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Task 41 - Lessons Learned

WP6.4: Human dimensions

Authors:

Alexander Hirschl-Schmol	hirschl@technikum-wien.at	UAS Vienna (FH Technikum)
Daniel Österreicher	oesterrd@technikum-wien.at	UAS Vienna (FH Technikum)
Jana Berg	jana.berg@technikum-wien.at	UAS Vienna (FH Technikum)
Flora Bachleitner	flora.bachleitner@technikum-wien.at	UAS Vienna (FH Technikum)

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www.technikum-wien.at

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1 WP6.4 – Human Dimensions

Work package 6 of the IEA Task 41 focuses on human related topics of small wind turbines. In the deliverable 6.4 special emphasis is given to practices on how to include communities to achieve public acceptance. Moreover, guidelines are created to improve approval processes and reduce hurdles involved in these procedures.

1.1 Project SmallWind4Cities

Small wind turbines (SWT) are one among different technologies for a sustainable and resilient energy supply for large and small cities based on local generation technologies, which, alongside photovoltaics, are one of the few options for generating environmentally friendly electrical energy in built-up areas. While some small and medium sized wind turbines made technical progress in recent years and developed into a safe and serious technology - especially for large and small towns - awareness of the technology and its advantages are still very low in Austria. The still relatively complex site evaluation as well as administrative aspects (federal state-specific approval procedures) are the reason why small wind power has not yet been able to establish itself on the Austrian market [1].

For this reason, the project SmallWind4Cities addresses three main aspects of this topic. Firstly, site assessment methods need to be more accurate. Secondly, the approval procedure has to be harmonized and hurdles have to be overcome. Finally, the acceptance of the technology has to be assessed by means of survey to develop guidelines for higher acceptance in the population. In order to achieve these goals three different horizonal axis small wind turbines with a rotor diameter of at least 1.5 m are being installed on six populated sites [1].

In detail, the following tasks are planned:

A) Raise awareness of the technology as well as its acceptance and dispel reservations, through the following measures:

- First-time survey of awareness and acceptance of small wind turbines as well as drivers and barriers in German-speaking countries.
- Raising awareness of small wind power by giving people the opportunity to experience a small wind turbine (SWT) live and directly in communities.
- Involving citizens and giving them the opportunity to actively participate in the project and thus also with regard to the future implementation of the technology.

(B) Simplification of planning, organizational and administrative aspects in the planning and implementation of SWT in populated areas, through the following measures:

- Development of a simple method for site selection or assessment in populated areas.
- Survey / development and application of transdisciplinary criteria for site selection and evaluation.
- Elaboration of best practice examples for the approval of SWTs.

2 Simplified Site Assessment

A detailed evaluation of the wind potential of a site for small wind turbines (SWT), requires a wind measurement device at the planned hub height for at least one year. Such a wind measurement is usually not cost-effective, especially for micro wind turbines and should only be carried out if moderate wind conditions are already expected. In order to make a first assessment of the wind potential, a simple and easy to carry out method for a site evaluation is needed. Based on the site evaluation results, decision can be made whether a possible site can be considered for the installation of a SWT or not.

2.1 Site selection

Small wind turbines are usually installed in exposed locations with strong winds where there are no obstacles in the vicinity that could interfere with the rotor of the turbine (see examples Figure 1) . Such sites can be hilltops, open agricultural land, industrial areas with low buildings, or in rare cases, the roofs of buildings. When choosing an installation site, the following aspects should be considered:

- No obstacles in main wind direction.
- Good wind resource.
- Exposed site.

Should these requirements be met, a wind resource assessment can be initiated at the specified location using map data. If wind measurement equipment is located in close proximity to the desired location (e. g. less than one kilometer), the data sets from that equipment can be utilized.

Figure 1: Good rural site (1); moderate industrial site (2); poor rural site (3)

The subsequent step is to select a small wind turbine, with the **rated power** and **hub height** specified by the manufacturer being the most important parameters to consider at first. It is generally accepted that the higher the tower, the better the yield.

2.2 Average annual wind speed

The annual mean wind speed is a significant factor for evaluating a potential SWT site. It is defined as the average of all measured wind speed values over a year. Conventional SWTs have a cut-in wind speed of 2 to 3 m/s and begin to generate power at 3 to 4 m/s. The power output of a SWT increases exponentially with increasing wind speed. Therefore it is crucial to choose a site with a high annual average wind speed for the installation of a SWT [2]. Based on empirical values at urban and rural sites, from an energetic point of view, an installation of a SWT is reasonable at roughly 3.5 m/s annual mean wind speed (average site 3 to 4 m/s).

The wind data from GlobalWindAtlas can be used to calculate the Rayleigh distribution. The GlobalWindAtlas provides the annual average wind speed at the heights of 10 m, 50 m, 100 m, 150 m and 200 m, a rough windrose, roughness length data, as well as other additional data layers. These are extracted from the map in a web-browser or GIS-software (see Figure 2). For this purpose, the coordinates of the respective location are entered and marked on the map. The annual mean wind speed of the marked area is displayed by means of a colour scale and can be used for further calculations. By moving the cursor, the current annual wind speed is displayed in the colour bar and can be adjusted for different heights.

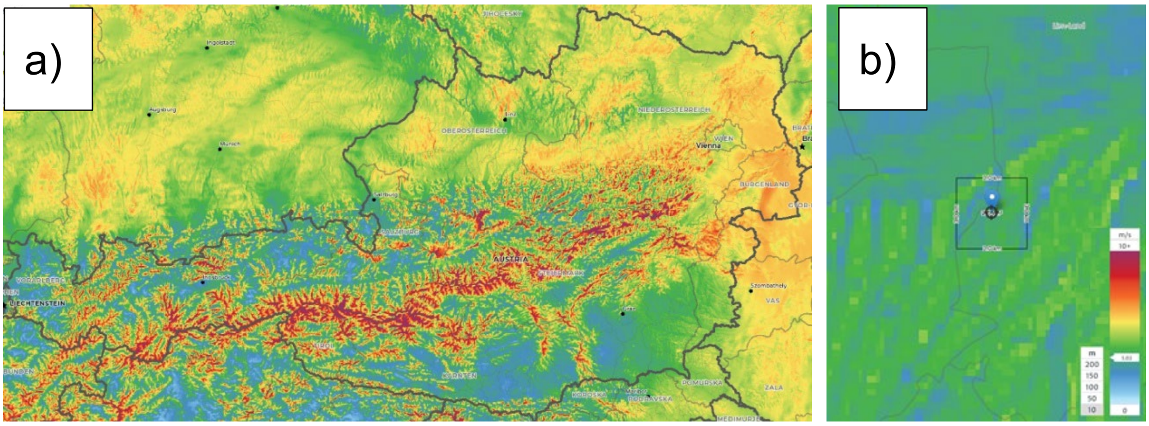

Figure 2: Annual wind speed Austria a) at 50 m, b) 10 m of a specific site from Global Wind Atlas

If the planned site is in a height between 10 m and 50 m the wind speed has to be approximated to the specific height (hub height). This is done by addressing a roughness length to the site. Subsequently the average annual wind speed in hub height is calculated by using the logarithmic wind profile.

A good wind site is characterized by a high average annual wind speed and a high number of full load hours. The following table shows the respective guideline values for the evaluation of a wind site:

Table 1: Factors for site evaluation [2]

	yield SWT [kWh/m²] at cp ~30%	average annual wind speed	Wind measurement
excellent site	>380	>5 m/s	Not necessary
good site	>210 & ≤380	4 – 5 m/s	Not necessary
moderate site	>92 & ≤210	3 – 4 m/s	Recommended
poor site	≤ 92	<3 m/s	site neglected

If an initial assessment of the site indicates at least moderate wind potential at hub height, the site evaluation can proceed. However, on moderate sites, a wind measurement campaign is recommended, especially for small wind turbines having a rotor diameter >2 m. For good and excellent sites wind measurement are usually not necessary. For larger investments (e.g., >€20,000), wind measurement is recommended to avoid costly misinvestments. Furthermore, the wind potential of a site also dependents on smaller obstacles (not covered by map data) and other aspects:

- Obstacles in main wind direction
- Hub height below or above given map height

2.3 Windrose

As demonstrated in Figure 3, a wind rose is a useful tool for visualising the probability of wind speed in different wind directions, including the dominant directions (e. g. south and north-west in Figure 3). The width of the coloured bars indicates the frequency of the corresponding wind class. Wind roses are primarily used to assess the predominant wind direction and any potential obstacles. Wind roses from Global Wind Atlas only show the total probability of each wind direction at an angle width of 30°. Nevertheless, this approach is still sufficient for assessing obstacles.

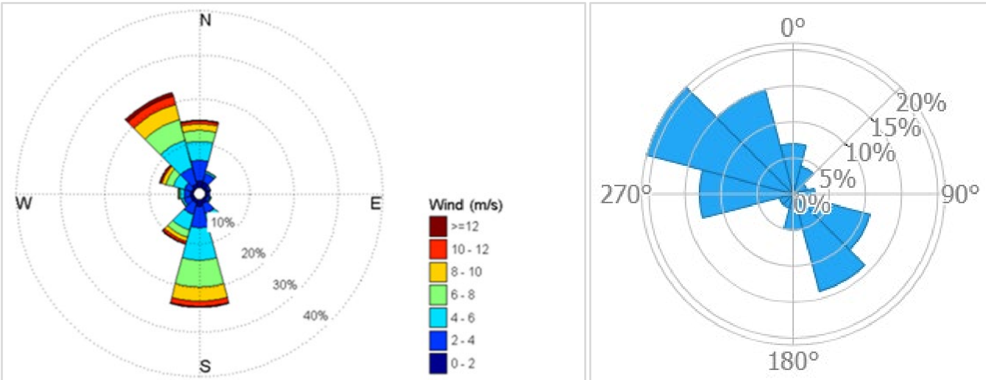

Figure 3: Wind rose derived from measurement and wind rose from Global Wind Atlas

2.4 Obstacles

The wind conditions at a site are primarily influenced by the topography of the surface area. Individual obstacles can cause significant turbulence. It is imperative that SWTs are installed in areas that are free from harsh turbulent conditions. Furthermore, a SWT should be placed at the highest point of gentle hills or buildings to avoid stall and turbulence. If it is not possible for the SWT to be free of obstacles, at least a free flow in the main wind direction should be ensured. At a height equal to twice the obstacle's height, turbulence is caused by obstacles. Furthermore, turbulence can still occur far behind the obstacle. Such turbulences can appear at a distance 20 times the height of the obstacle behind it [2].

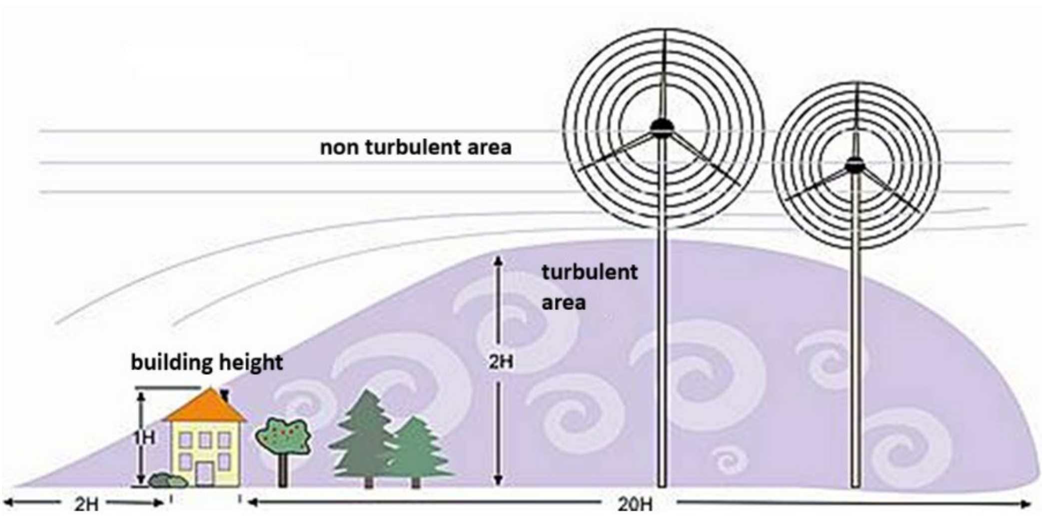

Figure 4: Turbulent area behind obstacles [2]

The following obstacle assessment method is an approach to classify obstacles for decision making, whether an installation is feasible or not. The ratio between obstacle height and hub height as well as the distance between those are decisive for this approach.

- Size ratio R between obstacle and hub height:
  - Small obstacle: <0.3
  - Medium obstacle: 0.3–0.6
  - Large obstacle: >0.6
- Observed distance D for obstacles starting from the turbine:
  - 20x hub height H

Based on the terrain assessment according to IEC 61400-1:2020-01-01, an observed radius of 20 times the hub height was defined. Relevant obstacles outside this area should be adequately considered in the map material. The size ratio R is a key factor in determining whether the obstacle affects the turbine.

Figure 5 displays an example of an obstacle assessment. In this case four obstacles were identified. The turbines hub height is 10 m which results in an observed distance D of 200 m.

- Annual average wind speed in hub height → 3.5 m/s → wind measurement recommended

The obstacles were analyzed as follows:

1. Obstacle height 3 m → R <0.3 → no further action
2. Obstacle height 6 m → R >0.3 → wind measurement recommended (influence by obstacle possible)
3. Obstacle height 8 m → R >0.6 → wind measurement strongly recommended (influence by obstacle present)
4. Obstacle out of observed distance → influence not likely → generally covered by map data

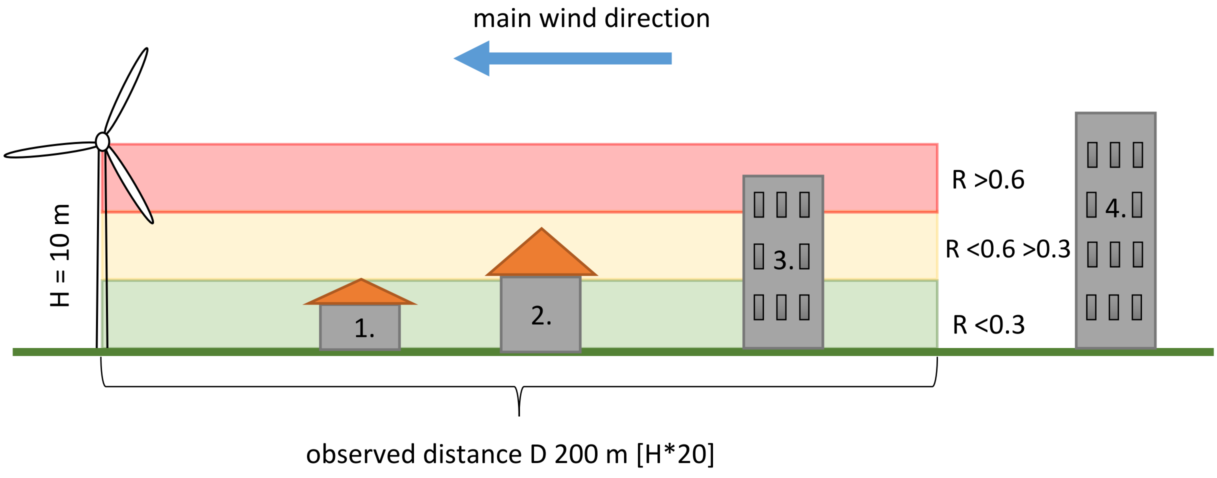

Figure 5: Example obstacle assessment

2.5 Log wind profile

Between 0 and 100 m above ground (Prandtl layer), the wind speed increases exponentially with height, depending on the ground roughness. The ground roughness is described by the roughness length z_0. This parameter indicates the height at which statistically the wind reaches 0 m/s on average [5]. Table 2 shows roughness lengths and the corresponding terrain surfaces, which can be addressed to a specific site.

Table 2: Roughness length as a function of orography [5]

z_0 [m]	Orography
1.00	Cities
0.50	Suburbs, settlements
0.30	Built up area
0.20	Many trees and/or bushes
0.10	Agricultural terrain with closed appearance
0.05	Agricultural terrain with open appearance

Additionally, z_0 can be calculated by using the annual mean wind speeds from 10 m and 50 m above ground. The ground roughness can be calculated by inserting the wind speeds and heights into the following equation:

$$z_0 = e^{\left(\frac{v_1 * \ln(h_2) - v_2 * \ln(h_1)}{v_1 - v_2}\right)} \qquad \text{Equation 1}$$

v_1 wind speed [m/s] (e. g. 5 m/s)

v_2 wind speed [m/s] (e. g. 4 m/s)

h_1 height [m] (e. g. 50 m higher point)

h_2 height [m] (e. g. 20 m lower point)

z_0 roughness length [m]

The relationship between two average wind speeds at different heights and the roughness length is shown in the following equation:

$$\frac{v_2}{v_1} = \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \qquad \text{Equation 2}$$

Figure 6 shows a possible progression of wind speed with increasing height. By calculating the ground roughness and determining two average wind speeds, the annual mean wind speed at a given height can be determined. If only the wind speed at one height is available, the ground roughness can be estimated using Table 2.

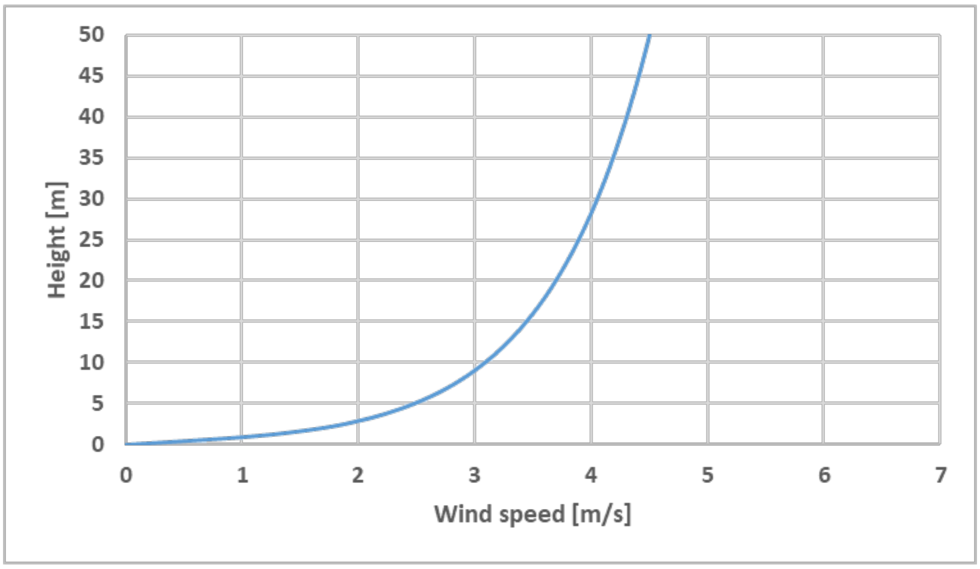

Figure 6: Increase in wind speed with increasing height

2.6 Rayleigh distribution with map data

Through map data usually only the annual average wind speed is derived. Hence, the Rayleigh distribution function can be used as an approximation of the annual wind speed probability distribution. Comparisons showed that the Rayleigh distribution is a relatively good approximation of the wind distributions for locations in Central Europe [5]. An exemplary plot can be seen in Figure 7, the shape of the curve always remains the same and no varying probabilities can be represented.

The Rayleigh distribution can be calculated with the following equation.

$$f_{Rayleigh}(v) = \frac{\pi}{2} * \frac{v_i}{v_m^2} * \exp\left(-\frac{\pi}{4} * \frac{v_i^2}{v_m^2}\right) \qquad \text{Equation 3}$$

$f_{Rayleigh}(v)$	Rayleigh probability for represented wind speed [1]
v_i	represented wind speed [m/s]
v_m	average annual wind speed [m/s]

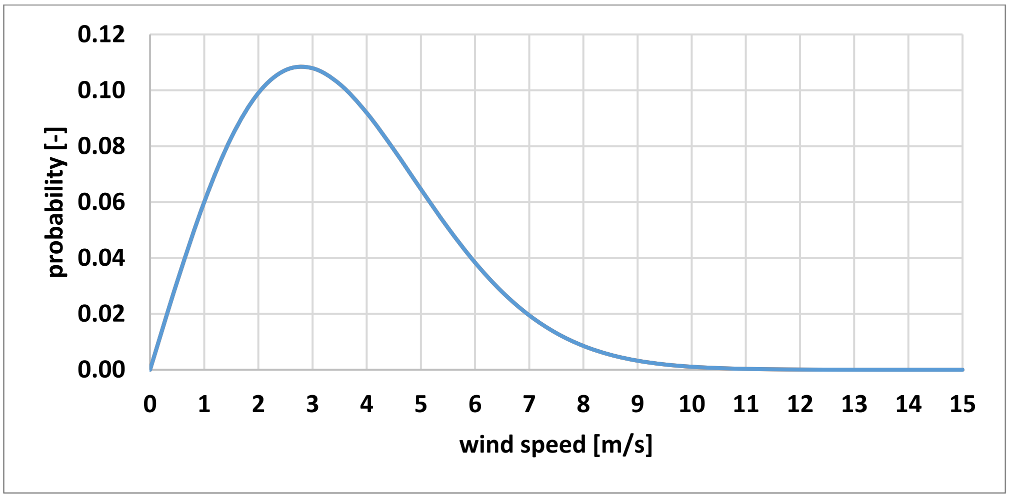

Figure 7: Rayleigh distribution with an average wind speed of 4m/s

2.7 Power curve

For further yield calculations, the power performance curve of the selected turbine must be known. Ideally, this should have been carried out in accordance with IEC 61400-12 and should cover the range from the cut-in to the cut-out wind speed. Figure 8 shows the performance curve of a horizontal axis turbine with a rotor diameter of 5.6 m and a rated power of 5 kW. The curve was measured in accordance with the standard and is shown for a standard air density of 1.225 kg. For further calculation it is crucial, that the performance curve is based on the standard air density.

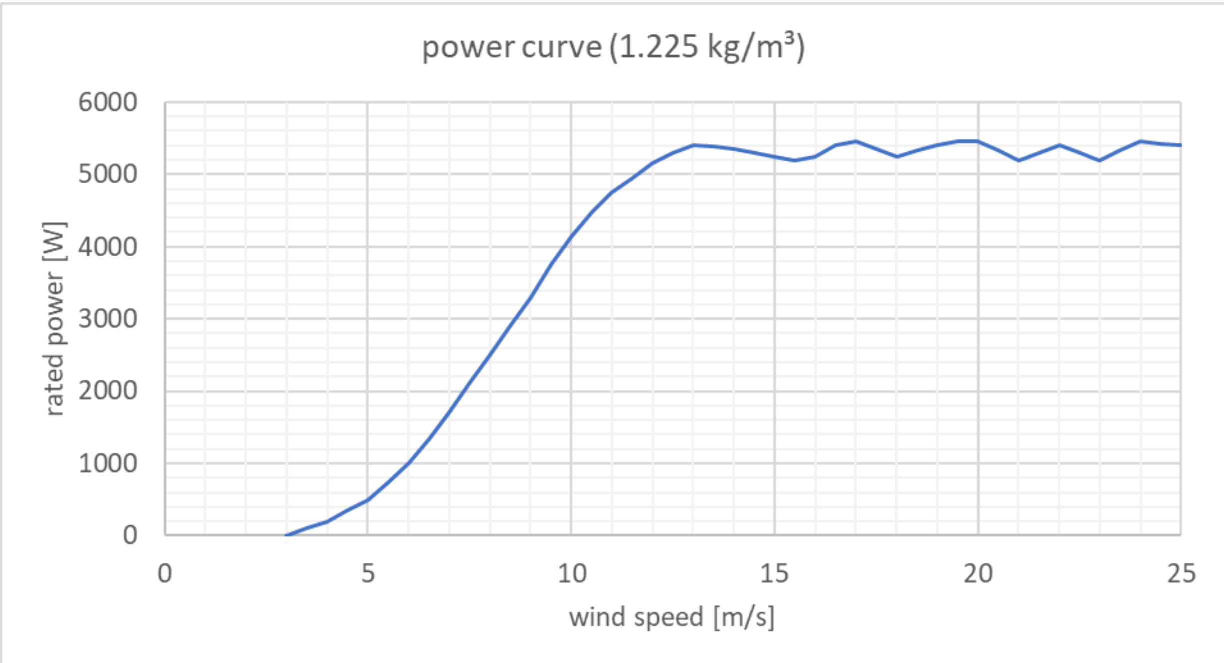

Figure 8: Example power curve

2.8 Annual energy production (AEP)

The annual energy production (AEP) of SWTs is calculated using the power performance curve and the previously calculated Rayleigh distribution. Utilizing the power and probability data for each wind speed, the energy yield in kWh/a can be calculated for each wind speed BIN.

$$AEP = \sum f_{Rayleigh}(v_i) * P(v_i) * t \qquad \text{Equation 4}$$

AEP annual yield [Wh]

v_i wind speed [m/s]

$f_{Rayleigh}$ wind speed probability at v_i[-]

P power at wind speed v_i [W]

t 8760 hours per year [h]

2.9 Exemplary site evaluation

Site selection:

A rural site was selected for the following project. No significant obstacles were identified in the immediate vicinity in main wind direction and the location is exposed on a hilltop. The turbine is used for a small carpenter business, which is why a turbine with a rated output of 10 kW (based on consumption) was chosen. The turbine data is listed below:

- Rated power 10 kW (at 11 m/s)
- Rotor diameter 7.4 m
- Hub height 15 m
- Power control passive pitch
- Yawing passive

Figure 9: 10 kW small wind turbine (left) and selected site red dot and main wind direction (right)

Average annual wind speed & wind rose:

The average annual wind speed was extracted from the global wind atlas at a height of 10 m above ground level. The result was 5.8 m/s, which represents an excellent site. Given the clarity of the result, wind measurement is not absolutely necessary in this case. The wind rose given by the wind atlas shows the highest frequency of wind coming from north west.

- Simulated height 10 m (above ground)
- Annual average speed 5.8 m/s
- Site class excellent site
- Main wind direction north west

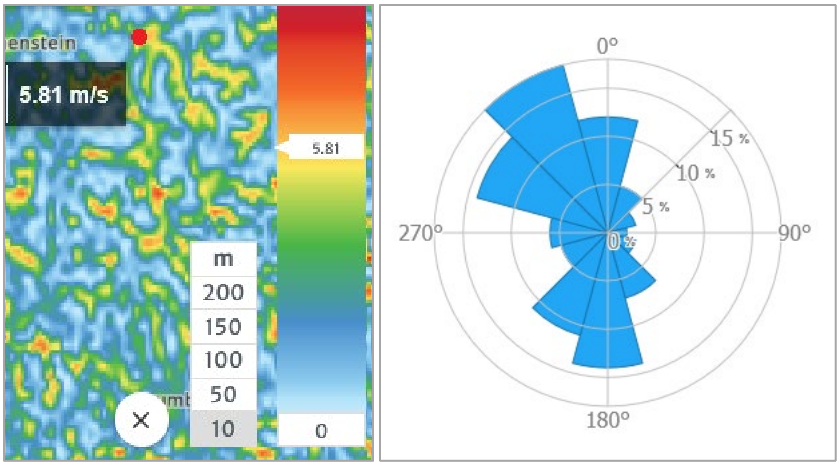

Figure 10: Results global wind atlas - site see red dot

Obstacles:

The assessment of obstacles is based on a viewing radius of 20 times the hub height. Given a hub height of 15 m, this results in 300 m. In the main wind direction northwest (330°), there are no obstacles greater than 0.3xhub height (4.5m) within a distance of 300 m. However, in the secondary wind direction south (180°), the buildings may constitute an obstacle. Following an initial assessment, the building has been found to be located 40 m from the turbine, with a height of 6 m. This obstacle falls into the category of "possible influence". In this case, a wind measurement may be advisable.

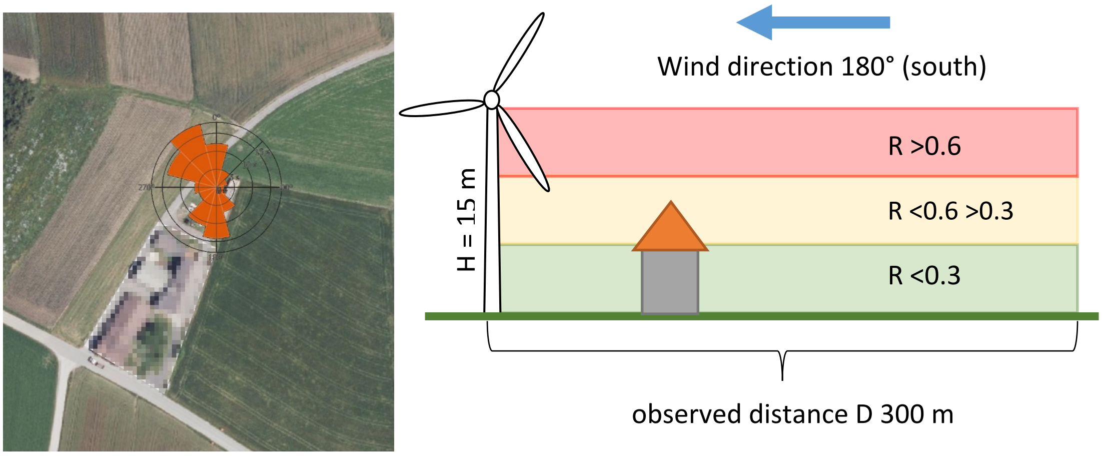

Figure 11: Obstacle evaluation

Log. wind profile:

Based on the map view, a roughness length of 0.1 m is assigned to the location in order to convert the annual average wind speed from 10 to 15 m hub height. The following equation shows the conversion to hub height:

h_1	10 m
h_2	15 m
z_0	0.1 m
v_1	5.8 m/s

$$\frac{v_2}{v_1} = \frac{\ln\left(\frac{h_2}{z_0}\right)}{\ln\left(\frac{h_1}{z_0}\right)} \rightarrow \ v_2 = 5.8 \cdot \frac{\ln\left(\frac{15}{0.1}\right)}{\ln\left(\frac{10}{0.1}\right)} = \boldsymbol{6.3\ m/s} \qquad \text{Equation 5}$$

Rayleigh distribution:

The frequency distribution of wind speed for the location can then be determined using Equation 3 . In this case, the distribution shown in Figure 12 was obtained.

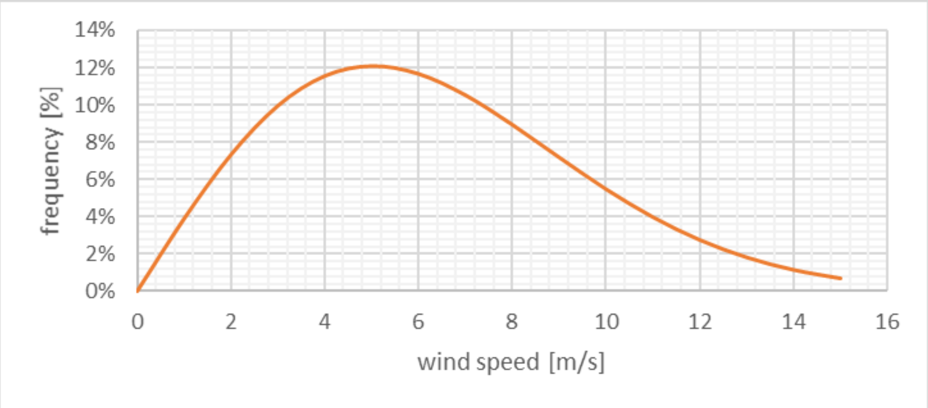

Figure 12: Rayleigh distribution at site (6.3 m/s)

Power performance curve and AEP:

The calculation results for the exemplary site are presented in Table 3. The performance curve (third column) was provided by the manufacturer. The AEP was calculated using Equation 4 for each wind BIN, and then added up. It has been calculated that 27,257 kWh of energy may be produced within a 12-month period. This results in 633 kWh/m² yield per square-meter of swept rotor surface each year, representing excellent operation of the turbine according to Table 1 column two.

Table 3: Performance curve and AEP per wind BIN

wind speed	frequency	power	AEP
m/s	%	kW	kWh
0	0%	0,0	0
1	4%	0,0	0
2	7%	0,0	0

3	10%	0,1	87
4	12%	0,4	404
5	12%	1,0	1057
6	12%	2,0	2041
7	11%	3,2	2945
8	9%	5,0	3908
9	7%	6,2	3895
10	5%	8,0	3834
11	4%	10,0	3479
12	3%	10,0	2408
13	2%	10,0	1590
14	1%	10,0	1004
15	1%	10,0	606
			27,257

3 Simplification of legal steps for approval

For the approval of small wind turbines, the "Requirements catalog for the assessment of small wind turbines including explanations 2019" [1] is currently the guideline for the approval of SWTs for each municipality or federal state in Austria. The following is a summary of the steps required for approval, including additional points that have arisen during the approval process.

The requirements only apply to small wind turbines which, according to ÖVE/ÖNORM EN 61400-2, are defined as turbines with a swept rotor surface of less than 200 m².

3.1 Approval procedure of SWTs in Austria

1. Building applications and construction documents

In most cases, SWTs are installed on towers with foundations. An exception is installation with ground anchors, where no foundation work is required [6]. The construction application includes:

- Building application/description
    - Technical description including details of the installation site
- Construction permission plan (3 copies)
    - Site plan (M1:500 or 1:1000) - location of the wind turbine and objects in the vicinity (buildings, sewer, water pipe, etc.)
    - Extract from the zoning plan
- Technical description:
    - Information on site conditions (reference wind speed, turbulence)
    - Details of the foundation (material, dimensions)
    - Details of loads on the supporting structure
    - Information on fasteners / vibration dampers
        - Building installation - information on space utilization
    - Information on safety of use/access security
    - Information on the type of energy generated and use (parallel grid operation, off-grid operation)
- Structural engineering: Confirmation from a civil engineer regarding the professional and stable construction.
- Mechanical engineering: Confirmation from an authorized person regarding installation and commissioning in accordance with the operating instructions.
- Electrical engineering: Confirmation from an authorized electrician regarding the professional commissioning and instruction of the electrical system.

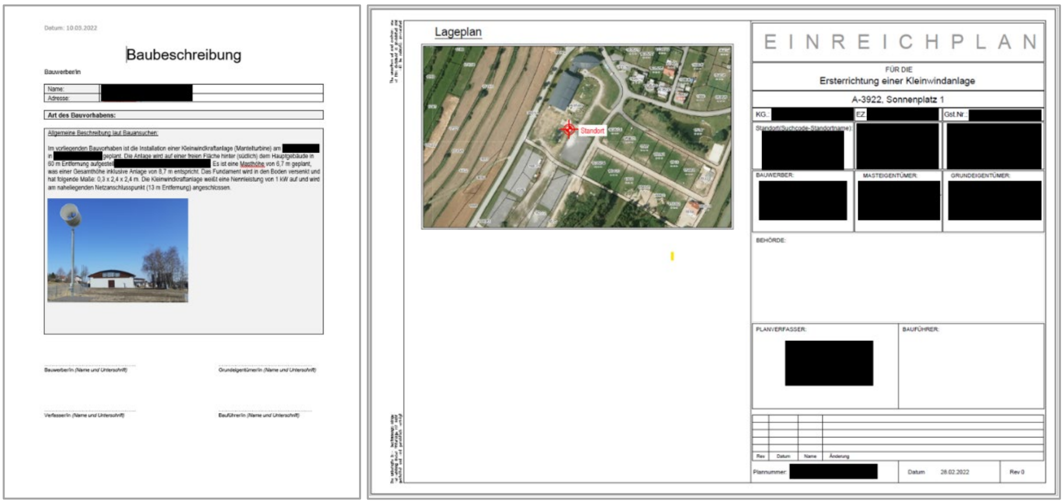

Figure 13: Example building application and construction permission plan

2. Technical description

The type of electrical generation and use of the electrical energy must be described [6]:

- Details of the electrical energy - data sheets for:
  - Generator
  - Inverter (rated voltage, rated power)
  - Off-grid operation or parallel grid operation
- Electrical circuit diagram
  - Starting from the generator to the consumer unit, including all protective devices (generator, inverter, disconnection points, emergency stop, decoupling, circuit breaker, residual current circuit breaker, fuses, overvoltage protection, monitoring devices).

3. Durability test - consumer label

As part of the testing module in accordance with ÖVE/ÖNORM EN 61400-2, a duration test lasting at least six months is required. The systems must be assigned to the following classes depending on the location for which they are designed [6]:

- Class 1: Annual average speed 10 m/s
- Class 2: Annual average speed 8.5 m/s
- Class 3: Annual average speed 7.5 m/s
- Class 4: Annual average speed 6 m/s
- Class S: Values to be determined by the designer

Testing according to IEC 61400-2:

- Structural integrity and material degradation (corrosion, cracks, deformations)
- Quality of the environmental protection of the wind turbine
- Dynamic behavior of the system

Tests according to IEC 61400-12-1 - performance behavior:

- Evaluation of the performance curve according to the standard
- Evaluation of the annual energy yield (AEP)

Testing in accordance with IEC 61400-11 - acoustic emissions

During the endurance test, measurement methods must be used to determine whether and when the system to be tested satisfactorily fulfills the criteria required in the standard ÖVE/ÖNORM EN 61400-2, point 13.4.1.

4. **Operating instructions**

The operating instructions for the small wind turbine must contain the following information in German in accordance with the Machinery Safety Ordinance 2010 - MSV 2010 [6]:

- Electrical: rated electrical power, type of current, rated voltage, rated current, frequency.
- Mechanical: number of rotor blades, axis position, rated speed, maximum rotor speed, rotor diameter, hub height, tower design, cut-in and cut-out wind speed.
- Structural: SWT class in accordance with ÖVE/ÖNORM EN 61400-2; static and dynamic loads to be derived.

5. **EU declarations of conformity**

All components must have a declaration of conformity in German, including [6]:

- Small wind turbine
- Inverter and control box

6. **CE marking**

CE marking is required for the entire system. The manufacturer has thus checked whether all EU-wide requirements for safety, health protection and environmental protection have been met [6].

7. **Grid feed-in**

A written agreement must be drawn up with the grid operator confirming that the system may feed into the local grid [6].

8. **Test report on the electrical system**

An initial test in accordance with ÖVE/ÖNORM E 8001-6-61 must be carried out for the system before it is handed over to the operator. This also includes testing the inverter in accordance with the R25 protocol for approval in the Austrian distribution grid [6].

9. **Structural integrity - static and dynamic calculation**

All loads generated by the small wind turbine must be taken into account (ÖNORM EN 1990). The swept rotor surface is the reference surface for the wind load. The foundation / ground anchor must be designed for loads up to a hurricane gust.

Furthermore, the dynamic loads (in accordance with ÖVE/ÖNORM EN 61400-2) must be carried out in the form of a resonance analysis. A Campbell diagram must be used to prove whether significant resonances occur during operation [6].

- Turbines ≤2m² rotor area: Proof that the stability of the supporting structure is given.
- Turbines ≥2m² rotor area: Proof that the stability of the SWT and the supporting structure is given depending on the ambient conditions (incl. ground conditions).

10. **Shadow impact**

If there are no relevant objects (windows, buildings) in the vicinity of 5x total height (hub height + rotor diameter/2), no shadow impact analysis must be carried out. Otherwise, a shadow analysis must be carried out; the duration of shading must not exceed 30 hours per year and 30 minutes per day. The prerequisite for this is that the shadow immission point has a height of 2 m and 1 m² [6].

11. Acoustic emissions

Acoustic emissions must be available for the system to be installed in the form of a report in accordance with OVE/ÖNORM EN 61400-11. This report includes the A-weighted sound pressure level and sound power level (up to 11 m/s according to the standard) and a sound map (sound pressure level decrease with distance) as well as a frequency spectrum analysis [6].

- Installation on buildings should be avoided due to structure-borne noise.
- Shutdowns are permitted if the sound immissions are exceeded.

12. Ice throw

Warnings about the danger of ice must be provided in the form of signage. In addition, a distance to accessible terrain must be maintained under the following conditions:

- No ice detection and no shutdown - distance: (hub height + rotor diameter)x1.5
- Ice detection and shutdown - distance: (hub height + rotor diameter/2)x1.3

These distances apply to the transportation of ice at 20 m/s [6].

13. Lightning strike

To protect against lightning strikes, SWTs must be equipped with a grounding system. The design must comply with ÖVE/ÖNORM EN 62305-3 [6].

14. Fire

Before protection against fire, the harmonized standard ÖNORM EN ISO 19353 must be complied within the course of the declaration of conformity [6].

3.2 Hurdles in legal steps for approval

The approval and installation of small wind turbines involves a number of bureaucratic, planning and technical hurdles in Austria. These include:

- Cost-intensive certification of turbines
- Lack of information on the necessary requirements
- No standardized procedure in the federal states / municipalities
    - A general legal guideline for the approval procedure exists
    - It is up to each federal state to decide to which extend the guideline is followed
- Interaction between many participants (property developers, construction companies, electricians, manufacturers, structural engineers, building authorities, experts, etc.)
- Technical difficulties in coordinating the components:
    - Tower and turbine
    - Inverter and turbine
    - Icing detection

Figure 14 shows hurdles which appeared during the approval of seven small wind turbines in lower Austria and Vienna. Problems which arose during the procedure were categorizes with numbers, where negative numbers (min. -1) indicate hurdles and positive numbers (max. +1) indicate no hurdles. The small wind turbines were installed at various locations in Lower Austria and Vienna (federal states) and the approval process was accompanied. Subsequently, wind and yield measurements were also carried out at the sites. During the approval process, it turned out that there were overlapping problems. These mainly concerned the issue of icing, which is handled by experts strictly in accordance with the applicable regulations. For some turbines, it was not possible to obtain a permit because either the inverter was not approved for the electricity grid (although it was in other EU countries) or noise reports or anti-icing measures were not sufficient.

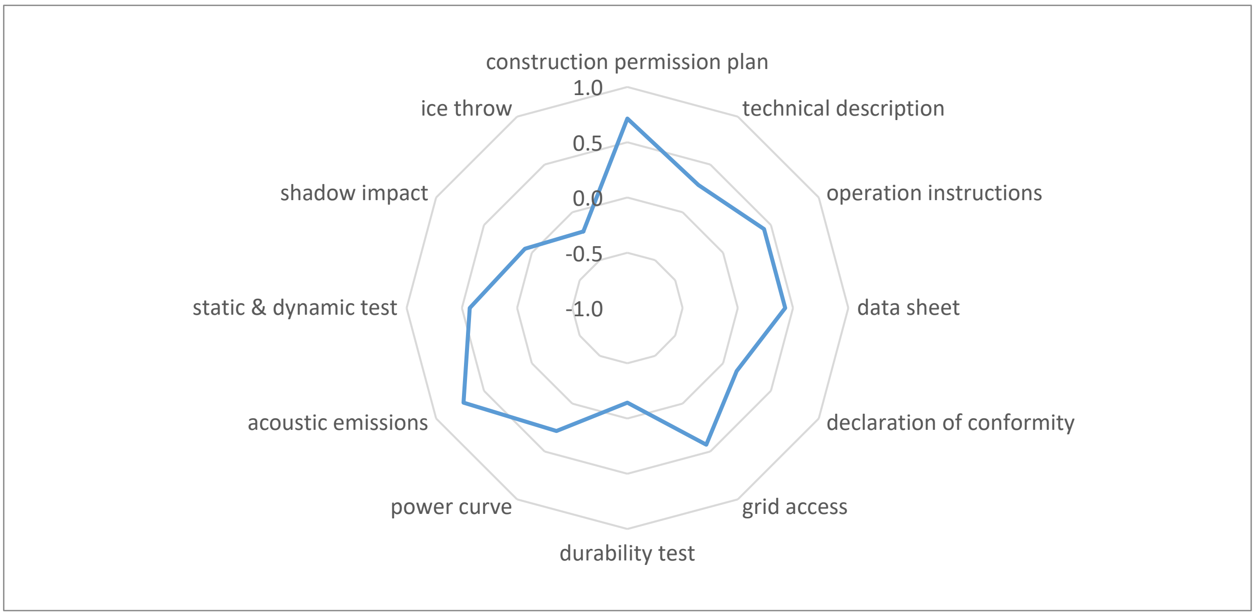

Figure 14: Hurdles during approval of SWT

In particular, the lack of inexpensive icing sensors on the market was a major problem. In municipalities where the catalogue of requirements was not followed in full or distances to populated areas were large, there were virtually no problems with approval regarding icing.

Figure 15: Approved and investigated sites and turbines

The main hurdles to approval were ice throw and noise reports, which were difficult or impossible for manufacturers to overcome from a technical and economic perspective. Depending on the location and the expert, these approval points were handled with varying degrees of strictness. After these problems were analyzed and processed, the following solutions were sought.

3.3 Improvement recommendations – approval procedure

New classification of small wind turbines (in approval procedure)

One initial simplification of the approval procedure is the separate consideration of micro wind turbines (≤0.8 kW or ≤Ø2 m) and small wind turbines (≤50 kW or ≤Ø16 m). These have not been considered separately in the approval process to date. Based on the reference power, the following two classes can be defined:

- Class A: Reference power 0 to 0.8 kW Rotor diameter ≤2 m
    - Notification required:
        - A checklist serves as a guide for manufacturers to ensure that all regulations are complied with. (see appendix)
    - In terms of electrical engineering, these systems fall under the regulations for small-scale generation systems (e.g., PV balcony power plants).
        - Notification to grid operator – Declaration of conformity for inverters
- Class B: Reference power 0.8 to 50 kW Rotor diameter >2 m to ≤16 m
    - Subject to approval:
        - Processing of the complete catalog of requirements (see chapter 3.1)

According to EN 61400-2:2014 p.17, the reference power is defined as the effective electrical power at 11 m/s and was determined for an efficiency of 30% (average for small wind turbines) and a standard air density of 1.225 kg/m³.

Building zones

In certain building zones, the dense development means that the safety distances for icing, noise, and shadowing cannot be maintained. These are therefore excluded in advance. Furthermore, the wind potential here is often insufficient.

- Class A: LC, LR, GL, LA
    - CC – no approval
- Class B: LC, GL, LA
    - LR, CC – no approval

The building zones are defined as follows:

- LC Land for commercial use (e. g. retail, office, industrial buildings)
- LR Land for residential use
- CC City center
- GL Grassland
- LA Land for agricultural use

Site assessment

Although site assessments are not required in the requirements catalogue, they form the basis for sustainable operation. In contrast to PV, the energetic potential can vary drastically depending on the site. Many wind locations offer too low wind potential to guarantee the sustainable operation of a small wind turbine. The result are turbines that generate little yield, which leads to a negative ratio of energy input for production and yield production during the turbines life span. It is therefore advisable to include site assessments in which a distinction is made between good and poor sites. The mandatory basis should be map material, wind measurement should be an option, as these include high costs.

To avoid this situation and ensure sustainable operation, rough site assessments must be carried out before the project begins. The site assessment should distinguish between the two turbine classes:

Class A: Notification requirement – no site assessment required.

Class B: Approval requirement – a site assessment must be carried out at least in broad terms using standard map materials (e.g. https://globalwindatlas.info/ or https://map.neweuropeanwindatlas.eu/) and an obstacle assessment. The wind potential is divided into:

Table 4: Factors for site assessment

	Yield SWT [kWh/m²] at cp ~30%	Average annual speed
Excellent site	>380	>5 m/s
Good site	>210 & <380	4 – 5 m/s
Moderate site	>92 & <210	3 – 4 m/s
Poor site	< 92	<3 m/s

No permits are issued for poor sites. In case of doubt, wind measurements are recommended for moderate sites or sites with significant obstacles.

Significant obstacles can have a horizontal impact of 20 times the height of the obstacle height and a vertical impact of twice the height of the obstacle in the main wind direction. Obstacles within these limits should be considered [1].

Point 9 – Structural integrity

A structural integrity calculation for each site results in additional costs in the approval process. To simplify the process, one structural integrity calculation per product should be sufficient. Since in most cases the same construction method is used for a turbine type, one structural integrity calculation should be sufficient for the product line. If the construction method differs, this must be re-evaluated.

A small wind turbine must withstand static and dynamic wind loads.

Class A: Notification requirement – submission of a structural analysis is not necessary, but must be confirmed by the company retailing the turbine and, in case of doubt, must be available for presentation.

Class B: Approval requirement – a structural and dynamic analysis must be submitted. The following documents are required for each type of turbine/product series:

- Ground mounting: one structural analysis per product series may be used for different locations, provided that it covers the prevailing ground class at the site.
- Roof mounting: a separate structural analysis and plans for vibration damping systems must be submitted for each location.

Point 10 – Shadowing

Online tools such as https://shademap.app/ or https://www.sonnenverlauf.de/ are recommended for shadow analysis. These tools can simulate the height of obstacles and the shadow pattern for every hour of the year.

Class A: Notification requirement – a review of the shading conditions can be carried out using online tools. However, due to the generally high rotational speed and small rotor diameter, the disturbance is assumed to be low.

Class B: Approval requirement – a simulation of the conditions must be carried out and submitted as a document with the application for approval.

Point 11 - Noise emissions

During the course of the project, cases became known in which noise measurements of a small wind turbine were required at each site. The massive costs associated with this are contrary to the current difficult economic situation. The catalogue of requirements does not clearly define whether a measurement of the type or a measurement per installed turbine is necessary. Furthermore, there is a contradiction in the measurement range in the catalogue of requirements. The text in the catalogue of requirements refers to an assessment range of 6 to 10 m/s, whereas the IEC 61400-11 Annex H standard refers to 3 (possible cut in wind speed) to 11 m/s. This should be standardized. Therefore, the following solutions are recommended:

- <u>Sound assessment per type</u>: the measurement of the sound pressure level, minus ambient noise in accordance with IEC 61400-11 Annex H, is sufficient for each type and a separate measurement does not have to be made for each location.
- <u>Competence reallocation</u>: Furthermore, sound is not a direct threat to life, which is why the costs of experts can be saved by transferring liability to the manufacturer. The manufacturer must prove, to the best of his knowledge, that the sound measurement was carried out in accordance with the applicable standard.

The low wind speed range (between cut-in wind speed and approximately 5 m/s) leads to low emissions, which are not relevant for the noise assessment on site. The Consumer Label therefore often only specifies a reference sound level at 8 m/s or in the range of 6 to 10 m/s. The following changes are therefore proposed:

Class A: Notification required – in the event of revocation, a sound assessment in accordance with IEC 61400-11 must be presented for the prevailing turbine type in the range of 6 to 10 m/s.

Class B: Approval requirement – a noise report in accordance with IEC 61400-11 must be presented for the prevailing turbine type in the range of 6 to 10 m/s.

In both cases, 40 dB(A) at the property boundary must not be exceeded, which is the limit value for the approved building zones according to ÖNORM S 5021, 2017-08, p.9.

Point 12 - Icing:

Currently, a minimum distance from small wind turbines to accessible terrain is required to prevent damage to property and personal injury. If ice is meteorologically detected, the distance can be reduced. However, there are no cost-effective synoptic ice detection methods (measurement of relative humidity and temperature) on the market. Furthermore, the large distances make approval in inhabited areas virtually impossible. No distinction is made as to whether it is a micro wind turbine or a larger small wind turbine or whether it is a high or low-tip-speed turbine. The latter can have a considerable influence on the possible ice-debris impact range. Hence, the following solutions are recommended:

- Relate the risk of icing to the type of rotor: the tip-speed-ratio should be used to differentiate how large the risk corridor is. A distinction can be made between low-speed and high-speed rotors. The latter were used for the evaluation from the requirements catalogue. For example, some Savonius rotors have speeds of less than 60 rpm, depending on their size, whereas high-speed rotors in the small wind power sector have speeds of up to 1000 rpm.
- The risk of icing relates to the rotor diameter: As mentioned in the requirements catalogue, the studies on ice were carried out on 100 kW wind turbines in alpine terrain. Therefore, on turbines with significantly larger rotor diameters than conventional small wind turbines in Austria, which are between 1 m and 6 m in diameter or less (micro wind power).
- The risk of icing relates to the impact force: Studies on the impact force of small wind turbines have already been carried out by Drapalik 2017 [7] at the Energy Research Park in Lichtenegg (Lower Austria), but only on model tests with test pieces of ice. An impact force of 40 J was found to be risk-relevant. This reference value should be used as a basis for assessment.
- Exception of shroud turbines: Shroud turbines can only lead to ice fall as from light poles, but the shroud around the rotor prevents the ice from being thrown away.
- Exclusion of locations with no or very low risk: Proven locations where icing does not occur should be excluded from the regulation.

The prerequisite for some of these changes are measurements on turbines of different sizes and speed rates. The amounts of ice aggregation must be determined and trajectories for different rotor diameters and speeds must be established.

Recent studies with small wind turbines suggest safety distances of 1xhub height+rotor diameter/2 [1]. Furthermore, studies conducted at the Lichtenegg Energy Research Park also suggest that the current model for determining ice throw distances greatly overestimates the distances [2]. Studies have shown that the hazard radius can also be reduced if an ice detection method is deployed (mainly for Class B turbines).

No ice detection: The following new regulations are therefore proposed for icing on small wind turbines:

Class A: distance (df) = 1x hub height(H) + rotor diameter(D)/2 to neighboring property

Class B: distance (df) = 1x hub height(H) + rotor diameter(D)/2 to neighboring property

Ice detection: If ice detection is available, the safety distance can be further reduced. The following formula can be used to limit the risk radius caused by thrown ice debris [3].

$$df = annual\ wind\ speed \cdot (\frac{D}{2} + H)/\ 15 \qquad \text{Equation 6}$$

For a small wind turbine with a hub height of 10 m, a rotor diameter of 2 m on a site with 5 m/s annual wind speed, this means a safety distance of 3.6 m when deploying ice detection devices.

4 Public acceptance of small wind turbines in Austria

4.1 Social monitoring

Previous studies on social perception and acceptance of wind power do not distinguish between small and large wind turbines and generally seem to implicitly assume the latter. Accordingly, the social monitoring in the SmallWinds4Cities project aimed to determine for the first time the extent and conditions of awareness and acceptance with regard to small wind power. The aim was not only to determine the extent to which citizens generally accept small wind power, but also to analyze the conditions and contexts of acceptance or rejection. These aspects were analyzed in relation to the characteristics of the wind turbines in terms of location, horizontal or vertical orientation, and shareholdership.

4.2 Methodology

The social monitoring is based on a representative survey of 1,642 people residing in Austria, which was conducted virtually in spring 2024. Participants were selected based on gender, age, educational attainment, household income and province of residence. The sampling criteria were divided into categories for which target values were specified in line with the total Austrian population [8]. The individual criteria were sampled randomly and independently of one another [9].

In the questionnaire, participants provided information about their political orientation, their assessment of statements about conspiracy theories and their perception of small wind power. The latter was surveyed using questions based on the Wind Attitude Index and a discrete choice model. Respondents were presented with various combinations of a) wind turbines (vertical vs. horizontal), b) location (town center, commercial areas / settlement edge, outside town and c) shareholdership. The combination and order of the variables were randomized to avoid bias based on the order of presentation and to test the influence of individual variables on the selection.

Finally, the completed questionnaires were selected based on a minimum processing time (>2 minutes). The remaining 1,453 cases were analyzed according to the following research questions:

1. What is the attitude of people in Austrian households towards the use of wind energy?
2. How do respondents assess a hypothetical expansion of small wind power in their community?
3. Do respondents attitudes differ significantly based on
    a. their socio-economic status,
    b. their exposure to wind turbines,
    c. whether they live in an urban or rural area,
    d. their political orientation, or
    e. their conspiracy mentality?
4. Do Austrian households differ in their approval of different approaches to small wind power use?
    a. If so, do differences in approval relate to
        i. the type of wind turbine (horizontal/vertical),
        ii. location, or
        iii. shareholdership?

4.2.1 Survey concept – small wind turbines

Three key factors were selected for the survey on the acceptance of small wind turbines:

- Location: this was divided into outside town, industrial/outskirts and central/inside town.
- Type of turbine: a distinction was made between vertical-axis and horizontal-axis turbines.
- Shareholdership: a distinction was made between external investors, local companies, public institutions (e.g. local authorities, fire brigade, etc.) and private individuals.

Figure 16 shows the matrix with the three categories, which can result in a total of 28 variants. The images were generated using AI and the small wind turbines were inserted into the images as photomontages based on known models. Care was taken to ensure that the turbines had a size typical for the current market, between 1 and 10 kW [10]. The profiles were combined randomly among the respondents in order to reduce bias.

Figure 16: Matrix for creating small wind power profiles

4.3 Results

4.3.1 General attitude of respondents towards the use of wind energy?

Support for wind power was surveyed using eight nominal scale items, which could be answered negatively, neutrally or positively and were formulated partly positively and partly negatively. The items that assessed wind power negatively received the least approval. The items that expressed a positive attitude towards wind turbines all received between 50% and 74% approval. However, a striking negative peak value of just over 20% contradicts the statement that wind power combats climate change. When the responses are categorized according to positive, neutral and negative attitudes towards wind power, the majority is in favor: 69% of respondents support wind energy, 15% are neutral and 16% are opposed.

Respondents were then asked for their opinion on the expansion of wind energy in their region. 60% of respondents were in favor of the local expansion of wind energy, while 18% were against it. With regard to the general attitude towards wind energy and the attitude towards local expansion, it is clear that support for wind power is increasing, but neutral positions are also gaining ground. Neutral positions are more pronounced in relation to local expansion than in the general perception of wind power, so approval seems to be more cautious or subject to greater uncertainty in this case.

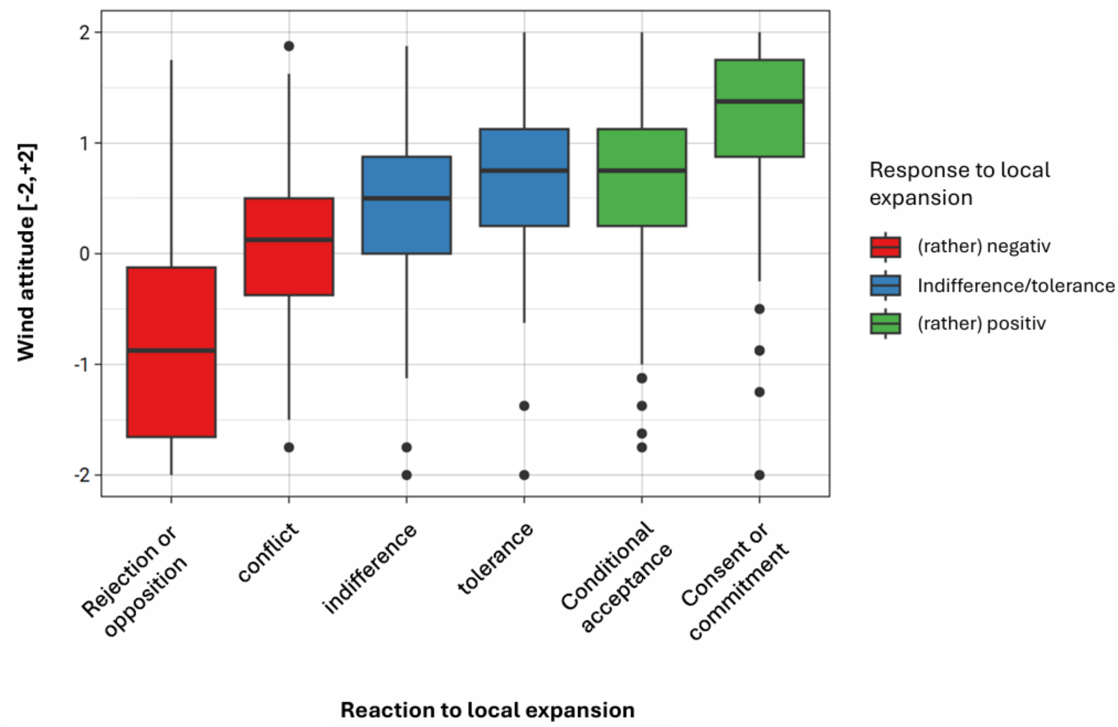

Figure 17: Wind attitude based on reaction to local expansion

4.3.2 Assessment of a hypothetical local wind power expansion

One focus of the study is the identification of factors that influence the general attitude of respondents towards wind energy. On the one hand, the characteristics of the respondents in relation to their attitudes were analyzed. In a later step, attitudes towards different characteristics of the turbines were analyzed, which is presented in research questions 3 and 4.

Possible individual variables influencing attitudes towards small wind power were evaluated, such as level of education, place of residence, political orientation and susceptibility to conspiracy myths, as well as proximity to existing wind power plants.

With regard to educational attainment, the analysis of the data collected clearly shows that attitudes towards wind power become more positive with increasing educational attainment. Age, on the other hand, has no influence in the survey. With regard to place of residence, differences can be observed in terms of the size of the place of residence. It appears that respondents from small and medium-sized towns have a lower affinity for wind energy. In contrast, residents of large cities and rural areas are on average more positive about wind turbines. A comparison across Austria as a whole reveals a slight west-east divide, with western provinces tending to be less open to wind energy. Proximity to existing turbines has no measurable influence on attitudes towards wind power in the evaluation.

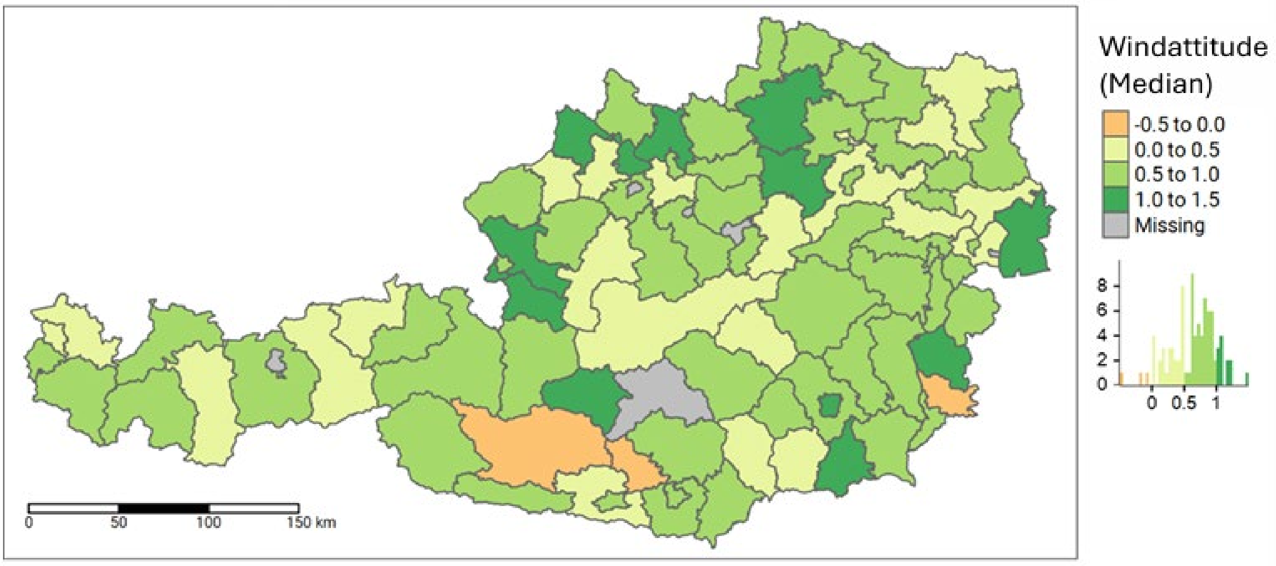

Figure 18: Regional distribution wind attitude

In principle, respondents have a positive attitude towards wind energy, regardless of their political views. However, the more strongly respondents identify with the political right, the more negative their assessment of wind turbines is. In addition, there is a correlation between attitudes towards wind power and a tendency to believe in conspiracy theories. The more open respondents are to conspiracy theories, the more negative their attitude towards wind turbines is.

4.3.3 What factors influence perceptions of wind power?

In order to measure preferences regarding various practical implementation scenarios, respondents were presented with different scenarios in a discrete choice model, in which the type of wind turbine, location and shareholdership varied randomly. The random combination and order of the characteristics is intended to reduce bias caused by the order of the questions and to make the impact of individual characteristics comparable.

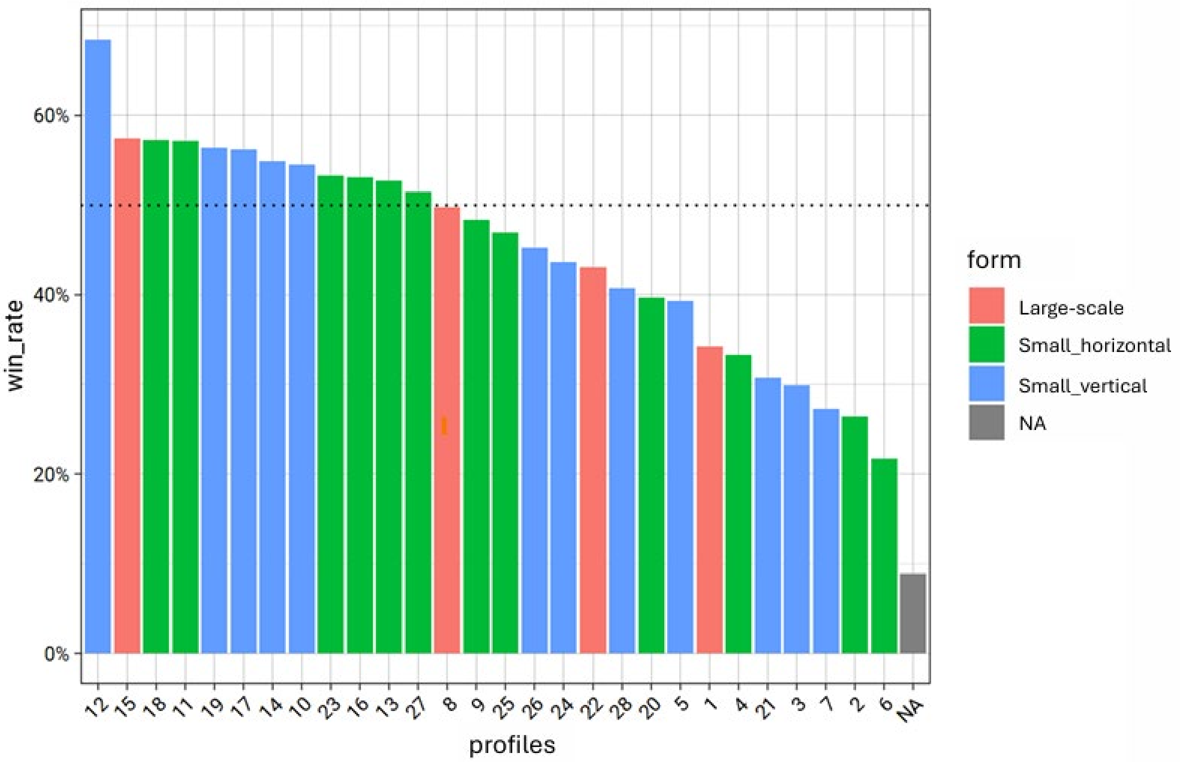

Figure 19: Approval rates of the discrete choice profiles according to turbine archetype, location and shareholdership

Shareholdership had the greatest influence on the acceptance or rejection of the random constellations (64% relative importance). This was followed by location (27% relative importance). The type of wind turbine, i.e. vertical or horizontal orientation of the wind turbine axis, had relatively little influence on the selection of preferred scenarios (10% relative importance). The most popular profiles within the discrete choice model are profiles 12, 15 and 18 from Figure 19:

12) Public or non-profit shareholdership and location outside the town.

15) Local companies or farmers as shareholders and location outside the town.

18) Local companies as shareholders and location in the industrial park.

The least popular profiles combine external shareholdership, i.e. non-local companies or energy suppliers. These are the profiles 6 and 2 from Figure 19.

6) Central location within the town and external shareholdership.

2) Location outside the town and external shareholdership.

Figure 20 and Figure 21 show a visualization of the most and least accepted profiles randomly created for the survey.

Figure 20: Most accepted profile (P12); Ownership: by the municipality or a non-profit organization; Position: industrial estates / outskirts of residential areas

Figure 21: Least accepted profile (P6); Ownership: by external companies; Position: in the city center

It can be derived from this that the acceptance of small wind turbines depends primarily on local participation and value creation, with respondents showing a particular preference for public and non-profit involvement, followed by local companies and citizens. The focus here seems to be on visible local and municipal benefits. In addition, public acceptance is determined by the location of the turbines, with a clear preference for remote locations outside the settlement and the outskirts of towns and industrial areas. It can be assumed that central locations are more likely to be perceived as identity-forming and/or aesthetically appealing spaces that are disrupted by wind turbines.

Based on the results, two key criteria can be derived for increasing the acceptance of small wind turbines in populated areas:

- Shareholdership: The survey identifies shareholdership as a key factor influencing the acceptance of wind turbines. When planning and implementing a small wind turbine project, local companies should be involved to ensure a high level of acceptance among those directly affected, and ownership and operational responsibility should lie with the local community. This allows the distribution of benefits and burdens to be controlled.
- Location: The location should be chosen away from densely populated areas. Therefore, the outskirts of towns and cities are to be favored. Locations that create a sense of identity, such as town centers, residential areas and historical landmarks, should be avoided. In contrast industrial areas and businesses are generally accepted for the deployment of small wind turbines.

5 Subjective perception of the noise emissions

The subjective perception of noise levels in small wind turbines can vary, which is why surveys were conducted to investigate the influence on subjective perception of sound. For this purpose, a questionnaire was created and completed by people residing at a distance of 20 m from a small wind turbine (Superwind 1250). Concurrently, wind speed was measured, and wind potential and noise emissions were compared with the responses. The test turbine chosen was a small wind turbine from Superwind (SW1250) with a rated power of 1.2 kW on the roof of the office building ENERGYbase at Giefinggasse 6 in Vienna's 21st district. The questions on socio-economic data (highest level of education, gender, etc.) were mainly collected using a nominal scale. The questions on the assessment of noise and wind speed as well as the visual impression were collected using an ordinal scale or a Likert scale.

Survey concept – noise emissions

The noise survey was conducted while the Superwind 1250 small wind turbine was in operation, with the wind speed of the turbine being measured in parallel with the survey. When a respondent completed the questionnaire, a time stamp was generated that corresponded to the current prevailing wind speed. The answers to the questions were then exported and compared with the wind speed using the time stamp. Subsequently, the noise emissions of the turbine were derived from the map in Figure 22 and could be assigned to the answers based on the distance of the people from the turbine and the prevailing wind speed.

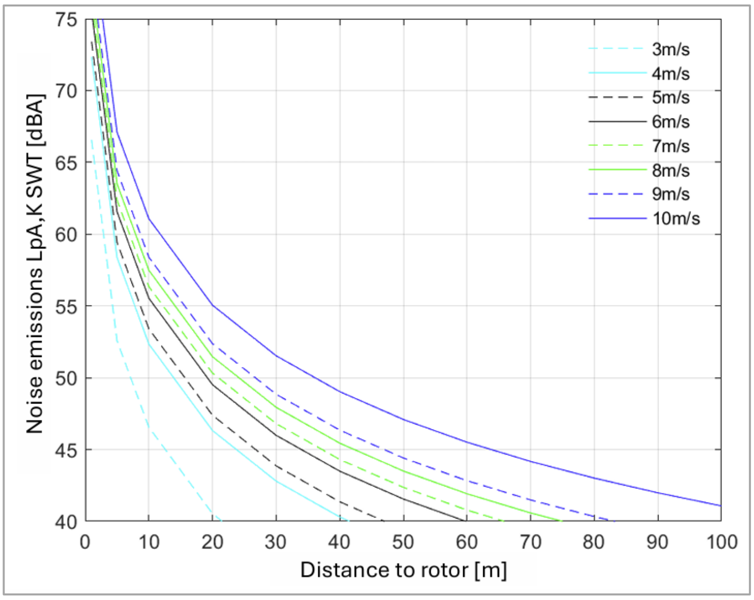

Figure 22: Noise emissions Superwind 1250

The survey collected data from 24 individuals. The survey cannot therefore make any generally valid statements about the perception of SWT. However, it can be used as an initial basis for further research.

The distances between the individuals and the turbine were chosen so that they could hear audible noise emissions and at the same time correspond to a typical distance from the property boundary. Therefore, a distance of 20 m was chosen. Figure 23 shows a sketch of the survey concept:

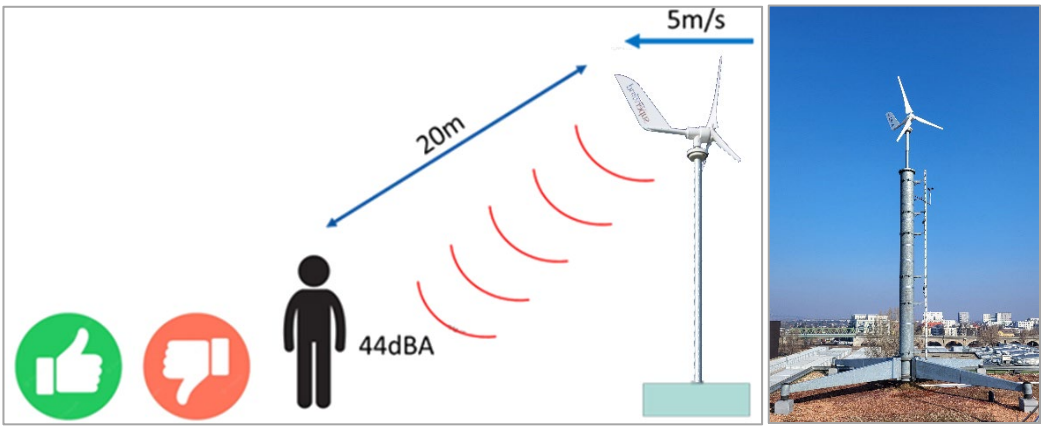

Figure 23: Concept noise survey

5.1 Sociodemographic results

The survey collected data from 24 individuals. Therefore, it cannot make any generally valid statements about the perception of SWT. However, it can serve as a basis for further research. The following subjective gender distribution emerged from the survey:

- Male 66.7%
- Female 29.2%
- No answer 4.2%

5.2 Perception of aesthetics

Acceptance of the appearance of small wind turbines depends heavily on subjective perceptions. To gain an understanding of these perceptions, people were asked about their opinions. The survey revealed that the majority had a positive or neutral attitude toward the visual appearance (see Figure 24). The largest group, at 37.5%, had a neutral attitude. Overall, 16.7% had a negative attitude toward the appearance.

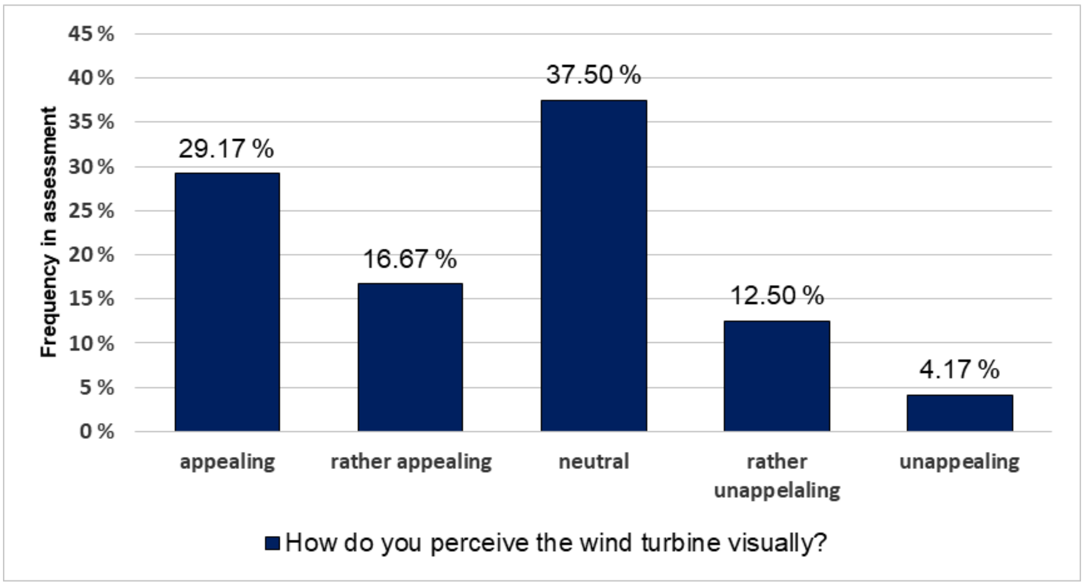

Figure 24: Visual perception

5.3 Perception of wind speed

Personal estimates of actual wind speed tend to be subject to a high degree of variation. Furthermore, even a slight misjudgment often leads to a significant error in the performance of a turbine. The SWT study on the perception of wind speed was based on categories from the Beaufort scale. For the scaling of the wind speed response options (see Table 5 column one and two), the Beaufort scale was grouped into five new categories (see Table 5 column three and four). Both the actual wind speed and the subjectively perceived (estimate by participants) wind speed were recorded for the study. Table 5 shows the results from the questionnaire for the measured and estimated wind speed by the participants. The results show the time duration of wind speed classes measured during the questionnaire as a percentage and the respondents estimates. It is noticeable that respondents generally underestimate gentle breezes and moderate breezes and assign them a lower wind potential. For example, 83% of the wind conditions during the survey period were "gentle breezes," but only 54% of these wind conditions were identified by the respondents as such. The findings indicate, that respondents generally underestimate the current wind conditions on a site.

Table 5: Estimated wind speed vs. measured wind speed

Wind speed [m/s]		Category	Terminology	Wind measured	Wind estimate
Start	End				
0.0	2	1	Light air	0 %	4 %
2.0	3	2	Light breeze	0 %	42 %
3.0	5	3	Gentle breeze	83 %	54 %
5.0	8	4	Moderate breeze	17 %	0 %
8.0	11	5	Gale	0 %	0 %

5.4 Perception of noise

Sound is perceived differently depending on personal sensitivity and is thus classified as disturbing or non-disturbing. Therefore, in addition to the volume, the frequency spectrum of the sound source/small wind turbine is also decisive. In the survey, sound categories were created in 20 dBA increments and classified into categories 1 (quiet) to 5 (too loud). In Table 6, column 4, a conceptual categorization was made from "quiet" to "too loud." During the observation period, only the volume categories "quiet" and "moderate" could be covered. Compared to wind speed, the participants accurately assessed these categories. Therefore, the measured sound corresponded for the most part to the perceived sound. This indicates that the applicable noise limits (see ÖNORM S 5021, 2017-08, S.9) can also be classified as appropriate for small wind turbines. For example, a sound pressure level between 40 and 60 dBA was derived from the noise map (see Figure 22) and the measured wind speed. This "moderate" noise was measured for 17% of the observation period. The participants identified this noise for 21% of the observation period.

Table 6: Measured sound vs. estimated sound

Noise level [dBA]		Category	Terminology	Sound measured	Sound assessment
Start	End				
10	30	1	quiet	83 %	79 %
40	60	2	moderate	17 %	21 %
70	90	3	loud	0 %	0 %
100	120	4	very loud	0 %	0 %
130	140	5	too loud	0 %	0 %

5.5 Conclusion

With regard to visual perception, the results can be summarized as follows: SWT are generally well accepted. However, not all respondents are yet accustomed to the sight of SWT, and they have the potential to attract attention.

The subjective assessment of wind speed by the participants in the study does not always seem to correspond to the actual conditions. The results show an overestimation and underestimation of the actual wind speed.

With regard to the subjective assessment of noise level, the respondents answer largely correspond to the actual noise level calculated from the wind speed. The distinction between loud and quiet shows realistic assessments by the survey participants.

A follow-up study will be needed to determine whether the present results were distorted by the uneven distribution of socio-demographic characteristics. The responses to the socio-demographic questions tended to be homogeneous.

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6 Appendix

Checklist – Class A small wind turbine

The following requirements must be fulfilled in order to register a Class A small wind turbine.

Checklist of documents required to register a Class A small wind turbine:

Turbine type:

Turbine output ≤800W or rotor diameter less than 2 m ☐

Location:

Location is not in a core zone of building land (or quiet area, spa area) ☐

Sketch of the construction project available ☐

Safety:

Components comply with static and dynamic requirements ☐

Sound limit of 40 dB(A) at property boundary complied with[1] ☐

Shadow nuisance excluded (less than 30 min/d & 30h/a)[2] ☐

Risk of ice throw excluded – distance from property boundary ≥ $1 \cdot (H+D/2)$[3] ☐

Ice detection available – distance ≥ $v \cdot (H+D/2)/15$ ☐

Energy distribution:

Grid-connected operation: ☐

CE mark and declaration of conformity for inverter available ☐

Feed-in power ≤800 W ☐

Notification to grid operator fulfilled ☐

Or stand-alone operation: ☐

[1] Reference to noise emission limits according to ÖNORM S 5021, 2017-08, S.9

[2] Shadow simulation verified in tool or distance > 5x hub height

[3] H…Hub height [m]; D…Rotor diameter [m]; v…Annual average wind speed [m/s] according to wind atlas in H

Compliance with the minimum requirements is confirmed by a licensed company:

place, date signature

Sketch small wind turbine project: