DVC as a Supplement to ZVI: Mapping Degree of Visible Change for Wind Farms

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Abstract: Wind farms can profoundly change the appearance of landscapes and how they are experienced. The proliferation of wind farm applications and the visual impacts of larger array footprints and taller turbines raise additional landscape concerns for users and observers. These trends require new assessment methods to evaluate such impacts and supplement visual assessments, stakeholder engagements and decision making. The new concept of Degree of Visible Change (DVC) is formulated to overcome some of the limitations associated with established techniques in Visual Impact Assessments (VIA), in particular Zone of Visual Influence (ZVI) mapping. Developed and tested for a proposed wind farm in Queensland, DVC calculates and maps horizontal (h) and vertical (v) view extents that are occupied by proposed wind turbines, combines these into a new parameter representing visual prominence and defines significance levels based on limits of human Field of View (FOV). DVC also allows the effect of distance attenuation on visibility to be represented, helping to identify affected receptors and their potential levels of visual impacts. This approach provides an additional layer of analysis to map the potential visual intrusion of wind farms and highlights the effect of existing land cover and potential mitigative planting to ameliorate visual impacts.

Keywords: Degree of Visual Change (DVC), Zone of Visual Influence (ZVI), Field of View (FOV), wind farm, Visual Impact Assessment (VIA)

1 Introduction

The demand for renewable energy is growing, resulting in an increase in proposals and planning applications to construct large wind turbine arrays (wind farms). Wind farms have significant impacts on the landscape and drive land-use change (PEVZNER et al. 2021). Visual impacts associated with wind farm proposals are among the greatest concerns expressed by nearby receptors and the wider community. These require new approaches to Visual Impact Assessment (VIA) of both land-based and offshore wind farms (MASLOV et al. 2017) in order to support clean energy production. In the USA, the Biden administration has recently announced plans to develop large-scale wind farms along significant tracts of coastline in a program to achieve a net-zero emissions economy by 2050 (PEVZNER et al. 2021, CASH 2021). In southern Australia, the largest Australian wind farm approved so far will comprise up to 228 turbines (GOLDEN PLAINS WIND FARM 2021).

The size of wind turbines is also increasing. Taller turbines with longer blades can take advantage of stronger and more consistent wind resources available at greater heights. The hub height for land-based wind turbines has increased 59% since 1998–1999, to about 90 meters in 2020 (EERE 2021). Typical land-based turbines in Australia have blades between 40-90 meters long with tower heights in the range of 150 meters. Offshore turbines are generally much larger, with blade tips reaching up to 270 meters (DOOLAN 2019).

The increasing scale of proposed wind farms, both in terms of array footprint area and turbine heights, has the potential to affect the scenic quality and character of landscapes. It also has the potential to influence the amenity of neighbours, and cause community concern resulting

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in potential divisions, even amongst conservation advocates ("green on green" conflicts). Other characteristics, such as the spacing and clustering of turbines, the dynamic rotation of blades, and associated shadow flicker and glint effects, add to the complexity of visual change associated with these elements. As the energy sector undergoes reform and wind farms proliferate, these concerns can be reduced through appropriate visual assessment tools, as well as through proactive engagement by landscape architects with local social, cultural, ecological sensitivities (GRIMM & ZEUNERT 2020). Improved approaches with credible and repeatable assessment methods, which can transparently and legibly demonstrate the impacts of tall wind turbine structures on the landscape, are required.

One of the most widely used techniques in VIA in practice is Zone of Visual Influence (ZVI) mapping or Zone of Theoretical Visual Influence (ZTV). Conducted in GIS, ZVI shows areas within view of a proposed structure, supported by photographs, diagrams and photomontages to illustrate likely visibility and appearance. ZVI is fundamental for VIA as it identifies sensitive landscapes and visual receptors likely to be affected, by defining areas from which any proposed development can be totally or partially seen, as determined mainly by topography. For wind farms, ZVI represents the limits of visibility of the proposed array of turbines likely to be seen in the landscape. The number of turbines visible, or the degree to which one or more is visible, can be modelled by locating observation points or visibility points on top of proposed structures, thereby showing proportional visual exposure in landscapes. However, ZVI mapping represents a worst-case scenario as it does not usually incorporate the existing screening by vegetation, built form or other localised effects.

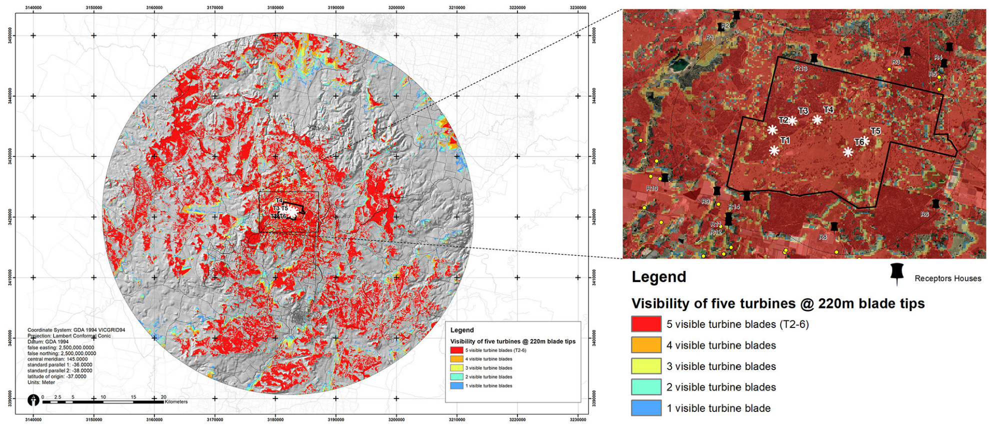


Fig. 1: Zone of Visual Influence (ZVI) of a proposed wind farm in Queensland including five turbines with 220m height to blade tips (2021)

Figure 1 displays a typical ZVI map. A proposed wind farm in southern Queensland is shown, which includes five turbines located in a rural production landscape setting. The proposed maximum height of 220 meters to the tip of blades, which is an increase over the previously-approved 180m height, has the potential to increase the significance of visual impacts on sensitive residential receptors. To increase the accuracy of ZVI a consistent height of vegetation cover (10 meters) where aerial photos indicated forest or woodland cover was assumed and added to the model. The visibility modelling was modelled based on a Digital Earth

Model (DEM) with a 25-meter cell size, and extended to a 30-kilometre radius from the project site. The red areas reflect the areas in the landscape where all five turbines would be visible above or between tree plantings. Multiple receptor houses have been identified surrounding the proposed wind farm.

As a general principle visual impact decreases with distance of view, as the visual dominance or prominence of large structures perceived by humans declines with increasing view distance. However, ZVI modelling *per se* does not reflect this distance attenuation and presents only a binary concept of visibility (either visible or not visible). For wind farms the visibility of one or more turbines from any one viewpoint may be expressed in different colours (as in Figure 1), however, distance attenuation is not addressed by this representation and remains a limitation on the effectiveness of ZVI mapping.

In order to address this issue, in VIA practice multiple generic distance zones have been defined to classify these impacts based on distance zones to proposed wind turbines. These include: 1) visually dominant to 2 kilometers; 2) visually intrusive within 1 to 4.5 kilometers; 3) noticeable between 2 to 8 kilometers; and 4) perceived in the distance, for distances over 7 kilometers. Although these viewing distance zones are generalised assumptions, they have become widely accepted in ZVI mapping as a basis for identifying sensitive receptors, informing field visits, and nominating and acquiring site photos for photomontage simulations. Such mapping is generally accompanied by true scale photomontages to appreciate the size and appearance of proposals from sensitive locations and reveal the screening potential of land cover. In VIA practice it is also common for such analyses to cover the human Field of Vision (FOV) as the extent of the observable world (124° horizontal by 55° vertical) based on best-practice guidelines (SCOTTISH NATURAL HERITAGE 2017).

The limitation of ZVI maps to reflect distance attenuation in the appearance of large-scale proposals and reliance of assessment on a limited number of photomontages across an expansive landscape through a labour intensive modelling process have been drivers for this research. In this paper, an innovative GIS mapping workflow is proposed which contributes to more comprehensive VIAs of large-scale wind farms. Moreover, it has the potential to also benefit other infrastructure projects characterised by tall vertical elements. A new mapping tool, the Degree of Visible Change (DVC), is developed to complement and supplement ZVI maps and represent the degree of the potential extent of visibility of wind farms that can be seen across the landscape.

2 Mapping of Degree of Visible Change (DVC)

2.1 DVC Significance Levels

In VIAs the extent of FOV occupied by proposed developments is a key parameter in defining the dominance and magnitude of change (TARA et al. 2021). For wind farms, clustering an array of wind turbines in order to consider the entire horizontal extent of the proposed development is an appropriate approach to model the magnitude of change. This approach is in accordance with Gestalt Theory, where similarity and continuity engage with human vision in the perception of projects with elements distributed across a large footprint. However, for projects with tall vertical elements, such as wind turbines, horizontal FOV alone is insufficient to analyse visual impact. The extent of vertical FOV affected also requires consideration.

In this research, a hypothetical bounding box was used to represent the proposed wind farm in Queensland based on turbine locations and potential blades rotations in 3D (Fig 2a). Multiple points were modelled at the horizontal and vertical limits of the proposed wind farm to define the extent of the proposed wind farm. These are used to quantify horizontal degree (h), vertical degree (v) and area (A), as well as the combined effect which can be seen from the surrounding landscape (Fig 2a & 2b).

An AILA awarded VIA in Southern Australia for Twin Creek Wind Farm (WAX DESIGN 2017), establishes a measurable method ('Grimke Matrix') to rank the extent to which the development is visible and predict the degree of visual change and the associated visual impacts on the landscape. Estimated based on photomontage simulations (124 degrees by 55 degrees FOV as shown in Fig 3), this method quantifies the degree of change by wind farms based on scoring of landscape absorption capacity, horizontal FOV, vertical FOV and the observer viewing distance. Based on the overall score, the author's defined impact significance levels of extreme (80-100%), severe (60-80%), substantial (40-60%), moderate (20-40%) and slight (0-20%). In the Twin Creek Wind Farm study, the degree of visual change was scored for a limited number of viewpoints but was not calculated and mapped for the entire study area which was identified as a potential area for development for wind farm assessments.

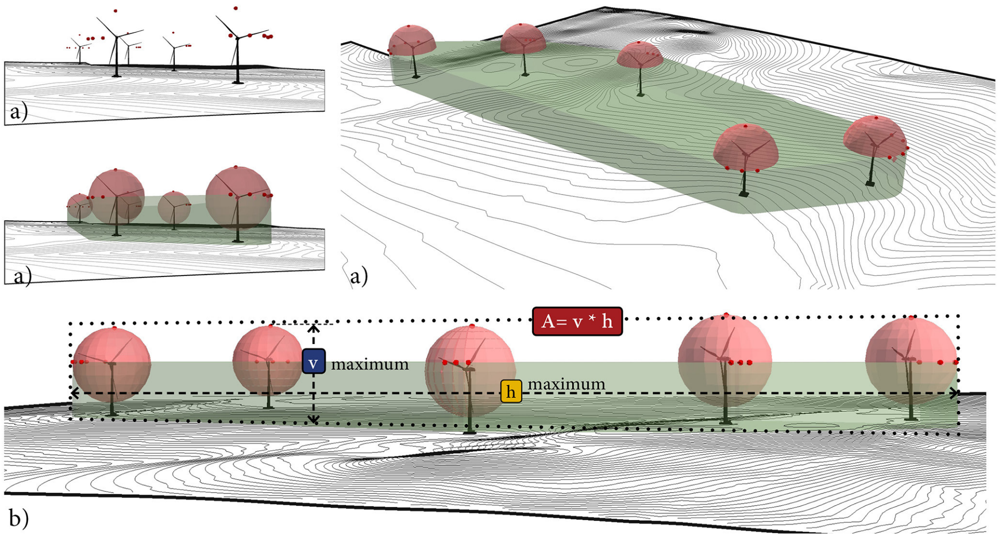


Fig. 2: a) Proposed wind farm bounding geometry defined by the location of turbines and potential multi-direction rotation of blades and modelling points; b) Measurable variables (v, h & A) to quantify DPVC using modelling points

In this research, multiple levels of significance (including negligible, low, moderate, major and extreme) were defined in relation to both the horizontal, vertical and proportion of FOV occupied by the proposed wind farm, as seen from different locations. The new parameter of DVC (Fig 3c) is simply a combination of the horizontal and vertical proportions of FOV occupied by the proposed structures. Vertical levels were defined within 25 degrees above the horizon based on human Field of View (FOV) constraints. For human FOV, vertical heights above 25 degrees result in an ‘overbearing’ or ‘looming effect’ for viewers (Fig 3a), and a horizontal FOV above 124 degrees can result in a ‘surrounding effect’ (Fig 3b).

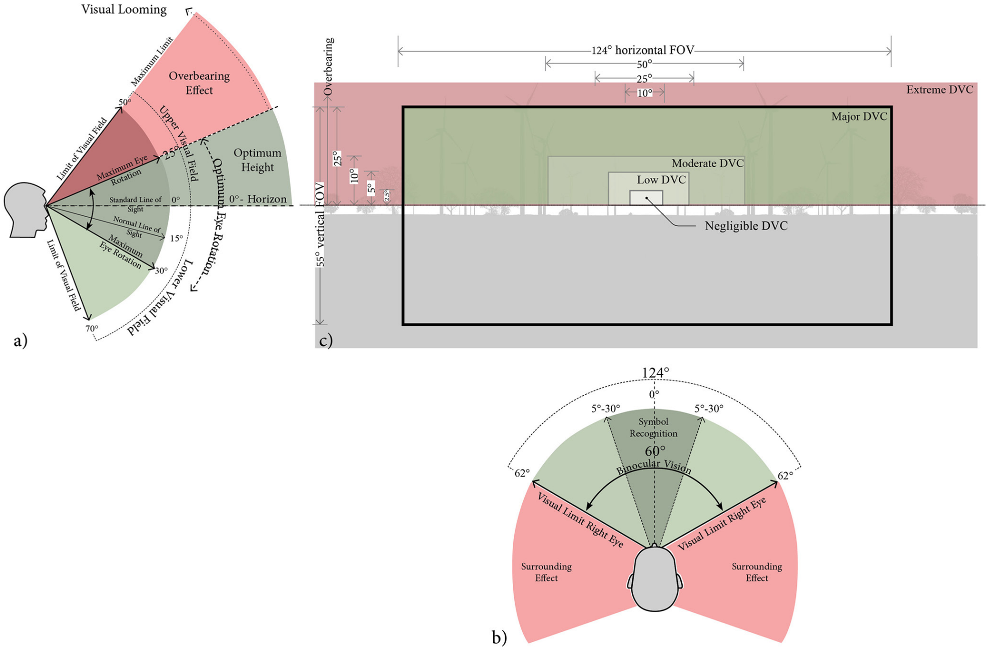


Fig. 3: a) Vertical FOV; b) Horizontal FOV; c) Defined significance levels for vertical, horizontal and combined-area DVC

2.2 Measuring DVC in GIS

The human FOV has been previously conceptualised as a ‘visual bowl’, or view sphere, and has been modelled and conceptualised as a 3D entity within the context of dense urban environments (TARA et al. 2019 and 2021). In these studies, the calculation of horizontal and vertical degrees of sightlines radiating from the observer to the surrounding context allowed the description of the unwrapped visual field in a vertical plane. The size of objects presented in this plane reflects the distance and size of objects visible in the scene, as perceived by an observer. Movement through landscapes would result in an observer experiencing different visual bowls and potential visual changes.

Based on these findings, a new workflow was developed in ArcGIS 10.6 to calculate the degree of visibility of a wind farm proposal in QLD in the production of DVC maps. Through this process, both horizontal and vertical FOVs were calculated and mapped for a high number of viewpoints across the landscape. To achieve this, an observation point layer was produced by converting visible areas within ZVI to an equally spaced viewpoints layer at 1.7 meter elevation above the ground, including areas within the project site. For ease of modelling, the observation layer was produced with a 200-meter spacing radius on the ground.

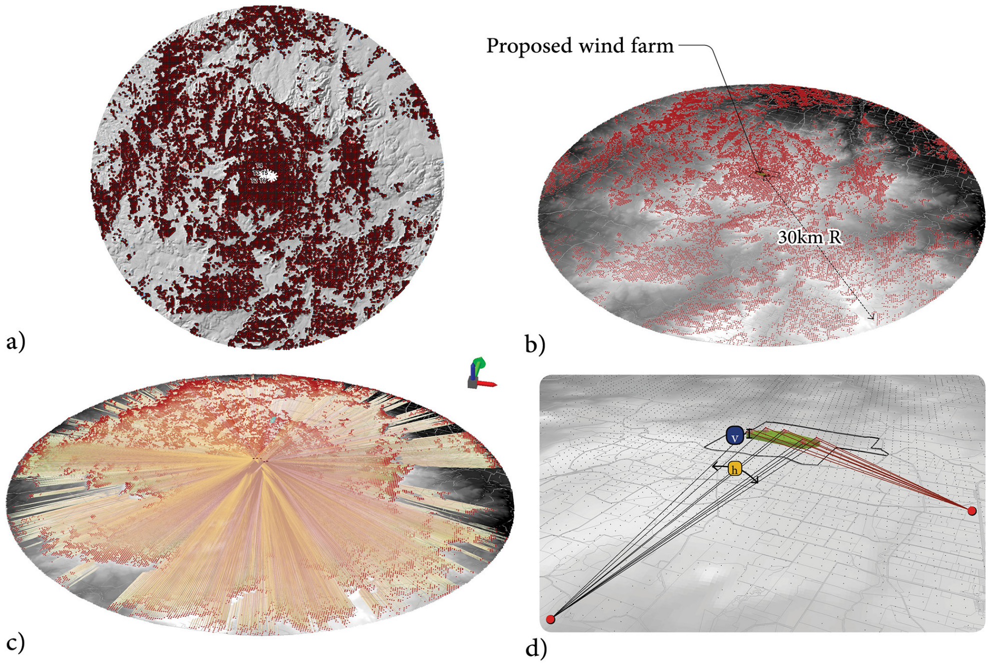


Fig. 4: DVC modelling: Observation points and sightline angles calculation in GIS; a) observer points identified within visible areas excluding treetops (plan view); b) perspective view of observation points in relation to the proposed wind farm within 30km radius surrounding landscape within ZVI; c) modelled 204,435 modelled sightlines for all observation points to the modelling points; d) Sightlines modelled for two sample viewpoints with different calculated variables

Approximately 22,715 viewpoints were identified within a 30 kilometer radius (Figure 4a &4b). Sightlines were modelled for all observation points, extending to the tip of blades of five turbines (220 meters above the ground) (Figure 4c & 4d). Figure 4d shows two sample viewpoints modelled with different sightlines different measurements (h, v & A), due to the location and orientation of the hypothetical observer in relation to the proposed wind farm. The maximum vertical angle in the range and the extent of horizontal angles occupied by the wind farm were calculated by ArcGIS using the Sightline function and post-processed in Microsoft Excel. The calculation of variables allowed these to be merged with the initial observation viewpoint dataset and for DVC defined significance levels to be applied in the preparation of vertical, horizontal and area DVC maps.

3 Results

3.1 DVC Maps

The modelling of sightlines from observation points to defined modelling points resulted in the calculation of the vertical and horizontal FOV occupied by the proposed wind farm. Calculation of variables for each observation point allowed the production of separate vertical, horizontal and combined area DVC maps (Figure 5a-d). Figure 5a shows the horizontal DVC values calculated for all viewpoints from 1.11 to 322.73 degrees (Figure 3a). The vertical angle of all viewpoints ranges from 0.11 to a maximum of 84.04 degrees. These two layers (Figure 5a & b) reflect the variation of landform and the orientation of the wind farm in defining the vertical and horizontal FOVs for all observers across the landscape.

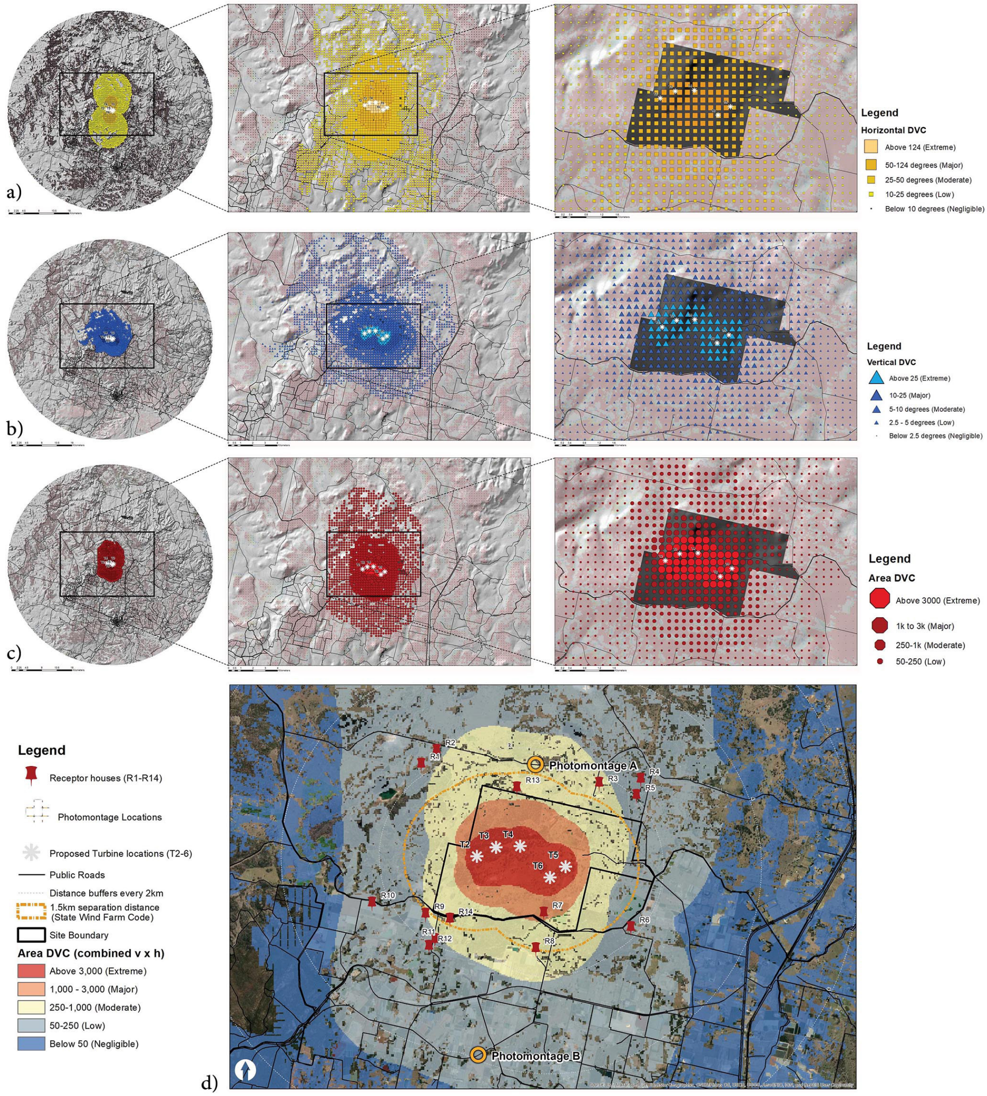


Fig. 5: Degree of Visible Change (DVC) maps; a) Horizontal DVC map presented by yellow squares; b) Vertical DVC map presented by blue triangles; c) Area DVC map presented by red hexagons; D) zoomed-in view of rasterised Area DVC map showing receptor houses and photomontage locations for validation

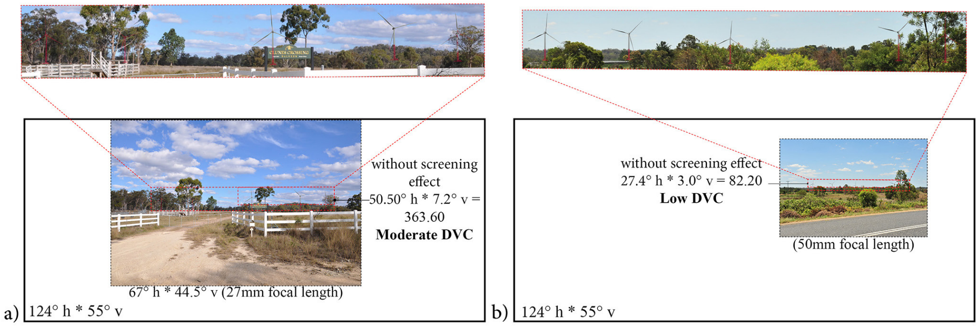
A combined layer was produced by multiplying vertical and horizontal angles for each viewpoint as the area of DVC with values between 0.43 to 23,343.33 (A-DVC). Calculated values were classified based on the defined significance levels and visualised with different point symbols for each separate parameter (Figure 5a, b & c). Each of the DVC variations reveals different aspects of the proposed wind farm development in terms of height and horizontal length. The visualisation of these maps by points was considered beneficial since it could be overlaid on the ZVI mapping. Area DVC (A-DVC) values were interpolated and presented as a raster as another representation. The size of points reflects the dominance or prominence of the wind farm in the view from that location. The resolution of modelling can be increased with a denser observation point dataset as required.

DVC maps indicate the visual prominence of tall wind turbines across the landscape. Observation points inside the project site revealed extreme DVC significance within this area. Since this area is owned by the developer, there will be no receptors inside this boundary. Fig 5d displays the location of private sensitive receptors surrounding the proposed wind farm which are located within low to major DVC significance zones. A 1.5 kilometer separation area is defined by the State Wind Farm Code and approximately correlates with the identified major DVC levels. However, the major DVC boundary is irregular, since it is dependent on the variations of landform and relative position of observer and modelling points. While the ZVI area is extensive, the visual prominence of the proposed wind farm is limited to identified areas of low to extreme levels, shown by the different point sizes. The modelling provides additional evidence that the DVC is negligible within the majority of the ZVI area within the 30 kilometer radius, and effectively reflects the effect of distance and landform on the visual experience.

3.2 Potential vs. Actual DVC

DVC maps represent the potential visibility of the wind farm in the surrounding landscape. The modelling does not take into account the screening effect of land cover. In order to validate the calculated DVC measures, two photomontage simulations were prepared as indicated in Fig 5d (Photomontages A & B). The existing condition photographs, used for the simulations, were taken in 2014 and 2016 with different focal lengths (27mm and 50mm respectively). The best practice procedure was followed to produce verified photomontages, superimposing the proposed wind farm on the existing condition photographs.

The screening effect of intervening vegetation was identified and shown using red-coloured transparency. The viewpoints for the photomontages were precisely located within a 124 degree horizontal by 55 degree vertical frame, to demonstrate the Potential and Actual DVC variables as compared with calculated GIS measurements (Fig 6a & 6b). Firstly, the comparison table (Fig 6c) illustrates negligible differences in Potential DVC measurements between the two methods (photomontage vs. proposed method). This highlights the effectiveness of the proposed method to model and map DVC. Secondly, the Actual DVC measurements confirm the effect of screening in reducing the DVC values in the horizontal (44% & 27%), vertical (22% & 10%) and combined area (60% & 34%) for photomontage A and B respectively. The screening effect can inform mitigative screening planting for different sensitive receptors. The Potential DVC calculation by the proposed method (Fig 5a-c) represent the worst-case situation without the screening effect and provide a conservative basis for ground-truthing followed by photomontage simulations.



c)

Photomontage		Measurements: Actual* DVC using montage	Measurements: Potential* DVC using montage	Measurements: Potential DVC using GIS	Comparisons: Potential DVC comparison: Photomontage vs GIS	Comparisons: Potential vs Actual DVC Comparison (reduction)
A	h-DVC	26.5	50.50	54.36	3%	44%
	v-DVC	5.10	7.20	8.26	2%	22%
	A-DVC	135.15	363.60	449.01	1%	60%
B	h-DVC	25.05	27.40	27.55	0%	27%
	v-DVC	1.5	3.00	2.73	0%	10%
	A-DVC	37.58	82.20	75.21	0%	34%

Potential DVC: hypothetical visibility without considering the screening effect.
Actual DVC: real visibility by considering the screening effect of intervening elements.

Fig. 6: Actual DVC calculation based on photomontages; a) Photomontage A-DVC calculation; b) Photomontage B-DVC calculation; c) Actual vs. Potential DVC measurements and comparisons

3 Discussion

While the initial purpose of this research was to reduce limitations of ZVI mapping to reflect the distance effect on the visibility of wind farms across an expansive landscape, the DVC maps that were produced quickly revealed the effectiveness of this method in evidencing and illustrating the prominence of large wind turbines in the surrounding landscape, considering the distance, elevation and orientation of views. Four key points were identified, and are discussed below.

Firstly, DVC only considers binary visibility (either visible, or not visible) and does not consider the effect of distance attenuation on object recognition, as the result of temporal climatic conditions and atmospheric scattering, air quality and colour, time of day, contrast, and other related factors which has been studied in previous research (BISHOP 2019 and 2002). The proposed combination of the horizontal and vertical proportion of occupied FOV applies a simple concept of visibility to support VIAs in defining the significance thresholds. In this approach, the potential for evident change is calculated as DVC. The proposed mapping process has the potential to study and integrate the effect of these distance attenuation factors as a future step.

Secondly, as a desktop study, DVC layers provided meaningful results and highlighted the effect of wind farms through separate lenses of vertical, horizontal effects in relation to human FOV. Using this approach, the visual effect of overbearing could be precisely monitored on different receptors exposed to wind turbines. Hence, DVC provides an effective supplement to ZVI mapping at the early stages of assessment to inform decision making and wider communications with the community or other lay individuals.

Thirdly, DVC maps can provide experts and decision-makers with information and considerations for wind farm design and siting to reduce the significance of visual impacts prior to site visits and modelling for photomontages. The proposed DVC modelling would allow testing turbine placement and heights through an iterative design process, which can reduce visual impacts and support more effective communication with stakeholders.

Fourth, the outputs from the DVC modelling have added to spatial awareness and logic in perceiving visual impacts of wind farms. The modelling results provide an evidence-based, transparent and scientific layer to justify potential visual impacts. The proposed workflow is adaptive, and could therefore be applicable to assessing the impacts of other large-scale development proposals such as solar farms, above-ground power lines or tall buildings. However, in its current form, it visualises a worst-case condition rather than providing a more typical or Actual DVC. This is considered as an area for further development of the concept. Moreover, the proposed method is not a fully automated process and requires post-processing in Microsoft Excel. Further development of the workflow through application in other wind farm proposals could be helpful for wider usage.

DVC as a visual impact assessment tool is likely to be useful in policy, guidelines and development controls. For example, State-wide policies for assessing impacts of wind farms could specify maximum acceptable DVC limits for various types of land use. At the local government level, similar limits could apply in viewsheds mapped or designated as scenic areas, or regional scenic sensitivity maps could trigger requirements for DVC analysis to accompany development applications. Potentially the naming of parameters can be refined for further applications as below:

1) Horizontal DVC can change to Horizontal Proportion of FOV (H-PFOV) or maybe H-EFOC (extent of FOV);
2) Vertical DVC can change to Vertical Proportion of FOV (V-PFOV) or V-EFOV;
3) Area DVC can change to Degree of Visible Change (DVC) refers to combined H-PFOV & V-PFOV.

4 Conclusion and Outlook

Degree of Visible Change (DVC) is not entirely a new concept to VIA, but the precise measurements and mapping described within this paper are innovative, new additions to the field in providing an evidence-based and objective layer to the assessment in place of photomontage simulations. The mapping can provide a logical basis in the early stages of assessment for rating impacts on landscape and visual receptors for further verification on the ground. As further developments of this research, screening potential and receptor sensitivities could be integrated into the mapping process, and significance levels can be further refined through community surveys and engagements. There are substantial benefits in applying the proposed method to identify visual impacts of wind farm developments, and proposing both off-site and on-site landscaping programs to mitigate these. This has the potential to contribute to increased plantings associated with these development programs and, as a result, contribute to the biodiversity of affected landscapes.

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