Cumulative Viewsheds in Wind Energy Visual Impact Assessments and How They Are Interpreted

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Abstract: Summing viewsheds for several turbines results in a cumulative viewshed representing the number of turbines that can be seen from locations in a study area. Viewshed methods for use in a VIA has changed little since its development in the 1970s. It is an expected component of wind energy VIAs, but how it is used and understood has not been previously reviewed. This paper reviews the use of cumulative viewsheds in VIAs prepared by 25 firms. It then shares the results from an exercise completed by 29 professionals in a GIS workshop to ascertain their understanding of a cumulative viewshed map. Ways are suggested to improve how we conduct and communicate the GIS-based analysis in VIAs.

Keywords: Cumulative viewshed, GIS, wind turbines

1 Introduction

"I don't get no respect" – RODNEY DANGERFIELD (2004).

This comedian's iconic slogan could easily have been about the cumulative viewshed map commonly found in wind energy visual impact analyses (VIAs). The VIA describes the data and methods used to determine the area where wind turbines are visible, but generally does not include any insightful analysis based on the results. Rather, the analysis of visual impacts depends on characterizing the potential visual change as represented by visualizations, most frequently high-resolution photo-realistic visual simulations printed in full-color on A3 paper.

Line-of-sight based on topographic sections has long been used by artillery units and to locate forest fire watch towers (GREITZER 1944). It took specialized knowledge and skill to generate and understand this analysis (NPS 1958). VIEWIT was the first widely available computer program for calculating the area visible from a viewpoint – its view shed (AMIDON & ELSNER 1968). CARLSSON (2021) documents a similar transition to computerized analysis in the UK. Provision was added to VIEWIT for calculating a cumulative view shed – for instance the number of viewpoints on a road that could see a specific location in the landscape – was promoted for use "to determine visual impact" (TRAVIS et al. 1975). ERVIN & STEINITZ (2003) note that at some point, whether the analysis was calculated from a viewpoint identifying a seen area or from an observed target identifying possible viewpoints was confounded and treated as equivalent. While proponents of computer analysis, they are concerned that we have lost sight of the difference "between what is 'visible', and what is 'seen in the landscape." CARLSSON (2021) shares their concern, stating that the analysis "offers clear and unambiguous accounts of visibility, but not of visuality. The technology gained popularity not primarily because it reliably describes how humans see the world, but because it communicates clearly and conclusively in a manner that is very difficult to achieve through direct participation of a large number of individuals." She is critical of the method because it overlooks the professional skills necessary to acquire an understanding of what is seen, and sub-

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stitutes an ostensibly objective scientific procedure that has been accepted uncritically by government authorities and more generally by society.

This paper investigates the use and understanding of visibility analysis in wind energy VIAs. It is divided into two distinct parts, a review of the viewshed analysis presented in wind energy VIAs, followed by the results of a class exercise designed to understand how the typical cumulative viewshed map is understood. The purpose is not to test a hypothesis or share a novel approach to analysis, but to shed light on one of the most ubiquitous parts of a VIA; one that goes largely unnoticed and underappreciated.

2 Visibility Analysis in Wind Project VIAs

This section reviews the visibility analysis found in the wind energy VIAs. Focusing on the actual presentation of visibility analysis is not intended to deny that there continues to be academic research in this field. Rather, it is grounded in how visibility analysis is being and has been used for decades with little change.

2.1 Methods

VIAs for proposed inland wind energy projects were gathered from the internet. Samples were selected for analysis based on three criteria: the VIA was written in English, it included a visibility map, and the firm preparing the VIA could only be represented once. In all, 25 VIAs were identified for review. They were prepared between 2006 and 2019 for projects as small as 3 to as large as 1,000 turbines, ranging from 6 to 3,000 megawatts (MW) that were located in seven US states and five additional countries.

2.2 Results

Among these 25 projects, the visibility analysis for 12 was conducted only for an upright blade tip, and only the hub at 3 projects. Eight projects evaluated both the tip and hub, and two added visibility of the whole turbine. The study area for these visibility analyses ranged from 10 to 50 km beyond the project turbines, with a mean of 24.2 km.

Nineteen of the reviewed VIAs showed buffer-lines on the visibility map at intermediate distances. These buffer-lines were typically labelled with just their distance, though a few maps labelled the distances as “distance zone limit,” “zones of visual influence,” or “buffer zones.” The text for 11 reports refers to these distances as foreground, midground and background, or uses similar terms, while 6 reports refer to them as indicating degrees of visual impact (e. g., high, medium or low). Some reports include a shorter distance for the very high impact immediate foreground, and some also distinguish near and far midground. Eight VIAs give thresholds that define the far extent of the immediate foreground; they range between 0.03 and 4 km with a mean of 1.5 km. The fifteen foreground thresholds are between 0.8 and 10 km with a mean of 3.7 km; the seventeen midground (or near-midground) thresholds are between 3 and 25 km with a mean of 8.7 km; the nine far-midground thresholds are between 10 and 50 km with a mean of 20.1 km. Nine VIAs indicate the background ends between 8 and 35 km, and an additional eight that it extends to the horizon. There were seven VIAs that did not show these buffer lines, though the text may discuss the distance from a viewpoint to the project.

Information could be found for 20 of these projects about the number of turbines approved or built. For two-thirds of these project, the permitted number of turbine sites was fewer than originally proposed in the VIA. Sometimes this was the result of using turbines with a higher generating capacity to achieve the permitted project capacity, but often the project was simply downsized. It should be noted that none of the VIAs for these projects attempted to evaluate the impact of individual turbines either in absolute or comparative terms, so there is no way for the VIA to influence which turbine locations should not be used.

2.3 Discussion

This review indicates that there is a consensus around the three visibility factors that are the primary determinants of visual impact: the exposure of individual turbines, the distance between the viewer and the turbine, and the number of visible turbines. While most VIAs discuss these three factors, there is no agreement in how to define thresholds of significance using them, or how to combine them into a summary measure of visual impact. All of the maps report the number of visible turbines, so when the cumulative viewshed is created, information about distance or exposure of individual turbines is lost. However, PALMER (under review) has demonstrated how to code and weight exposure, distance and extent information to predict the visual prominence of individual turbines as well as the overall visual impact. This analysis was validated with impact ratings of simulations, which were then used to calibrate significance levels on the visual impact map. This type of analysis becomes particularly important as developers propose permitting more turbine sites than are necessary.

3 Interpretation of a Cumulative Viewshed Map

This section asks a group of professionals involved with visual resources to respond to several questions about a typical viewshed map. It is acknowledged that the map is taken out of context – they only have the map and not the full VIA. However, it is presented here as one indication of how such maps are understood by a group of people that could be expected to produce or review VIAs.

3.1 Methods

On October 21, 2021 the author delivered a two-hour workshop entitled Rethinking the Role of GIS in VIA to 44 participants at the third Visual Resource Stewardship Conference. In preparation, those who registered for this workshop were given a homework assignment to interpret a cumulative visibility map based on the following scenario:

THE SCENARIO
You are an Environmental Specialist III in a state environmental agency overseeing the permitting of a wind project. The application is for 117 wind turbines; several turbine models are being considered. The preferred turbine is the basis for the VIA but if it is used there is only sufficient electricity transmission for a 55-turbine project, and not all 117 turbine sites will be needed. The VIA describes three distance zones – the foreground (0 to 0.5 mi), midground (0.5 to 4 mi), and background (4 to 10 mi); the 10-mile study area covers nearly 800 square miles. The VIA evaluates 17 photosimulations, but the only analyses that cover the whole study area are the four cumulative viewshed maps showing the number of blade-tips or turbine hubs visible above bare earth or existing land cover.

You decide to focus on the forest screened visibility of blade tips as the most realistic representation of turbine impacts. The PDF of the viewshed submitted with the application is attached to this email for your use.

Using the layers functionality in Adobe Acrobat, they could turn layers on or off to inspect the numbered turbine locations, distance zone boundaries, number of visible turbines, and roads. The image of the visibility map is shown in Figure 1.

The map shows the visibility of turbine blade tips above forest cover within 10 mi of 117 wind turbines. Each turbine is numbered, but that layer is turned off in Figure 1. A line identified as "Distance Zone Limit" is drawn abound the turbines at 0.5, 4 and 10 mi. While the map does not state that the line represents the "distance zone limit," it is easy to understand how someone reading the map would interpret these lines are being the distance zones described in the VIA report. The network of local and state roads is shown to aid orientation. There is also a north arrow and map scale.

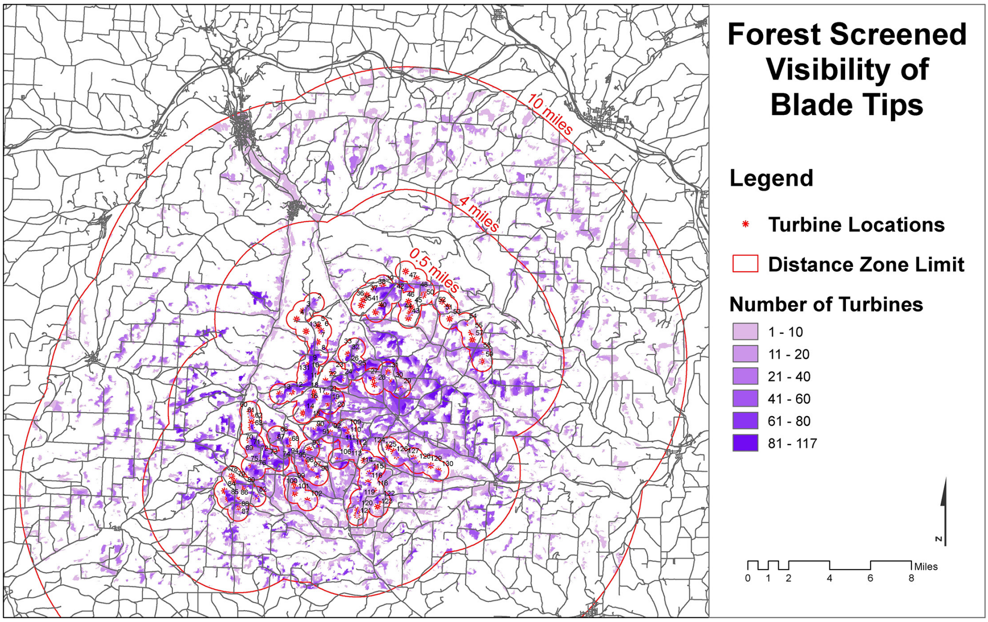

Fig. 1: Typical viewshed results from a wind energy project VIA.
Prior to the workshop, participants were asked to become familiar with the PDF version of the map and answer the following question, which would be discussed during the workshop.

A. As part of your review of this project's potential visual impacts, what are three of the most important things that you can learn from this map?

B. What are three of the most important things that you need to know about the project's visual impacts that cannot be learned from this map?

C. Do the distance zone limits on the map help you evaluate the potential impacts?
[ ] Yes [ ] No How?

D. Your agency wants you to indicate the five turbines with the highest visual impact to exclude from the final project as a condition of a possible permit. Listed in order beginning with the highest impacting turbine, what would the turbine numbers be?

E. How did you use this map or other information to make this recommendation?

F. Your agency wants you to indicate the five turbines with the lowest visual impact to include in the final project as a condition of a possible permit. Listed in order beginning with the lowest impacting turbine, what would the turbine numbers be?

G. How did you use this map or other information to make this recommendation?

H. What is your familiarity with visual impact assessments?
[ ] None [ ] Low [ ] Medium [ ] High

I. What is your familiarity with viewshed maps?
[ ] None [ ] Low [ ] Medium [ ] High

J. In what sector is your primary employment?
[ ] Academic [ ] Government [ ] NGO [ ] Private

K. In what year were you born? [ ]

3.2 Results

There are 29 respondents ranging in age from 25 to 66 years. They hold positions in government (59%) or the private sector (41%); none are primarily employed by NGOs or academia. Table 1 shows most were familiar with visual impact assessments, with only slightly less familiarity with viewshed maps. Familiarity was not significantly associated with employer.

Table 1: Familiarity with visual impact assessments and viewshed maps by employer

Employer	Familiarity with VIAs (%)				Familiarity with viewshed maps (%)			
	High	Medium	Low	None	High	Medium	Low	None
Gov't	23.5	41.2	17.6	17.6	23.5	41.2	29.4	5.9
Private	50.0	25.0	25.0	0.0	41.7	41.7	8.3	8.3
Total	34.5	34.5	20.7	10.3	31.0	41.4	20.7	6.9

Just over half of respondents (55%) identified turbine location and project visibility as important things represented by the map. However, many appeared to draw incorrect inferences about the relationship between distance zones (41%) or impact (21%) and the number of visible turbine blade tips – it is not possible to tell the distance to visible turbines from a cumulative viewshed map, and after a modest distance, one would not notice a blade tip rising behind the tree canopy, and whether one turbine has greater turbine exposure than another is not shown.

Among the things that respondents thought they needed to know that they could not tell from the map are the distance to visible turbines (41%) and how much of the turbine was visible (31%). They also needed to know the location of the simulation viewpoints (24%), about sensitive receptors (i. e., viewers and scenic resources) (63%), and the surrounding terrain and land cover (52%).

Respondents (76%) found the distance zone limits on the map helpful for evaluating impacts; 7% did not and the remainder did not respond. Of those who did respond, 50% indicated that it provided a sense of scale – which it does; 45% indicated it informed them about distance zones – which it does not. Failing to recognize that distance between a turbine and observer cannot be inferred from a cumulative visibility map is not significantly related to familiarity with VIAs or viewsheds.

When asked to identify five turbines to exclude from any project, ten respondents indicated that they could not tell from the information provided. Of the thirty-four turbines identified for exclusion, the nine identified by more than a fifth of respondents are mostly located toward the north-western edge of the project. Of those who identified turbines to exclude, 68% indicated they were turbines located in the darkest area of visibility; and 26% because the turbines were close to roads or towns. PALMER (under review) has identified which turbines have the highest visual prominence based on the turbine's exposure and the distance zones within their viewshed. The turbines with the greatest visual prominence are located to the south-east in a more open area with visibility from close by; those to the north-west should not be excluded because they are on hills where woods block views to the nearest turbine. While a large number of turbines are visible from the north-west area, they are in the distance.

Only seven respondents indicated that there was not enough information to determine five turbines to include in the project. Those who responded selected 44 of the 117 turbines; the eight identified by more than a fifth of respondents are mostly located toward the northern edge of the project. The lightness of the underlying color indicating few visible turbines was the reason given by most (73%), though some identified distance from potential viewers as the reason (23%). The turbines most frequently identified for inclusion were determined by PALMER (under review) to have among the lowest visual prominence.

At the close of the workshop, respondents were asked how useful it was to be able to turn the map's PDF layers on and off when answering the questions. Most found it moderately (52%) or very (26%) useful; some were unable to access the layers feature (9%).

3.3 Discussion

Respondents generally interpreted the project's visual impact with the number of visible turbines as indicated by color shading on the map. Few were concerned that the map only represented visibility of a blade tip, and not more substantial turbine exposures. About half made incorrect inferences of that distance zones, presumably based on the buffer lines to the nearest turbine that were created using distance zone thresholds. This error led many to identify the turbines surrounded by the darkest underlying color as having the greatest impact. The dark color represents a high number of turbines visible at various distances across the whole project and may not include the nearest turbines. There was no significant association between these errors and whether the responder held a position in government or private practice, or their familiarity with VIAs and viewshed maps.

4 Discussion and Conclusion

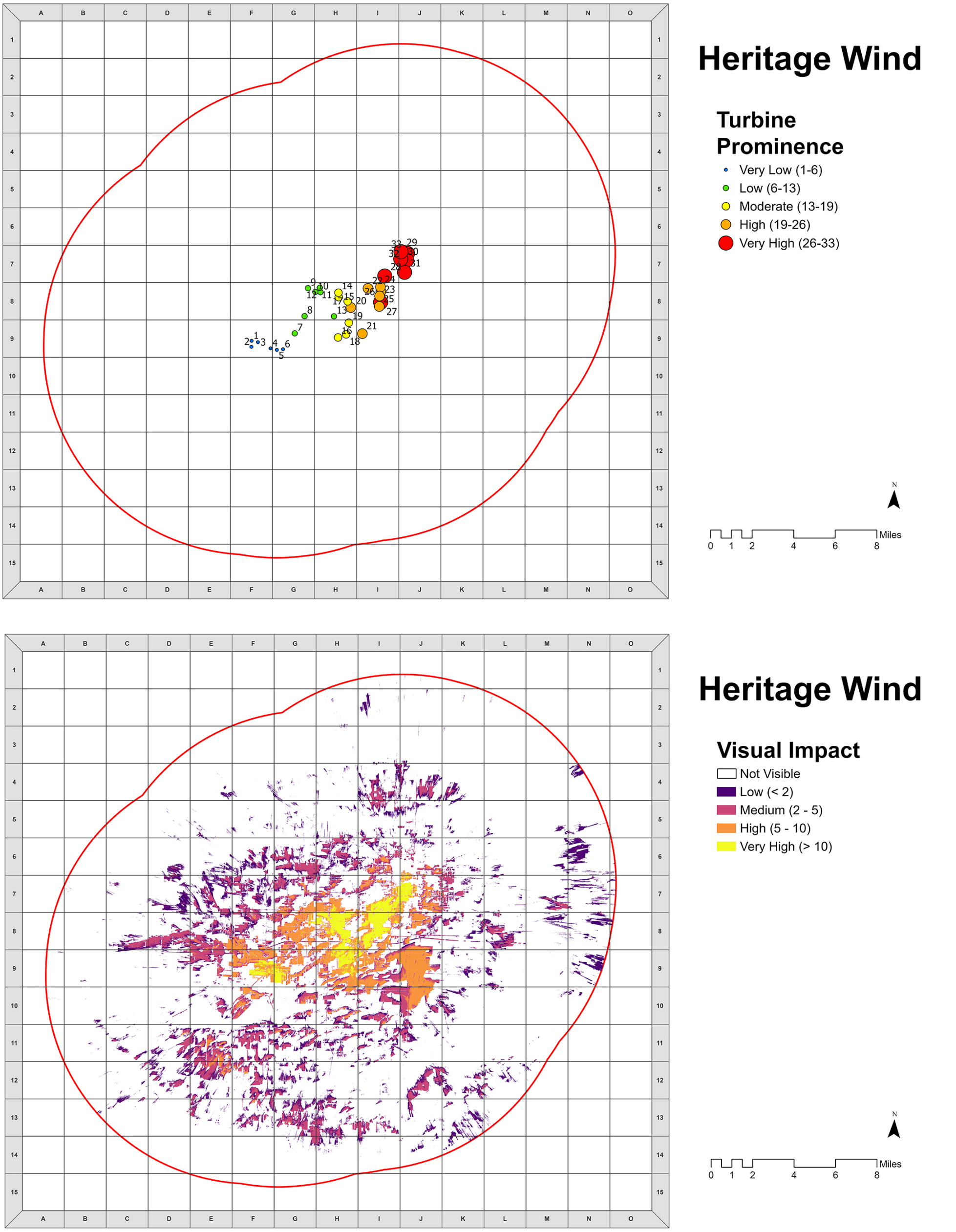

Fig. 2: Examples of maps that separate the visual prominence of individual turbines from the visual impact seen in the surrounding landscape

The findings in this paper are the result of a problem analysis to better understand how cumulative viewsheds are used in VIAs and how they are understood by those who use VIAs in their employment. The review of VIAs found general agreement that the important factors influencing visibility of wind turbines are exposure, distance zones, and project extent or number of visible turbines. Research indicates that there are non-linear relationships between these factors and visual impact (e. g., BETAKOVA et al. 2015, MOLNAROVA et al. 2012, SHANG & BISHOP 2000, SULLIVAN et al. 2012). A study by PALMER (under review) found that only 24% of the variation in visual impact evaluated at 17 simulation viewpoints was explained by the cumulative visibility map in Figure 1. This increases to 63% when the cumulative visibility is deconstructed to account for the exposure and distance zone for individual turbines, which are then combined and weighted to account for the project's visual extent. It is clear that VIA professionals know what needs to be considered, but they need help in how to do the analysis and display and interpret the results.

The results of the workshop survey identified several things that the respondents would like the visibility analysis to address: (1) the impact from individual turbines, (2) the impact to the surrounding area that incorporates exposure, distance zone and extent, (3) the location of the wind turbines and the simulation viewpoints, and (4) the sensitive receptors, such as concentrations of people and scenic resources. These were difficult or impossible to determine from the cumulative viewshed map in Figure 1, which led to misunderstanding and misinterpretation. The following suggestions are made to improve clarity of how the GIS analysis is presented in VIAs. Four maps are suggested: (1) Map the visual prominence of individual turbines (PALMER under review). (2) Map the visual impact of the project to the surrounding landscape and calibrate the impact level based on evaluation at simulation viewpoints (PALMER under review). There is no need to include turbines or distance zone lines on this map, since they contribute to the misunderstanding. (3) Locate the turbines and simulation viewpoints on a topographic map. (4) Map the sensitive receptors and create a table that summarizes the visual impact to each one. Each of these maps could be overlain with a grid at the same scale to provide distance and location information. The first two maps are illustrated in Figure 2. These recommendations do not require new software or programming skills beyond what VIA professionals are already using. What they do require is stepping back from a 50-year habit of preparing visibility maps that are frequently misinterpreted. And then we can step forward by better communicating our findings about visual impacts and properly leveraging the widely available tools offered by a GIS analysis.

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