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# Wind Farms as a New Element of the Polish Landscape

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Eliza Kalbarczyk, Robert Kalbarczyk and  
Beata Raszka

Additional information is available at the end of the chapter

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## Abstract

Fast development in the wind power industry in Poland resulted in construction of numerous wind farms, mainly in the north and center of the country. The construction of a wind power station is connected with a change in the structure of the landscape through location of new dominant and subdominant landscape elements. The goal of the work was to determine the previous practices of locating wind farms in Poland, effects resulting from the presence of wind turbines in the landscape, and guidelines for designing wind farms in the context of impact on the landscape. Until 2016, spatial planning lacked in clear regulations on locating wind turbines. In 2016, Poland passed new laws regulating the minimum distance of wind turbines from residential and mixed-use buildings. Based on selected examples of wind farms in West Pomerania Province and Kuyavian-Pomeranian Province, it was found that the existing wind turbines do not comply with the requirements of the minimum distance. Also, there were cases of damaging the esthetics of protected landscape areas. The appearance of new dominant elements of the landscape, i.e., wind power plants, may cause substantial transformations in the landscape, mainly in Northern and Central Poland.

**Keywords:** impact, landscape, Poland, regulations, wind turbine

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## 1. Introduction

In the first decade of the twenty-first century, Poland saw fast development of investments in the wind power industry, which was connected with construction of new wind farms in almost the whole country. Until 2004, energy from wind made up only 0.3%. In 2013, after 10 years, it rose to 6% [1, 2]. In 2009–2013, there was a growth in installed wind power plants of as much

as 277%, i.e., from 301 to 835 power generation units. The total installed power increased in this period from 724.657 to 3389.541 MW, i.e., nearly five times [3].

Single wind turbines were initially looked at with a typical interest for any novelty. However, in the course of time and with the growing number of turbines, negative effects of development of wind energy started to be noticed more frequently. The most important downsides of wind power plants included noise emission, infrasound emission, high investment costs, a threat to birds and bats, radio and television wave interference, a decrease in property value, and loss of agricultural production areas [4–7]. Plans for constructing installations in the vicinity of built-up areas were met with especially strong resentment. Similar to other EU countries, Poland witnessed the start of numerous protests against wind installations [3, 8–11]. One of the most frequently mentioned disadvantages of wind farms was also negative impact on the landscape [3, 12–14]. Mostly, such arguments were raised in the regions of high values of the landscape and with a developed tourist sector.

Negative reception of wind turbines may have been caused by the lack of precise rules of their location. The goal of the work was to determine the previous practices of locating wind farms in Poland, effects resulting from the presence of wind turbines in the landscape and guidelines for designing wind farms in the context of impact on the landscape.

## **2. Material and methods**

The work used data from the Central Statistical Office of Poland from 1990 to 2015 ([www.stat.gov.pl](http://www.stat.gov.pl)) regarding the installed power of wind installations in Poland in total and for particular regions, as well as data about location of wind turbines from the Institute for Renewable Energy (<http://ioze.pl>). The rules of locating wind turbines in force until 2016 and since 2016 were described on the basis of analysing legal acts from the Internet System of Legal Acts (ISAP) database (<http://prawo.sejm.gov.pl>); practices of locating farms were described after the analysis of a report by the Supreme Audit Office [3] and case studies of wind farms in Tymiń (West Pomerania Province) and farms in the communes of Strzelno and Mogilno (Kuyavian-Pomeranian Province). Specification of the guidelines and recommendations for construction of wind farms was based on the available scientific and specialist literature.

## **3. Rules of locating wind farms in Poland**

### **3.1. Rules of locating wind farms in Poland until 2016**

Until passing the law on investments [15], in spatial planning, there were no unambiguous regulations concerning the location of wind turbines. The regulations applicable to the location were contained in many documents, e.g., in laws regulating the issues of environmental

protection, protection of agricultural and forest areas, health resort protection, heritage preservation, construction law, water resources law and, in many ministry regulations [9, 16, 17]. Locating wind farms was mainly based on the regulations of the Spatial Planning and Land Development Act of 27 March 2003 [18]. The main document by means of which communes shaped their spatial order was the local spatial management plan. In case of the lack of such a plan, specifying the type of land management and development conditions was conducted through decision on land development conditions. Preparing the local spatial management plan for a commune was bound by the study of conditions and directions of spatial development. It was obligatory for a commune's study of conditions and directions of spatial development to include only the provisions regarding the location of renewable power installations of a power exceeding 100 kW.

The legal regulations in Poland did not specify in length units the safe location of wind power plants in the natural environment. The major criterion used for determining a distance of wind turbines from buildings, especially those inhabited by people, was the permissible level of noise emitted by wind power plants. However, the laws regulating the methodology of noise emission measurement did not guarantee reliable evaluation of nuisance generated by such facilities. Taking measurements could take place, in accordance with the binding requirements, only in conditions of low wind speed ( $<5 \text{ ms}^{-1}$ ). Wind power plants generate the most intense noise only with the optimal wind velocity, equating to  $10\text{--}12 \text{ ms}^{-1}$ , but in such conditions, measurements were not made. The legal regulations also did not define permissible norms for other potential threats, such as infrasound or the stroboscopic effect.

The solutions in this respect accepted in other EU countries were diverse. Location of wind turbines in relation to human-inhabited buildings was mainly determined by a distance expressed in metres and sometimes by the permissible level of noise. The permissible level of noise was used to define the distance e.g., in Germany, Holland, and Portugal. The criterion of distance is used e.g., in Denmark (the location of a turbine from buildings cannot be smaller than four times the total height of the turbine) and in Italy (e.g., Calabria) where the distance was specified to be 20 times larger than the turbine height, which in practice results in a distance from a wind farm to urbanised areas of approximately 2 km. In France, the distance from wind farms to buildings was determined by the level of sound, i.e., a difference in noise levels in relation to the background level so that the difference in the noise level would not exceed 5 dB during the day and 3 dB at night. The location of wind farms is determined differently in Sweden where it is specified by local building committees who consider impact on the environment and local development plans. Also, in Great Britain, there are no national regulations regarding the minimum distance from urbanised areas. The regulations in this respect depend on regional authorities. This way, in Scotland, the recommended distance from towns and villages is 2 km, in Wales 500 m from houses and in England, the distance should equal at least the turbine height plus 10% in case of its collapse (Najwyższa Izba Kontroli [Supreme Audit Office], Warszawa, [3]).

### 3.2. Rules of locating wind farms in Poland after 2016

In 2016, Poland passed new laws regulating the minimum distance of wind turbines from residential and mixed-use buildings. The provisions of The Investments of Wind Power Plants

Act of 20 May 2016 [15] introduced the notion of the minimum distance of a wind turbine from residential buildings. In accordance with the act, the required distance should be at least 10 times the wind turbine height (measured as the height of the tower with the length of the blade). The introduced limitation should work both ways; i.e., residential buildings, which could be built in the vicinity of the existing wind power plants, must also comply with the minimum distance requirement. The minimum distance requirement for wind farms is also obligatory in relation to nature protection areas such as national and landscape parks, nature reserves, *Natura 2000* areas, and also promotional forest complexes [15]. Moreover, location of new wind farms is possible only on the basis of the provisions of local spatial development plans. Thus, there is no possibility to obtain an individual decision on land development. The local plan must define the maximum total height of a planned wind power plant and cover the whole area where, in view of the specified permissible height of the power plant, there will be regulations as to the location of residential buildings. Once the law comes into effect, previous studies of spatial management directions and local spatial development plans will remain valid and in force. However, applying for building permission on their basis will be limited for investments (both power plants and residential buildings), which do not comply with the new requirements specifying a distance in relation to previously constructed buildings.

In the case of projects such as wind turbines, which may significantly influence the natural environment, it is obligatory to prepare environmental impact assessment. In Poland, this requirement applies to inland installations of a nominal power not less than 100 MW. The environmental impact assessment report should also contain the analysis of effects on the landscape. Such a solution gives local communities access to information and a possibility to influence decisions of authorities who grant permissions for building wind farms, which are considered projects which may significantly affect the natural environment. Further on, the work analyses possible impact of wind turbines on the landscape.

#### **4. Impact of wind turbines on landscape**

Locating wind turbines in the environment brought a necessity to assess their impact on the natural environment, including the landscape. Generally, it is agreed that the scale of such impact is affected by the height of towers and their number, a type of turbine, a type of tower and arrangement of towers, as well as terrain features [19–22]. For Gromadzki and Przewoźniak [4], the essential factors affecting exposition of wind turbines in the landscape are as follows: terrain, types of land management, geometry of the arrangement of wind farms and a distance from human settlements, a type of tower and a type of turbine, the height of a wind turbine structure, and colours of the structure.

Impact of the terrain may be diverse depending on the location of a turbine in the landscape. If a wind farm is not situated among dominant landscape elements, then the diverse terrain is conducive to a reduced visibility range of wind farms. However, a lower visibility range is not equal to lower impact on the landscape as visual and aesthetic values of diverse terrain are usually higher than that of flat land.



Diversity of land management types causes a change in the visual effect produced by a wind farm. A forest growing in the edge zone or the terminal moraine zone significantly reduces visibility of wind farms. On the other hand, the land used agriculturally, mainly to cultivate field crops, is an area that does not limit visibility of wind farms.

Exposition of wind turbines is also affected by the way of their arrangement and their number in wind farms. If turbines are situated symmetrically in one line, they form a greater dissonance in the landscape than the arrangement of turbines distributed non-symmetrically. In hilly terrain, power plants located on the slopes are far less visible than those situated on the top. However, such location of a power station is unfavourable in terms of the volume of generated power. Moreover, it was found that lattice truss towers are much less visible from a big distance than tubular towers.

Impact of wind farms on the landscape decreases in a non-linear way along with an increased distance of observation. The strongest visual nuisance persists within a radius of several kilometres. After exceeding the threshold above which wind turbine elements begin to merge with the background, a considerable reduction occurs in power plant visibility in the landscape.

Among the methods of determining impact of wind farms on the landscape, one can enumerate the following: determining visibility based on a digital elevation model (DEM), creating visualisations for potential investments [22–25], the index of visual impact on the general public [22], the visual impact assessment (VIA) for visual perception of wind farms at different distances supported by analyses of photographs [26, 27], the zone of visual influence (ZVI) to determine areas of possible, and actual visibility of wind farms [28].

A relationship between the visual effect of a wind farm and a distance became a basis for separating four impact zones of wind power plants in the flat land landscape. According to this division, in the first zone, at a distance up to 2 km from a wind farm, the wind power plant constitutes a visually dominant element, and the rotating movement of blades is clearly visible and seen by a human. In the second zone, at a distance of 1.0–4.5 km, the wind power plant is an important element of the landscape; it is easily noticeable, but it does not dominate; the rotating movement of blades is visible and attracts sight. In the next zone at a distance of 2–8 km, the turbine is a noticeable element; in good visibility conditions, it is possible to see the rotating blades, but against their background, the turbines seem to be relatively small. The fourth zone is further than 7.0 km; the turbine is a small element in the distant landscape and the rotation of blades from such a distance is practically indiscernible [6]. It results from the presented division that wind farms situated in the first and second zones significantly affect aesthetic values of the landscape. The above-presented values are approximate and may very often assume different parameters. In hilly terrain, these distances may be considerably smaller or bigger depending on the observation point and the location of a wind farm. Wind farms located away from the hills at the observation line may be invisible, despite a small distance. However, if they are situated on the tops of the hills, their visibility will considerably increase. For some sites, it may reach even 20 km [6].

According to Shang and Bishop [29], the distance at which wind turbines are visible is equal to 150 heights of the turbine. On the other hand, in the visual assessment of wind farms: Best

practice [27], it was assumed that depending on the height of a turbine, the value of a radius determining the zone of theoretical visibility (ZTV) equals from 15 to 35 km. In the same study, it was assumed that the maximum ZTV range is determined by a radius of 30 km from the wind turbine irrespective of its height.

The borders between the zones of impact on the landscape may also be determined taking into account parameters of the human visual field [30]. Then, five zones of impact can be distinguished: I—proximity, II—foreground, III—average distance, IV—distant view, and V—very distant view. The range of particular zones depends on the height of a wind turbine. The border of the first impact zone is determined in such a way that the wind turbine cannot be seen in one view; it can be discerned as a whole only while “scanning the space with one’s eyes.” In the second zone, the turbine is clearly visible and fills at least half of the visual field. In the third zone, the whole outline of the wind turbine is visible in one view, but it fills from a quarter to half of the visual field. In the fourth zone, the wind turbine is a subdominant object, which fills from one tenth to a quarter of the visual field. In the fifth zone, the turbine is visible only in the case when the tower colour is white, with good lighting and very good visibility; the upper boundary of this zone delineates the zone of theoretical visibility.

In Poland to assess the visual impact of particular wind farms on the landscape, the so-called Spanish method is also used [31]. Due to specific characteristics of the rural development, it was modified and adapted to the Polish conditions [32]. The Spanish method conducts assessment of the visual effect in three stages. Its final stage gives an average score of the visual impact of a wind turbine on the resident inhabiting the zone of a radius of 5 km from the central point of the wind farm. The accepted value of 5 km corresponds to the first and second zones of the visual impact where wind turbines are distinct dominant elements of the landscape. In the zones limited by the 5-km buffer, the areas are determined with no visible wind turbines. The visual effect of a wind farm increases when the number of inhabitants seeing the farm grows. The last stage of the analysis consists in calculating the coefficient of the final score of the farm’s visual effect (PA), which is a product of partial coefficients, and assigning one of the six levels of the visual impact on localities within the area delineated by the 5-km buffer from the wind farm centre.

The research conducted in the lowland landscape of Lower Silesia found that wind farms are a strongly dominating element of the landscape attracting attention of the observer and may dominate the elements and symbols important for preservation of identity of the rural areas [33]. Similar observations were made by Fiutowska and Dąbrowski [20] who examined a landscape aspect of wind power development in the north of Poland, in Central Pomerania. The exposition of wind power plants was strongly affected by terrain. Moreover, they also stated that impact of the wind farms went far beyond the area of their location.

## 5. Guidelines for locating wind farms with regard to impact on landscape

In order to decrease negative impact of wind farms on the landscape, certain recommendations were developed whose applications at the design and construction stage allow reducing the

visual effect of building such facilities. The most important ones include using towers of the same height within one wind farm or several neighbouring farms, using light colours for towers and rotor blades (e.g., grey, brown) or adapting the colour of the whole wind power plants to the surroundings, selecting wind turbines whose rotors consist of three blades [34]. It is also possible to apply technologies improving the aesthetics of turbines, i.e., resigning from truss towers, burying power lines underground, using nacelles of streamlined shape, placing obstruction lights only on the highest situated turbines, adapting colours to a specific site. Negative impact of turbines on the landscape may also be limited by painting rotor blades and towers with light colours, thanks to which it is possible to additionally eliminate flickering effects and by applying turbines with rotors of three blades. It is more favourable for the observer when a wind farm consists of a smaller number of turbines, but of a bigger power (National Wind Coordinating Collaborative).

In order to reduce negative impact of wind turbines on the landscape, it is also recommended to use appropriate proportions while designing turbines (specifically, the proportion of the rotor diameter to the tower height from 0.9 to 1.35) and for proper arrangement in space (the distance between turbines should not be bigger than 3 or 4 diameters of the rotor) [16].

Wind power plants should not be located near the sites with specified norms of acoustic environment and where they could constitute a dominant element in the landscape of high visual values. Locating wind turbines in the foreground of scenic viewpoints, view corridors, natural site scenery, historic monuments and valuable buildings, parks complexes, and also within planned landscape parks is considered highly inappropriate [35].

## 6. Practices of locating wind turbines in Poland

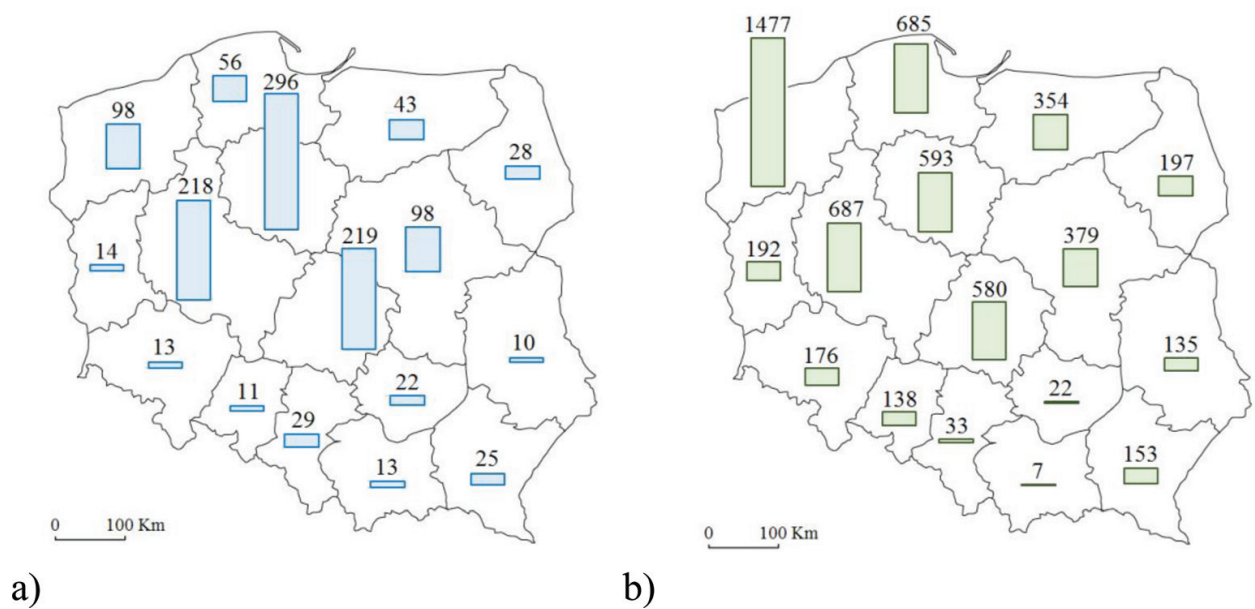
Distribution of wind farms in Poland corresponds mainly to the system of wind zones of the best wind conditions for energy generation, determined by institute of meteorology and water management (IMGW) on the basis of wind energy resources [16]. Special conditions for wind power are offered by the north Poland regions, which are dominated by lake landscape marked by big differences in relative height (**Figure 1**).

As it can be observed, a vast majority of wind power plants is white with red blade tips. It results from the aesthetic character of this colour and from increased visibility of the structure in the case when a wind power plant is an air traffic obstacle. Sometimes, also other colours are used, e.g., from grey to green, due to which wind power plants produce less contrast for the observer from a bigger distance.

On the basis of the examples of wind farms, the work examined practices of locating wind turbines in respect of a distance from residential buildings.

The first examined case is the Tymień wind farm in the commune of Będzino (West Pomerania Province). The size of the farm is approximately 700 ha (with 166 km<sup>2</sup> of the whole commune). It is equipped with 25 wind turbines, operating since 2006 (**Figure 2**). The total installed power





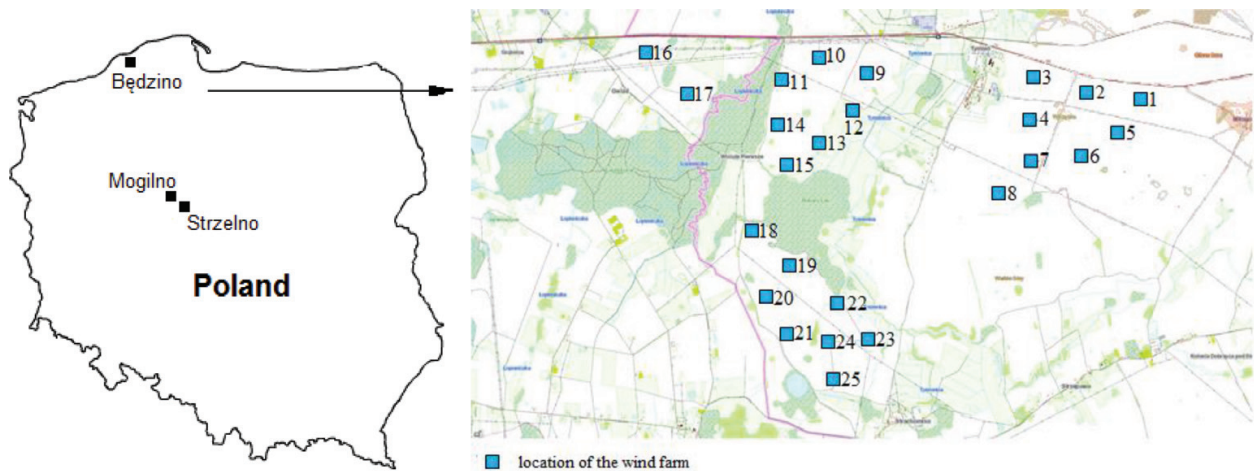
**Figure 1.** Number of wind installations (a) and installed power (MW) of wind installations (b) by provinces in Poland, in 2016.

amounts to 50 MW; the turbine parameters are the following: the towers of a height of 100 m, and the blades of a span of 80 m.

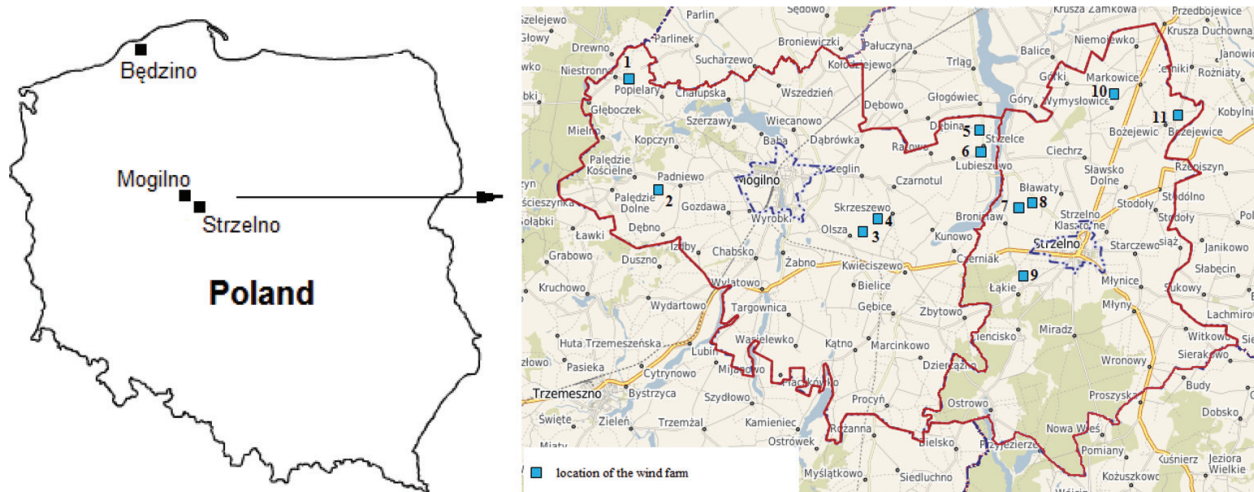
In accordance with The Investments of Wind Power Plants Act of 20 May 2016 [15], the distance of wind power plants from buildings should amount to at least 1400 m. In the vicinity of the Tymień wind farm and within its impact range, the development is dispersed, often consisting of individual, one-family buildings. The analysis of the distribution of turbines showed that the distance from buildings lies within a range from 500 (five turbines) to 1350 m. Thus, in each case, it is below the minimum specified in the act. Moreover, 21 out of 25 turbines (84%) are situated at a distance up to 1000 m from buildings.

The second analysed case is the communes of Strzelno and Mogilno in Mogilno District, Kuyavian-Pomeranian Province, which house 11 wind turbines in total, 6 in the commune of Mogilno, and 5 in the commune Strzelno (**Figure 3**). The landscape of both communes is the lake landscape, with numerous river valleys, watercourses and troughs, very diverse terrain consisting of hilly morainic upland with height differences reaching several dozen metres, flat morainic upland with small slopes and landforms up to several metres, and undulating morainic upland with slopes up to 5% and landforms of a height between 10 and 20 m.

The comparison of parameters, and the distribution of wind turbines and buildings, showed that the minimum distance from turbines to buildings is only about 160 and 190 m for the closest installations; none of the turbines complied with the legal requirements. All the turbines have a form of steel tower with an entrance from the outside. The colours of the facilities are calm, light pastel, and matte, which prevents the effect of glint. Some turbines for the reason of being air traffic obstacles were equipped with obstruction marking and lighting. The rotor blade tips are painted with five stripes of the same width, perpendicular to the



**Figure 2.** Distribution of the wind farms in the commune of Będzino (West Pomerania Province).



**Figure 3.** Distribution of the wind farms in the commune of Strzelno and in the commune of Mogilno (Wielkopolska Province).

longer dimension of the rotor blades and cover one-third of the rotor blade length. The obstruction lights are mounted at the top of the nacelle.

Relatively close, or even excessively close, location of wind turbines from buildings was confirmed by inspection results of the Supreme Audit Office [3, 10]. In more than one-third of the examined communes (10 communes), the location of wind turbines was less than 500 m from residential development. The closest wind turbines were located at a distance of 205 (the commune of Kleczew) and 230 m (the commune of Babiak). In eight communes (29%), wind farms were located at a distance from 251 to 500 m, in four communes (14%) within a range from 501 to 800 m. In 14 communes (50%), wind farms were located at a distance of more than 801 m from buildings. An extreme situation was found in the commune of Żurawica (Podkarpacie Province), where a wind turbine was situated at a distance of only 55 m from animal shelter buildings.

Wind farms were conditionally located even within natural protection areas of significant landscape and natural values, only except for national parks and nature reserves [3, 10]. Such practices and also the consent to locating wind farms in a protected landscape area were for example encountered in the Suwałki Lake District. At least 10 out of 14 turbines of the Suwałki Wind Park are situated in the protected landscape area of the Lake District of the northern Suwałki Region. In several view corridors (from the bank of the valley of the Czarna Hańcza, from Osowa to the east towards the Czarna Hańcza valley, from Stary Bród and towards Lake Okminek), wind farms constitute a dominant element in the protected landscape. Irrespective of the terrain, they block out the view at different levels and constitute an alien technological element in the typically agricultural landscape. Other examples are the commune of Przerośl in Podlasie Province, in which one of the six wind turbines of the Taciewo Wind Farm is located in the protected landscape area of the Lake District of the northern Suwałki Region, and the commune of Babiak, Wielkopolska Province. In the latter, wind turbines were located in the Gopło-Kujawy Protected Landscape Area, which is highly suited for any forms of tourism and leisure.

Similarly, in the case of building a wind farm, the commune of Pelplin (Pomerania Province) risks the loss or strong transformation of aesthetic and visual, as well as historical and symbolic values of the landscape [7]. The visibility range of the existing and planned wind farms was determined to amount to several kilometres from their location. The impact may be amplified by the motion of rotating blades. The planned investment will also lower the values of the Gniew Protected Landscape Area and reduce the sense of establishing the Kociewie Protected Landscape Area. The absolutely negative (significant) impact on the landscape mainly results from the fact that its area possesses great landscape value, and exceptional in Poland characteristics pertaining to a vast and clear view where landscape perception is only limited by the horizon [7].

## 7. Conclusions

Intensive development of the wind power industry, which occurred in Poland from the beginning of the twenty-first century, led to significant interference in the harmonious cultural landscape, mainly in the northern and central parts of the country. Until 2016, spatial planning lacked in clear regulations on locating wind turbines. Wind farms were most frequently located in agricultural areas of a high dispersion of residential development and utility buildings. Along with the expansion of inland wind power installations, there were cases of damaging the aesthetics of protected landscape areas.

The applicable regulations with regard to the location site were contained in many documents, and did not specify in distance units the safe location of wind farms in the natural environment. The major criterion used for determining a distance of wind turbines from buildings was the permissible level of noise emitted by wind farms. In 2016, Poland passed new laws regulating the minimum distance of wind turbines from residential and mixed-use buildings. In accordance with the new law, the required distance should be at least 10 times the wind

turbine height (measured as the height of the tower with the length of the blade). Moreover, location of new wind farms is possible only on the basis of the provisions of local spatial development plans. Based on selected examples of wind farms in West Pomerania Province and Kuyavian-Pomeranian Province, it was found that the existing wind turbines do not comply with the requirements of the minimum distance. In one case, a wind turbine was located only 55 m from buildings. The changes introduced in 2016 regarding the rules of locating wind turbines in the time perspective of the coming 20–30 years will cause significant limitations in locating wind farms in Poland.

## Author details

Eliza Kalbarczyk<sup>1\*</sup>, Robert Kalbarczyk<sup>2</sup> and Beata Raszka<sup>3</sup>

\*Address all correspondence to: [ekalb@amu.edu.pl](mailto:ekalb@amu.edu.pl)

1 Department of Spatial Econometrics, Institute of Socio-Economic Geography and Spatial Management, Adam Mickiewicz University in Poznań, Poznań, Poland

2 Institute of Landscape Architecture, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

3 Department of Spatial Management, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

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