energies

Article

Energy Efficiency of Small Wind Turbines in an Urbanized Area—Case Studies

Adam Zagubień * **and Katarzyna Wolniewicz**

Faculty of Civil Engineering, Environmental and Geodetic Sciences, Koszalin University of Technology, ul. Śniadeckich 2, 75-453 Koszalin, Poland; katarzyna.wolniewicz@tu.koszalin.pl
* Correspondence: adam.zagubien@tu.koszalin.pl

Abstract: This study aimed to determine whether the wind zone that characterizes a given area of the country in open area is reflected in the built-up area lying within the zone. Analysis included four Polish cities located in different wind zones. The two-parameter Weibull density distribution function was used to present the wind conditions at each location. Two 3 kW VAWT devices were selected to evaluate the productivity of wind turbines at the locations analyzed. It was shown that the wind zones characterizing the wind potential of a region in an open area have no significant influence on the wind conditions in the built-up area located in that area. It was determined that the study location's did not exhibit wind potential that could be economically justified by a wind turbine. WTs in the city do not reach their nominal productivity. A decisive advantage of very light winds was observed (up to 2 m/s) and a large proportion of so-called atmospheric calms. It was shown that the installation of small wind turbines in an urbanized area requires a minimum of annual wind measurements at the exact location and height of each future turbine planned.

Keywords: wind energy; wind conditions; Weibull distribution; wind turbine; energy prices

check for updates

Citation: Zagubień, A.; Wolniewicz, K. Energy Efficiency of Small Wind Turbines in an Urbanized Area—Case Studies. *Energies* **2022**, *15*, 5287. https://doi.org/10.3390/en15145287

Academic Editor: Roberto Alonso González Lezcano

Received: 13 June 2022
Accepted: 18 July 2022
Published: 21 July 2022

1. Introduction

Wind power deserves special attention among the energy technologies that use renewable energy sources [1,2]. The energy obtained from wind is environmentally friendly. This clean energy contributes to the energy security of a country (globally), or a specific region such as a municipality, county, or province (locally). In contrast to the extensive research on large wind turbines, detailed energy analyses of small wind turbines are still rare. Horizontal axis wind turbines (HAWTs) with large capacities are mainly installed in open areas where the roughness of the terrain is low. Owing to their high sound power level (greater than 100 dB), HAWTs are installed at considerable distances from residential areas [3–7]. Their high sound power level is mainly related to the design of the rotor blades [8,9]. However, increasing attention is being paid to the possibility of wind energy use in urban areas, where the wind potential is lower and the terrain roughness is higher [10]. Due to the relatively low sound power level (less than 80 dB) of vertical axis wind turbines (VAWTs), they can be located close to residential buildings [11–13]. The productivity of a wind turbine is mainly affected by wind speed [14]. The average annual wind speed varies greatly in different regions of the country. There are regions where the wind speed is less than 2 m/s, but there are also regions where the average annual wind speed is over 7 m/s.

Five wind zones can be distinguished in Poland: highly favorable, very favorable, favorable, slightly favorable, and unfavorable. Poland is located in the moderate zone characterized by average windiness, but locally there are sufficiently favorable conditions for the profitable generation of electricity.

Convenient conditions for wind energy investments are found wherever the average annual wind speed is above 6 m/s. This involves mainly coastal regions. Winds with an average speed of about 4 m/s occur in a significant proportion of the Polish territory.

High-power winds prevail in Poland in the winter months. It is estimated that over 60% of the annual energy generated in Europe from wind power can be obtained during the heating season, i.e., from November to March. A general knowledge of the wind potential (Figure 1) and the distribution of wind direction greatly facilitates the selection of wind turbine location. A detailed analysis of the wind energy potential is based on a minimum of one year's wind research carried out in a specific location [15].

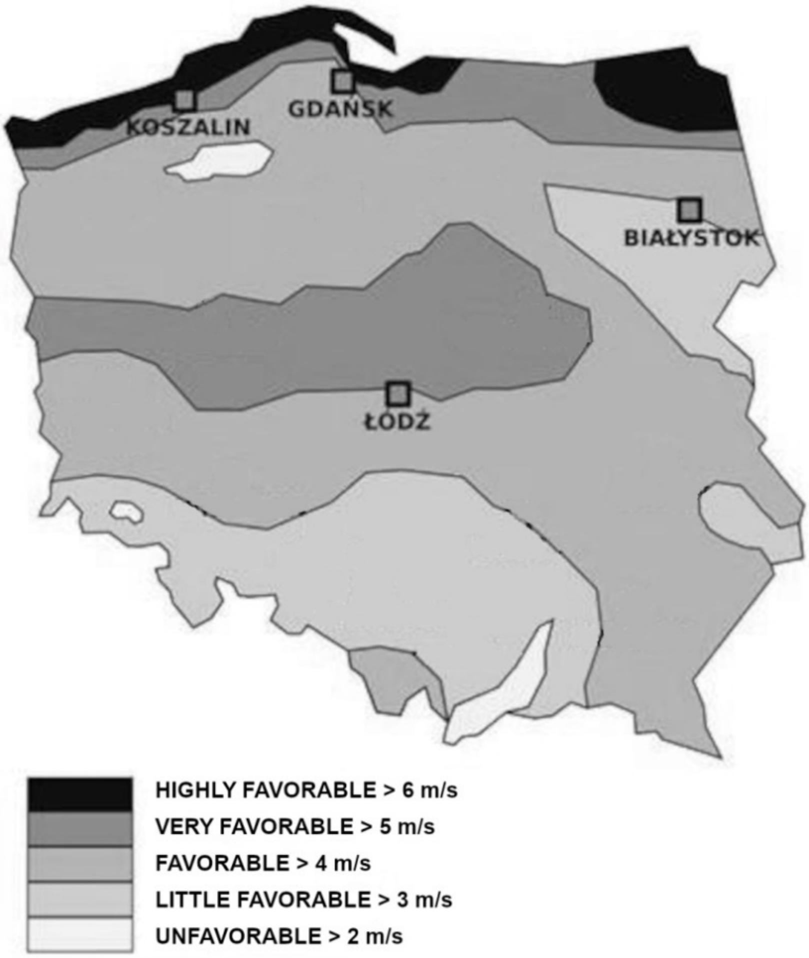

Figure 1. Wind energy zones in Poland and analysis sites.

Wind speed distribution depends to a high degree on local topographic and urban conditions. Architectural barriers that disrupt wind flow create "roughness" in the land surface. The reduction in wind speed is smallest over the surface of large bodies of water and greatest in densely developed urban areas. Wind flowing through an open area approaches the boundaries of the built-up area and encounters resistance caused by buildings. This resistance reduces the wind flow speed at the usable level of the urban area, which forms a disturbed transition zone between the ground and the undisturbed wind flow over the city. Near the ground, the wind experiences friction. Its speed is drastically reduced and flow turbulence increases [16–18]. The state of windiness in an urban area is a major factor affecting the living comfort of residents. Wind conditions in an urban area determine building ventilation, air purification, heat transfer through the wall barriers, and rain flooding of wind-exposed facades. Strong urban wind causes discomfort among pedestrians, especially in colder seasons [17–24]. Therefore, urban planners, when designing land use, are mainly guided by the criterion of residents' comfort. Concurrently, they affect the reduction of wind speed in the city, which hinders the utilization of wind energy potential in the urban area. Air movement velocity at street level and wind turbulence conditions depend on regional wind speed. Wind conditions over a larger area depend on climatic factors. In a city, urban characteristics must be additionally considered.

Buildings not only counteract the effect of wind, but also affect the air flow around them. Wind flow in the city develops very differently depending on wind direction, building shape, and wind properties [18,25,26]. Locally accelerated wind flows and turbulence resulting from the interaction of buildings with the actual wind flow illustrate the wind situation in an urban area. Typical selected effects of wind flow disturbances are shown in Figure 2.

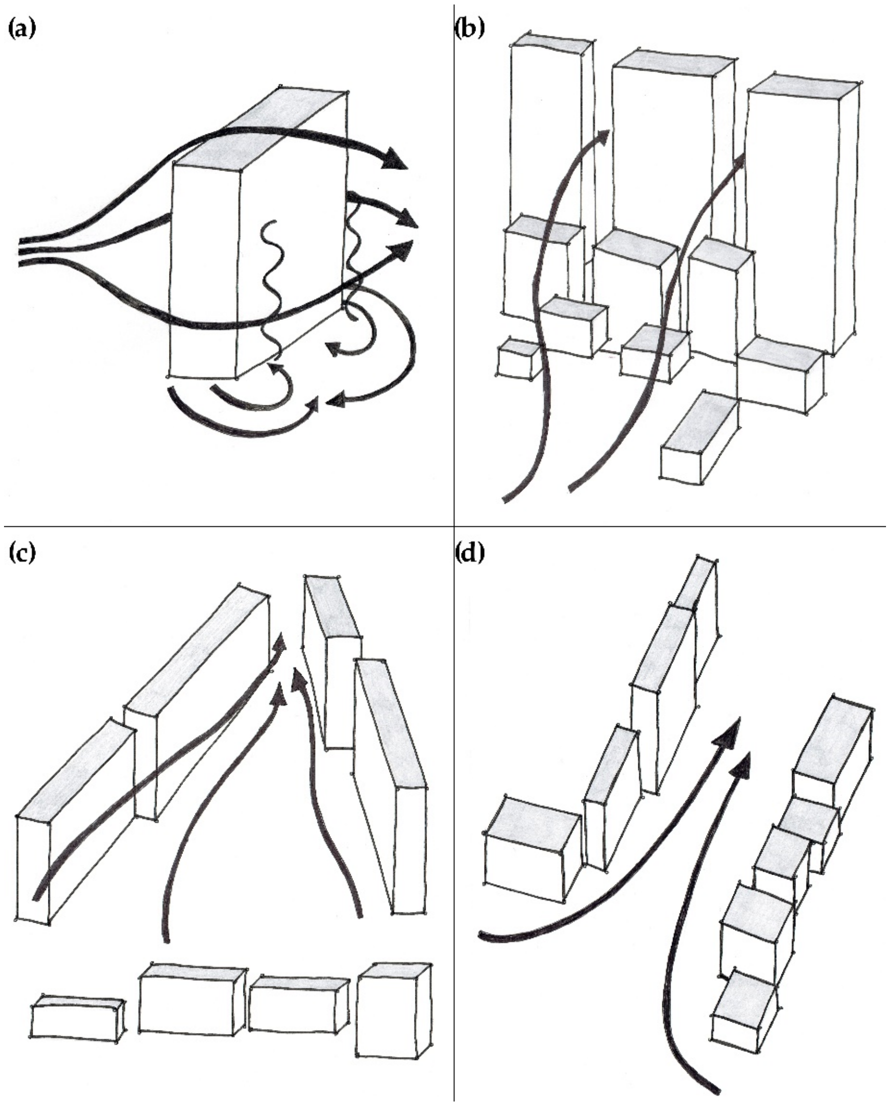

Figure 2. Disturbed wind flow in urban areas: (**a**) formation of vortices, (**b**) wind protection effect, (**c**) Venturi effect, (**d**) channeling.

Due to various flow effects, the global wind flow generates a discontinuous flow field in the discussed urban district, often with significant accelerating effects near and between the buildings.

To determine windiness for energy purposes at a specific point in a city, an individual annual wind speed measurement must be taken at the location and height of the future wind turbine installation. Due to the wind turbulence caused by buildings, windiness information from local weather stations can lead to a false estimation of wind turbine productivity, especially since most of the urban area is outside the long-term registration site of the meteorological station. In addition, weather stations record data at a single altitude, usually 10 m above the station area, and on flat, usually open terrain.

Due to the scarcity of publications on the energy use of wind potential in the cities, the task of calculating the energy efficiency of small wind turbines in selected locations was undertaken. Four case studies are included in the paper. On their basis, it was shown that the problem of obtaining a satisfactory energy efficiency of wind turbines installed in the city may occur frequently. It is shown that in order to assess the windiness of a specific location from an energy perspective, annual results from measuring instruments located at the exact site of the future turbine installation are necessary.

The aim of this study was to determine whether the wind zone that characterizes a given area of the country in open area is reflected in the built-up area lying within the zone. Four cities located in different wind zones were selected for analysis: Koszalin (very favorable zone), Łódź (favorable zone), Białystok (slightly favorable zone) and Gdańsk (favorable zone)—see Figure 1. The parameters of the wind conditions in Koszalin were determined on the basis of our own measurements conducted for a period of one year using a measuring mast. The results of wind speed measurements in Łódź, Białystok and Gdańsk were obtained from publications of other authors [27–29]. The results of the analyses were related to several urbanized areas outside Poland [10]. The installation of 3 kW VAWT turbines was assumed in each location investigated for efficiency evaluation.

Section 2 describes the wind potential of the studied locations and establishes a uniform method of data presentation. For each studied location, the wind speed density distribution was developed. Parameters of VAWT turbines used for productivity analyzes are also provided. Section 3 presents calculations and demonstrates graphically and numerically the amount of network energy obtained in a given studied location during the year by selected types of turbines. Section 4 describes results and conducts a simplified economic analysis. Section 5 provides the conclusions drawn on the basis of the performed research. Conclusions from the conducted analyses may be of practical use because they describe potential difficulties in obtaining adequate energy efficiency of wind turbines installed in the city. The selection of the optimal place for measuring wind conditions for energy purposes in built-up areas was indicated and justified, and may be used by other researchers to conduct further analyses.

2. Materials and Methods

2.1. Presentation of Measurement Results

Due to the different sources of the analyzed wind speed data at the study locations, the presentation of the results was standardized. The two-parameter Weibull density distribution function was used to graphically present the wind conditions at each location. The percentage results obtained from the density function were multiplied in each speed class by 8760 (number of hours in a year). This yielded the number of hours for each wind speed class.

The two-parameter Weibull probability density function is expressed by:

$$p(v) = \left(\frac{k}{A}\right)\left(\frac{v}{A}\right)^{k-1} e^{-\left(\frac{v}{A}\right)^{k}} \tag{1}$$

where v, k, A > 0.

Dimensionless factor k determines the shape of the curve and is called a shape factor. Parameter A is the scale parameter. The distributions take different shapes with different values of k and A. Although different wind speed distribution models are applied to fit the wind speed over a time period, the two-parameter Weibull function is accepted as the most popular technique [30,31].

2.2. Locations Studied

Four urban agglomerations of different sizes located in different wind zones in Poland were selected for analysis. Koszalin (the first location) covers an area of 98.3 km^2 (very favorable zone), Łódź (the second location) covers an area of 293.3 km^2 (favorable zone), Białystok (the third location) covers an area of 102.1 km^2 (slightly favorable zone), while

Gdańsk (the fourth location) covers an area of 262.0 km^2 (favorable zone). The parameters of wind conditions in Koszalin were determined based on own measurements. The results of wind speed measurements from the cities of Łódź, Białystok and Gdańsk were obtained from publications [27–29]. The measurements of wind conditions in each of the four cities lasted at least one year.

2.2.1. Location I (Loc I)

In order to acquire meteorological data on the Koszalin University of Technology campus, a telescopic tubular mast of a total height of 13.6 m was installed. The mast was equipped with two anemometers located at 13 m and 8.8 m above ground level (Figure 3). Data were recorded continuously for a period of one year, i.e., from 1 August 2019 to 31 July 2020.

Figure 3. View of the measuring mast.

It was found that the wind blows most often from the SSW direction (more than 8% of the time during the year), this is the dominant wind direction at this location. The wind from the SSW direction blows most often with the speed of 2–3 and 3–4 [m/s]. Weaker winds blow from the NNW direction, most often at 1–2 [m/s].

Graphical interpretation of the wind speed distribution at the height of 13 m at the studied location based on the results obtained is shown in Figure 4.

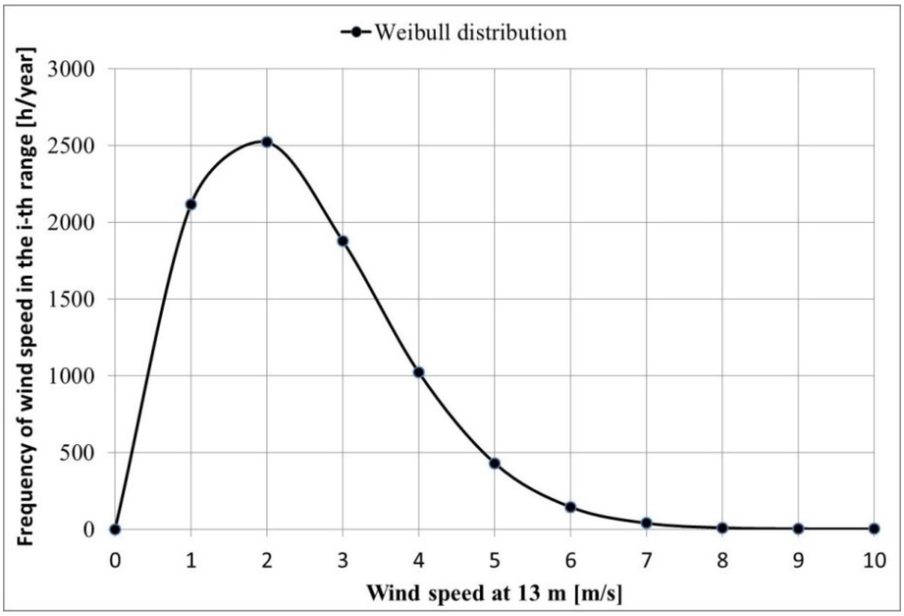

Figure 4. The Weibull distribution for the anemometer at 13 m above ground level for location I.

2.2.2. Location II (Loc II)

A comparison between the results of wind conditions in the center of Łódź (Loc-IIa) and at a distance of 6.5 km from the city, in an open area (airstrip in Lublinek, Loc-Iib) was made in publication [27]. The average annual wind speed at the airport was 3.2 m/s, while at the square in the city center it was approximately 2.1 m/s, calculated on the basis of monthly mean values. The average annual wind speed in the city is 35% lower than that recorded in the open area. The results of wind parameters cover a period of five years (1997–2001). Wind speed measurements were made with a Campbell anemometer placed at a height of 10 m above ground level. The results from 10 min measurement periods were averaged. Graphical interpretation of the wind speed distribution at the height of 10 m in the studied location based on the obtained results is presented in Figures 5 and 6.

2.2.3. Location III (Loc III)

According to the authors of the publication [28], annual measurements of wind conditions in Białystok were conducted on the campus of Bialystok University of Technology, which is located in the southern part of the city. Wind speed measurements were conducted from 1 January 2016 to 1 January 2017. The study was performed with a recorder equipped with an anemometer type Vintage Pro from Davis Instruments with an accuracy of ±0.1 m/s. Points were located at different heights above ground level. In order to compare the results, a measuring height of 13 m above the ground level (a point on the roof of the building) was used. The measurements were conducted continuously and the results recorded from 10 min measurement periods were averaged. Graphical interpretation of the wind speed distribution at the height of 13 m in the tested location on the basis of the obtained results is presented in Figure 7.

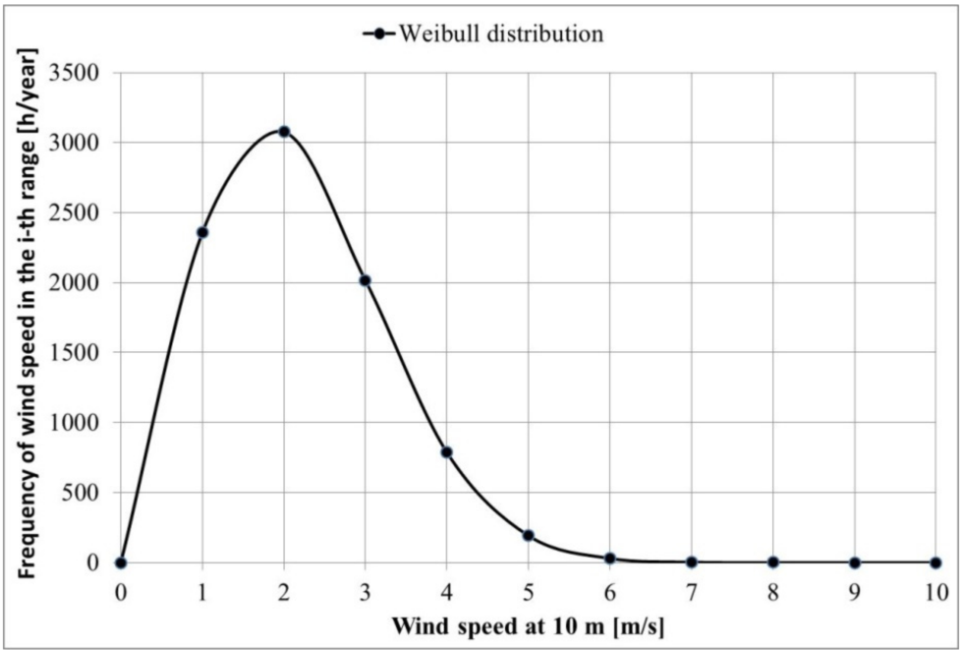

Figure 5. The Weibull distribution for the anemometer at 10 m above ground level for location Iia—city center.

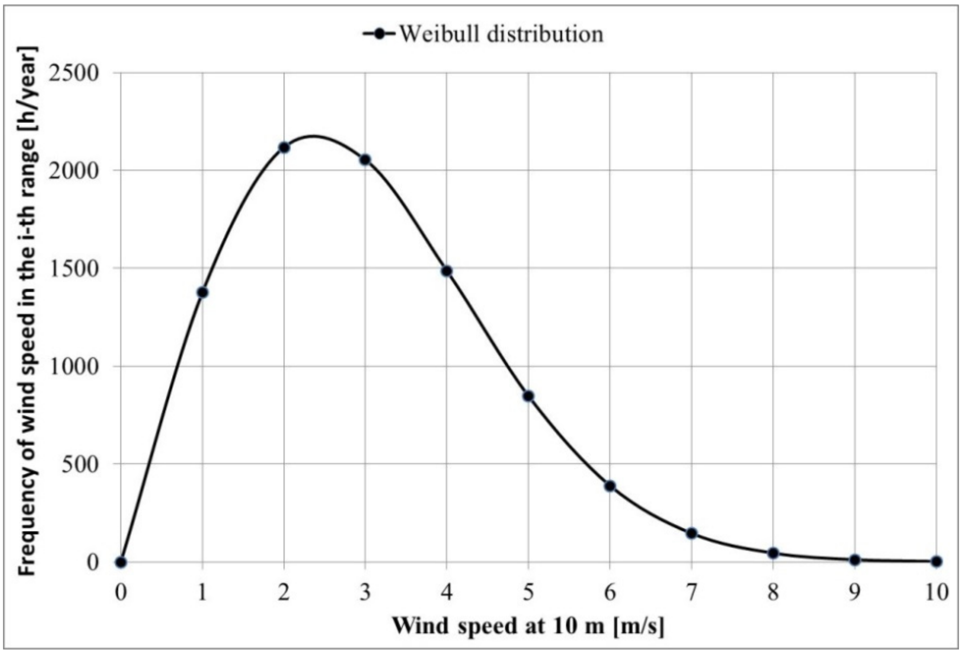

Figure 6. The Weibull distribution for the anemometer at 10 m above ground level for location IIb—airstrip.

The authors of the publication [28] determined that winds with a speed equal to 1 m/s are most common at the analyzed points. The probability of occurrence of winds of 5 m/s at the analyzed point is 4%.

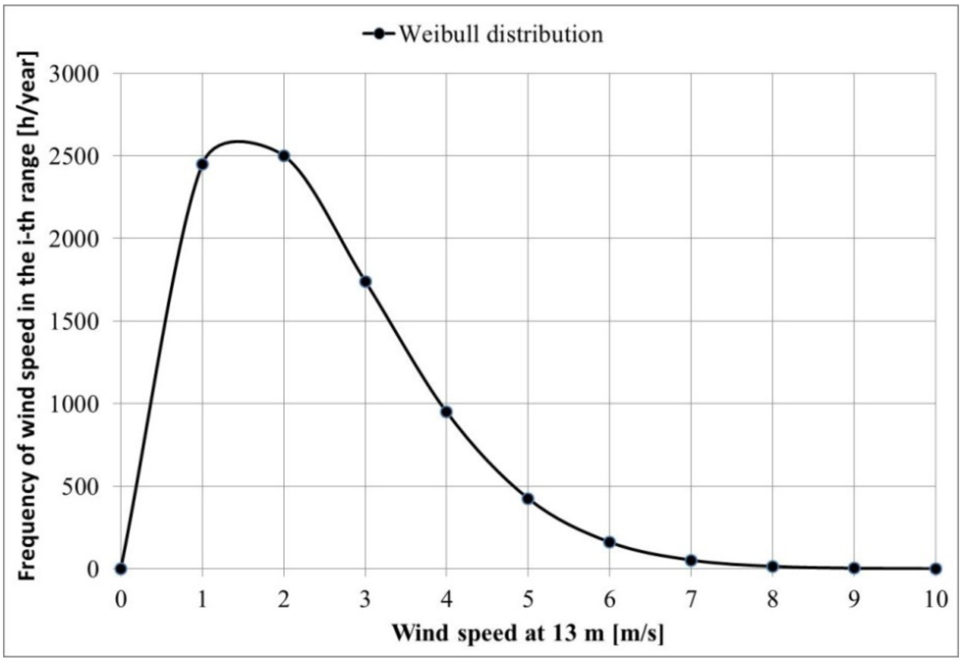

Figure 7. The Weibull distribution for the anemometer at 13 m above ground level for location III.

2.2.4. Location IV (Loc IV)

According to the authors of the publication [29], the average annual measurements of wind conditions in the center of Gdańsk were obtained from the commercial portal Open Weather Map [32]. Analyses were conducted using wind speeds from 1 January 2015 to 26 July 2021 measured at 10 m above ground level. It should be noted that the coordinates of the wind measurement point indicated in the publication indicate a location in the middle of two wide traffic arteries crossing. It is likely that the data encompass a channelized wind stream (see Figure 2d). Graphical interpretation of the wind speed distribution at a height of 10 m at the investigated location based on the acquired results is presented in Figure 8.

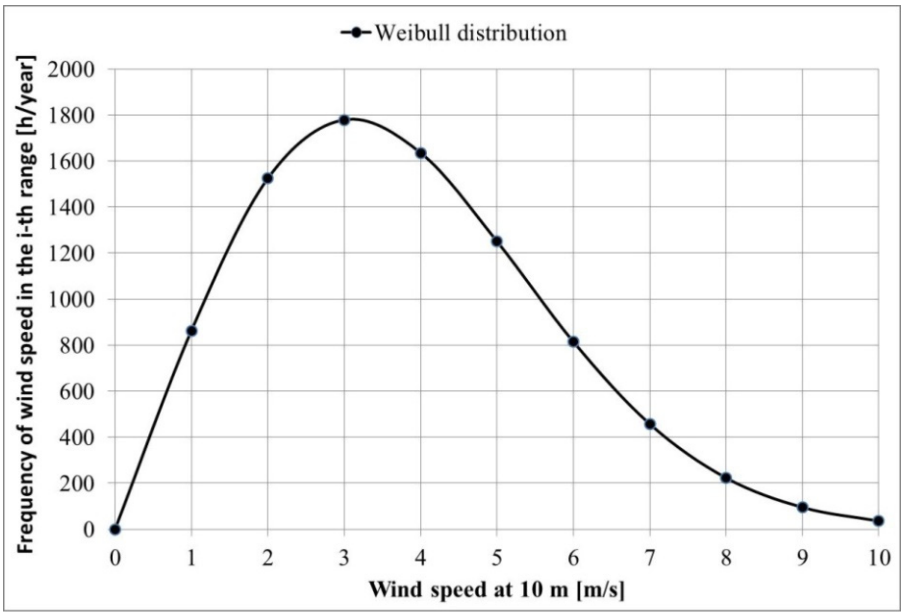

Figure 8. The Weibull distribution for the anemometer at 10 m above ground level for location IV.

The authors of the publication [29] determined that the best average wind conditions in the examined location occur in April (3.51 m/s) and the worst in August (2.38 m/s).

2.3. Comparative Turbines

Wind turbines use wind energy to generate grid power. The installation of wind turbines is intended to achieve a positive economic effect. The amount of energy generated to the grid over a set period of time must balance the cost of installation and service, and then generate a profit. Two 3 kW VAWT devices were selected to evaluate the productivity of wind turbines at the locations analyzed. Turbine WT1 (model TVK3) is a two-rotor Savonius + Darrieus-rotor—Figure 9a. WT2 turbine (model Aeolos V) has an H-Darrieus rotor—Figure 9b. Power curves of both turbines are shown in Figure 10. Basic technical data of both turbines are summarized in Table 1.

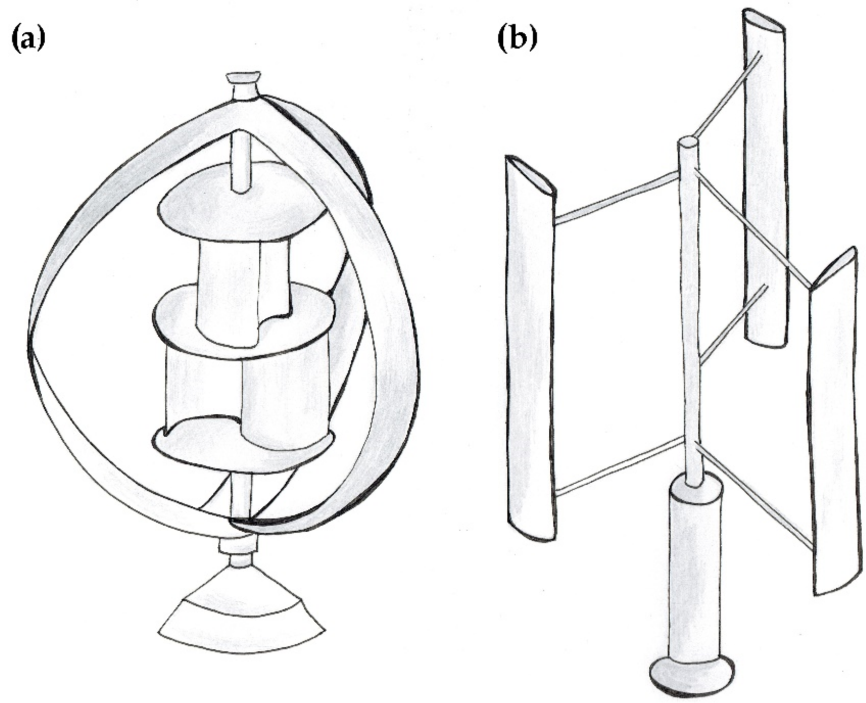

Figure 9. Turbine types selected for analysis (**a**) WT1, (**b**) WT2.

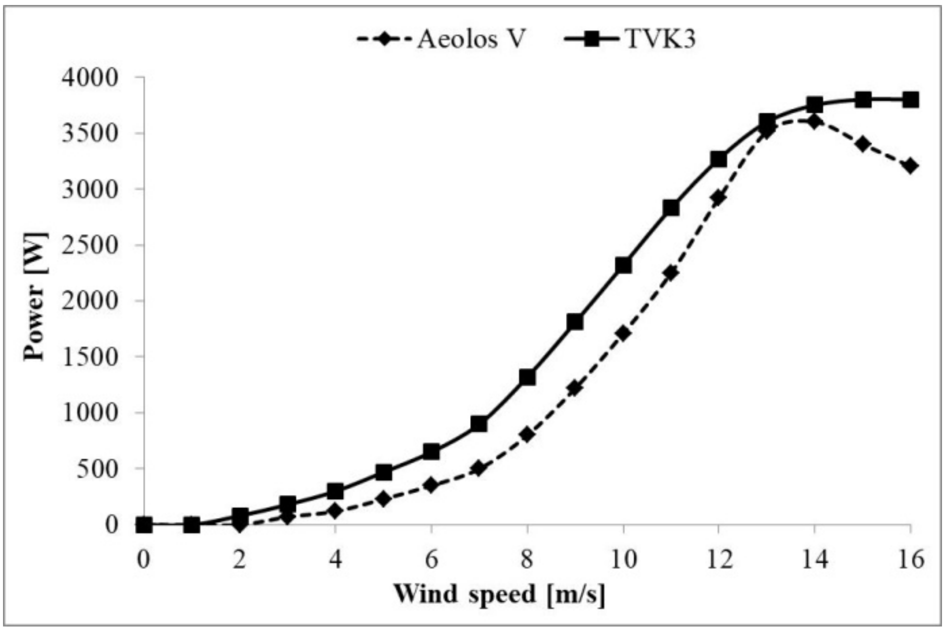

Figure 10. Power curves of the analyzed turbines.

Table 1. Selected technical data of the analyzed turbines.

Performance	Wind Turbine WT1	Wind Turbine WT2
	TVK3	**AEOLOS V**
Rated Power	3000 W	3000 W
Max Output Power	3800 W	3600 W
Cut In Wind Speed	1.5 m/s	2.5 m/s
Rated Wind Speed	13 m/s	12 m/s
Survival Wind Speed	60 m/s	55 m/s

WT1 and WT2 turbines have different power curves and take-off speed (Figure 10). For turbines installed in low wind areas, both of these parameters have a significant impact on grid power generation. They significantly affect the economic aspect of turbine installation.

3. Results

Based on the power curves of the selected power plants (Figure 10), the value of the generated power P_{we_i} was determined for the wind speeds v_i being the centers of the consecutive class intervals. In the next step, based on the Weibull distributions (Figures 4–8), the energy E_{we_i} generated by the power plant during one year in the next i-th class interval was calculated:

$$E_{we\_i} = P_{we\_i} \cdot t_i = P_{we\_i} \cdot f_i \cdot T_Y \quad (2)$$

where:

T_Y—one year expressed in hours, 8760 h
f_i—frequency of wind speed falling within the i-th range.

Basing on the productivity vs. wind speed data available for each turbine, the annual energy production was determined of each of the turbines. Summing the component energy from all the intervals gives the total energy generated during one year by the power plant E_{we}:

$$E_{we} = \sum_{i=1}^{k} E_{we\_i} \quad (3)$$

Figures 11 and 12 show the productivity of selected turbines as a function of wind speed.

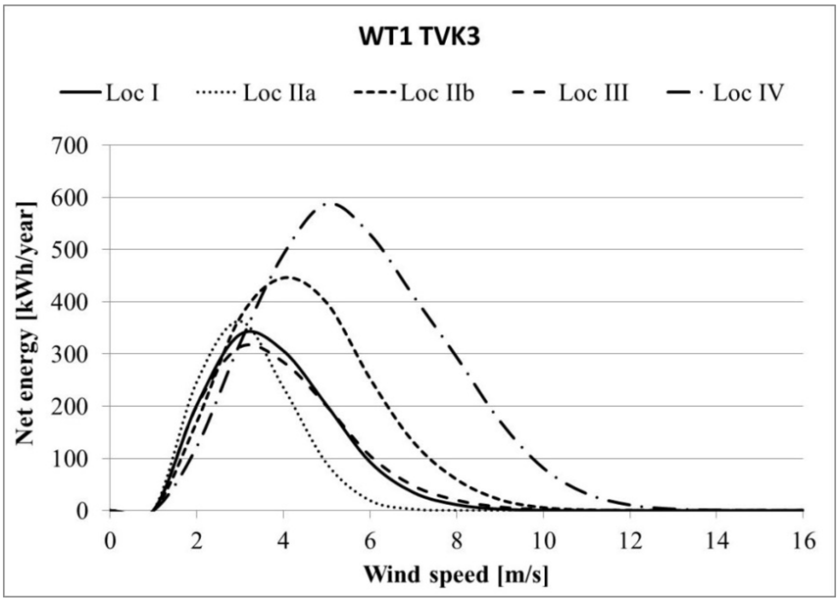

Figure 11. Amount of energy supplied to the power grid by the wind turbine as a function of the wind speed—WT1.

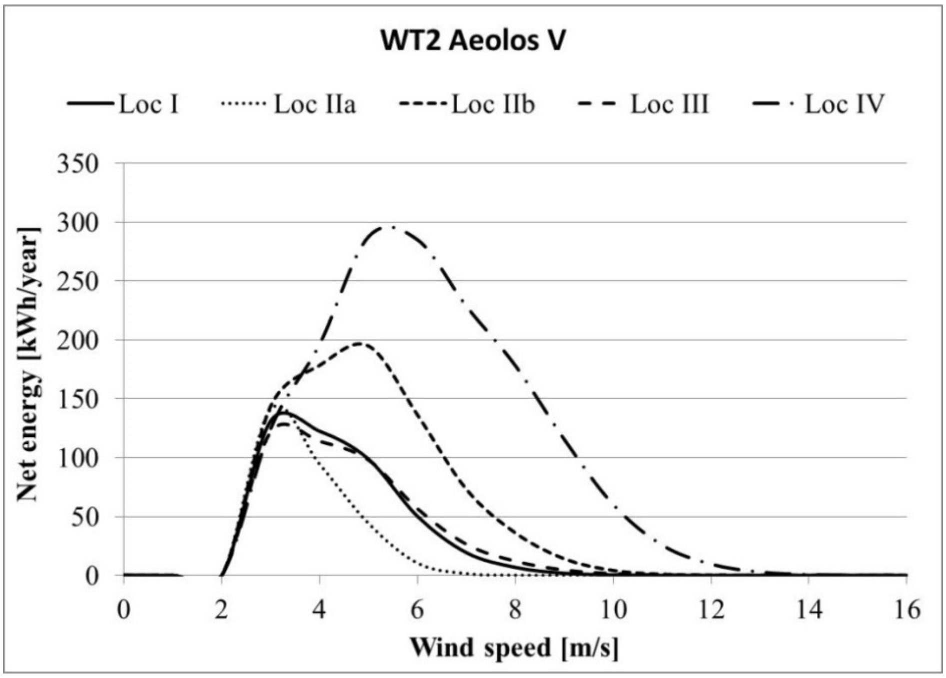

Figure 12. Amount of energy supplied to the power grid by the wind turbine as a function of the wind speed—WT2.

Figures 13 and 14 graphically show the amount of grid energy E_we produced by WT1 and WT2 turbines at a given location during the year. The numerical results are summarized in Table 2. Figures 11–14 show the highest productivity of both turbines at Loc IIb (airstrip near Łódź) and Loc IV (city of Gdańsk). WT1 turbine achieves more than twice the productivity of WT2 turbine at each of the studied locations.

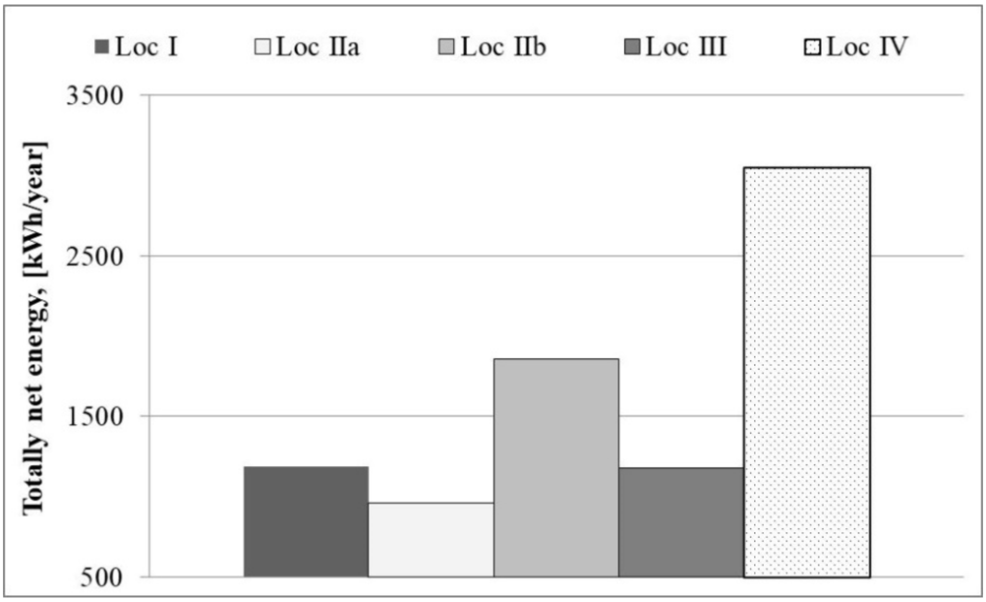

Figure 13. Amount of energy supplied to the power grid by the wind turbine WT1.

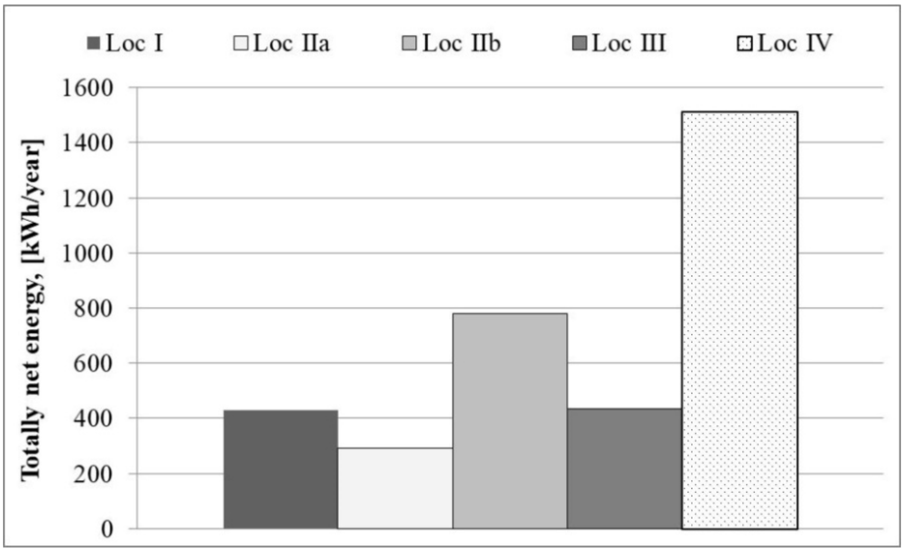

Figure 14. Amount of energy supplied to the power grid by the wind turbine WT2.

Table 2. Annual amount of energy delivered to the power grid by wind turbines.

Model WT	Total Net Energy, [kWh/Year]				
	Loc I	Loc IIa	Loc IIb	Loc III	Loc IV
WT1	1189	957	1855	1180	3054
WT2	431	292	782	435	1514

4. Discussion

Economic analyses of wind turbines have taken various forms in the literature, but have mainly focused on large wind turbines [33,34]. Few such analyses are available for small VAWT wind turbines that can be installed individually by urban residents. The main criterion for turbine selection is maximum productivity of the device under local wind conditions. The wind speed distribution at a given location and the power curve of the selected turbine determine the amount of energy generated to the power grid. The positive economic effect depends on the construction and operating costs of the equipment, as well as the amount of energy generated. Based on the wind speed distributions (Figures 4–8) and power curves (Figure 10), it can be concluded that the selected wind turbines do not reach their nominal power. The energy analysis indicates significant differences in the productivity of WT1 and WT2 turbines in the selected locations. The highest turbine productivity in the center of Gdańsk is probably due to the location of the measurement point in a channelized wind flow. Based on these results, it is difficult to predict the actual productivity of turbines placed on the roof of a nearby building or in their vicinity. Productivity results for locations in Koszalin (Loc I), Łódź (Loc IIa) and Białystok (Loc III) are similar. The location of the measurement point at the airstrip (Loc IIb) near Łódź indicates that the productivity of turbines in open terrain is higher than in urbanized areas in the Łódź region. It should be emphasized that wind speed measurements in the area of Koszalin, Łódź and Białystok were conducted in potential locations of future wind turbines. The wind speed distributions indicate a significant (more than 75%) proportion of winds below 3 m/s, i.e., below the take-off speed of the majority of manufactured wind turbines. The authors of publication [29] used the results of measurements from the center of the city of Gdańsk for a general assessment of the possibility of small wind turbines installation in Gdańsk.

Similar analyses of wind resource utilization for energy purposes were conducted in Morocco [10]. Five cities in the northern part of the country were selected for the analysis. Wind measurements carried out by local meteorological stations placed 10 m above the level of the terrain were used in the study. The analyses conducted in Morocco aimed to install high-capacity wind turbines (2.3 MW) on the outskirts of cities. Three locations showed poor results, with prevailing winds below 4 m/s and an average annual wind speed of about 4 m/s. Two locations, where average annual wind speeds of 6 to 7 m/s were obtained, proved to be suitable for wind turbine installation. Energy analyses on the basis of data obtained from an open area indicate that the installation of the turbines in an open area is sensible. Relating the results of measurements obtained from the open area to the possibility of the wind turbines installing in the city on roofs of buildings or near building façades may lead to significant overestimation of turbine productivity.

The case studies allowed us to formulate a thesis that the wind zone, which characterizes a given area of the country in open terrain, does not reflect the whole built-up area situated in the same zone. The cities of Koszalin (Loc I) and Białystok (Loc III) are situated in different wind zones in the country. Koszalin is located in a very favorable zone, whereas Białystok in a slightly favorable zone. The productivity results obtained for selected turbines in urbanized areas in these locations are almost identical (see Table 2). The cities of Łódź and Gdańsk are situated in the country's favorable wind zone. The productivity of selected turbines in Łódź (Loc IIa) turned out to be the lowest of all investigated locations. The results obtained in the center of Gdańsk (Loc IV) show by far the highest productivity among the investigated locations; however, the location of the measurement point raises many doubts.

The economic viability of wind turbine installation in the investigated locations should be also taken into account. The calculations were simplified to only estimate the result. A VAWT wind turbine with a nominal capacity of 3 kW costs approximately EUR 10,000. The cost of installation in Poland, i.e., support structure, installation, design documentation is also about EUR 10,000. The annual cost of renting a measuring mast and recording wind speed measurements at a particular location should also be included. For the purposes of this publication, this cost is also estimated at EUR 10,000. The cost of turbine servicing is not included. The average electricity price in Poland is currently 0.16 EUR/kWh. Based on Table 2, the annual profit per location was calculated and summarized in Table 3. The calculations were performed only for the WT1 turbine, which shows higher productivity in the selected locations. The WT1 turbine is one of the few commercially available devices that generate electricity from a wind speed of 2 m/s. It has a take-off speed of only 1.5 m/s.

Table 3. Annual profit from the sale of energy delivered to the electricity grid.

Model WT	Annual Profit, [EUR/year]				
	Loc I	Loc IIa	Loc IIb	Loc III	Loc IV
WT1	190	153	297	189	489

The result means that in order to cover the total wind turbine installation cost of approximately EUR 30,000, the WT1 turbine would have to operate at the selected sites for between 61 (Loc IV) and 196 (Loc IIa) years. The average lifetime of wind turbines is estimated to be about 25 years. The calculations ignore an increase in electricity prices, which will certainly increase; however, it is difficult to expect that the profit from the sale of energy will cover the cost of turbine installation during 25 years of average operation. The results of the analysis refer to a height of 10 to 13 m above ground level. This height corresponds to the installation of a wind turbine on the roof of a 3–4 story building.

5. Conclusions

The following conclusions were made based on the research and analysis conducted:

1. The location of a wind turbine requires individual analysis of wind speed over a period of at least 1 year and an assessment of energy potential.
2. The impact of neighboring buildings on wind parameters should be determined before selecting a wind turbine location in an urbanized area.

3. In the urbanized area, the wind reaches half of the speed throughout the year compared to the open area. There is a definite advantage of very light winds (up to 2 m/s) and a large proportion of so-called atmospheric calms, especially during night hours in spring and summer.
4. Compared with the non-built up area, there are significant deformations of wind speed and direction in the urban area due to the presence of high roughness of anthropological type (buildings and structures, towers, poles).
5. The locations studied do not demonstrate wind potential that can economically justify a wind turbine.
6. Wind zones that characterize the wind potential of a given location in open area do not have a significant impact on wind conditions in built-up areas located in that region.
7. It was demonstrated that energy productivity in a built-up area (Koszalin) located in a zone with very favorable wind conditions may be comparable to that in a zone with little favorable wind conditions (Białystok).

When designing a power plant consisting of many HAWT wind turbines with a capacity of more than 3 MW each in an open area, the wind data from one to two measuring masts for the entire project are generally sufficient. It is also possible, taking into account the roughness of the terrain, to convert the obtained results to a different height than the measured height. In the case of installing small VAWT wind turbines in an urban area, it is necessary to perform at least annual wind measurements at the place and height of each future turbine installation.

Author Contributions: Conceptualization, A.Z. and K.W.; methodology, A.Z.; software, A.Z.; validation, A.Z. and K.W.; formal analysis, A.Z. and K.W.; resources, A.Z.; data curation, K.W.; writing—original draft preparation, A.Z.; writing—review and editing, A.Z. and K.W.; visualization, A.Z. and K.W.; supervision, A.Z.; project administration, A.Z. 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: Data available on the request.

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

References

1. Enevoldsen, P.; Permien, F.H.; Bakhtaoui, I.; von Krauland, A.K.; Jacobson, M.; Xydis, G.; Sovacool, B.; Valentine, S.; Luecht, D.; Oxley, G. How much wind power potential does europe have? Examining european wind power potential with an enhancedsocio-technical atlas. *Energy Policy* **2019**, *132*, 1092–1100. [CrossRef]
2. Letcher, T.M. *Wind Energy Engineering: A Handbook for Onshore and Offshore Wind Turbines*, 1st ed.; Academic Press: Cambridge, MA, USA; Elsevier: Amsterdam, The Netherlands, 2017.
3. Zagubień, A.; Ingielewicz, R. The analysis of similarity of calculation results and local measurements of wind farm noise. *Measurement* **2017**, *106*, 211–220. [CrossRef]
4. Zagubień, A.; Wolniewicz, K. The impact of supporting tower on wind turbine noise emission. *Appl. Acoust.* **2019**, *5*, 260–270. [CrossRef]
5. Wolniewicz, K.; Zagubień, A.; Wesolowski, M. Energy and Acoustic Environmental Effective Approach for a Wind Farm Location. *Energies* **2021**, *14*, 7290. [CrossRef]
6. Kurpas, D.; Mroczek, B.; Karakiewicz, B.; Kassolik, K.; Andrzejewski, W. Health impact of wind farms. *Ann. Agric. Environ. Med.* **2013**, *20*, 595–605.
7. DTU. Available online: https://windenergy.dtu.dk/english/research/publicationslist?dtulistcode=ISTLIST46&fr=1&mr=100&ptype=all&qt=DtuPublicationQuery (accessed on 12 April 2022).
8. Jianu, O.; Rosen, M.; Naterer, G. Noise Pollution Prevention in Wind Turbines: Status and Recent Advances. *Sustainability* **2012**, *4*, 1104–1117. [CrossRef]
9. Kovalovs, A.; Barkanov, E.; Ruchevskis, S.; Wesolowski, M. Modeling and design of a full-scale rotor blade with embedded piezocomposite actuators. *Mech. Compos. Mater.* **2017**, *53*, 179–192. [CrossRef]

10. Bidaoui, H.; El Abbassi, I.; El Bouardi, A.; Moumen, D. Wind Speed Data Analysis Using Weibull and Rayleigh Distribution Functions, Case Study: Five Cities Northern Morocco. *Procedia Manuf.* **2019**, *32*, 786–793. [CrossRef]
11. Pierzga, R.; Boczar, T.; Wotzka, D. Measurements and Acoustic Analyses of Infrasound Noise Emitted by Operation of Small, Building Mounted Wind Farm. *Acta Phys. Pol. A* **2015**, *128*, 294–299. [CrossRef]
12. Wotzka, D.; Boczar, T.; Malec, T.; Pierzga, R. Analysis of Vibro-Acoustic Signals Generated during Operation of Micro Wind Turbines. *Acta Phys. Pol. A* **2013**, *124*, 595–597. [CrossRef]
13. Zalewska, J.; Damaziak, K.; Malachowski, J. An Energy Efficiency Estimation Procedure for Small Wind Turbines at Chosen Locations in Poland. *Energies* **2021**, *14*, 3706. [CrossRef]
14. Manwell, J.F.; McGowan, J.G.; Rogers, A.L. *Wind Energy Explained: Theory, Design and Application*; Wiley: Hoboken, NJ, USA, 2009.
15. Jakubowski, M.; Mech, Ł.; Wolniewicz, K. A methodology of wind turbines selection for the given wind conditions. *J. Mech. Energy Eng.* **2017**, *1*, 171–178.
16. Chen, X.; Jeong, S.; Park, H.; Kim, J.; Park, C.R. Urbanization has stronger impacts than regional climate change on wind stilling: A lesson from South Korea. *Environ. Res. Lett.* **2020**, *15*, 054016. [CrossRef]
17. Palusci, O.; Cecere, C. Urban Ventilation in the Compact City: A Critical Review and a Multidisciplinary Methodology for Improving Sustainability and Resilience in Urban Areas. *Sustainability* **2022**, *14*, 3948. [CrossRef]
18. Mittal, H.; Sharma, A.; Gairola, A. A review on the study of urban wind at the pedestrian level around buildings. *J. Build. Eng.* **2018**, *18*, 154–163. [CrossRef]
19. Baidar, S.; Bonin, T.; Choukulkar, A.; Brewer, A.; Hardesty, M. Observation of the Urban Wind Island Effect. *EPJ Web Conf.* **2020**, *237*, 06009. [CrossRef]
20. Tsichritzis, L.; Nikolopoulou, M. The effect of building height and façade area ratio on pedestrian wind comfort of London. *J. Wind Eng. Ind. Aerodyn.* **2019**, *191*, 63–75. [CrossRef]
21. Palusci, O.; Monti, P.; Cecere, C.; Montazeri, H.; Blocken, B. Impact of morphological parameters on urban ventilation in compact cities: The case of the Tuscolano-Don Bosco district in Rome. *Sci. Total Environ.* **2022**, *807*, 150490. [CrossRef]
22. Allegrini, J.; Dorer, V.; Carmeliet, J. Influence of morphologies on the microclimate in urban neighbourhoods. *J. Wind. Eng. Ind. Aerodyn.* **2015**, *144*, 108–117. [CrossRef]
23. Yang, P.; Ren, G.; Yan, P.; Deng, J. Tempospatial Pattern of Surface Wind Speed and the "Urban Stilling Island" in Beijing City. *J. Meteorol. Res.* **2020**, *34*, 986–996. [CrossRef]
24. Wang, J.W.; Yang, H.J.; Kim, J.J. Wind speed estimation in urban areas based on the relationships between background wind speeds and morphological parameters. *J. Wind. Eng. Ind. Aerodyn.* **2020**, *205*, 104324. [CrossRef]
25. Stathopoulos, T. Wind environmental conditions around tall buildings with chamfered corners. *J. Wind. Eng. Ind. Aerodyn.* **1985**, *21*, 71–87. [CrossRef]
26. Lam, K.M. Wind environment around the base of a tall building with a permeable intermediate floor. *J. Wind. Eng. Ind. Aerodyn.* **1992**, *4*, 2313–2314. [CrossRef]
27. Siedlecki, M. Urban–rural wind speed differences in Łódź. In Proceedings of the Fifth International Conference on Urban Climate, Łódź, Poland, 1–5 September 2003; University of Lodz: Łódź, Poland, 2003; Volume 1, pp. 459–462.
28. Jasiūnas, K.; Teleszewski, T.J. Wind Energy. In *Buildings 2020+ Energy Sources*; Printing House of Bialystok University of Technology: Białystok, Poland, 2019.
29. Aydın, O.; Igliński, B.; Krukowski, K.; Siemiński, M. Analyzing Wind Energy Potential Using Efficient Global Optimization: A Case Study for the City Gdańsk in Poland. *Energies* **2022**, *15*, 3159. [CrossRef]
30. Celik, A. Energy output estimation for small scale wind power generators using Weibull representative wind data. *J. Wind. Eng. Ind. Aerodyn.* **2003**, *91*, 693–707. [CrossRef]
31. Wais, P. Two and three-parameter Weibull distribution in available wind power analysis. *Renew. Energy* **2017**, *103*, 15–29. [CrossRef]
32. Open Weather Map. Available online: https://openweathermap.org (accessed on 24 October 2021).
33. Sakka, E.G.; Bilionis, D.V.; Vamvatsikos, D.; Gantes, C.J. Onshore Wind Farm Siting Prioritization Based on Investment Profitability for Greece. Renew. *Energy* **2020**, *146*, 2827–2839. [CrossRef]
34. Ayodele, T.R.; Ogunjuyigbe, A.S.O.; Amusan, T.O. Wind Power Utilization Assessment and Economic Analysis of Wind Turbines across Fifteen Locations in the Six Geographical Zones of Nigeria. *J. Clean. Prod.* **2016**, *129*, 341–349. [CrossRef]