Cloud-based Visibility Analysis for Energy Infrastructure: Investigating the Cost-efficiency and Validity as Preconditions for Practical Implementation

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Abstract: Visibility analysis plays a significant role in environmental assessments for the rollout of renewable energy production systems. Wind farms, large open-field photovoltaic installations, transmission pylons and biomass cultivation for bio-electricity often faces public resistance due to their impacts on the visual landscape. Visibility analysis assists in the process of determining proper locations for renewable energy plants to assess and subsequently minimize their visibility and hence their visual impact. As a basis for visibility analysis, digital terrain (DTM) and digital surface data (DSM) are required. As these data are still very costly in Germany, cheaper data with a lower accuracy are often used in practice, leading to inaccurate results of the visibility analyses. The cloud-based platform CLOUDEO offers the possibility to rent data and conduct visibility analyses on a virtual desktop, which is an affordable alternative to buying expensive data. In this paper we compare the results based on the NextMap DTM 5 and DSM 5 data offered by CLOUDEO with those based on the more expensive DTM 10 data using ATKIS-data for extruding landuse-heights and DTM / DSM 1 data (LIDAR) provided by state surveying authorities, to judge if the cloud-based platform is a valid alternative. Assuming that the DTM 1 and DSM 1 data lead to the most accurate results, it could be shown that the results of visibility analyses based on NextMap DTM 5 overestimate visibility in comparison to those based on DTM 1 and DTM 10 data. When using the digital surface data (DSM 5), which represents the more common and realistic alternative, it could be shown, that the visibility analyses based on DSM 5 only differ slightly from those based on DSM 1, whereas results based on DSM 10 show greater differences to those based on DSM 1. Summarizing, it can be stated that CLOUDEO offers an affordable and valid alternative to buying expensive data for visibility analysis of energy infrastructure.

Keywords: Viewshed analysis, server-based GIS, visual impact assessment

1 Introduction

Visibility analysis plays an important role in the context of visual landscape impact assessment. With the continued implementation of renewable energy production facilities and arising public resistance against installations such as wind turbines or transmission pylons, the determination of proper locations for renewable energy plants is supported by visibility analysis. The analysis helps to minimize the visibility and hence the visual impact of the energy infrastructure. As a basis for visibility analysis, LIDAR-based digital terrain data (DTM) and digital surface data (DSM) with a resolution of at least 10 m should be used to achieve valid

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results (TÄUBER & ROTH 2011, ROTH et al. 2015, KLOUČEK et al. 2015). In Germany, these data are still very costly, and as a consequence, cheaper or free data, such as SRTM data, with lower accuracy and raster resolution, are often used in practice. This in turn leads to inaccurate or in specific cases even useless results of the visibility analysis. Following GRIFFIN et al. (2015, p. 218) it can be stated that "insufficient analytical tools to assess visibility across a large number of alternate sites prior to siting typically results in the omission of visibility in multi-criteria siting processes, leading to inferior site selection and often costly litigation."

Another problem from a practice perspective is the need of extensive storage space for the required raster data, as well as the need of powerful hard- and software to process this data. To solve these problems, we have developed a workflow, using the cloud-based platform CLOUDEO, which offers affordable alternatives to integrate visibility analyses in the planning process of renewable energy infrastructure: Users can rent the data required for visibility analyses and work with it on a virtual desktop, where they also have access to free GIS software packages. NextMap DTM 5 and DSM 5 can be accessed for less than 1 € km^2 for limited time use or bought for 1,88 € per km^2. In comparison, DTM 10 data for the study area of Middle Hesse are available for 2,50 € per km^2 if they are ordered for more than 5.000 km^2. Up to an area of 500 km^2 state authorities are charging 10 € per km^2. The DTM with a raster resolution of 1 m is even more expensive, with 20 € per km^2 for an area of more than 5.000 km^2 and 80 € per km^2 for an area up to 500 km^2.

This paper aims at comparing the data offered by CLOUDEO and the visibility analysis results that can be achieved using these data with the much more expensive data provided by state surveying authorities. We investigated if this cloud-based platform could be an affordable and valid alternative to the classical way of buying expensive data and conducting visibility analyses with one's own hard- and software.

2 Methodology and Data

The study area used for this investigation was the regional district of Middle Hesse in Germany. Several visibility analyses were performed for possible wind power plants on the level of the regional land use planning process. Therefore, midpoints of possible priority zones for wind energy were chosen as location of fictitious wind turbines for which visibility analyses could be conducted. A radius of 10 km around the site of each wind power plant was used for the analyses. A limiting factor was the availability of the digital surface model with a resolution of 1 m, which was not available for the whole area of Middle Hesse, whereas the digital terrain data with the same resolution, as well as both the DTM and DSM data with resolutions of 5 m and 10 m were available for the whole region. Consequently, for some priority zones visibility analysis could be conducted with DTM as well as with DSM data. Other midpoints of priority zones were chosen randomly to conduct visibility analysis with either DTM or DSM data.

For visibility analysis, different methods can be used: binary, frequency and cumulative visibility analysis (ROTH & GRUEHN 2014, ROTH et al. 2015). Different definitions of the latter two methods are still used (comparing CHAMBERLAIN & MEITNER 2013 and ROTH & GRUEHN 2014). For this study, the standard binary visibility analysis method as described by ROTH & GRUEHN (2014) was chosen. This type of visibility analysis determines from which areas the investigated wind turbines can be seen. All visibility analyses in this study were conducted with the visibility algorithm implemented in the extension Spatial Analyst of Esri's ArcGIS.

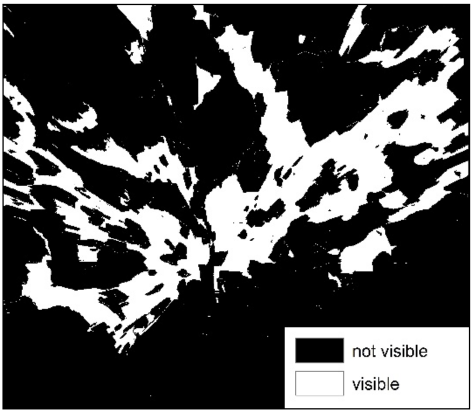
In the first step, the analyses were conducted using the CLOUDEO workbench. This virtual desktop can be rented for a certain time and enables the user to access different digital data and open source software for GIS-based analyses. For our study, we chose access to the NextMap DTM 5 and DSM 5 data, both with a raster resolution of 5 m and based on radar interferometry. It is also possible to install your own software on a CLOUDEO workbench, so we installed Esri's ArcGIS for conducting the visibility analysis. In the end, results of the analysis can be downloaded from the virtual workbench.

In the second step, the same analyses that were conducted on the CLOUDEO workbench were performed with state DTM 10 and using ATKIS-data for extruding land use heights, as well as with the DTM 1 and DSM 1, all based on laser scanning. These were the more costly data, provided by the Hessian State Office for Land Management and Geoinformation and the regional administration of Gießen. For all analyses, Esri's ArcGIS was used to guarantee comparability of the results.

Finally, a statistical comparison between the results was calculated to find out where the DTM 5 and DSM 5 can be ranged regarding the data quality. We assumed that the DTM 1/ DSM 1 data set with a very fine raster resolution of 1 m and high z-accuracy provides the most valid results (high content validity). Using this as a reference, deviations in the analyses based on the other datasets were calculated. Therefore, we subtracted the results of visibility analyses based on DTM and DSM data with a raster resolution of 1 m and 5 m from the results of the analysis based on the DTM / DSM 10 data. We also subtracted the results based on 1 m data from those based on the NextMap data with 5 m raster resolution. As the results of visibility analyses for a single wind turbine, like in this case, are either 1 (visible) or 0 (not visible), the results of the subtraction can be 1, 0 or -1. A negative value indicates that the subtracted (subtrahend) raster overestimates visibility at this certain point in comparison to the raster it is subtracted from (minuend raster), which means that according to the subtrahend raster the wind turbine should be visible whereas the minuend raster indicates it is not visible from this certain point. A positive value of 1 shows that the subtrahend raster underestimates visibility, which indicates the opposite case: According to the subtrahend raster the wind turbine is not visible and according to the minuend raster it can be seen from this location. The value of 0 finally indicates that both results correspond at this certain raster cell, which can be 1 (visible) or 0 (not visible).

As an example, figure 1 shows a part of the results of a visibility analysis based on the DSM 10 data and figure 2 shows the result for the same area based on DSM 1. In both figures, the areas from which the investigated wind turbine is not visible are marked black, the areas from which it is visible are left white.

Subtracting the results based on DSM 1 from those based on DSM 10 results in the raster shown in figure 3. The blue areas have a value of 1, which means that DSM 10 indicates visibility of the fictitious wind turbine at this location while DSM 1 indicates its non-visibility. So DSM 10 overestimates visibility at these locations in comparison to DSM 1. The yellow areas have a negative value (-1) indicating that the result based on DSM 10 underestimates visibility in comparison to the one based on the DSM 1, which means that DSM 10 indicates non-visibility whereas DSM 1 indicates visibility of the wind turbine. The black areas (with a value of 0) mark the area where the analysis based on either data source correspond in terms of visibility or non-visibility.



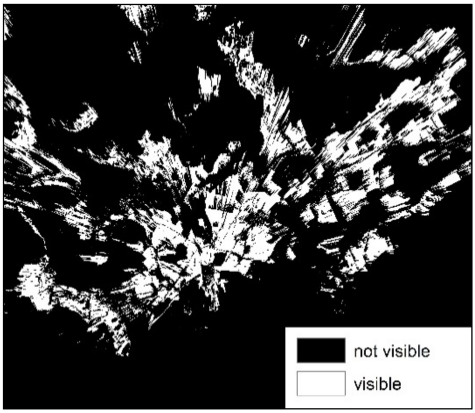


Fig. 1 and 2: Result of visibility analysis based on DSM 1 provided by the Hessian State Office for Land Management and Geoinformation

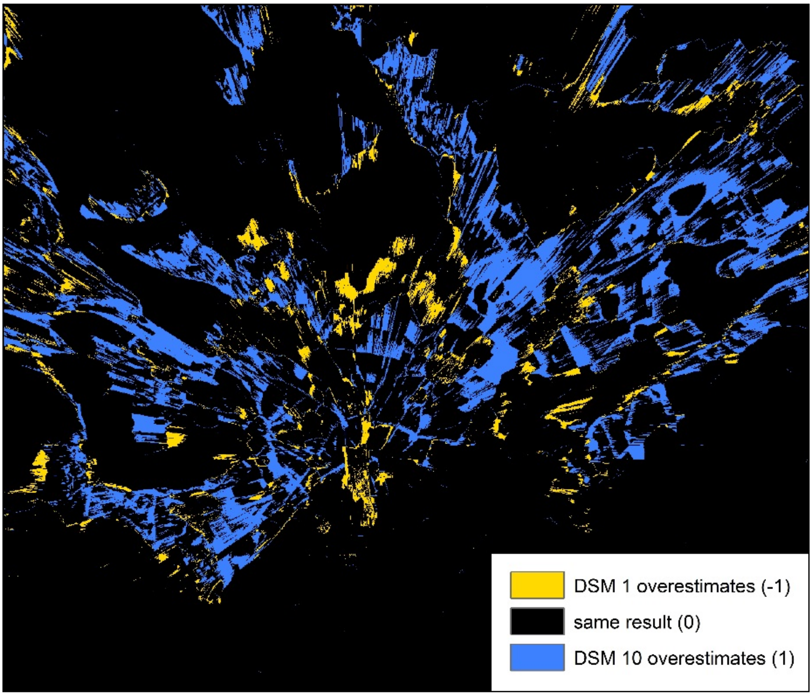


Fig. 3: Comparison of the results based on DSM 10 and DSM 1, both provided by the Hessian State Office for Land Management and Geoinformation

3 Results and Discussion

Of the three aspects data quality/validity, costs, and accessibility mentioned above, quality and validity was the most important one for this study as this paper aims at investigating the validity of the DTM 5 and DSM 5 data as an alternative to the more expensive data with a raster resolution of 1 m and 10 m, and therefore this aspect is most extensively described and discussed in this section.

The following table shows the results of the subtraction of the raster data resulting from the visibility analyses based on mere terrain data without buildings and vegetation. Results based on the DTM 5 and DTM 1 data were subtracted from those based on DTM 10 ('DTM 10 minus DTM 5' and 'DTM 10minus DTM 1'). The results based on DTM 1 data were also subtracted from those based on NextMap DTM 5 ('DTM 5 minus DTM 1').

The table shows the results of these subtractions for the areas around four different fictitious wind turbines. As stated before, a negative value indicates an overestimation of visibility by the subtracted raster while a positive value shows an underestimation. The value 0 means that both raster data sets have the same value at this location.

Table 1: Comparison of the results of visibility analyses based on DTM data with different resolutions

Test Area	Resulting value	DTM 10 minus DTM 5 (%)	DTM 10 minus DTM 1 (%)	DTM 5 minus DTM 1 (%)
A	**-1**	3,31	0,21	1,20
	0	95,48	99,20	95,31
	1	1,21	0,59	3,59
B	**-1**	4,84	0,12	1,81
	0	93,26	99,45	93,12
	1	1,91	0,43	5,07
C	**-1**	4,14	0,15	1,45
	0	94,29	99,23	94,07
	1	1,57	0,62	4,48
D	**-1**	2,91	0,12	1,16
	0	95,84	99,34	95,62
	1	1,26	0,54	3,22

Based on this data, it could be shown that if using the different DTM data without considering the land use heights, the visibility analysis based on NextMap DTM 5 overestimates visibility in comparison to the DTM 1 as well as to the DTM 10 at about 3 % to 5 % of the surface area. In contrast, comparing the results based on DTM 1 and DTM 10 showed only a very small difference between these data models: Visibility analysis based on DTM 10 overestimates visibility at only less than 1 % of the surface area. So in this case, results based on DTM 10 are more accurate than those based on the NextMap data available through the CloudEO workbench, although the difference between the analysis with DTM 5 and analysis with the more accurate DTM 1 is still not very big: At about 94,7 % of the areas around the wind turbines both resulting raster data sets correspond.

Table 2 shows the results of subtracting the results of visibility analyses based on NextMap DSM 5 and DSM 1 from those based on DSM 10 ('DSM 10 minus DSM 5' and 'DSM 10 minus DSM 1'). The results based on DSM 1 were also subtracted from those based on DSM 5 ('DSM 5 minus DSM 1'). Now, landuse heights such as vegetation and buildings are included in the analyses, which is the more realistic scenario which also has a higher relevance from a practical perspective.

Concerning the fictitious wind turbines used, the areas C and D, which were used for comparing the results based on different DTM data were used again for comparing the different DSM data. As stated before, the availability of the DSM 1 for the study area was a limiting factor and therefore the areas A and B could not be used in the case of investigating the difference between the different DSM data, as the DSM 1 data was not available for these areas. So the area around another fictitious wind turbine (area E) was used instead.

Table 2: Comparison of the results of visibility analyses based on DSM data with different resolutions

Test Area	Resulting value	DSM 10 minus DSM 5 (%)	DSM 10 minus DSM 1 (%)	DSM 5 minus DSM 1 (%)
C	**-1**	2,21	1,62	1,47
	0	94,49	94,09	95,49
	1	3,31	4,29	3,04
D	**-1**	2,07	1,60	1,35
	0	93,53	92,26	95,08
	1	4,41	6,14	3,56
E	**-1**	3,03	1,43	1,13
	0	93,14	92,96	94,41
	1	3,83	5,61	4,47

When using the digital surface models, which represents the more usual and much more realistic data basis for visibility analyses, we found out that visibility analysis based on NextMap DSM 5 overestimates visibility in comparison to analyses based on the DSM 1, but underestimates visibility in comparison to the results based on the ATKIS-DSM 10. There's a difference of about 3 % to 4.5 % between the results of DSM 5 compared with those of either DSM 1 or DSM 10. The analysis using ATKIS-DSM 10 clearly overestimates visibility in comparison to DSM 1. The table shows an overestimation at more than 4 % up to more than 6 % of the surface area. So in this case, DSM 5 evidently leads to the more accurate results than DSM 10. This can be explained by the fact, that DSM 10 uses ATKIS data for extruding land use height, resulting in a generalized representation of buildings and vegetation such as forests, whereas DSM 5 and DSM 1, based on radar interferometry and laser scanning, offer a much more detailed representation of actual landscape structures.

4 Conclusion and Outlook

We conclude that the NextMap DTM and DSM data with a raster resolution of 5 m, which are an affordable alternative to the more expensive data provided by state authorities, can compete in terms of the quality of results with the ATKIS-DTM 10. The results of the visibility analyses based on DSM 5 provide the same values as the analyses based on DSM 1 on 95 % of the area around the investigated fictitious wind turbine. The results based on DSM 10 provide the same values as the analyses based on DSM 1 on about 93 % of the same area. So because of the generalized land use heights of ATKIS-DTM 10, visibility analysis based on NextMap data has a smaller difference to the results based on DSM 1, which is the most accurate data available.

It can further be concluded, that using NextMap DTM 5 and DSM 5 and calculating visibility analysis on a virtual workbench is a good alternative to buying expensive data from a practice perspective. Although DSM 1 would lead to the most accurate results of visibility analysis, from a practical perspective DSM 5 data can be seen as an attractive alternative as it saves computing time in comparison to DSM 1, and at the same time the results will not differ significantly in comparison to DSM 1.

The concept of renting data on a cloud-based platform for conducting visibility analyses is a practical and valid alternative to buying expensive data provided by state authorities and thus offers huge benefits for example for planning authorities, landscape architects and landscape planners. The results that can be achieved with this server-based approach can compete with those of the visibility analyses based on ATKIS-DTM 10 in terms of validity and costs can be kept much lower by using the cloud-based solution. The need of storage space can also be drastically reduced by only renting the data instead of buying it.

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