Comparison of small wind turbines for urban areas, a market analysis

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Abstract

This document presents a comparative analysis of horizontal and vertical small wind turbines for urban areas in three power classes up to 10 kW in different categories. The main objective was to conduct a market analysis to assess the marketability of these wind energy systems. The aim was to make it easier for potential customers to make a decision. However, due to the limited availability of data, the project encountered considerable difficulties. As a result, the study became a comparative assessment, which led to results that may not be readily transferable to urban environments, slightly missing the original objective of the study. The results underline the difficulties associated with conducting a comprehensive market analysis in this sector and highlight the need for an independent series of tests under specific conditions. The paper concludes with a plea for future research efforts to adapt data collection methods to urban conditions in order to improve the relevance and applicability of such studies in practice.

1 Introduction

The need to supply urban regions with sustainable energy has led to a growing interest in small wind turbines as a promising solution [1]. In the wake of this energy transition, the market for small wind energy is facing a remarkable challenge that needs to be addressed. However, the number of technologies, performance characteristics and economic aspects is confusing and has led to a complex landscape that needs to be untangled. This market analysis looks at the current confusion in the market for small wind turbines in urban areas. It looks at different models and manufacturers to help urban planners, energy experts and investors select the optimal solution for their specific requirements. In an environment where innovation is the norm, it is of great importance to keep an overview of the best available technologies. The aim of this analysis is to shed light on the current confusion in the market in order to help guide the urban energy transition.

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2 Methodology

To prepare the paper, suitable sources were initially researched using the "Google Scholar" platform. However, high-quality sources were difficult to find, as both topicality and citation frequency and ratings had to be taken into account. Furthermore, search terms such as "market analysis of small wind turbines" in the context of urban areas did not lead to any useful results. There are many good sources on the topic of urban wind energy, but the market is very volatile, making it difficult to find up-to-date sources for a market analysis. After a suitable paper was found, the search was extended with the AI tool "researchRabbit". However, the sources found were not sufficient to create our own market analysis. For this reason, sources of lower quality and therefore less trustworthy were used. Some of these sources have not been verified by third parties.

With regard to the market analysis, it should be noted that various public market analyses were used for an initial overview. It was found that many of these analyses had qualitative shortcomings and only a little good information could be obtained from them [2–4]. When checking the facts, you often end up on the manufacturers' websites, which contain the information mentioned. It is noticeable that the manufacturer websites often provide more information than the compared analyses and further information can be provided on request.

Due to the size of the market for small wind turbines, only a small selection of available turbines are compared. The selection is based on a list of the most relevant companies in this sector. The list was compiled by "Market Research Future" in 2022 [5]:

- Kingspan Group Plc. (Ireland)
- Bergey Wind Power Co. Inc. (U.S.)
- S.L. (Spain)
- Guangzhou HY Energy Technology Co. Ltd (China)
- Shanghai Ghrepower Green Energy Co. Ltd (China)

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- Aelos Wind Energy Ltd (U.K.)

A distinction is made between the horizontal and vertical axis. The key difference between these models is the position of the axis of rotation - horizontal or vertical - which distinguishes between horizontal and vertical axis wind turbines. The advantages and disadvantages of both variants will be worked out. A direct performance comparison is not possible due to the principle of operation. The following performance classes are also differentiated:

- less than 2 kW
- 2 kW up to 5 kW
- 5 kW up to and including 10 kW

The following criteria are to be examined for the various systems:

- Investment
- Security
- Maintenance
- Power
- Noise emissions

The data collection comes from various sources and therefore a direct comparison cannot be guaranteed.

3 State of the art

The vast array of small wind turbine models available in today's market poses a significant challenge for prospective buyers seeking an overview. Horizontal wind turbines currently dominate the market and have established themselves as the technical standard in both the small turbine and megawatt range. There are no quality labels for the German market that are comparable to those in the USA or Japan. However, the IEC 61400-2 standard does exist, which prescribes comprehensive tests for wind turbines[6]. The international standard IEC 61400 is designed for large wind turbines. The following standards are relevant for small wind turbines:

- IEC 61400-2: Design requirements for small wind turbines
- IEC 61400-12-1: Measurement of the performance of a wind turbine
- IEC 61400-11: Sound measurement method
- ISO 9001

The certificate remains valid for a period of 5 years. If a change is made to the system, the certificate must be a new test must be carried out. Systems with IEC 61400-2 certification fully comply with the safety standards set out in the standard.

Alongside China, America is one of the largest markets for small wind turbines. In 2009, the American standard for small wind turbines was developed and published for certification by the American Wind Energy Association (AWEA) in cooperation with the American National Standards Institute (ANSI), manufacturers, technical experts, public authorities and consumers. Like most national standards, it is based on the IEC 61400 series of standards and focuses on ensuring the performance, quality and operational safety of turbines. The most important technical data, such as rated power at 11 m/s, noise emissions at 5 m/s and energy yield for a defined location, are presented in the form of a label and made available to consumers.

The systems in England are tested and approved by the Microgeneration Certification Scheme (MCS). This standard was developed jointly by consumer and public interest groups, manufacturers and interest groups. It applies to small wind turbines with an output of up to 50 kW (micro and small wind certification) and a swept rotor area of up to 200 m^2. The tower and foundation are not tested. The implementing institutes are nationally recognized and accredited certification bodies of the United Kingdom Accreditation Service (UKAS). MCS006 (Micro and Small Wind Certification) refers to the "Renewable UK Small Wind Turbine Standard", or RUK for short, which was published in January 2014 and replaces the BWEA Small Wind Turbine Performance and Safety Standard. Similar to the US standard, quality (endurance test), performance and noise emissions are tested.

The operation of a small wind turbine in densely populated areas, in the immediate vicinity of buildings close to or on top of buildings requires additional requirements or changes to the assessment of aspects already taken into account. These additional requirements are not included in any recognized standard [7].

Small wind turbines are of particular interest in urban areas due to their use as a decentralized energy source in the immediate vicinity of consumers. The availability of this technology in urban environments is influenced by various factors such as building structures, local wind conditions and regulatory frameworks.

Real-world experience in urban environments provides valuable insights into the effectiveness of small wind turbines. Case studies and examples of successful implementations show not only positive results, but also challenges faced by users in cities. The evaluation of practical experience enables a realistic assessment

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of the performance and potential impact of small wind turbines in urban areas. Unfortunately, not all small wind turbines available on the market are tested under urban conditions. Therefore, the turbines have to be compared based on the available data.

4 Use of wind power in urban areas

Wind conditions in the countryside and in the city differ due to various factors. In the city, the so-called "Urban Wind Island Effect" (UWI) occurs, where the average wind speed can be surprisingly higher than in the countryside, even though the city is rougher. This effect occurs in the afternoon and is caused by differences in the growth of the atmospheric boundary layer, surface roughness and ageostrophic wind between urban and rural areas [8]. But in generally the increased roughness of the city leads to a reduction in wind speed compared to open land [9]. The turbulence caused by buildings in urban areas increases the turbulence and thus deepens the boundary layer. This impairs the use of wind turbines [8]. Over urban areas or uneven terrain, the wind gradient effect can lead to a reduction in wind speed of 40 to 50 percent [10]. The change in wind speed over height in different environments is shown in Figure 1. Despite the difficult conditions, the use of wind energy in the city is possible. The following points must be observed for efficient use:

1. Location
2. Turbine
3. Approval process
4. Maintenance

The site of a potential wind turbine should have sufficient wind potential and be characterized by low turbulence and low interference from other structural elements and activities. The frequency of wind speeds above the starting speed of the turbine used should be as high as possible. No clear figures are available, as the economic efficiency also depends on the varying investment size. To avoid possible bad investments, it is advisable to carry out a one-year measurement at the site before the actual installation. Predictions of wind conditions in urban areas are often associated with a high degree of inaccuracy [11]. The choice of turbine has a significant influence on points 3 and 4. When making the decision, attention should be paid to noise emissions and maintenance intensity. Noise emissions and shadow impact in particular influence the approval. In areas with a high population density, these factors are much more likely to disturb local residents than in rural areas.

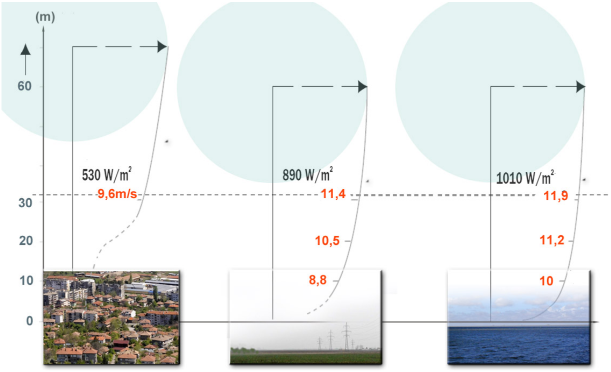

Fig. 1: Wind potential in different environments [12]

5 Results

To improve clarity, the company names and models in Table 1 have been numbered. The numbers are used in Tables 2, 3, 4 and 5.

There is only one company on the list that deals with the sale of small vertical axis wind turbines. The horizontal axis dominates the market, but the number of vertical axis small wind turbines for urban areas is increasing [13]. Table 2 compares the small wind turbines with a vertical axis.

All vertical small wind turbines are CE certified and have been tested in accordance with ISO 9001. They can be installed in urban areas and can also be installed on the roofs of buildings with suitable statics. The cheapest turbine is number 13 with a specific price of 2.51 €/W. The most expensive system is number 10 at 6.61 €/W, more than twice as much. The cut in speed, guarantee period and noise emissions are identical for all systems. The survival speed is 50 m/s for the three smaller systems and 52.5 m/s for the two larger ones.

Table 3 compares the small wind turbines with a horizontal axis. The table is sorted in descending order of turbine output.

The system with index number 2 belongs to the medium performance class and has the highest price of all the systems. It's specific price is 9.14 €/W. In contrast, the system with the index number 15 belongs to the lowest performance class and has the lowest specific price of 1.30 €/W.

The survival speed ranges from 45 m/s to 70 m/s. The most expensive system is at 70 m/s and the cheapest at 45 m/s. This shows a clear correlation between price and strength. Particularly in urban areas, strong turbulence and gusts of wind can occur, which cause a short-term and strong increase in wind speed. A wind turbine with insufficient strength therefore represents an increased risk in urban areas. The most expensive turbines come from the Kingspan Group and have the ability to bend their blades backwards elastically if the wind is too strong. This allows the rotor to continue

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Tab. 1: Company and model of the small wind turbines analysed

company	model	nr.
Kingspan Group Plc. (Ireland)	KW6	1
Kingspan Group Plc. (Ireland)	KW3	2
Bergey Wind Power Co. Inc. (U.S.)	BWC Excel 10	3
S.L. Borney (Spain)	wind 13	4
S.L. Borney (Spain)	wind 25.2	5
S.L. Borney (Spain)	wind 25.3	6
Guangzhou HY Energy Technology Co. Ltd (China)	HY 400 L	7
Guangzhou HY Energy Technology Co. Ltd (China)	HY 600	8
Guangzhou HY Energy Technology Co. Ltd (China)	HY 1000	9
Aeolos Wind Turbine	Aelos-V 300W	10
Aeolos Wind Turbine	Aelos-V 600W	11
Aeolos Wind Turbine	Aelos-V 1000W	12
Aeolos Wind Turbine	Aelos-V 3000W	13
Aeolos Wind Turbine	Aelos-V 5000W	14
Aeolos Wind Turbine	Aelos-H 500W	15
Aeolos Wind Turbine	Aelos-H 1000W	16
Aeolos Wind Turbine	Aelos-H 2000W	17
Aeolos Wind Turbine	Aelos-H 3000W	18
Aeolos Wind Turbine	Aelos-H 5000W	19

Tab. 2: Comparison of small wind turbines with vertical axis

nr.	price [€]	power [kW]	rotor diameter [m]	cut in speed[m/s]	survival speed[m/s]	warranty [a]	Noise emissions[dB(A)]
10	1982,16	0.3	1.2	1.5	50	5	45
11	2971.72	0.6	1.6	1.5	50	5	45
12	4032.71	1	2	1.5	50	5	45
13	7516.18	3	2.8	1.5	52.5	5	45
14	14109.14	5	4.5	1.5	52.5	5	45

Tab. 3: Comparison of small wind turbines with horizontal axis

nr.	price [€]	power [kW]	rotor diameter [m]	cut in speed[m/s]	survival speed[m/s]	warranty [a]	Noise emissions[dB(A)]
3	60320.65	10	7	2.5	60	5	42.9
1	33621.04	6.1	5.6	3.5	70	5	40
6	8275.00	5	4.05	3	60	3	-
19	-	5	6.4	3	45	5	45
5	5675.00	3	4.05	3	60	3	-
18	-	3	4.8	2.5	45	5	40
2	22859.77	2.5	3.8	3.5	70	5	-
17	2766.35	2	3.2	2.5	45	5	30
4	4100.00	1	2.65	3	60	3	-
9	-	1	1.96	2.5	50	-	33
16	1657.66	1	3.2	2.5	45	5	30
8	1187.74	0.6	1.75	2.5	50	-	38
15	649.15	0.5	2.7	2.5	45	5	25
7	887.46	0.4	1.5	2.5	50	-	25

turning with a reduced area of attack and increases the survivability of the turbine. The less expensive variants use a simple brake for the rotor, which means that the area exposed to the wind remains the same and the mast supporting the rotor is not relieved. Although this variant has the advantage of being considerably cheaper, it loses survivability.

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The warranty period is 3 to 5 years and some providers offer their own service centers to support the product even after the sale. For maintenance, systems 1 and 2 require an inspection every 2 years, system 4 every 6 months, 7, 8 and 9 also every 6 months, but here the blades and possibly the battery must also be replaced every 5 years. This maintenance work means considerable additional costs. No maintenance information could be obtained for the remaining systems.

There is a correlation between system size and noise emissions, with larger systems emitting more noise. However, this correlation cannot be confirmed in the upper performance class. Notably, there are significant differences in price, which could indicate that cheaper models have lower quality sound insulation.

The systems can be divided into three categories: Systems with a starting speed of 2.5 m/s, systems with a starting speed of 3 m/s and the vertical systems with a starting speed of 1.5 m/s. At first glance, this does not appear to be a major difference. The incidence of wind speeds above this threshold in urban areas is quite low compared to rural areas. This difference can therefore have a major impact on the annual amount of energy produced [14].

Not all small wind turbines are suitable for roof mounting. In particular, systems from a size of 5 kW can only rarely be installed on roofs in urban areas for structural reasons. These systems are often installed on offshore platforms to ensure reliable self-sufficiency [15–17]. In the medium power range, there are only a few systems installed in urban areas [18]. Here too, the systems are often too large to be accepted in these areas. The smallest output class, on the other hand, is very often used in urban areas. Aeolos systems are a good example of this. Hundreds of Aeolos 300W and 500W wind turbines have been installed in China, Japan, Romania, Brazil and Spain for hybrid wind-solar street lighting [19]. Smaller systems have the advantage that they are often quieter and do not generate large static loads, which increases acceptance in the surrounding area.

6 Discussion

The results have shown that there are sometimes considerable differences between the individual systems. One of the most significant differences is the price. The price range of the systems is very wide. This is partly due to the differences in quality, but also to the production process. The most expensive systems are only produced in small quantities, which means that the specific price of a system is significantly higher than for mass-produced systems. However, it is unclear why the higher quality products have not made it into mass production. One assumption is that the difference in quality was not communicated well enough to the consumer and therefore a large

Tab. 4: Certificates of individual small wind turbines

nr.	certificate
1	IEC61400-2
2	IEC61400-2
3	AWEA
4	IEC61400-2
5	-
6	-
7	ISO9001, CE
8	ISO9001, CE
9	ISO9001, CE
10	ISO9001, CE
11	ISO9001, CE
12	ISO9001, CE
13	ISO9001, CE
14	ISO9001, CE
15	ISO9001, CE
16	ISO9001, CE
17	ISO9001, CE
18	ISO9001, CE
19	ISO9001, CE

Tab. 5: Sources of prices and data

nr.	source of the price	general source
1	[20]	[15]
2	[21]	[16]
3	[22]	[17]
4	[23]	[18]
5	[23]	[18]
6	[23]	[18]
7	[24]	[25]
8	[26]	[25]
9	-	[25]
10	[27]	[28]
11	[29]	[28]
12	[30]	[28]
13	[31]	[28]
14	[32]	[28]
15	[33]	[28]
16	[34]	[28]
17	[35]	[28]
18	-	[28]
19	-	[28]

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number of pilot projects did not materialize. Only when a company can forecast a certain level of product sales with sufficient certainty will it go into mass production.

With regard to the installation potential in urban areas, it can be stated that vertical small wind turbines perform significantly better than some horizontal ones. However, an exact statement about the respective yield for urban areas cannot be derived from the data collected. All publicly available data was generated under standard conditions and is therefore difficult to transfer to urban areas. In order to secure a market advantage for urban areas, interested companies should adapt the environmental conditions to urban areas when collecting data. It has been shown that the wind potential in this area deviates significantly from the standard conditions [36].

The purpose of this document is to offer a basic outline of various small wind turbines to aid potential customers in decision-making. Nevertheless, customer requirements vary widely, hence it is essential to specify the desired performance class and the resultant yield first. For better comparability, it would be sensible to examine systems with the same output as much as possible, although acquiring the data presents a challenge. The limited number of systems within the three performance classes in this study prevents any overarching claims about generally available systems. The study shows, though, that a larger comparison is worthwhile, because even with this small sample, large differences in the individual categories could be identified. It would be prudent to increase the number of categories for further analysis. The comparison of yield under certain conditions would have been a suitable criterion to consider, although it could not be included here due to a lack of data. Some corporations conduct such tests, but the framework and parameters of these assessments differ. It would be more appropriate to administer a standardized test conducted by a neutral entity.

7 Conclusion

The market analysis reveals distinctions among the individual systems within their respective performance classes. It was not possible to identify the best system for a given power class, as all systems have their advantages and disadvantages. Nevertheless, a prospective purchaser can select a system for themselves if they specify particular weightings in each category. However, it is worth noting that this sample is only representative and therefore, it is possible that there are significantly more suitable systems available in individual cases. The actual suitability and comparability of the systems for urban areas could not be accurately analyzed. The effectiveness of some systems for urban areas can only be inferred from their real-life applications. No tests were conducted in this particular environment for any of the systems, thus making it challenging to interpret the comparison. The values given under standard conditions are the only reference available. Additionally, the collection of data was either carried out or commissioned by the companies themselves, thereby raising doubts about its authenticity. Consequently, the paper's goal could not be fully achieved. In order to achieve the aim of the paper, an investigation is recommended according to the following criteria:

- Selection of a performance class with minor deviations
- Construction of/ finding a test field representing the urban area
- Acquisition of the systems to be tested
- Testing the systems as an independent person
- Evaluation of the results

Significantly better comparability can be achieved through independent tests under defined conditions. However, this approach is associated with enormous costs for the purchase of the equipment and for the construction and operation of the tests. In addition, the market is subject to constant change, so that the results of this complex procedure can lose their significance after a short time. For these reasons, the implementation of such a test is considered unlikely. The question therefore remains as to how one can currently obtain a good overview of the market for small wind turbines for urban areas. As a customer, you are still faced with a large selection of turbines and are dependent on comparisons with little data or data that is unsuitable for the planned environment. When implementing larger projects, it is advisable to consult an energy consultant who may be able to provide information from various pilot projects. However, even this information will only relate to a small proportion of the systems available on the market.

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