Proposal of a methodology for the planning of a small wind turbine installation for a multi-site company based on a technical-economic analysis

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Abstract: Over the years, the diffusion of wind technology has heavily increased as wind farms are steadily being implemented as government regulations towards the reduction of carbon footprint are being confirmed worldwide and attention is drawn to sustainable development. However, while regarded as a feasible and interesting renewable alternative for utility companies, at the industrial level, organizations have only recently begun to approach this technology with the aim of self-producing energy. In this context, the most favorable situation is the one regarding large companies with multiple sites located throughout the territory and with good investment capacity. For these companies, the primary issue is represented by the lack of proper knowledge about the actual technical and economic feasibility of the project. Thus, this work aims to propose a comprehensive and structured methodology for the planning of small wind turbine installation for multi-site companies, providing the organization with a preliminary assessment about which among the various sites available are the most suitable. The proposed methodology takes into account several factors, such as the logistical, territorial and social characteristics of the various available sites, enabling the organization to obtain a clear picture of the feasibility of this application. The methodology comprises two phases: in the first phase, three major criteria are used to perform a first exclusion of sites according to technological, regulatory and logistics restraints, while the second phase aims to classify the remaining sites through the application of a multi-criteria analysis to identify the sites with the highest installation priority. Finally, the proposed methodology has been applied to a multi-site company with over fifty sites over all of Italy in order to test its applicability.

Keywords: Wind turbine, Industrial sustainability, Small wind technology, Self-generation, Multi-criteria analysis

1.Introduction

Over the years, the diffusion of wind technology has heavily increased as wind farms are steadily being implemented as government regulations towards the reduction of carbon footprint are being confirmed worldwide and attention is drawn to sustainable development. For instance, Europe installed 14.7 GW of new wind power capacity in 2020 (Wind Europe, 2021) and the global annual net wind capacity additions in 2020 have been expected to reach up to 8% more than in 2019 (IEA, 2020).

However, while regarded as a feasible and interesting renewable alternative for utility companies, at the industrial level, organizations have only recently begun to approach this technology with the aim of self-producing energy. Indeed, as stated in the "Global Wind Report 2019" by the Global Wind Energy Council "Progress in building new wind capacity is consistently falling short of what is needed, leading to a growing divide between top-down targets and the private sector's ability to deploy and invest at the right pace (Global Wind Report 2019, 2019).

In this context, one of the most interesting situations is the one regarding large companies with multiple sites located throughout the territory and with good investment capacity. For these companies, among the primary barriers for the development of this kind of renewable energy installation there is usually the lack of proper knowledge about the actual technical and economic feasibility of the project. Indeed, opportunities to realise the potential represented by small wind turbines are hampered by the failure to carry out a proper assessment (Wandera et al., 2021; Pambudi and Nananukul, 2019).

As stated by Bukala et. al. "the dissemination of SWTs (Small Wind Turbines) involves great expectations in the field of eco-energy production. Some opinions suggest that without the dissemination of SWTs, the fulfilment of legal requirements for energy efficiency and energy production from renewable sources will be relatively difficult" (Bukala et al., 2016).

The issue of properly assess the feasibility of small wind turbines installations is further complicated for large companies with multiple sites by the fact that the implementation of a thorough technological and economic feasibility analysis for all the possible sites of the organizations would require extensive investments. Thus, this work aims to propose a comprehensive and structured methodology to enable a preliminary assessment of the suitability of the various sites available for small wind turbine installation in the case of multi-site companies. Moreover, most companies that for the first time show interest for this kind of opportunity are not able to provide extensive data about all of their sites.

Therefore, the value of the present work is to present an innovative methodology that is both enough detailed to provide a deep assessment of the alternatives available to the organizations but is also enough simplified to guide the analysis for multi-site companies in a cost-effective manner.

The paper is structured as follows: Section 2 describes the background of the theme. Section 3 provides a description of the proposed methodology while Section 4 shows its application to a real case study. Finally, Section 5 concludes the paper, presenting the main conclusions and the possible developments of this work.

2.Background

Small wind turbines represent a distinct group of devices within the wind energy sector. Following the definition provided by the IEC 61400-2 standard, small wind turbines are characterized by a rotor area inferior to 200 m^2 and rated power below 50 kW (IEC, 2013). Moreover, wind turbines are divided into two major groups based on the position of rotor axis of revolution: horizontal axis wind turbines (HAWTs), that represent the majority of the installations, and vertical axis wind turbines (VAWTs).

As regards the search for the most advanced performances for small size HAWT turbines, various authors focused on the variation of some parameters for the improvement of performance (Refan and Hangan, 2012). Furthermore, Mayer et al. worked on the effect of wind turbine performance when there is a fluctuation with wind speed (Mayer et al., 2001). This situation is very common for most small wind turbines, as they are positioned at low heights (around 10 - 15 m) (Tummala et al., 2016).

In order to fight the still present sense of general public mistrust in wind energy Bukala et al. studied formulated and described the most important parameters of influence for the efficiency and power output of a small wind turbine (Bukala et al., 2015).

Scientific literature regarding site selection has mainly focused on the wind sector in terms of medium and large installations, through three types of approaches: Multicriteria Decision Making (MCDM), Geographic Information Systems (GIS), and Statistical Methods (Rediske et al., 2021). The MCDM methods applied vary: the ELECTRE-II method was used analyse the locations of seven wind/solar hybrid power plants (Jun et al., 2014), AHP (Analytic Hierarchy Process) was applied to evaluate potential locations in Pakistan (Ali et al., 2018) and the PROMETHEE method has been applied in Saudi Arabia (Rehman et al., 2019). While these methodologies provide extensive results, flexibility and are certainly preferable when applicable, often this is not possible since companies that are just approaching the idea of implementing small turbine installations are unable to invest enough resources. Thus, a simplified methodology, based on the collection on a limited amount of information might be preferable to conduct a preliminary assessment of this opportunity.

Despite the growing interest in this field, until now no author has focused their research to the objective of provide a method for the preliminary planning of a small wind turbine installation for a multi-site company.

3.Methodology

The proposed methodology for a multisite company that faces the problem of choosing the most suitable site for the installation of the small wind turbine system comprises two phases.

In the first phase, relevant criteria are identified and used to perform a first exclusion of sites according to the most important restraints.

Then, in the second phase, a multi-criteria analysis is applied to the remaining sites to define an ordered list among the various sites, thus identifying the sites with the highest installation priority.

The proposed method has no aim to substitute more in-depth analysis for the optimization of wind turbines' locations. Indeed, the aim is to provide a preliminary, cost-effective, tool to restrict the range of the sites analysed more thoroughly in the following analysis. The use of a limited number of criteria, whose weight has to be assessed by the company, has the advantage of providing an initial screening tailored to the specific characteristics of the organization.

3.1 Step 1: enabling criteria

Three fundamental aspects have been identified among the enabling criteria concerning wind technology:

- technological;
- regulatory;
- logistical.

First of all, the presence of wind is obviously critical for the functionality of wind turbines. Indeed, scientific literature defines as convenient an investment in this technology only if the average annual wind speed in the site is greater than or equal to 5 m/s or if the instantaneous wind speed is greater than or equal to 4 m/s for at least 2000 hours per year. Therefore, in order to identify the company's plants that fall within these specifications, specific websites can be used (such as the wind atlas available on the website atlanteeolico.rse-web.it, setting the reference height to 25 m above sea level). Superimposing this information on the map of the analysed sites, it is possible to divide them according to the average annual wind speed and exclude the sites deemed not convenient.

The regulatory aspect, instead, is linked to the landscape constraints regulated at national and regional level, in this regard for instance in Italy the website http://sitap.beniculturali.it/, can be used to highlight areas and assets subject to the landscape constraints. Sites that do not appear to be in restricted areas are considered suitable, otherwise the other sites must necessarily be discarded.

Furthermore, the availability of the land necessary for the construction site, installation and commissioning of the turbine is an exclusionary criterion because there may be sites that, due to the lack of the necessary square footage, will have to be excluded. To provide a reference quantity, a practical example is proposed: considering a turbine with a nominal power of 60 kW and a hub 50 m high, this will have a diameter of 6 m and therefore a minimum area of 30 m^2 must be considered for the installation of a single turbine.

Following the application of Step 1, a group of possible sites to be considered suitable is obtained and their classification is carried out in Step 2.

3.2 Step 2: classification of sites

The goal of this step is to define a real classification among the various sites and then choose the most profitable one for the installation of the mini wind power plant. To address this management decision-making problem, it was decided to apply the multi-criteria analysis. The analysis has fallen on this methodology because the problem presents several conditions that have to be verified to render a site profitable.

The multi-criteria analysis method can be divided into several phases:

- definition of the decision matrix;
- normalization of the matrix;
- assignment of weights;
- ranking evaluation.

Table 1: Decision Matrix

Criterion	Description criteria	Evaluation scale for each criterion
A.	**Available quantity of land on the site**	- 1 for availability of 30 m^2; - 3 for availability of 360 m^2; - 5 for availability of 690 m^2.
B.	**Usability of the site** (Influences the profitability of the site)	- 1 for the presence of large-sized buildings and/or vegetation; - 3 for the presence of small vegetation (hedges and shrubs); - 5 for the absence of obstacles in the chosen terrain.
C.	**Distance from the electricity connection** (Implies additional costs)	- 1 for the absence of the transformer substation within the site property; - 3 for the presence of the transformer substation on the site, but it and the electrical system are distant from the point indicated for the installation of the small wind turbine system; - 5 for the presence of the transformer cabin on the site and in proximity to the installation point of the small wind turbine system.
D.	**Potential future obstacles**	- 1 point for surrounding building land; - 3 points for surrounding arable land; - 5 points for surrounding land that is neither building nor arable.
E.	**Social acceptance**	- 1 if there is an active environmental committee in the area and the local population is sensitive to environmental issues; - 3 if there is no committee, but the population is historically conservative in regards to the landscape and the environment; - 5 if there is no committee and the population has not been opposed to similar environmental changes in the past.
F.	**Medium-term company perspectives**	- 1 for a site that will be decommissioned in the medium term; - 3 for a site deemed non-strategic; - 5 for a site considered strategic.

The core of the model consists of the decision matrix: a two-dimensional matrix *n* x *m*, where one dimension represents the n criteria and the other the m choice options, therefore in our case the m sites resulting from Step 1.

For the construction of the matrix, the research, the identification and the subsequent choice of all those criteria that take into account the criticalities and the sufficient conditions relating to the installation of a small wind power plant required both technical knowledge and experience in the specific field, thus was conducted consulting experts in the field.

Several logistical, economic and socio-environmental aspects have been taken into consideration. To make these data homogeneous and operable, the matrix needs to be normalized.

This activity is carried out through the use of a rating scale. For every criterion, a value from 1 to 5 has been assigned to represent the different degree of satisfaction of the decision-maker, which in this case translates in terms of influence on project times and cost 1 presents the description in reference to the possible scores assignable to each criterion and their weights.

Then, weights are assigned to each criterion to establish an order of importance among them, representing the priorities that are assigned to the various aspects of the problem. The weights were assigned directly on the basis of a predetermined score scale ranging from 1 to 3 and have been identified with the personnel of the organization in order to tailor the assessment to the requirements of the company.

Finally, the ranking of the alternatives is calculated by combining weights and scores with respect to each alternative. The method used here is that of the weighted sum. The weighted sum (Si) of an alternative (Ai) requires that each indicator (ai,j) is multiplied by the weight (wj) of the corresponding criterion (Cj) and added to those belonging in the same row:

$$Si = \Sigma j\ (wj \cdot ai,j)$$

With this procedure we arrive at the classification of the sites and we can therefore create an investment plan structured over time based on the financial resources available.

Finally, the organization is able to analyse the sites, starting from the technical-economic feasibility of "HIGH" priority installation sites, as described by Table 2.

Table 2: Installation priority classes

INSTALLATION PRIORITY	
HIGH	45 ÷ 60 POINTS
AVERAGE	28 ÷ 44 POINTS
LOW	12 ÷ 27 POINTS

Figure 1 present a schematic representation of the proposed methodology.

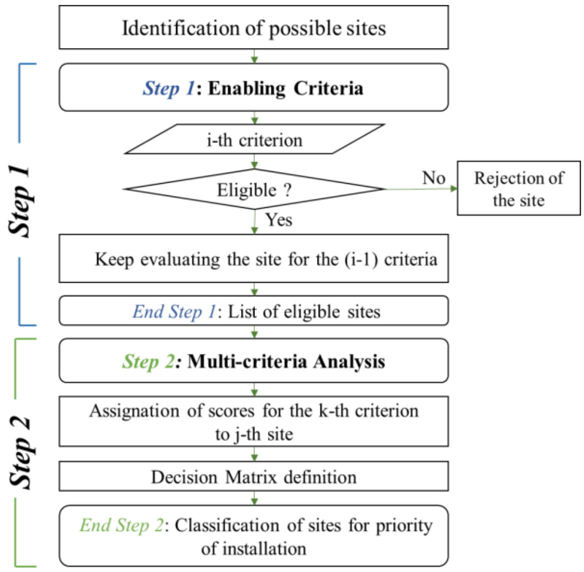

Figure 1: Schematic representation of the proposed methodology

3.3 Technical- economic feasibility analysis

Once the methodology has been implemented, the sites with "HIGH" priority of installation are identified and it is necessary to move on to the analysis of technical feasibility. The analysis involves the choice of the small wind turbine, the arrangement of the plant if more turbines are foreseen and finally the evaluation of the energy producibility based on the use of weather data for the sites (Bukala et al., 2015).

Three factors have been identified for choosing the most suitable turbine for the site. The first factor is the "nominal efficiency" which is defined by the ratio between the nominal power and that available at the corresponding nominal speed. The higher this factor, the greater the producibility of the turbine with the same power size.

The second factor is the "ratio of nominal speed to lower cutting speed". In fact, it can be seen that to obtain maximum efficiency the nominal speed should be equal to √3 times the cutting speed.

The third factor is the "utilization factor" which relates the energy yielded to that theoretically available if the turbines were able to continuously deliver the installed power.

Therefore, through the optimization of these three factors, one can discriminate between the various turbines that the market offers.

Energy can be calculated by integrating the instantaneous power over time.

The economic feasibility analysis allows to make the final decision on whether to implement the investment or not. The cost-benefit analysis quantifies the energy and therefore economic savings.

The economic parameters necessary for the assessment of the profitability and feasibility of the site identified are two: the Net Present Value (NPV) and the Payback Period (PBP).

4.Case study application

Finally, the proposed methodology has been applied to a multi-site company with over fifty sites over all of Italy in order to test its applicability. The first activity carried out was the identification of all the sites of the company and their geolocation. The number of sites was 57.

4.1 Step 1

In this phase all those sites with an average annual wind speed greater than or equal to 5 m/s or an instantaneous wind speed greater than or equal to 4 m/s for at least 2000 hours per year.

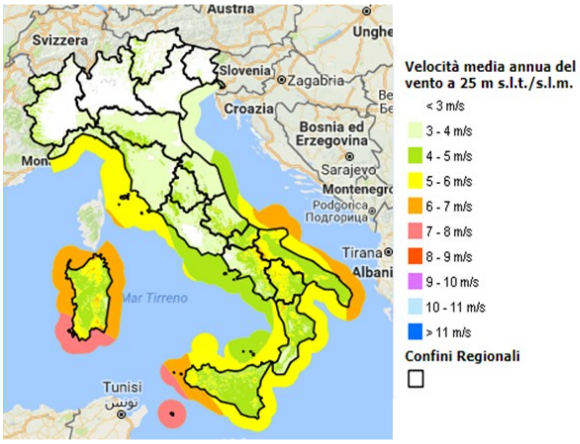

Figure 2: Wind atlas with average annual wind speed at 25 m from the sea level.

To this end, a wind atlas was used and the result is shown in Figure 2. As seen in the figure, it is expected that the areas with the greatest windiness will be the coastal ones and the islands, therefore in general southern Italy, while the urban and inland areas will have low windiness.

By superimposing the wind atlas on the map showing the maintenance sites, it is possible to identify those of interest for our objective.

They are initially divided and reported in Table 3. Table 4 reports the results of this first analysis in terms of the eligibility of the sites.

Table 3: Sites’ classification based on wind speed

Average wind speed	Number sites identified
< 3 m/s	21
3 - 4 m/s	9
4 - 5 m/s	16
5 - 6 m/s	10
6 - 7 m/s	1
> 7 m/s	0

Table 4: Sites’ classification based on convenience of installation

Convenience of installation		
No (speed < 4 m s)	30	52.63%
Maybe (speed = 4 - 5 m/s)	16	28.07%
Yes (speed > 5 m/s)	11	19.30%

The second exclusionary aspect is the regulatory one, linked to the landscape constraints at national and regional level.

Fortunately, no site fell within an area subject to landscape restrictions or of archaeological interest. Therefore, no exclusion has been derived from this criterion.

The last exclusion criterion concerns the logistical characteristics of the sites: the minimum availability of space for the installation of at least one small wind turbine. Planning for the installation of small wind power, a minimum size of 30 m^2 has been identified, which is an area present in each site as declared by the Energy Manager of the organization.

Thus, not even this criterion, for this specific case of application, leads to the exclusion of any additional site.

4.2 Step 2

In the implementation of this phase, all the sites found suitable in step 1 were analysed with respect to the identified criteria.

The sites that fell in the intermediate band of average annual wind speed were also included in the study, in order not to run the risk of neglecting sites with a possible unexpressed potential at a primary and not in-depth analysis. Of the total 27 potential sites, 6 were excluded due to the Energy Manager choice due to managerial reasons.

Therefore, 21 sites were considered and classified by applying the multi-criteria analysis for the development of the small wind installation, creating the decision matrix.

Criteria A and C, respectively "amount of land available on the site" and "distance from the electricity grid connection", were not relevant as all sites of the organization had both a large size and a connection to electricity grid present on the site. Therefore, with regard to these two criteria, all the sites recorded the same score, with the exception of a few establishments with less land availability.

As regards criterion E: “presence of environmental associations rooted in the place”, we based on the data relating to the “Environmental Protection Associations recognized pursuant to art. 13 law n. 349/86 and subsequent amendments” of which the Ministry of the Environment and Protection of the Territory and the Sea provides the complete list.

For the other criteria, the Energy team and the Manager responsible for interventions on the industrial sites provided precise knowledge of each site in order not to encounter any critical issues regarding the analysis.

The analysis of criterion F "Medium-term business prospects" was very important since it led to exclude a site, which seemed to be the most "promising" thanks to the highest average annual wind speed, but was indeed going to be decommissioned in the future.

The weights are shown next to each criterion in Table 5.

Table 5: Sites' classification based on convenience of installation

Site	Criteria (Weights)						Total
	A (1)	**B** (2)	**C** (1)	**D** (2)	**E** (3)	**F** (3)	
Genova	5	3	5	3	1	3	34
Pisa	5	3	5	1	3	3	36
Ancona	5	3	5	3	3	5	46
Campobasso	3	3	5	1	1	3	28
Benevento	3	3	5	1	3	3	34
Napoli	5	3	5	1	1	3	30
Salerno	3	3	5	1	3	3	34
Foggia	3	3	5	3	3	3	38
Lecce	5	3	5	3	3	5	46
Paola	3	3	5	3	3	3	38
Sassari	3	3	5	3	3	3	38
Savona	5	3	5	3	3	5	46
Bari	3	3	5	3	3	3	38
Taranto	5	3	5	3	3	3	40
Catanzaro	5	3	5	3	3	3	40
Reggio Calabria	5	3	5	3	3	5	46
Messina	5	3	5	3	3	5	46
Catania	5	3	5	3	3	3	40
Siracusa	5	3	5	3	3	3	40
Palermo	5	3	5	3	1	3	34
Cagliari	3	3	5	3	1	1	26

LEGEND:

Criterion A: Available quantity of land on the site
Criterion B: Site usability
Criterion C: Distance from the mains connection
Criterion D: Potential future obstacles
Criterion E: Social acceptance
Criterion F: Medium-term business prospects

Therefore, the resulting classification is the following Table (Table 6).

Table 6: Sites' installation priority results

INSTALLATION PRIORITY	
HIGH	# 5 SITES
AVERAGE	# 15 SITES
LOW	# 1 SITE

4.3 Technical–economic feasibility analysis

Before moving on to the actual technical-economic analysis it was necessary to define the size of the small wind turbine so as to be able to carry out a market research among the various manufacturers. The Energy team, in agreement with the Manager responsible for interventions on the industrial plants, chose 60 kW as the size of the small wind turbine.

This choice was substantially dictated by the absence of bureaucratic constraints for turbines up to the size of 60 kW.

Moreover, it was chosen to install only a single turbine as an experimental project and then in the future to evaluate the possibility of implementing further installations.

Table 7: Comparison between the three 60 kW turbines on the Italian market based on evaluation parameters

	Model 1	**Model 2**	**Model 3**
Nominal efficiency	0.35	0.25	0.38
Nominal speed / cutting speed	3.00	3.00	2.50

Table 7 reports 3 wind turbine model found on the market. The turbine that appears to be more efficient, that is the one for which the design focuses above all on maximizing efficiency, is the third model.

The choice, therefore, fell on this turbine and the economic feasibility, during which the utilization factor has been calculated, has been carried out based on the technical specifications of this small wind turbine.

The energy producibility for the five sites found to have "high priority of installation" so as to be able to classify them for profitability using the data of the average hourly wind speed for the sites.

The results are in Table 8.

Table 8: Comparison among sites of high interest on the basis of the energy that can be produced

Site	Annual Consumed Energy	Annual Producible Energy
Reggio Calabria	≈ 1210 MWh	≈ 156 MWh
Savona	≈ 945 MWh	≈ 92 MWh
Ancona	≈ 2000 MWh	≈ 89 MWh
Messina	≈ 178 MWh	≈ 55 MWh
Lecce	≈ 1310 MWh	≈ 43 MWh

For the economic feasibility analysis, the input data used are: initial investment (i.e. the cost of the turbine) equal to 230,000 € (without VAT), useful life of the plant = 20 years; discount rate of 4.5% and an incentive tariff of 0.190 €/kWh.

With these parameters, the following economic result is obtained: NPV = 122,000 € and PBP = 11 years.

5.Conclusion and future developments

In the present paper, a methodology for the identification and evaluation of the most suitable sites for a small wind turbine application in a multi-site organization has been proposed. The proposed method comprises of two main phases which are concluded by a technical-economic feasibility assessment. The first phase is used to define a first selection of sites through the use of enabling criteria for the choice of site. The second phase applies a multi-criteria analysis to obtain a ranking among the selected sites and therefore focus the attention of the management on the most attractive options.

The originality of the proposed methodology is represented by the combination of a simplified input with a strong methodological structure. This allows to have reliable results with little a relative minimum effort required to the management. The proposed methodology has been applied to the case study of a multi-site Italian company with 57 sites.

The application has verified not only the applicability of the method but also the usefulness since it highlighted specific cases in which relevant criteria used were critical to the assessment in order to target the efforts only to truly profitable options.

The proposed method does not aim to substitute the use of more complex MCDM approaches but is designed to provide a preliminary, cost-effective, tool to restrict the range of the sites that are going to be analysed more thoroughly in the following technical and economic feasibility analysis. The limitation in the number of criteria has the benefit of enabling a preliminary screening for less structured organizations.

Further developments of this study will see the creation of a tool to automate this application thus providing more effective help to multi-site organizations in the assessment.

References

Ali, Y., Butt, M., sabir, M., Mumtaz, U. and Salman, A. (2018) Selection of suitable site in Pakistan for wind power plant installation using analytic hierarchy process (AHP). *Journal of Control and Decision*, 5(2) 117–128.

Bukala, J., Damaziak, K., Kroszczynski, K., Krzeszowiec, M. and Malachowski, J. (2015) Investigation of parameters influencing the efficiency of small wind turbines. *Journal of Wind Engineering and Industrial Aerodynamics*, 146 29–38.

Bukala, J., Damaziak, K., Kroszczynski, K., Malachowski, J., Szafranski, T., Tomaszewski, M., Karimi, H.R., Jozwik, K., Karczewski, M. and Sobczak, K. (2016) Small Wind Turbines: Specification, Design, and Economic Evaluation. In: A.G. Aissaoui and A. Tahour (eds.) *Wind Turbines - Design, Control and Applications*. InTech,.

Global Wind Report 2019 (2019) Global Wind Energy Council.

IEA (2020) *Wind – Renewables 2020 – Analysis*.

IEC (2013) *IEC 61400-2:2013 - Wind turbines - Part 2: Small wind turbines*.

Jun, D., Tian-tian, F., Yi-sheng, Y. and Yu, M. (2014) Macro-site selection of wind/solar hybrid power station based on ELECTRE-II. *Renewable and Sustainable Energy Reviews*, 35 194–204.

Mayer, C., Bechly, M.E., Hampsey, M. and Wood, D.H. (2001) The starting behaviour of a small horizontal-axis wind turbine. *Renewable Energy*, 22(1) 411–417.

Pambudi, G. and Nananukul, N. (2019) A hierarchical fuzzy data envelopment analysis for wind turbine site selection in Indonesia. *Energy Reports*, 5 1041–1047.

Rediske, G., Burin, H.P., Rigo, P.D., Rosa, C.B., Michels, L. and Siluk, J.C.M. (2021) Wind power plant site selection: A systematic review. *Renewable and Sustainable Energy Reviews*, 148 111293.

Refan, M. and Hangan, H. (2012) Aerodynamic Performance of a Small Horizontal Axis Wind Turbine. *Journal of Solar Energy Engineering*, 134(2) 021013.

Rehman, A.U., Abidi, M.H., Umer, U. and Usmani, Y.S. (2019) Multi-Criteria Decision-Making Approach for Selecting Wind Energy Power Plant Locations. *Sustainability*, 11(21) 6112.

Tummala, A., Velamati, R.K., Sinha, D.K., Indraja, V. and Krishna, V.H. (2016) A review on small scale wind turbines. *Renewable and Sustainable Energy Reviews*, 56 1351–1371.

Wandera, F.H., Andersen, M.H. and Lema, R. (2021) Learning from global suppliers: the diffusion of small wind in low- and middle-income countries. *International Journal of Technological Learning, Innovation and Development*, 13(1) 24.

Wind Europe (2021) *Wind energy in Europe: 2020 Statistics and the outlook for 2021-2025*.