Predictive Study on the Application of the Soweto Wind Turbine Results in the Coastal Region of South Africa

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Abstract – *This study evaluates the performance of three wind turbine prototypes (Prototypes 1, 2, and 3) in Soweto, South Africa, by analyzing their monthly energy generation under different time of day/month conditions. Prototype 3 emerges as the most efficient, generating 39.5 W at a wind speed of 1.17 m/s and projecting a maximum of 40 kWh per month. Building upon these results, a predictive study examines the feasibility of implementing the same technology in coastal regions, specifically Gqeberha, where stronger winds prevail. Utilizing empirical data from Soweto, the study forecasts an improved energy output of up to 54.3 W at a wind speed of 5.16 m/s (18.6 km/h) and up to 100 kWh per month. The findings highlight the potential benefits of utilizing wind turbine technology in coastal areas, contributing valuable insights to renewable energy system development in similar geographical contexts.*

Keywords: Predictive study, Coastal regions, Soweto, Port elizabeth result.

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I. Introduction

In the past, South Africa heavily relied on electricity generated from fossil fuels like oil and coal, which has limited the country's overall electricity supply. However, South Africa possesses abundant solar resources, with an average of 2,500 hours of sunshine per year and radiation levels ranging from 4.5 to 6.6 kWh/m^2. This places South Africa among the top three countries in the world in terms of solar potential. Additionally, the country has a significant wind power potential, estimated at 67,000 GW, which proves to be competitive alongside its solar potential [1].

Wind energy is a viable source of power in regions with consistent and strong winds. South Africa's climate offers favorable conditions for substantial wind energy production, particularly in the coastal regions of the Eastern and Western Capes. In 2014, the first major wind farm in South Africa began operating, marking a significant milestone in the country's wind energy sector.

According to the South African Wind Energy Association (SAWEA) report, there are currently 33 wind farms in the country, with 22 fully operational and 11 under construction [2].

Amidst the increasing global demands for decarbonization and sustainability, South Africa has embraced the proliferation of wind energy. This support stems from the recognition of the risks posed by climate change to various resources in the country, including water security, agriculture, and shorelines. The growing renewable power sector not only addresses these challenges but also reduces the country's reliance on coal, aligning with international policies and lowering the demands for coal-related ventures. The impact of wind energy spill-overs is particularly evident in the Eastern Cape province, which has secured 51% of South Africa's wind farm allotments, benefiting the impoverished region. Furthermore, major banks have become hesitant to provide financial support for coal-related projects, indicating a shift in capital spending towards the development of high-tech wind turbines on wind farms [3-8]. Moreover, the use of fossil fuels in the generation of electricity contributes significantly to Greenhouse Gas (GHG) emissions, which further contributes to climate change [9, 10].

According to [11], utilizing renewable energy as an alternative energy source will help reduce environmental problems, essentially GHG emissions and air pollution.

In this article, presentation will be done on results of the 7 rotor-blade prototype (Design-3) wind turbine that was optimally designed and eventually implemented and tested in residential area in Soweto, Johannesburg, South Africa. A predictive study will be done using the Design 3 results to predict the possible implementation of the same technology in the high gust area of South Africa.

II. Selection of Appropriate Hardware and Implementation

In this section, the selection and implementation of the required hardware will be discussed. The following hardware components were selected: AC-DC inverter, anemometer, storage batteries, rotor coupling hub, three-phase AC permanent magnet generator, battery regulator/ charge controller, AC cabling and monitoring devices. .

II.1. Windy Boy Vertiv Inverter

A Windy boy inverter as in Figure 1, has 93% to 95% efficiency [12], and the cost of this electronic device is approximately R800.00. It has the ability to protect itself from spikes, surges and over voltages. It can be used for both off-grid and grid tied applications.

Figure. 1. Windy Boy Vertiv Inverter [12]

II.2. UT363-B Anemometer

This instrument was acquired to measure wind and temperature for the applications at the test household in Soweto. The UT363-BT Mini Anemometer is a mini wind speed and temperature tester. This lightweight device is equipped with the latest magnetic sensing technology, and directly displays the airflow speed on an LCD screen. Bluetooth function can be added for data transfer and analysis by means of the iENV cell phone App; this can be downloaded from Google Play or Apple Store. The UT363-BT Mini Anemometer was taken for calibration at a South African National Accreditation System (SANAS) accredited laboratory and this calibration cost approximately R550.00. Figure 2 shows a UT363-BT Anemometer.

Figure. 2. UT363 Wind Anemometer

II.3. Storage Batteries

Storage of power is an important factor in wind turbine use. These battery store the generated energy of the turbine, and then the stored energy is sent through an electronic regulator to the inverter for output supply.

Figure 3, illustrates two 12V 100A/h VRLA batteries coupled in series, which suited system implementation. Each battery cost approximately R850,00. The batteries can be connected in series or parallel depending on the wind turbine charge controller specification.

Figure. 3. 2x 12V 100 Ah VRLA Batteries coupled to the Soweto SWT

II.4. Rotor Coupling hub used for the Soweto project

A rotor hub was purchased from a Chinese supplier and this was used to couple the wind turbine blade to the generator shaft. The rotor hub is the component that usually holds the blades and connects them to the main shaft of the wind machine. It is a key component not only because it holds the blades in their proper position for maximum aerodynamic efficiency, it also rotates to drive the generator. Hubs come in many different shapes and configurations, mostly dependent on the type of generator used and the design of the rotor blades as shown in Figure 4.

Figure. 4. 7-Blade wind turbine blade hub used for Soweto Project

II.5. Three Phase AC Permanent Generator

In terms of the generators for wind-power application, there are different concepts in use today. The major distinction among them is made between fixed speed and variable speed wind turbine generators. In the early stage of wind power development, fixed-speed wind turbines and induction generators were often used. Figure 5, shows permanent magnetic synchronous generators (PMSGs) used for the Soweto project.

Figure. 5. Soweto's Three-phase PMSG used.

II.6. Battery Regulator / Charge Controller

The battery regulator/ charge controller essentially forms a protection against overcharging a bank of batteries. It also acts as monitoring system when the batteries are fully charged; the controller sends a full energy stored code from the charge controller to the load [13]. Figure 6, shows the charge controller connected to the battery bank during testing in Soweto.

Figure. 6. Charge controller connected to the batteries during testing in Soweto.

II.7. AC cabling routing for the Soweto SWT project

The importance of neat cabling in wind turbines should be considered when constructing a system. Figureure 7, shows a medium AC cable running from the wind turbine tower to the charge regulator during testing in Soweto. The anticipated current delivery of the cable is a maximum of 50 Amps.

Figure. 7. Three-phase AC medium cabling routing during testing in Soweto

II.8. 7- Designed Rotor blades for prototype 3

In my recent 2022 article [14] showed the blade design and optimisation using BEM Theory. Different blade design aspects were taken into consideration while adapting and developing further blade designs in the

Soweto project.
The finished blade designs for Prototype 3 when implemented are shown in Figure 8. The design procedure and final specifications were further detailed in [14].

Figure 8. Prototype 3 (design 3) 7- rotor blades for Soweto SWT project

II.9. Developed wind turbine tower for the Soweto project

Wind turbine towers are usually made out of concrete, steel (tubular), or lattice (steel). Their purpose is to create balance within the structure of the wind turbine whenever there is movement of wind. It is known that the greater the height of the wind tower, the better the wind turbine will perform. Figure 9, shows a chosen wind turbine tower designed for this project.

Figure. 9. Developed steel tower for the Soweto SWT.

II.10. Power Wattmeter and DP-3051 Software package

The power wattmeter was compatible with the DPA-3051 software package and thus used together. A power wattmeter was used to record data and stored in the device memory. The DPA-3051 software package was used to extract data from the power wattmeter and therefore give outcomes of the wind turbine in the form of graphing. See Figure 10:

Figure. 10. Power wattmeter and DPA -3051 software used for the Soweto project.

III. Result and discussion

III.1. Case study for the Eastern Cape province, South Africa

[15] Stated their research problems to be as follows:
An assessment of generating electricity from wind for six sites of the Eastern Cape Province: Gqeberha (PE), Queenstown, Fort Beaufort, Makhanda/Grahamstown, Graaff Reinet and Bisho.
The research was done at the Fort Hare University in South Africa from June 2014 to December 2014.

III.2. Research methodology used for the Eastern Cape province study

The following technique and procedures were used in order to accomplish the project [15]:
The series of five-year wind speed average data (01/2009 to 12/2013) for 6-Eastern Cape Weather Station were acquired at South African Weather Services (SAWS).
The analysing of data with MATLAB was done with the use of a Weibull distribution.

III.3. Results and conclusion obtained for the Eastern Cape Province from case study: Reviewed.

Figure 11, shows location of six sites in the Eastern Cape Province that research was conducted on. Table 1, shows weather station coordinates that were used for Eastern Cape case study. Figure 12, shows the variation of wind speed per day for Eastern Cape sites from (2009-2013). Figure 13, shows the annual Weibull Probability

Frequency Density for part of the Eastern Cape for period under consideration.

As depicted in Figure 13, it is the observation of variation of wind speed for six Eastern Cape sites from 2009 to 2013. The respective maxima fluctuate from site to site. Most inland sites trends have lower wind speed conditions, except Gqeberha (PE) and Bisho, which are located very near the coast.

Moreover, the minimum probability of an event in Gqeberha (PE) is 0.13 but the city also has the highest wind speed, while Fort Beaufort has the least spread among these sites/regions [15].

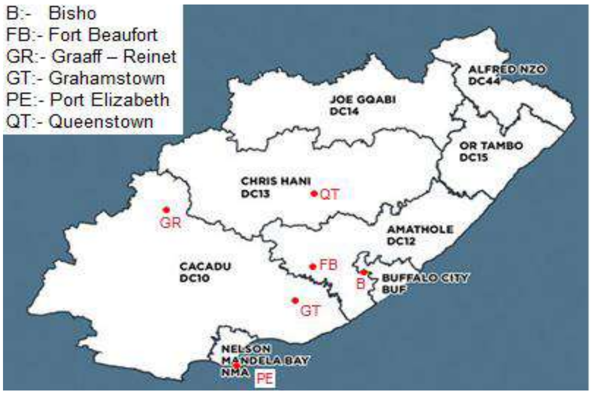

Figure. 11. Location of six Sites in the Eastern Cape Province [15]

Table1. Weather station coordinates used for Eastern Cape case study [15]

Weather stations	Latitude	Longitude	Height(m)
Bisho	-32.8940	27.2860	590
Fort Beaufort	-32.7880	26.6290	455
Graaff - Reinet	-32.1930	24.5430	792
Grahamstown	-33.2900	26.5020	642
Port Elizabeth	-33.9840	25.6100	63
Queenstown	-31.9170	26.8770	1104

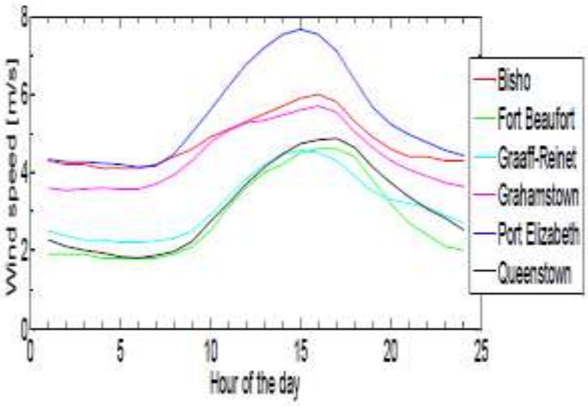

Figure. 12. Variation of wind speed per day for Eastern Cape sites (2009-2013) [15]

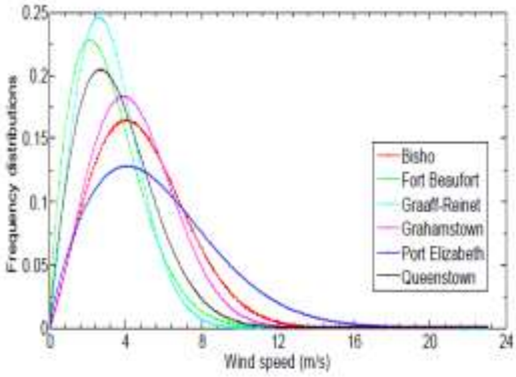

Figure. 13. The annual Weibull Probability Frequency Density for part of the Eastern Cape for period under consideration [15]

Therefore, in this study, it was determined to use characteristics of P.E (Gqeberha) region in the Eastern Cape Province with Soweto's in order to determine the feasibility of implementing the Soweto Technology in the coastal region of P.E.

III.4. Predictive study results for soweto and eastern cape province regions

It is of major importance that the assessment of wind potential is performed correctly. All characteristics must be considered as they will impact every aspect of the assessment, such as the evaluation of physical performance, investment viability and system design.

Figure 14 illustrates the Unit-T anemometer tool that was used in Soweto to measure the effectiveness of wind periods for the area. According to [16], this tool is mostly used by meteorologists to analyse weather**.** The device has the ability to measure wind speed in (m/s) and (km/h) and temperature in (°C) and (°F***)***, with data logging capture. It also has the ability to give outputs in the form of waveforms for analysis**.**

The device has Bluetooth functionality to transfer data to the user after measuring wind speed. The portable device can be plugged into the wind turbine and allowing convenient extraction of data.

Figure 14. Unit-T 363-B Anemometer [16]

Table 2, 3 and 4 shows data that was collected for Soweto wind measurement effectiveness with the use of a Unit-T Bluetooth Anemometer every 24-hour intervals. The highest wind power probability as in Figure 15 was found to be 2.3 m/s (8.28 km/h) using Soweto data recorded in Table 2, 3 & 4 and results were compared to that of Statistics of South African weather services.

Table 2. Phase two of Soweto Wind Measurement Data

Date	Time	Temperature (°C)	Wind Speed (km/h)
28 07 2022	23:04:35	24.5	1.2
28 07 2022	23:04:05	24.5	0.0
28 07 2022	23:04:30	24.5	6.0
28 07 2022	23:04:55	24.6	5.8
28 07 2022	23:04:20	24.6	8.0
28 07 2022	23:04:45	24.3	4.2
28 07 2022	23:04:10	24.3	3.7
28 07 2022	23:04:35	24.5	6.3
28 07 2022	23:04:00	24.5	3.7
28 07 2022	23:04:55	24.6	5.8
28 07 2022	23:04:30	24.6	4.6
28 07 2022	23:04:05	24.6	7.9
28 07 2022	23:04:40	24.6	7.5
28 07 2022	23:05:15	24.5	3.7
28 07 2022	23:05:50	24.4	3.7
28 07 2022	23:05:54	24.4	5.0
28 07 2022	23:05:56	24.5	4.6
28 07 2022	23:05:35	24.6	0.0
28 07 2022	23:05:55	24.6	7.1
28 07 2022	23:05:20	24.6	0.0
28 07 2022	23:05:45	24.5	5.4
28 07 2022	23:06:10	24.5	1.4
28 07 2022	23:06:35	24.5	5.4
28 07 2022	23:06:00	24.5	1.4
28 07 2022	23:06:25	24.6	3.7
28 07 2022	23:06:50	24.6	0.0
28 07 2022	23:07:15	24.5	2.8
28 07 2022	23:07:02	24.5	1.4
28 07 2022	23:07:45	24.5	3.7
28 07 2022	23:07:20	24.5	0.0
28 07 2022	23:07:55	24.5	2.8
28 07 2022	23:07:30	24.5	4.2
28 07 2022	23:07:05	24.6	7.1
28 07 2022	23:07:40	24.5	0.0
28 07 2022	23:07:15	24.5	4.2
28 07 2022	23:07:50	24.5	4.6
28 07 2022	23:07:45	24.5	7.6
28 07 2022	23:07:10	24.5	5.4
28 07 2022	23:07:35	24.4	5.8
28 07 2022	23:07:00	24.4	6.3
28 07 2022	23:07:25	24.5	5.2
28 07 2022	23:07:50	24.5	6.3
28 07 2022	23:07:15	24.4	4.5
28 07 2022	23:07:40	24.5	3.4
28 07 2022	23:08:05	24.5	7.5

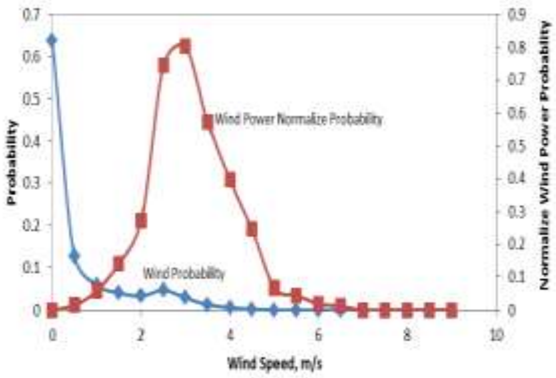

Figure 15. Probability of wind and normalized wind power for Soweto area

Table 3. Phase three of Soweto Wind Measurement Data.

Date	Time	Temperature(°C)	Wind Speed (km/h)
26 03 2022	17:56:55	26.9	7.1
26 03 2022	17:56:20	26.8	6.3
26 03 2022	17:56:45	26.6	3.7
26 03 2022	17:57:10	26.4	4.6
26 03 2022	17:57:35	26.3	6.3
26 03 2022	17:57:00	26.2	7.1
26 03 2022	17:57:25	26.5	5.4
26 03 2022	17:57:50	26.9	7.1
26 03 2022	17:57:50	26.8	7.5
26 03 2022	17:57:15	26.7	7.1
26 03 2022	17:57:40	26.6	6.7
26 03 2022	17:57:05	26.5	8.8
26 03 2022	17:57:30	26.4	4.6
26 03 2022	17:57:50	26.2	6.7
26 03 2022	17:57:25	26.9	6.7
26 03 2022	17:57:00	26.8	5.4
26 03 2022	17:57:35	26.7	0.0
26 03 2022	17:57:45	26.6	3.7
26 03 2022	17:57:20	26.5	6.7
26 03 2022	17:57:55	26.4	6.3
26 03 2022	17:57:30	26.2	6.7
26 03 2022	17:58:05	26.8	5.0
26 03 2022	17:58:40	26.7	5.8
26 03 2022	17:58:15	26.6	5.8
26 03 2022	17:58:10	26.5	6.7
26 03 2022	17:58:35	26.4	0.0
26 03 2022	17:58:00	26.3	7.9
26 03 2022	17:58:25	26.9	7.4
26 03 2022	17:58:50	26.7	7.9
26 03 2022	17:58:15	26.6	5.4
26 03 2022	17:58:40	26.5	6.9
26 03 2022	17:58:05	26.4	7.0
26 03 2022	17:58:30	26.0	8.3
26 03 2022	17:58:05	25.9	4.2
26 03 2022	17:58:30	25.7	6.7
26 03 2022	18:07:55	25.6	4.6
26 03 2022	18:08:20	26.1	2.8
26 03 2022	18:08:45	25.9	7.9
26 03 2022	18:09:10	25.8	7.0
26 03 2022	18:09:35	25.6	6.7
26 03 2022	18:09:30	26.1	3.7
26 03 2022	18:09:05	25.9	4.2
26 03 2022	18:08:40	25.8	3.7
26 03 2022	18:12:15	26.1	7.5
26 03 2022	18:12:50	26.2	4.2
26 03 2022	18:12:25	26.0	2.8
26 03 2022	18:12:00	26.0	5.0
26 03 2022	18:13:55	25.4	6.3
26 03 2022	18:14:20	25.4	5.8
26 03 2022	18:15:45	25.6	5.0
26 03 2022	18:16:31	25.5	5.4

Table 4. Phase four of Soweto Wind Measurement Data

Date	Time	Temperature (°C)	Wind Speed (km/h)
12 04 2022	13:34:44	29.3	7.2
12 04 2022	13:34:14	29.4	8.8
12 04 2022	13:34:14	29.6	6.9
12 04 2022	13:34:39	29.6	9.6
12 04 2022	13:34:04	30.3	3.5
12 04 2022	13:34:29	29.2	4.3
12 04 2022	13:35:09	29.3	2.3
12 04 2022	13:35:34	29.7	8.3
12 04 2022	13:35:59	29.6	2.8
12 04 2022	13:35:24	30.1	0.0
12 04 2022	13:35:04	29.2	0.0
12 04 2022	13:35:29	29.1	3.7
12 04 2022	13:35:54	29.7	6.0
12 04 2022	13:35:19	29.7	5.3
12 04 2022	13:35:59	30.0	3.3
12 04 2022	13:35:24	29.3	0.0
12 04 2022	13:35:49	29.6	0.0
12 04 2022	13:35:14	29.6	6.7
12 04 2022	13:35:54	29.8	7.7
12 04 2022	13:35:19	29.2	3.1
12 04 2022	13:35:44	29.5	7.1
12 04 2022	13:36:09	29.6	7.7
12 04 2022	13:36:34	29.7	7.1
12 04 2022	13:36:54	30.4	6.7
12 04 2022	13:36:19	30.9	2.9
12 04 2022	13:37:44	31.4	8.8
12 04 2022	13:37:09	31.8	8.1
12 04 2022	13:37:49	30.8	0.0
12 04 2022	13:37:14	31.3	0.0
12 04 2022	13:37:39	31.7	3.7
12 04 2022	13:38:04	32.0	8.8
12 04 2022	13:38:44	30.6	0.0
12 04 2022	13:38:09	31.2	4.6
12 04 2022	13:39:34	31.7	1.4
12 04 2022	13:39:59	32.0	2.8
12 04 2022	13:39:39	30.5	3.7
12 04 2022	13:39:04	31.1	5.0
12 04 2022	13:39:29	29.3	4.2
12 04 2022	13:40:54	32.0	0.0
12 04 2022	13:40:59	31.0	6.7
12 04 2022	13:41:24	31.5	0.0
12 04 2022	13:41:34	33.5	7.1

The average wind speed per year for Gqeberha (PE), as determined by Weather Spark [17], is 11.6 mph (approximately 5.16m/s). Knowing that Soweto has an average wind speed of 2.3 m/s, characteristic variables were found as shown in Table 5.

As per my recent article published by ETASR peer review open journal (Engineering, Technology and Applied Science Research), Titled: Implementation and Evaluation of a Low Speed and Self-regulating Small Wind Turbine for Urban Areas in South Africa, results showed that Prototype 3 with maximum pitch angle of 12° produced the maximum output power of 39.5 W during testing and the maximum power output was achieved at average wind speed of 1.17 m/s (4.2 km/h) with energy production to generate a maximum 40 kWh per month.

Figure 16, thus shows the predicted power output for Prototype 3 (Design 3) when it is applied in the Gqeberha (PE) region, assuming that it operates continuously. The analysis yields a maximum output power of 54.3 W at the average wind speed in Gqeberha.

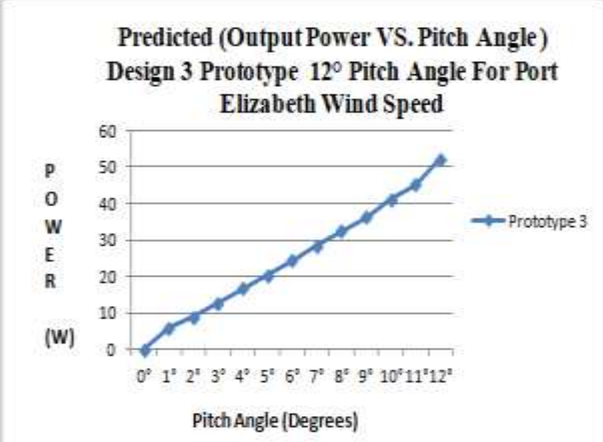

Figure 16. Predicted (output power vs. blade maximum pitch angle as derived for Prototype 3 in Gqeberha (PE) region).

Table 5. Predicted wind speed between Soweto and Gqeberha (PE).

Variables	Location	Location
	Soweto	Gqeberha (PE)
$C(ms^{-1})$	4.2	6.3
Vmp (ms^{-1})	3.2	4.1
Vop (ms^{-1})	8.2	9.5
Pd (Wms^{-2})	99.5	207.8
Vm (ms^{-1})	3.6	5.6
K	1.1	1.8

Figure 17 shows kWh energy production per month over a year, when the Soweto Technology results were predicted for Gqeberha (PE)'s wind speed. It can be seen that the predicted production of energy per month in Figure 17 was positive when compared to energy production for the prototype 3 when it was implemented in Soweto.

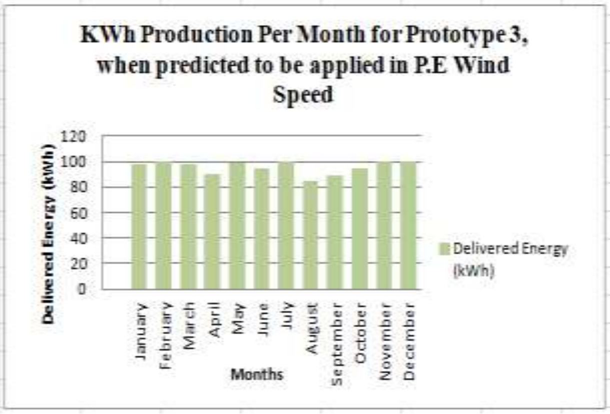

Figure 17. Projected (kWh production vs. months) for Prototype 3 when predicted to be applied in the Gqeberha (PE) region.

Scientific research showed that while the minimum probability of an event in Gqeberha was 0.13, the city also has the highest wind speed [15]. Then the predicted annual Probability Density Frequency for Gqeberha (PE) and Soweto in Figure 18 shows that Soweto has the maximum event probability of 0.16 with least wind speed.

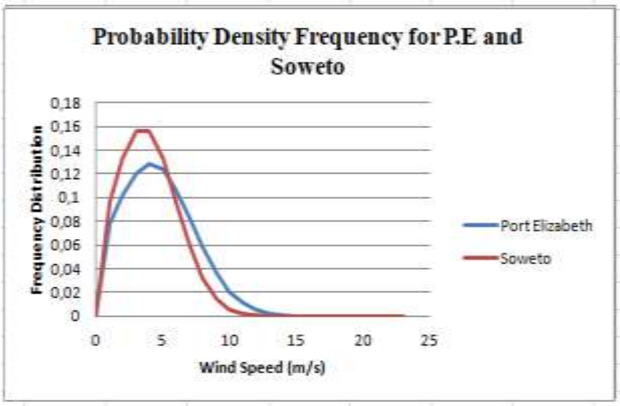

Figure. 18. The predicted annual probability density frequency for Soweto and Gqeberha (PE)

- Predictive Investment Analysis for the Soweto Wind Turbine

An investment analysis for the Soweto project is crucial as this will determine the viability of the project in the long term. In this section, the lists of materials that will be used for this project will be given together with the estimated prices. Next, the project viability in terms of investment versus profitability and pay-back period of the investment will be analysed.

A. Budget for the Soweto project

Table 6 shows the total wattage that was consumed for this project, and Table 7 shows a list of all material that were used for this project. The prices of the main hardware and electronic devices were taken from the internet sources. The total energy consumption is 2910 W/day.

Table 6. Energy consumption of appliances in Soweto

Household Appliances	Power (W)	Consumption per hour (h/day)	Total (W/day)
DSTV decoder	14	13	182
LG LCD TV	200	12.9	2595
Bluetooth Speaker	65	2	130
TOTAL	279		2910

However, to calculate the minimum power of a generator, it is necessary to add the loss of energy from the electrical system; this can be estimated as 10 % of the electrical system's total consumption. [18] Stated that electrical energy consumption can be calculated as follows:

$$Pelec - wind - gene = Elec - loss \times Soweto\ Energy\ Consumption \ldots\ldots\ldots\ldots (1)$$

$$= 2619\ W$$

B. The predicted study of pay-back period and profitability for this project

The predicted energy yielded using the Soweto Wind Turbine System in kWh will be compared to the energy yield of electricity suppliers in South Africa such as Eskom and City Power. The conclusion will be given on the expediency of this project, based on economic considerations. It is already known that the start-up investment is R15,600.00 (Table 7).

Table 7. List of materials for the Soweto project.

N	Quantity	Description	Price per unit (Rand)	Total Price (Rand)
1	2	BATTERIES	875.00	1750.00
2	1	500 W WIND GENERATOR SET WITH CHARGE CONTROLLER	5000.00	5000.00
3	1	4.5 METRE STEEL TOWER	1800.00	1800.00
4	1	1.5 MM OF AC 3 PHASE ELECTRICAL CABLE (6 METRES)	450.00	450.00
5	1	INVERTER	800.00	800.00
6	1	150 A WATTMETER WITH SOFTWARE ADAPTERS	1900.00	1900.00
7	1	WIND ANEMOMETER	750.00	750.00
8	1	POWER MONITOR DEVICE	800.00	800.00
9	1	3- & 5-BLADE HUB	1200.00	1200.00
10	1	7-BLADE HUB	450.00	450.00
11	1	LABOUR	450.00	450.00
12	1	SET OF BOLTS AND SCREWS	250.00	250.00
		TOTAL (EXCLUDING VAT)		15 600.00

The internal rate of return is given as IRR; to calculate the (IRR), total start-up investment (R15,600.00) should be included. As shown in Table 7, the life span of a small wind turbine will be given as (n) and (r) as rate of interest. According [18], the formula to calculate (IRR) then becomes:

$$IRR = \frac{r}{1-\frac{1}{(1+r)^{n}}} \quad \text{.....................} \ (2)$$

"r" is the rate of average interest of the total start-up investment, as shown in Table 7. Therefore, the Soweto technology life span is estimated to be 20 years and rate of interest to be 7% of the start-up investment. Thus we get an Equation (3) as follows: [18]

$$IRR = \frac{0{,}07}{1-\frac{1}{(1+0{,}07)^{20}}} = 0{,}0943 \tag{3}$$

The Capital cost (Cc) for production of energy in (kWh) taking into account that (I) is regarded as the Initial investment and will be included in the equation of (IRR). (CF) is the Capacity Factor and (P) is the minimum power generated. Moreover, we will assume that the wind functions for 10.5 hours per day. Then (Cc) will be calculated as follows in Equation (4): [18].

$$C_c = \left(\frac{I}{P}\right)\left(\frac{\text{IRR}}{FC.8760}\right) \tag{4}$$

$$CF = \frac{hworking}{hyear} = (10.5 \times 365) \div (24 \times 365) = 0.4375 \tag{5}$$

$$\text{Cc} = \left(\frac{15600}{2619}\right)\left(\frac{0.0943}{3832.5}\right) = R0.1461\ /kWh \tag{6}$$

[19] Stated that maintenance is performed to prevent failures, that is preventive maintenance or it is for correcting a failure event, which is corrective maintenance. The importance of Operation and Maintenance in wind turbine site is to ensure the Wind Turbine Generator (WTG) availability. When the WTG works, there would be possibility of issues such as errors / warning signals which may affects the availability of the WTG.Operation and maintenance (O&M) costs make up 25-30% of the total costs of a wind turbine. This is almost as much as the cost of the wind turbines and about as much as the costs of construction and installation.

According to [20], O&M costs are related to a limited number of cost components, and include: (i) Regular maintenance (batteries, etc.) (ii) Repairs; (iii) Spare parts replacement and (iv) Administration. Thus, for the Soweto small wind turbine, if we assume that O&M is 20% of the initial investment, then Equation (7) will be as follows: [18]

$$\text{Co\&}m = \left(\frac{I\times 0.2}{\text{P}\times\text{FC}\times 8760}\right) \mapsto \frac{15600\times 0.2}{2619\times 0.4375\times 8760} = R\ 0.3108/kWh \tag{7}$$

Therefore, the cost of power production (R /kWh) is the total cost of maintenance and operation plus the cost of capital (Cc) as shown in Equation (8): [18]

$$\frac{\boldsymbol{Price}}{\boldsymbol{kWh}} = Cc + Co\&m = R\ 0.4567/kWh \tag{8}$$

As per Equation 8, it is seen that the estimated average cost to generate 1 kWh was R0.4567 /kWh with the Soweto turbine, considering all initial capital outlay costs.

However, according to [21], the average cost of generating 1 kWh in South Africa is about R1.85 /kWh + 15 % tax = R2.13 /kWh for an average household that consumes between 100 and 1000 kWh per month, with a tariff addition of R5.00 per kWh where 1000 kWh usage is exceeded per month.

C. The predicted pay-back of the capital investment calculations

The payback period is the time period (generally in years) in which a return is required from an investment or the amount of time it takes for the positive cash flow to exceed the initial investment, without concern for the time value of money [22, 23].

[18] Further stated that to calculate the AEO = Annual energy output (kilowatt-hours/year) use the following Equation (9):

AEO = Emean × 365 (where Emean is appliances energy consumption shown in Table: 6): 2910 × 365 ↦ 1062.15 kWh/yea (9)

Table 8 and 9 [24], was used to analyse the annual energy production of selected turbines at the different sites and estimate the payback period of the investment. The total predicted energy generated per year by means of the Soweto technology would be 1062,15 kWh/year. Looking at Table 8, under: region - Northern and site location - Johannesburg, it is apparent that the AEO calculated would fall under the power category of Johannesburg as shown in Table 8.

Table 8. Annual energy production of selected turbines at different sites [24].

Region	Site Location	e300i (1 kW) (kWh/year)	e400n (3.5 kW) (kWh/year)
Cape Peninsula	Cape Town	2125.18	3316.36
	Oudtshoorn	683.54	239.85
	Worcester	1758.22	2268.66
South Eastern	Port-Elizabeth	2160.69	3432.52
	Grahamstown	1758.22	2268.66
	Richards Bay	1482.19	1557.35
Central	De Aar	1487.79	2358.36
	Bethlehem	1132.49	847.18
	Potchefstroom	683.54	239.85
Northern	Johannesburg	1681.56	2056.58
	Nelspruit	683.54	239.85
	Polokwane	916.47	504.05

This project initial plan was to use 500W Wind Generator as a departure point, therefore, Table 9, further shows that with the range of 300 W-1 kW modern designed wind turbine application, the predicted payback period would be 16 years if all regular maintenance (batteries, etc.), repair, supply of spare parts and administration are taken into consideration.

Table 9. Estimated payback period of selected turbines at different sites [24]

Region	Site Location	e300i (1 kW) (year)	e400n (3.5 kW) (year)
Cape Peninsula	Cape Town	12	18
	Oudtshoorn	38	255
	Worcester	15	27
South Eastern	Port-Elizabeth	12	18
	Grahamstown	15	27
	Richards Bay	18	39
Central	De Aar	18	26
	Bethlehem	23	72
	Potchefstroom	38	255
Northern	Johannesburg	16	30
	Nelspruit	38	255
	Polokwane	29	121

IV. DISCUSSION

- The highest wind power probability derived from wind anemometer collected data in Soweto was approximately 2.3 m/s, demonstrating that the Anemometer was calibrated correctly as compared to average wind speed referenced in South African Weather Service (SAWS).
- The results showed that a predictive case study which was done for regions in Eastern Cape, specifically for the Gqeberha (PE) area, utilizing the empirically obtained data in Soweto, projected an energy output of up to 54.3 W per wind speed of 5.16 m/s (18.6 km/h) at Gqeberha and up to 100 kWh per month production energy.
- A predictive investment analysis to determine profitability and viability of prototypes revealed that when all initial capital outlay costs and operational costs over a 20-year period were considered, the average cost of generating 1 kWh was R0.4567 /kWh. This derived cost compares extremely favorably with the amount charged by electricity companies in South Africa such as Eskom and City Power, which is (in 2022) approximately R1.85 /kWh + 15% tax = R2.13 /kWh) for an average household that consumes between 100 to 1000 kWh per month. Moreover, at above 1000 kWh usage, the tariff increases to R5.00 per kWh, which then raises the anticipated cost savings even further. It was also predicted that the payback period for the Soweto project to be 16 years.
- Social and environmental impact of the Soweto technology as well as challenges and barriers to its widespread adoption can be found in my 2022 article [25].

V. CONCLUSION

The following are the major conclusions drawn from the research:

1. The benefits of this research was to achieve possible application of low-cost small-scale wind turbine in South Africa for low wind speed areas, thereby providing low-cost electricity to households and inhabitants in urban as well as in rural areas for a very large region in South Africa. This was achieved by developing a test prototype for low wind speed condition in Soweto, Johannesburg, South Africa, and Moreover prediction case study using Soweto test results were shared in number (2).
2. A predictive case study for the Eastern Cape, focused on the Gqeberha (PE) area, was conducted using the empirically obtained data for the Soweto and Gqeberha (PE) areas, and it was concluded that it would be feasible to implement the Soweto technology in Port Elizabeth due to the results emanating presumably from the conditions at lower altitude (higher density air), and much higher wind speed resources at or near the coastal region.
3. Finally, the predictive case study between Soweto and P.E that was carried out contributed to new knowledge created within the field of study as it hasn't been done before and it is original.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism

Reference

[1] S. Jain and P.K. Jain. "The rise of renewable energy implementation in South Africa." Energy Procedia, 143, 2017, pp. 721-726.

[2] N.N. Rad, A. Bekker, and M. Arashi. "Enhancing wind direction prediction of South Africa wind energy hotspots with Bayesian mixture modeling." Sci Rep 12, 2022, 11442 https://doi.org/10.1038/s41598-022-14383-8

[3] G. Josie. "The Science Behind Decarbonization: The Race To Zero." Stanford Earth Matters Magazine, 2021.

[4] E.C. Merem. "Appraising Variations In Climate Change Parameters Along The Lower West African Region." Journal of Safety Engineering, 7:1:1-19, Climate Change and Shorelines, May. 2018.

[5] E.C. Merem. "Techniques of Remote Sensing and GIS as Tools for Visualizing Impact of Climate Change-Induced Flood in the Southern African Region." American Journal of Climate Change, vol 6, 2017, 306-327.

[6] B. Babalwa. "South Africa: Kangnas Wind Farm kicks off operations." ESI Africa, 2020.

[7] M. Jamie. "South Africa Will Be A Wind Energy Powerhouse." Olifansfontein, South Africa: My Broadband News, 2020.

[8] PR Newswire. "Second Wind's Technology Gains Ground in South Africa's Expanding Wind Energy Market." 2011. https://www.prnewswire.com/news-releases/second-winds-technology-gains-ground-in-south-africas

[9] Memon, M. H., Baloch, A. H. Memon, S. H. Qazi, R. Haider, and D. Ishak. "Assessment of Wind Power Potential Based on Raleigh Distribution Model: An Experimental Investigation for Coastal Zone." Engineering, Technology & Applied Science Research, vol. 9, no. 1, 2021, pp. 3721-3725. https://doi.org/10.48084/etasr.2381

[10] Y. Kassem, H. Gokcekus, and H. S. A. Lagili. "A Techno-Economic Viability Analysis of the Two-Axis Tracking Grid-Connected Photovoltaic Power System for 25 Selected Coastal Mediterranean." Engineering, Technology & Applied Science Research, vol. 11, no. 4, Aug. 2021, pp. 7508-7514. https://doi.org/10.48084/etasr.4251

[11] F. Elmahmoudi, O. E. K. Abra, A. Raihani, O. Serrar, and L. Bahatti. "Elaboration of a Wind Energy Potential Map in Morocco using GIS and Analytic Hierarchy Process." Engineering, Technology & Applied Science Research, vol. 10, no. 4, Aug. 2020, pp. 6068-6075. https://doi.org/10.48084/etasr.3692

[12] SMA. "Wind Power Inverter." Available from: http://ust.su/upload/iblock/bb1/Sollight-SMA-WindyBoy5000-6000.pdf Accessed: 15th January 2020.

[13] Myint, A. S., Tun, H. M., and Naing, Z. M. "Implementation of Wind Turbine Controller Design for Smart Campus." International Journal of Scientific and Research Publications, Jun. 2014, vol. 4, no. 5, pp. 1-10.

[14] T.S Sithole, V.R Veeredhi, and T. Sithebe. "Small Wind Turbine Blade Optimization using blade elementary method theory (BEMT)." IJISRT, Dec. 2022, vol. 7, no. 12, pp. 16-21. https://doi.org/10.5281/zenodo.7444983

[15] C. Shonhiwa, G. Makaka, and K. Munjeri. "Estimation of Wind Power Potential of Six Sites in Eastern Cape Province of South Africa." Physical Science International Journal, June 2015, pp. 209-218.

[16] ElectroMann SA. "Wind Power (Technology and Economics)." Aug. 2021. Available from: https://www.electromannsa.com/products/uni-t-ut363bt-bluetooth-mini-wind-speed-meter

[17] Weather Spark. Average Weather in Port Elizabeth. 2020. https://tinyurl.com/y6kd795c

[18] Moreno, F.G. Design of a Small Wind Generator. 2008. https://tinyurl.com/yy45y38z

[19] Rajeesh, K.C. and Sankar, S. IMPROVING BATTERY LIFE IN THE WIND TURBINE GENERATOR USING ULTRACAPACITOR. International Journal of Advanced Technology in Engineering and Science, no 03, 2015, pp. 2348–7550.

[20] Castellà, a.t. operations and maintenance costs for offshore wind. 2020. Available: https://upcommons.upc.edu/bitstream/handle/2117/329731/master-thesis-xavier-turc-castell-.pdf

[21] Business -Tech. South Africa’s Petrol and Electricity prices vs. the world. 2019 Jun. Available: https://tinyurl.com/y6gkx49p

[22] Ayompe, L. Performance and policy evaluation of solar energy technologies for domestic application in Ireland. 2011. https://tinyurl.com/3rbpt938

[23] Mostafaeipour, A. Economic evaluation of small wind turbine utilization in Kerman, Iran. Energy Conversion and Management, 73, 2013, pp. 214-225.

[24] Olatayo, K.I. A development path for small wind energy systems in South Africa. 2017 May.: http://repository.nwu.ac.za/bitstream/handle/10394/25628/Olatayo_KI_2017.pdf?sequence=1&isAllowed=y

[25] T.S Sithole, V.R Veeredhi, and T.Sithebe. A Review on Small Wind Turbine Aerodynamic Performance for Contribution of Power Supply for Low Wind Speed Areas. IJCEEE, May 2022, vol. 4, no. 5, pp. 1-6. https://wairco.org/IJCEEE/May2022.html