EVALUATION OF WIND ENERGY RESOURCE: A COMPARATIVE STUDY OF EAST RIDING OF YORKSHIRE AND CORNWALL COUNCILS, UNITED KINGDOM

Abstract

This study aimed to assess the wind energy potential in the United Kingdom, focusing on the East Riding of Yorkshire and Cornwall Councils. A comparative analysis was conducted by sampling two weather stations from each region to obtain and analyze wind characteristics. The annual energy yield for both regions was calculated over a four-year period. Data analysis involved frequencies, averages, T-tests, tables, and charts. The results indicated that wind speeds in the East Riding of Yorkshire ranged from 1 m/s to 23 m/s, with an average speed of 5.9 m/s, while Cornwall exhibited wind speeds from 1 m/s to 29 m/s, with an average of 8 m/s. The Hummer H25.0-200KW turbine was recommended for smaller installations, such as companies and schools, while the Enercon E-160 EP5 E3 turbine was suggested for larger installations, such as government projects. The potential annual energy yield in the East Riding of Yorkshire was estimated to be between 40,792 kWh and 111,695 kWh, while in Cornwall, it ranged from 50,580 kWh to 83,983 kWh. The T-test results revealed no significant difference in wind speed characteristics between the two counties ($p = 0.248$, $p > 0.05$) and no significant difference in their annual wind energy potentials ($p = 0.417$, $p > 0.05$). These findings suggest that to achieve the UK Government's wind energy target of 55 GW by 2030, a substantial number of turbines and large wind farms must be installed across all suitable sites in both counties.

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1. **Introduction**

1.1. Background

As population and economic growth have driven an increased demand for energy, the need for sustainable solutions has become more pressing (Shi et al., 2021). In response, national governments globally are striving to decarbonize their electricity supply, aiming to reduce CO_2 emissions and mitigate the impacts of climate change, even as energy consumption continues to rise (Wang et al., 2017).

To limit global warming to 1.5°C above pre-industrial levels by the end of the century, 130 countries made a significant pledge at COP 28: to triple global renewable energy production and double the annual rate of energy efficiency improvements by 2030 (IEA, 2023). In regions such as Africa, the primary focus is on transmission grids, energy storage, food-energy-water nexus, domestic growth, and demand management. Meanwhile, Europe's priorities include transmission grids, energy storage, affordability, infrastructure, and capital costs (World Energy Council, 2024).

The adoption of renewable energy faces significant challenges and opportunities amid a rapidly changing macroeconomic and geopolitical landscape (REN21, 2024). Among the most prominent renewable energy sources in recent years is wind energy (Shi et al., 2021).

Renewable energy has become the most cost-effective power source in many regions worldwide (World Economic Forum, 2021). Due to their environmental and economic advantages over fossil fuels and nuclear power plants, along with policies aimed at reducing dependence on non-renewable resources, wind turbines are now recognized as a viable alternative for generating electrical energy (Pereyra-Castro et al., 2020).

Wind energy is a vital component of the energy supply, like solar energy in that it is a free resource harnessed through turbines. A wind turbine converts wind energy from kinetic to mechanical form (Purav, 2017). The UK government has updated the National Planning Policy Framework (NPPF) to guide the development of wind and other renewable energy infrastructure, including the approval of large onshore projects under the Nationally Significant Infrastructure Project regime.

The population of East Riding of Yorkshire is 600,259, while Cornwall has a population of 575,413 (Office for National Statistics, 2024), indicating a substantial demand for energy. To meet this demand, it is crucial to explore various renewable energy sources. At COP28 in 2023, a strategy was outlined to advance climate action toward the 2030 goal, emphasizing the need to phase out fossil fuel subsidies and facilitate an energy transition by doubling energy efficiency and tripling renewable energy by 2030 (World Energy Council, 2024). Achieving these targets will require the development of wind farms—clusters of wind turbines that generate electricity from wind power (Purav, 2017). This research aims to assess the wind energy potential in East Riding of Yorkshire and Cornwall councils to address the challenges of unsustainable energy sources, enhance energy access and affordability, and drive economic growth.

1.2. Research Aim and Objectives

The aim of this research is to evaluate the wind renewable energy potential in the East Riding of Yorkshire and Cornwall councils. The specific objectives are:

i. To analyze wind speed data in the East Riding of Yorkshire and Cornwall councils from 2020 to 2023 and identify the optimal wind turbines for maximizing energy capture.

ii. To estimate the power output and annual energy yield for both regions from 2020 to 2023.

iii. To compare the wind speed characteristics and energy resource potential of the East Riding of Yorkshire and Cornwall councils from 2020 to 2023.

2.0. Literature Review

2.1. Wind Energy: An overview

Wind energy, like solar energy, is a free power resource derived from natural forces. Wind turbines convert the kinetic energy of wind into mechanical energy (Purav, 2017). Wind is defined as the movement of atmospheric air, driven by the sun's uneven heating of the Earth's surface, which creates a heat imbalance (Roger, 2013). The Wind Energy Conversion System (WECS) harnesses this kinetic energy, generated by the air's movement, and transforms it into mechanical energy (Bassyoumi et al., 2015).

However, the unpredictability of wind speed poses significant challenges for power system planning and operation. A key concern with the growing integration of wind power is its impact on power system reliability (Kurbanov et al., 2021). Nevertheless, generating electricity from wind energy could significantly reduce the pollution associated with traditional power plants (Al-Ghamdi, 2021).

A key drawback of wind power plants is their intermittent nature. Unlike other renewable energy sources, such as hydroelectric power, which can be stored and released as needed, wind energy cannot be stored, potentially leading to a lower base load capacity—the capacity needed to consistently meet the minimum demands of all users connected to an electricity grid (Mukasa et al., 2012).

Wind farms can utilize two types of turbines: vertical and horizontal axis turbines. Multiple turbines are often installed together to maximize energy production at a single site, enabling large-scale wind energy generation. Onshore wind farms are typically located in hilly or mountainous areas to capitalize on favorable wind conditions. Offshore wind farms, on the other hand, are situated in the ocean, at least 10 kilometers from the coast, where wind speeds are generally higher, further enhancing energy output (Purav, 2017).

2.2. Wind resource assessment techniques

Kirsten Stasio (2024) suggests that several key factors should be considered when selecting a renewable energy site, including resource availability, environmental restrictions and sensitivities (such as cultural and archaeological sites), transmission infrastructure, power plant retirements, transmission pricing and congestion, electricity markets, population and industry-driven load growth, policy support, land rights, and permitting, among others.

The assessment of wind resources is a critical first step in the development of wind power plants. Wind resource maps play a vital role in the initial identification and selection of sites for offshore wind projects, as they help mitigate the high costs of conducting year-long, on-site wind resource measurement campaigns (Dhanju et al., 2008; Möller et al., 2012).

After identifying potential development areas, wind power developers can utilize various measurement technologies, such as meteorological stations and LiDAR, to obtain in-situ wind resource data. This approach enables them to focus on the most promising sites for development (Shu et al., 2016).

Energy yield can be calculated using the following formula developed by Purav (2017), which models a wind energy conversion system based on the collected wind data and the selected turbine model. The formula below is used to model a wind energy conversion system;

$$The\ tip\ ratio\ \lambda = \frac{\text{Vtip}}{\text{Vwind}} = \frac{\omega R}{v}$$

$$\omega = \text{Angular velocity } \left(\frac{\text{rad}}{\text{sec}}\right)$$

$$R\ = Rotor\ radius$$

$$V = Wind\ speed$$

$$\text{Cp} = \text{Coefficient of performance} = \text{Power extracted} \div \text{Power of wind Kinetic Energy}$$

$$E = \frac{1}{2}(mv)^2 ------------------------(1)$$

$$Power\ in\ the\ moving\ air\ = \frac{dE}{dt} = \frac{1}{2}m \times\ v2 ----(2)$$

$$Air\ =\ Mass — sec\ =\ velocity\ \times\ Area\ \times\ Density ----(3)$$

$$Power\ P\ = \frac{1}{2} \times\ swept\ area\ \times\ Air\ Density\ \times\ Velocity$$

$$= \frac{1}{2} \times\ (\ r2\ )\ \times\ \rho\ v2 \times\ v\ =\ 1/2\ (\ r2\ \rho\ v3\ )(4)$$

$$Power\ in\ the\ wind\ P\ =\ (\ \rho\ A\ v\ ).$$

$$\frac{v^2}{2} = \frac{1}{2}\ (\ \rho\ A\ v3\ )\ \rho\ is\ the\ air\ density\ (\frac{kg}{m^3})$$

$$A = Area\ (m^2)$$

$$V =\ wind\ speed\ (\frac{m}{s})$$

$$P = \text{ power of the wind } \left(watts\ or \frac{J}{s}\right)$$

$$Power\ of\ blade\ P\ =\ Cp\ \frac{1}{2}\ A\ \rho\ v3$$

2.3. Factors influencing wind energy potential

One of the major challenges in the wind industry is managing abrupt and sharp changes in wind power, known as ramp events. Accurate assessment of wind variability is crucial for the efficient operation of wind farms and their integration into the electrical grid (Pereyra-Castro, 2020). Renewable energy sources, such as wind, are dependent on local climate conditions, leading to variability in the electricity they generate (Cepede and Rios, 2021). As noted by Cepeda and Mario (2021), wind power is also influenced by factors such as wind speed uncertainty, the performance of network components, wind farm topology, and the correlations between various wind power plants (WPPs) connected to the power system (Vergara, 2018).

2.4. UK wind energy policy and targets

With over 11,000 wind turbines and a total installed capacity of 30 gigawatts (GW)—split evenly between 15 GW onshore and 15 GW offshore—the United Kingdom ranked sixth globally in wind capacity by 2023 (WindPower, 2021; Renewable UK, 2023). The UK government, through the Department for Energy Security and Net Zero (2021), announced a world-leading climate target under the sixth Carbon Budget, aiming to reduce emissions by 78% by 2035 compared to 1990 levels, setting the nation on a path to achieving net-zero greenhouse gas emissions by 2050.

According to the Department for Energy Security and Net Zero (2024), the Energy Act of 2013 granted Great Britain the authority to establish a Strategy and Policy Statement (SPS) for energy policy, marking the first use of this power under section 131(2) of the Act. Over the years, the government has released several key documents outlining its strategic priorities for the energy sector, including the Energy White Paper (2020), Ten Point Plan for a Green Industrial Revolution (2020), Net Zero Strategy (2021), British Energy Security Strategy (2022), Energy Security Plan (2023), Net Zero Growth Plan (2023), and Transmission

Acceleration Action Plan (2023). These documents collectively define a clear set of strategic objectives aimed at transforming the energy system into one that is low-carbon, low-cost, and secure. Supported by these policies and goals, wind power, along with other renewable energy sources, continues to advance in the UK.

Following royal assent, the Energy Act 2023 was enacted into law. This Act introduces new environmental obligations for the offshore wind sector and outlines anticipated impacts on future offshore wind projects. The government aims to achieve up to 50 GW of offshore wind capacity by 2030, including up to 5 GW from floating offshore wind installations. The Act establishes a framework to support the accelerated deployment of offshore wind while ensuring the protection of the marine environment, which has become a significant concern for the industry. To meet its ambitious clean energy targets and reach 55 GW by 2030, the UK government under Prime Minister Keir Starmer is considering increasing subsidies for offshore wind developers in an upcoming auction (Farhat, 2024).

Utilizing advanced policy tools such as the Contracts for Difference (CfD) scheme, the UK is at the forefront of offshore wind development. In preparation for COP28, the UK government has announced initiatives to keep the 1.5°C climate target within reach. These initiatives include actively monitoring the phase-down of coal and the phase-out of all fossil fuels, with a goal for emissions to peak before 2025. Additionally, there are plans to rapidly decarbonize key economic sectors to meet sector-specific commitments made at COP26, particularly through the Breakthrough Agenda (HM Government, 2023).

3.0. Methodology

3.1. Data Collection

Wind speed data was sourced from local weather stations, specifically those with accessible public records and historic wind data available from before 2018 through to the present, located within the counties under study.

For the East Riding of Yorkshire, wind data for Bridlington and Leconfield from 2020 to 2023 was retrieved from historical weather and climate records at [Weather and Climate (https://www.weatherandclimate.eu/archive/?id=uk)] and [Time and Date (https://www.timeanddate.com/weather/uk)].

In Cornwall, wind data for Newquay was obtained from a private weather station at [Newquay Weather] (https://www.newquayweather.com/wxwinddetail.php?year=2023), while data for Camborne was sourced from [Time and Date] (https://www.timeanddate.com/weather/uk).

Secondary data for selecting the optimal turbine based on wind characteristics was sourced from [Wind Turbine Models] (https://en.wind-turbine-models.com/powercurves).

3.2. Data Analysis

Data analysis was conducted using Microsoft Excel to calculate the hourly frequency of wind speed occurrences for each year across the sampled weather stations. Each wind speed value was multiplied by the corresponding wind power output from the wind power model used in the study. The cumulative energy yield was subsequently calculated for all the years, resulting in the annual energy yield for each sampled weather station. The analyzed data was presented using tables, charts, Student T-tests, and graphs to facilitate comparative analysis.

3.3. Comparative Analysis Framework

A Student's T-Test was employed to compare the wind energy potentials of the East Riding of Yorkshire and Cornwall counties to determine if there are significant differences. Line graphs, tables, and charts were specifically used to visually compare the potential wind energy yield over the temporal scope.

4.0. Study Area Description

4.1. East Riding of Yorkshire

4.1.1. Geographic location and topography

The East Riding of Yorkshire, located in the Yorkshire and the Humber region of England, is geographically positioned at 0.30°W longitude and 53.55°N latitude. It shares borders with North Yorkshire to the north and west, South Yorkshire to the southwest, and Lincolnshire to the south, across the Humber Estuary (Baker, 1912; Ordnance Survey, 2023). Covering an area of 2,479 km² (957 sq mi) and with a population of 600,259, the county ranks 28th out of 296 councils in England (Office for National Statistics, 2024). The East Riding's diverse topography includes features such as chalk grasslands, arable fields, ponds, springs, chalk streams, woodlands, hedgerows, scrublands, and historic churchyards (English Nature, 1997).

4.1.2. Climate and weather patterns

According to Weatherandclimate (2024), the East Riding of Yorkshire features a warm summer climate typical of the marine west coast (Cfb classification) and is situated at an elevation of 13.54 meters above sea level. The region experiences an average annual temperature of 10.55°C, which is 0.2% cooler than the UK's national average. The East Riding records an average of 114.46 rainy days per year, accounting for 31.36% of the year, with an average annual precipitation of 38.62 millimeters. Timeanddate (2024) reports that July is the warmest month, with an average temperature of 17°C, while January is the coldest at 5°C. February is the windiest month, averaging wind speeds of 38 km/h, and October is the wettest month, with an average precipitation of 55.4 mm, contributing to an overall annual precipitation of 534.7 mm.

Existing wind energy infrastructure

The United Kingdom, specifically off the coast of Yorkshire, hosts the world's largest offshore wind farm (Office for National Statistics, 2021). The East Riding of Yorkshire has a long history of wind farm development. By 2015, over 50 wind farm applications had been approved, making this region one of the most turbine-dense areas in England (ERYC, 2015; ERYC, 2009; Yorkshire Post, 2014). By 2021, local governments aimed for their on-grid renewable energy installations to generate 148 MW. The area's consistently strong winds have attracted significant interest from various stakeholders.

Notable wind farms in the East Riding of Yorkshire include the Sixpenny Wood Wind Farm, with a capacity of 20.5 MW (still pending operation), and the Fraisthorpe Wind Farm, which comprises nine turbines, each with a capacity of 3.3 MW. Fraisthorpe became operational in 2016 (BayWa r.e., 2016). Another example is the Spaldington Wind Farm, which features five turbines with a combined capacity of 2,350 kW (thewindpower, 2023).

4.2. Cornwall

4.2.1. Geographic location and topography

Cornwall, located at 5°W longitude and 50.5°N latitude, is a ceremonial county in the southwest of England. It ranks fifth out of 296 councils in terms of population, with 575,413 residents, according to the Office for National Statistics (2024). The county spans an area of 1,369 square miles (3,545 square kilometers).

4.2.2. Climate and weather patterns

Cornwall, situated at an elevation of 6.17 meters above sea level, enjoys a marine west coast climate, classified as Cfb. The region has an average annual temperature of 12.23°C, which is approximately 1.48% higher than the UK average. Cornwall experiences an average of 139.26 rainy days annually, accounting for 38.15% of the year, with an average precipitation of 60.54 millimeters (Weatherandclimate, 2024). The area is characterized by mild winters and cool summers, with average annual temperatures ranging from 9.8°C in the central uplands to 11.6°C on the Isles of Scilly (Met Office, 2024).

4.2.3. Climate and Weather Patterns

Cornwall, situated at an elevation of 6.17 meters above sea level, enjoys a marine west coast climate, classified as Cfb. The region has an average annual temperature of 12.23°C, which is approximately 1.48% higher than the UK average. Cornwall experiences an average of 139.26 rainy days annually, accounting for 38.15% of the year, with an average precipitation of 60.54 millimeters (Weatherandclimate, 2024). The area is characterized by mild winters and cool summers, with average annual temperatures ranging from 9.8°C in the central uplands to 11.6°C on the Isles of Scilly (Met Office, 2024).

Existing wind energy infrastructure

Cornwall has been a leader in wind power, having established the UK's first commercial wind farm at Delabole in 1991 (Cochrane, 2023). The region is also at the cutting edge of Floating Offshore Wind (FLOW) technology. Hayle in Cornwall is set to host one of the world's inaugural FLOW Test and Demonstration sites, where Hexicon's TwinHub, a 32 MW facility, is scheduled for installation by 2026. This project will leverage existing infrastructure to advance the development of floating wind technologies (Cornwallti, 2023).

5.0. Wind Energy Resource Assessment

5.1. Wind Speed Analysis

Table 5.1.1: Wind Speed Analysis of East Riding of Yorkshire, United Kingdom

		Bridlington				Leconfield			
S/ N	Wind Speed	2020 Frequency	2021 Frequency	2022 Frequency	2023 Frequency	2020 Frequency	2021 Frequency	2022 Frequency	2023 Frequency
1	0	0	0	0	**0**	**0**	**0**	**0**	**0**
2	1	76	103	82	72	249	328	287	261
3	2	921	1055	1102	1219	1847	2576	2025	1791
4	3	527	610	543	629	902	1211	943	917
5	4	602	604	612	660	1078	1340	1124	1126
6	5	1228	1062	1072	1178	2363	2679	2313	2379
7	6	967	887	1006	1157	2247	2222	2089	2189
8	7	803	661	760	833	1897	1509	1546	1615
9	8	593	423	578	559	1507	968	1213	1179
10	9	456	293	368	408	1248	785	895	867
11	10	367	185	257	237	821	536	581	563
12	11	246	105	177	146	297	241	193	194
13	12	156	77	108	93	331	238	215	227
14	13	72	71	82	62	236	126	104	129
15	14	50	81	39	55	138	44	45	62
16	15	33	62	13	24	66	27	12	34
17	16	20	25	11	32	33	4	6	9
18	17	10	22	4	15	10	3	2	6
19	18	5	3	3	7	5	0	0	1
20	19	0	2	1	4	1	0	0	1
21	20	3	2	0	7	3	0	0	0
22	21	0	0	0	0	1	0	0	0
23	22	0	1	0	3	0	0	0	0
24	23	0	2	0	1	0	0	0	0
25	24	0	0	0	0	0	0	0	0

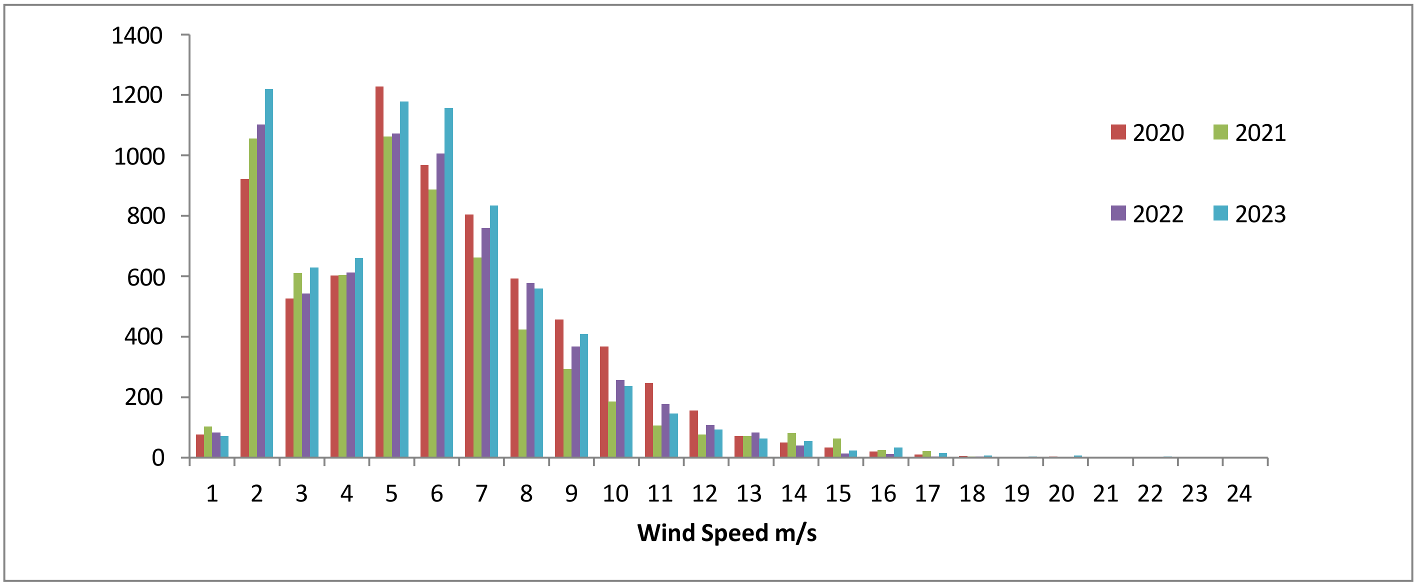


Figure 5.1.1: Wind Speed Analysis of Bridlington, East Riding of Yorkshire, United Kingdom

According to Table 5.1.1 and Figure 5.1.1, the annual wind speed values for the years 2020 through 2023 ranged from 1 m/s to 24 m/s.

For Bridlington, East Riding of Yorkshire, the most frequent wind speeds were observed between 2m/s and 7m/

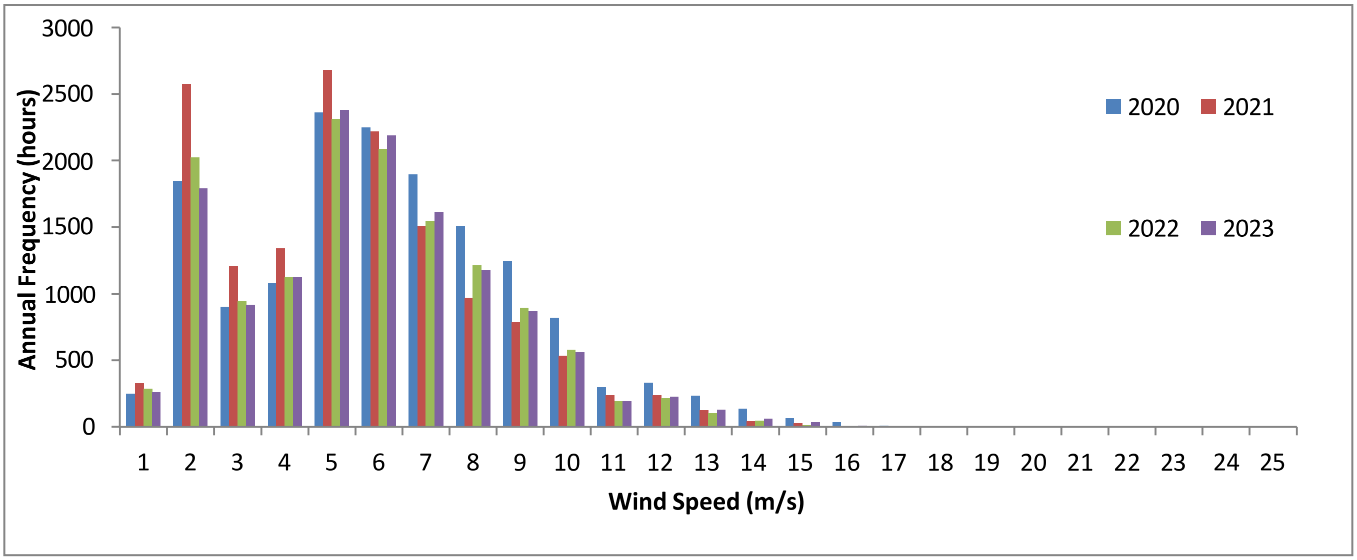


Figure 5.1.2: Wind Speed Analysis of Leconfield, East Riding of Yorkshire, United Kingdom

According to Table 5.1.1 and Figure 5.1.2, the annual wind speed values for 2020, 2021, 2022, and 2023 ranged from 1 m/s to 21 m/s. The highest frequency of occurrences for Leconfield, East Riding of Yorkshire, was between 2 m/s and 10 m/s.

Table 5.1.2: Wind Speed Analysis of Cornwall, United Kingdom

		Newquay				Camborne			
S/N	Wind Speed	2020 Frequency	2021 Frequency	2022 Frequency	2023 Frequency	2020 Frequency	2021 Frequency	2022 Frequency	2023 Frequency
1	0	0	0	0	**0**	**0**	**0**	**0**	**0**
2	1	192	216	132	168	27	136	142	145
3	2	768	996	960	960	512	1255	1643	1609
4	3	852	1176	1092	1056	437	776	816	844
5	4	768	648	912	804	569	759	870	985
6	5	600	480	528	564	1249	1297	1391	1663
7	6	564	768	540	624	1427	1349	1831	1920
8	7	528	432	372	540	1108	985	1593	1581
9	8	396	468	456	384	1138	700	835	951
10	9	336	456	456	396	911	625	815	838
11	10	324	348	432	408	821	463	361	510
12	11	360	336	528	432	337	199	190	198
13	12	444	468	396	408	385	265	179	258
14	13	336	264	228	360	241	126	46	137
15	14	240	156	252	216	163	115	49	124
16	15	228	216	216	168	97	42	12	56
17	16	168	84	156	204	59	29	7	22
18	17	108	72	96	96	41	21	4	6
19	18	96	72	96	120	14	0	1	3
20	19	48	24	12	24	9	0	1	0
21	20	156	144	12	48	17	0	0	2
22	21	84	24	36	36	2	0	0	0
23	22	72	12	24	36	9	0	0	2
24	23	0	0	0	0	1	0	0	1
25	24	24	24	12	12	1	0	0	1
26	25	12	0	12	0	0	0	0	0
27	26	0	12	0	0	0	0	0	0
28	27	0	0	0	0	0	0	0	0
29	28	0	0	0	0	0	0	0	0
30	29	0	0	1	0	0	0	0	0

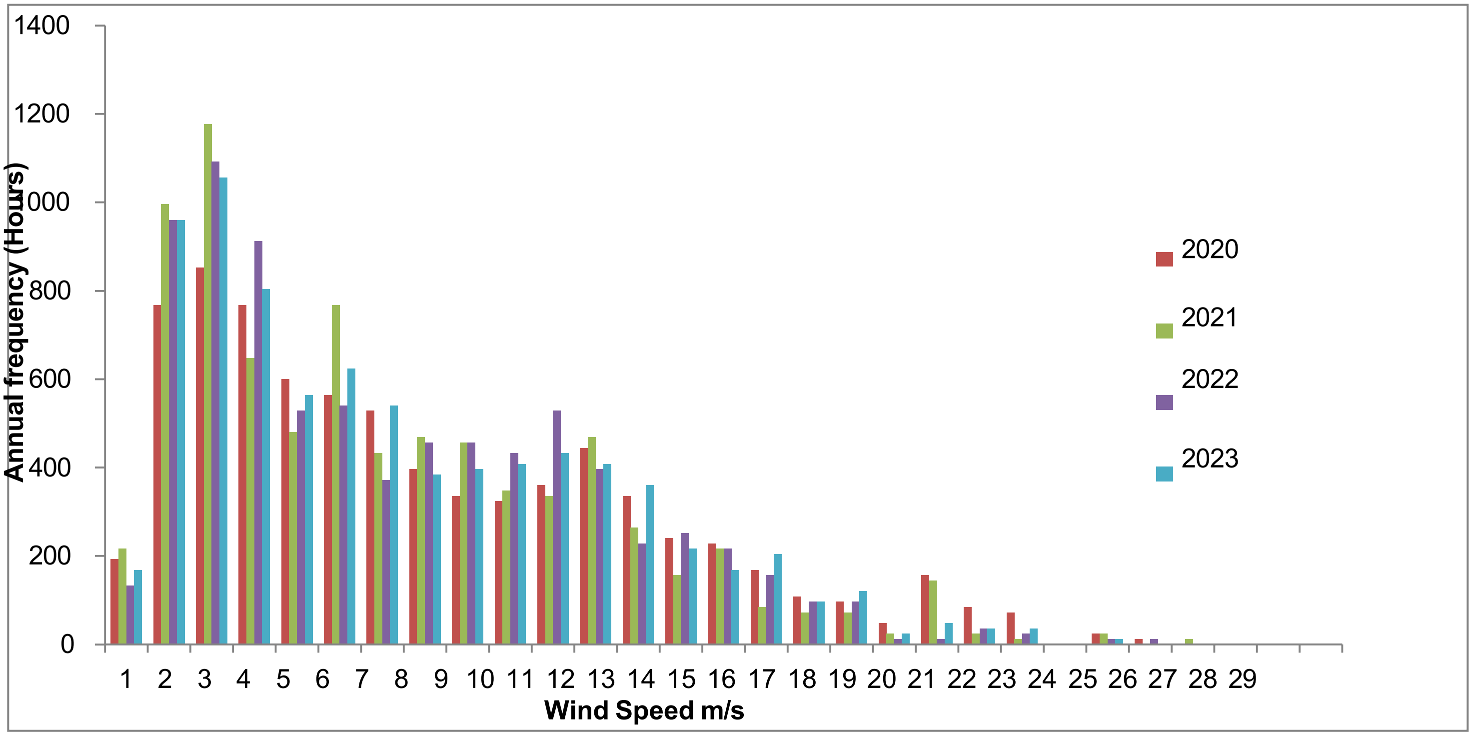


Figure 5.1.3: Wind Speed Analysis of Newquay, Cornwall, United Kingdom

According to Table 5.1.2 and Figure 5.1.3, the annual wind speed values for 2020, 2021, 2022, and 2023 ranged from 1 m/s to 29 m/s. For Newquay, Cornwall, the most frequent wind speeds were around 3 m/s, while wind speeds between 21 m/s and 29 m/s were observed less frequently.

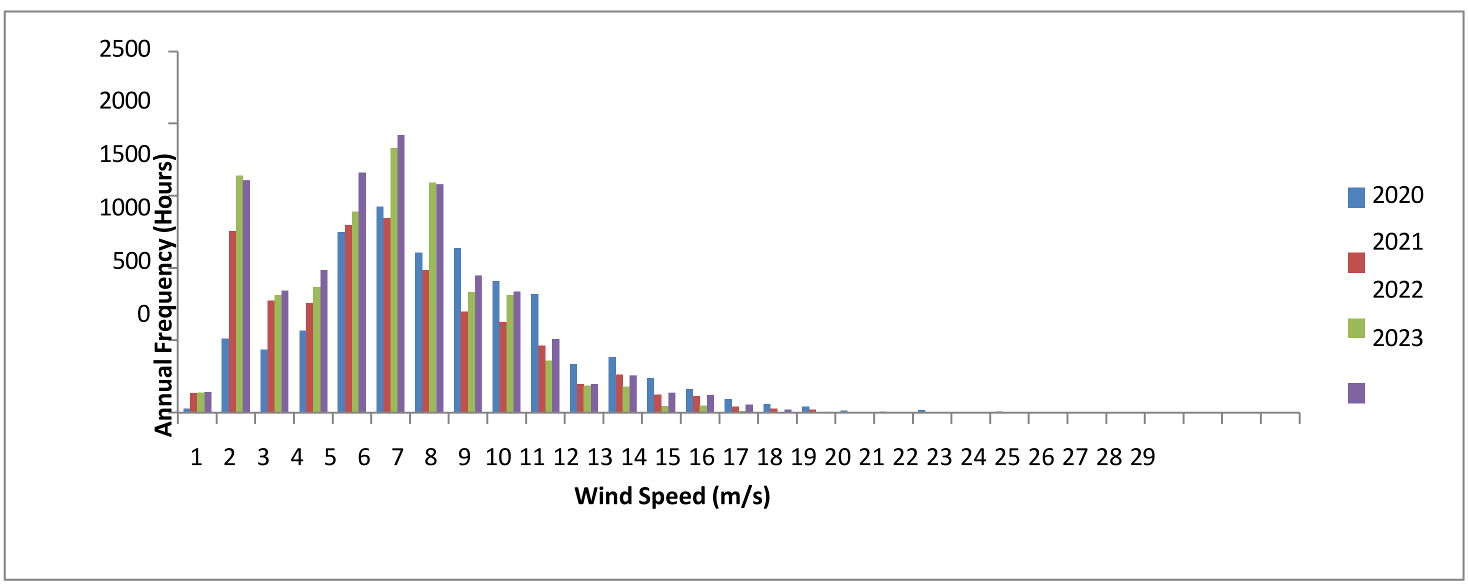


Figure 5.1.4: Wind Speed Analysis of Camborne, Cornwall, United Kingdom

Based on the data presented in Table 5.1.2 and Figure 5.1.4, the annual wind speeds for 2020, 2021, 2022, and 2023 ranged from 1 m/s to 24 m/s in Camborne, Cornwall. The highest frequency of occurrences was observed within the 3 m/s to 10 m/s range, while the least frequent wind speeds were between 19 m/s and 24 m/s.

Table 5.1.3: Annual average, minimum and maximum wind Speed in East Riding of Yorkshire and Cornwall, UK.

United Kingdom						
East Riding of Yorkshire				**Cornwall**		
Bridlington, East Riding of Yorkshire				**Newquay, Cornwall**		
Year	**av WS m/s**	**min WS m/s**	**max WS m/s**	**av WS m/s**	**Min WS m/s**	**Max WS m/s**
2023	6	1	23	11	1	24
2022	6	1	19	11	1	29
2021	6	1	23	12	1	26
2020	6	1	20	12	1	25
Average	6	1	21.5	11.5	1	26
Leconfield, East Riding Yorkshire Camborne, Cornwall						
2023	5.8	1	19	6	1	24
2022	5.7	1	17	5.7	1	19
2021	5.4	1	17	6.1	1	17
2020	6.2	1	21	7.4	1	24
Average	5.8	1	18.5	6.3	1	21
Grand Average	**5.9**	**1**	**20**	**8.8**	**1**	**23.5**

***WS = Wind Speed m/s**

According to Table 5.1.3, the average wind speed for the East Riding of Yorkshire over the study period is 5.9 m/s, whereas Cornwall exhibits a higher average wind speed of 8.8 m/s.

5.2. Wind Power Output Calculation

Table 5.2.1: Annual Wind Power Yield Estimate for East Riding of Yorkshire, UK

Year	Annual (WP kwh)	
	Bridlington	Leconfield
2023	49,146	94,469
2022	45,806	77,147
2021	40,792	95,259
2020	57,549	111,695
Annual Average	**48,323**	**94,643**

***WP = Wind Power Density**

The potential wind power that can be harnessed in Bridlington, East Riding of Yorkshire, for the years 2020 through 2023 is as follows: 57,549 kWh in 2020, 40,792 kWh in 2021, 45,806 kWh in 2022, and 49,146 kWh in 2023, yielding an average potential of 48,323 kWh. In Leconfield, East Riding of Yorkshire, the potential wind power for the same period is: 111,695 kWh in 2020, 95,259 kWh in 2021, 77,147 kWh in 2022, and 94,469 kWh in 2023, resulting in an average potential of 94,643 kWh.

Table 5.2.2: Annual Wind Power Yield Estimate for Cornwall, UK

Year	Annual (WP kwh)	
	Newquay	Camborne
2023	53,976	83,983
2022	53,100	74,761
2021	50,580	63,522
2020	51,228	70,602
Annual Average	**52,221**	**73,217**

*WP = Wind Power Density

The potential wind power that can be harnessed in Newquay, Cornwall, UK, for the years 2020 through 2023 is as follows: 51,228 kWh in 2020, 50,580 kWh in 2021, 53,100 kWh in 2022, and 53,976 kWh in 2023, resulting in an average potential of 52,221 kWh. In Camborne, Cornwall, the potential wind power for the same period is: 70,602 kWh in 2020, 63,522 kWh in 2021, 74,761 kWh in 2022, and 83,983 kWh in 2023, yielding an average potential of 72,217 kWh.

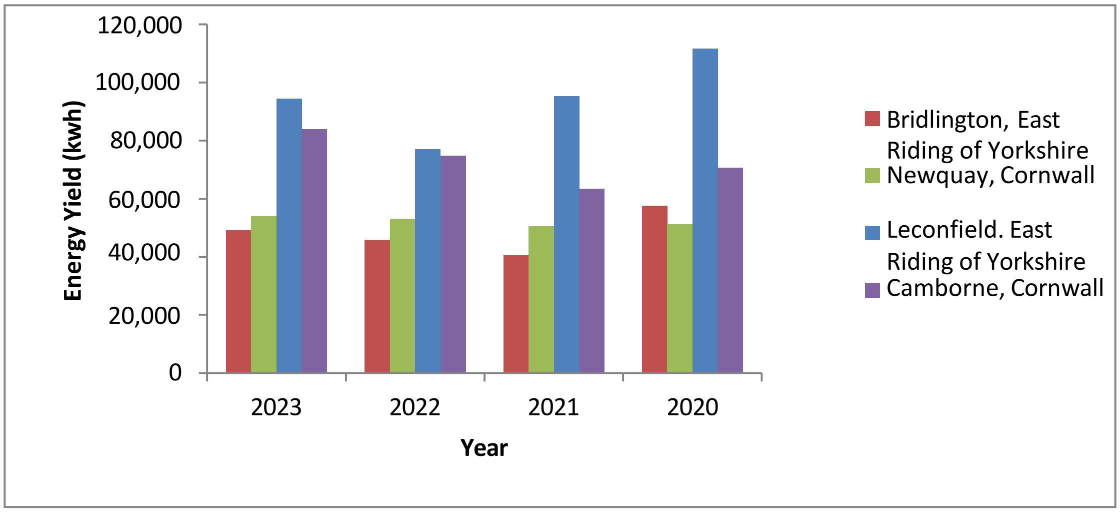


Figure 5.2.1: Annual Wind Power Yield Potentials of East Riding of Yorkshire and Cornwall

5.3. Wind Turbine Suitability Analysis

Table 5.3.1: Wind Turbine suitability Analysis

S/N	Turbine Product Type	Wind speed range	Swept Area	Hub height	Installation	Rotor Diameter	Rated power	Power Density	Suitability remark
1	**ACSA A27/225**	Cut-in wind speed: 3.5 m/s Rated wind speed: 13.5 m/s Cut-out wind speed: 25.0 m/s	573.0 m²	30 m	onshore	27.0 m	225.0 kW	2.5 m²/kW	
2	**Enercon E-16**	Cut-in wind speed: 3.0 m/s Rated wind speed: 12.0 m/s	206.1 m²	22.5m 28.5 m	Onshore	16.2 m	55.0 kw	3.7 m²/kW	

		Cut-out wind speed: 25.0 m/s						
3	**Enercon E-160 EP5 E3 GPO / Lagerwey Manufacturer**	Cut-in wind speed: 2.5 m/s Rated wind speed: 12.0 m/s Cut-out wind speed: 28.0 m/s	20,106.0 m²	98m 114m 120m 166m	Onshore	160.0 m	5,560.0 kW	3.6 m²/kW
4	**WinWinD WWD-1 D56 Manufacturer: ABB**	Cut-in wind speed: 3.6 m/s Rated wind speed: 12.5 m/s Cut-out wind speed: 20.0 m/s	2,463.0 m²	50/70 M	onshore	56.0 m	1000.00kw	406.0 W/m² 2.5 m²/kW

		Survival wind speed: 59.5 m/s						
5	**Hummer H25.0-200KW**	Cut-in wind speed: 2.5 m/s Rated wind speed: 11.5 m/s Cut-out wind speed: 20.0 m/s	490.9 m²		onshore	25.0 m	200.00 kw	407.4 W/m² 2.5 m²/kW
6	**Adani 5.2-160 Eickhoff**	Cut-in wind speed: 3.0 m/s Rated wind speed: 12.0 m/s Cut-out wind speed: 20.0 m/s	20,106.0 m²	120m	Onshore	160.0 m	5,200.0 kW	258.6 W/m² 3.9 m²/kW
7	**Hummer H8.16-**	Cut-in wind speed:	50.3 m²	Site specifi	Onshore	8.2 m	10kw	198.8 W/m²

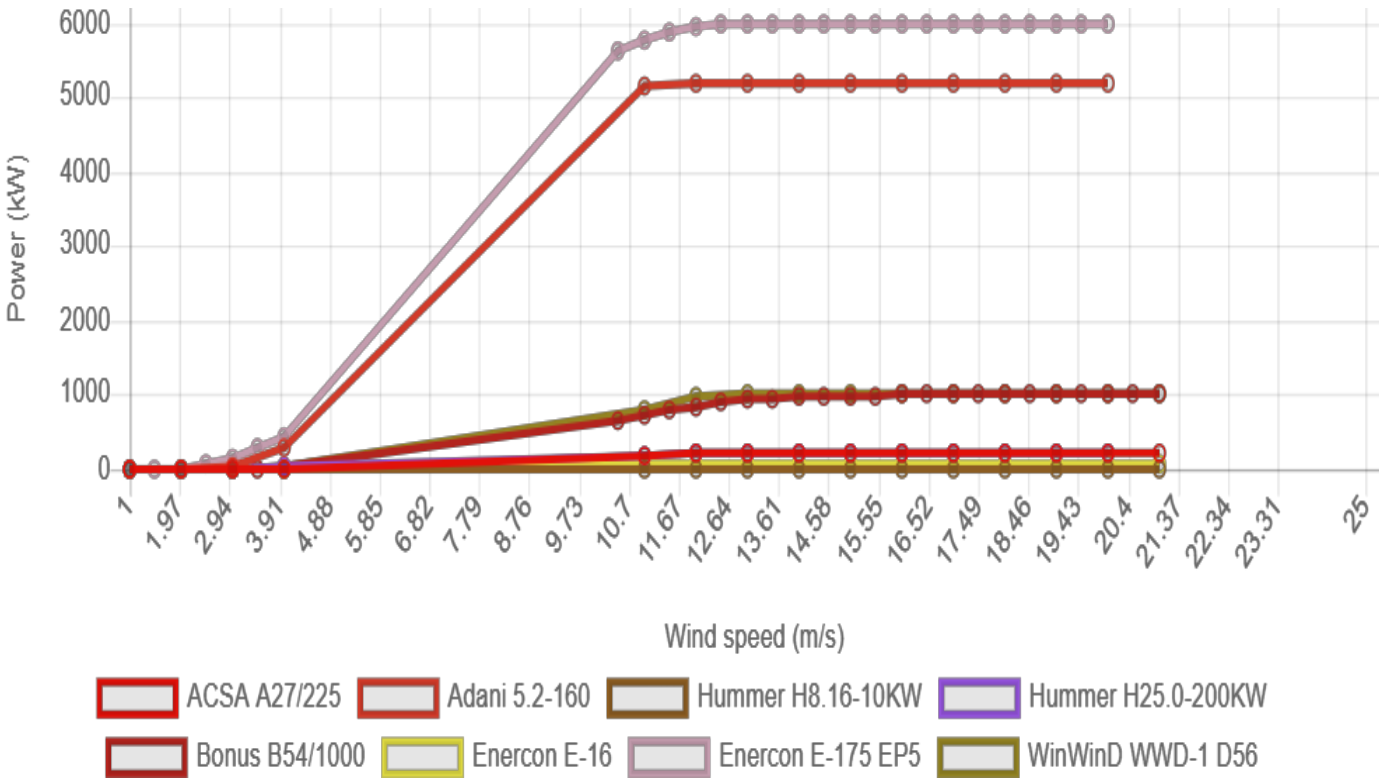
	10KW	3.0 m/s Rated wind speed: 11.0 m/s Cut-out wind speed: 25.0 m/s		C				5.0 m²/kW
8	**Bonus B54/1000**	Cut-in wind speed: 3.0 m/s Rated wind speed: 15.0 m/s Cut-out wind speed: 25.0 m/s	2,290 .0 m²	50/60/ 70 m	onshore	54.2 m	100 0kw	436.7 W/m² 2.3 m²/kW
9	**Bonus B82/2300**	Cut-in wind speed: 3.5 m/s Rated wind speed: 15.0 m/s Cut-out wind	5,300 .0 m²	80/90/ 100 m	Onshore and offshore	82.4 m	2,3 00. 00k w	434.0 W/m² Power density 2: 2.3 m²/kW

		speed: 25.0 m/s						
10	**Aeolos Aeolos-H 60kW**	Cut-in wind speed: 3.0 m/s Rated wind speed: 9.0 m/s Cut-out wind speed: 25.0 m/s	390.4 m²	site specific m	Onshore	22.3 m	60.00kw	153.7 W/m² 6.5 m²/kW

Based on the wind characteristics, turbines with a cut-in speed between 2 to 3 m/s and a cut-out speed between 20 to 25 m/s are deemed effective. For smaller installations within urban areas, the Hummer H25.0-200KW is recommended. This turbine features a swept area of 490.9 m² and aligns well with the wind characteristics of the region, with a cut-in wind speed of 2.5 m/s and a cut-out speed of 20 m/s. This recommendation is consistent with the findings of Charabi and Abdul-Wahab (2020) in Oman.

For larger installations and where cost is less of a constraint, the Enercon E-160 EP5 E3 is ideal, particularly in areas with extensive land availability, such as coastal regions. This turbine, despite requiring a substantial swept area, can generate up to 5,000 kW of capacity and is well-suited to the local wind conditions, with a cut-in speed of 2.5 m/s and a cut-out speed of 28 m/s. The Enercon E-160

EP5 E3 is available with hub heights ranging from 98 to 166 meters.



`**Figure 5.3.1: Comparing Power Curve of Different Wind turbines.**

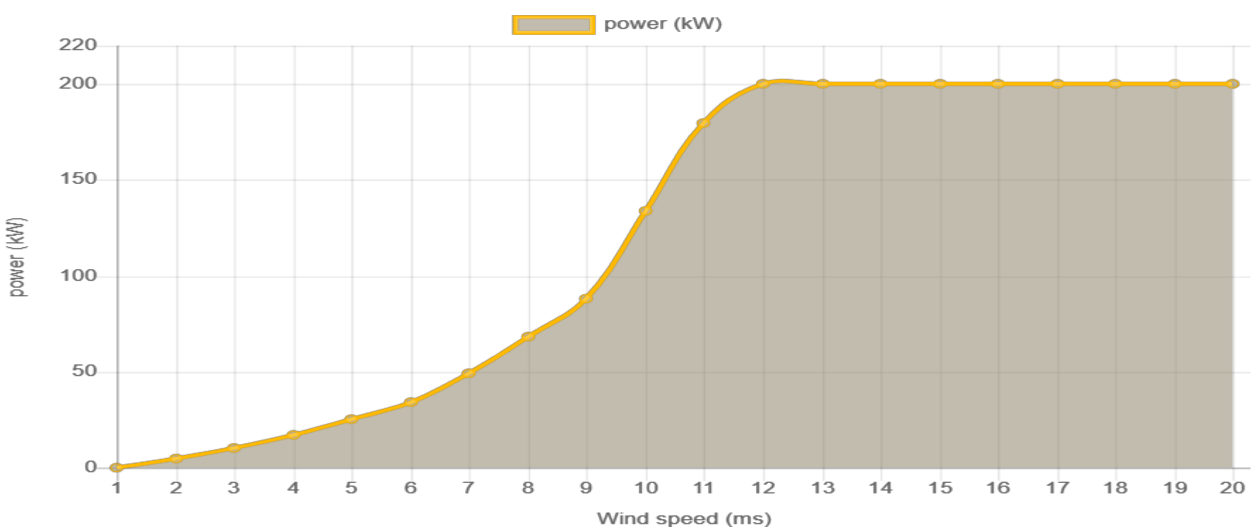


Figure 5.3.2: Selected Wind Turbine Power Curve (Hummer H25.0-200KW) Source: https://en.wind-turbine-models.com/powercurves

6.0. Results and Discussion

6.1. Comparative Analysis of Wind Energy Potential

6.1.1. Summary of findings for each region

The findings indicate that wind speeds in the East Riding of Yorkshire vary from 1 m/s to 23 m/s, with an average wind speed of 5.9 m/s. The annual energy yield potential for this region ranges from 40,792 kWh to 111,695 kWh.

In contrast, wind speeds in Cornwall range from 1 m/s to 29 m/s, with an average wind speed of 8 m/s. The annual energy yield potential for Cornwall varies between 50,580 kWh and 83,983 kWh.

6.1.2. Comparative graphs and tables

Table 6.1.2.1: Comparative analysis of Potential Annual Energy Yield of East Riding of Yorkshire and Cornwall Counties

Year	East Riding of Yorkshire	Annual Energy Yield (kwh)	Cornwall	Annual Energy Yield (kwh)
2023		49,146		53,976
2022		45,806		53,100
2021	Bridlington	40,792	Newquay	50,580
2020		57,549		51,228
Average		48,323		52,221
2023		94,469		83,983
2022		77,147		74,761
2021	Leconfield	95,259	Camborne	63,522
2020		111,695		70,602
Average		94,643		**73,217**
Grand		71,483		62,719

Average		
Grand Total	142,966	**121,830**

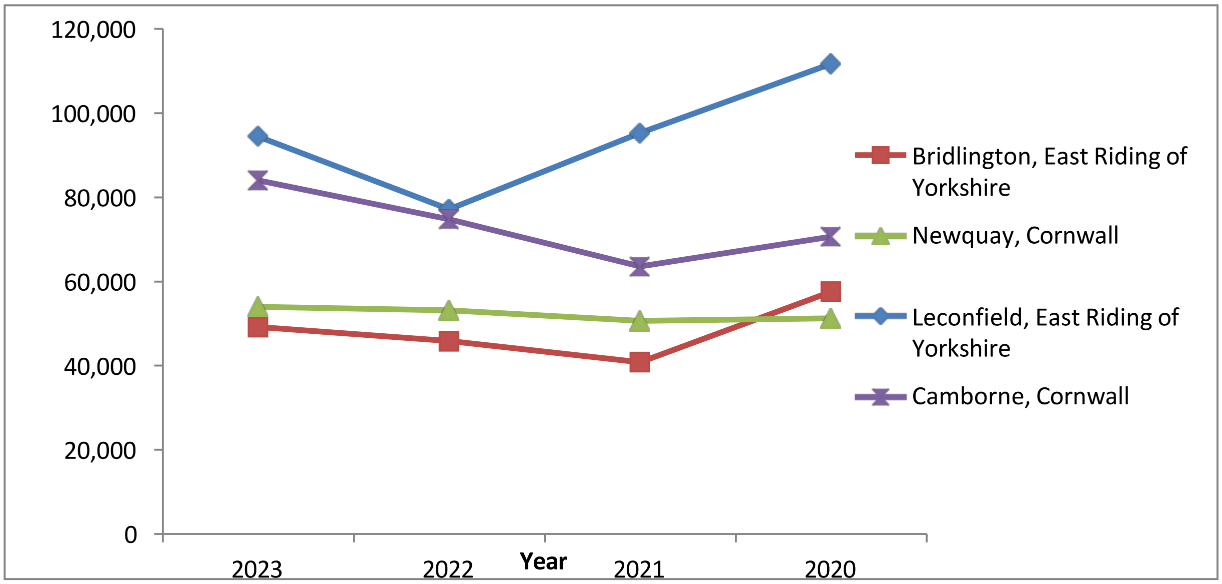


Figure 6.1.2.1: Comparative analysis of Potential Annual Wind Energy Yield of the Districts.

Table 6.1.2.1 and Figure 6.1.2.1 illustrate the differences in wind energy potentials across the sampled districts in the East Riding of Yorkshire and Cornwall. The annual energy yield for Bridlington, East Riding of Yorkshire, was 57,549 kWh in 2020, 40,792 kWh in 2021, 45,806 kWh in 2022, and 49,146 kWh in 2023. In comparison, Leconfield, East Riding of Yorkshire, recorded annual energy yields of 111,695 kWh in 2020, 92,259 kWh in 2021, 77,147 kWh in 2022, and 94,469 kWh in 2023.

For Cornwall, Newquay had annual energy yields of 52,228 kWh in 2020, 50,580 kWh in 2021, 53,100 kWh in 2022, and 53,976 kWh in 2023. Camborne, Cornwall, reported energy yields of 70,602 kWh in 2020, 63,522 kWh in 2021, 74,761 kWh in 2022, and 83,983 kWh in 2023

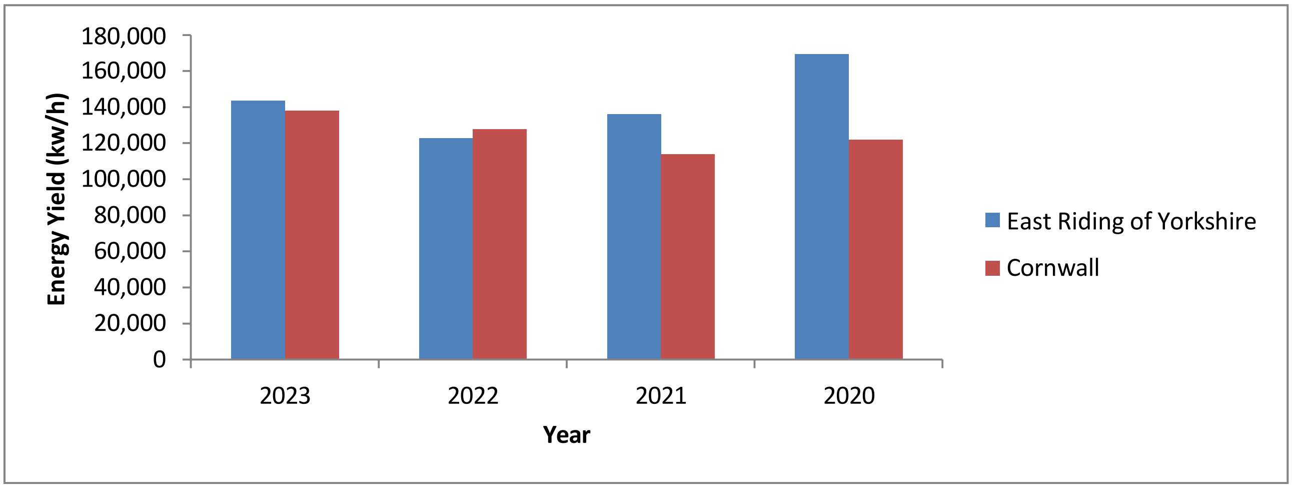


Figure 6.1.2.2: Comparative analysis of Potential Annual Energy Yield of East Riding of Yorkshire and Cornwall Counties.

Figure 6.1.2.2 illustrates the differences in total wind energy potentials between the East Riding of Yorkshire and Cornwall counties in the United Kingdom. The total annual energy yield for the East Riding of Yorkshire was 169,244 kWh in 2020, 136,051 kWh in 2021, 122,953 kWh in 2022, and 143,615 kWh in 2023. In comparison, Cornwall's total annual energy yield was 121,830 kWh in 2020, 114,192 kWh in 2021, 127,861 kWh in 2022, and 137,959 kWh in 2023.

6.1.3. Testing of Hypothesis

H_1= There is no significant difference between the wind speed characteristics of the East Riding of Yorkshire and Cornwall

Table 6.1.3: Summary Table for Test of Hypothesis One (1)

Region	Mean Wind Speed (m/s)	Standard Deviation (m/s)	Sample Size (n)	T-statistic	P-value
East Riding of Yorkshire	12.88	7.4	16	-1.178	0.248
Cornwall	16.14	8.24	16		

Based on the results, the p-value of 0.248 exceeds the alpha level of 0.05, indicating that the null hypothesis cannot be rejected. This suggests that there is no statistically significant difference in wind speed characteristics between the East Riding of Yorkshire and Cornwall counties in the United Kingdom.

H_2= there is no significant difference between the wind energy potentials of the East Riding of Yorkshire and Cornwall

Table 6.1.4: Summary Table for Test of Hypothesis Two (2)

Region	Mean Energy Yield (kWh)	Standard Deviation (kWh)	Sample Size (n)	T-statistic	P-value
East Riding of Yorkshire	71,482.88	26,825.05	8	0.837	0.417
Cornwall	62,719.00	12,582.97	8		

Given that the p-value is 0.417, which is greater than the significance level of 0.05, the null hypothesis is not rejected. This indicates that there is no significant difference between the estimated annual energy yields of the East Riding of Yorkshire and Cornwall based on the collected and analyzed data.

Interpretation of Results

6.1.4. Discussion on the differences observed

The analysis revealed minor differences in both wind speed and annual energy yield potential between the regions.

The wind speed characteristics in the East Riding of Yorkshire ranged from 1 m/s to 23 m/s, with an average of 5.9 m/s. In contrast, Cornwall experienced wind speeds ranging from 1 m/s to 29 m/s, with an average of 8 m/s. The total annual energy yield in Cornwall was 121,830 kWh, 114,192 kWh, 127,861 kWh, and 137,959 kWh for the years 2020, 2021, 2022, and 2023, respectively. For the East Riding of Yorkshire, the annual energy yields were 169,244 kWh, 136,051 kWh, 122,953 kWh, and 143,615 kWh over the same period.

Comparatively, the East Riding of Yorkshire has an average annual wind energy yield potential of 142,966 kWh, which is higher than Cornwall's average of 127,226 kWh. The p-value for the wind speed characteristics comparison was 0.448 ($p > 0.05$), suggesting no significant variation between the two regions. Similarly, the p-value for the annual energy yield comparison was 0.417 ($p > 0.05$), indicating no significant difference in the estimated yearly wind energy potentials between the East Riding of Yorkshire and Cornwall.

6.1.5. Factors contributing to the differences.

The slight differences observed can be attributed to spatial and temporal variations in the wind speed characteristics and distribution between the two counties.

6.2. Implications for Wind Energy Development

The findings indicate a positive implication for wind energy development. The study suggests that each installed turbine can generate a minimum of 5 MW of power. Consequently, capacity can be significantly increased through the installation of multiple turbines and the construction of additional wind farms.

6.3. Economic and Technological Factors

The cost of wind turbines and the willingness of investors to finance wind farm development are critical factors influencing the success of wind energy infrastructure projects. Additionally, the procurement of state-of-the-art, high-capacity wind energy systems and the availability of skilled installation engineers are crucial for both the development and operational efficiency of wind turbines and wind farms.

7.0. Conclusion

7.1. Summary of Findings

In the East Riding of Yorkshire and Cornwall, there are open fields, coastal areas, and offshore habitats with minimal swept areas and no shadow flicker issues, making them suitable for wind turbine and wind farm installations.

The East Riding of Yorkshire exhibits wind speeds ranging from 1 m/s to 23 m/s, with an average wind speed of 5.9 m/s. The region's potential annual energy yields span from 40,792 kW/h to 111,695 kW/h. In contrast, Cornwall experiences wind speeds from 1 m/s to 29 m/s, with an average wind speed of 8 m/s. The potential annual energy yields in Cornwall range from 50,580 kW/h to 83,983 kW/h.

In Bridlington, East Riding of Yorkshire, the potential annual wind power generation was 49,146 kWh, 45,806 kWh, 40,792 kWh, and 57,549 kWh for the years 2023, 2022, 2021, and 2020, respectively, yielding an average potential of 48,323 kWh. In Leconfield, East Riding of Yorkshire, the average annual wind power potential for the same period was 94,643 kWh.

For Newquay, Cornwall, UK, the potential annual wind power generation was 53,976 kWh, 53,100 kWh, 50,580 kWh, and 51,228 kWh for the years 2023, 2022, 2021, and 2020, respectively, resulting in an average potential of 52,221 kWh. Camborne, Cornwall, had an average annual wind power potential of 72,217 kWh, with annual values of 83,983 kWh, 74,761 kWh, 63,522 kWh, and 70,602 kWh for the years 2023, 2022, 2021, and 2020, respectively.

The total wind energy potential for East Riding of Yorkshire and Cornwall Counties in the United Kingdom was assessed for the years 2020, 2021, 2022, and 2023. The annual energy yield for East Riding of Yorkshire was 169,244 kWh, 136,051 kWh, 122,953 kWh, and 143,615 kWh, respectively. In comparison, Cornwall's annual energy yield was 121,830 kWh, 114,192 kWh, 127,861 kWh, and 137,959 kWh for the same years.

The average annual wind energy yield for East Riding of Yorkshire is 142,966 kWh, whereas Cornwall has an average of 121,830 kWh.

Statistical analysis revealed that the p-value for the first null hypothesis was 0.448, exceeding the alpha significance level of 0.05, indicating no significant difference in wind speed characteristics between the two counties. Similarly, the p-value for the second null hypothesis was 0.417, also greater than the significance level, indicating no significant difference in the estimated annual wind energy potentials between East Riding of Yorkshire and Cornwall.

Based on the findings, the Hummer H25.0-200KW wind turbine is recommended for smaller installations, such as those in companies and schools, while the Enercon E-160 EP5 E3 is suitable for larger-scale installations, such as government projects.

7.2. Contribution to knowledge

This research has assessed the wind energy potential in East Riding of Yorkshire and Cornwall Counties, highlighting opportunities for investment in the renewable energy sector. The findings confirm the substantial availability of wind energy resources in the United Kingdom, supporting the achievement of the UK government's renewable energy targets. The study indicates that each installed turbine has the potential to generate a minimum of 5 MW. Consequently, overall capacity can be significantly enhanced through the installation of multiple turbines and the construction of larger wind farms.

7.3. Suggestions for future research

Further research could explore the application of multi-criteria analysis using geographical information systems (GIS) for identifying optimal sites for wind turbine installations. Additionally, investigating the potential of offshore wind turbines warrants attention. An evaluation of the wind energy policies in both East Riding of Yorkshire and Cornwall should also be undertaken to understand their impact on wind energy development.

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Appendices

NOMENCLATURE

A Rotor sweep area, m^2.

C Shape parameter, m/s.

CF Capacity factor, %.

Cp Maximum power coefficient, ranging from 0.25 to 0.45, dimensionless.

f_R Rayleigh probability density function.

F_R Rayleigh cumulative distribution function.

f_W Weibull probability density function.

F_w Weibull cumulative distribution function.

H1, h2 Wind turbine hub height, m.

K Scale parameter, dimensionless.

N The number of reading within the time period.

P_R Power density per unit area based on the Rayleigh probability density function, kW.

P(v) Power of the wind, kW.

Pw Power density per unit area based on the Weibull probability density function, kW.

V Wind speed, m/s.

V_i Ith wind speed, m/ s.

Vm Mean wind speed, m/s.

V1, V2 Steady wind speeds, m/s.

α Hellman‘s wind shear exponent.

σ Standard deviation, m/s.

Γ Gamma function.

ρ Standard air density, kg/m3 (= 1.225 kg/m3 dry air at 1 atm and 15°C)