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Application of Spatial Models in Making Location Decisions of Wind Power Plant in Poland

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Abstract. In this paper,we explore the process of making decisions on the location of wind power plants in Poland in connection with a gradually increasing consumption of energy from renewable sources and the increase of impact problems of such facilities. The location of new wind power plants attracts much attention, and both positive and negative publicity. Visualisations can be of assistance when choosing the most advantageous location for a plant, as three-dimensional variants of the facility to be constructed can be prepared. This work involves terrestrial laser scanning of an existing wind power plant and 3D modelling followed by. The model could be subsequently used in visualisation of real terrain, with special purpose in local land development plan. This paper shows a spatial model of a wind power plant as a new element of a capital investment process in Poland. Next, we incorporate the model into an undeveloped site, intended for building a wind farm, subject to the requirements for location of power plants.

1. Introduction

Electrical power from renewable sources is ecological and emission-free. Such sources are also a substitute for fossil fuels, which are finite and are being depleted. By using renewable energy sources, countries' energy independence is growing, and so energy security is rising. Therefore, more and more people are beginning to consider issues related to sustainable and environmentally safe development.

The use of renewable energy sources in Poland has been growing in popularity since the country's accession to the European Union in 2004. Since then, every year the percentage of energy from renewable sources in total electricity production increased. This is also connected with the need to meet the European Union requirements as to the generation of energy from renewable sources (in Poland 15% in 2020).

The most popular renewable energy source is wind. Countries around the world are introducing requirements to significantly increase their proportion of energy from renewable sources, such as wind [1]. According to 2012 data, wind power constitutes 57.6% of the installed power capacity (excluding co firing) of all renewable electrical power resources [2]. In Poland, as follows from the data released by the Polish Wind Energy Association, in the years 2004-2011, a nearly 17-fold increase in the production of electrical power from wind was recorded. In 2004, wind farms produced a total of

142.30 GWh, in 2006 -388.4 GWh, in 2008 -790.2 GWh, in 2010 - 1485 GWh, and in 2011 - 2348 GWh.

The trend to use energy from wind farms is definitely agathering momentum. Because of this, one can only assume that the wind power industry in Poland will be subject to further development, and that wind will remain the principal source of renewable energy.

Growing concern over global climate changes, energy sustainability, and security has led to increasing interest in developing renewable energy sources. In this respect, wind energy has become the most dynamically developing sector. However, development is not as fast as expected in many countries and wind turbines (hereafter WT) projects are at both local and regional levels subject to considerable social controversy [3; 4; 5; 6; 7; 8].

The wind power industry currently constructs new turbines with a capacity of 1.5-2.5 MW and up to 160 m of the rotor rotation highest point. Unfortunately, due to economic reasons, investors increasingly build turbines with aunit capacity of 3.5-5.5 MW and up to 250 m height. As a result, the size of the turbines repeatedly exceeds the height of the tallest buildings in rural areas. Their total height, rotation, change in colour due to cloud cover, etc. exerts a notable influence on rural landscape [9]. This concerns objects of high cultural and historical importance, such as churches, palaces and castles.

Because of the many other effects, wind turbines are also the subject of environmental hazards. As showed in the paper by Wolsink [10], they might affect population and its social aspects. The numerous discussed forms of impact of wind power plants on the environment include, apart from the occupation of land for structures, roads and other infrastructure elements, also transformation of soils and the top layer of geological settlements. Of most importance is the visual element, including the siting of new landscape dominants and subdominants in the form of turbines and accompanying features, and imbuing landscape with dynamism thanks to the rotational movement of blades - shadow flicker effect [11]. In addition, the effects can be distinguished to direct and indirect ones that pose a threat to birds and bats or to physical state of the atmosphere by generating noise, electric and magnetic fields, with associated vibrations and shocks.

Planning information pertaining to the potential visual impacts of proposed construction developments is particularly important in the case of wind farm planning, given the high levels of concern amongst members of the public regarding the perceived negative visual impacts of wind turbines on the landscape [12].

The wind energy development, no more than other energy sectors, has brought about some negatively perceived impacts on the landscape and the familiar life of local residents [13]. The high visibility of WT itself is generally regarded as its most serious misconduct; consequently, an ideal area does not exist, only more or less acceptable areas do [8].The noise annoyance and connected direct, long-term, time-varying influences, are reversible when the wind power plant would be abandoned. The noise nuisance range for a single 1.5-2.5 MW turbine is rated at 250-350 m, depending on the background and landscape type.

This includes direct impact, long-term impact, and reversible impact after the turbine is decommissioned. The extent of any impact depends on the nature of the local landscape, principally the lie of the land and forms of land development, but also on the number, arrangement and sizes of the turbines. The optimisation of wind power plant location with a view to mitigating their impact has been discussed, among others, by: Pasqualetti et al. [14], Allen [15], Priestley[16].A separately standing wind turbine or a small compact group can be regarded as a new landscape dominant. Larger or smaller groups of wind turbines spread in the landscape cannot be perceived as individual dominants but as a brand new characteristic presented both horizontally and spatially. Some authors (e.g. Simon [3]) employ a term of visual pollution in this connection. By using this term, Simon describes a specific phenomenon when the overall landscape image completely changes after placing wind parks of large size [17].

The location of wind infrastructure attracts much attention, and both positive and negative publicity, so 3D visualisations may be of great help in making such decisions and solving site selection problems. The study was to determine the ability to make use of a 3D wind turbine model during the decision-making process regarding the location of a wind power plant as a new element of a capital investment project by fitting a turbine model in an undeveloped area, taking account of the principles applicable to location wind power plants.

The paper briefly discusses 3D visualisations as a tool to be used during the site selection process. The study involved a measurement by means of a terrestrial laser scanner of an existing wind power plant and a creation of its three-dimensional model. The next step was the visualisation of a wind power plant in an area located in Poland.

The visualisation was prepared for a site intended in the communes land development plan for the construction of wind power generation facilities.

2. Materials and methods

The use of tree-dimensional digital land modelling is not a universal practice, and is done on a pilot basis. To date, attempts have been made to use 3D visualisations to enrich public debate on land development changes. This has been done both in Poland and abroad. The more noteworthy studies include:

- Assessment of the impact of wind turbines on landscape character: implications for landscape planning [17];

- Negative effects from the construction of wind turbines on the landscape image and tourism potential of affected areas, using the example of two comparative recreational localities in the Czech Republic [8];

- Used GIS to examine the impact of wind turbine developments and to determine the potential for wind energy developments, defined as the amount of wind energy that could be harnessed, as well as whether the land was appropriate for development, for both onshore and offshore wind turbines [18; 19];

- New approach to participatory planning pursued in Zurich to provide a broad forum for discussion and to examine the level of acceptance of the proposed wind turbines. Introducing a virtual landscape model to a participatory planning workshop for which the different interest groups and stakeholders were invited. During the workshop, different alternatives were discussed and suggested changes by the participants were incorporated in the 3D model and visualized [20].

- Visualization of capital investment projects in environmentally valuable areas has also been discussed by Hełdak and Raszka[21] and Hełdak et al. [22].

Optimal locations for various capital investment projects can be found by 3D visualisation. 3D visualisation also helps to decide on the form of development of a specific area of land.

The results of the workshop [20] show that 3D visualization is an important means of communication among the different interest groups.

Head-tracked projection-based virtual reality systems can show the wind power engines and the landscape on large screens and with the size as it would be perceived by users within a real landscape. So, it can be anticipated that virtual environments are very valuable in helping members of the general public to formulate their opinion before or during participation in polls and interviews [23].

One of the methods to obtain a spatial model of large, intricate construction object, like wind power turbine, and to incorporate it into a selected space, can be measured by means of a terrestrial laser scanner. Subsequently, point clouds can be registered using one of the following three methods: the creation of automatic links in the target to target, cloud to cloud or plane to plane registration [24; 25; 26; 27]. The automatic target identification function offered by the application automatically identified the HDS targets and found links between them. Consequently, the scanning process produced a point cloud that was an accurate representation of the measured facility.

However, because of a high scanning resolution, point clouds captured during measurements with a terrestrial laser scanner can constitute a sufficient representation of an object. However, due to the sizes of data sets, the use of such models can be cumbersome [28]. In order to overcome this difficulty, it is necessary to create a spatial geometric model.

Spatial geometric models possess a certain degree of detail acc. to the CityGMLLoD (Level of Detail) scale. Such standardization enables products and product requirements to be distinguished depending on geometric complexity, accuracy and completeness of 3D objects. The LoD 0 level means a presentation of a numerical model of land covered by an orthophotomap. At LoD 1, buildings are represented as simple solids with flat roofs (degree of detail: five metres), and at LoD 2, buildings and structures are shown as in real life, with textures, differentiated roof types and volume (degree of detail: one metre). At levels LoD 3 and LoD 4, modelled objects are visualised faithfully: LoD 3 with all elements bigger than 0.5 m, and LoD 4 - from 0.2 m upwards and the facility interior modelled as well [29].

During the successive stage of the study, a spatial visualisation of the land to be developed was prepared using the MicroStation v8i software. Apart from a 3D model of a wind power plant, it was necessary to use a map base (an orthophotomap) and 3D models of buildings, greenery and trees. The visualisation was executed at the level of detail LoD 2, i.e. with a real-life rendering of buildings and structures and with the differentiation of roof types and their volumes.

3. Results

In order to obtain a model of a working turbine, a wind power plant was measured by terrestrial laser scanning. The plant in question is located at Gruszów in the Marcinowice Municipality. The measurement took place on 11 July 2012 and involved preparatory work and proper measurements taken from four scanner sites, as a result of which a total of over 41 million points representing the object under study were obtained. The measuring process was carried out using a Leica ScanStation 2 laser scanner, a computer with the Cyclone application and geodetic equipment.

The ScanStation 2 is an impulse scanner that enables measurements to be taken over long distances (up to 300 m in the case of surfaces with a 90% reflection capability). The device has an accuracy of 4 mm in respect of a single distance measurement and 6 mm in respect of point position determination. The instrument has a built-in digital camera, which can be used to take a full panorama of the site (111 photos).

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Afterwards, due to the sizes of data sets, we created a spatial geometrical model of wind power plant in MicroStation v8i software by fitting plain and solids into point cloud.

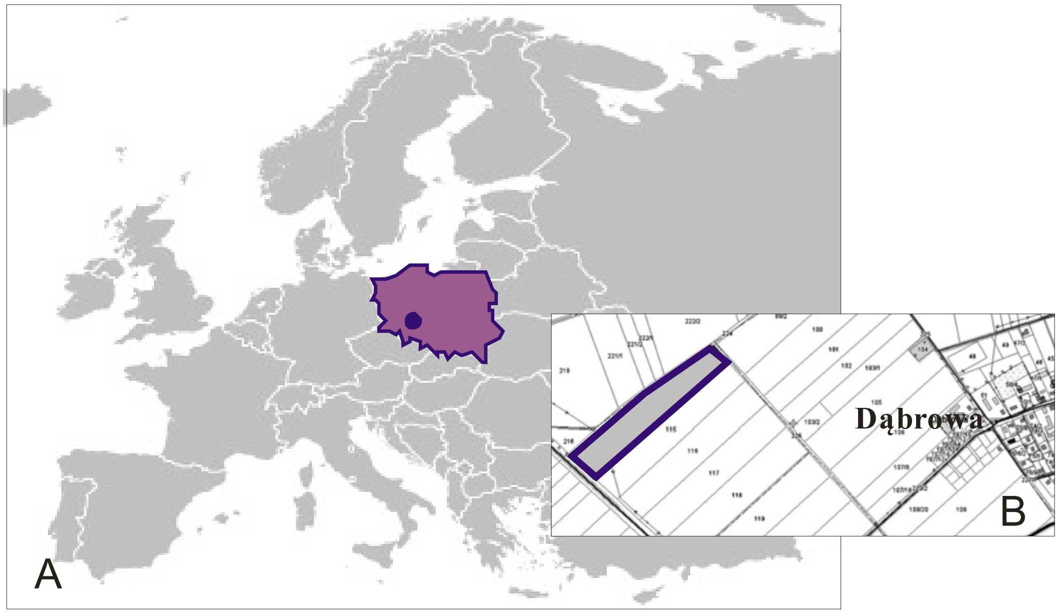

Figure 1: Location on the background of Polish and Europe (A) and the area intended for siting a wind power plant (B)

The preparation of the 3D visualisation began with the incorporation of the orthophotomap into the design file from the Geoportal spatial information system (geo- portal.gov.pl) by means of the WMS client (Web Map Service) built into MicroStation v8i. The map has an enclosed georeference, thanks to which the visualisation retains the 1992 layout.

The 3D models of buildings, greenery and trees were acquired from the online 3D Warehouse resources. This is a gallery of works produced by users of the SketchUp application, which is currently developed by the Trimble company.

Using a map base as a plain of reference, a 3D model of a wind power plant that had been produced earlier was inserted on plot of land No. 114, AM 1, district of Dąbrowa (Oleśnica Municipality) (figure 1A, 1B). In the Study on the Conditions and Directions of Land Development in the Oleśnica Municipality, the area is intended for the erection of a power wind plant with an output of 1 MW 25 MW and the maximum height of 150 m.

Research in GIS technology were determined possible location of wind turbines in the range of 150 m from the building zone (figure 2).

Investigated area offers favourable wind conditions. Without zone building on a piece of land, there are no factors that could be included in a study of environmental limitations, i.e. the area has no protected land, Natura 2000 land or any other elements subject to protection. According to the datafrom the Oleśnica Integrated Spatial Information System (zsip.powiat-olesnicki.pl), the plot has class IIIa, IVa, IVb and V soils. The plot is used as agricultural land, which is in line with the information recorded in the Land Registry (figure 3).

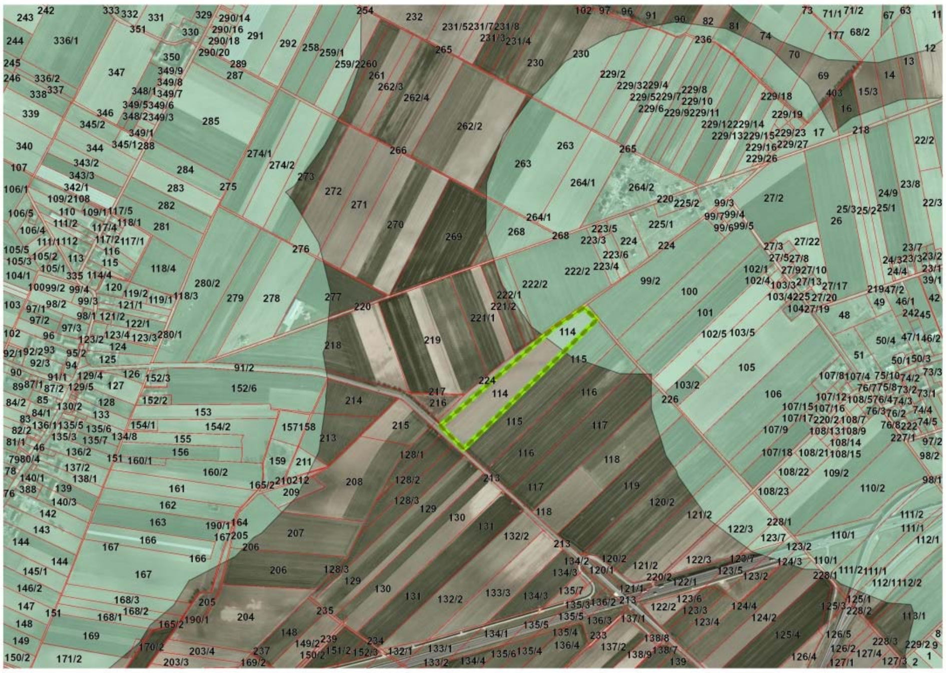

Figure 2: Location analysis area within 150 meters of residential areas using GIS tools

Figure 3: The study area

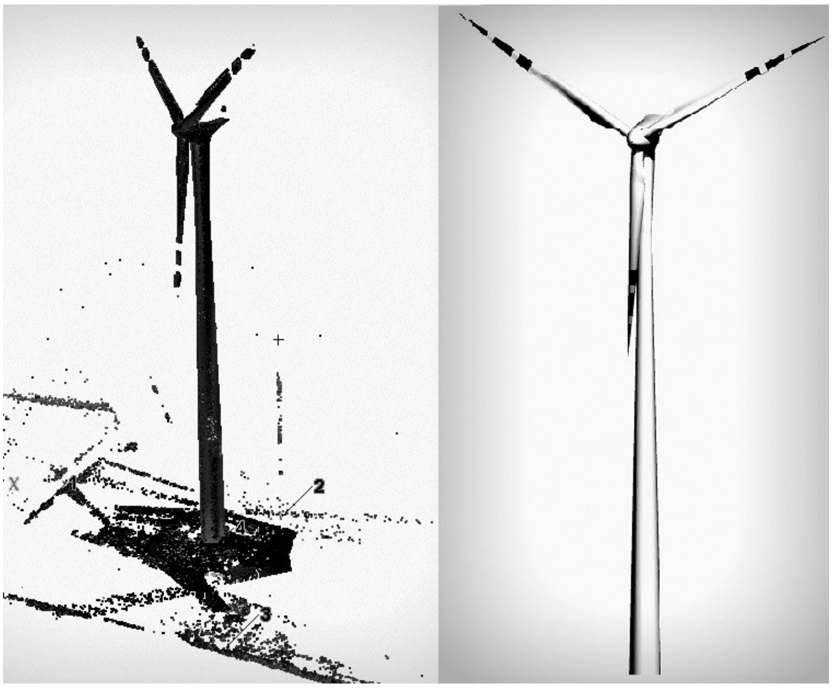

Figure 4: The point cloud (left) and geometric model (right)

Wind power plant model construction required the performance of a number of filtration operations on the point cloud, i.e. the deletion of points that were not constituents of the plant. In developing the object, an elementary approach was adopted, i.e. individual components of the wind power plant - the blades, the turbine and the column - were separated (figure 4). With a view to bringing out the geometry of the measured object, simple solids and plains were fit into cloud fragments. This method results in a loss of high accuracy data, but is sufficient enough for making visualisations [30].

After an example, spatial model of a wind power plant was prepared, a 3D visualisation was executed by placing 3D models of buildings and trees where they really were and inserting the plant on the plot intended for its construction.

For this, the MicroStation v8i and its option enabling online access to the 3D Ware- house resources ware used. The tool greatly facilitates work when developing extensive visualisations. During the study, several variants of the visualisation and a number of slides showing the impact of the intended construction project on the environment, including landscape, were prepared (figure 5; figure 6; figure 7).

The models were created in line with the main principles of location wind farms and free-standing wind power plants, including the principles of protection of road axis extensions, the farm deconcentration principles, the principles of location turbines in the horizon line and the principles of protection of existing dominants in rural layouts.

4. Discussion

Conducted studies have shown that it is very disadvantageous to construct wind power plants along road axis extensions (figure 4). Turbines, especially when operating with a red, blinking light, seem to interfere with the perception of the road situation, can distract drivers and so contribute to road traffic dangers.

The freedom to site power plants at any location, to add successive turbines, poses a threat that industrial wind power plant landscapes can be produced. The number of turbines making up a wind farm should be in line with the nature of the local landscape, in particular the density of settled areas. As it is now, the projected development of wind power generation may lead to a complete change in the nature of contemporary urban landscapes as a result of the accumulated impact of numerous nearby farms. Visualisation enables a wind turbine to be located in accordance with and in a manner emphasizing the existing landscape rhythm, along the major layout lines of fields, roads, alleys, etc. Visualisation also allows turbines to be located along viewing axes, not transversely to the observer.

Figure 5: A spatial model showing wind power plants sited on road axis extensions

Figure 6: A spatial model showing wind power plants sited in the horizon line

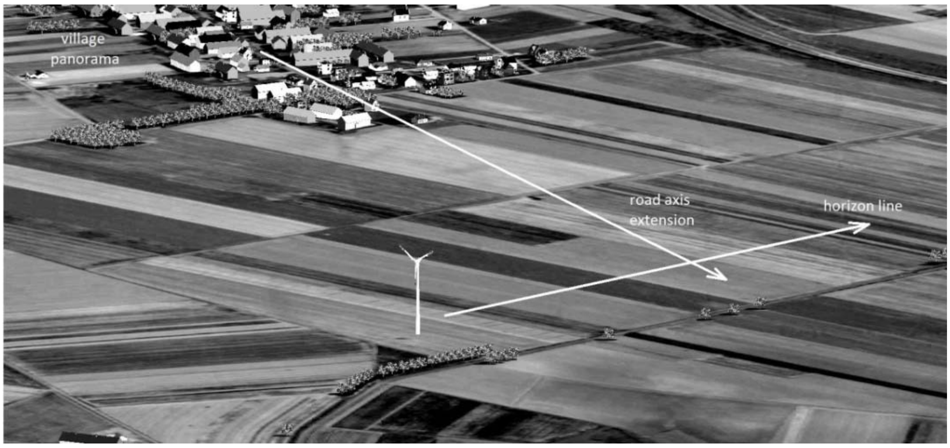

Figure 7: A spatial model showing a wind power plant sited against a rural layout - a village panorama

The next model (figure 6) was created in line with the principle of location in the horizon line. In a majority of cases, panoramas of rural areas end on a junction between rural land and the sky or tree stands (forests) and the sky. The location of a power plant in such a line is more favourable than in panorama plains that are closer to the observer. A spatial power plant model suitably fitted into a village panorama can be of great help when defending an intended construction project for rural layout. One of the location principles prohibits the situation of wind turbines in the background of rural layouts. The model presented in figure 6 shows the projected unfavourable changes to the rural layout if the wind power plant were to be located at the indicated site.

The last model (figure 8) depicts the plant situated in the area intended for the purpose in the communes development plan. The wind power plant construction project has met with the approval of the local authorities, because, among other things, of its benefits. The implementation of the project will generate additional income for the municipality, attract a long-term investor to the area, create new workplaces, build an image of a modern and pro-ecological municipality, boost prospective investors interest in building facilities related to renewable energy sources, result in an expansion of the local power infrastructure and the construction of new roads.

Figure 8: A spatial model of a wind power plant sited in the area intended for the purpose in the commune's land development policy

This spatial visualisation, supplementing the capital investment project related to the location of a wind power plant, was executed with the level of detail LoD 2, i.e. it includes real life representations of buildings and structures, differentiates roof types and volumes, and contains textures. The turbine model was developed with a greater degree of detail, corresponding to LoD 3.

5. Conclusion

In the area of power generation from renewable sources of energy, in which many factors are of much importance, including the impact of the construction project on the environment or the location conditions, it is necessary to carry out a plethora of various analyses and studies that enable the area of investment to be properly determined. The development of wind power generation, because of its peculiar impact on the environment and a very sizeable investment dynamism, is one of the biggest challenges of planning, land development and environmental protection in Poland.

A three-dimensional presentation of a wind power plant should become an inherent tool supporting the making of decisions regarding land development or the location of wind power generation facilities. Three-dimensional imaging not only allows a construction project to be presented faster and more comprehensively, but it is also helpful when creating planning documents or seeking finance. The study shows that visual aspects need to be taken into account to assess the impact of the investment on the nature. In this regard, the visualization is the best tool to protect the environment from adverse effects of ill-considered objects.

Visualisations are helpful when assessing the location of wind power plants in rural landscapes. Frequently, during preparatory work, a number of possible locations are considered. Modelling helps the investor to satisfy the basic requirement to identify and protect key panoramas, beauty spots and viewing routes, and to site turbines. This means that not all passive exposure facilities and areas, or active exposure points and routes can be protected in the process of siting wind farms.

Achieved model was used as a part of supporting social dialogue used at the stage of land local development plan creation. Visualizations have convinced the local com- munity, and also the investor. Therefore, they decide to place only one wind turbine rather than the wind farm.

Depending on the purpose and used data source, 3D visualization can be performed on different levels of accuracy. The applied 3 cm x 3 cm grid (corresponding to the model resolution) and Microstation software were fully sufficient to present the wind turbine model due to the grid size and low detailed object of interests.

Based on the performed analysis, created fully measurable spatial model and its 3D visualization allowed to determine appropriate power plant location. Alternate com- pounding of the wind power as a single object as well as in groups into the spatial model were helpful to choose the most optimal placement from the point of view of the ecosystems protection. As a result, one wind turbine has been approved to the implementation in the farthest point from the village.

References

[1] Bishop, I. D., Stock, C.,"Using collaborative virtual environments to plan wind energy installations",*Renewable energy*, 35(10), pp. 2348-2355, 2010
[2] Energetyka wiatrowa w Polsce – raport październik 2012, Polskie Stowarzyszenie Energetyki Wiatrowej, [Wind power generation in Poland – a report 2012. Polish Wind Energy Association] (Polish), Available from Internet: http://www.paiz.gov.pl/files /?id_plik=18856 [in Polish]
[3] Simon, Ch.A., "Alternative energy: political, economic, and social feasibility", *Rowman& Littlefield,* pp. 233, 2006
[4] Breukers S., Wolsink M., "Wind power implementation in changing institutional landscapes: An international comparison", *Energy Policy*, 35(5), pp. 2737–2750, 2010
[5] Van der Horst, D., "Spatial planning of wind turbines and the limits of 'objective' science", *Moravian Geographical Reports*, vol. 17, no. 2, pp. 46 – 51, 2007
[6] Van der Horst D., "NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies", *Energy Policy*, 35(5), pp. 2705–2714, 2007
[7] Wűstenhagen R., Wolsink M., Bűrer, M. J., "Social acceptance of renewable energy innovation: An introduction to the concept", *Energy Policy*, 35(5), 2683–2691, 2007
[8] Frantál B., Kunc P., "Wind turbines in tourism landscapes. Czech Experience", *Annals of Tourism Research*, vol. 38, no. 2, pp. 499–519, 2011.
[9] Sullivan, R.G., Kirchler, L.B., Lahti, T., Roche, S., Beckman, K., Cantwell, B., Richmond, P., "Wind turbine visibility and visual impact threshold distances in western landscapes", *National Association of Environmental Professionals 37th Annual Conference*, May, pp. 21–24, 2012
[10] Wolsink, M., "Wind power implementation: the nature of public attitudes: equity and fairness instead of backyard motives", *Renewable And Sustainable Energy Reviews*, 11 (6), pp. 1188–1207, 2007
[11] The wind energy fact sheet. Department of Environment, Climate Change and Water of New South Wales. New South Wales Government, pp. 12, 2010 [online]. Available from Internet: http://www.environment.nsw.gov.au resources/climatechange/10923windfacts.pdf
[12] Berry, R., Higgs, G., Fry, R., Langford, M., "Web-based GIS Approaches to Enhance Public Participation in Wind Farm Planning", *Transactions in GIS*, 15(2), pp. 147-172, 2011
[13] Frantál B., Kučera P., "Impacts of the operation of wind turbines as perceived by residents in concerned areas", *Moravian Geographical Reports*, 17(2), pp. 34–45, 2009
[14] Pasqualetti, M.J., Gipe, P., Righter, R. W., "Wind power in view: energy land - scapes in a crowded world",*Academic Press*, London, 2002
[15] Allen, M. W., "Tools for evaluating wind turbine visibility", *Technical Cansiderations in Siting Wind Developments: NWCC Research Meeting*, Dec. 1-2, 2005. Washington, D.C., pp. 15-17, 2006
[16] Priestley, T., "Visual impast assessment: practical issues and links to research", *Technical Cansiderations in Siting Wind Developments: NWCC Research Meeting*, Dec. 1-2, 2005, Washington, D.C., pp. 23-27, 2006
[17] Cetkovsky S., Novákowá E., "Assessment of the impact of wind turbines on landscape character: implications folandscape planning", *Moravian Geographical Reports*, 17(2), pp. 28 – 34, 2009
[18] Christidis T., Law J., "The use of geographic information systems in wind turbine and wind energy research", *Journal of Renewable and Sustainable Energy*, 4(1), 2012

[19] Simao A., DenshamP.J., Haklay, M.M., “Web-based GIS for collaborative planning and public participation: An application to the strategic planning of wind farm sites”, *Journal of Environmental Management*, 90(6), pp. 2027-2040, 2009
[20] Lange, E., Hehl-Lange, S., “Combining a participatory planning approach with a virtual landscape model for the siting of wind turbines”, *Journal of Environmental Planning and Management*, 48(6), pp. 833-852, 2005
[21] Hełdak, M., Raszka, B., “Prognosis of the natural environment transformations resulting from spatial planning solutions”, *Polish Journal of Environmental Studies*, 20(6), pp. 1513–1519, 2011
[22] Hełdak, M., Szczepański, J., Patrzałek, C., “Using the 3D computer scanning method in the environmental impact assessment”, *Infrastruktura i Ekologia Terenów Wiejskich* [Infrastructure and Ecology of Rural Areas] (Polish), 1(IV), pp. 49-59, 2012
[23] Zehner B., “Interactive Wind Park Planning in a Visualization Center-Giving Control to the User”. *In Buhmann, E., Pietsch, M. & M. Heins (Eds.): Digital Landscape Architecture,* 2009
[24] Van Genechten, B., “Theory and practice on Terrestrial Laser Scanning: Training material based on practical applications”, *Universidad Politecnica de Valencia Editorial*, 2008
[25] Vosselman, G., “ Advanced Point Cloud Processing”, *Photogrammetric Week*, vol. 9, pp. 137–146, 2009
[26] Vosselman, G.V., Maas, H.G., “Airborne and terrestrial laser scanning”, *Whittles Publishing*, 2010
[27] Szczepański, J., Orczykowski, T., Tokarczyk, T., “Using 3D terrestial laser scanning (TLS) for surveying hydrotechnical structures when preparing flood hazard maps”, *Polish Journal of Environmental Studies*, 21 (5), pp. 1405–1412, 2012
[28] Borkowski, A., Jóźków, G., “Accuracy assessment of building models created from laser scanning data”, *ISPRS–International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 39-B3, pp. 253–258, 2012
[29] Groger, G., OpenGIS City Geography Markup Language (CityGML) Encoding Standard. [online], 2008, Available from Internet: http://www.opengeospatial.org
[30] Lorenz, H., Dollner, J., “3D feature surface properties and their application ingeovisualization” *Computers Environment and Urban Systems*, 34 (6), pp. 476–483, 2010