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Renewable Energy Solutions in War-Conflict-Affected Regions

Soraya Mercedes Pérez*

Tafila Technical University, Faculty of Engineering, Natural Resources and Chemical Engineering Department, P.O. Box 66110, El Ais, Tafila, Jordan.

Abstract

The ongoing war in Gaza has plunged the region into a severe energy and humanitarian crisis, leaving it desvasted and in urgent need of sustainable solutions. This study investigates the potential of combined renewable energy sources -solar and wind- to address the areas's critical energy needs. Irradiation solar and wind velocity were taken from NASA database. Peak sun hours (Psh) were calculated and the average wind speed allowed to quantify the contained energy (Pc) in the wind. Pc results are adjusted, using the power coefficient (Np), to obtain the maximum extractable energy of wind energy (Pe). Daily electrical consumption (DEC) and Daily array size (DAS) of a basic tent was determined together with the number of solar panels necessary to cover this consumption, during Psh. A wind turbine model IT-100 used in rural areas of Perú and Sri Lanka, economical and easy to build, was chosen to provide electrical energy as an alternative to the solar array. Discrete statistical distribution of wind speed and the turbine power curve were used to determine the energy produced by aeroturbine. The results revealed that average speed of wind around 8.1 m/s, indicate that is feasible the use of eolic energy. Other parameters as Relative humidity (68.2%), wet (17.96 ºC) and dry temperature (21.91 ºC), also were measured. DEC and DAS found per tent were 1.66KW.h/d and 0.42 KW respectively. Two solar panels of 250 W are needed to cover DEC per tent. Comparing the results of Pe (209.89 W) and Pc (723.7 W), as expected, Pe was lower than Betz limit. Results of the energy generated annually (PG) and daily (DEE_A) for aerogenerator were 639.3 W.h/y and 1.75 KW.h/d respectively. This work concludes that the solar array is efficient and can cover the electrical needs of a basic tent during Psh. At night and during the day when the photovoltaic array operates inefficiently due to the lack Psh, the aeroturbine analised in this study is capable of supplying the electrical equipments being utilized.

Paper type: Research Paper

Keywords: Betz limit, Aeroturbine, Power number, Solar arrangement, Peak sun hours

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1. Introduction

The war after the October 7th of 2023 against Gaza Strip destroyed almost all existing energy sources. In times of war, the preservation of life naturally takes precedence. However, once the conflict subsides, people begin to seek other essential needs—chief among them, access to energy sources. Reconstruction will undoubtedly be a key priority, but drawing on the region's extensive experience with displacement, initial shelter solutions often take the form of camps, where displaced individuals typically reside in tents or prefabricated housing units (caravans). This paper explores solutions to the energy crisis through the deployment of alternative renewable energy sources, particularly in the short term, to support displaced survivors living in temporary shelters and tents during the reconstruction phase.

* Corresponding author: E-mail: soraya@ttu.edu.jo ORCID: : https://orcid.org/0000-0003-1089-3597
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Palestine's total electricity demand in 2018 was around 5800 GW/h. In the current year, Israel Electric Company (IEC) managed to cover approximately 92.6% of its electricity needs (Khatib et al., 2021). The remaining electricity was supplied by other providers, including Jordan (1.5%), Egypt (0.6%) and Gaza power plant (4.4%) (Hilmi, 2019). Statistical data reveals that approximately 10.2% of total demand in 2018 came from renewable energy sources (Palestinian Central Bureau of Statistics, 2025). The substantial outflow of foreign currency resulting from energy imports from the IEC contributed to the Palestinian Authority (PA) accumulating a debt of around 574 million USD (Rabi & Ghanem, 2025). Furthermore, the cost of energy (COE) in Palestine is notably high (0.6215 ILS/kWh) for residential stratum compared to Israel (0.4516 ILS/kWh) (Juaidi et al., 2016). Palestine possesses significant renewable energy resources that could contribute to improving its energy situation. According to statistical data, the region receives an average solar irradiation ranging from 5.40 to 6.0 kWh/m², with approximately 3,000 hours of sunlight annually. Seasonal variations are observed, with the lowest irradiation levels occurring in December (2.6 $KW.h/m^2$) and the highest in June (8.4 $KW.h/m^2$) (Nassar & Alsadi, 2019). Gaza Strip is located on Mediterranean coast. The Mediterranean climate is characterized by a short, cold, and rainy winter, in contrast to a long, hot, and dry summer season (Yihdego et al., 2019). Wind in this zone tend to flow in direction west to east.
Gaza Strip located at southwestern part of Palestine, has high population density index around 3823 persons/Km^2 (statistics reported before the attack of Israel of October, 7, 2023) and an area of 360 Km^2. The majority of the population in the Gaza Strip are descendants of generations of refugees who fled their homes during the Arab-Israeli wars of 1948 and 1967 (Khatib et al., 2021), making the Gaza Strip one of the most densely populated areas in the world.

This vulnerability situation, led this work to analyse the use of solar and wind energy as a possible source of energy, considering the notable values of solar irradiation and wind velocity existing in this region. The highest average speed of wind recorded in Gaza strip during 2005 was 12.7 Km/h (Zohuri, 2018); It leads us to think that implementation of policies to promote the use of wind and photovoltaic systems is feasible.

The interaction of the sun's radiant energy with the conductive materials of photovoltaic cells (PV) is named photovoltaic energy. It is currently one of the cheapest forms of energy (De Lima et al., 2017). When solar photons are absorbed, they transfer their energy to the atoms within the photovoltaic cell's conductive material, resulting in the generation of electrical energy. These photovoltaic cells are assembled into modules or panels, which capture sunlight and convert it into direct current (DC) electricity (Tillahodjaev & Mirzaev, 2020). The DC is then transformed into alternating current (AC) through an inverter, making it usable for most electrical systems. A photovoltaic panel is the smallest commercially available unit in a photovoltaic system, with power capacities typically ranging from 10 to 700 watts. Panels are commonly connected in series to increase total power output and reduce overall system cost (Aoun et al., 2017; Brar et al., 2017).

Eolic power now represents an innovative and economical source of renewable energy. Actually, it is is competitive with conventional energy sources such as hydroelectric or thermal power (Chaudhuri et al., 2022). However, in regions lacking access to the electrical grid—whether due to poverty, conflict, or natural disasters—domestic wind turbines may offer a viable solution to ensure electricity supply during periods of low solar intensity or at night. An aerogenerator or wind turbine system (WTS), is a device that converts wind energy into electrical energy . The operation of a wind turbine is based on a straightforward principle: wind flows cause the turbine blades to rotate, driving a rotor that is mechanically coupled to an electrical generator. This mechanical motion is then converted into electrical energy. The primary components of WTS consists of the rotor with its blades, a gearbox (omitted in direct-drive systems), an electrical generator and a power electronic converter (Fig.1a). An aerogenerator transforms wind energy into direct current (DC) of 12 or 24 volts. This energy can be delivered to converter device to transform DC to AC . Or it may be stored in batteries. These systems include an electronic voltage regulator that monitors battery charges, distributes the current, and compensates for voltage losses in the transmission line.

Currently, Spain, Germany, and Denmark are the countries with the highest number of wind power installations, with annual growth exceeding 2,500 megawatts. Large wind generators are being built by these countries, with capacities ranging from 1 to 2 MW, diameters of around 70 meters, and heights of 150 meters (Pérez, 2024).

Vertical-axis wind turbines (VAWT) are the most commonly used for domestic use with low production volumes. They also require less installation space compared to horizontal-axis wind turbines (HAWT). VAWT is constituited of vertical and rotational axis perpendicular to the wind flow producing electricity at low wind speed (Hand & Cashman, 2020).
The maintenance of VAWT is easy compared to HAWT turbine (Herbert et al., 2007). HAWT turbine is widely used for the highest volume of production which requires huge investment and occupies more space for the installation. The rotational axis of horizontal HAWT wind turbine is parallel to direction of wind (Herbert et al., 2007). It needs large tower and blade to install and the transportation cost is around 20% of the cost equipment.

Skilled labour is required to install the horizontal axis wind turbine of last technology and its production cost is decreased when generating higher volume of electricity. The horizontal axis wind turbines are most suitable for sea shores, hill tops etc.

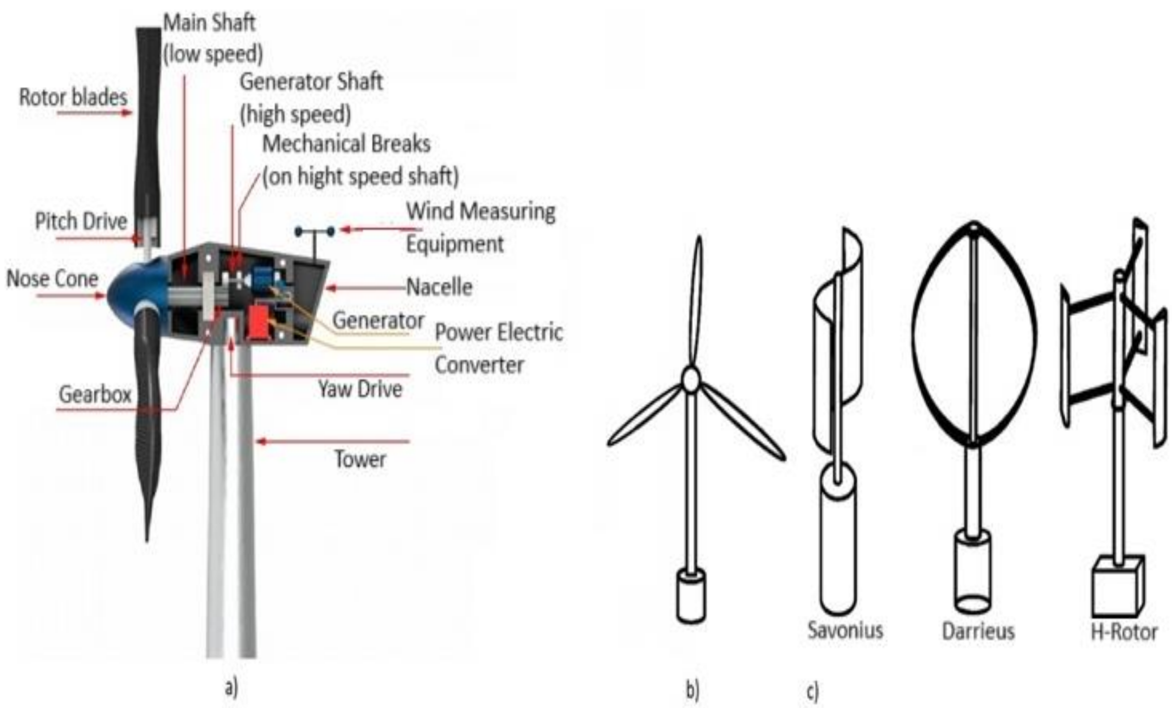

Fig. 1. a) Components of Wind Turbine System (WTS). b & c) Types of Wind Turbines: (b) Horizontal Axis HAWT, (c) Vertical Axis VAWT: Savonius, Darrieus, H-Rotor (Chaudhuri et al., 2022; Vivek et al., 2017).

2. Materials and Methods

Utilizing meteorological data from NASA data base, 2025, this study is carried out. Table 1 provides specifics about Gaza's weather, wind speed and solar irradiation.
For determination of the number of solar panels (Np) is necessary the calculation of Daily electrical consumption and Daily array size, obtained according to Eqs. (1), (2), and 3 (Pérez, 2024):

*Daily electrical consumption (DEC) = wattage of equipment * consumption hours/d;* [W.h/d] (1)

*Daily array size (DAS)= DEC/(Psh*ε);* [W] (2)

Number of panels (Np) = DAS/(panel wattage) (3)

Peak sun hours (Psh) = irradiation per month/days in the month; [h/d] (4)

Value of $\varepsilon = 0.66$ is used in eq. (2). It represents the efficiency factor for solar panel systems (Franklin, 2019). Using eq. (4) (Pérez, 2024); the Peak sun hours Psh for Gaza region was found to be around 6.09 h/day. This value was applied in the calculations of results in Table 3.

Psh refer to the number of hours when sunlight is at its strongest, typically around midday, and is employed to measure the amount of solar energy a location receives. Mathematically, a peak sun hour is defined as one hour when sunlight intensity reaches an average of 1,000 watts per square meter ($Kw.h/m^2$). This is a crucial factor in determining the potential of solar energy production in a specific area.

An aerogenerator of low power, model IT-100, type HAWT was also analysed in this study. It was designed by Sánchez et al., 2025; within the framework of project ITDG-CONCYTEC-UNI, Perú. Some characteristics of aeroturbine IT-100 type HAWT are presented in Figure 2 and Table 2.

Table 1. Wind parameters and solar irradiation values.

Month	Velocity (m/s)	%Relative Humidity	T_{wet} (ºC)	T (ºC)	Solar Irratidation (Kw.h/m^2)
Jan	4.19	68.47	11.56	21.39	147.03
Feb	5.17	69.10	11.95	23.34	139.58
Mar	6.01	69.26	13.52	27.43	188.53
Apr	7.15	68.37	15.47	27.18	208.70
May	7.03	67.74	18.57	24.14	220.81
Jun	9.80	69.53	21.65	21.17	207.42
Jul	10.05	69.94	23.74	15.37	231.52
Aug	11.07	69.92	24.38	17.32	215.01
Sep	12.11	68.47	23.26	15.99	209.83
Oct	10.49	67.49	21.2	21.21	171.78
Nov	8.25	64.01	16.93	24.11	146.48
Dec	6.15	66.23	13.36	22.17	140.00
Av.	8.10	68.21	17.96	21.91	185.55

Sanchez et al., 2005; describe the details about materials, fabrication; mechanical and electrical operation. Monterrubio - Montesó, 2006, complemented this model of wind turbine, which was made for social purposes, aimed at low-income families and people from rural zones, where the daily consumption of energy is low.

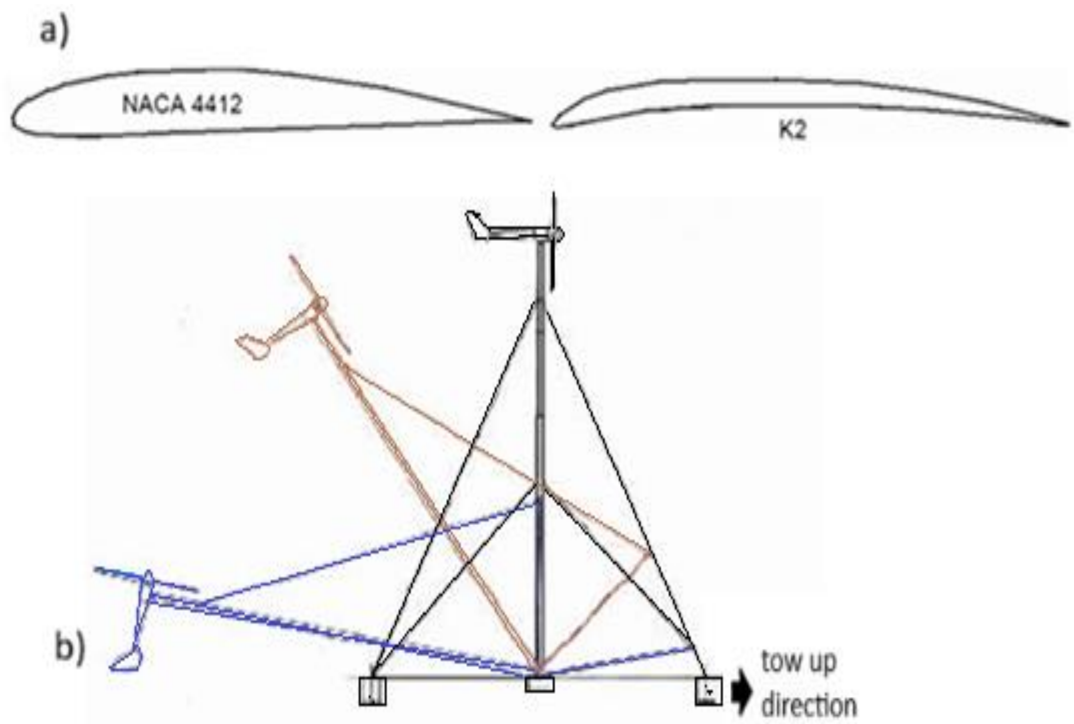

Fig. 2. a) Types of blades. b) Aeroturbine model IT-100 type HAWT at tower supported by cables and tensioners (Monterrubio - Montesó, 2006).

The energy generated annually (P_G), for wind speed interval, is calculated by summation P_{Gi}, eq. (6) (Monterrubio - Montesó, 2006). P_{Gi} results define the energy generated annually for each interval of wind speed, which are calculated by eq. (5). P_i is the output electrical power for wind speed interval at units of [W], taken from power curve provided by manufacturer (Fig. 4). Values of h_i are annual hourly frequency for the wind speed of interval i.

$$P_{Gi} = P_i * h_i /1000; \text{ [KW.h/y]} \quad (5)$$

$$P_G = \sum P_{Gi}; \text{ [KW.h/y]} \quad (6)$$

Table 2. Some characteristics of aerogenerator of horizontal axis model IT-100.

Parameter	Data
Maximum external speed ratio	5
Number of blades	3
Height of tower	10 m
Type of blade	NACA 4412
Designer	Teodoro Sánchez
Diameter	1.7 m

3. Results and Discussion

This work focuses on addressing the energy problem through combined renewable sources. Proposing the analysis of an optimal solar array for using during peak solar hours; and an aerogenerator when exist low solar irradiation and during at night.

3.1 Solar energy system

Table 3 presents the monthly peak sun hour (Psh) results derived using Eq. (4). A value of 6.09 Psh indicates the average number of hours per day during which solar irradiation reaches its peak intensity in the Gaza Strip. This value is strongly influenced by geographic location. Gaza, situated in the Middle East at 31°25′ N latitude and 34°20′ E longitude, exhibits approximately 33% higher Psh levels compared to Jordan. This favorable solar resource, represented by the 6.09 PSH value, implies that nearly 50% of the 12 daylight hours available per day can be effectively utilized for electricity generation via a photovoltaic system (PV).

Table 3. Monthly solar irradiation and peak sun hours (Psh) for Gaza strip.

Month	Irradiation (Kw.h/m^2)	Days per month	Monthly Psh
Jan	147.03	31	4.74
Feb	139.58	28	4.98
Mar	188.53	31	6.08
Apr	208.70	30	6.95
May	220.81	31	7.12
Jun	207.42	30	6.91
Jul	231.52	31	7.46
Aug	215.01	31	6.93
Sep	209.83	30	6.99
Oct	171.78	31	5.54
Nov	146.48	30	4.88
Dec	140.00	31	4.51
		Average Psh	6.09 (h/d)

Results of total daily electrical consumption (DEC), daily arrangement size (DAS) and number or photovoltaic modules (Np), for a simple tent occupied for a modest family in Gaza, are presented in Table 4. These results were calculated according to Eqs. (1), (2) and (3).

Table 4. Daily consumption for a basic tent.

Dispositive	Quantity	Load$_{actual}$(KW)	Load$_{Total}$(KW)	Operating time (h/day)	(DEC) Daily electrical consumption (KW.h/day)
Light bulb	4	0.030	0.120	6	0.72
Fridge	1	0.029	0.029	24	0.7
Television	1	0.04	0.04	6	0.24
Np = 2 panels of 250 W ; DAS = 0.42 KW					Total (∑ DEC) = 1.66 KW.h/day

The total daily Electrical Consumption (DEC) value of 1.66 KW.h/day is relatively low when compared to the typical energy demand of a basic household in Jordan, which ranges between 3 and 5 KW.h/day. In the context of countries facing economic challenges and high poverty levels, this DEC value is more closely aligned with the electricity consumption of a basic household in Sri Lanka, where average daily usage is approximately 1 KW.h/day (Monterrubio - Montesó, 2006).

The Daily Array Size (DAS), calculated as 0.42 KW using Eq. (2), incorporates a photovoltaic system efficiency factor of ε = 0.66. This efficiency value was previously employed by Franklin (2019) in the modelling of a grid-connected solar energy system, and accounts for real-world losses due to system inefficiencies, including temperature effects, wiring losses, and inverter performance.
Once the Daily arrangement size (DAS) was calculated, the next step is to quantify the solar panels (Np) needed to produce the electrical power. The calculations demonstrated that two solar panels of 250 Watt would be enough to cover the electrical demand of a tent during 6.09 hours of peak sun. Panels availability and price are two factors that need to be considered for the installation. Most common types of solar modules have been widely used: polycrystalline and monocrystalline (single) panels. The selection is function of relation price-quality. Monocrystalline panels offer better quality and but higuer in cost. However polycrystalline panels are cheaper than monocrystall and durable. System installers recommend to buy modules in bulk to reduce the cost per unit (Kayode and Enock, 2022).

3.2 Eolic energy system

3.2.1 Analysis of the wind

The results obtained in Figure 3 shows the highest recorded average wind speed for September was 12.11 m/s , and the lowest recorded average wind speed of 4.19 m/s was for the month of January. In general, for all months in Gaza, the average values are higher than 4 m/s; achieving an average wind velocity of 8.1 m/s. Velocity of 4 m/s is considered the minimum wind speed required to start the generation of electrical power by systems of wind turbine (Eraso et al., 2018). Speeds above 4 m/s increase energy production. Exist a range of high speeds where the maximum energy production of the wind turbine is reached, also named nominal energy. A value of 120 W is the nominal energy between the ranges of 8.5 to 10 m/s of wind speed; for the IT-100 aeroturbine; as is demonstrated in the speed-power curve (Fig. 4).

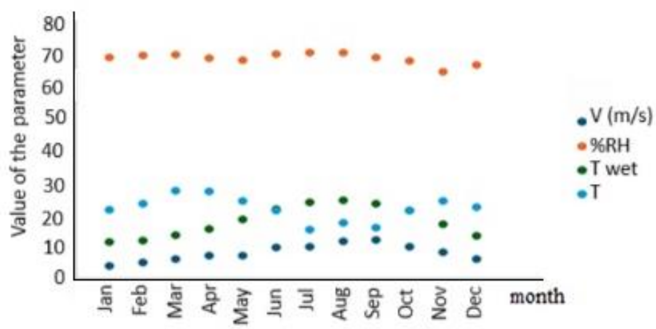

Fig. 3. Wind speed and other weather parameters for Gaza Strip.

Optimal operation of the aerogenerator IT-100 achieved into the velocity range of 8.5 to 10 m/s does not requiere pitch control. Above 10 m/s, the blades are reoriented to maintain a constant speed with the turbine rotating at approximately 150 rpm. For values of wind speed that of 10.5 m/s, the blades orient themselves so that the turbine stops rotating and turns off. Preventing by this mechanism the destruction of the wind turbine. Therefore, this study demonstrated that the implementation of Eolic technologies for the generation of electrical power is feasible. Power curve of aeroturbine IT-100 type HAWT was provided by the manufacturer (Figure 4).

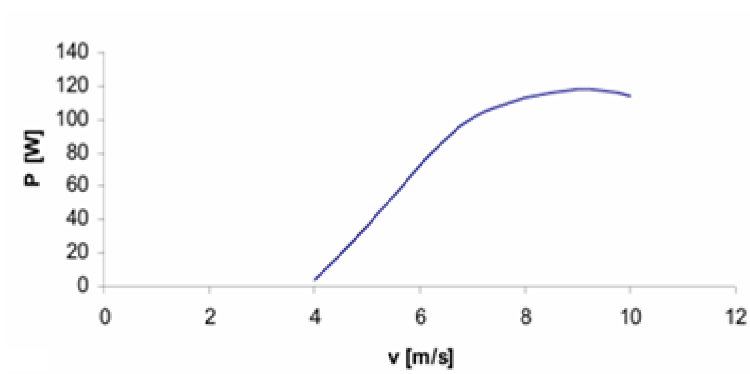

Fig. 4. Power curve for aerogenerator IT-100 type HAWT

Additionally, the results of Figure 3 reveleaded slight tendency to increse the relative humidity and T_{wet} with wind speed. Respect to dry temperature, it doesn't present a clear tendence in relation to other parameters.

3.2.2 Characterization of the wind turbine

The calculations of the wind's contained (Pc) and extractable (Pe) energy were carried out based on Equations (7) and (8) (Eraso et al., 2017), which quantify the theoretical and practical energy potential, respectively. Where the variables D, V_{av} and Cp are defined as diameter of turbine, average velocity of wind and power coefficient, respectively.

$$Pc = (½)\,\rho.\pi.(D^2)V_{av}^{3/4};\ [W] \quad (7)$$

$$Pe = (½)\,Cp.\rho.\pi.(D^2)V_{av}^{3/4};\ [W] \quad (8)$$

Observing that result of wind energy contained (Pc = 723.7 W) is higher than that of extractable energy (Pe = 209.89 W). Pe represents real values of recovery energy, because Pc is not fully utilized. Then the ideal values of Pc are adjusted to practical values of Pe by the Power coefficient (Cp). Betz's Law explains this by defining that in the case of an ideal wind turbine (with maximum efficiency), the output wind speed would be at least 1/3 or 59% of its inlet speed (Eraso et al., 2017). Aeroturbine can n't operate at maximum limit Cp_{max}= 0.59. Cp value is specific to each turbine type and is a function of wind speed that the turbine is operating in. Once incorporated various engineering requirements of a wind turbine, strength and durability in particular, the real limit is well below the Betz limit with practical values of Cp between 0.35 to 0.45 even in the best designed aeroturbine (Hasanah, 2025). By the time taking into account that due to other factors considered in a complete aeroturbine system as: gear box, bearings, generator, etc..; only 10-30% of the power of the wind is ever actually converted into usable electricity. For this reason, values of Cp between 0.1 to 0.3 can be considered for Pe calculations (Hasanah, 2025). For wind turbine IT-100, Cp value around 0.3 was provided by the manufacturer.

3.2.3 Discrete distributions of the wind speed for determine the energy production of aerogenerator

Table 5 presents the values of energy Pi for each wind speed, obtained from power curve of aerogenerator (Figure 4), and the annual frequency at hours/year for each wind speed at Gaza zone. Energy generated annually P_{Gi} for each interval, was calculated using Eq. 5. Resulting P_{Gi} values between a maximum of 156.1 KW.h/y and a minimum of 5.73 KW.h/y.

A discrete statistical analysis was applied to carry out the distribution of wind speed frecuency. Resulting in a value of 639.1 KW.h/y, the summation of energy generated annually for wind speed interval (P_G). By division of P_G per 365 days, (DEE_A) Daily electrical energy generated by aeroturbine of 1.75 KW.h/d is obtained. Therefore, this work demonstrated that DEE_A= 1.75 KW.h/d generated by aerogenerator IT-100 HAWT proposed in this study, cover the total daily electrical consumption DEC of 1.66 Kw.h/day for a house of very low resources, such as tent. This analysis is in accordance with investigations presented by Monterrubio - Montesó, 2006; and Pérez-Ramírez, 2012; for use of aerogenerator in rural mediums as Sri Lanka and Mexico respectively.

Table 5. Discrete distribution of wind speed frequency and power generated by the wind turbine IT-100

P_i (W)	V (m/s)	h_i (hours/y)	P_{Gi} (KW.h/y)
0	0	20	0
0	1	45	0
0	2	31	0
0	3	72	0
8	4	716	5.73
34	5	876	29.78
70	6	857	60.1
96	7	1183	114
110	8	1415	155.6
119	9	1311	156.1
106	10	1110	118
0	11	612	-
0	12	372	-
0	13	67	-
0	14	42	-
0	15	16	-
0	16	11	-
DEE_A= P_G /365 d = 1.75 KW.h/d		P_G= ∑ P_{Gi}= 639.31 KW.h/y	

4. Conclusions

An arrangement of two 250 W photovoltaic panels per tent appears to be viable solution for supplying electrical energy for up to to six hours during peak sunlight. The favorable wind conditions in the Gaza region, with an average velocity of wind of 8 m/s as analized in this study, confirm that wind energy is also a feasible option.

The use of the IT-100 aerogenerator can effectively meet daytime electricity demands during periods of low solar irradiation and provide power including at night.An aspect of great relevance that deserves further study is the more precise analysis of the electrical losses occurring in the generator and rectifier. As well as the actual behavior of a battery, since the load applied to the wind turbine significantly affects its performance.

This proposed study is presented in a way economical, simple, and practical, with the hope that its implementation may be viable in the short term.

Credit Author Contribution Statement

All roles were carried out by Soraya Mercedes Pérez, unique author of this manuscript.

Declaration Statements

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This research received no external funding.

Conflicts of Interest

The author declare no conflict of interest.

Use of AI Tools (if applicable)

Nothing.

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Nomenclature

Symbol	Description	Unit
D	Turbine diameter	M
DAS	Daily array size	W
DEC	Daily electrical consumption	KW.h/d
DEE_A	Daily electrical energy from aeroturb.	KW.h/d
ε	Efficiency	-
Np	Number of panels	-
Pc	Power contained	W
Pe	Extratable power	W
P_G	Annual power generated for wind speed	W
P_{Gi}	Energy generated annually for interval	KW.h/y
Phs	Peak sun hours	h/d
Pi	Outpout electrical power for wind speed	W
T	Dry temperature	ºC
Tw	Wet Temperature	ºC
$Vav.$	Average speed of wind	m/s

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