Concept for collaborative design of wind farms facilitated by an interactive GIS-based visual-acoustic 3D simulation

Madeleine MANYOKY, Ulrike WISSEN HAYEK, Thomas M. KLEIN, Reto PIEREN, Kurt HEUTSCHI, Adrienne GRÊT-REGAMEY

1 Introduction

Planning of wind farms appears to be a complicated matter in Switzerland and all over Europe, causing growing government and business frustration. The implementation often fails on the local level when it comes to choosing a suitable location for a wind farm, although the public generally supports wind power (DEVINE-WRIGHT, 2005; WOLSINK, 2005). Social acceptance is a key issue for successful wind energy market development. The choice of the location is most crucial for public stakeholders and there is growing awareness amongst policy makers that not only the physical characteristics of a wind farm but also the process of planning a wind farm is an important factor influencing public acceptability (DEVINE-WRIGHT, 2005). However, 75% of all stakeholders in Switzerland state that there is a lack of planning instruments to improve or support social acceptance (BFE, 2009). Thus, participatory wind power planning needs adequate new instruments.

This paper presents the concept and preliminary results of the development of a visual-acoustic simulation integrating realistic acoustic soundscape modeling into GIS-based 3D landscape visualizations. Movie and sound recordings were generated for a reference site of an existing wind farm at the Mont Crosin (Canton Berne, CH) as basis for validating the visual and the acoustic simulation. A first interactive GIS-based 3D visualization with high level of detail was generated using a game engine, offering sophisticated tools for animating 3D objects or realistic representation of lights and shades. This 3D visualization will be further developed to a prototype of an audio-visual reproduction system. Then, visual-acoustic simulation models for specific areas with different landscape characteristics will be established and used in virtual reality choice experiments for valuation of alternative wind farm scenarios. The final simulation tool will allow for an improved impact assessment in strong collaboration with the public, which provides a better, more comprehensible decision basis for designating suitable locations for wind farms.

2 Theoretical Background

In Europe, there is a strong demand for renewable energy. Wind is an important energy source, however, the development proceeds very slowly in Switzerland. One of the most significant factors explaining acceptance or rejection of wind farms is the impact of the new infrastructures on a specific type of landscape characterized by aesthetic quality and a sense of place (DEVINE-WRIGHT, 2005; WOLSNIK 2005). Besides these factors, noise made by rotating turbine blades is the most prominent environmental annoyance factor, which is strongly correlated with the visual impact on the landscape (PEDERSEN ET AL., 2008). Research results show that the soundscape can have a substantial impact on aesthetic and affective assessments of visual landscapes, and particularly anthropogenic, technical sound can impact scenic enjoyment and thus the recreational quality of locations (BENFIELD ET AL., 2010). But it is less known how to adequately represent a multi-sensory environment, how such representations might influence landscape assessments, or how they could influence decision-making in planning the environment (LANGE, 2011).

There is common agreement in the point that technical information about noise in form of dB values alone is inaccessible to the public (MCDONALD, 2009). Noise is an inherently
psychological perception wherefore reliance on just physical measures of sound is not sufficient (MACE ET AL., 2004). The sound level can be rated very objectively, however there are also other factors such as expectation, source attribution, prior experience, motives, and difference thresholds, which have an impact on the subjective response and evaluation of the environment (MACE ET AL., 2004). Thus, in environmental assessment of wind turbine noise, including the human perspective regarding the acceptability of noise in certain landscapes is mandatory. With regard to visual aesthetic quality assessment of landscapes studying from a psychological perspective is required too, including objective judgments as well as human perception (DANIEL, 2001). Hence, approaches are needed to assess both, the response to the visual and the acoustical impact of a wind farm scenario taking into account human perceptions and preferences. In this context, visual-acoustic simulations have high potential to facilitate a more comprehensive appreciation of values and for detecting acceptable places for wind power technologies.

2.1 Current simulation and modelling tools

Current planning tools including 2D maps, tools and techniques available for determining visibility and simulating wind farm projects (e.g. WindPRO, www.emd.dk) and data for noise levels fail to adequately integrate visual and acoustic factors into site planning for collaboratively identifying suitable places for wind power technologies. However, GIS-based 3D visualizations have proved to facilitate the communication between various stakeholders, professionals and the public in the context of participatory wind power development (LANGE AND HEHL-LANGE, 2005).

With today’s visualization software programs virtual landscapes of tremendous visual realism as well as interactivity can be generated (PAAR AND REKITTKE, 2005). The rapid development of hard- and software for interactive visualization is mainly pushed by the growing market for computer games (HERWIG ET AL., 2005). 3D game engines are optimized for real-time navigation in a virtual environment (HERWIG AND PAAR, 2005). Benefits are the possibility of interactively experiencing the virtual environment and the high level of detail. Particularly a high level of detail in the foreground is required in order to allow for reliable visual landscape assessment (APPLETON AND LOVETT, 2003; LANGE, 2001). Therefore 3D game engines are interesting alternatives to professional GIS-based 3D landscape visualization software such as, for example, Visual Nature Studio (www.3dnature.com).

Crytek's CryENGINE (http://mycryengine.com), for example, is a sophisticated 3D game engine, which offers suitable functions for developing a visual-acoustic simulation of wind farms. It is possible to import a digital terrain model and orthophoto (both raster data) and to animate landscape objects such as wind turbines. The wind speed parameter can be increased in the virtual landscape and can affect the speed of the turbine's blade rotation, shaking of leaves etc. accordingly. Even sound can be integrated into the virtual reality.

Auralization is the technique of creating audible sound files from numerical (simulated, measured, or synthesized) data (VORLÄNDER, 2008). As an engineering tool it has recently been discovered for environmental noise applications. The main factors influencing sound propagation of wind turbines are well understood today. There are engineering models such as ISO 9613-2 (1996) or Harmonoise (2005) available that take into account ground reflection and in a simplified manner the effects of inhomogeneous atmosphere due to varying meteorological conditions. For research purposes reference models exist which solve the wave equation in the propagation region considering the situation specific boundary conditions (SALOMONS, 2001; HEUTSCHI ET AL., 2005). Such instruments are the basic tools to acquire adequate auralizations of wind turbine noise.

In conclusion, there are sophisticated software tools and simulation models available for either landscape visualization or auralization. 3D landscape visualizations providing realistic, accurate and evaluable representations of the real-world environments with integrated spatially explicit noise emissions of wind turbines are not yet available.
3 Material & Methods

3.1 Development and implementation of a visual-acoustic simulation

The overall goal is the development of a combined virtual 3D visual and acoustic simulation tool for wind power plants to assess and adequately discuss choices of locations with experts and public stakeholders. The workflow presented in Figure 1 is divided into 2 phases: (1) development of the integrated visual-acoustic simulation model (VisAsim model) and (2) implementation of the VisAsim model for landscape assessment.

In Phase 1, we deal with the question how to adequately link and display the 3D landscape model with acoustic sound of wind power plants providing an adequate level of detail as well as ensuring the correlation of noise variations and spatial movement (e.g. synchronization of moving objects and noise modulations). In order to reduce complexity of this task, we focus on the validation of the integrated simulation and its implementation at selected viewpoints. Based on the spatially referenced parameters in the GIS-based landscape model, the spatially explicit sound signals are linked with the visual landscape representation. In a later phase, an interface will be developed that links the information about the three dimensional position and orientation in the 3D landscape model to the soundscape model. This will allow stakeholders to walk through the virtual landscape and to have a more personal role in the planning and evaluation process of wind turbine placement (BISHOP AND MILLER, 2007).

In order to test the validity of the VisAsim model it has to be compared to environment conditions close to reality. For this purpose we are simulating an existing wind farm in the first phase. As reference area, the existing wind farm at Mont Crosin (Canton Berne, Switzerland) was selected because it serves as a model example for a successful wind farm and is highly accepted in the public.

“Validity refers to the degree that something is as it purports to be.” (PALMER AND HOFFMAN, 2001: 154). Thereby it can be distinguished between response validity and accuracy in the representation (SHEPPARD, 2005). With regard to the acoustic simulation the same sound has to be generated as in the real environment and thus, the stimuli can be analyzed through a direct listening comparison. However, since the real world comprises much more visual detail than a computer generated representation can provide, 3D visualizations are always an abstraction from the real environment. For this reason, it is not possible to generate precisely the same stimulus as the real environment, but one can test if the response is the same for both stimuli (WILLIAMS ET AL., 2007). Therefore, we will check if the test persons’ assessments (response equivalence) based on the VisAsim model
are the same as the ones based on the video of the reference site (accuracy in representing sound, physical and visual qualities).

In the second phase, we implement the validated tool for assessing public preferences for wind farm options, accounting for the impacts on landscape aesthetics and noise in specific landscape contexts. The methods, workflows and tools elaborated in Phase 1 are then applied for generating VisAsim models of three focus areas with different landscape characteristics and of different landscape sensibility. Three scenarios per focus area will be simulated with low, medium and high numbers of possible wind turbines in the respective perimeter.

We want to find out, what are the effects of the simultaneous presentation of visual and acoustic effects of wind power plants on the preferences for a wind farm scenario. Furthermore, is there a difference in the influence of the noise of wind turbines on the assessment of landscape aesthetics depending on the landscape type? To answer these questions, the (mutual) effects of the integrated visual-acoustic simulation on the evaluation of landscape aesthetics and noise perception are investigated in experiments.

Developed in the early 1980s, discrete choice experiments are increasingly being used by economists to elicit preferences for different non-market goods and services, such as landscape aesthetical or recreational quality (CHAMP ET AL., 2003). Drawing upon socio-psychological concepts such as motives or expectation, choice experiments can be used to find out about segments of respondents showing different preference levels. Segmentation analysis such as latent class analysis is especially useful to evaluate the impact of different management scenarios and to conclude on optimizing actual wind turbines planning projects (BIROL ET AL., 2006). Therefore, we will conduct a virtual reality choice experiment (BATEMAN ET AL., 2009) with selected experts and lay people in a laboratory experiment to determine the impact (aesthetics/noise) of the scenarios on the landscape.

4 Results

4.1 Reference Data

Movie and sound recordings were generated for the site of the existing wind farm at the Mont Crosin as reference for the visual and the acoustic simulation (see Figure 1, Module 1). Suitable locations for these recordings were chosen based on the following visual and acoustic criteria: From a visual point of view the choice of location is based on the behavior of pedestrians, ideally along roadsides (BRAUN AND ZIEGLER, 2006). In the recordings should be no disturbing objects, e.g. cows, buildings and other complex objects that may be difficult to visualize. Different contents of views were defined: a frontal wind turbine, a wind turbine in the background, several wind turbines and no wind turbine. From an acoustical point of view, locations fulfilling the following criteria are needed: an emission recording (in close vicinity of a wind turbine), an ambiance recording (close to a forest edge), a propagation recording (up to 500m distance to a wind turbine) and a multi-source recording (two wind turbines from different directions). The acoustic criteria are based on the principle of auralization comprising the basic elements of sound generation, propagation and reproduction (VORLÄNDER 2008). The accomplished reference recordings meet these predefined visual and acoustic criteria ensuring an optimal modeling and validation of the visual-acoustic simulation tool.

The videos and the sound recordings were produced when the vegetation was fully foliated (Figure 2). A Soundfield microphone and a single-lens reflex camera with movie recording capability were used as an acoustic and visual recording system. For recording the movie, a 10-20 mm lens was used and fixed to 10 mm to capture a field of view of 100° which comes close to a human’s field of view. Simultaneously, wind speed measurements at 10 m above ground were gathered. In order to assess the visual and acoustic impact of the wind turbines
on the landscape under different wind conditions, we took recordings at a wind speed of 3 m/s and over 9 m/s. The recordings serve as basic information for developing and testing the VisAsim model (see Figure 1, Module 5).

**Fig. 2:** Simultaneous video and sound recordings at the wind farm Mont Crosin (BE)

In addition, aerial images from the reference site were captured using an unmanned aerial vehicle (UAV) (Figure 3). UAVs are usually equipped with different sensors for navigation, positioning, and mapping such as still-video cameras. The position of the UAV as well as the camera shutter can be controlled remotely from the ground (MANYOKY ET AL., 2011). The aerial images were photogrammetrically processed and a digital terrain model of high resolution in decimetre range was calculated. This data allows for highly detailed and up-to-date landscape visualizations (see Figure 1, Module 2).

**Fig. 3:** Acquisition of aerial images using an UAV

### 4.2 First interactive GIS-based 3D visualization integrating sound

A first interactive GIS-based 3D visualization with high level of detail was generated using the Sandbox-Editor of Crytek’s CryENGINE Version 3.2.1 (Figure 4). The developed prototype is a 3D landscape simulation based on a digital elevation model and an orthophoto. Objects of landscape elements such as vegetation and 3D models of wind turbines were added according to the corresponding coordinates of their actual locations. The user is able to go to any location in the visualization in order to explore the visual and acoustic situation. Moreover the lighting and the daytime can be changed interactively so that the scenery can be experienced at night time as well.
Audio recordings of actual wind turbine immissions served as base data for sound implementation. We calculated sound levels using a simplified physical acoustic noise propagation model. The audio files were then modified according to these sound levels with FMOD Designer (www.fmod.org), a software to create interactive audio. These audio files were integrated into the visualization model in CryENGINE where the sound can be reproduced on a multichannel surround system. At any location in the visualization the estimated ambient circumstances can now be experienced (Figure 1, Module 2).

However, based on the result it was decided not to integrate audio recordings directly into CryENGINE. The applicable sound models are too simplified and do not represent realistic soundscapes yet. For example, the sound propagation model does not take into account reflections at landscape objects such as buildings or vegetation (for further details see MANYOKY, 2011). In the next step, thus, a sophisticated auralization will be developed and linked to an enhanced version of the 3D landscape model. Major challenge is thereby to synchronize the movement of the animated landscape objects with the sound depending on the wind speed and wind direction. Particularly the specific sound frequencies of blades passing the turbine pole ("swish-swish" sound) have to be synchronized. Failures in this synchronization were immediately perceived and criticized by test persons. Furthermore, the georeferenced locations as well as width and height of all 3D landscape objects (wind turbines, vegetation) in the scene have to be reported as input for the auralization model.

5 Conclusions & Outlook

The presented concept for the development of an interactive GIS-based visual-acoustic 3D simulation provides a feasible approach of integrating spatial noise emission into virtual landscapes to assess possible locations for wind farms. Thereby the chosen game engine CryENGINE turned out as suitable software for visual landscape representation offering high level of detail and interactivity required for comprehensive visual landscape assessment (objective and subjective). However, with regard to sound representation the CryENGINE does not provide enough functionality for adequate auralization yet. Thus, a separate auralization has to be established and linked to the 3D visualization.

Implementing this tool for evaluating the impact of different wind farm scenarios in virtual reality choice experiments (VRCE) will result in stated preferences of the public. The assessment results will reveal the impact of different wind farm scenarios in different landscape types. These will allow for recommendations for wind farm planning, informing decision-makers on the various planning levels about the general potentials of the wind farms' societal acceptability in specific landscapes.
Beyond that it may be suggested that the VisAsim tool can facilitate participatory wind farm planning. The final visual-acoustic simulation tool will allow for an improved impact assessment on the perceived landscape quality in participatory processes, which provides a better, more comprehensible decision basis for designating suitable locations for wind farms (Figure 5). Combining the results of both, the choice experiment and local participatory approaches, realistic visions for landscape development with wind farms can be elaborated taking into account the public needs with regard to aesthetical and acoustic landscape quality. The methods developed for VisAsim will be transferable to assess also other landscape changes with visual and acoustic impacts such as new streets or high voltage power lines.

Fig. 5: Visual-Acoustic simulation of wind turbines for a more comprehensible decision basis for choosing suitable locations for wind farms

6 Acknowledgements

The presented concept is the basis of the interdisciplinary project "VisAsim - Visual-Acoustic Simulation for landscape impact assessment of wind farms" (2011-2014) funded by the Swiss National Science Foundation.

7 References


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