Could landscape intervisibility be a suitable criterion for location of wind turbines?

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Extended abstract

INTRODUCTION

It seems obvious to apply spatial modelling to wind energy planning: All aspects of this renewable energy source are closely related to location and space. Wind resources are unevenly distributed over the surface of the Earth, and so is the technical, economical, environmental and socially acceptable potential of utilisation. Technological advances in the past two decades have improved feasibility of wind power but also increase pressure on spatial planning in regions blessed with good wind regimes.

In Denmark wind energy planning has proven increasingly difficult in recent years. The former world leader in wind energy has not seen the erection of land based turbines since 2003. Reasons are foremost a much less attractive feed-in tariff but also a public planning process, which has not followed technological development. During the 1990's a nationwide planning programme was elaborated, which laid out permission areas with prescribed number and size of turbines. During this period, however, turbine size in terms of total height has grown by 15% per year on a 20 year average, making most planning zones obsolete: Turbines outgrew planning requirements. Another criterion in municipal and regional wind energy plans are distances to settlements, technical installations and landscape features (Nielsen, 1996). Binary in nature, this buffer approach has effectively ruled out most suitable locations. Few alternative planning methods as in Hansen (2005), who proposed a fuzzy buffer distance approach in a multi criteria fashion, have been developed for the regional scale. Several of them, e.g. Baban and Parry (2001) have used GIS-based analysis to facilitate the location process. Viewshed analysis has been used for wind energy planning in the UK.

The current planning approach (Agnolucci, 2007) favours repowering schemes replacing older, poorly located or paid-back turbines with new turbines yielding much better energy output per area consumption, and at lower costs. Finding locations for repowering, however, has proven to be equally difficult. Hardly any areas are left suitable in the process. The compulsory environmental impact assessment of remaining sites is critical. The former county administration has ruled out all proposed sites in the year 2005, showing that finding locations for new turbines is not a matter of objective choices.

One of the limiting factors is visual impact. Exposed locations are essential for wind turbines, because obstructions like hills, forests or buildings not only reduce visual impact but also energy production. Ideal locations seek to minimise landscape roughness in a 2 to 10 km distance, where visibility peaks. In Northern Jutland landscapes, dominated by glacial geomorphology, topography clearly is expected to influence both visibility and energy output. The challenge is thus to find locations with good wind regimes *and* low visibility. But visibility is no absolute measure and must be weighted against surrounding land use. Furthermore, some areas are such towns, forest, and natural protection zones must be excluded. In order to economically gauge the loss of wind resources by visibility threshold, cost-supply curves are used to quantify energy output by electricity production costs.

This paper presents an analysis of intervisibility and its use for wind energy planning. Intervisibility is a property of landscape that quantifies visibility of a location from all other locations. A visibility count is influenced by topography as well as landscape inventories (forests, buildings etc.). Intervisibility could therefore be used as a measure of visual exposure of locations in a region, practically as a data layer in a geographical information system (GIS). Using spatial statistics, pairing an intervisibility map with a wind resource map, the effectiveness of intervisibility mapping as a planning tool shall be analysed.

MATERIALS AND METHODS

Visibility maps are produced using surface analysis tools in a raster-based GIS, where line-of-sight analysis (LOSA) is a standard procedure. LOSA draws lines-of-sight between an observer location and all cell centroids in a digital elevation model (DEM) raster. If no obstacle obstructs the view, a value 1 is added to an observer location's visibility score, otherwise a value 0. The result is a regional map quantifying visual exposure from a given observer location (Fisher, 1995). An intervisibility map performs LOSA from all locations to all locations in a region. It is therefore incredibly time-consuming, but, once produced, no further alteration or recalculation is needed. Alternative, time-saving algorithms as in Sansoni (1996) and Mills et al. (1992) were not considered.

Choice of raster resolution is crucial for accuracy and computation effort. Reducing cell size by factor c results in c^2 cells and in c^4 times of LOSA calculations. Accuracy is mainly determined by the DEM resolution. Stiles (2000) has determined increased agreement between calculated and observed intervisibility from 70% for a 100 m DEM to 90% for a 30m DEM. Tests carried out for a small proportion of the Northern Jutland case area with a "typical" representation of landscape types, reveal that a 200 m DEM delivers appropriate results, see figure 1. The diagram shows how the deciles of visibility develop with increased raster resolution. At a resolution of 1000m, 75% of the land cells are visible from more than 90% of the remaining locations. Smaller resolutions reduce the number of areas highly visible. A 100m resolution would be optimal, as the observed tendency of improved differentiation is decreasing. Smaller cells size is technically impossible without significant hardware upgrades. A 100m resolution is impossible to calculate for the region on a Pentium 4, 3 GHz pc with 2 GB. Apart from using grid-computing and super-computers, a performance improvement could be obtained by overlaying visibility points generated in a random manner, or by random samples, which however did not produce consistent results.

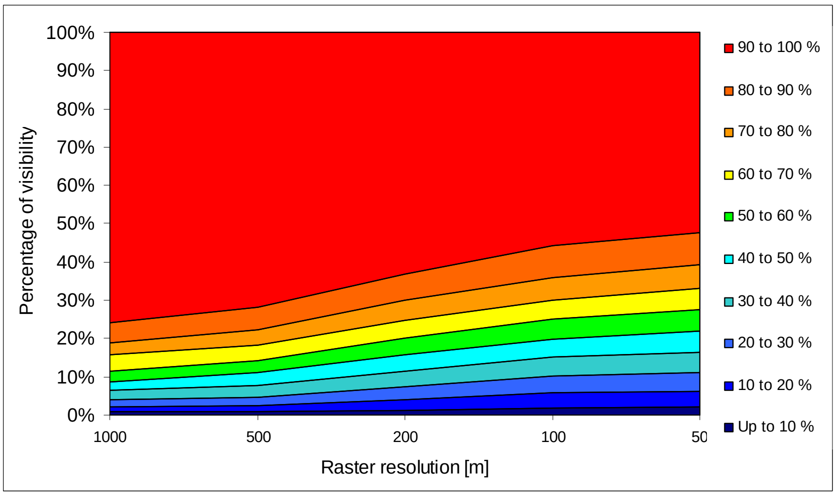

Figure 1: Statistics on the development of differentiated intervisibility for increasing raster resolution. Large cell size overestimates the intervisibility of landscape.

Also, a large cell size reduces small scale variations of landscape and works like a filter. The smaller the cell size, the larger is the influence of smaller objects. A trade-off has to be found between the importance of objects such as buildings and forests and the computation time allowed. Due to the large range of values of the produced intervisibility maps, even a reduction of detail does not affect the final result very much. It was therefore assessed that a raster resolution of 200m would yield acceptable results. A DEM was bilinearly resampled from a 10m raster by KMS (2007). Bilinear resampling smoothes the landscape and keeps values within the range of existing values.

LOSA analysis allows for cut-off distances, to be used to effectively reduce the number of calculations and the influence of remote locations to local visibility. An outer radius can enhance the weight of local disturbances. This makes sense because wind turbines become practically invisible at distances > 10 km. Slender constructions, atmospheric haze and the Earth curvature reduce long-distance visibility. Using experiences from earlier studies, a cut-off radius of 30km was chosen.

Objects located further away have less visual impact than objects close by. The likely weight of visual impact therefore can be modelled using a distance decay function. This however is not implemented in standard viewshed tools. Multiple visibility maps can therefore be added to a composite, where maps with different cut-off radii are added to each other, equipped with a weight decreasing with distance in a weight = 1/distance fashion.

An intervisibility map was prepared for the Northern Jutland region, see outline in figure 2. To avoid border effects a buffer of 30 km was added. The resulting experimental area covers 14.200 km^2, excluding sea and inland waters. The finished standard intervisibility map with a visibility count is shown in figure 2.

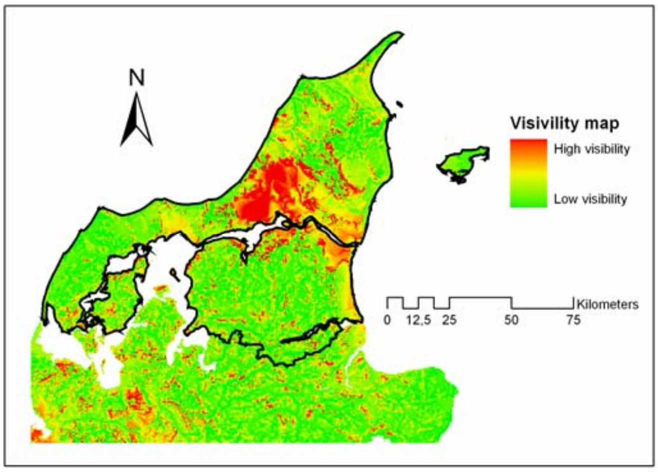

Figure 2: An intervisibility map describes how visible a location is from surrounding neighbour cells. This map shows the North of Jutland, with red tones indicating high visibility, and green tones low visibility. The analysis was restricted to contributing cells on land locations in a 30 km radius.

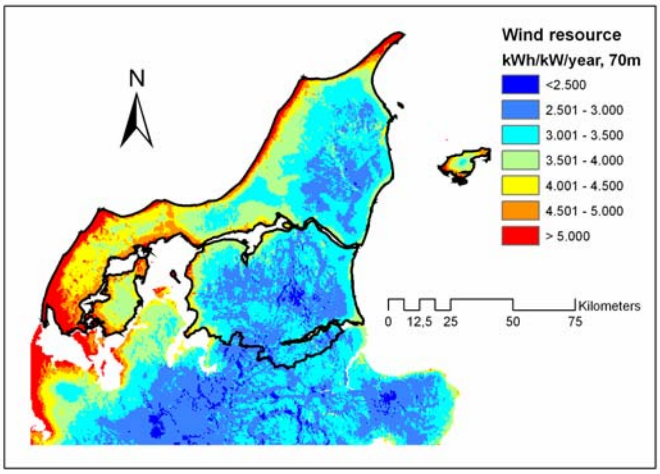

Figure 3: A wind resource map for Northern Jutland reveals pristine wind resources along the western coasts and some inland locations. The map was prepared using Wind Resource Mapper software by EMD International, Denmark (www.emd.dk).

To assess the relation between wind regime and visibility, a wind resource map was prepared with Wind Resource Mapper by EMD International, which uses topographical information and local influences, following the Wind Atlas (WAsP) methodology. Energy content of the wind in 70m hub height in kWh/kW/year was converted to a 500m raster, see figure 3. For economic assessment it is worth to note that the costs of producing electricity decrease nonlinearly with increasing wind resources (Morthorst, 1999).

The entire model framework including data conversion, terrain modelling, and spatial statistics has been implemented with ArcGIS 9.1 software by ESRI, including Spatial Analyst. The model itself has been programmed using the graphical model extension Model Builder, with allows for consistent and documented model design.

LIMITATIONS

An entirely data-driven approach is unlikely to produce results applicable in a real situation. Any outcome of this study therefore needs field testing and a backup of empirical data to be applicable. The methods themselves have been used earlier in another context and within different disciplines, and are fully documented in literature. It shall also be stressed that this preliminary description of ongoing research lacks the full input data. The limitation to a 500m raster resolution has been mentioned already, but also planning maps are missing at the time being. Economic data has to be reviewed before included in the model.

PRELIMINARY RESULTS

In order to test intervisibility as a location criterion, geostatistical analyses with wind resource, land use and sensitive area maps have been carried out.

It can be demonstrated that it is not necessarily obvious that good wind resource locations are highly sensitive to visual impact because of good visibility. From an analysis of area availability and the costs of supply it can be seen how degrees of intervisibility as a criterion will affect the costs of utilising wind energy. A visual representation of this is shown in figure 4, where visibility and wind resources have been normalised on a 0 to 100 scale and subtracted. Figure 5 shows the content of this map in different form. Visibility is rather low in most locations with good wind regime.

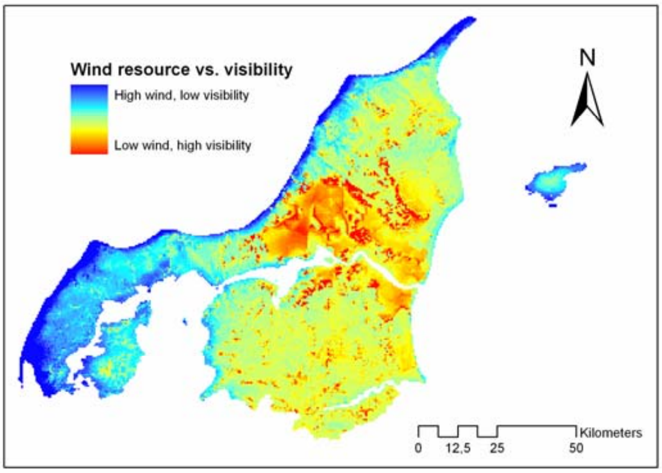

Figure 4: A normalised intervisibility map (0…100%) has been subtracted from a normalised wind resource map (min = 0%, max = 100%). The result documents that a good wind turbine location not necessarily is visually exposed and vice versa.

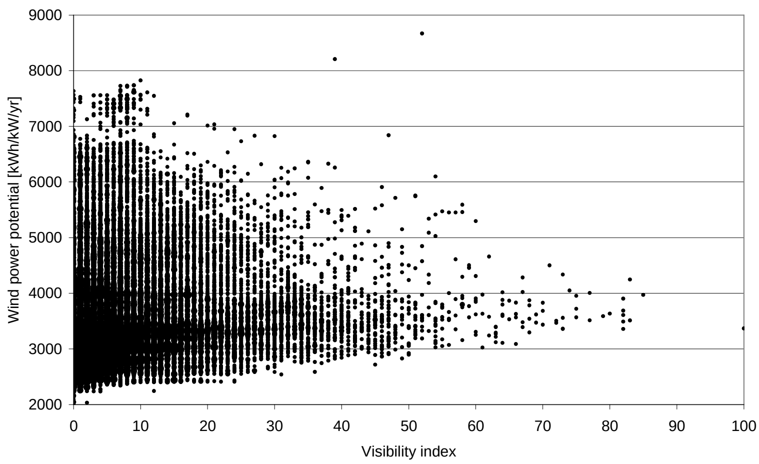

Figure 5: Wind resource and intervisibility index for all locations in the region. It can be observed that visibility is low at the majority of wind locations.

It is furthermore clear that intervisibility of landscape locations is not evenly distributed. Locations such as peninsulas and islands have generally lower visibility than large and flat areas. It can be seen from the intervisibility map in figure 2 that hilltops expectedly have high visibility, but small available areas and a lower wind regime than planes. Coasts such as the West coast have low visibility but a high wind energy potential, making them obvious locations to build turbines that are highly productive but little visible. Unfortunately these areas are all under heavy natural protection, and for good reasons.

A quantification of the economic effects of using visibility as a planning criterion is required. A cost-supply curve is shown in figure 6, which visualises the amount of wind energy from all agricultural areas excluding areas that are protected. The cost supply curve was created by plotting visibility over accumulated wind resources, using the spatial statistics from the overlay of both themes. The cost-supply curve is preliminary. It excludes an economic evaluation and uses the wind resource in kWh/kW/yr instead. The cost-supply curve also assumes a linear relation between visibility count and likely visual impact, which might not be the case in the real world. The regional cost-supply curve establishes a mathematical relation between the wind resource supply in Northern Jutland and the "costs" connected with visual impact. It can be seen that the vast majority of wind resources in the area are available at rather low "costs" of visibility.

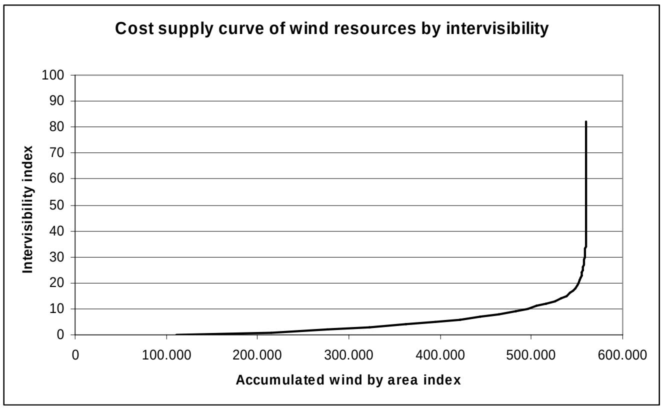

Figure 6: A cost-supply curve of wind resources by intervisibility reveals the spatial relation between the potentially harvestable wind energy and the intervisibility as a proxy for visual impact. Excluded are areas that are protected (habitats, preservations etc.) and all other areas except agricultural fields, pasture etc. The graph reveals a tendency that most of the wind resource is available at low visibility, while only a few locations are highly exposed.

CONCLUSION

Visibility is difficult to quantify. An area might be visible but a spectator will not necessarily see it as such. Visibility is affected by differences between model and reality, by physical effects such as atmospheric haze, by the frequency of spectators and by landscape inventories such as vegetation.

This work in progress shows that wind resources and visibility as drivers of and limits to wind power development are not necessary contradictions. They are unique landscape properties and need therefore to be analysed for each region in question. Intervisibility of landscape locations seems to be efficient to tell apart areas where turbines are likely to be seen from many other locations. The spatial overlay with wind resources allows for an assessment of the areas that need to be "sacrificed" for preservation of precious landscapes. The visual and arithmetic overlay alone, however, does not allow for an economic assessment or, if this path is followed, for a prioritisation of land use for wind energy development contra preservation.

What the cost curve tells is that most wind resources in the area, excluding those located in areas that are subject of protection and preservation, are not exposed to high visibility. The highest visibility in the area was computed for some flat areas in the central planes and for hilltops. If setting a threshold for acceptable visibility, the cost curve can in its final version reveal a relation between acceptable visual impact and the costs of wind energy generation.

The ongoing research needs to include a more detailed DEM in order to include many local effects in the hilly landscapes of Northern Jutland. An economic calculation of wind energy costs as a function of wind resources will be added, as well as an assessment of area consumption. The spatial statistics mentioned earlier, which will essentially test the correlation between land use, visibility and wind regime, will be added. The expected outcome will be a more thorough analysis of intervisibility as a suitable criterion for location of future wind turbines.

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