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K. Petrenko*, I. Ivanchenko, O. Karmazin

Institute of Renewable Energy, National Academy of Sciences of Ukraine
Kyiv, 02094, Ukraine

*** Corresponding author:** KaterynkaPetrenko@gmail.com

Prospects for the use of wind energy resources at the Akademik Vernadsky station

Abstract. Renewable energy and other methods of minimizing emissions into the atmosphere should be a priority for each country. This approach should be extended to Antarctica scientific stations.The study main objective was to obtain the necessary estimates of the wind energy potential of the Galindez Island territory to estimate the feasibility of installing wind turbines on the territory of the Akademik Vernadsky station. The study of the wind properties over the territory was based on the British Antarctic Survey archive of meteorological parameter average annual values (1950–2020), 3-h wind speed and direction data, registered by the Akademik Vernadsky station (2011–2020), and average daily data from meteorological observations (2014–2018). The Hellman parameter was calculated from satellite data. A number of statistical methods were used to analyze the vertical wind profile, particularly the method of minimizing the arithmetic mean relative modeling error. To assess the amount of generation, the wind speed data at the height of the anemometer sensor were recalculated to the height of the wind turbine axis. Using the wind power characteristics provided by the developers, average annual wind power generation was avaluated. For calculations of wind energy potential, we chose the technique developed by the Department of Wind Power of the Institute of Renewable Energy of the National Academy of Sciences of Ukraine. The analysis of the wind conditions showed a high average daily wind speed (3.9 m/s) and the prevailing wind direction (north – northeast 24%). The results support the hypothesis about the expediency of installing wind turbines on the territory of the Akademik Vernadsky station. The wind turbine was selected for further wind power calculations based on the other countries experience of using wind turbines in Antarctica and considering the specifics of installation and operation in conditions of high wind speeds, low temperatures and high relative humidity. Based on information on fuel consumption at the Akademik Vernadsky station, it was estimated that the installation of 10 wind turbines SD6 would meet 28.4% of the station's yearly electricity needs.

Keywords: Antarctica, electricity generation, Galindez Island, renewable energy, wind energy, wind speed

1 Introduction

Antarctica is the coldest continent on Earth. Due to the harsh climate, operating an Antarctic base requires a lot of energy, and for a long while, the only source of it had been fossil fuels brought overseas. The Ukrainian Antarctic Akademik Vernadsky station is powered by diesel generators. The fuel can only be delivered during the navigation season several months a year. The diesel fuel and transportation cost is a large part of the annual expenditure for the station's functioning.

The costliness and potential environmental hazards of buying, shipping, and storing vast amounts of fossil fuels encourage to provide research of efficient use and renewable energy sources (Tin et al., 2010). According to a number of international directives (ATCM, 2016), the Parties to the Antarctic Treaty have to implement measures to minimize their research bases' environmental impact (including procedures for storage and efficient use of fuel, employing renewable energy sources (RES) and other ways to minimize emissions into the atmosphere, etc.).

Harnessing the RES such as the Sun and the wind on the Galindez Island requires a detailed analysis of the annual dynamics of incoming irradiation and long-term dynamics of the wind speed (both at the annual and the daily levels).

As the Akademik Vernadsky station is located close to the Antarctic circle (65°15′ S 64°15′ W), it receives minimum radiation over the whole Antarctic winter, exactly when most energy is required, for the illumination and heating. The wind as an energy source displays no such clear seasonality. Thus, our work is dedicated to estimate local wind resources and the expediency of installing a wind turbine (WT) on Galindez Island.

Several factors might limit the installing and exploiting a WT. The first and foremost are the maximum wind speeds and their repeatability, since most of the WTs have upper wind speed limits. Moreover, the equipment can be damaged by icing in humid and cold environment. There is a sparse experience of the WT use in Antarctica. Most of the wind generators have been installed at inland stations where the air temperature and humidity are lower than at Antarctic Peninsula. These wind power plants are operated at Amundsen-Scott (USA), Mawson (Australia), Princess Elisabeth (Belgium), Mario Zucchelli (Italy) stations and at Ross Island by New Zealand and USA (*The first Pole wind turbine*, n.d.; Department of Agriculture, Water and the Environment, 2020; Power Technology, 2010; Winter, 2019; Herenz et al., 2018; *Antarctica: first wind farm*, 2018). Harsh environment in Antarctica produces many challenges for designing and constructing the turbine. However, the difficulties are not just in the choice of the WT that able to adequately function in the given climatic conditions, also in finding the way to install it.

2 Materials and methods

The Akademik Vernadsky station is located on the Marina Point (Galindez Island), near the western shore of the Antarctic Peninsula in the area of the prevailing oceanic winds. In the station's area, the airflow is largely shaped by the meridional orientation of the seashore. On the other hand, the geography of mountains on the Antarctic Peninsula (average height 2000 m) promotes mesoscale circulation (foehn winds). Moreover, the cooling of air masses over the ice sheet coupled with their gravitational sinking lead to local katabatic winds (Tymofeyev et al., 2017).

According to the data of the British Antarctic Survey (n.d.), from 1950 to 2018, the average multi-

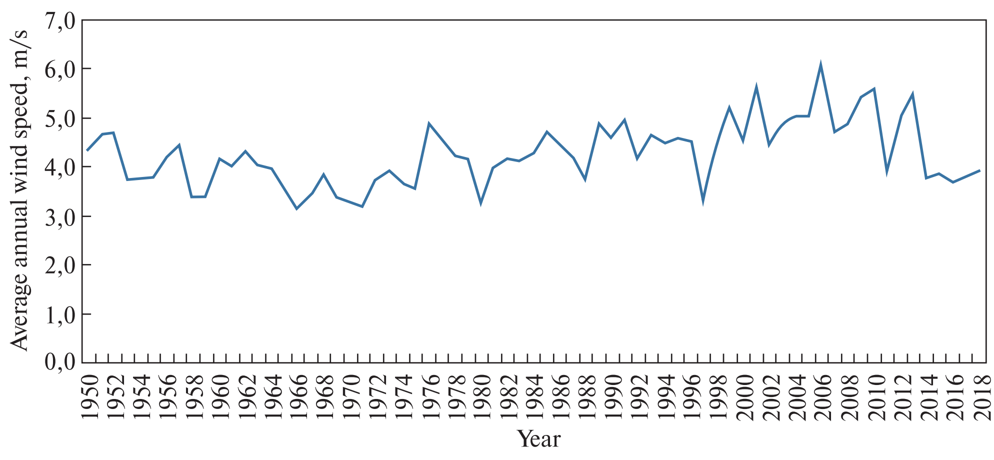

Figure 1. Long-term wind speed dynamic at the Faraday (1950–1995) – Akademik Vernadsky (1996–2018) station

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year wind speed was 4.3 m/s, the maximum average annual wind speed was recorded for the 2006 (6.1 m/s), and the minimum average annual wind speed (3.2 m/s) — for 1966 (Fig. 1). The data for 2019—2020 were not included in the calculations as pending verification by the system (British Antarctic Survey, n.d.).

For the following calculations, we used 3-h records for wind speed and direction for 2011–2020 and average daily data from the Meteorological Observations Table (MOT) for 2014–2018.

According to the MOT data, the average wind speed at the Akademik Vernadsky station in 2014–1018 was 3.9 m/s, and the maximum average daily wind speed — 18.5 m/s (August 5, 2018). Maximum values of the annual distribution of wind speed were seen for the austral winter (July–September) and autumn (February–April) (Fig. 2). The histogram and the cumulative frequency plot of the wind speed distribution are given in Fig. 3.

Maximum wind speeds are also recorded mostly in the autumn and winter seasons (up to 38 m/s); in almost 96% of cases, the maximum wind speed does not exceed 25 m/s, and in 99%, 30 m/s. The wind speeds over 30 m/s constitute only 0.9% of cases (Fig. 4).

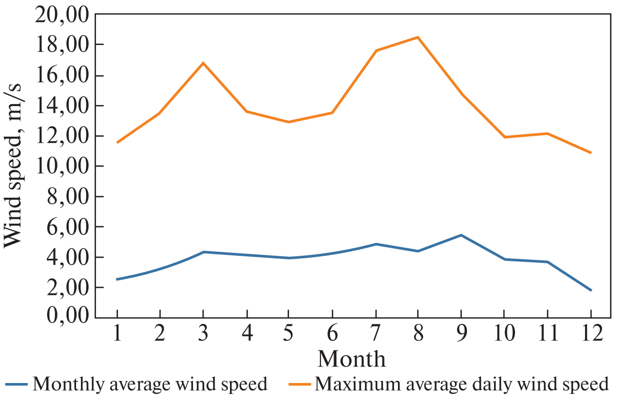

Figure 2. Annual distribution of wind speed at the Akademik Vernadsky station (2014–2018)

Daily wind speed distribution is smoothed, with a slight maximum at night (4.05 m/s at 21:00–00:00) and minimum in the morning (3.93 m/s, 03:00–09:00).

During the whole year, the prevailing winds at the Akademik Vernadsky station are the NNE winds (Fig. 5). They take up 24% of the annual wind rose (21.7% in July to 27% in April).

Taking satellite data (NASA POWER, n.d.) for wind speeds at the 10 m and 50 m heights over Galindez Island, we used the method of minimization of mean

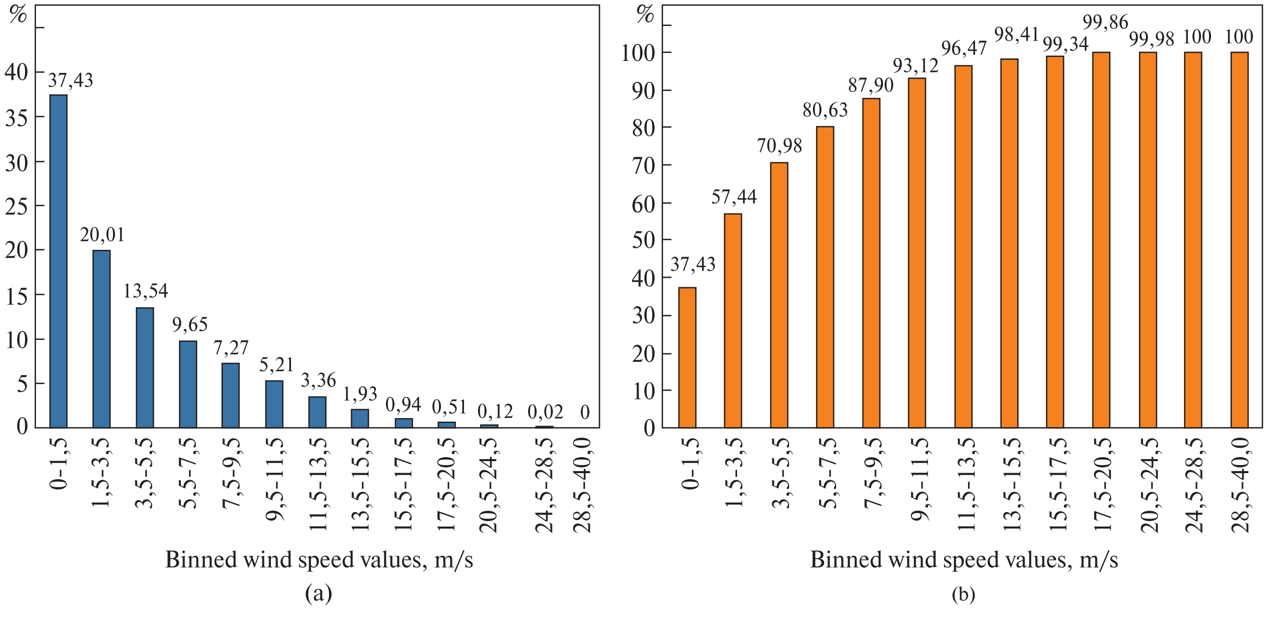

Figure 3. Histogram (a) and cumulative frequency plot (b) of 3-h wind speed data at the Akademik Vernadsky station

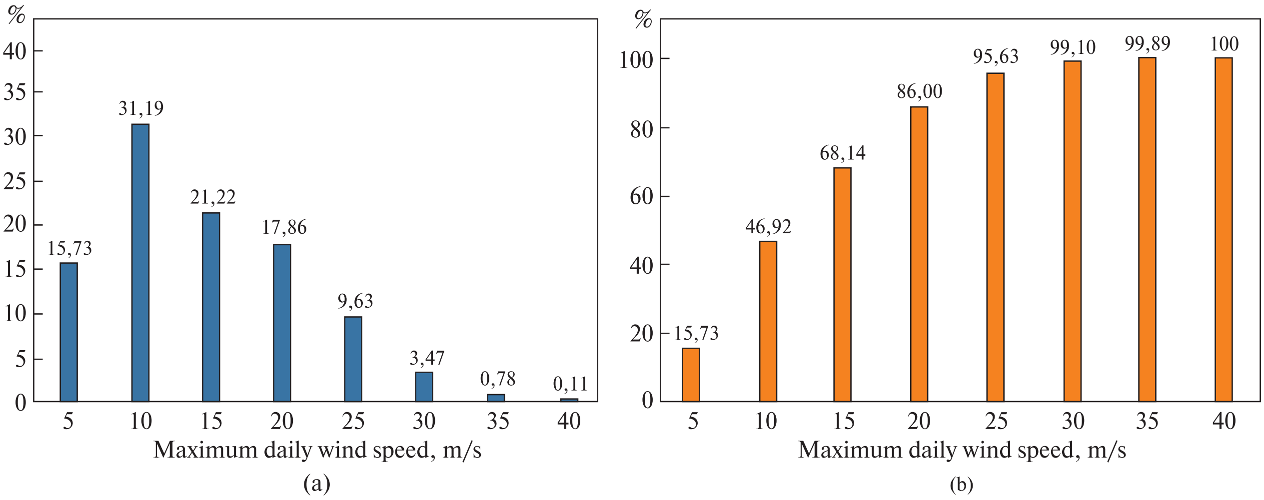

Figure 4. Histogram (a) and cumulative frequency plot (b) of maximum wind speed data at the Akademik Vernadsky station

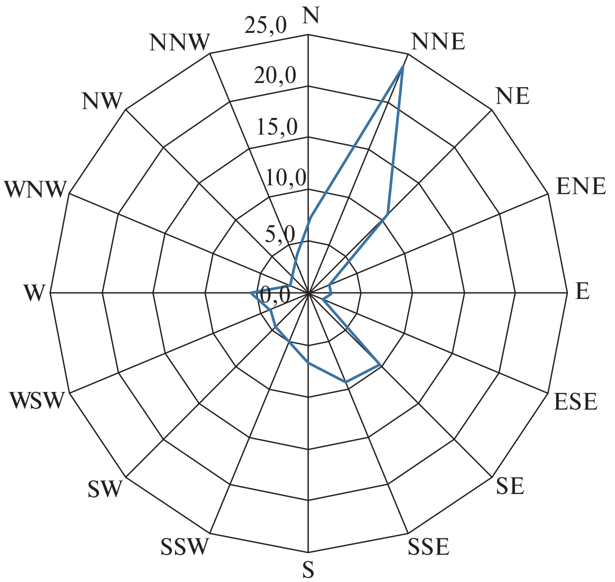

Figure 5. Wind rose in 16 rhumbs at the Akademik Vernadsky station for 2013—2020 (according to Meteorological Observations Tables)

absolute percentage error (Tochenyi et al., 2011) to study the vertical wind profile and calculated the Hellman parameter (α), which was 0.1.

3 Results and discussion

The history of wind energy use in Antarctica began in 1991 at the Neumayer Station (Germany), with a vertical-axis WT prototype (VAWT). Currently, the Neumayer Station uses a WT with a horizontal axis providing 30 kW (Enercon E-30), able to accommodate changes in snow cover by adjusting the tower's height. The turbine covers around 12% of the base's annual energy needs (Dupre, 2020).

In 1997, a two-year-long pilot project was implemented at the Amundsen-Scott Station (USA) (*The first Pole wind turbine*, n.d.). The analysis was favorable, and in 2005 the National Renewable Energy Laboratory proposed to install another 100 kW wind farm (WF) (NPS Northwind 100 turbine), which would cover up to 50% of the station's overall energy needs.

A joint USA-New Zealand project for the Ross Island to build WTs for two Antarctic stations (2008—2009) was done using the WT Enercon E-33. Similar WTs were set up on the Mawson Research Station (Australia) in 2003 (Enercon E-33).

The seasonal base Princess Elisabeth (Belgium) was built with an energy-efficient design to minimize the fossil fuel use. 48% of the station's energy comes from wind using nine SD6 turbines (Table 1).

As can be seen from Table 1, the temperature conditions of the Akademik Vernadsky station are comparable with the temperature conditions of some Antarctic stations which already used wind energy. The humidity conditions are somewhat different as the relative humidity in the area is the highest of all

Figure 6. Installation of SD wind turbine on a rock surface (SD Wind Energy Limited, 2019)

(83%), which coupled with low temperatures can cause ice damage of the equipment.

The main requirements to the choice of a wind energy plant suitable for the Akademik Vernadsky station are:

• Stable output under the expected wind speeds;

• Installation not relying on a crane or another large equipment;

• No concrete-filled gravity foundation or deep drilling is required;

Table 1. The main meteorological parameters of Antarctic stations using wind energy

Station	Country	WF installment year	Power, kW	Average annual temperature, °C	Minimum average daily temperature, °C	Average annual relative humidity, %	Reference
Ross Island (McMurdo, Scott Base)	USA, New Zealand	2010	999	−17.8*	−27.9*	63.8*	1
Mawson	Australia	2003	300	−12.0	−23.0	55.0	2
Princess Elisabeth	Belgium	2010	54	−19.1**	−34.0	61.7**	3
Mario Zucchelli	Italy	2018	—	−14.0	−25.0	16.0	4
Jang Bogo	South Korea	2014	9	−15.0	−36.3	55.0	5
Neumayer-Station III	Germany	2003	30	−16.0	−31.0	80.0	6
Comandante Ferraz	Brazil	2020	48	−1.8	−12.0	78.1	7
Akademik Vernadsky	Ukraine	—	—	−2.5	−28.3	83.0	—

Note: * averaged for McMurdo and Scott Base
** measured only in summer
1 — Power Technology, 2010; Winter, 2019; Department of Agriculture, Water and the Environment, 2020; Time and Date AS, n.d. 2 — Time and Date AS, n.d. 3 — International Polar Foundation, 2013; Herenz et al., 2018; Reliable Prognosis rp5.ua (https://rp5.ua/). 4 — *Antarctica: first wind farm*, 2018; Time and Date AS, n.d. 5 — United States Antarctic Inspection Team, 2020; Dupre, 2020; Reliable Prognosis rp5.ua (https://rp5.ua/). 6 — Tin et al., 2010; Time and Date AS, n.d. 7 — COMNAP, 2020; Time and Date AS, n.d.

Table 2. Estimation of electricity generation by wind turbines SD3 and SD6 at the Akademik Vernadsky station

WT type	SD3	SD6
WT power, kW	3	6
Hellman parameter α	0.1	
Height of sensor position, m	10	
Measurement metadata		
Time period	01.01.2011—31.12.2020	
Number of measurements	28662	
Duration of measurements, hours	85986	
Wind speed		
At sensor height		
Mean wind speed, m/s	3.980	
Standard deviation, m/s	4.179	
Variation coefficient, %	105.036	
Average energy-producing wind speed, m/s	5.933	6.308
At rotor axis height (9 m)		
Mean wind speed, m/s	3.94	
Proportion of energy-producing wind speed, %	42.56	51.53
Average energy-producing wind speed, m/s	5.80	6.28
WT energy output parameters		
Total generation for the whole measurement period, kWh	43330.61	88444.15
Generation per year, kWh	4414.39	9010.43
Capacity factor, gross	0.180	0.171
Wind potential, W/m^2	220.865	220.865
Wind potential at rotor height, W/m^2	213.993	213.993
Capacity factor, net	0.153	0.146
Average annual electricity generated, net, kWh	3752.240	7658.860
Work period in the nominal regime, h	1340.084	1276.477
Average power, kW	0.428	0.874

• Previous experience of operating a WT in low temperatures and high humidity.

A WT is commonly installed with special hoisting mechanisms and cranes, securing the tower and lifting the blades to the rotor axis. Also, as working WTs experience significant horizontal and vertical loads which have to be transferred to the foundation, drilling is needed to anchor the structure reliably. In remote island conditions, employing a crane appears unfeasible. Moreover, Galindez Island is composed of superhard volcanic rocks (Mytrokhyn & Bakhmutov, 2019). Drilling deep boreholes is difficult, time-consuming, and energy intensive process. That is why the set of installable WT designs is limited.

With the complex assembly conditions and lack of special WT installation machinery in place, the designs, which we selected for further examination were WT SD3 and SD6 produced by SD Wind Energy (SD Wind Energy Limited, 2019), mountable on hydraulic towers. This kind of tower has many advantages, the most evident being the mechanism to lower the turbine for maintenance and service check-ups and raise it back up. The SD wind turbines on hydraulic towers can be lowered to the ground and raised again in as little as twenty minutes, providing the possibility for technical maintenance without using cranes to install or handle the equipment. These turbines can be fastened on in several ways, one of which was specifically developed for highland conditions and rocky terrain by the rock anchor (Fig. 6).

This type of WT has been manufactured for three decades. The power output of 3 and 6 kW is achieved with a tower of up to 20 m high. Since 2010 the SD6 turbines have been successfully employed by the Princess Elisabeth Station and, since 2020, by the Comandante Ferraz Station.

SD3 begins producing energy at the wind speed of 3.1 m/s, reaches nominal power output at 13.9 m/s, and keeps working in the nominal regime at wind speeds of up to 70 m/s.

SD6 begins producing energy at the wind speed of 2.5 m/s, reaches nominal power output at 12 m/s, and keeps working in the nominal regime up to 70 m/s (SD Wind Energy provided the power curves for the calculations).

By the meteorological recommendations for robust statistical forecasting calculations for electricity output (Makarovskiy & Zinych, 2012), the minimum sample of wind speeds should be at least ten years.

Table 3. The main groups of electricity consumers at the Akademik Vernadsky station

Consumer group	Power, kW	Working regime
Lighting, office equipment, electric heating	25	24 hours/day, year-round
Kitchen appliances	6	4 hours/day, year-round
Water desalination	8	3 hours/day, year-round
Electrical heating of the Carpentry Unit	5	24 hours/day, seasonal
Crane manipulator	10	3 hours/day, seasonal
Total power required	54	

Table 4. Calculation of consumers' needs for electricity at the Akademik Vernadsky station

Consumer	Electricity consumption			
	Daily, kW · hour	Monthly, MW · hour	Monthly, given seasonal consumers, MW · hour	Yearly, MW · hour
Kitchen	24			
Crane*	0			
Lighting	600	19.440	23.940	269.280
Carpentry workshop*	0			
Desalinator	24			
Total	**648**	**19.440**	**23.940**	**269.280**

Note: * — seasonal consumers.

The Akademik Vernadsky station data meet this recommendation, as they were collected from January 1, 2011, to December 31, 2020. According to the World Meteorological Organization (WMO) standards, these data are recorded eight times a day, every three hours, 10 m above the ground.

Our task is to evaluate the electricity output of the chosen WT model if installed at the site of the weather station at the time when the data were recorded. The following parameters are given:

- the height at which the measurements are taken;
- the periodicity of the measurements;
- the wind speed;
- the estimated Hellman α parameter to model the vertical wind profile;
- the height of the WT rotor axis;
- the mathematical model for characterizing the power output of the WT, which allows calculating its working power with minimal approximation error under any wind speed at the height of its rotor axis.

To calculate the WT's projected output, we used the method developed by the Department of wind power of the Institute of Renewable Energy of the National Academy of Sciences of Ukraine (Kudria et al., 2021). Analyzing the wind roses for the station allowed to plot the WT arrangement on the territory according to the Rules for designing of wind power plants GKD 341.003.001.002-2000 (2000) [1].

The results of the calculations are presented in Table 2.

Since the station does not keep records of energy consumption, the electricity amount need was calculated by the power required by the main consumers according to their operating modes (Table 3) and by average daily fuel consumption. The results are given in Table 4.

According to the data of the maintenance personnel of the Akademik Vernadsky station, the average

[1] State Enterprise "State Research and Development Institute of Innovative Technologies in Energy and Energy Saving" (2000). *Rules for designing of wind power plants GKD 341. 003.001.002-2000.*

diesel fuel consumption is around 13 liter per hour, which is approximately equal to the generator load of 34 kW · hour. Over a year, this is equal to 297.84 MW · hour, which exceeds the amount of consumer-required power (Table 4) by approximately 10% by precise calculations.

According to the calculations, installing ten SD3 WTs on the Galindez Island would produce on average 37.5 MW · hour per annum, covering 13.9% of the station total energy needs and preventing the emission of 38 tons of CO_2 according to Methodology for calculating greenhouse gas emissions (CO_2-equivalent) (2012)[2]. If ten SD6 WTs are installed the average annual production of 76.6 MW · hour will cover 28.4% of the station's needs, and the CO_2 emissions would be cut by up to 78 tons per year.

4 Conclusions

Implementing renewable energy sources to replace the fuel consumption technologies is not just an environmentally friendly but also an economically sound tendency. Fuel shipping and storing in remote lands are expensive and potentially hazardous. Renewable energy sources could significantly cut the station's fossil fuel requirements up to full substitution in the future.

A study of the winds over the Galindez Island showed that the average long-term wind speed was 4.3 m/s; in almost 96% cases the maximum wind speed did not exceed 25 m/s, and in 99%, it did not exceed 30 m/s. Only in 0.9% cases wind speed increased above 30 m/s. We determined the prevailing wind direction (24%) as NNE, which allows to provide correct direction of the WT installation. Satellite data were used to calculate the Hellman parameter ($\alpha = 0.1$) for the Galindez Island.

There are already successful experience of WT installation and exploitation at Antarctic stations, in spite of every station has unique geophysical, climatic, and logistical circumstances. While consideration of the established systems is highly fruitful, one needs to weigh all specific ground surface features on the Galindez Island and climate conditions to plot out the local WT requirements for the Akademik Vernadsky station.

The site is one of the warmest compared to the WTs-outfitted stations, with an average annual temperature of −2.5 °C and minimum historical average daily temperature of −28.3 °C. Nevertheless, the humidity is also higher, with an average annual relative humidity of 83%.

We identified the WT with the nominal working wind speed range of 12 to 70 m/s, encompassing even strong gusts of wind. This WT is also mounted on a hydraulic tower, allowing for a crane-less installation and the possibility of lowering and raising the turbine for maintenance and check-ups. The turbines have several fastening possibilities, including one for highland conditions and rocky terrain.

According to the wind regime of the Akademik Vernadsky station, the data on its annual energy consumption, and the SD3 and SD6 WTs power parameters, it was found that ten SD3 WTs would meet 13.9% of the station's energy requirements while cutting the yearly CO_2 emissions by 38 tons. Ten SD6 WTs would provide for 28.4% of the station's needs and prevent 78 tons of CO_2 from being released annually.

A promising way for further research would be to consider both sun and wind energy in tandem as a method to generate electricity for the Ukrainian Antarctic Akademik Vernadsky station.

Author contributions KP — The idea of the article, information analysis, analysis of primary data, writing the main text, illustrations; II — Wind energy calculations, conclusions; OK — Electricity consumption data analysis, choice of wind turbine for calculations.

Conflict of Interest. The authors declare that they have no conflict of interest.

[2] *Methodology for calculating greenhouse gas emissions (CO_2-equivalent)*. (2012). SRO-E-150 NP "MAE". Retrieved September 5, 2021, from https://sro150.ru/index. php/metodiki/371-metodika-rascheta-vybrosov-parnikovykh-gazov

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К. Петренко*, І. Іванченко, О. Кармазін

Інститут відновлюваної енергетики НАН України,
м. Київ, 02094, Україна

*** Автор для кореспонденції:** KaterynkaPetrenko@gmail.com

Перспективи використання вітроенергетичних ресурсів на станції «Академік Вернадський»

Реферат. Використання відновлюваної енергії та інших засобів мінімізації викидів в атмосферу має бути пріоритетним напрямком розвитку для кожної держави. Цей підхід має поширюватися і на території антарктичних наукових станцій. Метою роботи було отримання необхідних оцінок вітрового енергетичного потенціалу території острова Галіндез для визначення доцільності встановлення вітроелектричних установок (ВЕУ) на території Української наукової станції (УАС) «Академік Вернадський». Для дослідження вітрової картини території використовувався архів середньорічних значень метеопараметрів British Antarctic Survey (1950–2020 рр.), строкові дані швидкості та напрямку вітру, що реєструвалися метеостанцією УАС «Академік Вернадський» (2011–2020 рр.) та середньодобові дані з таблиць метеорологічних спостережень (2014–2018 рр.). Для розрахунку параметру Хелмана використовувалися супутникові дані. Для аналізу вертикального профілю вітру використовувався ряд статистичних методів, зокрема метод мінімізації середнього арифметичного відносної похибки моделювання. Для оцінки показників виробітку електричної енергії вихідні дані швидкостей вітру на висоті давача анемометра перераховувалися на висоту осі ротора ВЕУ і, використовуючи характеристики потужності ВЕУ, надані розробниками, перераховувалися в середньорічний виробіток електроенергії ВЕУ. Для розрахунків вітроенергетичного потенціалу використовувалася методика, розроблена відділом вітроенергетики Інституту відновлюваної енергетики НАН України. За результатами аналізу вітрової картини, розраховано середньодобові показники швидкості вітру — 3.9 м/с та встановлено переважаючий напрямок вітру (північ — північний схід — 24%). Отримані результати розрахунків не відкидають гіпотезу про доцільність встановлення ВЕУ на території УАС «Академік Вернадський». ВЕУ для подальших вітроенергетичних розрахунків була вибрана, базуючись на досвіді використання ВЕУ іншими країнами в Антарктиді та з урахуванням особливостей монтажу та експлуатації в умовах високих швидкостей вітру, низьких температур та високої відносної вологості. На основі інформації про витрати пального на УАС «Академік Вернадський», було розраховано, що інсталяція десяти ВЕУ SD6 дозволить щороку задовольняти 28.4 % потреб станції в електричній енергії.

Ключові слова: Антарктида, виробіток електроенергії, відновлювані джерела енергії, вітроенергетика, острів Галіндез, швидкість вітру