



Factors Limiting the Location Possibilities of Photovoltaic and Wind Power Plants in Poland

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Abstract: This article focuses on factors limiting the development possibilities of Poland's photovoltaic and wind power plants. Technical, environmental and legal conditions were found and indicated as a result of research based on legal acts and literature on location possibilities of renewable energy installations under discussion. Also, formulas that can show limiting factors in absolute value are proposed. These formulas consider all limiting factors and allow for comparison between different regions of Poland concerning location impossibilities.

Keywords: renewable energy potential, location conditions, photovoltaic, wind power plants

1. Introduction

Photovoltaic and wind power plants are types of renewable energy installations whose level of participation in Polish energy production will slowly increase in the coming years (Rusin & Wojaczek 2023). To better understand the potential of renewable energy installations in Poland, it is essential to indicate factors that make their development impossible. Environmental, technical, and legal conditions play a major role in the case of photovoltaic and wind power plants. The listed conditions are very important for keeping the development of renewable installations sustainable, mitigating their negative impact on the environment and society, and making the exploitation of installation under discussion safe from a technical point of view. Research of limiting factors and their importance is a fundamental way to indicate the future maximum potential of photovoltaic and wind power plants. Shaping these factors by legal acts is also essential for creating sustainable space in Poland.

This article aims to indicate all factors that impact the location possibilities of photovoltaic and wind power plants. The paper also aims to propose a way to measure the level of "limiting influence" of these factors.

2. Materials and Methods

Legal acts and scientific literature were used to describe factors affecting the location possibilities of Poland's photovoltaic and wind power plants. Legal, environmental and technical constraints were shown as a result of this research. All of them are described in the next chapter as the result of research.

Furthermore, the mathematical apparatus of basic interconnection between variables was used for standardisation. Formulas describing the impact of individual factors were proposed to better describe limiting location factors.

3. Results of Research on Limiting Factors

3.1. Location factors relating to photovoltaic power plants

Photovoltaic (PV) power plants are one type of renewable energy installation. The principle of operation of this installation is to convert electromagnetic radiation into direct current, which is then converted into alternating current using inverters (Saraniak 2019). Considering the installed capacity of PV power plants, they can be divided into small (<1 MW) or utility-scale (>1 MW) renewable installations, as opposed to micro-installations, whose installed capacity is less than 50 kW (Act of 20 February 2015). Installed capacity is a factor that influences the final size of the PV power plant, because more installed capacity means using more PV modules and associated infrastructure. It causes PV power plants to take up significant space, impacting the environment, such as the landscape (Pelczar & Śliwka 2022). Moreover, the size of a PV power plant infrastructure is a factor in classifying these projects as potentially capable of significantly impacting the environment due to the so-called EIA Regulation (Regulation of 19 September 2019). In the mentioned EIA Regulation, PV power plants are classified as a project potentially capable of having a significant impact on the environment whether the area of PV modules (calculated as an outline of the modules) is larger than 2 ha in areas not covered by the boundaries of national parks, nature reserves, landscape parks, protected landscape



areas, Natura 2000, ecological areas and nature and landscape protection complexes (or larger than 0.5 ha on listed forms of nature protection).

It is also necessary to underline, in the context of the Nature Conservation Act (Act of 16 April 2004), that in the landscape parks and nature and landscape protection complexes may be introduced a prohibition of realisation of projects capable of having a significant impact on the environment by an appropriate resolution of the voivodeship assembly (so both types of projects: potentially (so-called group I projects) and always (so-called group II projects) capable of having a significant impact on the environment). However, regarding the Nature Conservation Act (Article 17(3) and Article 24(3)) mentioned prohibitions do not apply to projects for which preparation of the EIA report is not mandatory by the EIA Act (Act of 3 October 2008). It means that it does not also apply to PV power plants (for group I projects, EIA report-making is non-compulsory – due to Article 59(1) and Article 60(2)) of the EIA Act.

Regarding prohibitions that may be entered into local legal acts laying down rules of nature conservation forms, it is necessary to point out the remaining ones affecting the possibility of locating PV power plants. These rules are shown in Table 1.

Table 1. Prohibitions affecting PV power plants' location possibilities in areas covered by nature conservation forms. Own elaboration based on the Nature Conservation Act

Type of nature conservation form	Rule	Legal basis from Nature Conservation Act
National parks and nature reserves	Construction works and rebuilding of new building objects and technical facilities	15(1)(1)
	Conducting of productive, commercial and agricultural activities	15(1)(11)
Landscape parks	Building new construction objects 100 m from natural watercourses, rivers and lakes and the edge of the water table of artificial water bodies	17(1)(7)
	Location of new construction objects 200 m from cliff edge	17(1)(8)
	In landscape protection zones (specified in the protection plan of the landscape park), a prohibition of new construction objects location is binding	17(1a)
Protected landscape areas	Building new construction objects 100 m from natural watercourses, rivers and lakes and the edge of the water table of artificial water bodies	21(1)(8)
	Location of new construction objects 200 m from cliff edge	21(1)(9)
	In designated priority landscape areas, a prohibition of new construction objects location is binding	21(1a)
Ecological areas, nature and landscape protection complexes	The prohibition on destroying, damaging or transforming the object or the area	45(1)(1)

Notably, there are no concretised legal prohibitions in the Natura 2000. Nevertheless, under article 33(1) of the Nature Conservation Act, it is not allowed to take action that will significantly adversely affect the conservation objectives of the Natura 2000 (Jermaczek & Pawlaczyk 2004).

It should also be underlined that prohibitions listed in Table 1 concerning landscape parks and protected landscape areas may not be introduced into local law acts by an appropriate authority (voivodeship assembly).

Furthermore, regarding the Nature Conservation Act, developing industrial infrastructure in ecological areas and nature and landscape protection complexes is possible. Still, we need to consider these nature protection forms' role in the nature conservation system. Of course, the municipal council may decide that these prohibitions will not be binding by the local legal act. Nevertheless, these kinds of nature conservation forms are naturally valuable areas. Both are small in area, local nature protection forms, but they complement and enrich the entire nature conservation system (Ratajczyk & Wolańska-Kamińska 2014). So, considering the ecological aspect, it is necessary to indicate the need to avoid developing PV power plant projects in these areas.

In the context of available space under PV power plants in Poland, it is necessary to identify other factors that impact the terrains that these investments can develop. First, it is worth noting that regarding the Act on public roads (Act of 21 March) construction objects (which power plants are also) must be located at an appropriate distance from the public roads. This distance depends on the road's type and whether the potential object will be situated in the building area, as shown in Table 2.

Table 2. Required distance from public roads for construction of objects. Own elaboration based on the Act on Public Roads

Type of public road	Distance from the road edges	
	Inside the building area	Outside of the building area
Highway	30 m	50 m
Expressway	20 m	40 m
Publicly accessible national road	10 m	25 m
Publicly accessible district and voivodeship road	8 m	20 m
Publicly accessible municipal road	6 m	15 m

Maintaining adequate distance from water bodies and watercourses also impacts the area available for PV power plants. Regarding the Act on Water Law (Act of 20 July), it is prohibited to fence the area of properties within 1.5 m of inland water (article 232 of the Act on Water Law). The same normative act forbids the construction of building objects within 50 m of the embankment and some activities within 3 m of the embankment (e.g. cultivating the soil). However, an appropriate water authority may exempt from these requirements if they do not negatively impact the embankment's tightness.

As for the distance from residential buildings, no length is imposed by legal acts. Nevertheless, the acceptance of many renewable energy installations decreases whether they develop in closer residential areas (Micek 2021). This is why developing PV power plants too close to residential areas should be avoided, mainly to avoid social tensions. Also, to mitigate the visual impact of PV power plants on landscape and, ultimately, on space users, it is possible to introduce solutions limiting this impact, e.g. "green" fencing. Therefore, an appropriate distance from residential buildings chosen at the project phase of the PV power plant, or even when analysing the available space, is a significant factor that could reduce future potential social tensions. Because of this, there is a need to consider local conditions of region and municipality. Moreover, shaping the spatial order and an appropriate realisation of sustainable development ideas require actions that will not result in chaotic development that will bring spatial disorder. It is also a problem how to project the PV power plant in conditions of its negative impact on the landscape, given that these power plants are being introduced (and planning to be introduced) in rural areas (Pelczar & Sliwka 2022).

Forest areas are a vital part of the environment. Forest ecosystems assimilate much carbon dioxide, especially during the development cycle. What's more, it can be said that forests are living carbon dioxide storage systems (Jabłoński & Stempski 2017). It is worth noting that further research is needed to indicate the role of old trees in CO₂ assimilation and emissions balance (however, it is indicated that old-growth forests still accumulate carbon dioxide, but the rate of the assimilation is lower) (Jaroszewicz et al. 2021). Forests are also highly relevant habitats for many species and play a critical role in biodiversity protection (Forest's Europe, 2020). Forests can also be described as a small water retention. The role of forests in water management is significant, for example, in slowing down the duration or shaping an amount of precipitation (Janusz et al. 2011). Given these and many more functions that forests play in ecosystems, avoiding locating PV power plants in areas where logging would take place is crucial. Thus, the ratio of forest cover in administrative units prevents location possibilities of installations under discussion (but it must be strongly underlined – it is not disadvantage, taking into account benefits coming from forest areas functions).

Also, wetlands are valuable elements of the environment and play an important role in environmental protection (Martinez-Guerra et al. 2020). Due to their positive impact on the environment and mitigation of climate change effects, it is necessary to maintain wetlands as natural areas, not change them into industrial areas (which PV power plants also are).

The quality of soils found in administrative units may also prevent the location of PV power plants. Poland is a country where agricultural lands cover about 60% of the land, significantly more than Europe's average (Pelczar 2022). In Poland, the Regulation on the Soil Science Classification of Land (Regulation of 14 October) regulates the way and conduction of soil classification. Soil bonification is based on criteria, among others:

the granulometric composition, thickness of soil humus, landform, pH soil, and calcium carbonate content. Arable soils are divided into 9 groups (I, II, IIIa, IIIb, Iva, IVb, V, VI, VIRz). The most valuable arable soil classes are I (the best), II (very good), IIIa (good), and IIIb (averagely good) (Korzeniowski S., 2018). Due to the role these soils play in shaping agricultural production space, they are under special law protection, guaranteed especially by the Act on Protection of Agricultural and Forest Land (Act of 3 February). Protecting arable soils relies on the limitation of their designation on purposes other than agriculture, prevention of devastation and degradation, reclamation, and improvement of their useful value (Świdyński 2016). Regarding the Act of 3 February, the exemption from agricultural production of arable soils I-IIIb and IV-VI of organic origins requires obtaining the decision provided by an appropriate authority. Furthermore, a change of zoning of arable soils classes I-IIIb for purposes other than agricultural requires obtaining an Agricultural and Rural Development Ministry decision upon the application of component authority of local administration (mayor, president of the city). Mentioned zoning is made based on the local development plan (art. 7 of Act of 3 February). Because these soils are the most valuable in agricultural production (also, the exemption of these soils is related to high charges, which aim to protect them), it is necessary to avoid the location of PV power plants in areas covered by high-quality farmlands. Thus, if a municipality is characterised by a high coverage rate of high-quality arable soils, it prevents the location of installations under discussion.

Another parameter that should be considered when analysing PV limitation factors is the presence of mining areas. After reclamation and revitalisation, these terrains could be designed as energy production areas in the future. Nevertheless, when considering currently available space useful for PV power plants, it is necessary to reject areas such as those discussed in this paragraph. What's more, mining terrains may affect the lower location possibilities of PV power plants, especially if explosives are used for exploitation purposes in the mining facility. Regarding the Act on Geology and Mining law (Act of 9 June), it should be explained that, in short, the mining area is the space in which mining entrepreneur is allowed to mineral exploits. On the other hand, mining terrain is a space affected by foreseeable detrimental influences of the mining plant.

The land surface is also a factor that should be considered when analysing the PV power plant's available area. It is a significant factor in a PV power plant location. High north steep slopes exclude the possibility of a PV power plant location. It is related to a low irradiance and technical constraints. Furthermore, south highly steep slopes make a PV power plant location impossible (Imamverdiyev N. 2021).

Furthermore, landslides (and landslides risk areas) determine PV power plant location possibilities. Most landslides occur in the Carpathians. In that region is located about 95% of all landslides in Poland (Cała 2009).

The power grid is another factor affecting PV power plant location possibilities. The transmission system operator needs to agree upon the location of power plants under discussion near the high-voltage grid. Maintaining the appropriate distance from high-voltage lines is essential for the safety of their use, exploitation, or potential repair after a failure. It is also connected to the safety of using a high-voltage grid system. For PV power plants potential measuring purposes, this distance can be identical to the so-called servitude buffer zone. An indicated buffer zone makes easy access to the power line when necessary to make renovations or other works to maintain the grid's safety. For each kind of power line, we can propose the optimal width of the servitude buffer zone from the edge of a power line: 3 m for low-voltage lines, 8 m for medium-voltage and 15 m for high-voltage lines. For the highest voltage lines, we can take as a base of non-developing areas for PV power plants the technical buffer zone, which can be assumed as designed by 25-70 m distance from the edge of the grid line based on Spatial Planning Act (depending on the voltage: 25 m from 220 kV, 40 m from 220-400 kV and 70 m from lines in which voltage is more than 400 kV).

Concerning the exploitation phase of PV power plants, avoiding areas endangered by floods is also necessary. It is essential to exclude potential development areas threatened by flooding whose probability of occurrence equals 10% (an area subject to flooding once per ten years) from PV power plants.

The last factor related to the PV power plant location is spatial planning in the municipality. The most important spatial planning document in Poland is the local development plan. This planning document indicates the possible land use in a municipality. It is adopted by the municipal council and connected with so-called "planning control", in which administrative units are equipped based on the Spatial Planning Act (Act of 27 March 2003). Considering the revolution of spatial planning system introduced in 2023, through which a new spatial planning document will be obligatory to adopt in a municipality (the general plan), it is essential to underline that from the time the current biding municipal planning documents (studies of spatial development) will unenforceable, the location of PV power plants will be possible exclusively based on the local spatial plan (Pelczar 2023). Until the unenforceable studies of spatial development (up until a general plan entry into force, but no longer than 31.12.2025), change of land use for PV power plants is possible on the basis of zoning decisions. Factors shaping the PV power plant's potential in Poland are included in Table 3.

Table 3. Factors shaping PV power plants potential in Poland. Own elaboration

Ordinal number	Factor
1	Presence of conservation forms of nature
2	Roads and their types
3	Presence of water bodies
4	Presence of residential buildings
5	Embarkments
6	Forest cover
7	Wetlands presence
8	Soils quality
9	Presence of mining areas
10	Land surface
11	Presence of landslides
12	Power grid
13	Flooding risk
14	Spatial planning situation

3.2. Location factors relating to wind power plants

Legal conditions play a fundamental role in shaping the available space for wind power plants in Poland. The Act on Wind Power Plant Investments (Act of 20 May 2016) indicate the rules under which basis wind turbines can be located. Without going into the intricacies of that normative act too much, it is necessary to underline that the location of wind power plants is possible based on the local development plan. It is mandatory to keep a distance of 700 m from residential buildings (or combined function buildings, meaning more than 50% of buildings are used for residential purposes).

Also, wind turbines cannot be located in national parks, nature reserves, landscape parks, and Natura 200 areas. Despite the Act mentioned above not prohibiting the location of wind turbines in protected landscape areas, projects under discussion can significantly negatively impact the objective of protecting these nature conservation forms (unique landscape). Due to this, implementing wind power plants in protected landscape areas may not be possible based on the Act on Nature Conservation and an appropriate local law act (resolution of the parliament of voivodeship). Wind power plants are industrial components with very high visual impact. Because of this, their location in protected landscape areas may not be possible in practice. It is recommended by the Nature Protection Authority (Badora 2017) to limit the number of wind turbines in these nature conservation forms to 10.

Furthermore, wind power plants cannot be located within 500 m of nature reserves. More restrictive rules apply to national parks. The distance of the so-called 10H must be maintained from these most valuable conservation forms. The indicated rule means that the distance between a national park and the wind turbine must be greater than the total height of the wind turbine multiplied by 10. The total height of the wind turbine, in turn, means the height counted from the ground level to the highest point of the wind turbine during the maximum blade lift.

The Polish law does not indicate a minimum distance from other, not residential buildings. It means that the distance from other buildings must meet other technical requirements, for example, those related to the appropriate foundation location, noise emission, or optical impact. All impacts on industry workers in industry areas who will be working near wind turbines should be considered during the environmental impact assessment procedure if a wind power plant is planned in a neighbourhood other than industrial buildings. For wind power plant potential assessment, it can be assumed that a distance of 300 m from other than residential buildings may limit wind turbine location.

The Act on Wind Power Plant Investments also regulates the distance of wind power plants from the power grid. Potential wind power plant location is required to maintain the distance of the diameter of a rotor with blades multiplied by three or the total height of the wind turbine multiplied by two (depending on which value is higher). Furthermore, it is necessary to maintain the appropriate distance from other types of the power grid, especially medium-voltage lines. For available space for wind turbines, this distance can be assumed to be 100 m (Pamucar et al. 2017).

Furthermore, planning to build wind turbines to keep the distance from other topographical objects is essential. Wind power plants should be localised from forests, wetlands, and aquatic areas. Also, the best terrains for building wind turbines are flat terrains (Pamucar et al. 2017). In addition, wind and PV power plants must be located at an appropriate distance from roads.

Forest's presence relates to the surface roughness parameter. A higher surface roughness parameter means lower wind speed, resulting in lower energy production. Furthermore, wind turbines close to forests may affect avifauna higher mortality. Due to that, it is proposed to situate wind turbines at a distance of 200 m from the edges of forests, according to EUROBATS guidelines (EUROBATS, 2015).

Table 4 shows the factors shaping the potential of wind power plants in Poland.

Table 4. Factors shaping wind power plants potential in Poland. Own elaboration

No.	Factor
1	Legal conditions (the distance from residential buildings)
2	The presence of nature conservation forms
3	Residential building density and their spatial distribution
4	The presence of other types of buildings
5	Density of power grid
6	Presence of roads and their type
7	Presence of forests
8	Wetlands presence
9	Presence of water bodies and rivers

3.3. Location factors relating to wind power plants and their impact

Since all of the constraints resulting in lower location possibilities of investments under discussion were indicated, it is necessary to categorise them. The categorisation of factors may help analyse the area that can be developed by PV or wind power plants. It is possible to divide all location factors into three groups of constraints: legal, technical, and environmental, relating to PV and wind power plants. These groups are shown in Table 5.

Table 5. Categories of factors limiting location possibilities. Own elaboration

Category of factors shaping PV power plants and wind power plants' location possibilities	Factor
Legal	General law requirements
	Lower legal acts requirements
	Spatial planning situation
Technical	Presence of roads, their types and density
	Building density
	Presence of grid
	Presence of embankments
	Presence of mining areas
Environmental	Presence of nature conservation forms
	Forest cover
	Presence of residential areas
	Presence of water bodies and watercourses
	Wetlands presence
	Land surface, steep slopes
	Quality of soils
	Flooding risk
Presence of landslides	
Spatial conditions	Buffer zones from individual factors

3.4. Influence of individual factors

The influence of individual factors and categories can refer to the area that they occupy. It is justified by the fact that all factors, including their buffer zones, are spatial. However, when it comes to legal factors, it is not possible to assess them as spatial factors. Lower legal acts can prohibit the development of PV and wind power plants in administrative units (municipalities, by local spatial development plan). When this condition occurs, this factor's importance is the highest, making PV and wind power plants impossible to locate in an administrative unit. However, local spatial development plans may be amended when necessary, so the rest of the factors are much more important in typifying location opportunities.

Considering the influence of the mentioned, more important factors, included in the technical and environmental categories (and also for wind power plants distance rule from residential buildings), with their buffer zones, we can express their level of impact on location possibilities as:

$$I = \frac{A_f + A_{b(f)}}{A_a} \cdot 100\% \quad (1)$$

where:

I – level of impact of individual factor (f), [%],

A_f – area occupied by factor f , [ha],

$A_{b(f)}$ – area occupied by buffer zone ($b(f)$) from individual factor, [ha],

A_a – area of the analysing terrain a (municipality, district, voivodship area), [ha].

The proposed equation shows that when a larger area is occupied by an individual limiting factor, the lower location possibilities of PV or wind power plants in the analysed terrain are. The equation also takes into account buffer zones from limiting factors. The area occupied by a limiting factor and buffer zone relates to the region's total area under analysis (for example, municipality or district), thus enabling an assessment of the "limiting level" of individual factors.

It is also possible to calculate the level of total impact of all factors using:

$$I_T = \sum_{i=1}^n \frac{A_{f_i} + A_{b(f_i)_i}}{A_a} \cdot 100\% = \left(\frac{1}{A_a} \cdot \sum_{i=1}^n A_{f_i} + A_{b(f_i)_i} \right) \cdot 100\% \quad (2)$$

where:

I_T – total level of impact of all factors, [%],

A_{f_i} – the area occupied by f_i factor, [ha],

$A_{b(f_i)_i}$ – the area occupied by the buffer zone ($b(f_i)$) from f_i factor, [ha],

A_a – area of the analysing terrain a (municipality, district, voivodeship area), [ha].

Also, we can comprise how one factor impacts location possibilities concerning other factors as a relative size using all indicators listed in previous equations:

$$I_f = \frac{I}{I_T} = \frac{\frac{A_f + A_{b(f)}}{A_a}}{\frac{1}{A_a} \sum_{i=1}^n A_{f_i} + A_{b(f_i)_i}} = \frac{A_f + A_b}{\sum_{i=1}^n A_{f_i} + A_{b_i}} \quad (3)$$

where:

I_f – level of impact of factor I concerning the rest of factors, [-/%].

4. Summary

The potential location possibilities of photovoltaic and wind power plants are affected by many factors, which may be divided into three main categories: legal, technical, and environmental. Indicating these factors makes it possible to assess where, in which region or administrative unit, location possibilities of PV and wind power plants are highest.

Using proposed equations, it is possible to assess limiting locating factors for discussed investments in selected regions. It is also possible to compare different regions and assess where limiting factors are lower or higher. Also, the individual factor can be compared concerning all of the factors by using the proposed equation.

The locating possibilities in different administrative units in Poland are very diversified (on local – municipal level and regional – voivodeship level as well), which is related to factors in each area.

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