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Evaluating the Eligibility of Abandoned Agricultural Land for the Development of Wind Energy in Lithuania

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Abstract: Land requirements of wind power (WP) are often seen as a constraint to future broad-scale deployment. The aim of the study is to evaluate the eligibility of abandoned agricultural land (AAL) areas, covered with woody plants, for the development of wind energy (WE) in Lithuania. Agricultural land abandonment (ALA) has numerous negative aspects and its use for WE must be a profitable choice for the landowner, as for the energy developers also. A newly developed methodological approach, a multi-criteria decision-making (MCDM) method known as TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) was applied to select suitable areas for wind power plants (WPP). The authors have used various data sets, as follows: protected areas (reserves, parks) combined into one common geographic information system (GIS) layer, forest cadaster data, water (lakes, rivers) area layer; abandoned land area layer; buildings layer, taken from the Lithuania Georeferenced Data Base. The results were generated for the entire territory of Lithuania and separately for AAL using the algorithms of the open source QGIS program. The results showed that the central part of Lithuania is most suitable for the development of WE. However, ALA in this part is low, because of the high soil yield potential and suitable conditions for farming. According to the selection criteria, about 7% of AAL are suitable for WE, and more than 18% of AAL have an average suitability.

Keywords: wind energy; abandoned agricultural land; MCDA method; renewable energy

Citation: Tumelienė, E.; Sužiedelytė Visockienė, J.; Maliene, V. Evaluating the Eligibility of Abandoned Agricultural Land for the Development of Wind Energy in Lithuania. *Sustainability* **2022**, *14*, 14569. https://doi.org/10.3390/su142114569

Academic Editors: Hua Li and Ruipeng Tan

Received: 22 September 2022
Accepted: 3 November 2022
Published: 5 November 2022

1. Introduction

Because of growing energy consumption and the declining reserves of fossil fuel, alternative energy sources are currently being investigated. Renewable energy (RE) sources are energy resources that occur naturally, such as solar, wind, hydro energy, biomass and geothermal energy. In 2020, RE accounted for 22.1% of the energy consumed in the European Union [1]. The development of RE sources is an effective way to alleviate carbon emissions [2]. The use of RE sources is also growing rapidly in North and South America, Europe and Asia. According to the installed capacity, the largest users of RE are China, the USA and Germany. Rapid growth is observed in South Korea, Australia, France and other countries. The wind and solar energy sectors are expanding particularly quickly [3]. WE has become an attractive choice around the globe for generating clean, cheap and commercially viable power [4].

The RE Order of the Republic of Lithuania [5] and the National Energy Independence Strategy of Lithuania [6] ensure that the development of renewable resources for electricity production is one of the strategic state energy goals. In 2020, RE represented 26.8% of the energy consumed in Lithuania [1]. WE is one of the main methods for electricity production in Lithuania (Figure 1). According to the Lithuanian Electricity Transmission System Operator (LITGRID) data, the total capacity of the installed WPP in Lithuania is 671 MW, accounting for almost 60% of the total capacity of RE sources [7].

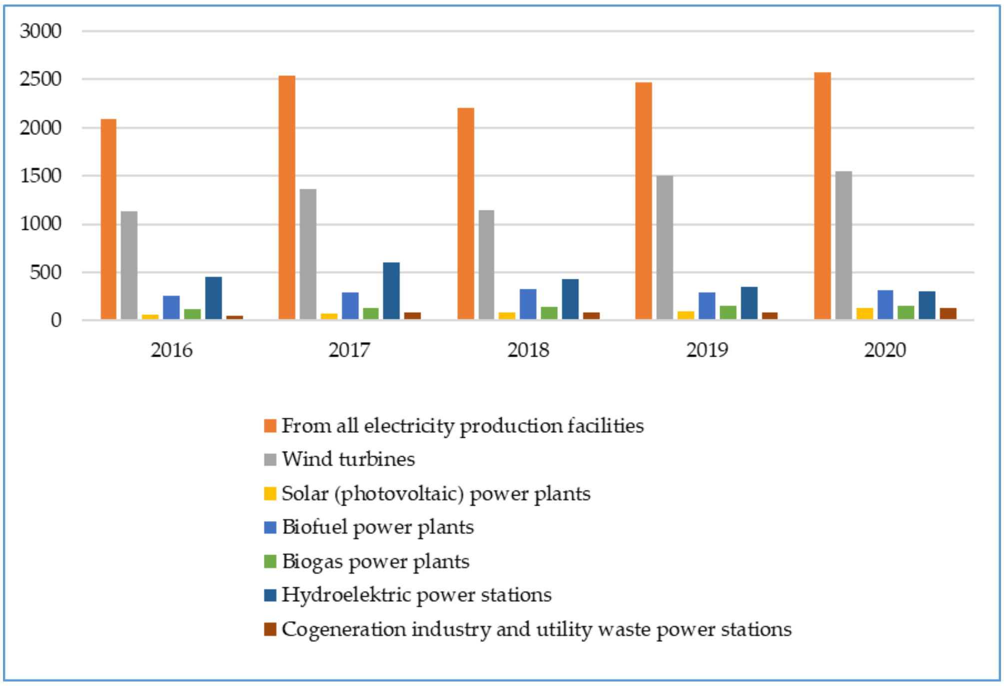

Figure 1. Electricity production (GWh) from RE sources in Lithuania (data from [8]).

Although the demand for WE is constantly growing, it is unclear how its expansion could affect other key sustainability objectives [9]. To reduce the negative impacts on the environment and human health, one of the concerns regarding the deployment of WE is effective land use. Land requirements of WP are often seen as a constraint to future broad-scale deployment. This perception is based on the conventional assumption that WP typically require larger land areas per megawatt (MW) of capacity than solar technologies and fossil fuel-based sources [10].

Most often, respective life cycle assessments have focused on the impacts of WP plant and photovoltaics on the environment. Nevertheless, there is an increasing amount of work assessing land availability for RE, in particular for WP [11]. The availability of land for the installation of WP turbines is restricted by numerous factors. Besides climatic conditions, the deployment of WE is limited by technical, social, economic and environmental factors [11]. The area of a WP plant includes not only the land directly disturbed by the installation of the turbines but also the surrounding area that potentially may be impacted [12]. Land eligibility analyses are, and will remain, a crucial piece of energy-related research [13,14] and therefore the questions of AAL eligibility for the development of WE are considered in this paper.

ALA can have both positive as well as negative consequences. ALA can provide opportunities to contribute to environmental policy goals, including biodiversity conservation, ecosystem restoration and climate change mitigation and adaptation [15,16]. However, ALA has numerous negative aspects, such as the risks of invasive species (such as *Heracleum sosnowskyi* plants) spreading in AAL [16,17]. ALA can also lead to the loss of farmland biodiversity and cultural landscapes, as well as increased fire frequency and intensity [18].

The aim of this work is to evaluate the eligibility of AAL areas, covered with woody plants and not used for their intended purpose, for the development of WE in Lithuania. Wind farms (WF) will inevitably affect the landscape in many natural areas and their locations have to be considered carefully [19].

A MCDM approach, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was selected to choose suitable areas for evaluating the eligibility of AAL for the development of WE in Lithuania. The MCDM method is the most widely used method in many fields, such as energy planning, resource allocation and policy making, and it is also the most suitable method in the rapidly developing energy field [2,20]. The approach TOPSIS has been successfully applied to various MCDM problems in several disciplines [21–23]. In addition, the TOPSIS approach provides a simple yet effective mechanism to deal with multiple criteria, in addition to being computationally efficient [4]. The paper shows the application of the proposed novel method based on combining of TOPSIS, used for evaluation of the eligibility of AAL for the development of WE, and QGIS (ver. 3.4.3) GIS software for the processing of data and visualization.

2. Material and Methods

2.1. Study Area, Study Object and Data

The study area was Lithuania, a country on the eastern shore of the Baltic Sea in the Baltic region of Europe (Figure 2).

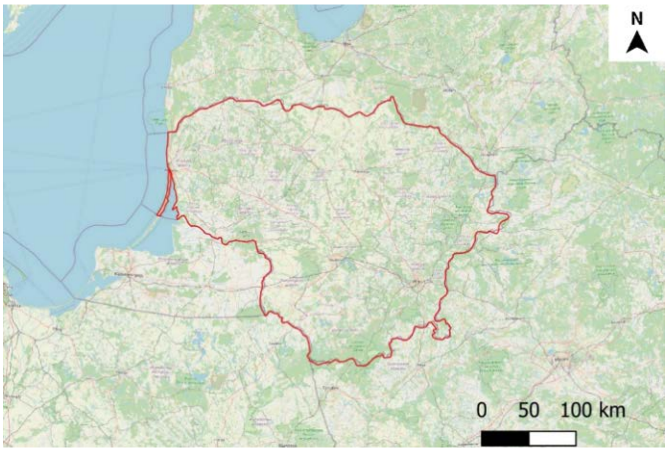

Figure 2. Map showing the study area (source: authors).

The country covers an area of 65,300 km^2, with the following land use distribution: 51.9% agricultural land, 32.9% forests and forested land, 5.8% other land, 4.1% land occupied by water, 3.7% built-up land, 1.6 roads [21]. Here, we focused on AAL. At the beginning of 2022, the AAL areas covered 1.1% of the total area of agricultural land in Lithuania [24].

Although the AAL areas are decreasing every year, they still remain in Lithuania and now AAL areas cover about 373.6 km^2 of the Lithuanian territory. Often AAL is generally located in areas with a low yield potential, an inconvenient shape, far from settlements and not easily used for other purposes.

Reasons for the selection of AAL for the development of WE are as follows:

1. small population density in the territories with the largest areas of AAL sites. For the social acceptance of WF, the greatest hindrance is visual impact, and studies have shown that opposition to WF most commonly stems from the fact that wind turbines degrade people's visual experience of nature [19]. Small population density is a big advantage in development of WPP;
2. AAL often has a marginal agricultural value and an inconvenient shape. These factors are not suitable for agriculture, but are not negative for VE;
3. AAL adopted for WE provides economic benefits to landowners. Land taxes for AL are applied in Lithuania and their use for WE would help to avoid land taxes and to obtain the benefits from WE;
4. the abandonment of land causes various issues, such as the spread of particularly aggressive invasive plants. After its adaptation for WE, the spread of invasive plants would be prevented.

Various land cover data were used, obtained from the Lithuanian Spatial Information portal (LSI) [25]; wind data were accessed from the Global Wind Atlas (GWA) [26]. The LSI is the main technological platform that is used for the implementation of the provisions of the Spatial Information in the European Community (INSPIRE) Directive. It provides national access to spatial data and services and serves as a free-of-charge platform for the provision of spatial data and services to the INSPIRE geoportal. The GWA is a free, web-based application developed to help policymakers, planners and investors identify high-wind areas for WP generation virtually anywhere in the world and then perform preliminary calculations [26].

2.2. Data Collection and Processing

The following vector features (the shape file format) data from the LSI portal [25] were used:

- Protected areas (reserves, parks) combined into one common layer;
- Forest cadastre (private, state) data combined into one layer;
- Water (lakes, rivers) area layer;
- Abandoned land areas;
- Buildings layer from the Georeferenced Data Base 1:10,000 scale (GDB10LT).
- The data view from the LSI presented in Figure 3.

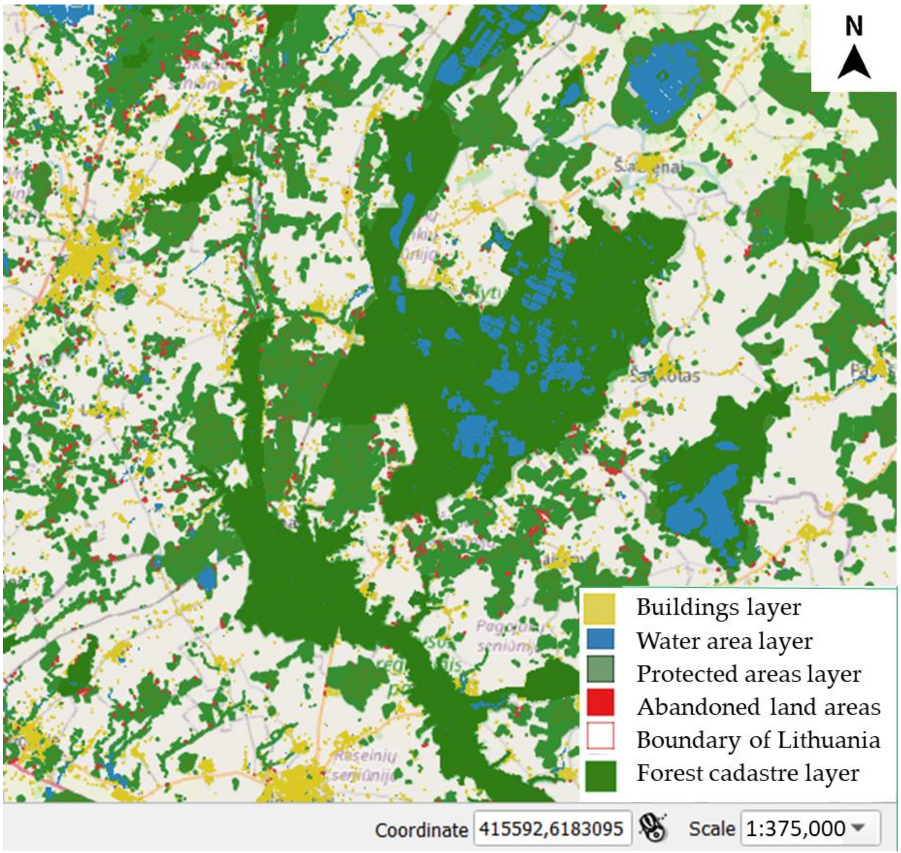

Figure 3. Data view from the LSI portal.

Data from GWA [26]: Mean Wind speed raster data at an altitude of 100 m presented in Figure 4.

The wind characteristics will determine the energy amount that can be effectively extracted from WP [16]. An important factor to estimate WE potential is mean wind speed. The highest mean wind speed potential is in the western part of country, in the coastal area, and in some places it is up to 8 m/s in 100. The lowest potential is in the southeastern part of Lithuania where in some parts wind speed potential does not reach 6 m/s in 100 m (Figure 4).

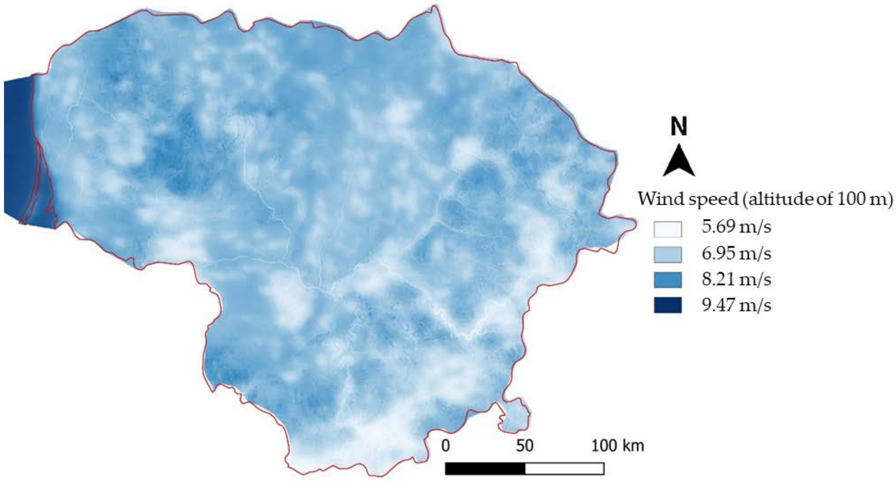

Figure 4. Mean Wind speed raster image from GWA.

Evaluating that wind speed potential in Lithuania is not high enough to obtain the desired economic effect was oriented to WPP of 100 m and higher in this work. For this purpose, the used mean wind speed raster image from GWA in Figure 4 is at an altitude of 100 m.

For the multi-criteria analysis, all vector data (points, lines and polygons) layers were transformed into a raster image, where pixels acquired values of 1 (for objects) and values of 0 (no objects). One pixel value was 10 × 10 m. An important consideration is that all rasters must be of the same extent, especially the coordinate system. For processing, the authors used the open-source software QGIS Toolbox vector conversion/rasterization (vector-to-raster) algorithm (Algorithm: gdal_rasterize).

2.3. Multi-Criteria Decision Analysis Method

The requirements for WPP largely depend on several factors. The main one is the power of turbines. The power of WPP was not determined in this experiment, therefore criteria of being most significant, most common and having the largest protection zones were selected for suitability for WF.

Thew MCDA method was applied to select suitable areas for WPP, using different data sets with different quantitative criteria. Each criterion may have different units of measurement, quality characteristics and relative weights [27]. The second most popular method among the MCDM approaches is TOPSIS, which was selected for this research. The scientists have reviewed 105 papers which developed, extended, proposed and presented the TOPSIS approach for solving Decision-Making problems [27]. It is used to solve simple and complex tasks and based on the idea that, when an alternative has the shortest distance to the ideal solution, it can be considered as the best [27–29]. The TOPSIS method allows trade-offs between criteria, where a poor result in one criterion can be negated by a good result in another criterion. The procedure of the classical TOPSIS method consist of several steps [27,28]:

Step 1. Calculate the normalized decision matrix. Construct the decision matrix and determine the weight of criteria [27,28]. The decision matrix (X_{ij}) is:

$$X_{ij} = \begin{bmatrix} x_{11} & x_{12} & x_{1n} \\ x_{21} & x_{22} & x_{2n} \\ x_{m1} & x_{m2} & x_{mn} \end{bmatrix} \quad (1)$$

where $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$; m—alternatives; n—attributes with the intersection of each alternative and attribute given as X_{ij}, were we have matrix $\left(X_{ij}\right)_{m \times n}$.

Step 2. Calculate the normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes which allows comparisons across criteria. The normalization of values can be carried out by one of the several known standardized formulas [28]:

$$n_{ij} = \frac{xX_{ij}}{\sqrt{\sum_{i=1}^{m} xX_{ij}^2}} \tag{2}$$

$$n_{ij} = \frac{X_{ij}}{\max\limits_{i} X_{ij}} \tag{3}$$

$$n_{ij} = \begin{cases} \frac{X_{ij} - \min\limits_{i} X_{ij}}{\max\limits_{i} X_{ij} - \min\limits_{i} X_{ij}} \\ \frac{\max\limits_{i} X_{ij} - X_{ij}}{\max\limits_{i} X_{ij} - \min\limits_{i} X_{ij}} \end{cases} \tag{4}$$

where i = 1, 2, . . . , m, j = 1, 2, . . . , n.

Step 3. Calculate the weighted normalized decision matrix.

$$V = (v_{ij})_{m\times n} = (w_j r_{ij})_{m\times n},\ i = 1,\ 2,\ \ldots, m, \tag{5}$$

where

$$w_j = \frac{W_j}{\sum_{j=1}^{n} W_j},\ j = 1,\ 2, \ldots,\ n \tag{6}$$

here, $\sum_{j=1}^{n} W_j$ = 1, and W_j is the original weight given to the attribute v_j, $j = 1,\ 2, \ldots,\ n$.

In the next step 4, we determined the unacceptable solution A^- and the ideal acceptable solution A^+:

$$A^- = \{\max(t_{ij} I\ i = 1,\ 2, \ldots m) Ij \in J_- >, < min(t_{ij} I\ i = 1,\ 2, \ldots m) Ij \in J_+ >\} \equiv \{t_{wj} I\ j = 1,\ 2, \ldots n\}, \tag{7}$$

$$\begin{aligned} A^+ = \{\min(t_{ij} I\ i = 1,\ 2, \ldots m) Ij \in J_- >, < max(t_{ij} I\ i = 1,\ 2, \ldots m) Ij \in J_+ >\} \\ \equiv \left\{t_{bj} I\ j = 1,\ 2, \ldots n\right\}, \end{aligned} \tag{8}$$

where $J_+ = \{j = 1,\ 2, \ldots,\ n\}$ j is associated with the attribute having a positive acceptable impact, and $J_- = \{j = 1,\ 2, \ldots,\ n\}$ is associated with the attribute having a negative unacceptable impact.

Step 5. Calculate the separation measures from the positive ideal solution and the negative ideal solution.

$$d_i^+ = \left(\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^p\right)^{1/p} \tag{9}$$

The separation of each alternative from the negative ideal solution is given as

$$d_i^- = \left(\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^p\right)^{\frac{1}{p}} \tag{10}$$

where $p \geq 1$. For p = 2 we have the most used traditional n-dimensional Euclidean metric; i = 1, 2, . . . , m.

Step 6. Calculate the relative closeness to the positive ideal solution.

$$R_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{11}$$

where $0 \leq R_i \leq 1$, i = 1, 2, . . . , m.

The requirements for WE vary in different countries, and regulations are often changing. In Lithuania, the requirements for WE largely depend on the power of turbines. Therefore, only the following criteria for suitable places for WE were used in this experiment:

1. distance from forests;
2. distance from buildings;
3. distance from water reservoirs (lakes, rivers);
4. land does not belong to a protected area.

The Euclidean, Minkowski or other algorithms could be used for calculating the distances between points.

The calculation process in shown in Figure 5.

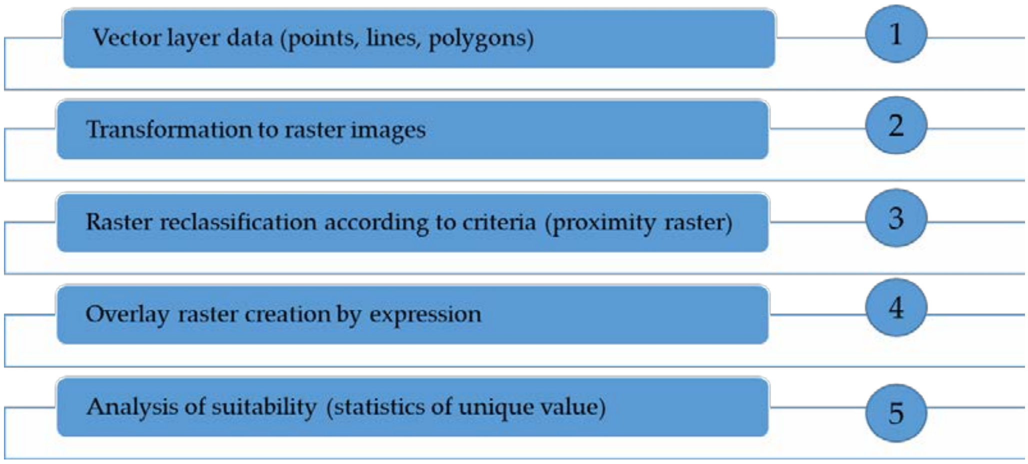

Figure 5. Calculation process.

The first and second steps are procedures of data preparation, and the third and fourth steps are calculations by the MCDA. The expression of the quantitative criteria and the calculation results are provided in the Results section.

3. Research Results

Special proximity rasters were prepared according to the following criteria by the raster analysis/proximity (raster distance) algorithm. The pixels of the raster data break into classes according to their suitability. All layers only had three different values, 10, 50 and 100, indicating the relative suitability of the pixels with regards to the distance from the object. The criteria and expression for raster image calculation are shown in Table 1.

Table 1. Image reclassification criteria and expressions.

Objects	Distances (m)	Criteria	Expression
Forests	0–30 30–500 >500	not suitable—10 average suitability—50 fully suitable—100	10 ∗ ("Proximityforest@1" ≤ 30) + 50 ∗ ("Proximity forest@1" > 30) ∗ ("Proximity forest@1" ≤ 500) + 100 ∗ ("Proximity forest@1" > 500)
Buildings	0–100 100–500 >500	not suitable—10 average suitability—50 fully suitable—100	10 ∗ ("Proximitybuildings@1" ≤ 100) + 50 ∗ ("Proximity buildings@1" > 100) ∗ ("Proximity buildings@1" ≤ 500) + 100 ∗ ("Proximity buildings@1" > 500)
Water bodies	0–20 20–110 >110	not suitable—10 average suitability—50 fully suitable—100	10 ∗ ("water_proximity@1" ≤ 20) + 50 ∗ (water_proximity@1" > 20) ∗ ("water_proximity@1" ≤ 110) + 100 ∗ ("water_proximity@1" > 110)

Distances from forests, buildings and water reservoirs can partially or completely limit WE development. Longer distances from these objects causes less problems both for residents living near WPP and for institutions executing construction and maintenance of WPP. Distances from the objects (forests, buildings and water reservoirs) are the criteria (10, 50 and 100) allowing the division of AAL into categories: fully suitable, average suitability and unsuitable. The distances from these objects for determination of the criteria have been identified by information from legal acts, or based on the information from completed WF projects.

According to the existing legal regulations in Lithuania, the Special Land Use Conditions [30], the size of the sanitary protection zone for WPP ranges from 200 to 440 m, depending on the installed power of the WPP. However, an amendment proposes to change the sanitary protection zone for WPP. Taking into account the changing situation, selecting criteria and evaluating the distances from buildings to wind turbines, a distance of 100 m was selected as the average suitable distance and a distance of 500 m as fully suitable.

The Layer Forest raster criteria are based on the same principle. Distances more than 500 m from the power plants were selected as fully suitable. An average suitable distance from 30 to 500 m was selected by analyzing the environmental impact assessment report of the implemented WE park in the Pagėgiai municipality [31].

There are many areas in Lithuania where the development of WE is prohibited or allowed only with considerable reservations. This is the case for protected areas and for cultural, ornithological, natural and complex reserves. Restrictions are also applied in priority conservation zones in state parks (reserves) and for objects of natural and cultural heritage. The environmental impact report is prepared, along with a conclusion regarding the significance of the impact on the Natura 2000 territory of the European ecological network. All these mentioned territories were assessed in this work as unsuitable for WE development.

Water raster criteria were selected in accordance with the Order of the Minister of Environment of the republic of Lithuania, the approval of the order description regarding the establishment of protection zones and coastal protection bands for surface water bodies [32]. However, in Lithuania, different protection zones apply to different water bodies, ranging from 10 to 500 m. Therefore, the distance which apples for most water bodies in Lithuania was selected as the most suitable one.

The building, forest and water raster reclassification results are presented in Figure 6.

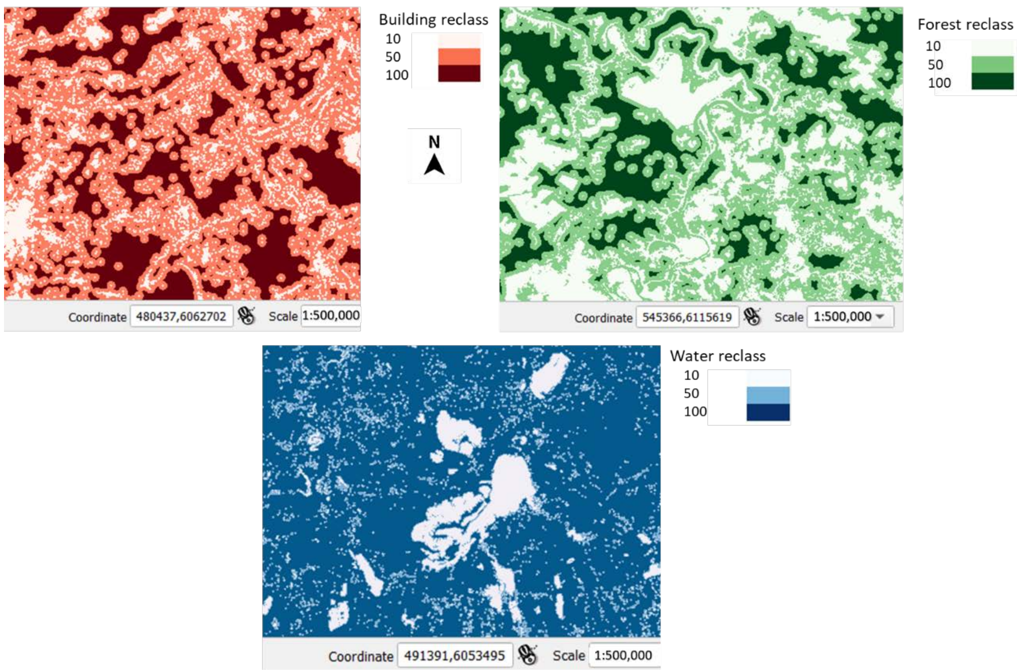

Figure 6. Raster reclassification results.

The research criteria for determining suitable areas for the establishment of WPF were as follows: distance from buildings, forests, water and areas that are not protected. The brightest color in each raster in Figure 6 shows the territories, which have criteria 10 and are not suitable. Medium light color—territories, which have criteria 50 and which are of verage suitability. Darkest color—territories, which have criteria 100 and which are fully suitable for WE.

The overlay analysis was performed with the QGIS Raster analysis—Raster calculator function:

$$(\text{"forest\_reclass@1"} + \text{"buildings\_reclass@1"} + \text{"water\_reclass@1"}) * (\text{"protected\_areas@1"} \mathrel{!}= 1) * \text{"Boundary\_Lithuania@1"}$$

The results of overlays of forests, buildings, waters and protected areas are presented in Figure 7.

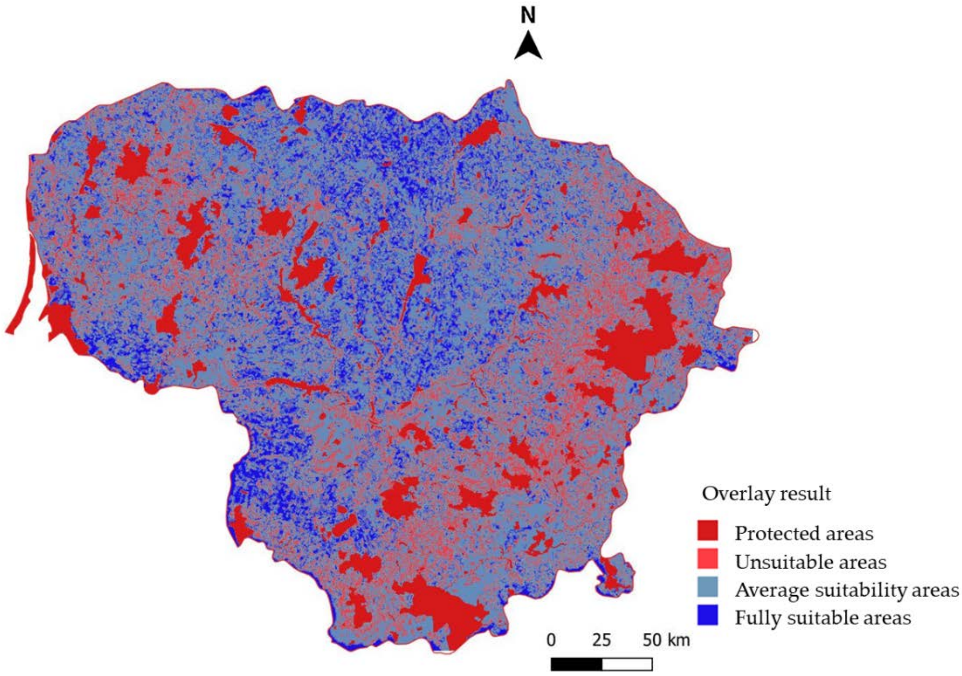

Figure 7. Overlay results for forests, buildings, waters and protected areas.

The obtained results (Figure 7) show that the central part of Lithuania is most suitable (blue color) for the development of WPP, with pixel values from 210–300. The mean wind speed potential at 100 m height in this part of Lithuania is around 7 m/s (Figure 4). However, the amount of AAL in this part is low and varies from 0.1% to 0.4% of the total area. The reasons for this is mainly because the soil yield in this part is the highest in the country.

The southeastern part of Lithuania is most unsuitable (Figure 7, red color) for the development of WPP. The mean wind speed potential in 100 m height in this part is lowest in the country and in some places does not reach 6 m/s (Figure 4). The amount of AAL in this part is one of the largest in the country.

The unique values of the "Overlay_result" layer are shown in Table 2 and Figure 7.

Pixel width: 28,475 (units per pixel 10), pixel height: 37,331 (units per pixel 10), total pixel count: 1,063,000,225.

The analysis of the suitability of territories of Lithuania for the establishment of WE parks shows that according to our criteria, defined in Table 1, 19.6% of the area was not suitable, 21.6% had an average suitability, and 22.6% was fully suitable for the establishment of WPP.

Table 2. Suitability of territories of Lithuania for the establishment of WE parks.

Pixel Value	Pixel Count	Area, km^2	Area, km^2	Area, %	Area, %	Criteria	Suitability
No data	385,256,897	23,666	23,666	36.2	36.2		No data
0	154,027,459	9462	12,785	14.5	19.6	10	Protected areas and unsuitable areas
30	800,490	49		0.1			
70	10,500,414	645		1.0			
110	34,058,705	2092		3.2			
120	8,740,525	537		0.8			
150	13,865,817	852	14,103	1.3	21.6	50	Areas with average suitability
160	101,745,549	6250		9.6			
200	113,962,275	7001		10.7			
210	106,229,421	6526	14,746	10.0	22.6	100	Fully suitable areas
250	105,037,723	6452		9.9			
300	28,774,950	1768		2.7			
Total	1,063,000,225	65,300	65,300	100	100		

In the following stage, we present the evaluation of the sustainability of 'overlay abandoned' layers, with the following formula:

(“forest_reclass@1” + “buildings_reclass@1” + “water_reclass@1”) ∗ (“pro tected_areas@1” ! = 1) ∗ “abandond_raster@1”.

The results are presented in Figure 8 and Table 3. The systematized results regarding the suitability of abandoned land areas for WE are presented in Table 4.

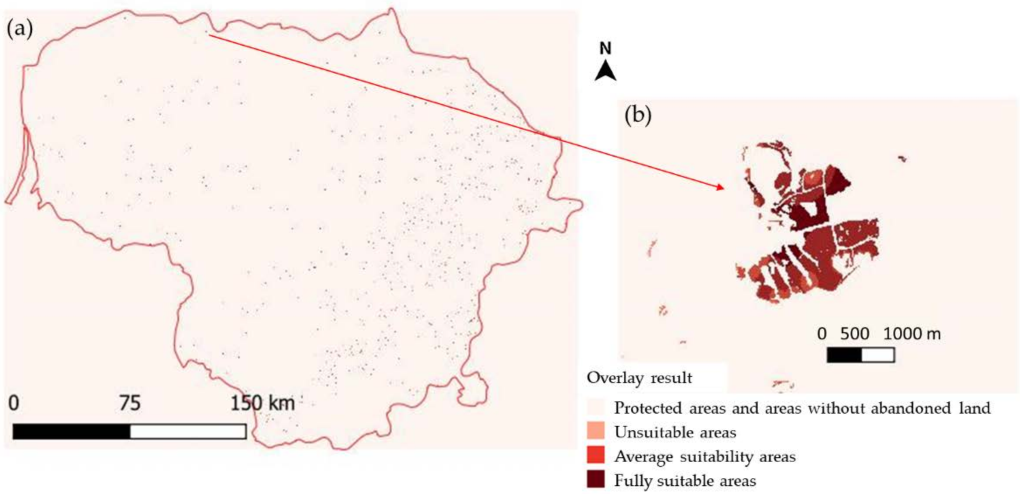

Figure 8. Overlay result of AAL: (**a**) whole territory, (**b**) magnified image.

Figure 8a demonstrates different overlay results for AAL: unsuitable, average suitability and fully suitable are distinguished in different colors. This research was performed for the whole country, but AAL areas are hardly visible on a whole country map. For a clearer view, the magnified image (Figure 8b) of the selected territory was made. For the magnified image the area was selected in which all possible AAL suitability categories in different colors are visible: unsuitable, average suitability and fully suitable.

ALA in Lithuania cover about 373.6 km^2 of the Lithuanian territory. This is only 0.57% of the total area of Lithuania or 1.1% of the total area of AL. Our results show that part of the AAL falls into the category of protected areas and cannot be used for WE, and part of the land was assigned to the category "no data". However, the obtained results show that 26.2 km^2 or 7% of the AAL are suitable for WE, 69.5 km^2 or 18.6% of the AAL have an average suitability for WE, and 16.1 km^2 or 4.3% of AAL are not suitable for WE.

We identified suitable AAL for further analysis. For this reason, the pixel cells of 0-values in the raster were removed, and raster data were converted to vector data, with the following formula:

$$(\text{“over210@1”})/(\text{“over210@1”} \; ! = 0).$$

Table 3. Suitability of AAL areas of Lithuania for the establishment of WE parks.

Pixel Value	Pixel Count	Area, km^2	Area, km^2	Area, %	Area, %	Criteria	Suitability
No data	15,285,865	939.0	939.0	1.44	1.44		No data
0	1045,893,983	64,249.2	64,249.2	98.39	98.39		Areas without abandoned land, protected areas
30	1537	0.1	16.1	0.00	0.02	10	Unsuitable abandoned land
70	40,139	2.5		0.00			
110	176,402	10.8		0.02			
120	43,268	2.7		0.00			
150	121,945	7.5	69.5	0.01	0.10	50	Abandoned land with average suitability
160	558,561	34.3		0.05			
200	451,342	27.7		0.04			
210	200,158	12.3	26.2	0.02	0.05	100	Fully suitable abandoned land
250	160,137	9.8		0.02			
300	66,888	4.1		0.01			
Total	1,063,000,225	65,300	65,300	100	100		

Table 4. Final results of the suitability of AAL areas for WE.

Pixelt Value	AAL Area, km^2	AAL Area % of the Total Area of Lithuania	AAL Area % of the Total Area of AL	Suitability of AALfor WE
30–120	16.1	0.02	4.3	Not suitable
150–200	69.5	0.10	18.6	Average suitability
210–300	26.2	0.05	7.0	Fully suitable

Figure 9 shows the results of the vector data of AAL suitable for the establishment of WE parks.

In the street view map fragment (Figure 9) the same territory of AAL areas as in the (Figure 8b) magnified image are presented. Unsuitable AAL areas marked in red; suitable and average suitability AAL areas in yellow.

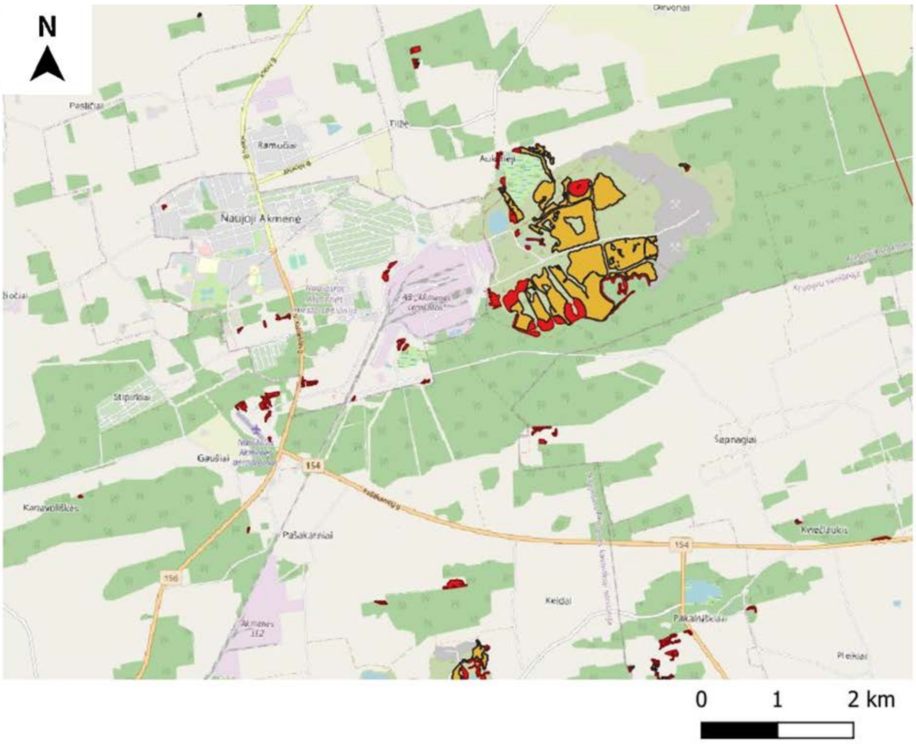

Figure 9. Fragments of the AAL areas in the street view map: red color—unsuitable AAL areas; yellow color—suitable AAL areas.

4. Discussion and Conclusions

The availability of land for the installation of WP turbines in Lithuania is restricted by numerous factors such as climatic conditions and the protection status of an area, as well as social, technical, economic and environmental factors. Because of this, land eligibility for WE analyses is an important issue, along with the proper selection criteria. It is important to maintain a balance between both sides—the side interested in the development of wind parks and the broader society, which is sometimes opposed to the establishment of WPP.

Lithuania, as well as other EU countries, has nature protection obligations, but the current political situation makes it possible to revise the different quantitative criteria and facilitate the issuance of permits for the construction of WF. The Parliament of the Republic of Lithuania has prepared changes to legal acts which would allow easier and faster development of wind and solar projects.

Based on our results:

1. 19% of Lithuanian territory falls into the category of protected areas. In such territories, not only is construction of WPP not allowed, but there are many restrictions to other activities as well. According to the provided criteria, 19.6% of the area of Lithuania was not suitable, 21.6% had an average suitability, and 22.6% was fully suitable for the establishment of WPP.

According to the selection criteria, the central part of Lithuania is most suitable for the development of WE, with a mean wind speed potential at 100 m height of 7 m/s. However, AAL is sparse in this region, accounting for 0.1% to 0.4% of the total area, mainly because of the high soil yield potential.

2. AAL areas in Lithuania cover about 373.6 km^2 or 0.57% of the total area. Our results show that part of the AAL falls into the category of protected areas and cannot be used for WE, 26.2 km^2 or 7% of the AAL are suitable for WE, and 69.5 km^2 or 8.6% of the AAL have an average suitability for WE.
3. A MCDM method TOPSIS was used to select suitable areas for WPP, using different data sets with different quantitative criteria, and GIS software, used for the processing

of data and visualization, is appropriate for evaluation of eligibility of all areas and AAL for the development of WE.

4. Although this study was conducted using the example of Lithuania, the method used to determine the eligibility of AAL for the development of WE can be applied to other countries. The selection criteria can be changed or supplemented with new ones, depending on the needs and requirements. It is also important that the method can be applied to assess the suitability of the various categories of land for WE, and this method can also be applied for the development of sun energy or bioenergy.

Author Contributions: Conceptualization, E.T. and J.S.V.; methodology, E.T., J.S.V. and V.M.; software, J.S.V.; validation, E.T., J.S.V. and V.M.; formal analysis, E.T. and J.S.V.; investigation E.T. and J.S.V.; resources, E.T. and J.S.V.; data curation, E.T. and J.S.V.; writing—original draft preparation, E.T., J.S.V. and V.M.; writing—review and editing, E.T., J.S.V. and V.M.; visualization, E.T.; supervision, V.M. and J.S.V.; funding acquisition, V.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Please contact the authors.

Acknowledgments: The authors gratefully acknowledge the institutional support provided by the Vilnius Gediminas Technical University and Vytautas Magnus University Agriculture Academy.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

AAL	Abandoned agricultural land
ALA	Agricultural land abandonment
GIS	Geographic information system
GDB10LT	Georeferenced Data Base 1:10,000 scale
GWA	Global Wind Atlas
INSPIRE	Spatial Information in the European Community
LITGRID	Lithuanian Electricity Transmission System Operator
LSI	Lithuanian Spatial Information portal
MCDM	Multi-criteria decision-making
RE	Renewable energy
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
WE	Wind energy
WF	Wind farms
WP	Wind power
WPP	Wind power plants

References

1. Eurostat. The Statistical Office of the European Union. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics (accessed on 21 September 2022).
2. Li, T.; Li, A.; Song, Y. Development and Utilization of Renewable Energy Based on Carbon Emission Reduction—Evaluation of Multiple MCDM Methods. *Sustainability* **2021**, *13*, 9822. [CrossRef]
3. International Renewable Energy Agency (IRENA). Future of Wind. 2019. Available online: https://www.irena.org/-/media/files/irena/agency/publication/2019/oct/irena_future_of_wind_2019.pdf (accessed on 21 September 2022).
4. Rehman, S.; Khan, S.A.; Alhems, L.M. Application of TOPSIS Approach to Multi-Criteria Selection of Wind Turbines for On-Shore Sites. *Appl. Sci.* **2020**, *10*, 7595. [CrossRef]
5. Renewable Energy Order of the Republic of Lithuania. 2011. no. XI-1375. Available online: https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.398874/asr (accessed on 21 September 2022). (In Lithuanian)
6. National Energy Independence Strategy of Lithuania. 2018. Available online: http://enmin.lrv.lt/uploads/enmin/documents/files/National_energy_independence_strategy_2018.pdf (accessed on 21 September 2022).

7. Lithuanian Wind Power Association. Available online: https://lvea.lt/en/statistics/ (accessed on 21 September 2022).
8. Official Statistics Portal of Lithuania. Available online: https://osp.stat.gov.lt/ (accessed on 21 September 2022).
9. United Nations (UN). Transforming Our World: The 2030 Agenda For Sustainable Development. 2015. Available online: https://sdgs.un.org/2030agenda (accessed on 21 September 2022).
10. Harrison-Atlas, D.; Lopez, A.; Lantz, E. Dynamic land use implications of rapidly expanding and evolving wind power deployment. *Environ. Res.* **2022**, *17*, 044064. [CrossRef]
11. Nitsch, F.; Turkovska, O.; Schmidt, J. Observation-based estimates of land availability for wind power: A case study for Czechia. *Energy Sustain. Soc.* **2019**, *9*, 1–13. [CrossRef]
12. Denholm, P.; Hand, M.; Jackson, M.; Ong, S. Land-Use Requirements of Modern Wind Power Plants in the United States. National Renewable Energy Laboratory. Technical Report. 2009. Available online: https://www.nrel.gov/docs/fy09osti/45834.pdf (accessed on 21 September 2022).
13. Ryberg, D.S.; Robinius, M.; Stolten, D. Evaluating land eligibility constraints of renewable energy sources in Europe. *Energies* **2018**, *11*, 1246. [CrossRef]
14. McKenna, R.; Pfenninger, S.; Heinrichs, H.; Schmidt, J.; Staffell, I.; Bauer, C.; Gruber, K.; Hahmann, A.N.; Jansen, M.; Klingler, M.; et al. High-resolution large-scale onshore wind energy assessments: A review of potential definitions, methodologies and future research needs. *Renew. Energy* **2022**, *182*, 659–684. [CrossRef]
15. Fayet, C.M.J.; Reilly, K.H.; Van Ham, C.; Verburg, P.H. The potential of European abandoned agricultural lands to contribute to the Green Deal objectives: Policy perspectives. *Environ. Sci. Policy* **2022**, *133*, 44–53. [CrossRef]
16. Fayet, C.M.J.; Reilly, K.H.; Van Ham, C.; Verburg, P.H. What is the future of abandoned agricultural lands? A systematic review of alternative trajectories in Europe. *Land Use Policy* **2022**, *1*, 112. [CrossRef]
17. Visockienė, J.S.; Tumelienė, E.; Malienė, V. Identification of *Heracleum sosnowskyi*-invaded land using earth remote sensing data. *Sustainability* **2020**, *12*, 759. [CrossRef]
18. Levers, C.; Schneider, M.; Prishchepov, A.V.; Estel, S.; Kuemmerle, T. Spatial variation in determinants of agricultural land abandonment in Europe. *Sci. Total Environ.* **2018**, *644*, 95–111. [CrossRef] [PubMed]
19. Sæþórsdóttir, A.D.; Wendt, M.; Tverijonaite, E. Wealth of Wind and Visitors: Tourist Industry Attitudes towards Wind Energy Development in Iceland. *Land* **2021**, *10*, 693. [CrossRef]
20. Pohekar, S.D.; Ramachandran, M. Application of multi-criteria decision making to sustainable energy planning. *Renew. Sustain. Energy Rev.* **2004**, *8*, 365–381. [CrossRef]
21. Maliene, V.; Fowles, S.; Atkinson, S.; Malys, N. A sustainability assessment framework for the high street. *Cities* **2022**, *124*, 103571. [CrossRef]
22. Maliene, V.; Dixon-Gough, R.; Malys, N. Dispersion of relative importance values contributes to the ranking uncertainty: Sensitivity analysis of Multiple Criteria Decision-Making methods. *Appl. Soft Comput.* **2018**, *67*, 286–298. [CrossRef]
23. Mulliner, E.; Malys, N.; Maliene, V. Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. *Omega* **2016**, *59*, 146–156. [CrossRef]
24. Reports of the State Land Fund of Lithuania 2022. Available online: http://www.nzt.lt/go.php/lit/Lietuvos-respublikos-zemes-fondas (accessed on 21 September 2022). (In Lithuanian)
25. Spatial Information Portal of Lithuania (LSI). 2022. Available online: http://www.geoportal.lt (accessed on 21 September 2022).
26. The Global Wind Atlas. Available online: https://globalwindatlas.info/area/Lithuania (accessed on 21 September 2022).
27. Zavadskas, E.K.; Mardani, A.; Turskis, Z.; Jusoh, A.; MD Nor, K. Development of TOPSIS Method to Solve ComplicatedDecision-Making Problems: An Overview on Developments from 2000 to 2015. *Int. J. Inf. Technol. Decis. Mak.* **2016**, *15*, 645–682. [CrossRef]
28. Roszkowska, E. Multi-Criteria Decision Making Models by Applying the TOPSIS Method to Crisp and Interval Data. Available online: https://mcdm.ue.katowice.pl/files/papers/mcdm11(6)_11.pdf (accessed on 21 September 2022).
29. Garduño-Ruiz, E.P.; Silva, R.; Rodríguez-Cueto, Y.; García-Huante, A.; Olmedo-González, J.; Martínez, M.L.; Wojtarowski, A.; Martell-Dubois, R.; Cerdeira-Estrada, S. Criteria for Optimal Site Selection for Ocean Thermal Energy Conversion (OTEC) Plants in Mexico. *Energies* **2021**, *14*, 2121. [CrossRef]
30. Legal Regulations of the Republic of Lithuania. Order of Special Land Use Conditions. 6 June 2019. no. XIII-2166. Available online: https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/46c841f290cf11e98a8298567570d639/asr (accessed on 21 September 2022). (In Lithuanian)
31. Coastal Research and Planning Institute. Environmental Impact Assessment Report of the Installation and Operation of the Wind Power Park in Pagėgiai Municipality, 2021, 331. (In Lithuanian) Available online: http://corpi.lt/wp-content/uploads/2021/03/PAV-ataskaita_VE-Pagegiai_2021_0318-viesinimui.pdf (accessed on 21 September 2022).
32. Order of the Minister of Environment of the Republic of Lithuania. The Approval of Order Description Regarding the Establishment of Protection Zones and Coastal Protection Bands for Surface Water Bodies. 7 November 2021. no. 540. Available online: https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.153823/asr (accessed on 21 September 2022). (In Lithuanian)