exist for solar projects. A pragmatic reason not to use distance decay is the computation time it takes to calculate the distance of 203,285,569 cells from each project-point, of which there are 303, and then apply a non-linear function to the results in a second step. In the end, it is unclear whether using calculated distances would provide significantly more useful results than prominence weights for distance zones.

Five distance zones were proposed based on TJBA's experience conducting VIAs for solar energy projects of this size (e. g., PALMER 2019), and the distance zone thresholds the US FOREST SERVICE (1995) used to evaluate forest harvest openings, which are often the same area as the Mount Solar case study. The distance zones are described in Table 1 along with their visibility weights.

Table 1: Solar Project Visual Prominence Weights by Distance Zone

Distance Zone	Description	Weight
Immediate Foreground 0 to 80.5 m	Close proximity, such that a short walk of a minute or two would allow you to touch project structures, limited space for intervening objects, clear recognition of materials, textures and shapes. Awareness of sounds at 40 dB.	8
Foreground 80.5 to 805 m	Walking to foreground object may take several minutes. Textures and materials are apparent but become less detailed. Shapes of small and large project elements are clearly visible.	4
Near-midground 805 to 3219m	Walking to near-midground objects may take tens of minutes. Textures and materials and smaller shapes are not clearly visible, but larger shapes are still easily distinguished.	2
Far-midground 3219 to 6437 m	The walk to far-midground objects may be more than an hour. The pattern of solar panels rows may still be apparent, but no other details.	1
Background Beyond 6437 m	The large shape of uniform color and texture may be visible from elevated positions without it being apparent that it is a project with rows of PV solar panels.	NoData

The process of analysis is conducted in three steps, as described below. For those interested in the workflow, the Appendix describes it in more detail.

Step 1 Preparation. This involves obtaining: (1) project files (solar panel area and secured fenced area), (2) digital terrain and surface elevation models (DTM and DSM). The DSM is adjusted by assigning a height of 3.66 m (12 ft) above the DTM elevation for cells within the solar panel area. The project-point sample is located on a grid space 40 m apart within the solar panel area, and every 40 m along the perimeter of the solar panel area.

Step 2 Individual Weighted Viewsheds. A viewshed is determined separately for each project-point using the normal method, which causes some confusion since it is calculated by looking from the project to the viewer in the landscape.[1] In this case study, the viewer in the landscape is given an eye-level of 1.5 m, and visibility is calculated over the DSM to a radius of 6,437 m (4 mi). The results of this calculation show locations where the uppermost part of the land cover is visible; values are 1 for locations where the project-point is visible and 0 for locations where it is not visible. Since viewers cannot see the project if they are standing in an area where the land cover is over their head (i. e., DSM – DTM > 1.5 m), those areas are change to no visibility. In addition, since viewers are not permitted within the project's security fence, it is unreasonable to assign impact weights to this area and it is assigned a value of 0 (i. e., no visibility).

Distance zones are represented as concentric bands around the project-point and assigned the corresponding visual prominence weight. This is multiplied by the viewshed producing a weighted viewshed for each project-point. The mean value for the weighted viewshed is saved to the cumulative viewshed table along with the point ID and X Y coordinates.

Step 3 Impact from Project Locations. The mean visual prominence at a project-point location is an index that can be compared to other locations to determine which parts of a project create a relatively greater or lesser visual impact. Nonetheless, they are just a selection of points that do not represent an equal probability sample, which would allow the calculation of statistics for comparing different projects. The solution is to interpolate the mean prominence rating for all the raster cells within the solar panel area, not just the project-points. Inverse distance weighted (IDW) interpolation is selected because it is most appropriate for a well distributed dense sample of points. The IDW parameters were a 50 m radius search and a power of 2; the interpolation is confined to the solar panel area.

Once all cells have a mean visual prominence value it is possible to calculate the mean value for the project or sections of the project. A cost-benefit index of the project's utility can be calculated from the mean visual prominence for the project or section, multiplying it by the area of the project (sq m), and dividing it by the nominal power (MW) to create a standardized index describing the degree of visual impact per unit of potential energy production.

3 Results

The map in Figure 2 displays the interpolated results on a linear scale between the highest and lowest values. Mama – the midsized section – has high visual prominence on its east side. Papa also has a higher visual prominence in its southeast corner. Overall, Mama displays warmer colors, indicating its visual prominence is higher than Papa. This generalization is borne out by Table 2, which gives the summary statistics for the Mount Solar project and the three project sections. The Cost-Benefit Index, (i. e., the ratio of the visual prominence sum to the nominal power production) for Mount Solar is 162. These results support the observation in Figure 2, Papa's Cost-Benefit Index is approximately 80 percent of the project's value and Mama is at approximately 140 percent. Said another way, Papa's impact per MW is approximately 60 percent of Mama's.

[1] The ArcGIS term for the project-point is termed OBSERVER and the viewer is the TARGET.

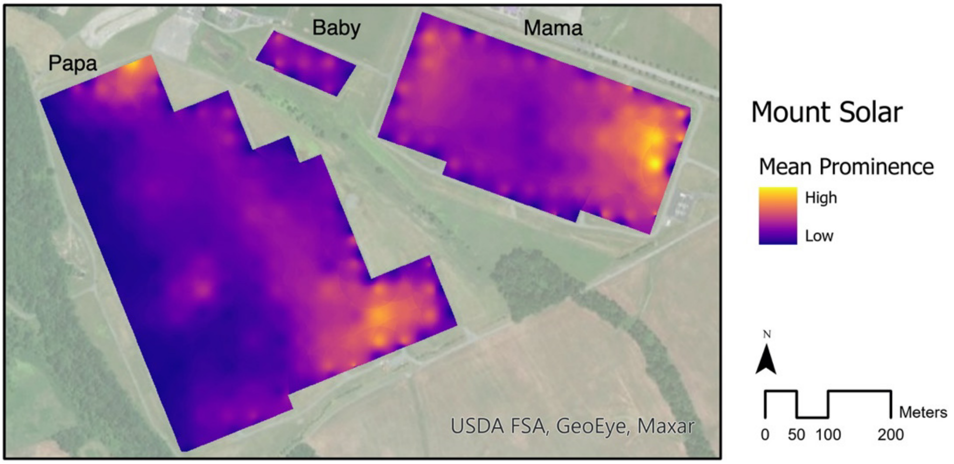

Fig. 2: Interpolated visual prominence of locations in the Mount Solar field

Table 2: Descriptive Statistics for the Solar Project and its Sections

Project Section	Area (sq m)	Sum Visual Prominence	Mean Prominence	Nominal Power (MW)	Cost-Benefit Index
Papa	208,621	1377	0.0066	10.5	131
Mama	101,998	1178	0.0116	5.2	229
Baby	8,170	61	0.0074	0.4	148
Overall	318,858	2616	0.0082	16.1	162

4 Discussion

It is becoming more common for VIAs to be included as part of the environmental analysis accompanying an energy project's permit application. Often the VIA relies solely on a descriptive narrative based on professional judgement, for instance describing how distance moderates the visual effects of the project. Sometimes they are accompanied by visualizations of how the project will appear from a viewpoint selected by the developer. The limitation of a viewpoint analysis is that it considers a very limited selection of possible views. Less often, a VIA includes a cumulative viewshed map showing how many of the project features or sample points are visible from locations in the surrounding landscape. Even so, these maps are of limited value in determining impact because they do not consider how the visual prominence of a project decreases with distance. While academics demonstrated how to incorporate a distance decay function in a visibility analysis over three decades ago (e. g., HULL & BISHOP 1988), it has not become accepted by the professionals conducting VIAs. Instead, they have preferred the more intuitive (and less mathematical) concept of distance zones. This paper demonstrates how to associate visual prominence weights with distance zones and incorporate them in a visibility analysis. While not demonstrated here, simply merging individual weighted viewsheds provides an improved description of a project's visual impact on the surrounding landscape.

This paper concerns an important visibility question that is not addressed, but should be addressed in VIAs: Which project locations or features have the greatest impact on the surrounding area? A method is described to answer this question using standard ArcGIS Pro tools without relying on coding custom scripts to complete the analysis. It demonstrates how to map the results and proposes a Cost-Benefit Index that is a ratio of a project area's visual prominence to its nominal power capacity. This index can be used to compare separate sections of a project, as demonstrated here, or to compare different projects. With wide acceptance of this approach, it would be possible to evaluate how a proposed project compares with other projects.

5 Conclusion and Outlook

A method is demonstrated to map and measure the visual prominence different project locations have on the surrounding landscape. This is a concern of obvious importance to environmental permitting agencies who must determine whether portions of a project must be relocated or receive mitigation treatment. The case study presented here is a photovoltaic solar project, but the same approach could be applied to planning a land fill, permitting a mine expansion, or evaluating a proposed Amazon distribution center.

The analysis requires specification of distance zone thresholds and visual prominence weights appropriate to the project under consideration. These should be grounded in observations of similar projects in the field and not photographs (e. g., SULLIVAN et al. 2014, PALMER 2020). With increased knowledge based on these observations, it may be possible to propose calibrated mathematical functions of the relationship between perceived visual prominence and distance for different project types and conditions.

This method has the potential for wide application in VIAs. Though it is somewhat more complicated than the current implementation of cumulative viewsheds, it answers a question of particular relevance to a permitting decision. If it comes into common usage it may warrant inclusion as a standard part of the GIS visibility analysis toolset.

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Appendix: Project Workflow

This appendix describes a simplified schematic workflow to conduct the analysis in ArcGIS Pro. The two figures primarily refer to the tools used, and only reference the primary input and output files. Tools are orange rectangles, and the iterator is an orange hexagon. Shapefiles are ovals and tables are rectangles with rounded corners; blue represents an input file and green an output file. This information will supplement rather than repeat the description of the process in the methods section.

Step 1 is Preparation. In addition to gathering data, it is necessary to prepare an empty cumulative viewshed table to write the viewshed values and counts. It is also necessary to use the *Geometry Calculator* to write the X and Y coordinates to the project-Points shapefile.

The workflow for Step 2 Individual Weighted Viewsheds is represented in Figure 3. This step uses an iterator to process each project-point, one at a time. The visibility tool identifies the areas that are visible (value of 1) or not visible (value of 0) from the project-point. Two masks with a value of 0 are multiplied by the project-point's viewshed, one for areas with view-obstructing land cover (i. e., above eye-level) and the other for areas within the project's security fence.

The multi-ring buffer tool creates concentric distance zones around the project-point. The associated prominence weights are written to the buffer shapefile using the add field and calculate field tools. The multi-ring buffer is converted to a raster that is registered to the viewshed where the value of each cell is its prominence weight. This is multiplied by the project-point's viewshed, resulting in a new raster where all the cells with visibility have the value of a prominence weight. The table for this raster (i. e., the weight value and the cell count) and the project-point are written to the cumulative viewshed table.

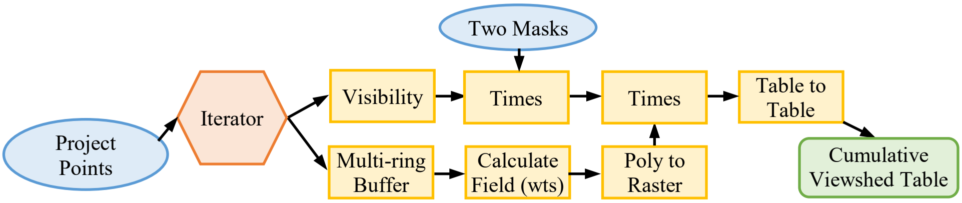

Fig. 3: Schematic workflow of iterative visibility analysis for a sample of project -points. Visibility is weighted by distance zone. The viewshed table for each point is written to the Cumulative Viewshed Table.

The workflow for Step 3 Impact from Project Locations is represented in Figure 4. The X Y coordinates from the project-point shape file are added with a join to the cumulative viewshed table. Use calculate field to multiply value (i. e., prominence weight) by count (i. e., the number of cells with that value) to obtain a weighted cell count. Using the project-point ID and X Y coordinates as the case identifiers to calculate summary statistics: mean of the weighted cell count, and the sums for value and count. Use XY table to point tool to convert the summary statistics table output to a point shapefile. Inverse distance weighting (IDW) interpolation uses these points to assign a mean prominence value to each cell within the solar panel area. The statistics for the project and any sections are calculated using zonal statistics to table.

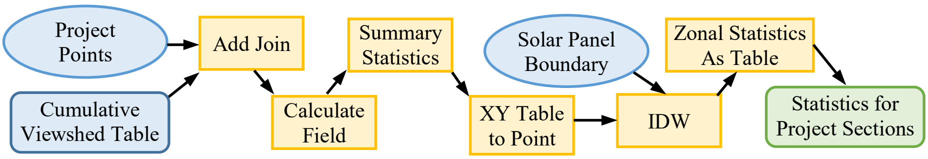

Fig. 4: Schematic workflow to determine mean prominence of sampled project-points and then interpolate mean prominence for solar panel area using inverse weighted distance. The statistics for the projects identified sections are written to a table.