Real-Time VR Landscape Visualization for Wind Farm Repowering: A Case Study in Eastern Austrian World Heritage Sites

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Abstract: The expansion of wind energy is key for achieving the EU's sustainable energy targets. One of the main hurdles, however, is a lack of social acceptance: Resistance against new or repowered wind farms is still common. Particularly valuable regions such as World Heritage Sites pose additional challenges, as the introduction of energy infrastructure in the vicinity of such landscapes carries the risk of losing their status. Stakeholders need objective tools to assess the impact of wind farms on a landscape. This article presents and evaluates one such tool: an interactive landscape visualization framework which allows users to view arbitrary visual axes with a virtual reality headset. Given high-quality geographic data, this visualization objectively recreates landscapes with accuracy high enough for viewers to recognize the scenery and orient themselves. It was used in three workshops as part of a case study in the Austrian federal state of Burgenland. According to the participants' statements, the sense of scale conveyed by virtual reality technology and the perceived accuracy of the visualization allowed them to make a more informed decision on the matter. However, particularly in one transnational workshop, the lack of consistent high-quality data posed a challenge: When the visualization is deemed inaccurate, it loses its credibility and therefore its use in decision-making processes. This reinforces the call for openly accessible high-quality pan-European GIS data.

Keywords: Virtual reality, open data, 3D visualization, renewable energy, godot engine

1 Introduction

In order to meet the EU renewable energy targets (DIRECTIVE (EU) 2018/2001) and derived national development paths, new wind farms and a *repowering* of existing wind turbines is required. In a repowering, existing wind turbines are replaced with new models with increased height and rotor diameter. These new wind turbines are more efficient: compared to the removed old turbines, their power rating is typically more than doubled (LACAL-ARÁNTEGUI et al. 2020). Their larger size and efficiency results in a reduced number and density of wind turbines per wind farm. However, due to their larger dimensions, visibility is also increased, which can have a negative impact on the landscape's appearance.

Such major visual landscape changes may lead to conflicts, e. g. in the form of citizen opposition (PASQUALETTI 2011). World Heritage Sites and comparable sensitive landscapes are particularly vulnerable in this regard, as renewable energy may jeopardize their status (BAILONI 2016). Therefore, adequate tools and processes are needed to discuss and assess these changes.

Previous studies on the visual impact of wind turbines have predominantly used no visualizations or highly generic ones, even though dynamic and specific visualizations are a valuable tool for wind energy planning (HEVIA-KOCH & LADENBURG 2019). They can create a "common language" (KWARTLER & LONGO 2008) for the discussion and assessment. As such visualizations are often criticized as a tool for manipulation (BORCH et al. 2023), we expect

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that an objective and verifiable data basis is crucial. Moreover, as stakeholders have specific knowledge, concerns, and needs, we propose that it should be fully interactive and able to display any chosen viewpoint within the study space and adjust atmospheric conditions and time-of-day settings.

By fully immersing viewers in a 3-dimensional 360° panorama of the landscape, virtual reality devices allow them to better grasp the overall perspective and scale of the landscape and changes within it (SCHAUPPENLEHNER et al. 2018). PORTMAN et al. (2015) provide a theoretical framework for the use of VR technology in environmental planning. Some studies have been done on the perception of wind turbines with VR technology: CRANMER et al. (2020) have used a pre-recorded VR video and reported that "cinematic virtual reality" can be suitable to communicate wind development plans. Using panoramic photos with overlaid wind turbines, TEISL et al. (2018) found that "VR respondents felt they had more information and less decision uncertainty than those seeing a SP [static picture]" and that VR viewing led to more negative responses on average. With a similar approach, LIZCANO et al. (2017) found that "virtual reality and 3D models are a powerful combination for stakeholders to understand and experience the induced landscape and visual effect"; in their recommendations for future work, they highlight the potential usefulness of non-static visualizations with arbitrary viewpoints.

This article will outline the visualization process from data collection to 3D rendering and reflect on the suitability for regional wind farm planning projects. The guiding question is how interactive and immersive 3D visualizations can support wind farm planning processes in participatory workshops. Finally, the benefits of our approach as well as current limitations are discussed.

2 Materials and Methods

Three stakeholder workshops were conducted to discuss the visual landscape impact of the new wind farm layouts among various stakeholders. A landscape visualization technology that uses different types of (geographic) data was used in these workshops. This section describes this technology and how data was gathered, followed by an overview of how the workshops were set up, run, and analyzed.

2.1 Visualization Technology

As described above, the goal for the visualization was to be highly interactive (arbitrary view points and axes, adjustable atmospheric conditions) and immersive (viewable in VR). Current game engines offer sufficient real-time rendering technologies required for this: their value for landscape visualization was already recognized in 2002 (HERWIG & PAAR 2002), and the capabilities for realistic rendering including support for up-to-date VR technology (EDLER et al. 2019) has made this even more relevant.

Our visualization software, the *LandscapeLab,* is built with the *Godot* game engine. Similar previous studies have commonly used *Unreal* or *Unity* (EDLER 2020, KEIL et al. 2021), but contrary to these engines, *Godot* is licensed under an open source license, making it highly extendable and usable without licensing fees. This extendability was utilized for loading GIS data into the engine: whereas the aforementioned earlier studies have usually used a complex pre-processing pipeline in order to bring the raw GIS data into a format usable by the game engine, a plugin was developed for *Godot* to load GIS data directly from standard formats such as GeoPackages, Shapefiles and GeoTIFFs.[1] This data can be arbitrarily large: the visualization loads only relevant parts for the current perspective, and level-of-detail techniques are employed to make the computational cost manageable. By reducing the need for pre-processing and providing a visualization tool which can work directly with arbitrary GIS data, the cost for visualizing a case study is significantly reduced. Although the use-case here is renewable energy planning, the visualization tool could be used for a wide range of landscape planning purposes.

SHEPPARD (1989) postulates three criteria for useful visualizations: they should be *understood by people*, *convincing to people*, and *unbiased*. Our visualization aims for a realistic depiction of the real world; therefore, if this visualization is accurate, users should be able to orient themselves, making it understandable. Similarly, if the users recognize the landscape being visualized and find it to be accurate, it is likely to be convincing. Impartiality is achieved by directly accessing open GIS data. However, this means that biases in the underlying data inevitably lead to biases in the visualization.

2.1.1 Distance and VR Resolution

SULLIVAN et al. (2012) recommend a threshold distance of 32 km for wind turbines "unlikely to be missed by a casual observer", but the technical limitations of the utilized displays need to be taken into account, especially when using Virtual Reality technology: the headset used in this case study, a Valve Index, covers 0.075x0.065 degrees of view per pixel. Therefore, at a distance of 32 km, one pixel covers an area of approximately 42x36 meters. This is far larger than the width of a tower or rotor blade of a wind turbine, indicating that it cannot meaningfully be visualized at this distance in VR — its size is either greatly exaggerated or zero. Assuming that an area of at least 10x10 meters per pixel is required for a meaningful representation of a wind turbine (as the tower and rotor blades of large turbines have an average width of approximately 10 meters), the maximum distance for VR viewing can be said to be approximately 7.7 km. As seen in figure 1, even this estimate may be optimistic.

2.2 Case Study Area and Data Preparation

Our case study takes place in two regions with existing wind farms close to the border of a World Heritage Site in the federal state of Burgenland (Austria). In one region, the wind farm is located in the immediate vicinity of the Hungarian border, which means that impairments are also to be expected in the neighboring country.

As described above, the visualization software accesses GIS data to render 3-dimensional landscapes. Therefore, it was necessary to gather and prepare different types of data for the case study regions. Data was collected for extents encompassing at least 30x30 kilometers for each region, centered around the relevant wind farm. This allows rendering 360-degree panoramas for any location up to 10 kilometers from the wind farm which, as laid out in section 2.1.1, is more than sufficient.

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[1] GitHub page of the developed plugin: https://github.com/boku-ilen/geodot-plugin

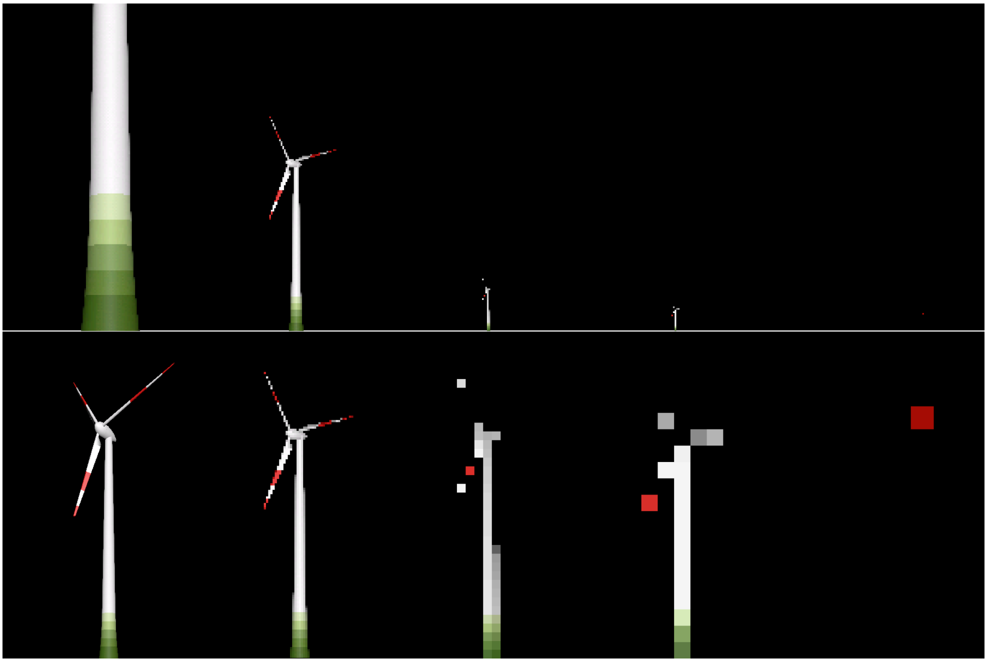

Fig. 1: Comparison of wind turbines being rendered onto a VR screen (Valve Index). Distances from left to right: 250m, 1km, 4km, 7.7km, 10km. Real proportions in the top row, scaled to appear the same size in the bottom row. Black background for exaggerated contrast.

In order to visualize arbitrary view points within extents of that size, comprehensive data is required. Small scale visualizations often use LiDAR scans or manually produced 3D assets (GRASSI & KLEIN 2016), but this is not feasible for large-scale visualizations with a limited budget. Our approach instead uses open data provided by Austrian authorities and the EU as well as volunteered geographic information (VGI).

Terrain data gives the visualized landscape its basic shape. In its fundamental form, it requires two inputs: height data and satellite images. In order to render additional detail such as vegetation and detailed ground textures at appropriate locations, a land cover map is needed. Surface height data (the difference between the surface model and the terrain model) is also required for accurate rendering of vegetation and buildings. Ideally, each of these datasets should have a resolution of 1 meter per pixel.

Furthermore, data for buildings and power lines from the OpenStreetMap project were included for higher detail. Lastly, the energy supplier provided datasets describing various different configurations of wind turbines within the wind farm, including the status quo. Some points of interest were also provided in order to streamline the workshop process by providing some pre-defined perspectives which are likely to be important.

2.3 Workshops

Three workshops were conducted as part of the case study. Workshops 1 and 2 evaluated the same repowering project in a region fully situated within Austria, whereas workshop 3 covered a different repowering project directly at the Hungarian border. Workshop 1 took place in November 2021, workshop 2 was approximately two years later in October 2023. Workshop 3 was conducted in September 2022.

In all cases, multiple stakeholders were present in addition to scientific staff: authorities of the energy supplier responsible for the planned project, representatives of the World Heritage Site, nature conservationists, and local decision makers. Each workshop was attended by 10 to 20 stakeholders. Before a workshop, the existing wind farm was viewed on-site by the stakeholders. This provided participants with an objective basis: both for the current status of the landscape, and for later being able to ascertain the accuracy of the 3D visualization. The workshops were then structured as follows:

1. Introduction: presentation on the state of the wind farm project, the relevant legal frameworks, and the reasons for the workshop and the visualizations.
2. Explanation of the visualization: what the visualization is and is not capable of, and what underlying data it uses. Introduction of the VR technology.
3. Viewing of the provided points of interest as well as any other requested viewpoints in the 3D visualization on a projector image. The different wind farm scenarios are viewed and some initial discussion takes place.
4. Open discussion about the insights gained from that visualization. Participants now have the option to view any view point with the VR device in order to deepen their understanding of the impact.
5. Conclusion and determination of next steps.

In order to minimize technical barriers, participants did not directly interact with the visualization at any point, but communicated their wishes (position, view direction, atmospheric conditions, daytime) to the workshop conductors, who moved the virtual camera and changed settings accordingly. Similarly, the VR headset was prepared and explained to participants if they wished to use it.

A protocol of all statements and discussions was written during steps 3 and 4. These protocols were later evaluated using *thematic analysis*, more specifically *codebook thematic analysis* as described by BRAUN et al. (2019). The aim was to evaluate the contribution of the visualization tool and the participants' attitude towards it. Therefore, themes were generated as *domain summaries*: surface-level categories of statements. A pre-defined initial classification was a division of statements into "Content" (statements and discussion about the planning case) and "Meta" (contributions which refer to the visualization technology or methodology more broadly). Specific themes were generated iteratively from the protocols; the results are described below.

3 Results and Discussion

After assessing the protocols with a thematic analysis as described above, 12 themes were generated. Examples of these include “Content: Discussion about visualized view”, “Content: Discussion unrelated to visualization”, “Meta: Comment on Importance of VR”, or “Meta: Technical Limitation”. These themes revealed some clear patterns which will be described below.

Both workshops 1 and 2 saw many requests for visualization, suggesting that participants were willing to get a better understanding of the wind farm’s visual impact. These requests included both pre-defined points of interest as well as user-requested locations, along with varied atmospheric and daytime settings. Therefore, the dynamic nature of the visualization software and its ability to visualize any point within the case study extent was highly valuable. Moreover, shortly before workshop 2, a photomontage was published by another party which suggested a very strong impact on the landscape from the new wind turbines by using strong contrasts and an increased focal length. The participants seemed to get a clearer understanding of this impact during the workshop, and its severity could not be confirmed in the interactive visualizations.

However, the specific role of the visualization was different in workshops 1 and 2: in workshop 1, the requested visualizations were viewed together on the projector screen and discussed among the stakeholders; VR was only used later by some participants to gain an even better understanding of some views. In workshop 2, VR was used much more frequently throughout the workshop. As putting on a VR headset isolates the user to some extent, there was less open discussion at this stage. However, the importance of VR was repeatedly emphasized in this workshop (twice as often as in workshop 1): Viewing the visualization in the headset was described as “bigger and sharper”; two participants said that it “makes a difference” to view the visualization in VR rather than the projected image. This shows that the landscape visualization can play different roles: it can facilitate open discussions through collective viewing, or it can deepen an individual’s understanding when viewed in VR.

Workshop 3, on the other hand, had few requests for visualization. From the outset, there was a more fundamental discussion about the visual impact of the wind farm on a historic property, largely without regard to the visualization. The wind farm being discussed in this workshop was situated close to the Hungarian border, and at the center of that discussion was a visual axis which was not known in advance, located entirely in Hungary. While Austria provides comparatively high-resolution national open data for terrain rendering, this is not the case for pan-European data. Therefore, the relief could only be visualized with a resolution of 25 meters instead of the 1 meter resolution available in Austria. In addition, the reference system and survey methods may have been different across the two height datasets, causing a discrepancy between the viewing height (in Hungary) and the wind turbine heights (in Austria). Furthermore, since only surface height data was available, precise vegetation heights were not known and the terrain was distorted further. Land cover data was also more coarse outside of Austria. This led to statements about the visualization focusing on its accuracy and limitations rather than the visualized content. The trustworthiness of the visualization and therefore its usefulness as an objective common language was limited. However, as the workshop progressed, particularly for views within Austria, there was also more discussion about the visualized content.

All workshops had participants reference the on-site viewing early in the discussion. In workshops 1 and 2, the similarity strengthened confidence in the visualization, as it was able to accurately recreate the view axes. In contrast, this comparison revealed the limitations of the low-resolution and inconsistent relief data in workshop 3: A wind turbine visible in reality was less visible in the visualization when configured to display the status quo. Furthermore, all workshops saw a discussion on the technical limitations posed by the VR display resolution as described in section 2.1.1 when participants were expecting to see wind turbines at distances which could not accurately be depicted by the Valve Index headset. Nevertheless, the use of modern 3D visualization and VR technology was positively emphasized ("high added value", "important to make use of such technology") in all three workshops.

Hardware required for the workshops consisted of a PC with a high-end graphics card and the Valve Index VR headset. Because of the use of established commercial technology, costs were manageable and in the range of typical high-end video gaming equipment. Transportability was also high, allowing the workshops to be conducted near the affected wind farms.

Fig. 2: Examples of different view axes within a workshop extent as visualized by our landscape visualization software

4 Conclusion

The ability to dynamically visualize arbitrary view points and atmospheric conditions was of high importance, allowing stakeholders to better understand the landscape impact of the wind farms. Viewing the visualizations together facilitated open discussions, whereas the sense of scale and realism of VR allowed participants to deepen their understanding individually.

A technical limitation which was apparent in all workshops was the limited resolution of the VR device: Wind turbines can be well visible at 10 kilometers in real-life, but the resolution of the Valve Index cannot accurately visualize a wind turbine's thin towers and rotors at such a distance. Therefore, the distance at which this tool can be used is limited by current VR display technology.

Apart from this, the main limitation for the visualization was the low quality of the elevation data in workshop 3. Due to the low resolution, visual axes can become inaccurate compared to reality, as small-scale relief differences are missing in the data. Furthermore, the issue of different reference systems and survey methods inevitably leads to a less accurate visualization across national borders.

Elevation data, especially surface heights, are also required for displaying accurate vegetation. Land cover and especially tree vegetation plays a major role in shaping sight lines (particularly in flat plain landscapes), so accurate data on tree distribution and height is needed. In the available European data, vegetation mapping is too imprecise since surface heights are missing and land cover data is very coarse. Consequently, there is a clear need for high-quality and consistent data to enable objective landscape visualizations across borders throughout the EU.

The development of renewable energy is an emotionally charged topic. While landscape visualizations cannot change underlying sentiments and beliefs, the case study showed that they can help objectify the landscape impact of renewable energy sources by providing a common language during the planning process. However, this requires data to be sufficiently accurate and high-resolution, which is currently not the case for pan-European data.

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