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Problems of Determining Size and Character of Wind Turbines' Visual Impact Zones on Lithuanian Landscape

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Visual impact of wind turbines depends on many qualities: their size, color, form, observation distance, landscape variety, time of the day, and other factors (Tsoutsos et al., 2009). In this paper the factors that influence the wind turbine's visibility are analyzed. One of the most important aspects determining wind turbine's visual impact is observation distance. The visual impact zones of wind turbines in different countries having been analyzed and the situation in Lithuania taken in, the Table of wind turbine's visual impact hypothetical degrees is set up. To determine the precision of visual impact degrees, the survey *in situ* is done and its results have been compared to the theoretical-hypothetical visual impact degrees (a comparative analysis). Visual impact zones of wind turbines are evaluated from ten pre-selected observation points. Six wind turbines (of 2 MW power each), installed in Kretinga district near village Vydmantai, are analyzed. At the end of the study, it is identified that the categorization of visual impact zones of wind turbines should be corrected in accordance with the visual character of Lithuanian landscape. Different observation distances have a great influence on the significance of a visual impact. Being 0-7 km from the wind farm (in this case the wind turbine's visual impact on the landscape varies from dominants to subdominants), the intervals of observation distances have to be shorter. It is noticed that forests, buildings, and other vertical objects that are located near the observation point change the visual impact significance very much. Weather conditions make significant influence as well, especially on visibility of wind turbine wheels.

Keywords: *wind turbines, wind farms, influence of wind turbines on the environment, zones of visual impact.*

1. Introduction

Visibility of the landscape is one of the immaterial resources of the living environment that make an impact on the quality of life. Therefore, for a higher quality of life, visual resources must be protected and increased by regulating their use (Kamičaitytė-Virbašienė, 2001).

Wind turbines turn to be an inseparable part of the Western Lithuanian landscape. The hub height of wind turbines reaches 80-120 m, the blade-tip height 120-160 m, thus these objects are becoming predominant verticals. Under ideal weather conditions wind turbines can be seen from the distance of 20-25 km. Integrating such objects into the landscape, it is very important to locate them properly with regard to the objects of cultural heritage, recreational zones, territories under protection, and all other valuable objects, and when constructing wind turbines, great attention should be paid to the evaluation of their visual impact on the landscape (Grecevičius et al., 2009).

Visual impact of wind turbines depends on many qualities: wind turbine's size, its color, form, observation distance, landscape richness, time of the day and other factors (Tsoutsos et al. 2009). Their visual contrast with the rural landscape can be also positively evaluated, e.g. the transitioning of tower whiteness into the greenness can visually be in harmony with green agricultural surroundings.

Visibility of wind turbine, when it is being observed, usually encompasses several landscape types. Therefore, in order to determine its visual impact properly it is necessary to determine the size of an area under the visual impact, i.e., it is important to establish the wind turbine's visual impact zone.

According to landscape expert S. Crowe, all the equipment that can become part of harmonious composition should be better shown than hidden. It is worth emphasizing, especially the case when an object can enrich the surroundings both by its scale and form (Crowe, 1958). The wind turbine near village Vydmantai, that was installed there as the first industrial wind turbine, can be mentioned as an example of such an object, which livens up a uniform and monotonous landscape.

The paper aims at both discussing factors, which determine wind turbine visibility, and giving directions for possible development of wind turbine's visual impact evaluation methods by comparing theoretical wind turbine's impact zone sizes and visual impact importance degrees with empirical survey results.

2. Methods

When visual impact zones of wind turbines in different countries have been analyzed and the situation in Lithuania taken in, the Table of wind turbine visual impact hypothetical degrees is made up.

To determine the precision of visual impact degrees, the survey *in situ* is done, and its results are compared to the theoretical-hypothetical visual impact degrees (a comparative analysis).

Wind turbine's visual impact zones were evaluated from ten pre-selected observation points. The study was carried out in the course of two periods of time. The observation points: No. 1-6 and No. 8-9 were evaluated on 15 April, 2012, at 0-3 pm. The day was sunny, and the visibility of wind turbines was very good. Evaluation at observation points No. 7 and No. 10 was made on 28 September, 2011. The day was a little cloudy, and the visibility of wind turbines was good.

The object of the study *in situ* is the wind farm situated in the territory of villages Kiauleikiai, Kviečiai and Rūdaičiai (between the towns of Palanga and Kretinga, near the village Vydmantai). The park consists of 15 wind turbines, and all of them are divided into three groups. Two groups consist of 6 wind turbines and the third – of 3. To obtain the precise results only one group of 6 wind turbines was evaluated (see Figure 2). All the turbines are of the same type Enercon E-70 (of 2 MW power each). The hub height is 85 m, the length of their blades is 34 m, and the rotor diameter is 71 m; the blade-tip height is 120.5 m. All the wind turbines were installed in 2006.

On the territory of the wind farm there is an agricultural and a little urbanized landscape of sandy and wavy plateaus and plains, with slight vertical dispersion (wavy, with gently sloping valleys). Half-open and entirely open visual spaces prevail. Predominant objects are the above mentioned wind turbines. The nearest towns are Palanga and Kretinga. The forests of Kiaupiškės and Palanga are close to the wind turbines.

Near the wind turbines being considered (in the southern direction) there are 3 standalone wind turbines. In 2009, in the southern direction (in village Liepynė), the wind farm consisting of 6 wind turbines was built.

3. Results and Discussion

3.1. Factors influencing wind turbines' visibility

Wind turbine's general parameters. Current wind turbine tower manufacturing technologies make it possible to build towers high and reliable. In Lithuania wind turbines Enercon E 82 (2 MW) prevail over the others. These wind turbines are of two types: with metallic tower and those with reinforced concrete tower. The characteristics of wind turbine with metallic tower: hub height - 86 m; rotor diameter - 82 m; blade-tip height - 126 m. The characteristics of wind turbine with reinforced concrete tower: hub height - 121 m; rotor diameter - 82 m; blade-tip height - 150 m. The wind turbine's visibility when observing them from certain viewing points depends very much on the height of a tower and the length of a blade.

The number of wind turbines. Wind farm produces a great amount of energy. Due to its general height it can become dominant, just like a standalone wind turbine. One of the main reasons why a wind farm gets very conspicuous in the landscape is vastness of the area it occupies. For example, in five wind farms in Kretinga district 51 wind turbines are located, together with 6 standalone wind turbines operating over there, too. A different layout of wind turbines at the wind park itself may also make an impact on the landscape quite differently.

Color and materiality. Color and materiality of wind turbine are two of the main factors of its visual impact size and significance. In Lithuania, there exist both wind turbines with metallic and reinforced-concrete towers, and there are also several small wind turbines of an openwork structure (formerly operated in other countries). The color of wind turbines being operated in Lithuania usually is white or a combination of green and white (green at the bottom of the tower with gradual transition to white at its top). Wind turbines of such a color in the rural landscape make visual contrast to the green agricultural surroundings (Cialdea et al., 2010).

Auxiliary infrastructure. Electric substations, access roads, power transmission line, and other infrastructure enhance the wind turbine's visual impact on the landscape, too.

Observing distance. Observing distance is one of the most important aspects in evaluating wind turbine's visual impact. With an increase in the distance both the vertical and horizontal viewing angles of a wind turbine proportionally decreases. When observing a wind turbine from a greater distance, the sight is also affected by an atmospheric effect caused by small dust particles and humidity of the air. Because of this effect wind turbines attain a greyish hue, and grey color decreases the visual contrast between the background and the wind turbine (Homewood, 2011).

Observer's dynamism. Wind turbine's visibility differs depending on whether the wind turbine is being observed in a static or dynamic state. When wind turbine is being observed from a static position, its view does not change in time. But when we study motor vehicle traffic and are in a dynamic state of observing, the visual relationship between the wind turbines and the landscape is in a constant change. The view field may be partly restricted by the lack of physical possibilities to observe wind turbines from the vehicle (e.g. due to the window's size) (Homewood, 2011).

Wind turbine's location and weather conditions. In cases when we look at a wind turbine from the place lower than the wind turbine is, its major part is seen in the background of the sky. A visual contrast is formed between the white color of a wind turbine and the color of clouds. The clouds of dark grey color contrast with a wind turbine more sharply than white clouds do. The level of contrast also depends on the sun's position and the location of a wind turbine. When the sun is in front of the observer, the wind turbine's visible part is in the shade. If background is dark, the contrast between it and the wind turbine is not so sharp. When the sun is behind the observer, the entire wind turbine gets lightened. If the background is lighter, then the contrast is not so sharp when the background is dark. Under cloudy weather conditions wind turbines are usually less visible. In some cases wind turbine blades can be totally invisible in the background of clouds.

Purpose of land use. Wind turbines (especially wind farms) are usually installed in terrains with small population, where the land is of agricultural use. Agrarian territories, if they are not hilly, can be overviewed widely (because open visual spaces prevail), thus wind turbines can be seen from afar. The forests that are present on these territories camouflage wind turbines and their visual impact is reduced. In such cases the towers of wind turbines or their bottom parts are usually prevented from being seen. Only the wheel and cabin are visible. Villages and towns, due to vertical elements present in them, also reduce the visibility of wind turbines.

Territory relief. In hilly territories there are places from which wind turbines are easier, or, on the contrary, more difficult to see. With relief being uniform, the wind turbines' visibility gradually decreases with a distance.

Time of the day. The time of the day is of special importance for the wind turbines' visibility. During bright period of the day, wind turbine's visibility is at its highest, and, when it is getting dark, it decreases. At night, only wind turbine's signal lights are visible.

3.2. Visual impact zone sizes and character of visual impact on landscape

At the time when there were no wind turbines in Lithuania (the first industrial wind turbine was built in 2004), vertical elements of anthropogenic activities were being evaluated according to the exposure zones of scale, sight, and psychological effect. The scale domination zone does not exceed 3 h (where h is the object's height). A person perceives each object outside these boundaries as a separate one. The zone of sight domination extends up to 3.5 km. Although the purpose of objects outside these boundaries is still perceived, in the landscape they lose their visual expression, merge with the background, and do not attract attention any more. The sight domination boundaries are usually called the boundaries of effective observation. The zone of psychological effect extends up to 6.0 km. Further, the object, though it is still visible, becomes impersonal in the background of a landscape (Bučas, 2001). When evaluating wind turbines, the boundaries of exposure zone change (the zone increases) due to the wind turbine's size (the blade-tip height is up to 120-150 m and the rotor diameter can be around 100 m).

The visibility of separate parts of a wind turbine may be classified as follows: the first zone of visual impact is the zone from which all the blades of wind turbine can be seen; the second zone of visual impact – the wheel of a wind turbine is seen; the third zone – the entire wind turbine is seen.

When analyzing the wind turbine's visual impact zones, its observation point (and the number of them) is used as the base and benchmark for visual evaluation. Degree of visual impact is determined considering the distance and visibility of a wind turbine. It is necessary to mention that adjacent zones (further from the wind turbine) differ from each other by visual impact degree only slightly. The main constituent part of the evaluation procedure of the wind turbine's visual impact zone is the observation point description, its assessment and determination. These indicators make the basis for the studying of wind turbine's visual impact on the landscape (Homewood, 2011).

Wind turbine's visual importance is divided into the following components:

a. Visual dominant: wind turbines dominate in the viewing field due to their large scale. They change the sight of the nearest surroundings fundamentally. The wind turbine wheel can be seen very clearly.
b. Visually unwanted (they dominate in general) – wind turbines look as being of a large scale and they become important elements of a landscape. Not necessarily they dominate in the observation field, though. The movement of blades is clearly perceived and attracts observer's attention.
c. Noticeable (accents). Wind turbines are clearly visible but they are not visually unwanted any more. Wind farm is noticeable as an element of a landscape. The movement is noticeable under a

good visibility. Wind turbines look small in the common field of viewing. Some landscape changes (because of wind turbines) are considered acceptable. The observing is under the influence of weather conditions.

d. Remote landscape elements (background elements). Wind turbines are blurred and insignificant, of small shape. The movement of blades is in general inconspicuous.. The common size of wind turbines is very small (University of Newcastle, 2002).

It is important to notice that wind turbines can be visible from 10 km distance, but knowing human eye's possibilities to observe surroundings the wind turbine, with its blade-tip height of, e.g. 120.5 m, will occupy only a very small fraction of a total sight when being observed from the distance exceeding 10 km, i.e., its vertical angle will be less than 1 degree, and, when an object is observed at such a small angle, it becomes visually insignificant.

In general (without going into details), the wind turbines' visual impact can be divided into three zones:

1. Distant zone (radius exceeds 10 km). In this zone, the visibility of wind turbines depends on relief, other natural and anthropogenic objects, and also on hydro-meteorological conditions. When observing wind turbines from such a distance, the nearest objects dominate in the field of viewing, thus the visual impact of a wind turbine is not great.
2. Intermediate zone (radius ranges from 1 to 10 km). When observing wind turbines from such a distance, the general sight of wind turbines is visible. The visual impact becomes significant.
3. Near zone (radius is less than 1 km). Wind turbines dominate in the perceptible space, and all the structural parts of them are visible. The visual impact is very important (Jallouli, Moreau, 2009).

The above-mentioned classification into zones corresponds to the visual impact degrees being set according to the visual impact zones, which are described beneath (see Table 1). But this description does not include details of a possible impact.

Table 1. Theoretical visual impact zones of wind turbines (author of the article, and Homewood, 2011, Environmental Resources Management, 2009)

Distance to the wind farm (km)	***Visual impact degree***	***Exposure zones of anthropogenic elements***
0-2	Wind turbines **dominate** because of their large scale, movement of blades, close proximity, and the number of them.	Scale domination zone (up to 500 m)
2-3	Wind turbines **generally dominate** in a landscape. The impact is more significant due to the proximity of wind turbine, which dominate in a landscape.	Sight domination zone (up to 3.5 km)
3-6	Wind turbines are clearly seen, and their impact is average. Also, with the distance their domination decreases. The blade movement is seen. Though wind turbines are seen, they are not totally dominating when being observed from the observation point (with enough level of visibility). They become landscape **accents**.	Psychological effect zone (up to 6.0 km)
6-10	Wind turbines are less clear, and, visually, their size is decreased, but movement can be noticed (level of **subdominants**).	Object is visible, but it becomes impersonal in the background of a landscape.
10-12	The visual impact is weak, and the movement can be noticed on a bright day – wind turbines get among all the common elements (**background elements**).	
12-18	Wind turbines become indistinct, with slight impact on the remote landscape. The movement of blades can be seen, but with greater distance they become **background** elements.	
18-20	Wind turbines can be seen on a bright day, but their visual impact is insignificant.	
20 +	No impact, or it is insignificant. Wind turbines can be seen, but usually they are blurred or indiscernible; also, the relief or vegetation can worsen the sight.	

When making an evaluation, the totality of observation points is the area that can be under the visual impact of a wind farm. Observation points have been picked based on specific distances from wind turbines (see Table 2). The assessment of the observation point depends on its relation to the wind turbine height and the landscape horizon line ratio as well as the number and character of anthropogenic objects and vegetation, which could potentially obstruct observing the object (see Figure 1). These observation points themselves can also be subdivided into those of a high, middle, and low intensity of observing.

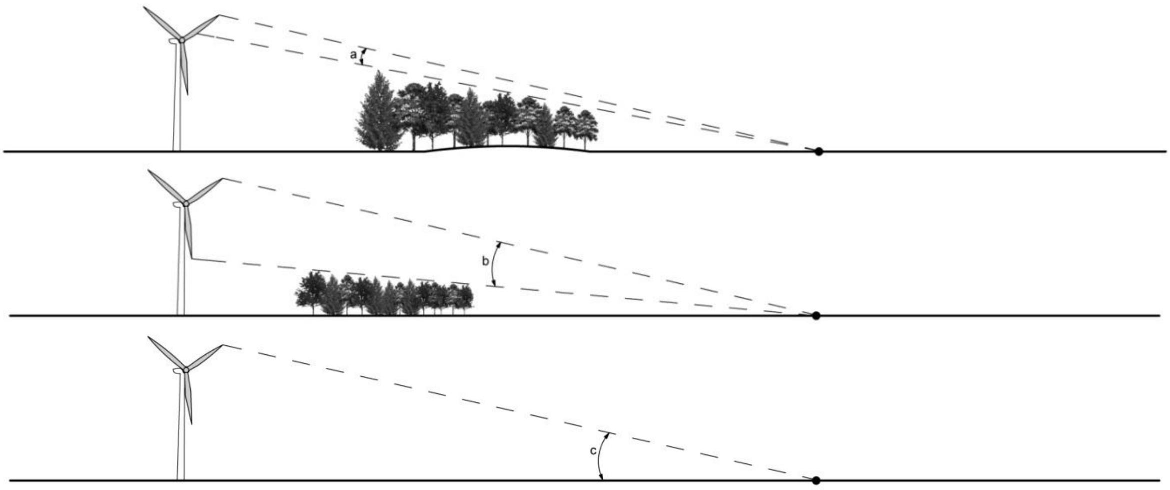

Fig. 1. Different schemes of visibility of wind turbine from the same observation point: vertical viewing angle depends on the place, number, size, and other characteristics of vertical obstacles (author of the schemes: J. Abromas, 2012)

Table 2. Sizes and degrees of visual impact zones of visual impact of wind turbines established during empirical survey (see Figures 2, 3)

The number and location of observation point	***Distance to wind turbines (km)***	***Visual impact degree***
1. Village Kveciai	1	On the first projection, six wind turbines (situated at 1km distance from the observer) **dominate** visually. All parts of wind turbines are clearly visible. In the distance other 9 wind turbines can be seen (distance is 3-3.5 km).
2. Road Kretinga – Vidmantai	1-2	The hill in the observation field looks visually higher because of wind turbines. The wind turbines are seen clearly (they **dominate**). The green lower parts of their towers can also be vaguely noticed.
3. Village Vydmantai	2,5	Wind turbines are seen clearly in the landscape (they dominate, in general). The blades with their red stripes can also be seen. Due to the nearby forest, half/two thirds of the lower part of their towers cannot be seen. This lessens visual impact.
4. Palanga flyover	4	Single high trees near the village Vydmantai camouflage some of the wind turbines. One of them cannot be seen altogether, and only half the wheel of the other two can be seen. Only some parts of all the rest can be seen. The wind turbines visually **lose their predominance** and become landscape accents.
5. Kretinga railroad flyover	4	Two thirds of the lower parts of the wind turbine towers are totally camouflaged by trees. The wind turbines visually "compete" with other verticals that are present over there – stacks of boiler houses, a water tower, etc. They get at the level of visual **accents**.
6. Road Kretinga – Darbėnai	5	Wind turbine blades partially "disappear" in the bright background of the sky. The towers of wind turbines can be seen in full, though (there is no forest near the observation point). The blade movement can be seen partially.
7. Road Kretinga – Šiauliai	7,5	Wind turbines can be seen in a cultural landscape. The sight of towers is partially obscured by both private residential houses and the forest in the remote distance. The blades can be seen in full. The visual impact degree of the wind turbine is similar to that of the 110 kV power line pylon that stands at the 1.5 km distance from the observer. The wind turbines get at the level of **subdominants**.
8. Road Palanga – Klaipėda	11	Wind turbines can be seen but they don't dominate visually in a landscape; they are just **background elements**. Blade movement is hardly visible.
9. Crossing of the roads Kretinga – Klaipėda and Palanga – Klaipėda	13	Wind turbines do not dominate in a landscape and they are among the background elements. The nearby-located forest blocks the sight of wind turbine towers. The wheel can be seen. The blade movement is visible.
10. Klaipėda University Hospital (Observation out of the window on the second floor)	18	The observation is done from a higher position (approximately 10 m high), nearby standing trees do not block the sight of objects under the observation. About two-thirds of the towers cannot be seen due to the forest farther off. Wind turbines do not dominate in a landscape (background element level). The wheel can be seen, and the blade movement is hardly visible.

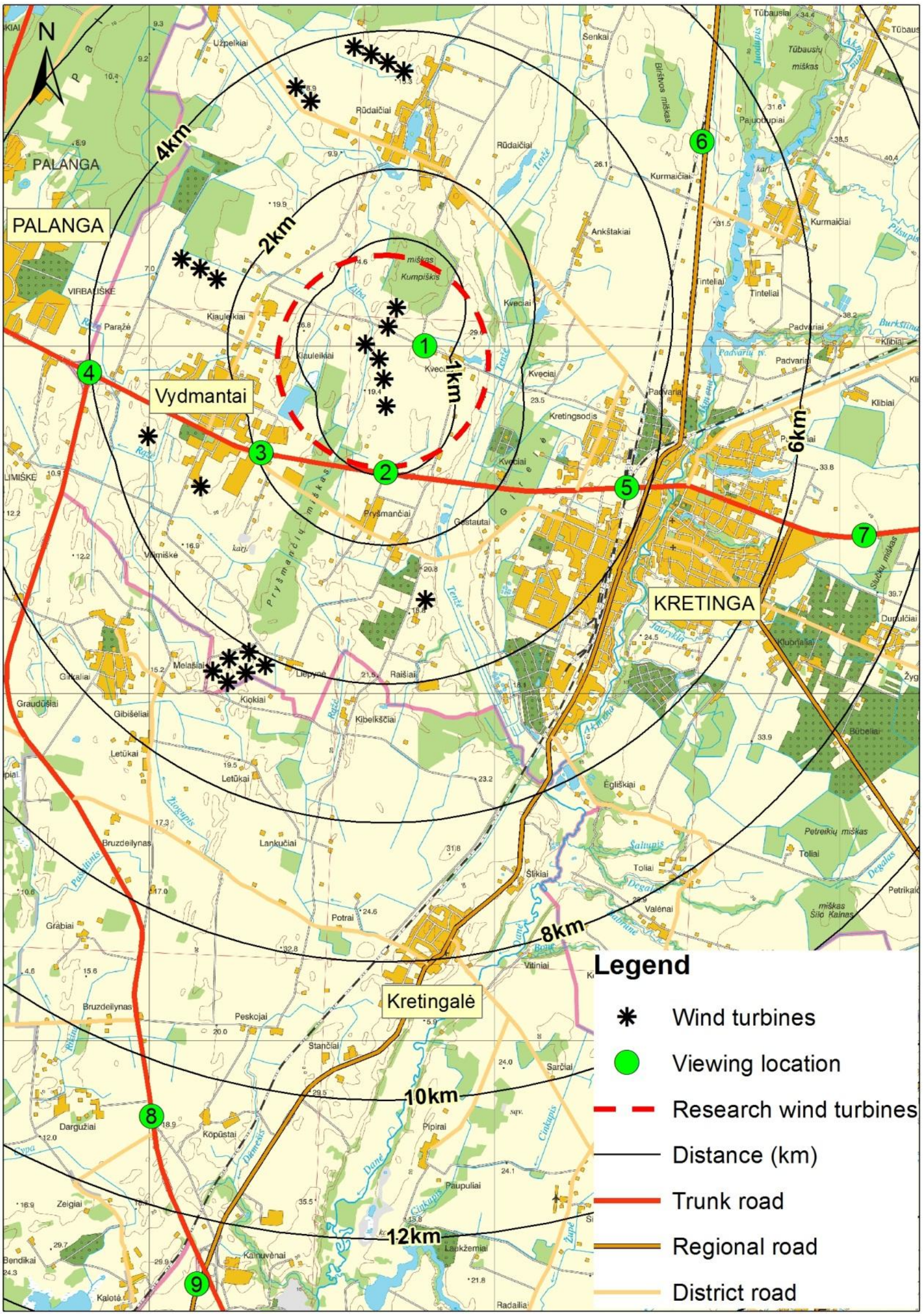

Fig. 2. Locations of impact zones for visual analysis (author of the map: J. Abromas, 2011)

Fig. 3. Photos made from observation points No.: 1, 2, 5, 7 (photos by J. Abromas, 2012)

4. Discussion

When the results have been systematized and compared to the theoretical data on the visual impact zones, it has been decided to adjust more precisely the distances of the latter.

When being at the distance of 0-7 km from the wind farm, it can be noticed that the 1-2 km interval is of great importance to the visual impact evaluation. When the distance is greater, the interval of 1-2 km loses its previous importance. Considering the above mentioned aspect, there are proposed the following intervals of the zones of visual influence: 0-1 km; 1-3 km; 3-5 km; 5-7 km; 7-10 km; 10-13 km; 13-16 km; 16-20 km; >20 km.

The forest that is situated close to the observation point bears great importance to the visual impact. This was noticed from the observation points: No. 3-5, 7, and 9-10.

At the observation points: No. 7 and No. 10, the wind farm was being evaluated at different time (28/09/2011). That day was cloudy therefore the visual impact was quite different. The wind turbine wheel was set off against the background of darker clouds, and the blade movement was more clearly visible. Because of these aspects, the blades were hardly noticeable from the observation point No. 6 (at 5 km distance from the wind farm), whereas those from the observation point No. 7 (at 7.5 km distance from the wind farm) could be seen very clearly. They even became more distinctive in the background of the darker clouds.

4. Conclusions

1. As the hub height of modern wind turbine can be up to 80-120 m, with the blade-tip height being 120-160 m, these objects become dominating verticals. Under ideal weather conditions wind turbines can be seen at the distance of 20-25 km. Therefore, wind turbines have to be grouped into separate farms, laid out in the places aloof from residential areas, important territories under protection, and recreational zones. The visual impact of wind turbines on the environment is to be evaluated.

2. Theoretical classification of visual impact zones of wind turbines should be corrected by taking into account the visual character of Lithuanian landscape. Different observation distances have a great influence on a significance of the visual impact. Being 0-7 km from a wind farm (in this case the wind turbine's visual impact on landscape varies from dominants to subdominants), the intervals of observation distances have to be shorter and equal to 1 – 2 km.

3. It is noticed that forests, buildings, and other vertical objects that are located near the observation point change the visual impact significance very much. Weather conditions make also a significant influence, especially for the visibility of a wind turbine wheel.

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Vėjo elektrinių vizualinės įtakos zonų dydžio ir poveikio pobūdžio nustatymo problemos Lietuvos kraštovaizdyje

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(gauta 2012 m. rugsėjo mėn., priimta spaudai 201 2m. gruodžio mėn.)

Vėjo elektrinių vizualinis poveikis priklauso nuo daugelio aspektų: elektrinės dydžio, spalvos, formos, stebėjimo atstumo, kraštovaizdžio įvairumo, paros laiko ir daugelio kitų veiksnių. Straipsnyje kaip vienas iš įtakos veiksnių analizuojamas elektrinės matomumas. Vienas svarbiausių aspektų, lemiančių vėjo elektrinės vizualinį poveikį, – stebėjimo atstumas. Išanalizavus skirtingų šalių vėjo elektrinių vizualinės įtakos zonas ir įvertinus Lietuvos situaciją, sudaryta vėjo elektrinių vizualinio poveikio hipotetinių laipsnių lentelė. Siekiant įvertinti vizualinio poveikio laipsnių tikslumą, atliktas žvalgomasis tyrimas vietoje, kurio rezultatai palyginti su teoriniais hipotetiniais vizualinio poveikio laipsniais (lyginamoji analizė). Iš dešimties pasirinktų regyklų įvertintos vėjo elektrinių vizualinio poveikio zonos. Tyrimo vietoje objektas – šešios Kretingos rajone (greta Vydmantų gyvenvietės) esančios vėjo elektrinės (Enercon E-70 (2 MW galios)). Jų bokšto aukštis – 85 m, menčių ilgis – 34 m, vėjaračio skersmuo – 71 m, bendras aukštis – 120,5 m. Susisteminus tyrimo rezultatus, nustatyta, kad teorinį vėjo elektrinių vizualinės įtakos zonų skirstymą reikia koreguoti atsižvelgiant į Lietuvos kraštovaizdžio vizualinį pobūdį. Kadangi skirtingas stebėjimo atstumas turi didelę įtaką esant 0–7 km atstumu nuo vėjo elektrinių parko (čia vėjo elektrinių vizualinis poveikis kraštovaizdyje kinta nuo dominančių iki subdominančių lygmens), būtina stebėjimo atstumų intervalą sutankinti. Taip pat pastebėta, kad vizualinį poveikio reikšmingumą labai keičia arti regyklų esantys miškų masyvai, pastatai, kiti vertikalūs objektai. Oro sąlygos taip pat turi didelę įtaką, ypač vėjaračio matomumui.