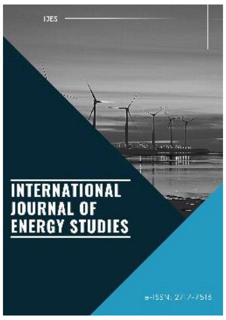
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2023; 8(2): 215-235

DOI: 10.58559/ijes.1275463

Received : 02 Apr 2023
Revised : 25 May 2023
Accepted : 27 May 2023

Site selection of Antarctic Research Stations in aspect of required optimum hybrid renewable system capacity

Gül Nihal Güğül*

Selcuk University, Faculty of Technology, Türkiye, ORCID: 0000-0002-5927-3308

*(*Corresponding Author: gul.gugul@selcuk.edu.tr)*

Highlights

- Energy demand of Antarctic reseacrh stations is compared for 16 locations
- Optimum renewable system is calculated for each location
- Maximum renewable factor is obtained for all locations

You can cite this article as: Güğül GN. Site selection of the Antarctic Research Stations in aspect of required optimum hybrid renewable system capacity. Int J Energy Studies 2023; 8(2): 215-235.

ABSTRACT

The population of Antarctica consists of scientific research personnel. The number of residents ranges from about 1,100 in the winter to about 4,400 in the summer and up to 1,000 additional personnel in the nearby waters. Even in summer, Antarctica's sub-zero temperature increases the energy consumption of buildings for heating purposes. At the same time, the absence of a grid system necessitates the use of off-grid fossil-based or renewable energy systems. Considering the natural environment and building conditions in the studies, the multiple evaluation of the ground process for research stations is grouped into four main criteria: scientific research, environment, logistical support and topography. In these studies, the capacity of the renewable energy system requirement was not examined. For this reason, in this study, the capacities of the optimum hybrid renewable energy systems in 16 locations selected from different regions of Antarctica were compared. In the study, typical meteorological climate data of 15 locations were obtained. The daily energy demand is obtained by calculating the daily electricity consumption of the electrical devices and heating system that can be used. Results of this study shows that according to purpose of the site, many locations that meets the requirements may exist with extremely different energy demands. In site selection, first the possile locations that supply the requirements should be determined, than energy demands and required systems should be compared.

Keywords: Cold climate, Electricity production, Renewable system, Optimization

1. INTRODUCTION

Antarctica has long been a significant location for scientific research. The demand for new research stations is increasing due to the Antarctica's extreme climatic conditions, transportation difficulties and isolation of its location. Multiple evaluation criteria is considered to locate research stations suitable for the extreme nature of the Antarctic environment. Spatial multi-criteria decision-making (SMCDM) method determines the optimum solution for various spatial problems. SMCDM needs spatial data to evaluate the optimum location [1]. Wind speed is one of the criteria. Wind speed is important for more than one reason. The impact of construction and operation activities of research stations on the Antarctic terrestrial ecosystem needs to be minimized. Therefore, sub-criteria focusing on the environment include physical (temperature and wind speed) and ecosystem factors. Prevailing winds can cause significant snow accumulation that can disrupt construction. Topographic conditions are essential for the construction of a station. High snow accumulation rates and strong winds are the main reasons for abandoning Antarctic research stations. Wind speeds above 8 m/s on the Beaufort scale in the summer indicate that a location may not be suitable for long-term field operations due to risks to personnel and buildings [2]. Indeed, wind energy serves as a primary renewable energy source in Antarctica due to limited solar radiation. Antarctica's population consists of scientific research personnel. The number of Antarctic inhabitants is about 1,100 in winter and about 4,400 in summer. The distribution of the population is shown in Figure 1.

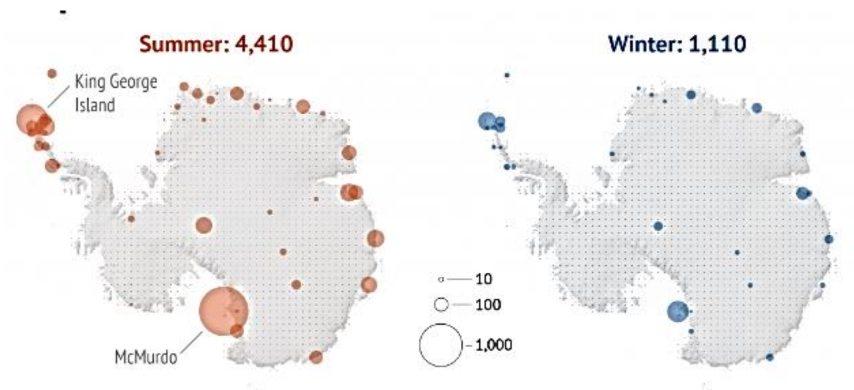


Figure 1. Antarctic population [3]

Even in summer, Antarctica's sub-zero temperature increases energy demand. Also, the absence of a grid system necessitates the use of off-grid fuel based or renewable energy systems. The most abundant and continuous renewable energy source in this region is wind energy. However, in addition to the high wind potential, the standard deviation value and turbulence are also quite high. Conditions in the South Shetland Islands coastal region were characterized in a study evaluating potential locations for the Colombia science station. This study demonstrated the rapid variability of atmospheric conditions in the South Bay with average wind speeds of 4-8 m/s with gusts up to 20 m/s for less than a year [4]. For this reason, wind turbines to be installed in the region should be selected from turbines that are resistant to high-speed winds, even at locations with low average wind speeds.

As of 2021, 29 facilities have installed renewables energy systems in Antarctica. However, only one permanent and four summer stations are able to meet more than 50% of their energy demand with renewable systems in order to decrease fuel cost, reduce the greenhouse gas emissions, supply electricity during the winter months and develop and/or testing of new technologies. Antarctica possess extreme weather conditions and hard-to-reach locations which make usage of renewable energy systems under stress [5]. Figure 2 represents the locations of renewable energy systems in Antarctica.

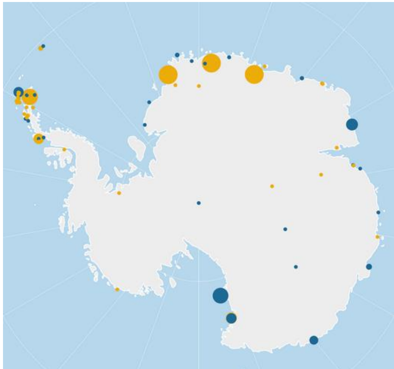


Figure 2. Year-round (●) and seasonal (●) renewable energy systems in Antarctica [6]

Studies are conducted to design hybrid renewable energy systems. Design of a photovoltaic-wind power station to be installed in the French-Italian Antarctic Base is described in a study. It is one of the three bases far from coast and is open all the year. The electrical demand of the station is presently supplied by diesel generators. An experimental study has been conducted to collect the necessary solar irradiance and wind data of the site. Models of the PV panels and wind turbine, previously set up and validated, have been used to simulate the plant behavior and to estimate the possible contribution of renewable energies to the base supply in the different seasons [7]. Design and analysis of a hybrid energy system for the Brazilian Antarctic Station is conducted in a study. The thermal and electrical annual profiles of the Station and the local measured weather data are used in study. In the renewables analyses, 25 years of local climatic data were assessed. The methodology supported the identification of an efficient and feasible energy system for the Brazilian Station. The proposed system reached 37% of fuel saves considering the original demand profile of the Station [8]. China has built four stations in Antarctica so far, and Zhongshan Station is the largest station among them. Power supply of stations relies on fuel. The increase in energy demand and cost of fuel traffic from China to Zhongshan station in Antarctica were urgent problems. As a result, an off-grid renewable energy system is developed for the station. First renewable energy distribution of area of Zhongshan station are analyzed. The physical model, operation principle, and mathematical modeling of the proposed power system were designed. The renewable system is composed of wind turbine, PV, battery units and a control system. A case study in Antarctica was applied and the results of the case study showed that the scheme of standalone renewable energy system can satisfy the power demands of Zhongshan Station in normal operation [9]. A feasibility study at Neumayer Station III (NM3) in Antarctica has been conducted which is now operated with polar diesel resulting in high CO_2 emissions. The station is modelled using the simulation program TRNSYS. Various scenarios that include wind turbines, photovoltaic systems, battery storage and thermal storage are applied to the developed model. Wind turbines found to make the largest contribution to increasing the share of renewables. Due to the limited space available, the PV system has only a share of 3 to 7 % on renewable energy [10].

As seen in the literature, weather data are considered in site selection in Antarctica. However, the electricity generated by the renewable energy system is not considered. To the best knowledge of the author, although hybrid system designs were carried out for a single location in literature, a study to compare the required hybrid renewable system for different locations of Antarctica has not been evaluated yet. This study aims to fill this gap.

In this study, the wind speed and solar radiation potentials of 16 locations selected from different regions of Antarctica were evaluated and compared. In addition, the capacities of renewable energy systems to meet the energy demand of a team of ten scientists were compared for the selected locations. It is thought that the study will create a new criterion to be considered in the site selection process for the stations.

2. MATERIALS AND METHOD

In this section, the characteristics of the selected locations, the methods followed during the acquisition and analysis of the data are explained. Then, by calculating the total energy consumption for the required electrical device and heating demand per capita, the methods followed during the determination of the required renewable energy system capacity are mentioned.

2.1. Selected Locations, Data Acquisition and Analysis

Sixteen locations from different regions of Antarctica were selected and compared in aspect of weather conditions and renewable energy potential. Locations close to the available areas on the suitability map are selected. The suitability map for the environment created for Antarctica is developed considering many criterias [2]. The locations selected in this study using the general suitability map and the names of the research stations located in the locations are shown in Figure 3.

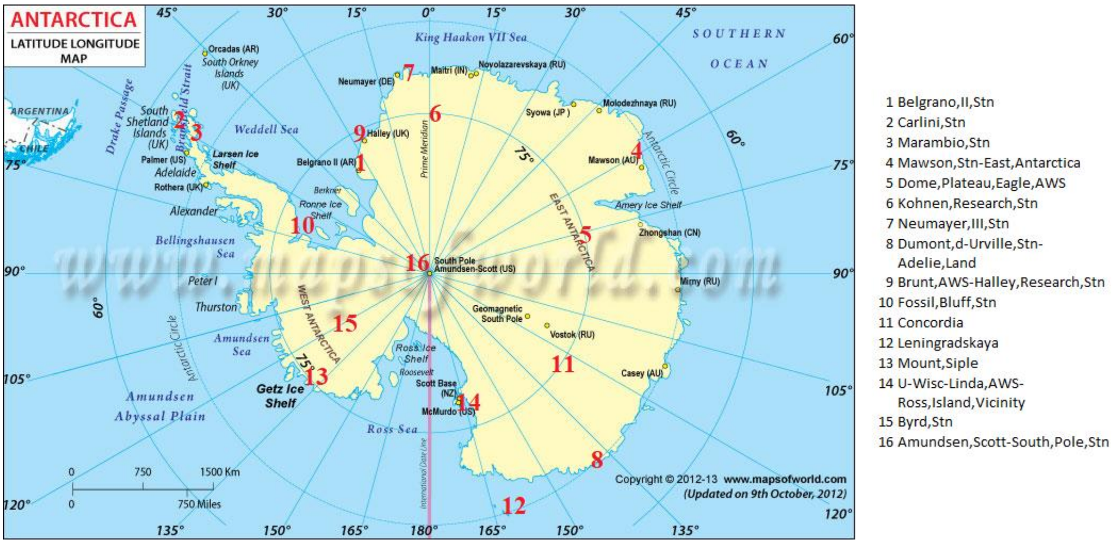


Figure 3. Selected locations

The names of the stations, the country they belong to, the latitude and longitude information of the selected locations are given in Table 1.

Table 1. Stations in selected locations

No	Name of station	Country	Latitude	Longitude
1	Belgrano,II,Stn	ARG	-77,8736	-34,6267
2	Carlini,Stn	ARG	-62,2383	-58,6678
3	Marambio,Stn	ARG	-64,2408	-56,6271
4	Mawson,Stn-East,Antarctica	AUS	-67,6022	62,87242
5	Dome,Plateau,Eagle,AWS	CHN	-76,418	77,03
6	Kohnen,Research,Stn	DEU	-75,0012	6,88E-02
7	Neumayer,III,Stn	DEU	-70,6666	-8,2667
8	Dumont,d-Urville,Stn-Adelie,Land	FRA	-66,6628	140,0019
9	Brunt,AWS-Halley,Research,Stn	GBR	-75,6055	-26,2066
10	Fossil,Bluff,Stn	GBR	-71,3293	-68,267

11	Concordia	ITA	-75,1	123,4
12	Leningradskaya	RUS	-69,5	159,383
13	Mount,Siple	USA	-73,198	-127,052
14	U-Wisc-Linda,AWS-Ross,Island,Vicinity	USA	-78,394	168,446
15	Byrd,Stn	USA	-80,011	-119,438
16	Amundsen,Scott-South,Pole,Stn	USA	-90	0

The climate data of the stations are Typical Meteorological Year (TMY) data, which consists of the data obtained between 2007-2021 [11].

2.2. Energy Demand

The devices likely to be used by the team, the usage duration and the device power obtained from the devices available in the market are assumed as given in Table 2.

Table 2. List of devices used and daily energy demand

Equipment	Usage duration, hour/day	Power, watt	Piece of devices	Energy demand, kWh/day
Computer	10	100	10	10
Mobile Phone Charge	1	67	10	0,67
Tea/Coffee Machine	10	200	1	2
Toaster	1	700	1	0,7
Electric Cooker	4	1400	2	11,2
Oven	1	1400	2	2,8
Television	3	200	1	0,6
Lighting	16	10	10	1,2
Refrigerator	24	44	2	2,1
Laundry Machine	3	1500	1	4,5
Electric Water Heater	1	1200	6	7,2
Total Consumption				43

The station building is designed as an area of 200 m^2 consisting of office space, bedroom, dining hall and kitchen. Wall/window ratio is 6% due to the high outdoor temperatures. Due to low window ratio, lighting equipment is on 16 hours a day as seen in Table 2. Indoor temperature is set to 20 °C during all year. The thermal conductivity value of the external walls and windows are selected as 0.2 W/ m^2-K and 0.2 W/ m^2-K respectively. The window/wall ratio was chosen as 6 % for each facade. Heating demand of the building is estimated using eQuest software. Developed model station is given in Figure 4.

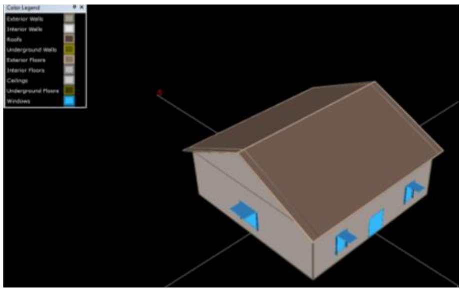


Figure 4. Developed model site in eQuest software

eQuest software does not include weather data of Antarctica. Therefore the data obtained from [11] is inserted to the software.

2.2. Renewable System Analysis

The turbulence index, mean wind velocity and average wind speed are calculated for each location. The mean wind speed was calculated by equation (1),

$$v_m = \frac{1}{n} \times \sum_{i=1}^{n} V_{(i)} \tag{1}$$

In this equation, n is the number of observations and V(i) is the wind speed at measurement height at time i. Standard deviation is calculated by equation (2),

$$\sigma = \sqrt{\frac{1}{n-1} \times \sum_{i=1}^{n} (V_{(i)} - v_m)^2} \tag{2}$$

One of the most important indicators of wind potential for designing a wind farm is the turbulence index. It is calculated by equation (3),

$$I_n = \frac{\sigma}{v_m} \tag{3}$$

Hybrid renewable energy system (HRES) consists photovoltaic panels (PV), wind turbine, batteries and diesel generator. System is off-grid. Heating, hot water and electricity demand of the research statin is supplied by HRES. Optimization has been conducted by Swarm Non-Linear Solver.

Antarctica lacks solar radiation from April to September. Therefore, PVs are fixed on the exterior wall with a 90° tilt and North orientation which also overcome the snow accumulation problem. In order to calculate the electricity generated by PV, global horizontal solar radiation data is used. Cell temperature of PV is not considered due to low enough temperature.

In this study, CW Energy 675 Wp photovoltaic panel is selected due to its high peak power. Efficiency and surface area of the PV are 20.92 % and 2.205 m^2 [12].

Electricity generated by PVs is calculated by Equation (4).

$$E_{pv}(t) = \eta \times A_{pv} \times GR_{pv}(t) \times P_f \tag{4}$$

In this equation, E_{pv} is the output power (Wh) of the PV at time t, A_{pv} is the total PV area (m^2), η is the PV efficiency, R_{pv} is the global radiation at relevant time (W/m^2) and P_f is the performance factor (%).

The SD3 wind turbine rated at 3kW is selected in this study which has low cut-in wind speed (2.5 m/s) and ideally suited for remote access sites. The main benefit of SD3 is the intelligent design that delivers consistently high performance in all wind speeds. Turbine is 3 Bladed with 3.9 meters' diameter Glass. Tower Height Options of the turbine is 6m-9m. In this study hub height is selected as 9 meters [13].

Wind speed data in weather data set is obtained at 10 meters' height. Therefore, wind speed at hub height is calculated [14]. Electrical energy generated by the wind turbine is calculated by equation (5) [15],

$$E_{WT}(t) = \frac{1}{2} \times D \times V_h(t)^3 \times \mathrm{A} \times C_p \tag{5}$$

In this equation, E_{wt} is the power output (Watt) at time t, D is the air density (kg/m^3), A is the swept area (m^2), V_h is the wind speed (m/s), C_p is the power coefficient.

The renewable energy based systems are PV and wind turbine. Diesel generator is used as fossil based electricity supply. The energy supply system is off-gird which requires a backup system.

Batteries are used as backup in order to store excess power and act as an energy pool to supply stable energy. System configuration is given in Figure 5.

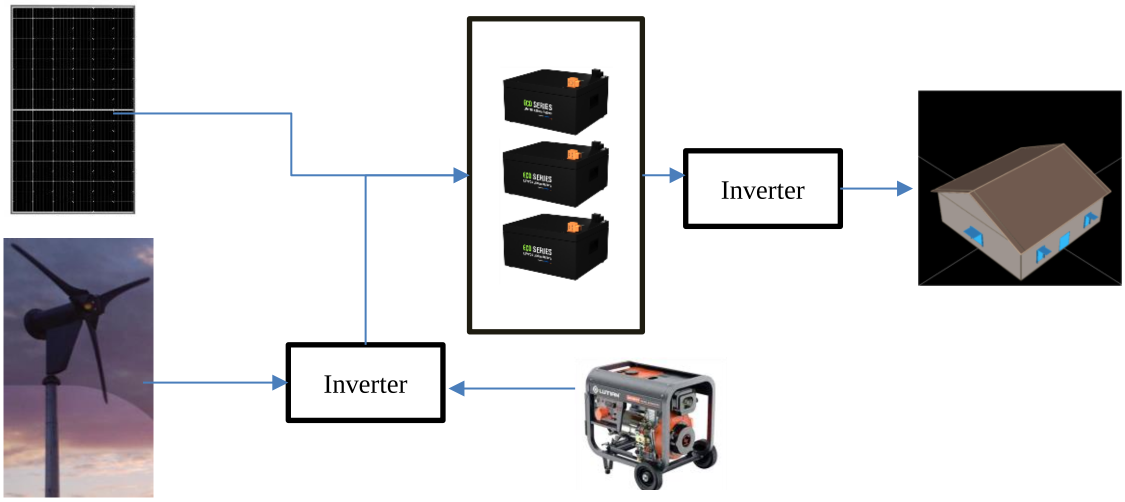


Figure 5. Design of energy system

State of charge (SOC) should be controlled in order to protect system and supply continuous power to the building. SOC depends on the charge already stored, electricity consumed by building and generated by HRES. SOC of the battery at time t+1 is calculated by equation (6);

$$\mathrm{SOC}\ (\mathrm{t}+1) = \mathrm{SOC}\ (\mathrm{t}) + \mathrm{BI}(t) - BO(t) \tag{6}$$

In this equation BI(t) and BO(t) are the input and output energy in battery. At first hour of the year all batteries are assumed to be fully charged. Therefore, BI is equal to zero at first hour of the year. Input energy at battery is calculated by (7) and (8),

$$\begin{Bmatrix} SOC(t) > BC * (1 - DOD) \rightarrow \ \mathrm{BI}(\mathrm{t}+1) = EG_{RES}(t) \\ SOC(t) \leq BC * (1 - DOD) \rightarrow \ \mathrm{BI}(\mathrm{t}+1) = EG_{DG}(t) + EG_{RES}(t) \end{Bmatrix} \tag{7}$$

$$\begin{Bmatrix} SOC(t) > BC * (1 - DOD) \rightarrow \ BO(t) = EC(t)/\eta_{inv} \\ SOC(t) \leq BC * (1 - DOD) \rightarrow \ BO(t) = (EC_{ht}(t) + EC_{elec}(t) * 0.5)/\eta_{inv} \end{Bmatrix} \tag{8}$$

In this equation, BC is battery capacity, DOD is depth of discharge, EG_{RES} and EG_{DG} are the electricity generated by Hybrid Renewable Energy System (HRES) and diesel generator, EC is the electricity consumed in the building at time t, η_{inv} is the efficiency of inverter which is 95%.

EC_{ht} and EC_{elec} in equation (8) are the electricity consumed for heating and cooling. As it is clear from equation 8, when battery decreases below DOD, heating system is running, however only 50% of electricity load is supplied to the building.

Efficiency of inverters and batteries are taken into account during calculations. Battery charge and discharge efficiencies are taken as 0.8 and 1 respectively [16]. The SOC must be between adjusted minimum and maximum values. SOC_{min} and SOC_{max} are the limits of the batteries charging. SOC_{max} is considered as the nominal battery capacity (BC). The minimum limit depends on depth of discharge (DOD) designated by user (selected as 80%) and calculated by equation (9),

$$SOC_{min} = (1-DOD) \times BC \tag{9}$$

Number of autonomy days (N_{ad}) is the number of days that HRES cannot supply energy (selected as one in this study). Required battery capacity (BC) is then evaluated by equation (10) [17],

$$BC = \frac{N_{ad} \times ED_{max}(t)}{T_f \times R_f \times 2} \tag{10}$$

In this equation, T_f and R_f are the temperature and rate factors of battery. ED_{max} is the difference between the maximum daily energy consumed and minimum daily energy generated during one year. Number of batteries required is finally obtained by (11);

$$N_b = \frac{BC}{I_b \times V_b} \tag{11}$$

In this equation, I_b and V_b are the current and voltage of the selected battery.

Diesel generators are used in case of renewable energy fall short of and the SOC reaches minimum value. The electricity generated by DG is evaluated by (12) [18].

$$EG_{DG} = \eta_{DG} \times P_{DG,p} \tag{12}$$

In this equation, EG_{DG}, η_{DG} and $P_{DG,p}$ are the electricity generated by diesel generator, efficiency ofgenerator and rated peak power of the generator. Fuel consumed by DG relies on its output power and expressed by (13) [19];

$$\mathrm{FC} = \mathrm{a} \times P_{DG,p} + b \times P_{DG,r} \tag{13}$$

In this equation, a and b are the constants as 0.246 and 0.08145 L/kWh. $P_{DG,p}$ and $P_{DG,r}$ are the generated and rated power of the generator [19]. CO_2 emission caused from the fuel consumption of generator generally in the range of 2.4–2.8 kg/l [20] (selected as 2.6 kg/l in this study).

2.3. Optimum System Capacity

Locations of stations in Antarctica has various logistic problems. Due to logistic problems cost of system installation can not be obtained accurately. In this study the system with minimum capacity and maximum Renewable Factor (RF) are investigated separately as the optimum system. In addition, limitations are set for renewable energy fraction to lower fuel consumption of DG. Limitations of the problem is set as follows;

- $RF \geq 0.7$
- $EC_b \leq EG_{RES} \leq EC_b*1.3$

As clear from the limitations, renewable fraction tried to set above 60%. Also maximum surplus renewable energy is set to below 130% of total consumption not to overestimate system capacity.

System calculations are developed in MS Excel. Then Excel calculations are transferred to Libreoffice software to put optimization in process in Swarm Non-Linear Solver tool. Libreoffice solver is proved to be used in artificial neural network design [21]. Flow chart of energy management of off-grid system is given in Figure 6.

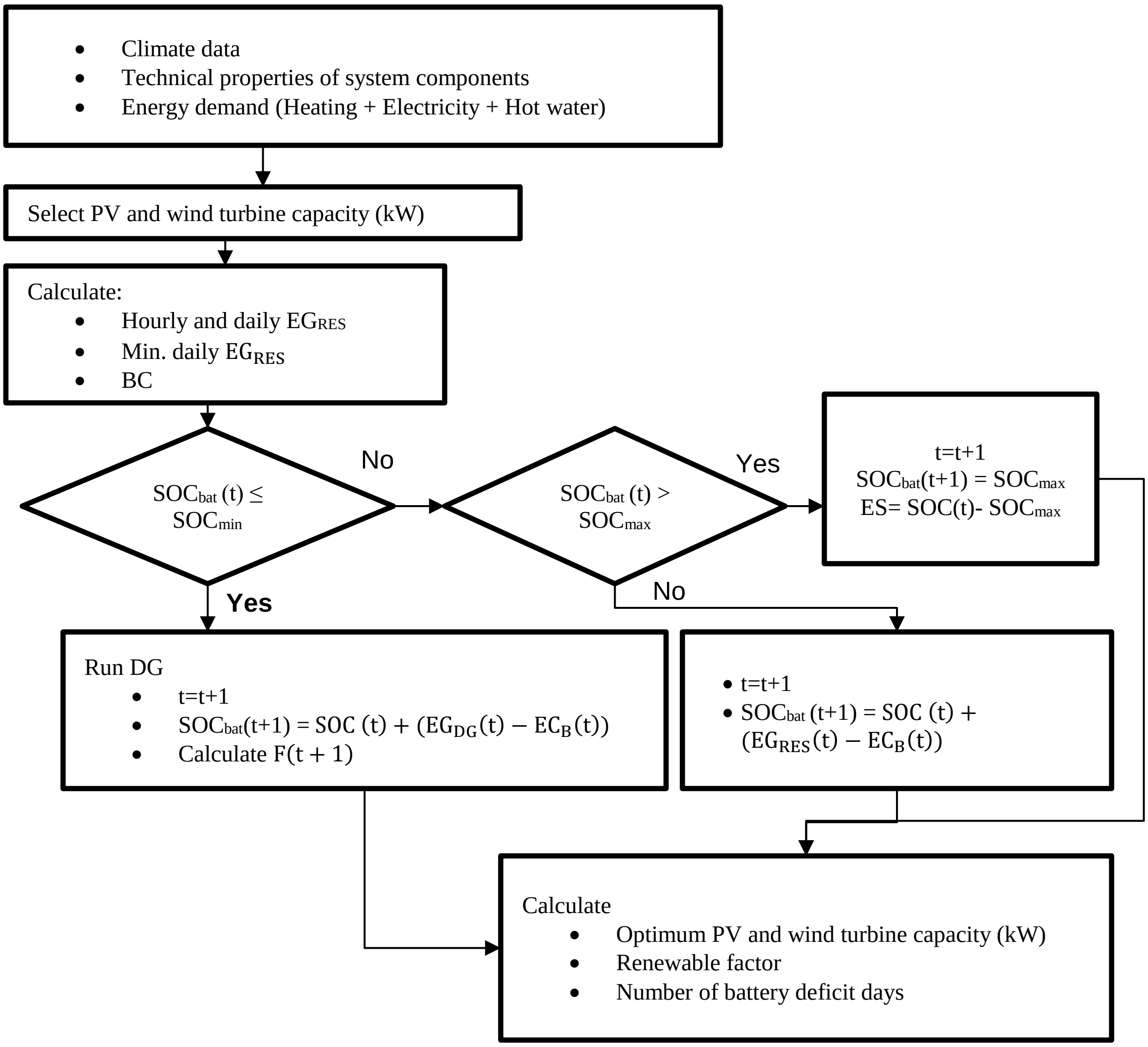


Figure 6. Flow chart of energy management of off-grid system

3. RESULTS

Daily average air temperature, total solar radiation and average wind speed of 16 selected locations are given in this section. Then, hourly heating demand is calculated and daily heating demand of each location are given. After the heating demand data is obtained, the total energy demand was evaluated and the optimum system capacity was compared for each location.

The air temperature in the Antarctic region is directly related to the final energy demand. The significant decrease in temperature affects the heating demand of research stations. For this reason, air temperatures were also compared in this study and the results is given in Figure 7.

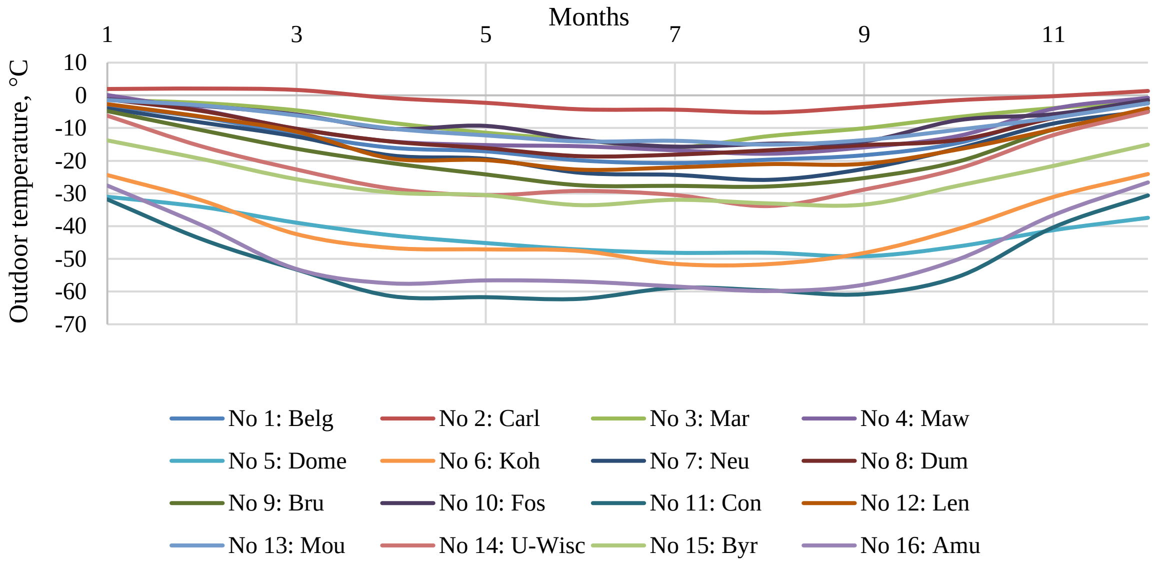


Figure 7. Ambient air temperature analysis

As seen in Figure 7, the temperature value was the highest at the Carlini station (No:2) located at the southernmost point. Carlini station is followed by the nearest station Maranbio (No: 3). The lowest temperatures among the selected stations were observed at the Concordia station (No:11). The annual average temperature value of the Concordia station is calculated as -51 °C.

The global radiation value is used in the calculation of the electricity to be produced by photovoltaic panels. Global radiation is the sum of direct and diffuse radiation. Figure 8 shows the monthly average direct radiation values for 16 locations. Diffuse radiation data were very similar to direct radiation.

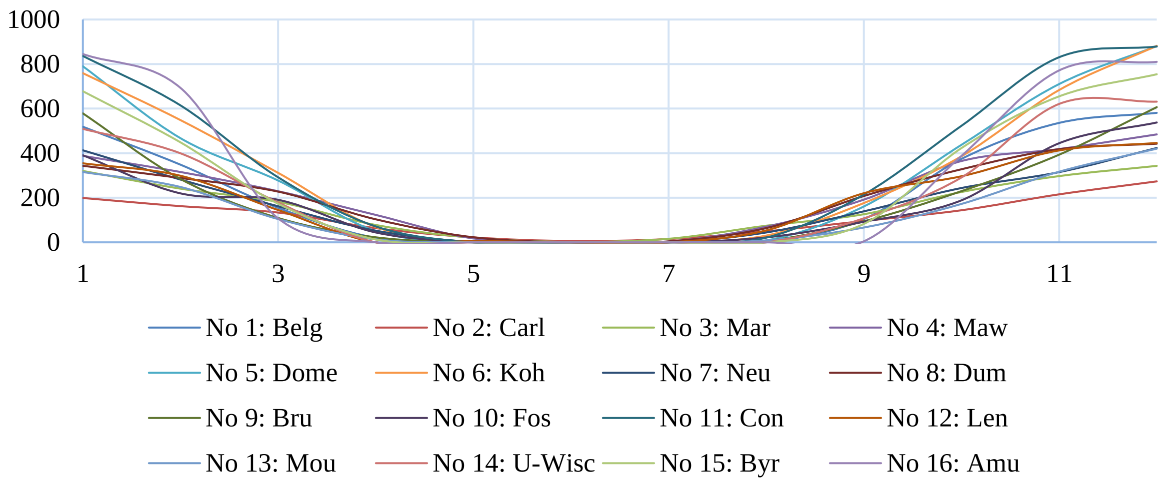


Figure 8. Direct Normal Radiation, W/m^2

As observed in Figure 8 the location with the lowest level radiation is Amundsen, Scott-South, Pole station (No:16). Although the radiation is zero at Amundsen station between April and August, the annual direct (2624 kWh/m^2) radiation rate is higher than other stations.

Direct solar radiation at the Fossil-Bluff research station (No:10), located near the Turkish Antarctic Research Station (-71,3293 -68,267) on Horseshoe Island, reached its highest value in December (537 W/m^2). At this station, the annual total global radiation value was obtained as 2072 kWh/m^2 [11].

Figure 9 shows the annual total direct, diffuse and global radiation rates.

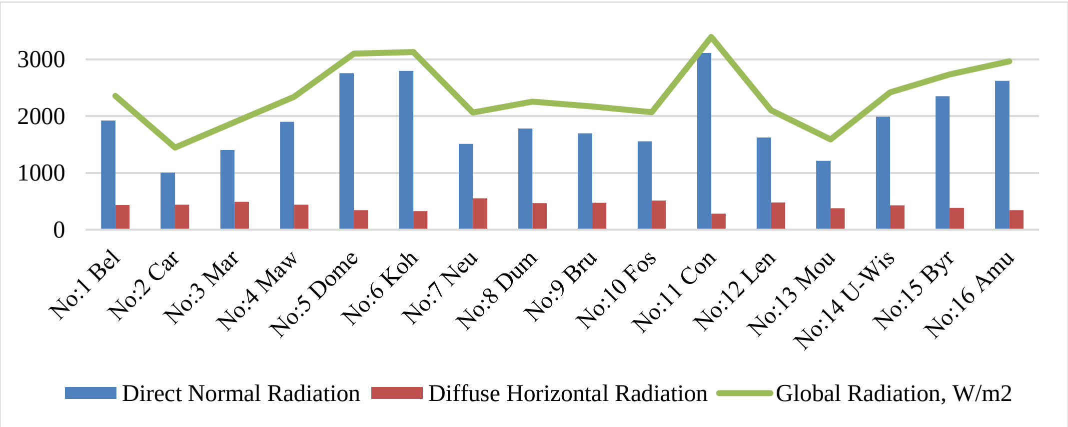


Figure 9. Annual total direct, diffuse and global radiation, kW/m^2

In Antarctic research stations, the wind speed can reach extreme values and demonstrate high turbulence. Wind turbulence generally refers to rapid fluctuations in wind velocity [22]. In this region, the wind speed should be high enough to meet the energy demand and low enough not to harm buildings and people. For this reason, it is an important criterion in location selection. In this study, the average monthly wind speed and standard deviation were calculated for the 16 selected locations.

Figure 10 shows the turbulence index and the annual average wind speed at each location.

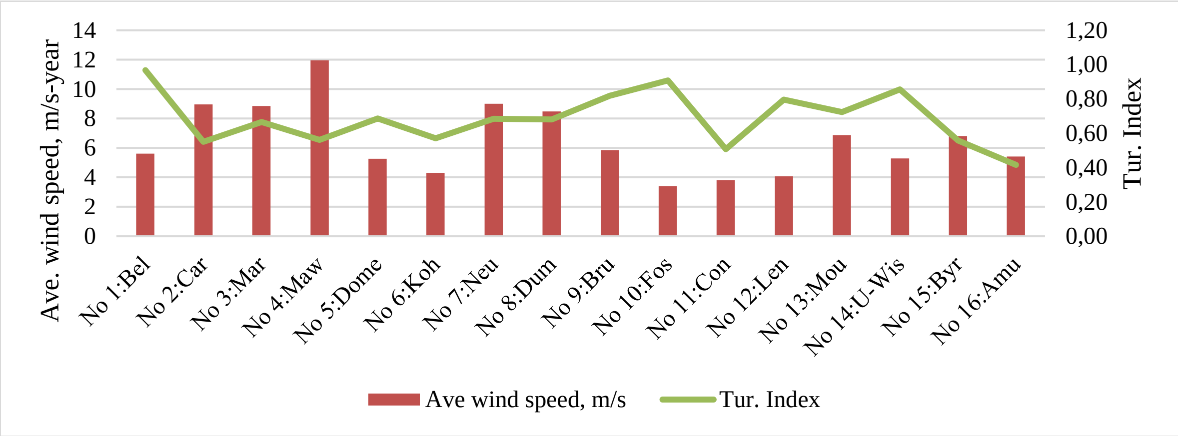


Figure 10. Annual average wind speed and turbulence index

As seen in Figure 10, the turbulence index of stations 1 and 10 are the highest and of station 16, located in the center of the South Pole is the lowest. Also, except for November, the highest monthly average wind speed was observed at Amundsen station (No:16). At Fossil, Concordia and Leningradskaya (No:10, 11, 12) stations, the monthly average wind speed was calculated as the lowest.

Energy demand of the buildings is calculated for three cases. Firstly, the Renewable Energy System (RES) system with minimum capacity is calculated for RF is equal to 0.7. Then, the system with maximum RF is calculated which generates energy not more than 130% of energy demand. Finally, required minimum system capacity is calculated for using only WT a RES. Results are given in Table 3.

Table 3. General Results

RES with minimum total capacity and min RF=0.7																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
EC, MWh/yr	60	44	53	57	101	98	64	58	68	54	114	63	56	73	78	110
E Gen., MWh/yr	78	58	69	74	131	128	84	75	88	70	148	82	73	95	102	142
PV	3	5	6	2	5	18	0	8	4	15	13	18	6	6	2	14
WT	19	7	9	9	26	41	15	9	23	22	82	16	15	23	19	29
Batterry	137	94	115	119	169	200	142	115	149	123	205	130	112	167	180	202
RF	0,79	0,91	0,86	0,92	0,74	0,70	0,80	0,81	0,70	0,71	0,70	0,70	0,77	0,70	0,85	0,71
DG Usage, day/yr	68	36	42	24	88	85	58	60	80	84	97	97	72	81	43	93
Fuel cons., bTon/a	5	2	3	2	9	10	5	4	7	6	12	7	5	8	4	12
DG capacity, kW	7	4	6	7	11	14	9	7	10	8	14	8	7	11	11	13
RES with maximum RF																
EC, MWh/yr	60	44	53	57	101	98	64	58	68	54	114	63	56	73	78	110
E Gen., MWh/yr	76	53	67	73	130	122	77	75	86	69	143	81	71	95	96	138
PV	6	7	3	2	16	15	4	5	14	9	13	10	20	9	7	5
WT	22	8	13	11	24	46	15	14	19	36	88	35	16	28	19	49
Batterry	137	94	116	119	169	200	142	113	149	123	205	130	112	167	180	202
RF	0,86	0,95	0,93	0,95	0,86	0,70	0,85	0,89	0,73	0,72	0,71	0,76	0,85	0,74	0,88	0,82
DG Usage, day/yr	50	21	21	15	54	84	42	36	72	79	92	80	48	70	33	59
Fuel cons., bTon/a	3	1	1	1	5	10	4	3	6	5	12	6	3	7	3	8
DG capacity, kW	7	4	6	7	11	14	9	7	10	8	14	8	7	11	11	13
RES with only WT (PV not used)																
EC, MWh/yr	60	44	53	57	101	98	64	58	68	54	114	63	56	73	78	110
E Gen., MWh/yr	62	48	57	69	102	99	69	59	68	55	116	64	58	73	81	111
PV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WT	22	9	12	11	30	60	15	13	23	39	102	37	17	28	20	44
Batterry	137	94	118	121	169	200	142	118	149	123	205	130	112	167	180	202
RF	0,78	0,91	0,90	0,94	0,67	0,60	0,80	0,83	0,65	0,61	0,61	0,63	0,74	0,64	0,84	0,73
DG Usage, day/yr	78	33	34	21	122	121	58	54	99	116	129	125	84	106	50	90
Fuel cons., bTon/a	5	2	2	1	12	14	5	4	8	8	16	9	5	9	5	11
DG capacity, kW	7	4	6	7	11	14	9	7	10	8	14	8	7	11	11	13

Annual energy demand and fuel consumed by diesel generator is given in Figure 11.

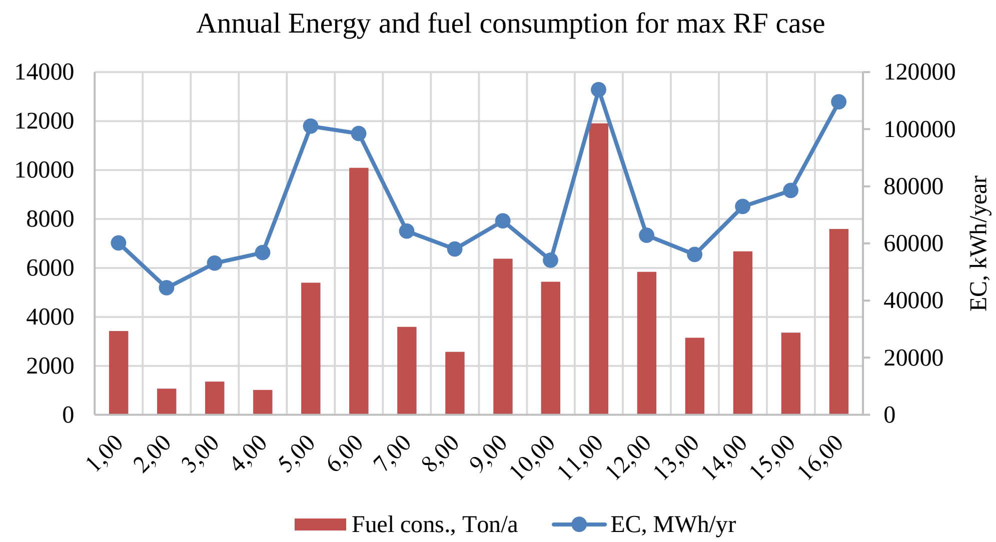


Figure 11. Annual Energy and fuel consumption for max RF case

Electricity consumption is assumed to be equal in all locations. Therefore, as it is clear from Figure 12, energy consumed for heating differs significantly according to location. Fuel consumed by diesel generator also changes parallel to the energy demand.

Due to the low solar radiation in Antarctica, the case of using PV and WT together and using only WT are compared in Figure 12.

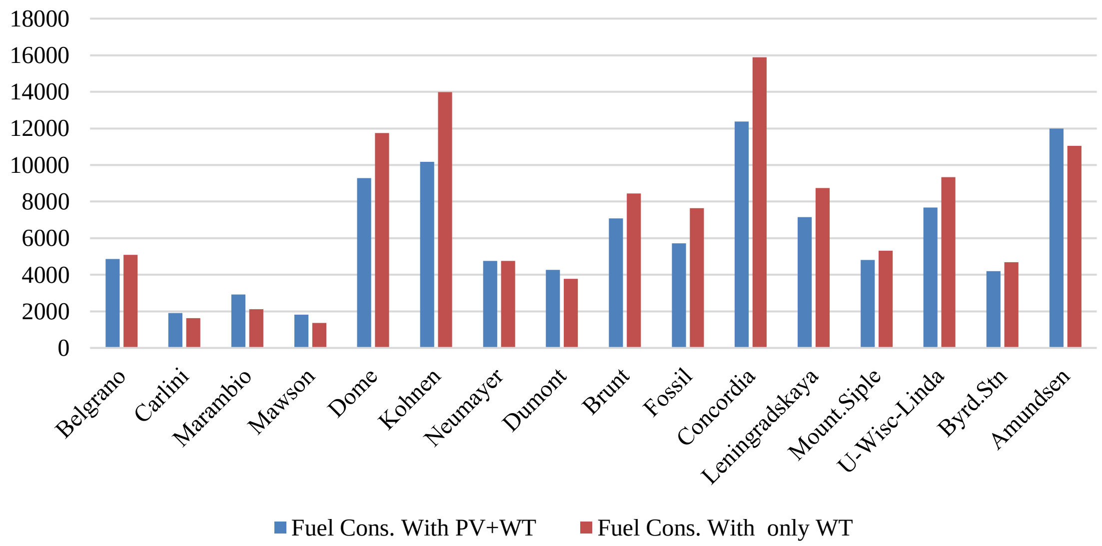


Figure 12. Fuel consumption of DG in case of using PV+WT and only WT

Figure 13, shows that a hybrid system is much more environmentally friendly in many locations of Antarctica. However, in some locations (1, 2, 3, 4, 7, 8) PV has low necessity.

Finally Figure 13, shows the required system capacity for the case of using PV+WT and only WT.

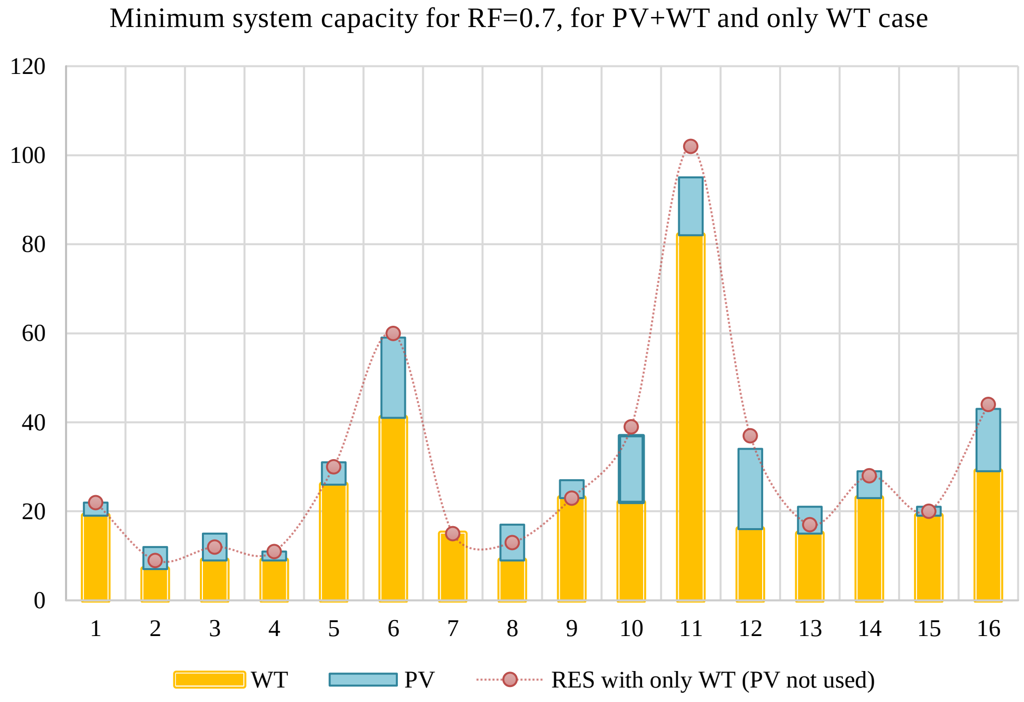


Figure 13. Required system capacity for the case of using PV+WT and only WT.

As it is clear from Figure 14, required total system capacity is higher in some locations in case of using PV+WT (2, 3, 8, 9 13).

4. CONCLUSION

In this study, the wind and solar energy potentials of 16 locations selected from different regions of Antarctica were evaluated and compared. Also, required renewable system capacity for a research station with the same electricity demand is compared for all locations.

As a result of the analyzes made, it has been determined that solar energy systems cannot provide energy for approximately three to five months at the research stations residing all year. It has been observed that the rate of direct radiation increases as it approaches the center of the continent. In the Carlini station region, where the most research stations are located, the annual total global radiation was observed to be the lowest (1446 kWh/m^2). In this region, the wind turbulence was calculated as 0.55 and the average wind speed as 8.9 m/s. It has been observed that it is the most suitable region in terms of wind potential. However, it has been determined that solar radiation is insufficient in this region.

The total annual direct solar radiation at the Fossil-Bluff research station (-71,3293 -68,267) located near the Turkish Antarctic Research Station on Horseshoe Island was calculated as 2071 kW/m^2. It has been observed that the annual average wind speed is low (4.4 m/s) and turbulence is high in this region.

Results of this study shows that according to purpose of site, many locations that meets the requirements may exist with extremely different energy demands. In site selection, first the locations should be determined and than energy demands and required systems should be compared.

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Gül Nihal Güğül: Collected data, Performed the analyses, Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Yavaşoğlu H, Karaman H, Özsoy B, Bilgi S, Tutak B, Gengeç AG, Oktar Ö, Yirmibeşoğlu S. Site selection of the Turkish Antarctic Research station using Analytic Hierarchy Process. Polar Science 2019; 22: 100473.

[2] Xiaoping P, Haiyan L, Xi Z. Selecting suitable sites for an Antarctic research station: a case for a new Chinese research station. Antarctic Science 2014; 26(5): 479–490.

[3] Trubetskoy S. Antarktika nüfusu, 2019. Available: https://sashamaps.net/docs/maps/population-of-antarctica/.

[4] Lonin S, Rios-Angulo WA, Coronado J. Swell Conditions at Potential Sites for the Colombian Antarctic Research Station. Sustainability 2022; 14(4): 2318.

[5] Lucci JJ, Alegre M, Vigna L. Renewables in Antarctica: an assessment of progress to decarbonize the energy matrix of research facilities. Antarctic Science 2022; 34(5): 374-388.

[6] Vigna L. Renewable Energy in Antarctic Research Facilities. 2022. Available: https://public.flourish.studio/visualisation/5888942/.

[7] Boccaletti C, Felice PD, Santini E. Integration of renewable power systems in an Antarctic Research Station. Renewable Energy 2014; 62: 582-591.

[8] Christo TM, Fardin JF, Simonetti DSL, Encarnação LF, Alvarez CE. Design and analysis of hybrid energy systems: The Brazilian Antarctic Station case. Renewable Energy 2016; 88: 236-246.

[9] Dou Y, Zuo G, Chang X, ChenY. A Study of a Standalone Renewable Energy System of the Chinese Zhongshan Station in Antarctica. Applied Sciences 2019; 9: 1968.

[10] Bockelmann F, Dreier AK, Zimmermann J, Peter M. Renewable energy in Antarctica - Photovoltaic for Neumayer Station III. Solar Energy Advances 2022; 2: 100026.

[11] Crawley D, Lawrie L. Climate.OneBuilding.Org, 2022. Available: http://climate.onebuilding.org/default.html.

[12] CW. CW 675 Wp, 2023. Available: https://cw-enerji.com/tr/urun/cw-enerji-675-wp-132pmbs-m12-hc-mb-gunes-paneli-1289.html.

[13] SD Wind Energy. SD3, 2023. Available: https://sd-windenergy.com/small-wind-turbines/sd3-3kw-wind-turbine/.

[14] Al-Ghussain L, Taylan O, Baker DK. An investigation of optimum PV and wind energy system capacities for alternate short and long-term energy storage sizing methodologies. International Journal of Energy Research 2019; 43(1): 204-218.

[15] Tazay A. Techno-Economic Feasibility Analysis of a Hybrid Renewable Energy Supply Options for University Buildings in Saudi Arabia. Open Engineering 2021; 11(1): 39-55.

[16] Li J, Wei W, Xiang J. A simple sizing algorithm for stand-alone PV/wind/battery hybrid microgrids. Energies 2012; 5(12): 5307-5323.

[17] Belmili H, Haddadi M, Bacha S, Almi MF, Bendib B. Sizing stand-alone photovoltaic–wind hybrid system: Techno-economic analysis and optimization. Renewable and Sustainable Energy Reviews 2014; 30: 821-832.

[18] Haidar AM, Fakhar A, Helwig A. Sustainable energy planning for cost minimization of autonomous hybrid microgrid using combined multi-objective optimization algorithm. Sustainable Cities and Society 2020; 62: 102391.

[19] Kaabeche A, Ibtiouen R. Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system. Solar Energy 2014; 103: 171-182.

[20] Jakhrani AQ, Rigit ARH, Othman AK, Samo SR, Kamboh SA. Estimation of carbon footprints from diesel generator emissions. International Conference on Green and Ubiquitous Technology, Bandung, Indonesia, 2012.

[21] Tomov P. Multilayer Perceptron Fast Prototyping with Differential Evolution and Particle Swarm Optimization in LibreOffice Calc. Bulgarian Academy of Sciences Problems of Engineering Cybernetics and Robotics 2021; 75: 5-14.

[22] MacEachern C, Yıldız I. Wind Energy, Comprehensive Energy Systems, Elsevier, 2018; 665-701.