

Masters Program in **Geospatial Technologies**



OPTIMAL SITING AND CONNECTION OF WIND ENERGY FARMS IN VALENCIA COMMUNITY.

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Optimal Siting and Connection of Wind Energy Farms in Valencia Community

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Abstract

Identifying the best locations for wind energy farms, determining the most efficient paths, and assessing the wind energy potential of these sites are essential for achieving climate neutrality and net-zero emissions by 2050. Utilizing GIS data and MCDA methodologies has proven to be an excellent approach to achieving a sustainable and green environment. Location is a key element in Geographical Information (GI) that plays a significant role in the use of geospatial technology across various environmental projects. The combustion of fossil fuels and the release of CO₂ and other greenhouse gases are mostly caused by the heavy reliance on non-renewable resources like coal, petroleum, and natural gas. Using renewable energy sources like wind, solar, hydropower, and biomass might help counteract the negative effects of fossil fuel usage such as global warming, extreme weather, biodiversity loss, health issues, and rising sea levels globally. This thesis integrates technological, environmental, social, and economic factors of site suitability to identify viable areas for optimal placement of wind energy farms in the Valencia community. The system utilized the optimal route algorithm included within the pathfinder architecture to connect specific sites (T1-T16) to the grid. The wind energy potential of the appropriate locations was assessed, and a Python code was developed to determine the number of wind turbines that may be placed on each of the sixteen sites (T1-T16) based on the chosen wind turbine architecture (5Dx7D and 12Dx4D). The methodology showcases the possibilities of having not just an optimal site, but a site that is well connected to grid. It also proposes a methodological framework for calculating the wind energy potential of the study area. The research outcome is useful for decision making by private agencies, stakeholders and government parastatals in the renewable energy space.

Keywords

Optimal sites

Optimal paths

Climate emergency

Wind energy potential.

Wind turbine configuration.

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Acronyms

1. ACEMP - International Aegean Conference on Electrical Machines and Power Electronics.
2. Apt Wind - Atmospheric Physics and Turbulence for Wind Energy.
3. ANN - Analytical Neural Networks.
4. ANP – Analytical Neural Network.
5. CFD - Computational Fluid Dynamics
6. CIEEC - IEEE 3rd International Electrical and Energy Conference.
7. COMITCon - International Conference on Machine Learning, Big Data, Cloud and Parallel Computing.
8. CONCAPAN - IEEE 40th Central America and Panama Convention.
9. CUF - Capacity Utilization Factor
10. CSR – Corporate Social Responsibility.
11. EC – European Commission.
12. EICEEI - International Engineering Conference on Electrical, Energy, and Artificial Intelligence.
13. ESB – Energy Supply Board.
14. EU – European Union.
15. FAHP - Fuzzy Analytic Hierarchy Process.
16. FGP - Fuzzy Goal Programming.
17. GI - Geographical information
18. GIS - Geographical information systems.
19. ICCEP - International Conference on Clean Electrical Power.
20. ICCUBEA - International Conference on Computing, Communication, Control and Automation.
21. ICPET - 4th International Conference on Power and Energy Technology.
22. ICSGSC - 7th International Conference on Smart Grid and Smart Cities.
23. ICSGCE - International Conference on Smart Grid and Clean Energy Technologies.
24. I2MTC - IEEE International Instrumentation and Measurement Technology Conference.
25. ISITIA - International Seminar on Intelligent Technology and Its Applications.
26. IIAI-AAI - IIAI International Congress on Advanced Applied Informatics.
27. ISGT Asia - IEEE Innovative Smart Grid Technologies.
28. ISGT - IEEE Power & Energy Society Innovative Smart Grid Technologies Conference.
29. IWEC - Iran Wind Energy Conference.
30. LCOE – Levelized Cost of Energy.
31. MCDA - Multi-Criteria Decision Making.
32. MSCA - Marie Skłodowska-Curie Action.
33. NAPS - North American Power Symposium.

34. OPTIM - International Conference on Optimization of Electrical and Electronic Equipment.
35. PLOCAN – the Oceanic Platform of the Canary Islands.
36. POWERCON - International Conference on Power System Technology.
37. PSO - Particle Swarm Optimization
38. SSSC - Static Synchronous Series Compensator
39. SVR - Support Vector Regression
40. TAP Energy - International Conference on Technological Advancements in Power and Energy.
41. TOPSIS - Technique for Order Preference by Similarity to Ideal Solution.
42. WLC - Weighted Linear Combination.

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1.0. Introduction

1.1. General background

Wind farms are environmentally friendly energy production facilities that harness wind turbines' power to generate electrical power. It demonstrated considerable success throughout the 1990s, with notable technological advancements over the years. The rising popularity of these facilities can be attributed to their capacity to mitigate carbon emissions and adapt to offshore and onshore environment (Larry, 2021). “To a certain extent”, Europe has been able to mitigate carbon emissions and offer sustainable and renewable energy alternatives such as wind energy and wind turbines. According to the research and innovation report on wind energy by the European Commission (EC), wind energy covers sixteen percent of the EU electricity in 2022 making it one of the major technologies to reach the EU energy and climate targets (European Commission, 2022). It currently covers nineteen percent (19%) of total electricity production in Europe (Wind Europe, 2024). In 2023, it was the largest contributor to electricity production with about 421 terawatt-hours of power supply (Statista Research Department, 2023). In addition, it accounts for over one-third (37%) of the total generated electricity from renewable sources (Eurostat, 2023). It has also been estimated that about 300,000 jobs were created in 2021 with more than 32,000 jobs in Spain, thereby supporting economic growth and institutional wealth creation (Wind Europe, 2020; Pineda, et al., 2020; BEC, 2022; European Commission, 2023). These notable achievements were outcomes of the EU agreements and the ambitious targets to attain climate neutrality in 2050 and cutting emissions by 55% in 2030, as opposed to the 1990 levels (d'Aprile, et al., 2020; European Commission, 2023).

There have also been investments in offshore wind, as well as ocean energies, which have the potential to provide more than ten times the current electricity demand in Europe (BBC News Services, 2020). Of recent, there have been supports for wind industries (both governmental and specific private brokers) through the European Wind Power Action Plan, which aims to accelerate deployment, improve auction design, provide access to finance, create a fair and competitive international environment and develop skills and industry engagement (European Commission, 2023; Álvarez, 2023).

The EU has also been working to foster research and innovations to improve the performance and cost-effectiveness of wind technologies and address environmental, social, and ecological impact practices through organizations like PLOCAN (which provides marine research infrastructures, services, and collaborations), ESG (which adopts the CSR) and projects like the Apt Wind program, which is a flagship program under MSCA for the European Industrial Doctoral network with an ambition to explore the productivity of wind turbines in unexplored and totally new terrains that are majorly offshore and also onshore (Cooney, 2016; Hogan, 2022; AptWind, 2023).

Offshore wind farms are preferable to onshore wind farms due to their higher power potential and the possibility of large-scale energy harvesting (Kim et al., 2023). According to projections, offshore wind energy in Europe has significant potential, with a capacity of about 8.6 terawatts (TW) and 40.0 petawatt-hours (PWh) by the year 2050 (Caglayan et al., 2019). However, there is little of this energy that has been explored so far. Based on Wind Europe's report of 2021, the total new onshore wind capacity for Europe in 2021 is 14 gigawatts (GW) which is 81% of the new wind installations. Although the EU represents 86% of the global offshore wind energy capacity in 2017 (Mbistrova & Pineda, 2017), there are only about 19% of new installations offshore in 2021. Going by this statistic, it could be seen that there is little progress so far in terms of implementations in the offshore wind sector. However, there has been ongoing research to improve the efficiency of wind turbines that can work effectively offshore. These turbines are the new generation wind turbines with large hub heights, longer and lighter blades, reliable drivetrains, performance-optimizing control systems, and capacity factor of 50% (Wind Energy Technologies Office, 2014; Wind Europe, 2024). They are wind turbines with associated characteristics to withstand high-tides, ocean waves and resist rusting or corrosion.

In the coming years, considerable attention will be given to wind energy production offshore. This development will better eradicate the lapses and create a balance between the onshore to offshore wind farm ratio. It will further lead to the creation of powerful wind turbines that can annex the high velocities at increased altitude since the previous energy production target for 2030 has been increased to 40%

(Komusanac, Brindley , Fraile, & Ramirez, 2022; Eurostat, 2023). There will also be a need to explore some difficult terrains to account for the increased energy target and contribute to the European green energy mix.

Aside from the investment in research, some industries also benefit from these action plans. These affiliated industries include the wind energy manufacturing industries, the offshore wind industry (which is usually managed by the manufacturing industries and has the potential to provide ten times more than the current electricity demand in Europe), and the energy-intensive industries such as steel, cement, and chemicals (which can benefit from the availability of cheap and reliable electricity from wind power) and many more.

There has been a lot of research around the world on optimization and connection of wind energy farms using different methodologies. A review of some of the methodologies for optimal siting and connection of wind energy farms from twenty-one (21) chosen literatures can be found in section 2.1 of this work. From the review, there is no singular methodology that can perfectly fit into all the problems of optimal siting and connection of wind energy farms and wind energy potential calculation, because of issues around data availability, compatibility and formats. To address this issue and answer research questions 1 and 2, the Multicriteria Decision Making Analysis (MCDA) was used based on some of the data that is available online. Furthermore, little work has been done in identifying which turbine configuration will be best for maximizing energy output and wake effect reduction. To answer this question or fill the research gap a little, the research question 3 addresses just one of the outlined steps to achieving this, which is to first calculate the total number of wind turbines that are available on each of the suitable sites using Python programming language.

1.2. Wind turbines and wind energy in Spain.

Wind turbines are widely regarded as a sustainable energy solution in the Valencian region and throughout Europe. One installed wind turbine in Europe has the capacity to generate ten million euros of economic activities in products like taxes, sales, direct payments, kind-benefit offers, community farm ownership, wealth creation and jobs (Wind Europe, 2020). There are various categories of wind turbines, this includes the Horizontal-axis wind turbines (HAWTs) and the Vertical-axis wind turbines (VAWTs) (U.S. Energy Information Administration, 2022; National Geographic Society, 2023). Horizontal turbines are like propeller airplane engines while vertical turbines are like eggbeaters (Clayton, 2021). The most popular type of turbines occupying both the World, European and Spanish ecosystem is the HAWT. Figure 1a. and 1b. gives a pictorial description of these two major types of wind turbines.

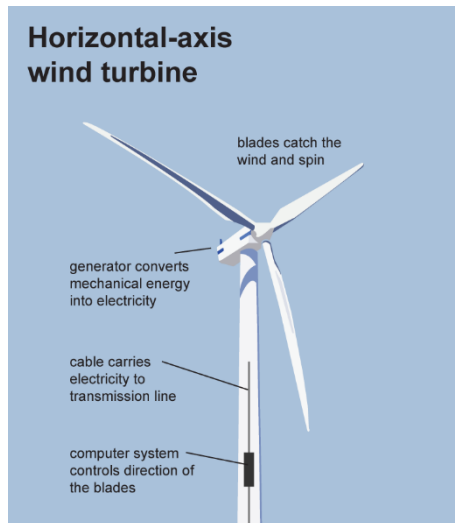


Fig. 1a: Horizontal-axis wind turbines (HAWTs)
Source: National Energy Education Development Project (public domain).

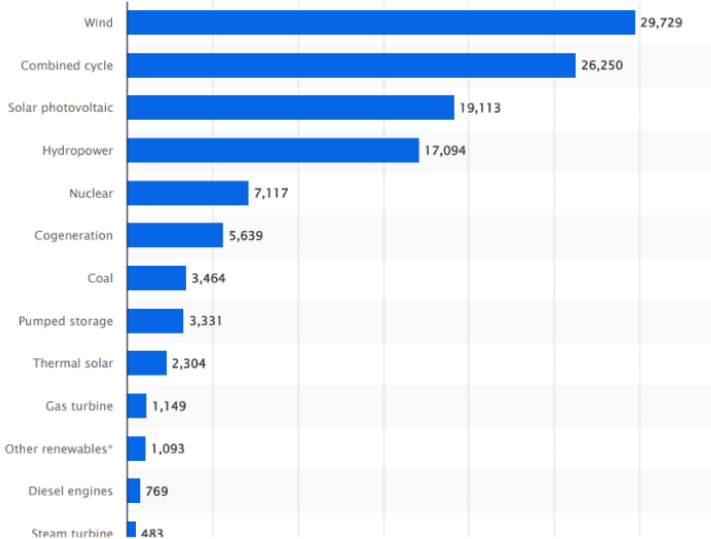


Fig. 1b: Vertical-axis wind turbines (VAWTs)
Source: Lysippos, Wikimedia Common author (public domain).

According to the U.S. Energy Information Administration, length of blades is directly proportional to the amount of electricity a wind turbine can generate. Small wind turbines can generate up to 10 kilowatts (kW) of energy, utility-scale turbines have about 15 megawatts (MW), and larger wind turbines are in development. When wind turbines are combined, they make up the wind farms that power major electricity grids (U.S. Energy Information Administration, 2022). The potential implementation of wind turbines as a sustainable energy option is currently under consideration in the region

of Valencia. The Port of Valencia currently incorporates various renewable energy projects into its operations. These activities include establishing a solar plant and the installation of windmills (Aquino, 2018).

Several European nations, such as Spain, are allocating resources to develop and implement renewable energy sources. The need to meet rising energy demands while reducing the negative effects of carbon dioxide (CO₂) emissions motivated this strategic move. Spain, particularly the region of Valencia, has established specific objectives for producing renewable energy, with wind energy emerging as a prominent force in this transition (Cascajo et al., 2020; Statista, 2023). The wind power capacity target set by the NECP as of December 2022 is 29,729 megawatts (MW) as shown in Fig. 2a.



Details: as of December 2022

Fig 2a: Wind power capacity targets set by the National Energy and Climate Plan (NECP) in Spain from 2020 to 2030. **Source:** Statista 2023

In 2021, Spain established a goal to achieve a 27% share of renewable energy in its final power consumption by 2030, with notable emphasis on harnessing wind energy (Simón-Martín et al., 2019). That same year, the wind industry in Spain added a total capacity of 842.61 gigawatts (GW) (IEA Wind TCP, 2022). The wind power generated by the wind industry has emerged as the leading technology, accounting for 25.7% of the total installed power capacity on the Spanish peninsula. Spain ranked seventh in

Europe for new investments, with 1.5 billion EUR (1.83 billion USD) allocated to new onshore wind farms (IEA Wind TCP, 2022).

Wind energy plays a vital role in Spain's endeavor to shift towards sustainable energy sources, as seen by its ambitious target of installing more than 50 gigawatts (GW) of wind energy by 2030 (Fernández, 2023; Statista, 2023). According to the Spanish National Integrated Energy and Climate Plan 2021-2030 (NECP), the government has pledged to raise the wind power capacity to 50 gigawatts (GW). This will require an investment of around 28.86 billion EUR (35.29 billion USD) to reach the European objectives for 2030 (IEA Wind TCP, 2022).

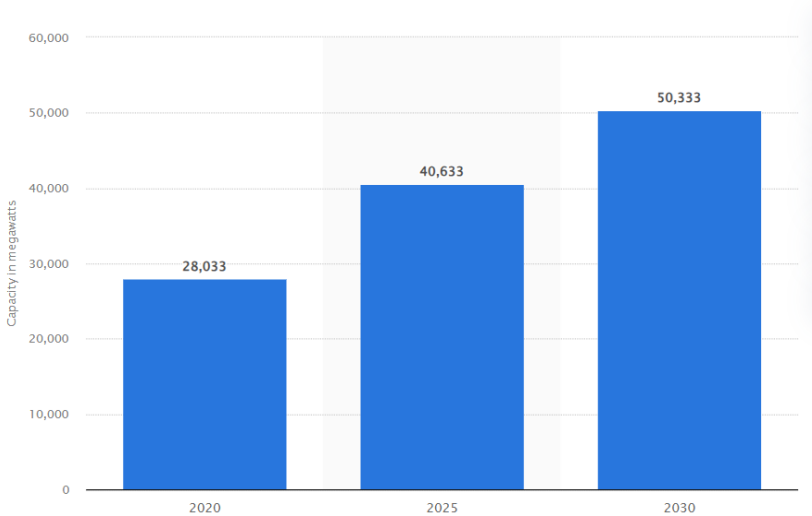


Fig 2b: Wind power capacity targets (onshore and offshore) set by the National Energy and Climate Plan (NECP) in Spain from 2020 to 2030. **Source:** Statista 2023

Furthermore, it has established specific zones for the placement of wind turbines (see figure 3). However, this initiative has encountered resistance from local organizations (Simón-Martín et al., 2019).

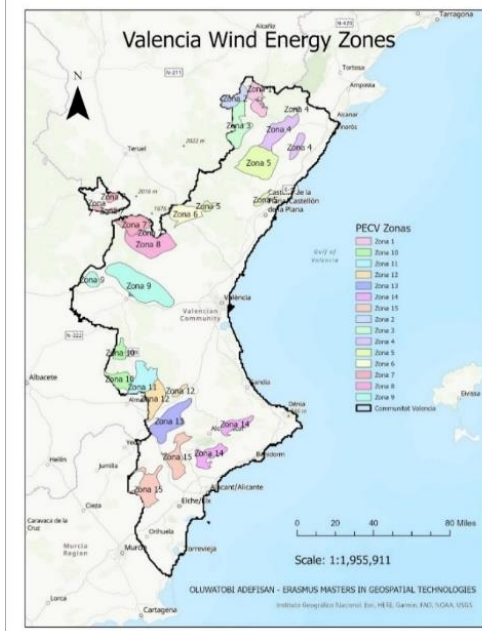


Fig 3: Valencia Wind Energy Zones

1.2.1. Motivation

This research is inspired by the climate emergency response of the Spanish and the Valencia government to produce 50 gigawatts (GW) of wind energy by 2030 (Fernández, 2023) and the existing work by Valmaña et al (2021) on “The Implementation of the Methodology GIS for the Optimal location of Photovoltaic Plants in the Valencia Community”.

According to the recent online publication by UNEP, it is evident that the burning of fossil fuels by humans has released enough greenhouse gases to alter the atmosphere's composition significantly. There has been a rapid increase in greenhouse gas emissions, and the consequent rise in global temperatures which severely threatens ecosystems, economies, and human well-being. Average global temperature has risen between 1.1^oc and 1.2^oc due to the emission of greenhouse gases from burning fossil fuels thereby leaving the world in a state of climate emergency (UNEP, 2023). A climate emergency can be described as a situation requiring urgent action to mitigate the impact of a changing climate. "It represents a new phase in climate change framing that many hope will invigorate more climate actions" (McHugh et al., 2021, p. 736). To meet the goals of the Paris Agreement, UNEP has called for a reduction in greenhouse gas emissions by 50% in 2030 and net-zero

emissions by 2050. In response to this, the United Nations (UN) in collaboration with other stakeholders and partners have set up the target for climate neutrality in 2050.

Conversely, there has been a gap in the study of various wind turbine configurations and their successful outcomes in active wind farm projects, although there has been a lot of work already done on wake effect reduction. As contribution to science and the existing work of literature, this research will focus on some of the state-of-the-art site selection and site optimization techniques for wind farm in the most suitable landscape (onshore) of the study area, while considering the cost and benefit factors of weather & climate (e.g. wind speed), environment, economy, and social impacts. It will explore some of the advanced spatial analysis techniques, including geographical information systems (GIS), Multi-criteria decision Analysis (MCDA), and optimization algorithms for optimal sitting and connection of wind energy farms, specifically to Valencia Community. It will further answer questions on the wind energy potential of each of the suitable sites (wind farm), and the amount of wind turbines that can be installed on each of the farms using the Python programming language. It will explore some of the popular wind turbine configurations used on wind farms and how this can be essential for minimizing wake effects on wind energy production.

The research outcome will be useful instruments for policy and decision making by industries, government agencies and stakeholders in the renewable energy sector, who are interested in wind energy and climate actions that encourages the absolute transition into sustainable green energy infrastructure, come 2050.

1.2.2. Research Questions

- Where are some optimal sites for constructing the Valencia wind energy farms (onshore)?
- What is the optimal connection route for some of the wind energy farms in the community?
- What is the average wind energy potential (in megawatts hour) of some of the optimal sites?
- What is the number of wind turbines that can be installed on some of the optimal sites?

1.2.3. Aim and Objectives

This research aims to identify some optimal sites, wind energy potential of the sites, number of wind turbines that can be installed on each site, and the best route for connecting some of the wind farms to grids. The following are the four objectives of this research:

1. To identify some optimal sites for constructing wind energy farms in Valencia community.
2. To provide some sample connections from the farms.
3. To assess and analyze the wind energy potential at some of the wind farm sites.
4. To develop a framework for calculating wind energy potential using GIS methodology.
5. To calculate the number of wind turbines that can be installed on some of the sites.

2.0. Literature Review

2.1. Review of Site Selection Methods

An extensive literature review based on *relevance* and *recent studies* on wind farm site selection was done using downloaded literature from IEEE Xplore database. These eligible studies are 21 conference papers published between the year 2013 and 2023 in reputable international conferences and academic journals such as NAPS, ICCEP, ICSGCE, ISITIA, IIAI-AAI, TAP Energy, POWERCON, I2MTC, ISGT Asia, COMITCon, ISGT, CIEEC, ACEMP, IWEC2021, ICCUBEA, CONCAPAN, EICEEAI, ICPET, and ICSGSC (see acronym section for meaning). They are works which cut across various methodologies for wind farm siting in countries of the world. A summary of each of the literature reviewed can be seen in table 1 below.

Url	Author	Title	Publication Year
1	(Sabitha & Punhani, 2019)	Identification of optimal wind farm sites for a high wind penetration future.	2013
2	(Djokic et al., 2015)	Modelling of wind energy resources and wind farm power outputs using Nested Markov Chain approach.	2015
3	(Li et al., 2016)	Simulation-based micro-site selection for wind farm in complex terrain	2016
4	(Multazam et al., 2016)	Wind farm site selection base on fuzzy analytic hierarchy process method; Case study area Nganjuk.	2016
5	(Rehman & Khan, 2017)	Application of Fuzzy Goal Programming to Wind Turbine Selection with Multiple Criteria - A Study of Three Potential Sites in Saudi Arabia.	2017
6	(Arun, 2017)	Geospatial approach for wind farm site selection — A Kerala scenario.	2017
7	(Sheng et al., 2018)	A GIS+MCDA based assessment method of potential onshore wind power development sites in Mongolia.	2018
8	(Aponte-Roa et al., 2018)	Evaluation of a low-cost, solar-powered weather station for small-scale wind farm site selection.	2018
9	(Wu et al., 2018)	A Novel Approach for Onshore Wind Farm Energy Production Calculation with Different Topographic Heights.	2018
10	(Sabitha & Punhani, 2019)	Identification of Potential Regions for Wind Power Development Using Data Mining.	2019

11	(Nishiyama et al., 2019)	Optimized Site Selection for New Wind Farm Installations Based on Portfolio Theory and Geographical Information.	2019
12	(Liu et al., 2019)	Review on Met Mast Site Selection Methods in Grid-Connected Wind Farm.	2019
13	(Asadi & Pourhossein, 2019)	Modelling and Siting of wind farms using Support Vector Regression (SVR).	2019
14	(Nazari et al., 2020)	Applying TOPSIS Method for Wind Farm site selection in Iran	2020
15	(Asadi, 2021)	Robust Site Selection of Solar/Wind Farms Using Neural Networks and Analytic Hierarchy Process.	2021
16	(Genc & Karipoglu, 2021)	Wind-Solar Site Selection using a GIS-MCDM-based Approach with an Application in Kayseri Province/Turkey.	2021
17	(Shaha et al., 2022)	Sizing of Wind Turbine for Repowering of Old Wind Farm: A Case Study Based Approach.	2022
18	(Ponce-Martinez et al., 2022)	Determination of Favourable Conditions for Profitability of an Off-Shore Wind Farm in Mexico.	2022
19	(Alzgoool & Ghannam, 2022)	Assessment of an Offshore Wind Farm Potential in the Gulf of Aqaba.	2022
20	(Zhu et al., 2022)	Research on Site Selection and Capacity of Flexible Control Equipment Considering Wind Power.	2022
21	(Zhang et al., 2023)	Layout of Wind Turbines on a Trapezoidal Hill.	2023

Table 1: Literature on wind farm site selection methods

2.1.1. GIS-MCDM Approach, Fuzzy goal programming (FGP) approach, Fuzzy Analytic Hierarchy process method and hybrid approach.

Genc & Karipoglu (2021) studied wind-solar hybrid energy systems in Kayseri Province, Turkey. The site selection of a hybrid energy system in Kayseri Province, Turkey uses Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDA) technique. The study analyzed the combined potential and environmental implications of hybrid energy sources. Based on the analysis, 12.3% (2,080 km²) of the study region was deemed eligible for investments in a hybrid (wind and solar) energy system. Limitations include the absence of site selection analysis for wind-solar hybrid energy systems and insufficient data for potential and environmental consequences assessments. The study thoroughly examined wind-solar hybrid energy systems utilizing GIS and MCDA. The research results provide valuable insights for investors,

politicians, and energy planners to identify appropriate places for investing in wind-solar power plants.

An earlier study by Multazam et al. (2016) takes a comparable approach to the research conducted by Genc & Karipoglu (2021). The study characterized wind power as a sustainable energy source used to produce electricity. The fuzzy Analytic Hierarchy Process (AHP) method of Multiple Criteria Decision Analysis (MCDA) was utilized to identify the optimal location for the wind farm. The fuzzy AHP approach achieved an 80% accuracy rate. The study also mentions the Goal question metric, the decision-making trial and evaluation laboratory, the ANP, and the AHP as additional methodologies. Technical, economic, and environmental variables significantly determined the wind farm sites in the research region. Wind availability, distance to the grid, geography, and cost were key elements influencing the selection of wind farm locations. The study identified the Sukomoro region as the optimal location for constructing a wind farm. It recognized Rejoso, Lengkong, Nganjuk, and Pace as viable locations for wind farms.

Sheng et al. (2018) introduced a technique for identifying appropriate locations for onshore wind power development in Mongolia. The study utilized wind resource data and Geographic Information System (GIS)-based Multi-Criteria Decision Analysis (MCDA) to assess wind power development in the research area. The weighted linear combination (WLC) technique assessed the wind resources and technical potential. The wind resource evaluation uses the ranking method, whereas distance calculation utilizes the raster distance transformation method. The investigation included parameters such as wind speed and proximity to infrastructure like roads, villages, substations, and other electrical facilities. A comprehensive map of the top locations was created using specific criteria and their corresponding weights. The report found four sites totaling 4,340 km² with a wind energy capacity 21.7GW suitable for wind power development. The research area's great wind development potential was due to its exceptional wind resources. The paper identified limitations such as restrictions, insufficient wind and solar information, and the absence of precise and reliable GIS tools for site selection. The article helped connect the Northeast Asian Power Grid,

allowing for the export of renewable energy from Mongolia. It offered a structured approach to choosing appropriate locations for wind power projects. The decision-making procedure incorporated precise wind resource data and considered the current electrical and road infrastructures.

Rehman & Khan (2017) utilized a goal programming-based multicriteria technique for selecting wind turbines in their study. The study combined four decision criteria (hub height, wind speed, zero output percentage, and rated output percentage) into a scalar decision function. It evaluated three potential wind farm sites in Saudi Arabia with seven distinct turbine types. Limitations observed included conflicts between factors like increasing wind speed with height and restrictions imposed by taller hubs. The study demonstrated that the fuzzy goal programming method successfully determined the optimal turbine for each location. The study determined that Qassim was the best location for wind farm development and recommended using the FL 600 model for all three sites.

Asadi (2021) outlined the constraints of MCDA and suggested a combined method employing AHP and Analytical Neural Networks (ANN) for choosing sites for solar/wind farms in East Azarbaijan, Iran. Limitations of MCDA include its robustness and the use of a local scoring approach. The AHP approach was utilized to assign weights to parameters (wind velocity, sun irradiation, air pressure, land slope, and distance), whilst the ANN method was employed to generate reliable scores for site selection. The hybrid approach entailed building a model that integrates the Analytic Hierarchy Process (AHP) and Artificial Neural Network (ANN) techniques for site selection.

Nazari et al. (2020) employed the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) as a Multi-Criteria Decision Making (MCDM) method to determine the optimal location for wind turbine installation in Iran. The method consists of three phases: quantifying qualitative data, normalizing attribute ratings, and using a suitable decision-making strategy to reach a solution. The study indicated that Shahrood is the most suited location for an optimal wind farm compared to other potential sites. The article outlined 100MW wind turbine goals for the appropriate site but did not analyze or measure each location's specific wind energy potential.

Arun (2017) employed remote sensing and geographic information technologies to aid in the selection of wind farm sites in Kerala. The methodology assessed appropriate sites for wind power generation by considering characteristics like slope, landform, proximity to roads, urban centers, water bodies, archaeological sites, and forests. We gave weights to the criteria (distance from archeological sites, urban areas, and roads) and constructed the final site suitability map by computing the seven thematic map layers. The areas were separated into five zones based on their potential for site suitability.

2.1.2. Simulation-based micro-site selection for wind farms in complex terrain.

Li et al. (2016) emphasized the significance of simulation in identifying suitable locations for wind farms in intricate landscapes, as selecting sites in such terrain poses a difficult challenge. The report examined earlier studies on mesoscale atmospheric conditions. Still, it concentrated its research and analysis on micro-siting for wind farms in complicated terrain utilizing computational fluid dynamics (CFD) software with the finite volume method. An analysis of the microscale wind field dispersion in difficult terrain was conducted by simulation and flow field analysis. The CFD program facilitated the numerical analysis of micro-location in intricate terrain and was beneficial for identifying the optimal placement of wind turbines through flow simulation. Two inflow boundary conditions were examined, and a realizable model was employed for turbulence modelling. The research provides guidelines for technical workers assessing wind resources in challenging terrain.

Wu et al. (2018) introduced a novel approach for calculating onshore wind farm productivity. The approach considered the wake effect, topographic amplitudes, and slopes. The study utilized a stereoscopic wake model and factored in the impact of wind shear to predict the energy output of onshore wind farms at varying elevations. The 3D wake model was based on the Jensen model, and the matrix method in Figure 6 was utilized to create equations for calculating energy production. The simulation trials demonstrated the efficacy of the suggested strategy without any constraints being defined. A new approach that considers the wake effect, topography amplitudes, and slopes was proposed and suggested for optimizing wind farm placement in the future.

2.1.3. Weibull parameters, Jensen model, matrix method, Support Vector Regression (SVR), statistical methods, Nested Markov Chains (NMC) approach, modelling, and data mining algorithm.

Nishiyama et al. (2019) integrated statistical variables such as mean, variance, and covariance with Geographic Information (GI) to enhance the site-selection process for new wind farm installations. The study method utilizes geographical data and limitations to pinpoint suitable locations for wind farm construction. The portfolio theory was applied to analyze efficient frontier curves for site selection, and mesh calculations were conducted to determine appropriate locations for wind farms. This study identified two ways for grouping suitable locations: limitations including maximizing wind speed or limiting covariance. Two mesh grouping approaches were suggested and assessed. The findings indicated that maximizing mean wind speed is more successful in choosing wind farm locations and that geographical data is useful for picking wind farm sites.

Ponce-Martinez et al. (2022) analyzed wind resources through virtual stations. It estimated the Weibull parameters for wind turbines and analyzed medium voltage underwater power cables. The study examined the financial viability of an offshore wind farm in Mexico by comparing wind data from two virtual stations spanning 42 years. The analysis focused on the location's yearly energy output, wake losses, and energy losses. The project involved selecting and analyzing medium voltage underwater power lines and conducting an economic analysis to assess the feasibility of the wind farm. Limitations identified: high initial investment needed for offshore wind farms, low electricity generation costs compared to other countries, higher electricity generation prices for profitability, profitability threshold of \$2200 USKW, and sensitivity analysis to identify profitable scenarios for offshore wind farms. The study examined the economic analysis to determine the viability of the offshore wind farm. Sensitivity analysis was conducted for various scenarios involving energy production and selling prices. The study indicated that offshore wind farms in Mexico may not be financially viable, given the present circumstances. Higher energy-generating prices and lower capital costs could lead to profitability for offshore wind farms. Additional potential profitability factors considered were limited land availability and benefits of offshore wind projects.

Alzgoool & Ghannam (2022) utilized the Weibull distribution function. The research explored the feasibility of constructing an offshore wind farm in the Gulf of Aqaba. The procedures employed include data collection, computation, initial design, feasibility analysis, and site identification. Jordan intends to boost its energy output for the national energy supply. The offshore wind farm in the Gulf was deemed practical and ideal because a wind farm with 9 turbines can meet the annual peak load in the study area. The payback period is 8 years and 3 months, yielding a total profit of \$121.23 billion (about \$370 per individual in the United States). The study noted limitations such as thoroughly examining electrical components post-power generation and a restricted investigation into transmission lines, grid connections, cable sizing, and cable losses. These areas were identified for future research in the publication.

Zhang et al. (2023) employed a numerical simulation method to investigate the wind farm architecture on a trapezoidal hilltop. The method utilizes the Actuator disk model to analyze wind velocity and velocity shortfall. The study found that wind speed and energy production change depending on the positioning of the turbines. It also identified a correlation between the terrain and wake patterns affecting the wind flow within the wind farm. The study analyzed how wind turbine arrangement affects wind speed and speed reduction. It found that the wind speed reduction is highest for the turbine at position 4 and lowest at position 1. The study also indicated that the working conditions of wind turbines 2 and 3 are comparable. Surface roughness was identified as a significant element in micro-site selection. The configuration of wind turbines can be optimized to enhance wind energy use and efficiency.

Shaha et al. (2022) explored the possibility of revitalizing wind farms in Maharashtra, India. The study determined how the size of wind turbines impacts the capacity utilization factor (CUF) in India. The visualization displayed the distribution of wind power throughout states such as Tamil Nadu, Gujarat, Maharashtra, etc., with India's total wind power capacity reaching approximately 37,505.07 MW as of December 31, 2019. The text highlighted MNES's role in advancing wind power development in India. The research created a flowchart and mathematical model to assist in choosing the appropriate wind turbine size. The methodology involved computing the cubic wind

speed, departure from the mean wind speed distribution, determining the mean wind speed, establishing the Weibull Scale and Shape parameters, and estimating the capacity utilization factor for repowering potential. The analysis and methodology provided statistics on the quantity of turbines in Maharashtra State. The significance of repowering ageing wind farms was discussed to enhance the nation's wind energy portfolio and decrease the number of wind turbines at locations. Overall, the study summarized wind power installation in India and the quantity of turbines in Maharashtra. It detailed a systematic procedure for choosing the appropriate turbine size for repowering.

Sabitha & Punhani (2019) utilized the Rapidminer's X-mean clustering approach to identify potential regions for wind power development in India. The researchers utilized data mining techniques and clustering algorithms to analyze three meteorological characteristics (wind speed, relative humidity, and temperature) from NIWE. Data mining techniques were effective in identifying crucial meteorological characteristics, while clustering algorithms were beneficial in recognizing trends for wind energy generation. The results indicated that wind speed data is a crucial factor for wind power generation. The clustering method identified three clusters based on three climatic factors. Cluster 0 includes the peak months from June to September, whereas cluster 1 represents weather conditions from October to January. The clusters were illustrated by scatter plots and parallel plots, showing that the wind speed fluctuation was consistent across all locations in cluster 0.

Zhu et al. (2022) introduced a method for determining the placement and capacity of a Static Synchronous Series Compensator (SSSC) using Particle Swarm Optimization (PSO). The method suggests an optimization model to minimize transmission congestion, a wind power scenario generation method, and a reactive power optimization model to minimize system network loss. The Particle Swarm Optimization (PSO) algorithm demonstrated effective convergence, while the Static Synchronous Series Compensator (SSSC) decreased line congestion and network losses. The research findings indicated that PSO exhibits strong convergence and reliable

optimization outcomes. It also highlighted the effectiveness of SSSC in lowering line blockage degree and system network loss.

Asadi & Pourhossein's (2019) paper centres on utilizing Support Vector Regression (SVR) for modelling and siting wind farms. The major method for selecting sites for wind power plants is based on wind power density, with technical, economic, environmental, and social aspects considered crucial considerations in the decision-making process. One significant drawback of the study is the focus on prioritizing the case based solely on technical factors.

Aponte-Roa et al. (2018) discussed the creation of an affordable weather station for choosing wind farm locations. They use readily available gear, a LiPo battery, Raspberry-Pi for data collection and storage, and solar panels for energy. The system was utilized to collect meteorological data including air temperature, humidity, barometric pressure, wind speed, wind direction, and rainfall, which were then compared to measurements from a professional-grade weather station. The comparison results indicated that the readings from the setup are a viable choice for site assessment. Limitations of the study include a restricted analysis of data accuracy in comparison to industry-standard weather monitoring systems and the absence of measures for overall data correctness.

Djokic et al. (2015) utilized Nested Markov Chains (NMC) to provide a more precise depiction of the statistical and temporal features of the modeled wind energy resources and power outputs of a wind farm. The approach utilized an analogous power curve of the entire modeled wind farm to choose NMC states. The NMC model was verified using recorded wind speed data sets and power outputs from a real wind farm. The modeling findings demonstrated that achieving high accuracy in predicting power outputs of a wind-based generation system requires minimal processing resources.

2.1.4. Met Mast Site Selection Methods and Wake Impacts

The paper by Liu et al. (2019) examined met mast site selection in grid-connected wind farms by comparing the establishment conditions of grid-connected wind farms with planned wind farms. The text outlines the principles of met mast site selection, considers wake implications, and offers ideas and research possibilities for the process. It stresses the significance of considering wake impact when choosing a site for a meteorological mast. A constraint of this investigation is the variations in function and installation conditions between met masts in grid-connected wind farms and those in the design stage of wind farms.

2.2. Optimal siting and connection

The investigation and study of wind farms' most advantageous placement and interconnection is a subject of scholarly inquiry and has been explored in several academic publications. A scholarly article by Pandora et al. (2022) suggests utilizing the Analytical Hierarchy Process (AHP) technique with Geographic Information Systems (GIS) to determine suitable locations for offshore wind farms that align with sustainability principles. Various factors, such as wind speed, land availability, and environmental impact, determine specific zones for the placement of wind turbines. However, local organizations have encountered resistance due to concerns about the potential negative effects on wildlife, noise pollution, and visual impact on the landscape. For optimal siting and connection to be possible, it is important to balance the benefits of renewable energy with the concerns of local communities and ensure that any proposed wind turbine projects undergo thorough evaluation and consultation with all stakeholders.

2.3. Wind turbine configurations.

Wind farms often comprise many turbines, commonly positioned in predetermined configurations according to the prevailing wind patterns (Soto et al., 2021). Some notable wind turbines configurations are described in existing literatures include the 5Dx7D configuration and the 12Dx4D configuration (See Appendix A), where D = rotor diameter, 5D & 12D represents the horizontal spacing, and the 7D & 4D represents the vertical spacing between each turbine. To perfectly assess which configuration is best

for a particular site, it is important to understand and assess the prevailing wind patterns of the region.

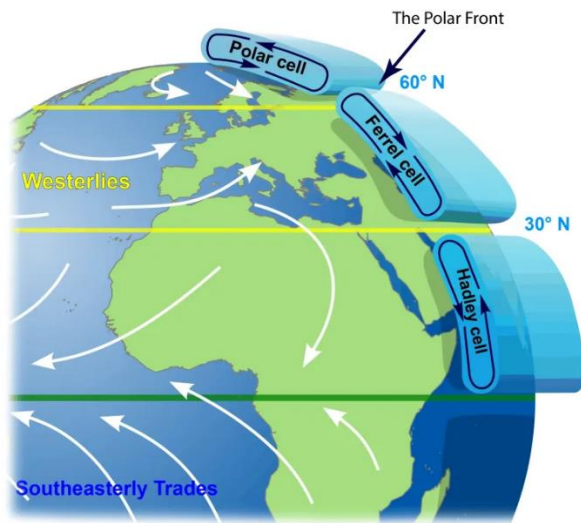


Fig 4a: Westerlies - Source: The CB-IR.

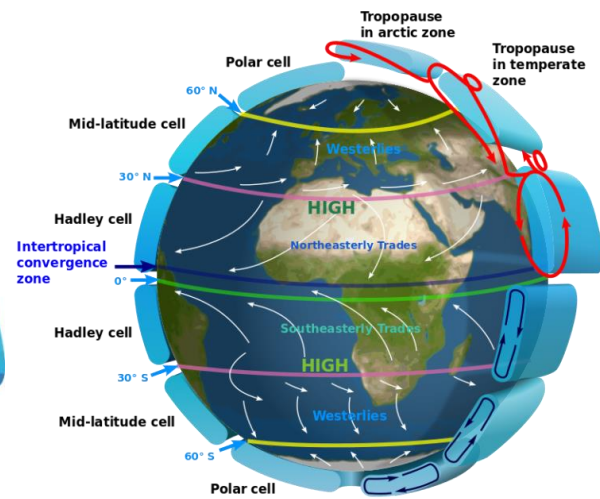


Fig 4b: Global Air Circulation Source: steelcitystrider.co.uk

More generally, Europe is situated in the mid-latitude region of the globe, with a *prevailing wind* characterized by the Westerlies, and blows from the north-west region to the east. Aside from the understanding of the environmental and technical factors of wind turbine configuration which prevailing wind and wind turbine configuration falls under, it is important to consider the various socio-economic and cultural factors of wind turbine siting. Some of these factors include distance to natural reserves, impact on ecosystems, distance from protected areas, energy saving benefits, natural disasters, distance from historical sites, distance from protected landscapes, distance to roads, natural reserve area, wind speed, mean wind power density, and others.

2.4. Wind power and biodiversity impact.

Wind power has become a feasible and eco-friendly alternative to conventional electricity generation technologies, providing economic benefits and favorable environmental effects (Hatziaargyriou & Zervos, 2001). However, the rapid progress of wind energy has also led to conflicts and changes in land use and scenery in Europe (Balat, 2010). With the increasing integration of wind farms into power systems, there

is growing concern regarding the potential impact on the system's frequency response following a disruption (Cerveira et al., 2024). Consequently, wind farms have been employed to generate synthetic inertia. Integrating wind farms and solar photovoltaic power plants can potentially save expenses and optimize land usage in specific cases (Agrawal & Rao, 2022). However, the increasing number of wind farms has raised concerns about their possible impact on bird populations, leading to the development of techniques to minimize bird mortality in the vicinity of wind farms (Gradolewski et al., 2021). Researchers have estimated that wind turbines in the United States cause an annual mortality rate of up to 500,000 birds (Gradolewski et al., 2021). The main cause of this fatality is the direct impact of birds colliding with the wind turbines, rendering the wind farms suboptimal. There is significant variability in the mortality rates of birds caused by wind turbines in Europe. Studies have shown that the geographic location of wind farms has a significant impact on the rate of bird deaths worldwide (Kumara et al., 2022). The study conducted by Everaert (2014) found that wind turbines located near high tide areas and migration routes have the highest rates of bird fatalities. The bird species affected by these interactions include gulls, passerines, ducks, and raptors. The fatality rates vary depending on the size of the wind park, with larger parks being correlated with higher mortality rates (Everaert, 2014).

2.5. The levelized cost of energy (LCOE)

The levelized cost of energy (LCOE) is an economic term used to examine the competitiveness of different energy technologies. It is a crucial metric used in energy economics. It is the lowest price at which energy can be produced over the lifetime of a power station. It represents the average net present cost of electricity generation for a power plant over its entire lifetime. It is expressed in currency per energy unit (e.g. EUR per kilowatt-hour or AUD per megawatt-hour). Net present value has a lot to do with the net cost of total spending on each turbine facility (e.g. turbine, cables, transformers, etc.). It is often used to evaluate the cost competitiveness of renewable energy solutions compared to fossil fuel-based systems. However, there are drawbacks and limitations to utilizing LCOE as an indicator. Some analyses imply that the LCOE for renewable technologies, except concentrated solar and offshore wind, is lower than that for fossil fuel-based technologies at lower capital costs and discount

rates. However, LCOE calculations using realistic parameter values cannot account for the low solar power auction prices in some regions of the world (Emblemsvåg, 2021; Szymański, 2020). LCOE lacks a theoretical foundation and has flaws linked to discount rates, inflation impacts, and uncertainty in future commodity costs (Timilsina, 2020). Modified variants of LCOE, such as MLCOE and MLACE, have been created to account for elements like CAPEX and OPEX in power plant investments (Aldersey-Williams & Rubert, 2019).

3.0. Methodology and Software

The process implemented by Gilytics AG, as described in section 3.1 is a systematic approach used to determine some suitable locations for wind energy farms in the Valencia community and establishing their connection to grid. The second methodology, outlined in section 3.2, presents a proposed framework for calculating the wind energy potential of the sixteen suitable sites (T1 – T16). This framework utilizes only one of the two algorithms explained in the section (section 3.2).

3.0.1. Study Area

The research area encompasses the community of Valencia (Fig. 5a). It is the self-governing region located in the eastern part of Spain. With a population above five million people and a total area of 8,979 square miles. It ranks as the fourth most populated Spanish autonomous community. It is situated on the Mediterranean coastline and comprises three provinces (Castellon, Valencia, and Alicante). The region is bordered by the autonomous community of Catalonia to the north, Aragon to the northwest, Castile-La Mancha to the west, Murcia to the south, and the Mediterranean Sea to the east.



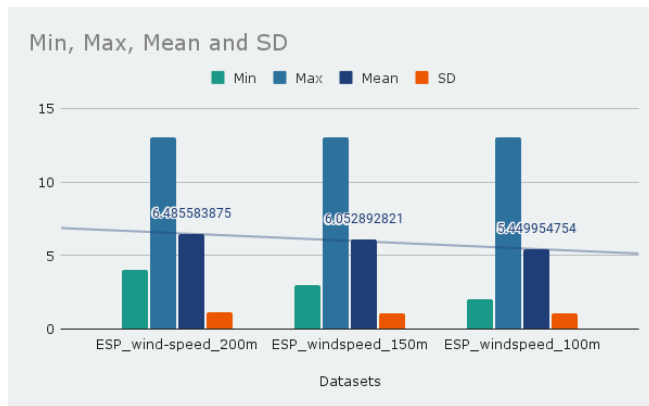
Fig. 5a: Study area – Comunitat Valencia

3.0.2. Data and Software.

The research utilizes the data obtained by Valmana, Llario, & Romar's (2021) for the previous work on Solar Energy. The data is succinctly presented in table 3. The major software utilized for data processing comprises ArcGIS Pro, Pathfinder, and the Python programming language.

3.0.3. Wind Resource Data

The wind resource data used for the analysis of wind energy potential of some of the suitable sites is the global reanalysis data from DTU Wind Energy called the Global Wind Atlas (GWA) 3.0 at 250m resolution. A summary statistic of the specific wind data used in this project can be found in the bar chart in Fig. 5b. From these three sets of data (at 200m, 150m and 100m above ground level), we found out that the average windspeed for the study area is between 5.45 m/s and 6.49 m/s. These made the wind class of the study area fall under class 2 (IEC S) of the wind class category. As a result, the wind turbine that is specific for class 2 (IEC S) was carefully selected (2MW onshore wind turbine) for the analysis of wind energy potential of the study area. Further details on the wind turbine characteristics can be found in Appendix 2.



Wind Class	Average wind speed (m/s)	Description
Class 1	<5.4	Very low wind sites
Class 2	5.4 -6.4	Low to moderate wind sites
Class 3	6.5 -7	Moderate wind sites
Class 4	7.1 -8	High wind sites
Class 5	>8	Very high wind sites

Fig. 5c: Wind Class of wind farm site

Fig. 5b: Bar chart of the Wind Speed data at 200m, 150m and 100m respectively.

The windspeed data is data at mesoscale level downscale to microscale level. The average windspeed at 150m is approximately 6.49 m/s while the average windspeed at 200m and the average windspeed at 100m are 6.05 m/s and 5.45 m/s respectively.

Category Criteria	Sub criteria. Layer	Source	Date	Accuracy / Scale4
01 Protected areas	ZEPA and ZEC C D zoning	-	-	-
	ZEPA and ZEC A B zoning	-	-	-
	Strategic forest floor of50	-	-	-
	RAMSAR	Green Infrastructure and Landscape Service – Department of Politics Territorial, Public Works and Mobility.	11/27/2019	1:5,000
	Protected landscape	Management Service of Protected Natural Spaces – Conselleria d’Agriculture, Medi Ambient, Canvi Climatic and Rural Development.	Publication 04/18/2007	1:100,000
	Natural reserve without planning	Management Service of Protected Natural Spaces – Conselleria d’Agriculture, Medi Ambient, Canvi Climatic and Rural Development.	Publication 04/15/2011 Revision 11/28/2011	1:5,000
	Natural parks and micro reserve	Wildlife Service – Conselleria d’Agricultura, Medi Ambient, Canvi Climatic and Rural Development.	Publication 04/19/2005 Revision 03/01/2021	1:10,000
	Natural Park	-	-	-
	Municipal places	-	-	-
	Livestock roads	-	-	-

	Landscape interest	Green Infrastructure and Landscape Service – Department of Politics Territorial, Public Works and Mobility.	11/27/2019	1:100,000
	High cultural value	Green Infrastructure and Landscape Infrastructure Service - Department of Politics Territorial, Public Works and Mobility	11/23/2020	1:10,000
	Ecological corridors			
	Area delimited by territorial planning	Green Infrastructure and Landscape Infrastructure Service - Department of Politics Territorial, Public Works and Mobility	11/27/2019	1:5,000
	Shoreline	-	-	-
02 Hydrology	Riverbed	-	-	-
	Humid areas	Management Service of Protected Natural Spaces – Conselleria d’Agriculture, Medi Ambient, Canvi Climatic and Rural Development	Publication 09/16/2002 Revision 04/08/2011	1:5,000
03 Communication network	Solar_project_Roads	-	-	-
	Roads Valencia	-	-	-
	Roads Castellon	-	-	-
	Roads Alicante	-	-	-
	Railway	-	-	-
	Minor Roads	-	-	-
	Highways	-	-	-

04 Lithology	Clay	Valencia Institute of Building – Department of Housing and Bioclimatic architecture.	Publication 01/01/1994 Revision 06/15/2006	1:100,000
05 Soil classification	Urban soil	ICV	02/23/2021	1:5,000
06 Energy	Substation 2	-	-	-
	Substation 1	-	-	-
	Proposed PV plant	-	-	-
	Oil pipeline	-	-	-
	Gas pipeline	-	-	-
	Electric lines 400kV	-	-	-
	Electrical lines	-	-	-
07 Risks	Flooding danger 5 7 PATRI46	Green Infrastructure and Landscape Infrastructure Service - Department of Politics Territorial, Public Works and Mobility.	11/24/2020	1:25,000
	Flooding danger 1 4 PATRI45	Green Infrastructure and Landscape Infrastructure Service - Department of Politics Territorial, Public Works and Mobility.	11/24/2020	1:25,000
	Risks	Green Infrastructure and Landscape Infrastructure Service - Department of Politics Territorial, Public Works and Mobility.	11/27/2019	1:25,000
08 Terrain	Slope		-	-
	DEM		-	-

10 Wind	ESP_wind-speed_200m	GWA 3.0	-	250m resolution
	ESP_wind-speed_150m	GWA 3.0	-	250m resolution
	ESP_wind-speed_100m	GWA 3.0	-	250m resolution
	ESP_power-density_50m	GWA 3.0	-	250m resolution
	ESP_power-density_200m	GWA 3.0	-	250m resolution
	ESP_power-density_150m	GWA 3.0	-	250m resolution
	ESP_power-density_100m	GWA 3.0	-	250m resolution
	ESP_bathy_int	GWA 3.0	-	250m resolution
Orientation	Orientation Castellon WGS84		-	

Table 2: Table of categories (criteria) and layers (sub-criteria)

3.1. Methodology for optimal site and connection route.

The summary of the method used for optimal siting and connection of wind farms include:

1. The identification and selection of farm suitability criteria using knowledge from existing literature and consultation with experts.
2. The creation and compilation of the list of criteria in a spreadsheet to better understand and at the same time analyze, prioritize and assign weights to the criteria.
3. The search and download of geospatial data which best describes the suitability criteria in both raster and vector formats from various open-online sources and government data archives of the Spanish and Valencia government.
4. The data preparation and processing in QGIS, ArcGIS and Python.
5. The addition of the derived (e.g. slope) and raw data into pathfinder web application and assigning of resistance values (see table 4) and layer or category weights (between 1 – 10) to each of the criteria.
6. The production of the resistance map, creation of the optimal site by specifying the total area in square kilometers (i.e. 200,000-kilometer square) and site shape (i.e. squares), adding the start and end points, creation of the corridor map, and the generation of the optimal paths in pathfinder.

NB: For this research, the square or rectangular shape was chosen as the site shape.

Resistance	Explanation
NC	Zone is not considered
-3	Zone is very suitable
-2	Zone is largely suitable
-1	Zone is suitable
+1	Zone is unsuitable
+2	Zone is largely unsuitable
+3	Zone is very unsuitable
FB	Zone is forbidden (value 9'999)

Table 3: Table of resistance values

Source: (Gilytics, 2023)

7. Downloading or exporting the suitable site as a geopackage (.gpkg) file in Pathfinder.

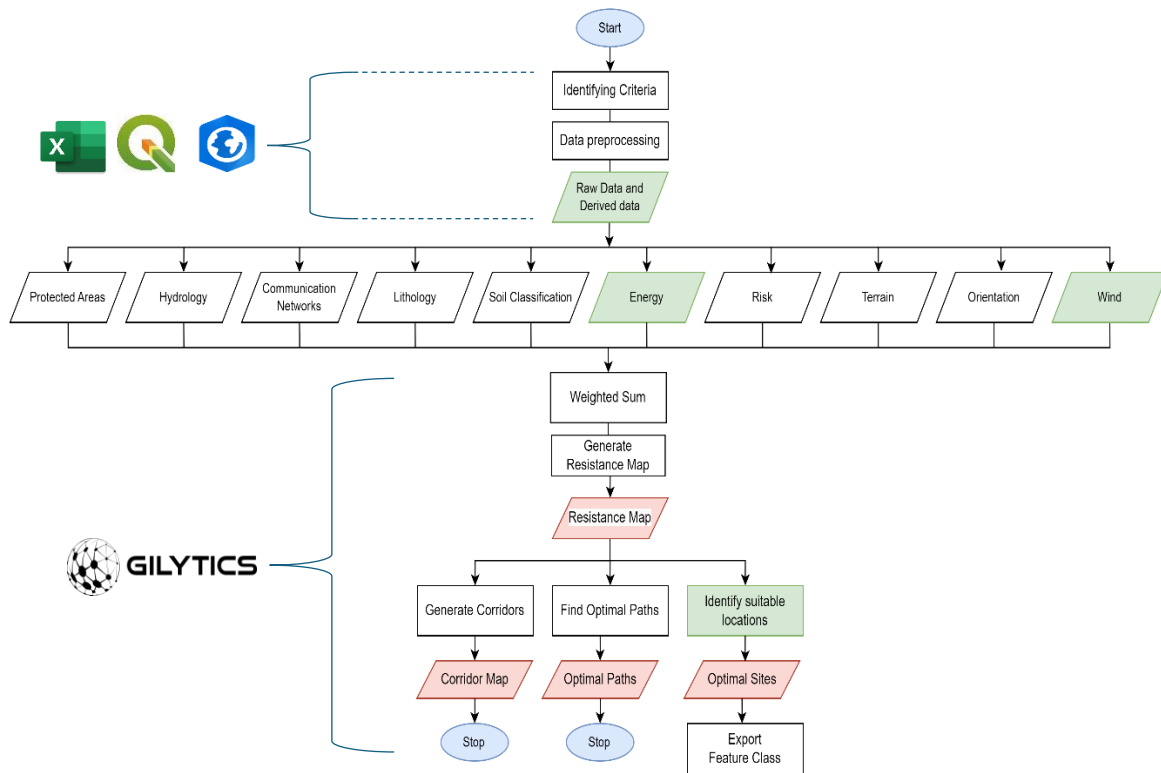


Fig. 6: Flowchart for objectives 1 & 2.

3.1.1. Optimal Siting and Connection of wind farms: Software, Setup, and products

The optimal siting and path connection was performed using the processed data from Gilytics and the robust architecture of [Pathfinder](#). Pathfinder is software for infrastructural data management, analysis, and planning. It is web-based, and it is the flagship software of [Gilytics](#). It has been used for many infrastructural planning and big projects across various countries in Europe such as Spain, Switzerland, and Germany. Its usage spans engineering & renewables, power utilities, and Rail. Please refer to the Gilytics website for more information: <https://www.gilytics.com/>.

For the derivation of some optimal sites, the geoprocessing tool for optimal sites in Pathfinder was used for scenario 2 (the scenario with the calculated resistance map), and the desired area was set to 200,000 square kilometers, the chosen site shape is fixed-size square (□) areas and the number of site results is sixteen (that is, T1 to T16).

See figure 7 below. Section 3.1.2 explains the project setup and data processing, while section 3.1.3 and 3.1.4 explain the two major products from the project setup.

The screenshot shows the 'Geoprocessing Tools' window with a close button (X) in the top right. It features two tabs: 'GEOPROCESS' (active) and 'RESULTS'. Below the tabs is a header bar with 'Select Geoprocess' on the left, 'Optimal sites' in the center, and 'MORE' on the right. The main area is divided into two columns of configuration options:

- Select SITING_SCENARIO:** A dropdown menu set to '[project] Scenario 2'. Below it, a note reads 'Scenario with a calculated resistance map'.
- Select SITE_AREA:** A text input field containing '200000'. Below it, a note reads 'Desired area for sites (square m.)'.
- Select SITE_SHAPE:** A dropdown menu set to 'Square'. Below it, a note reads 'Choose the shape of the site'. A separate input field below this section is labeled 'Force dimensions'.
- Select NUM_SITES:** A text input field containing '16'. Below it, a note reads 'Number of site results'.

At the bottom, there is an 'Output' section with a horizontal line. Below this line are three buttons: 'RESET' (dark blue), 'CLOSE' (light blue), and 'PROCESS' (dark blue).

Fig. 7: The geoprocessing setup for the sixteen (16) optimal sites.

3.1.2. Project setup and data pre-processing

Step 1: Create a New Project

The first stage of analysis is to create a new project in Pathfinder. See fig. 7 below for a sample of created projects.

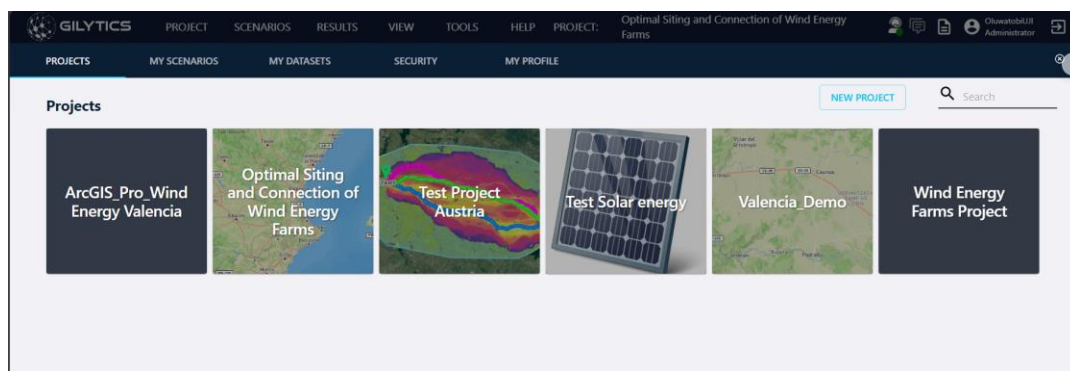


Fig. 8: Project samples in Pathfinder Web.

After the project has been created, the next stage will be to either draw a project area or import the project area, which is one of the first steps of the data pre-processing

(Gilytics, 2023). To achieve this, the islands were eliminated, and the Rincon de Ademuz was united to have a single polygon feature using ArcMap and QGIS (Valmana, Llario, & Romar, 2021). Another important step for the data pre-processing which is based on the principle of GIS and MCDA is to create buffer zones, union, and division by attribute for each layer based on environmental and institutional legislations (Valmana, Llario, & Romar, 2021). Table 5 below gives a summary of the applied buffers based on the legislations.

Layer	Area of influence
Cultural assets	500m
Channels	fifty
Runners	100
Protected landscapes	500
Humid areas	500

Table 4: Applied buffer areas

Source: (Valmana, Llario, & Romar, 2021)

Step 2: Creation of Scenarios

For the analysis of optimal site and connection route, only one scenario was used (Scenario 2) for the creation of the resistance maps, corridors and paths. For the scenario, Gilytics MCDA option was used, for the category weights, absolute weight option was chosen and for the corridor, the percentage method was chosen (See figure 8 below). The absolute weight is an independent value of numbers between 1 and 10 (Gilytics, 2023). For the layer resistances, an interval value between -3 and +3 was used (See Table 4 above). The Length optimization was left as 0 while the cap resistances per category was left also as 0.

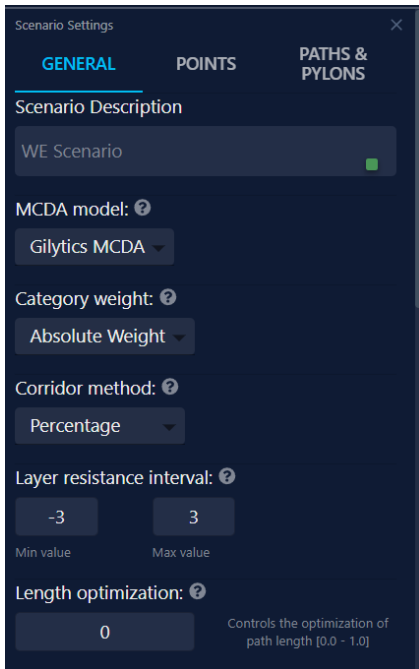


Fig. 9: Scenario variables

Step 3: Creation of categories and layers and assigning weights and resistances.

The creation of categories and layers and assigning of weights and resistances are part of the steps to performing the optimal siting and connection of wind energy farms in the study area. After the area of interest (AOI) has been imported the next step will be to import the datasets which are in raster and vector formats respectively (see figure 8 for a screenshot).

Layer Resistances

Change the layer resistances in your scenarios. These changes do not affect other users.

Scenario 1

Search Layers

IMPORT SCENARIO FILE EXPORT

VECTOR RASTER

Name	Mode	Resistance Values [-3, 3]			
		Ring 1	Ring 2	Ring 3	Ring 4
Area delimited by territorial planning	Assign Value	2			
Ecological corridors	Forbidden				
High cultural value	Forbidden				
Landscape interest	Assign Value	2			
Livestock roads	Forbidden				
Municipal places	Assign Value	3			
Natural park	Forbidden				
Natural parks and microreserves	Forbidden				

CLOSE

Fig. 10a: Layer resistances

The next step after data has been imported is to create categories and layers. Data can be imported either as public or private datasets (Gilytics, 2023). For this thesis, there are ten categories used (protected areas, hydrology, communication networks, lithology, soil classification, energy, risk, terrain, and wind) with protected areas and wind given the highest weight (value of 6) or priority (See figure 9). Furthermore, the default resistance value of -3 to +3 was used for assigning resistances to layers. Other resistance values (FB - forbidden, NC - Not considered and PR - Per Ring) can also be used for certain layers (or sub-criteria).

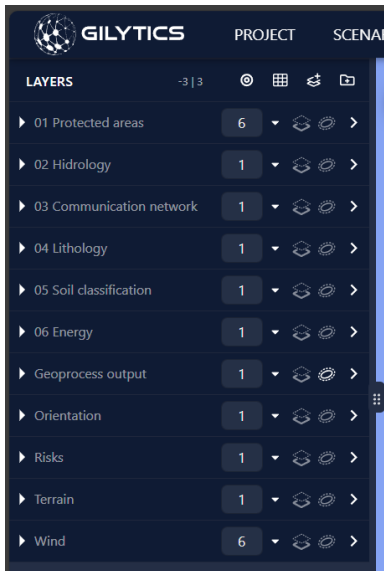


Fig 10b: Category weights or value.

Layers (regions) like Ecological corridors, High cultural value, Livestock roads, Natural parks and micro reserves, protected landscape, RAMSAR, ZEPA and ZEC A B zoning, are protected areas that are forbidden (FB) for the sitting of wind energy farms in the study area. Other forbidden regions include Humid areas, Riverbed, Gas pipeline or oil pipeline, and risk zones.



Fig. 10c: Protected area weights and resistances.

For the communication networks, buffers zones of twenty-five (25) meters, hundred (100) meters, two hundred (200) meters, and one thousand (1000) meters respectively were assigned based on the respective legislations and assigned resistance values such as forbidden (FB) for regions that are twenty to twenty-five meters away from these networks (Valencia roads, Castellon roads, railway and Alicante roads).

Step 4: Generation of the resistance map

The resistance map is generated as path of the results in pathfinder web. It involves the use of the *generate* button to generate resistance map containing the sum of all resistance values of all the layers or sub criteria in the project.

Step 5: Derivation of optimal sites.

The derivation of optimal sites can be achieved using the optimal site geoprocessing tool in pathfinder. This tool allows users to generate optimal sites for the installation of infrastructure seamlessly. Some parameters that can be set within the geoprocessing tool include:

1. The scenario with calculated resistance map
2. The desired area for the sites

3. The shape of the site
4. The number of site results
5. The force dimensions.

Step 6: Start and end points.

For the analysis of optimal path, it is important to create a start and end point at the beginning of every path analysis. The start and end point represent the beginning and end point of the paths. This helps to create a pre-defined region for the path analysis. For this project, the start and end points are set to connect site T1 (0°52'22"W 38°43'15"N) and T5 (0°13'36"W 38°38'31"N) to an assumed grid located in Valencia as seen in the figure below.

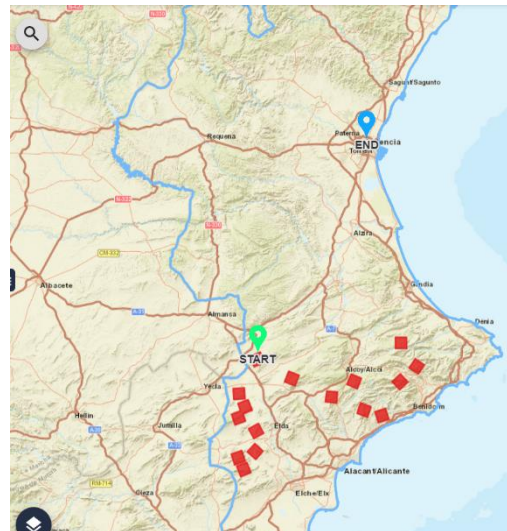


Fig. 11a: Start and end points for site T5. **Fig. 11b:** Start and end points for site T1.

3.1.3. Resistance Map.

The resistance map is one of the products or results in pathfinder. It is a map showing the sum of resistances for all the layers within a project after the scenario parameters have been set (Gilytics, 2023; Valmana, Llario, & Romar, 2021). See section 4.1.1 for further information (figures and results).

3.1.4. Corridor Map

The corridor map is a map showing the various corridors around the most-likely optimal path. It basically shows a combination of all the alternative paths including the most-likely optimal path itself. The optimal path is the best or most suitable path for the

connection of wind energy farms to the grid. The optimal path is by principle the path with the least minimal cost on installation. It is the path with less environmental, social, and economic cost. See section 4.1.3 for further information (figures and results).

3.2. Methodology for Wind energy potential (WEP) calculations.

The methodology for calculating wind energy potential (WEP) in this research is a proposed methodological framework for calculating wind energy potential using open-source data (vector and raster) from the European GIS Archive and ArcGIS Pro. Fig. 2a. Below shows the methodology flowchart for objective 3 & 4 while fig. 2b. shows a breakdown of the framework.

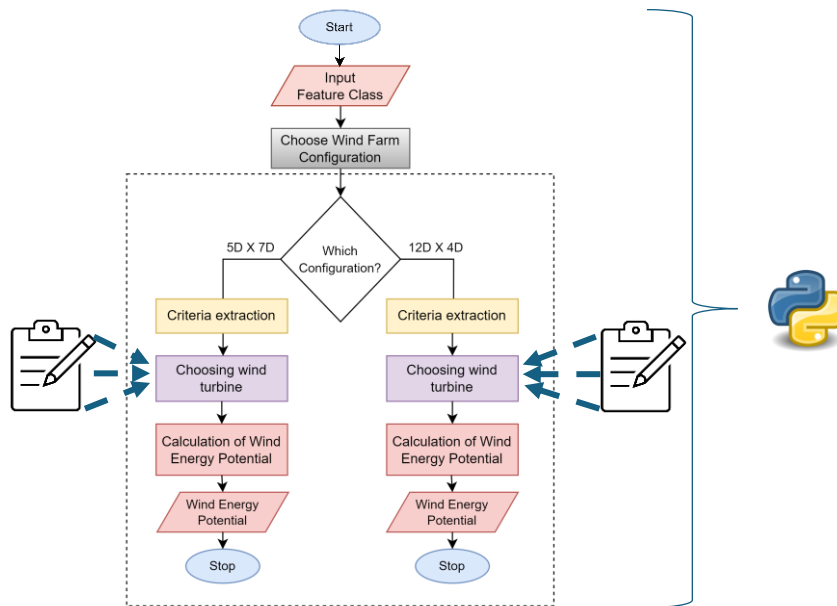


Fig. 12: Flowchart for objective 3 & 4.

The framework is divided into three major steps. It involves the selection of criteria, choosing of wind turbine characteristics, and the calculation of wind energy potential in terawatt-hours (MWh) using two wind energy potential algorithms (algorithm A and algorithm B).

Algorithm A.

$$\text{Energy } (E) = \text{Power output of the turbine } (P) \times \text{Time} \text{ ----- Equation 1}$$

$$\text{Time} = 1 \text{ year} = 365 \text{ days} = 8760 \text{ hours}$$

Note: For a period of ten years the value of time becomes 87600 hours

3.2.1. Power Density

Air power density is the measure of power per unit volume of air, where power is defined as the rate of energy transfer over time. The measurement is usually expressed in watts per square meter (W/m²) and provides information about the amount of power dispersed in a specific area. The statistics measure the available wind energy in each specific region. The value is calculated for different elevations above the ground and represents the average annual power that may be obtained per square meter of the turbine's swept area. The wind power density is quantitatively defined.

$$\text{Power density} = \frac{1}{2} \times \text{site air density} \times \text{wind speed}^3 \text{ ----- Equation 2}$$

3.2.2. Power Output

The power output (P) of the wind turbine can mathematically be described as the product of the Wind power density (W/m²) of the study area (that is, the suitable sites) and the swept area (m) of the wind turbine.

$$P (W/m) = \text{Wind Power Density} \times \text{Swept Area of the Turbine (A)} \text{ ---- Equation 3}$$

$$A = \pi \times \left(\frac{\text{Rotor Diameter}}{2}\right)^2, \text{ Rotor diameter} = 13685 \text{ m}^2 = 0.013685 \text{ km}^2, \text{ and } \pi = 3.14159$$

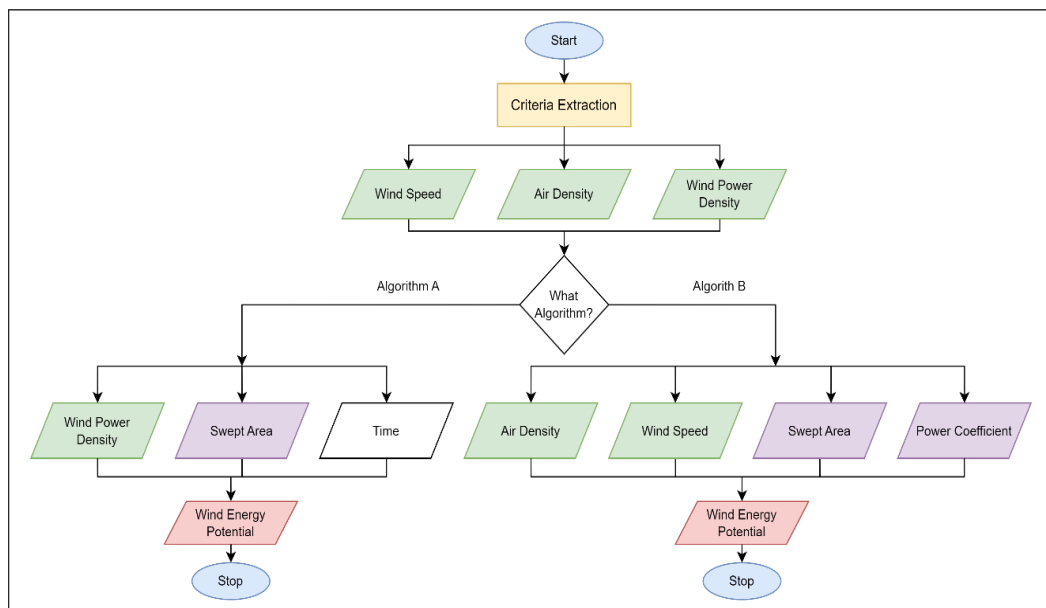


Fig. 13: Breakdown of the flowchart for objective 3 & 4.

Algorithm B:

Energy (P) = 0.5 * (Air Density) * (Rotor Swept Area) * (Wind Speed³) * (Power Coefficient). ----- **Equation 4**

- Rotor Swept Area = 13685 sq. meters
- Air density = Air density (Raster)
- Wind speed = Wind speed (Raster)
- Power coefficient = Constant

Note: The air density and wind speed data are both raster datasets while the rotor swept area is a value calculated from the formula above. It is important to also know that the density of air decreases with temperature and altitude, and the major factor in wind power generation is wind speed (The Engineering Toolbox, 2009). The power coefficient is a constant from the characteristics of the wind turbine. It is a crucial measure of how efficiently the turbine converts the energy in the wind into electricity. The Swept Area of the wind turbine is basically a measure of the circumference of the radius of the turbine blades during turbine rotation.

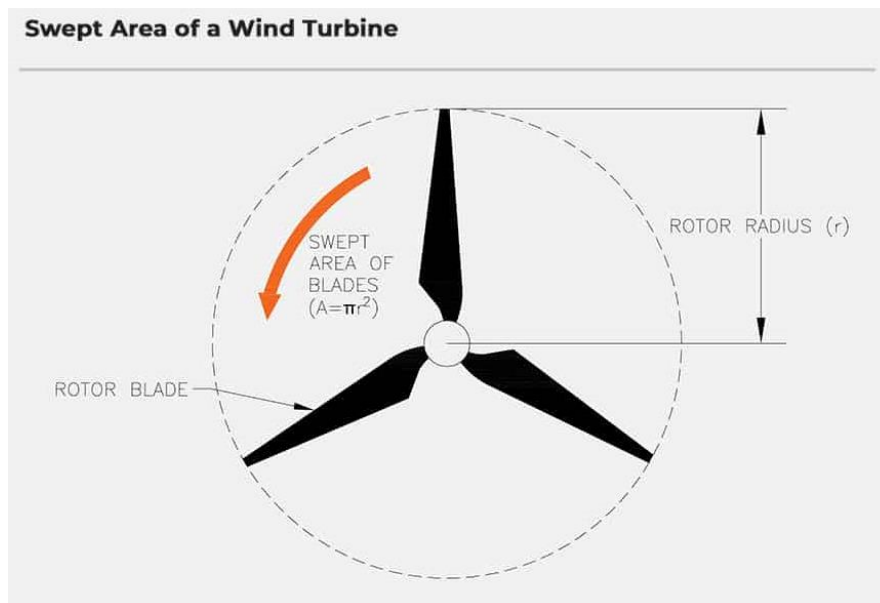


Fig. 14. Swept area of a wind turbine **Source:** engineercalcs.com

3.2.3. Air density.

Atmospheric density, also known as air density (measured in kg/m³), is the ratio of the mass of Earth's atmosphere to its volume. The symbol rho (ρ) denotes it. The phenomenon is subject to fluctuations in atmospheric air pressure, temperature, and humidity (Lambda Geeks, 2024). In addition, as height climbs, the air density drops. Under ordinary atmospheric circumstances, which include an absolute pressure of 101.325 kPa and a temperature of 20°C, air density is roughly 1.204 kg/m³. At sea level and 0 humidity, air density is 1.225 kg/m³. In identical conditions, the air density is approximately 1/800th of that of water. Air density is used in diverse domains such as meteorology, aeronautics, gravimetric analysis, and compressed air engineering (Lambda Geeks, 2024). It plays a pivotal role in comprehending atmospheric behavior, aerodynamics, and energy systems.

3.2.4. Wind Energy Potential (WEP).

Wind energy potential denotes the quantifiable amount of exploitable energy derived from wind currents. Wind power is the conversion of kinetic energy from wind into electricity by using devices such as wind turbines, windmills, and sails on ships (National Geographic Society, 2023). As the wind moves, it transfers energy to these devices, enabling them to produce power. It is mathematically described as the product of the power output (P) of the turbine and time (T).

$$\mathbf{Energy (E) = Power\ output\ of\ the\ turbine (P) \times Time}$$

4.0. Results and Discussion.

The results and discussion section are divided into two. The first section (4.1) is the results of optimal siting and connection of wind energy farms in some suitable areas using Pathfinder Web while the second section (4.2) is the results of the wind energy potential for the sixteen (16) suitable sites that are derived from pathfinder.

4.1. Optimal Siting and Connection of wind farms.

4.1.1. Resistance Map

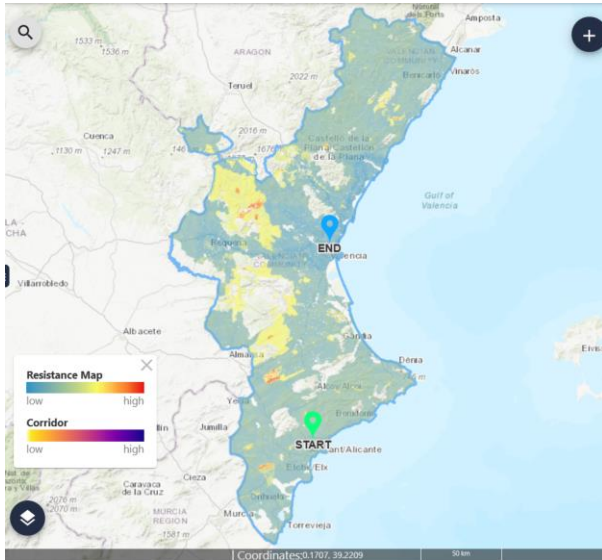


Fig. 15: The resistance Map.

The resistance map in fig. 8 above is the resistance map for the entire study area. By default, the map is symbolized by a blue to red color ramp, where the blue color regions (Benicarlo, Requena, Benidorm, Alcoy Alcol, Elche, and Orihuela) represents area with low resistances, the yellow regions (Almassa and north of Requena) represents the moderate resistance, and the red regions are areas with high resistances (middle-north of Requena and the middle-north of Orihuela). The blue/green areas in the resistance map show preferred locations for the wind energy farms (Gilytics, 2023).

On the resistance map, the transparent areas are areas marked out as *Forbidden* (Gilytics, 2023). More importantly, the derivation of the resistance map in pathfinder is the first step of the analysis and decision-making chain. It is an important step to deriving other pathfinder products such as the optimal site.

4.1.2. Optimal sites.

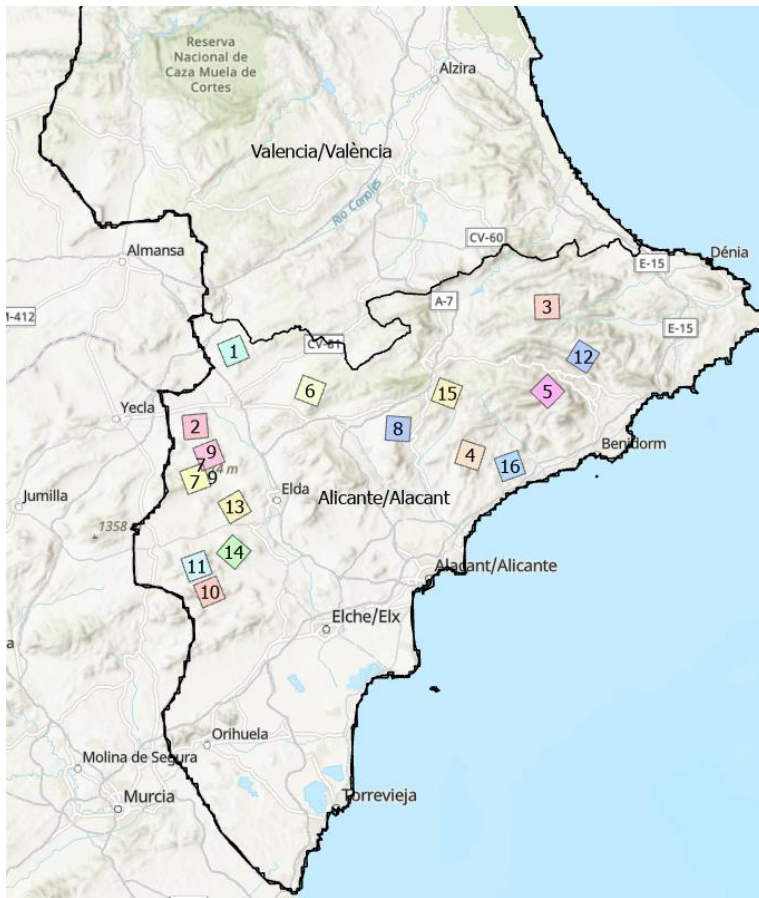


Fig. 16: Some optimal sites

The optimal sites in Fig. 16 above are a total of sixteen (16) square-sites with a total area of 200,000 square kilometers. It is an area situated majorly in the southern part of the study area (Alicante). The optimal 16 square sites are found fitting in low resistance zones. Table 6 below shows the geographical coordinates of the sixteen (16) sites.

Some Suitable sites (farms)	Location of wind farm (Decimal degrees)	Location of wind farm (Degrees Minutes Seconds)
T1	0.8727344°W 38.7208456°N	0°52'22"W 38°43'15"N
T2	0.9549489°W 38.6002257°N	0°57'18"W 38°36'1"N
T3	0.2224540°W 38.7788202°N	0°13'21"W 38°46'44"N
T4	0.3898721°W 38.5425819°N	0°23'24"W 38°32'33"N
T5	0.2265992°W 38.6419802°N	0°13'36"W 38°38'31"N
T6	0.7161691°W 38.6534705°N	0°42'58"W 38°39'12"N
T7	0.9579591°W 38.5147945°N	0°57'29"W 38°30'53"N
T8	0.5368580°W 38.5885650°N	0°32'13"W 38°35'19"N
T9	0.9275793°W 38.5541279°N	0°55'39"W 38°33'15"N
T10	0.9333371°W 38.3322363°N	0°56'W 38°19'56"N
T11	0.9584706°W 38.3741255°N	0°57'30"W 38°22'27"N

T12	0.1514973°W 38.6964805°N	0°9'5"W 38°41'47"N
T13	0.8778753°W 38.4686541°N	0°52'40"W 38°28'7"N
T14	0.8817260°W 38.3957395°N	0°52'54"W 38°23'45"N
T15	0.4344577°W 38.6435737°N	0°26'4"W 38°38'37"N
T16	0.3085777°W 38.5231717°N	0°18'31"W 38°31'23"N

Table 5: Location of the sixteen (16) wind farms.

4.1.3. Corridor Map.

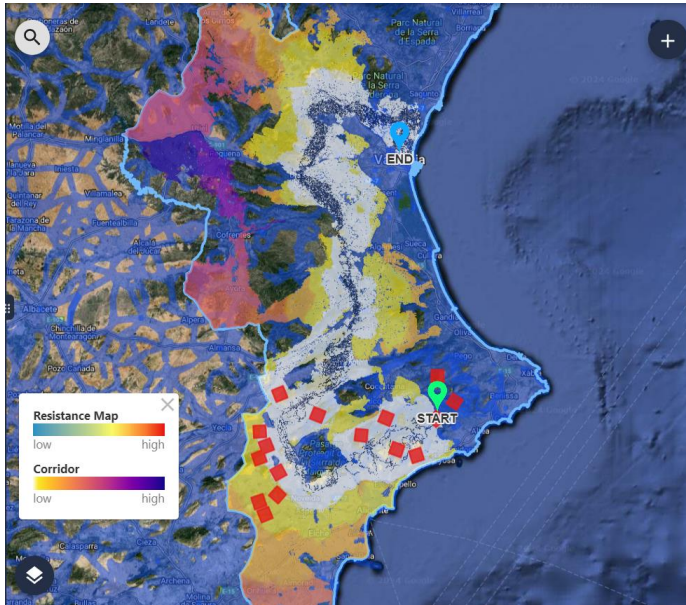


Fig. 17a: The corridor map for the connection of site T5 to grid.

Fig. 17a is the corridor map for the connection of one of the sixteen sites (T5) to grid. It is by default represented by bright yellow hues. It is the area where an optimal path is most likely to pass through. It can also be described as alternative regions with which an optimal path can be forged. In the map, there is a clear optimal track at the center of the corridors while possible alternative tracks are mostly to the left of the optimal track (Gilytics, 2023). It can also be observed that the low corridor regions correspond to the regions of low resistances, which is also the region where the optimal sites are directly situated. From this observation, it can be deduced that optimal path corridors are forged based on the limitations of the layer resistances of the area they are passing through. That is, paths are easily created in regions where there are lower resistances.

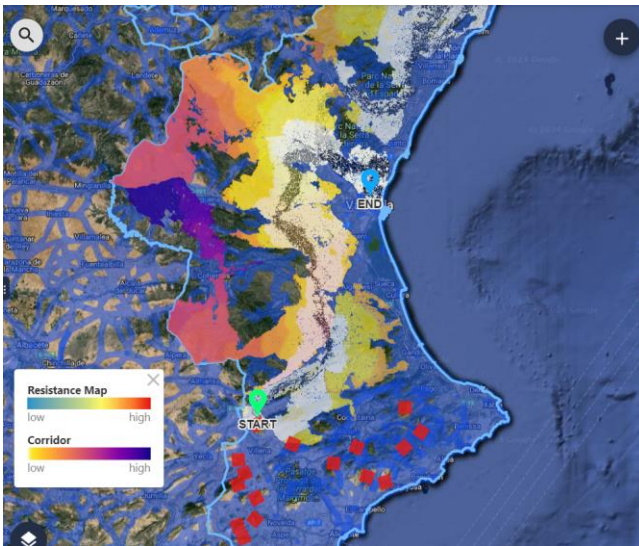


Fig. 17b: The corridor map for the connection of site T1 to grid.

Fig. 17a is the corridor map for the connection of site (T1) to grid. The map shows a concentration of high corridor areas to the left of the optimal paths just as we find it in Fig. 17a above. We can also deduce that layer resistance (value) of an area or region is a key determinant of the location of path corridors within the area or region. That is, low resistance regions correspond to low corridors and vice versa.

4.1.4. Optimal Paths and path analytics.

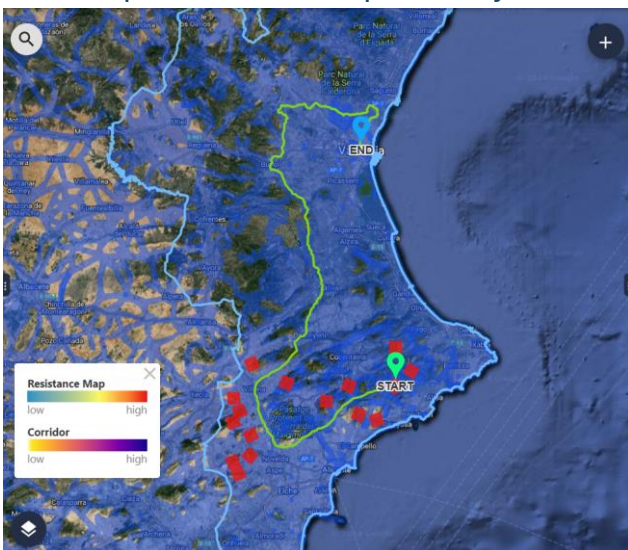


Fig 18a: The optimal paths for for the connection of site T5 to grid

Fig. 18a shows the optimal path for the connection of site (T5) to grid. The optimal path covers a total length of 298.75 kilometers (km) with Flooding danger 57 PATRICOVA (12.30%), Roads Valencia (12.05%), and Clay (6.76%) taking the highest coverage

distance (km), while the Gas pipeline (0.02%), humid areas (0.04%) and livestock roads (0.04%) are the layers with lowest coverage distance (km). See fig. 18b.

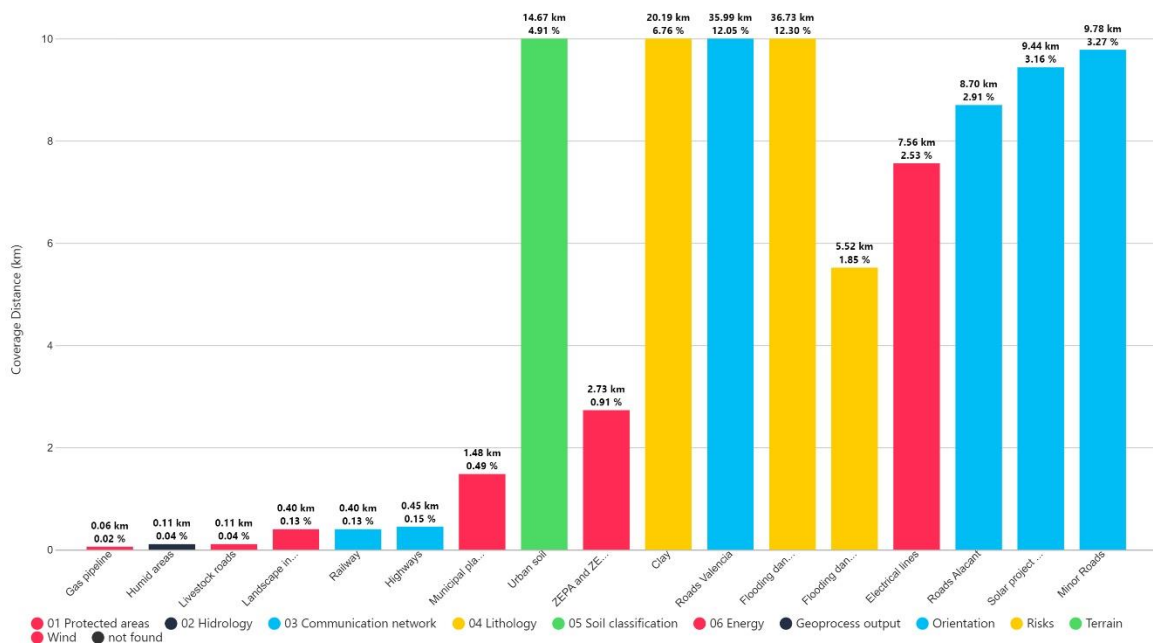


Fig 18b: Path coverage distance ratio for connection of site T5 to grid.

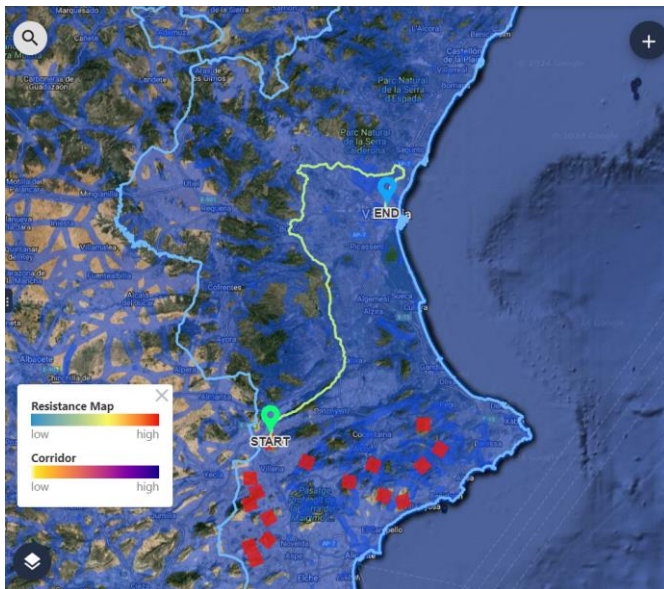


Fig 19a: The optimal paths for for the connection of site T1 to grid

The optimal path for the connection of site T1 to grid (fig. 19a) covers a total length of 208.35 kilometers (km) with Roads Valencia (16.88%), Flooding danger 5 7 PATRICOVA (11.07%), and Clay (7.38%) layers taking the highest coverage distance (km), while the

Gas pipeline (0.03%) and livestock roads (0.05%) are the layers with lowest coverage distance (km). See fig. 19b.

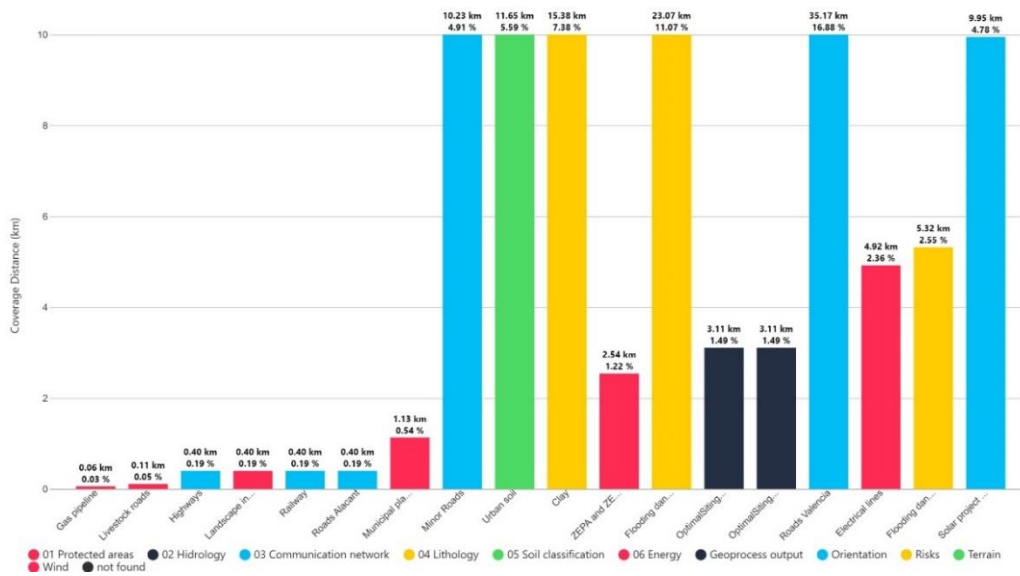


Fig 19b: Path coverage distance ratio for connection of site T1 to grid.

4.2. Wind Energy Potential of suitable sites.

4.2.1. Power density.

The wind power density is generally influenced by the wind speed. The distribution summary of the average wind power density, wind power output and the wind energy potential of the sixteen suitable sites can be found in table 6. Furthermore, Fig. 13a. to 13p. gives a pictorial representation of the power density distribution for each of the sixteen sites.

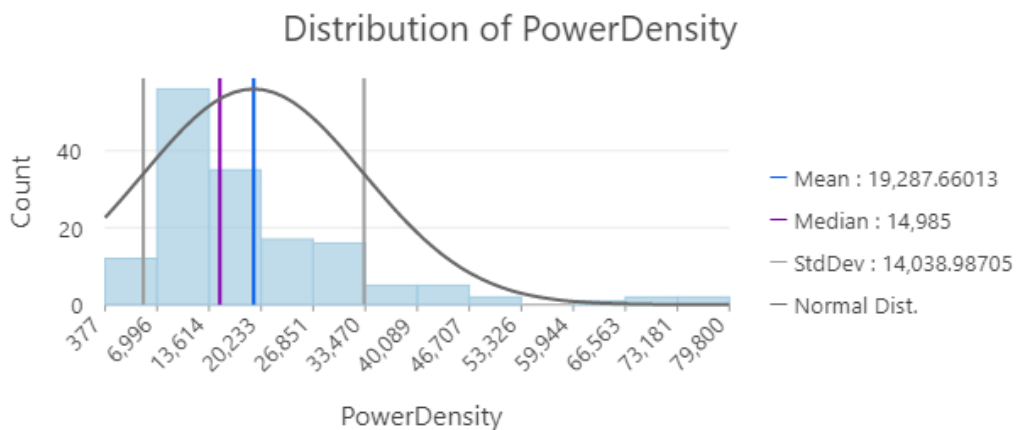


Fig. 20a: Wind power density of Site 1 (T1)

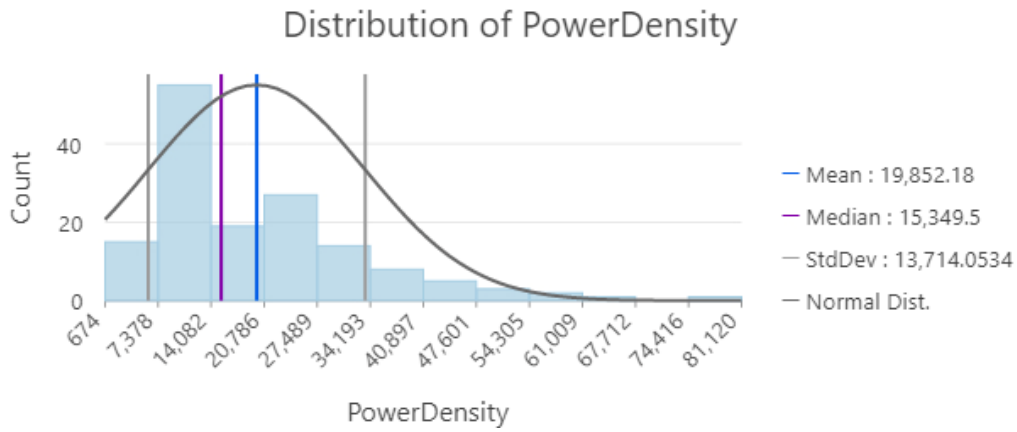


Fig. 20b: Wind power density of Site 2 (T2)

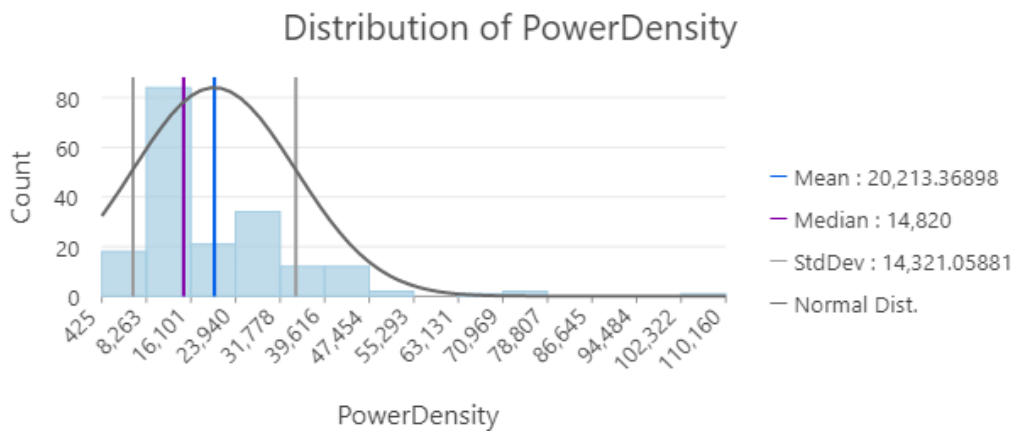


Fig. 20c: Wind power density of Site 3 (T3)

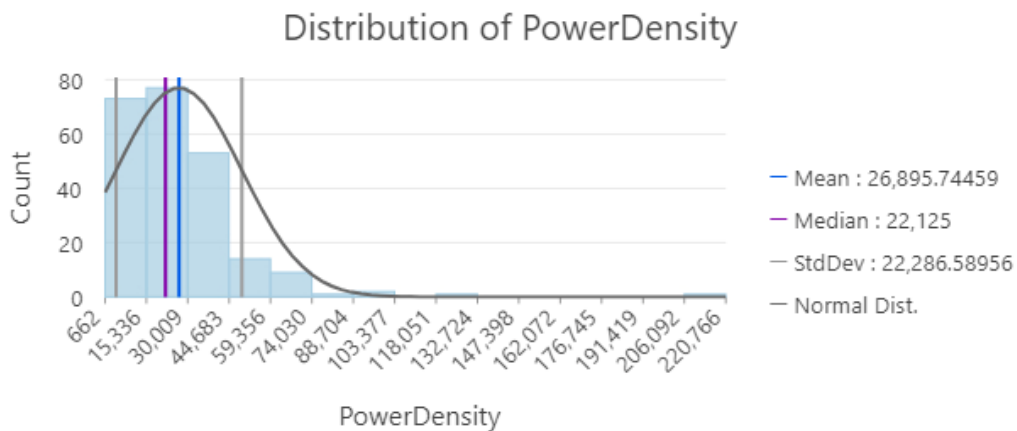


Fig. 20d: Wind power density of Site 4 (T4)

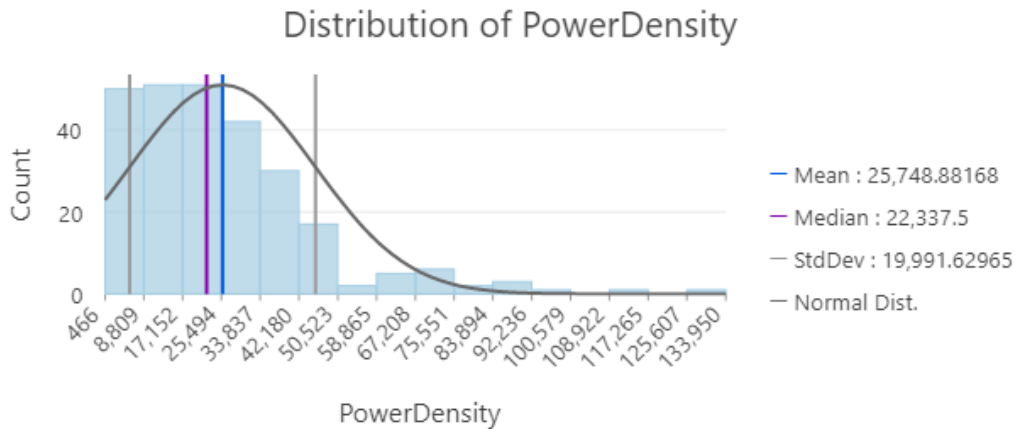


Fig. 20e: Wind power density of Site 5 (T5)

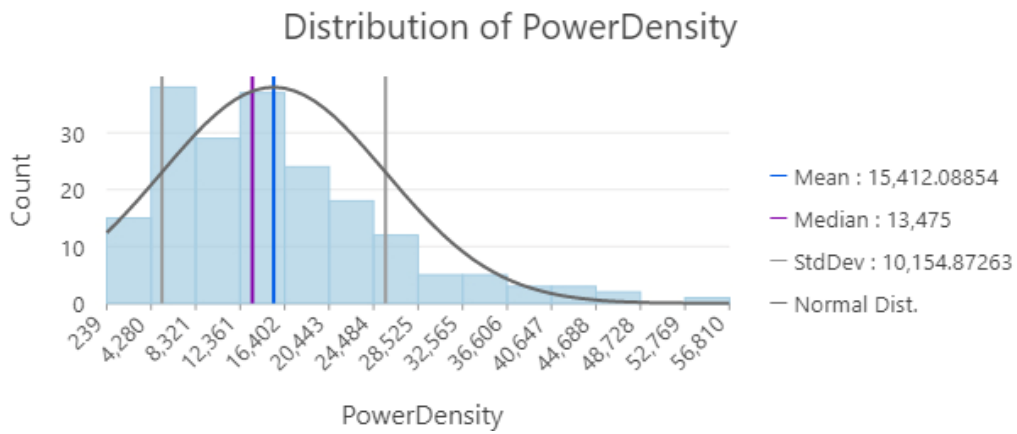


Fig. 20f: Wind power density of Site 6 (T6)

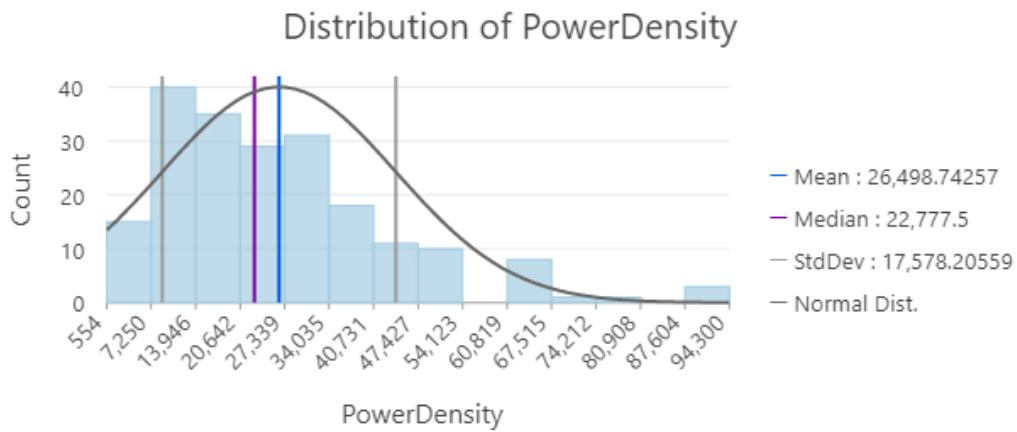


Fig. 20g: Wind power density of Site 7 (T7)

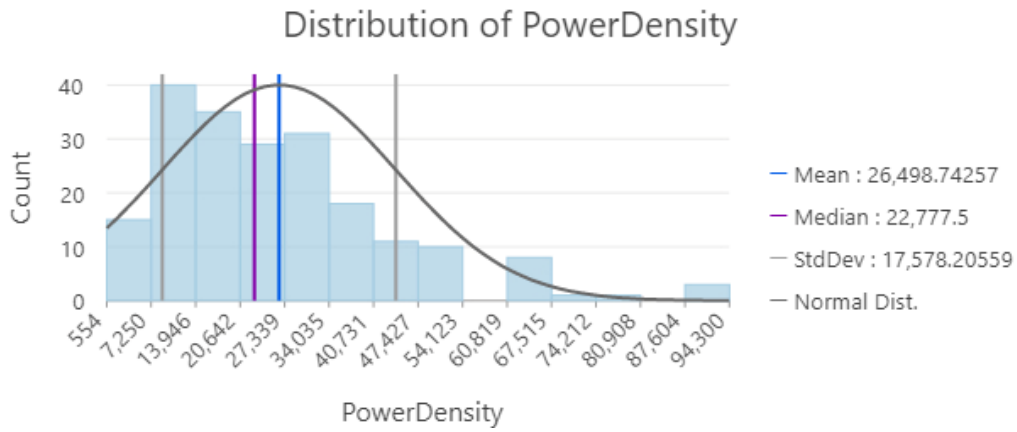


Fig. 20h: Wind power density of Site 8 (T8)

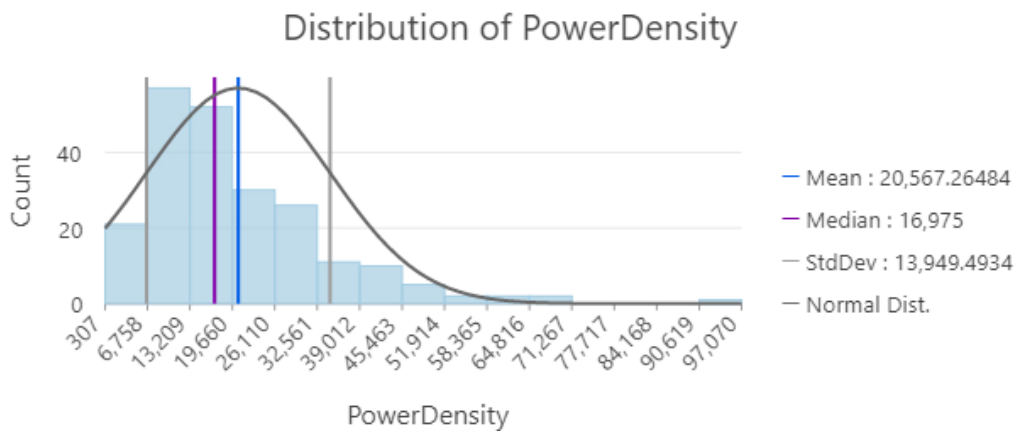


Fig. 20i: Wind power density of Site 9 (T9)

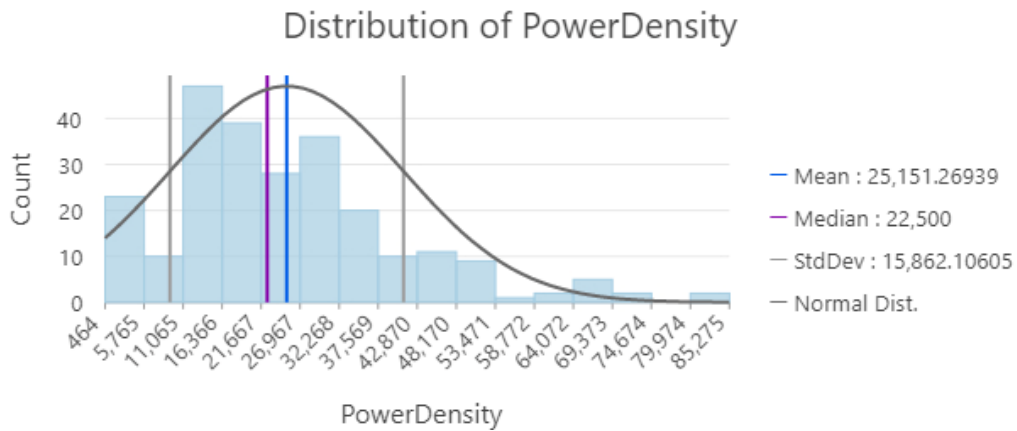


Fig. 20j: Wind power density of Site 10 (T10)

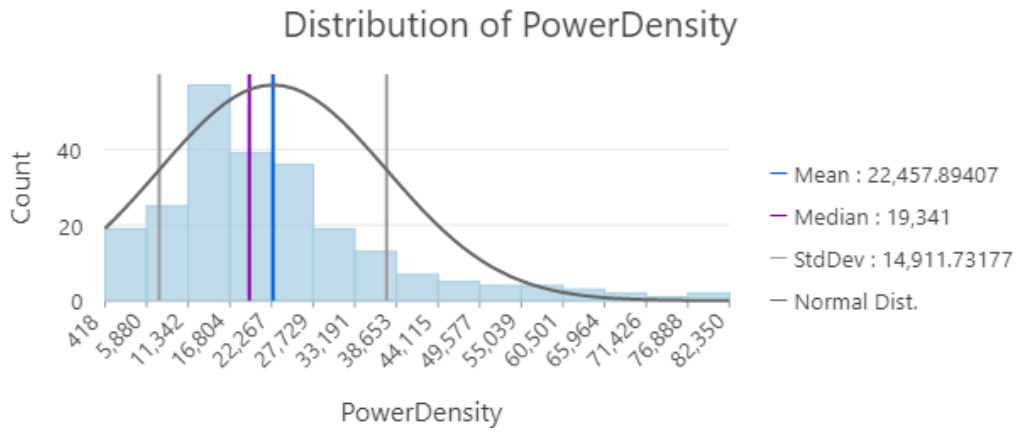


Fig. 20k: Wind power density of Site 11 (T11)

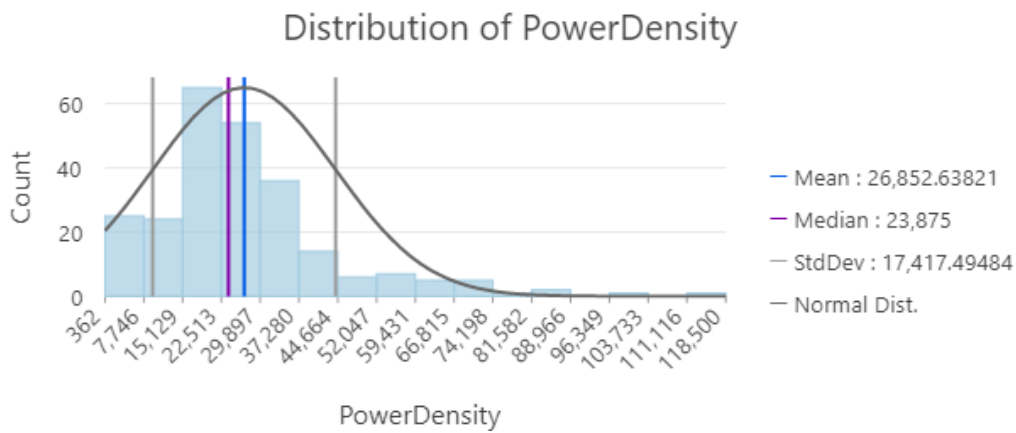


Fig. 20l: Wind power density of Site 12 (T12)

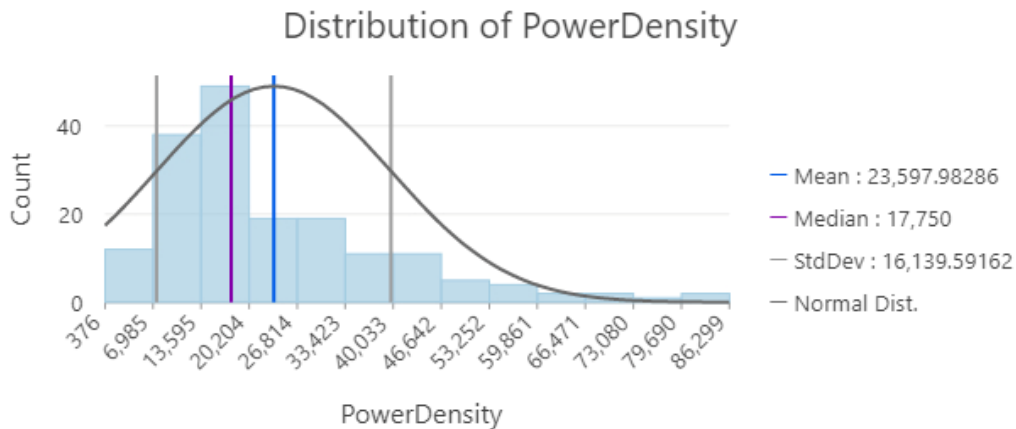


Fig. 20m: Wind power density of Site 13 (T13)

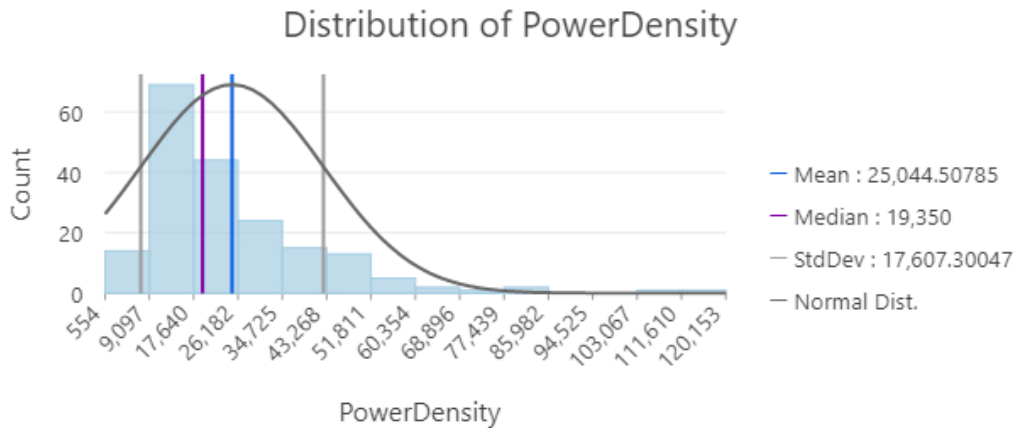


Fig. 20n: Wind power density of Site 14 (T14)

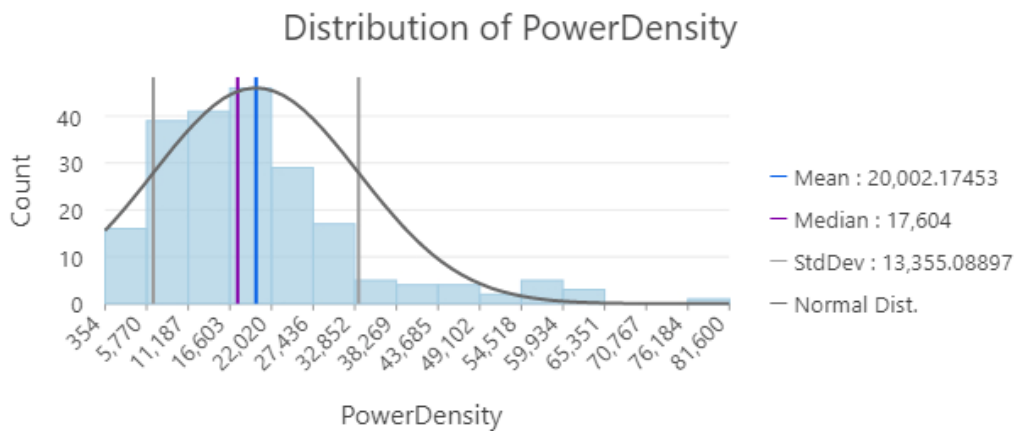


Fig. 20o: Wind power density of Site 15 (T15)

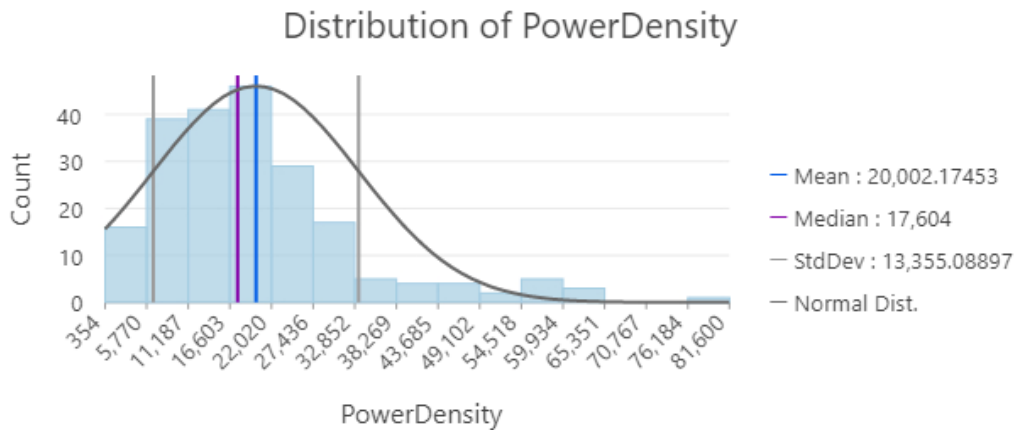


Fig. 20p: Wind power density of Site 16 (T16)

Some Suitable sites	Average wind power density (W/m²)	Average wind power output (W/m)	Average wind energy potential (Wh)	Average wind energy potential (MWh)
T1	19,287.66	263.954	2,312,239.20	2.31
T2	19,852.18	271.68	2,379,916.80	2.38
T3	20,213.37	276.5936	2,422,959.80	2.42
T4	26,895.74	368.065	3,224,248.80	3.22
T5	25,748.90	352.3855	3,086,896.90	3.09
T6	15,412.10	210.9167	1,847,630	1.85
T7	26,498.74	362.6535	3,176,844.40	3.18
T8	22,142.76	303.025	2,654,497.90	2.65
T9	20,567.26	281.434	2,465,360	2.47
T10	25,151.27	344.208	3,015,263.50	3.02
T11	22,457.90	307.318	2,692,103.90	2.69
T12	26,852.64	367.484	3,219,157.60	3.22
T13	23,598.00	322.96	2,829,129.60	2.83
T14	25,044.50	342.7016	3,002,065.80	3.00
T15	20,002.17	273.7406	2,397,967.40	2.40
T16	21,231.37	290.567	2,545,368.40	2.55

Table 6: Average wind power density, energy potential and power output of the sixteen (16) sites.

The wind power density, as depicted by the normal distribution curve (resembling dumbbells) in Figures 20a to 20p, exhibits symmetrical distribution around the mean. The data from the sixteen sites has a positive skewness, suggesting a larger probability of encountering higher power density rather than experiencing significant losses at any site. Hence, investors may perceive this as appealing due to the potential for substantial gains that can counterbalance repeated little setbacks. Additionally, it implies that higher values are extended, and there is a greater probability of encountering abundant energy availability, such as powerful winds for wind turbines. The inference drawn from these findings indicates that the outcome could additionally function as data to assist capacity, storage, and grid management decisions.

4.2.1. Power output.

To calculate the wind energy potential of the study area using Algorithm B, the power output of the wind turbine was calculated using raster calculator in ArcGIS Pro. The results of the average power output of each of the 16 suitable sites can be found in table 6 above.

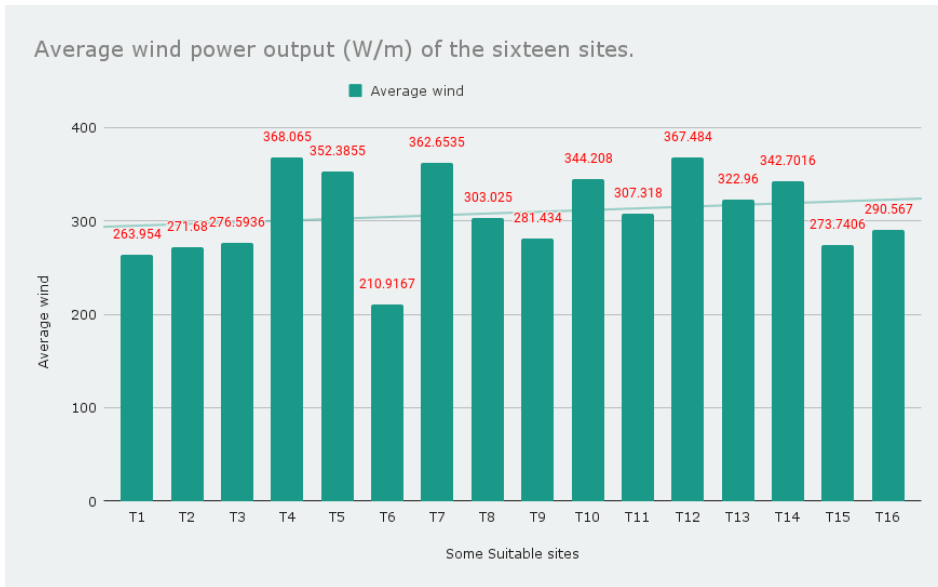


Fig. 21: Average wind power output (W/m) of the sixteen sites.

The graphic in Fig. 21 above illustrates the distribution of the average wind power outputs of the sixteen viable locations. The four sites with the highest wind power output are T4 (368.065 W/m), T12 (367.484 W/m), T7 (362.6535 W/m), and T5 (352.3855 W/m) respectively. Conversely, the sites with the lowest wind power output are T6 (210.9167 W/m), T1 (263.954 W/m), T2 (271.68 W/m), T15 (273.7406 W/m), and T3 (276.5936 W/m) respectively. Within the framework of energy systems and grid management, the locations with greater wind power outputs (such as T4, T12, T7, and T5) will have a substantial impact on meeting energy demands, particularly during peak hours. Conversely, sites with lower wind power outputs (such as T6, T1, T2, T15, and T3) will have a comparatively lesser influence on energy demands. Nevertheless, over dependence on wind power generation might pose a concern when wind conditions abruptly decrease, which can directly impact or jeopardize the stability of the power system. The significant wind power generation from the four locations (T4, T12, T7, and T5) will contribute to achieving renewable energy objectives and decrease dependence

on fossil fuel usage. Nevertheless, the expense of incorporating expansive wind farms into the power grid necessitates resilient infrastructure and intelligent grid management to accommodate the fluctuations that might burden the grid. Enhanced wind power generation can also have positive effects on local economies, such as creating employment opportunities and attracting investments, while simultaneously mitigating greenhouse gas emissions. However, decreased wind power generation could result in a greater dependence on costly alternative power sources like gas turbines. Furthermore, increased wind power diminishes air pollution and has the potential to alleviate climate change. However, in instances of poor wind power outputs, it may be necessary to resort to the utilization of fossil fuels, which can have a detrimental effect on air quality and emissions. Excess wind power can be stored in batteries for future use, but insufficient wind power necessitates alternative sources such as natural gas or energy storage technologies. Moreover, the utilization of various energy sources such as wind, solar, and hydro power significantly strengthens the robustness of the system. However, in situations of extended periods of calm weather, a scarcity of wind power can potentially burden backup systems.

4.2.2. Wind Energy Potential

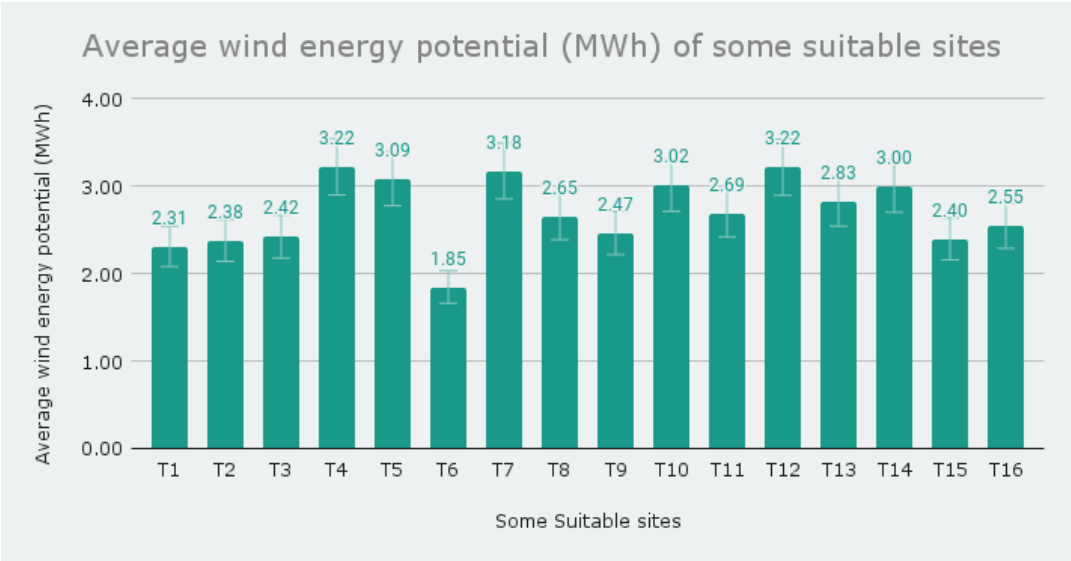


Fig. 22: Average wind energy potential (MWh) of the sixteen sites.

The graphic in Fig. 22 above illustrates the distribution of the average wind energy potential of the sixteen viable locations. The four sites with the highest wind energy

potential are T4 (3.22 MWh), T12 (3.22 MWh), T7 (3.18 MWh), and T5 (3.09 MWh) respectively. In contrast, the wind energy potential is lowest at sites T6 (1.85 MWh), T1 (2.31 MWh), T2 (2.38 MWh), T15 (2.40 MWh), and T3 (2.42 MWh) in descending order. The cumulative average wind energy potential of the sixteen (16) locations amounts to around **43.27 megawatts (MW)**, which falls short of the required 50 gigawatts (GW) of energy. This elucidates the inadequacy in the quantity and the necessity to augment the quantity of sites to a significantly larger magnitude (exceeding 16) to accommodate a greater amount of wind energy extraction.

	Wind power density (W/m ²)	Average wind power output (W/m)	Average wind energy potential (MWh)
Wind power density (W/m ²)	1		
Average wind power output (W/m)	0.9999999	1	
Average wind energy potential (Wh)	0.9999999	1.0000000	1

Table. 7: Correlation metrics for the three parameters (wind power density, average wind power output and average wind energy potential).

Table 7 above shows the correlation metrics for the three variables (wind power density, average wind power output and average wind energy potential). The correlation metrics shows the following:

1. A very strong relationship between the wind power density (W/m²) and the average wind power output (W/m).
2. A very strong relationship or correlation between the wind power density (W/m²) and the average wind energy potential (MWh).
3. A very strong correlation between the average wind power output (W/m) and the average wind energy potential (MWh).

From the correlation analysis between the factors of wind energy potential calculation (wind power density and wind power output), it can be established that there is a very strong correlation between all these factors of wind energy calculations.

Some Suitable sites	Average wind energy potential (MWh)
T1	2.31
T2	2.38
T3	2.42
T4	3.22
T5	3.09
T6	1.85
T7	3.18
T8	2.65
T9	2.47
T10	3.02
T11	2.69
T12	3.22
T13	2.83
T14	3.00
T15	2.40
T16	2.55

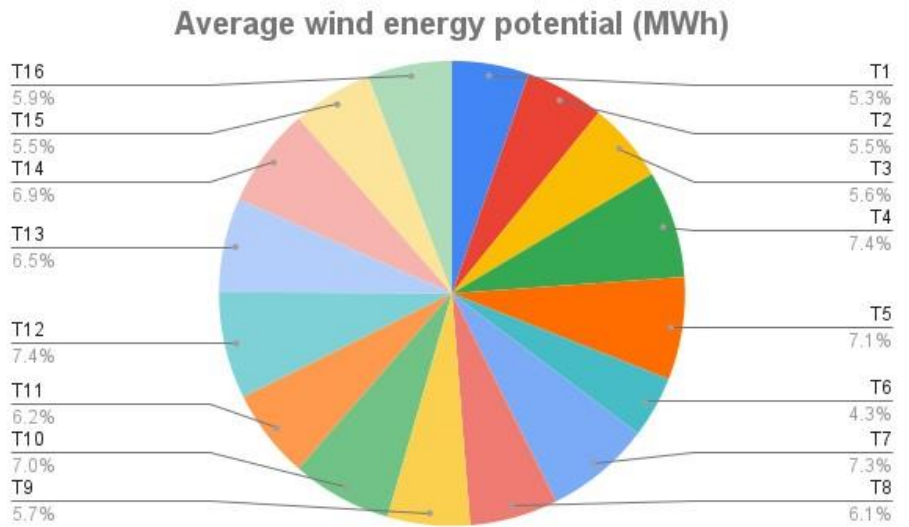


Table 8: Wind energy potential for each of the sixteen suitable sites.

4.3. Amount of wind turbine on each site

The amount of wind turbine that can be installed on each of the sixteen sites is calculated using the python script in Appendix 3. The script is written using arcgispro-py3 python interpreter in PyCharm. Important libraries used for establishing this workflow include Arcpy and GDAL. Since the sixteen sites all have near-uniform size (all square-shaped) the total number of wind turbines that can be installed in each of the sites is the same. For the 5D x 7D configuration, the amount of wind turbines that can be installed is **twelve (12)**, while for the 12D x 4D configuration, the amount of wind turbines that can be installed is **nine (9)**. One importance of the script is that it can be used for calculating the amount of wind turbines that can be installed on other wind farms with other polygon shapes such as rectangle, trapezium, rhombus, etc.

5.0. Conclusion.

The use of MCDA and GIS has proven to be an effective tool for the siting and optimization of wind energy turbines. More importantly, the use of Pathfinder has further showed that GIS in combination with its tools can be an effective instrument for analysis and derivation of optimal sites and routing for wind energy farms and Photovoltaic cells. In addition, python programming has been effective tool for automation and management of the geospatial data used for the calculation of the amount of wind turbines that can be installed on each of the sixteen (16) suitable sites using the 5Dx7D and 12Dx4D wind turbine configuration models.

More importantly, to achieve objective one (1), some sixteen (16) suitable sites with a total area of 200,000 km² have been derived as optimal sites for the establishment of wind energy farms in Valencia community (This is extensively described in 4.1.2 of the result and discussion section). To address research objective two (2), two sample connection routes that connect site T1 and T5 to an existing grid in Valencia, with connection distances of 208.35 km and 298.75km were generated respectively (This is extensively described in section 4.1.4). To address research objectives three (3), the wind energy potential of each of the sixteen (16) suitable sites were calculated and visualized in section 4.2.2. At the end of section 4.2.2, a methodological framework for the calculation of wind energy potential was developed, which carefully addresses objective four (4). Finally, to address objective (5), the number of wind turbines that can be installed for each of the sixteen sites using the two turbine configuration models (5D x 7D and 12D x 4D respectively) and python programming language was calculated as twelve (12) and nine (9) respectively.

Future work will be to explore other wind turbine configurations other than the 5D x 7D configuration and the 12D x 4D configurations for analysis and study of wake effect reduction and characteristics. It will also focus on deriving the wind energy potential of the sixteen (16) suitable sites using Algorithm B and checking the performance of the algorithm with respect to the performance of Algorithm A. The major drawback for not implementing this algorithm was the delay with acquiring information about the power coefficients of the wind turbine early enough. The derivation of the turbine

configuration using open-source programming languages such as the GDAL and Python programming language will be important for overcoming some of the current limitations of ArcPy and minimizing wake effect on wind energy production (potential). Furthermore, the implementation and comparison of the results from both algorithms (A and B) will be an efficient way of determining which algorithm would be best for the calculation of wind energy potential of the sixteen (16) suitable sites within the study area.

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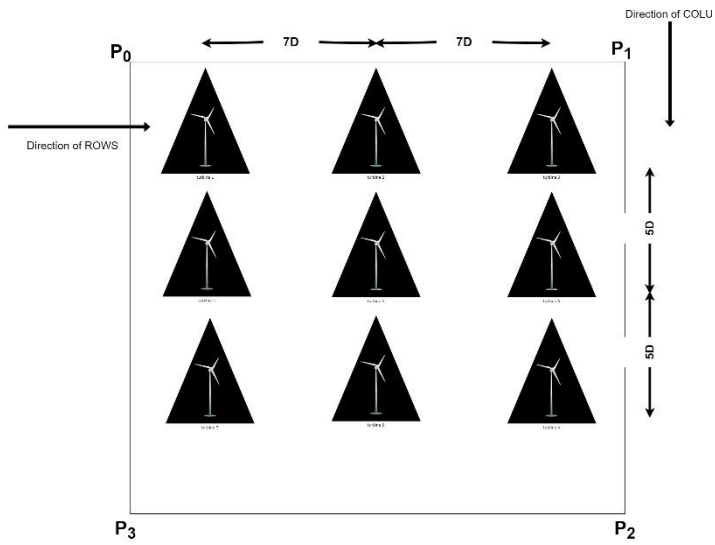
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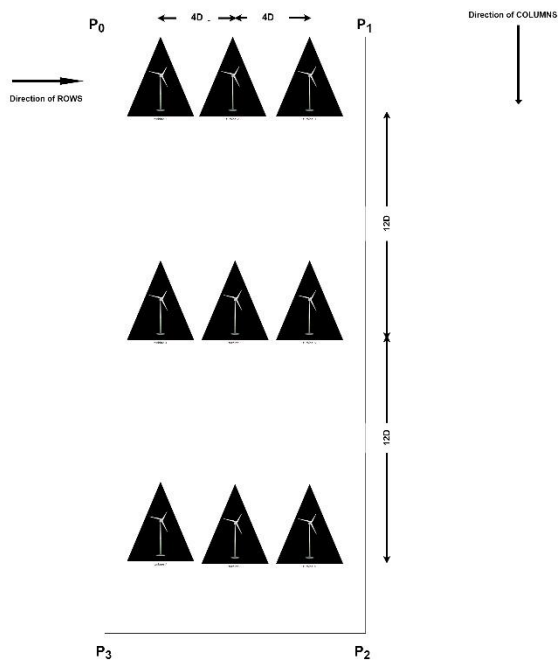
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APPENDIX 1

5D x 7D configuration model

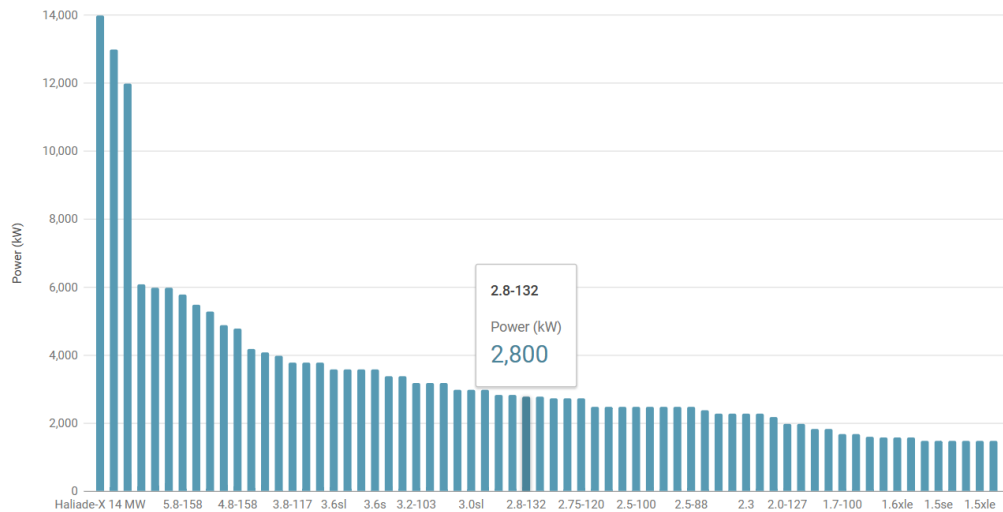


12D x 4D configuration model



APPENDIX 2

TURBINE CHARACTERISTICS



Source: <https://www.thewindpower.net>

2 MW wind turbine specifications table

2 MW platform	2 MW – 116	2 MW – 127	2 MW – 132
Output (MW)	2.3 to 2.7	2.5 to 2.8	2.5 and 2.8
Rotor diameter (m)	116	127	132
Hub heights (m)	80, 90, 94	89, 114	94, 130, 150*
Frequency (Hz)	50, 60	60	50
Vavg (m/s)	8.0	8.0	6.5
Ve50 (m/s)	53.2	56.0	49.0
Cut-in (m/s)	3.0	3.0	3.0
IEC Wind Class	IIS/IIIS	IIS/IIIS	IEC S

Source: GE (2MW onshore Wind Turbine)

General data

- Manufacturer: [GE Energy \(Etats-Unis\)](#)
- Model: 2.5-132
- [Product page](#)
- Rated power: 2,500 kW
- Rotor diameter: 132 m
- Available model
- Wind class: IEC S
- Offshore model: no
- Swept area: 13,685 m²
- Specific area: 5.48 m²/kW
- Number of blades: 3
- Power control: Pitch
- Commissioning: 2020

Source: GE (2MW onshore Wind Turbine)

APPENDIX 3

PYTHON CODE

<https://drive.google.com/file/d/1mzYWHjvTR0rniOcmzNs1XmXsudy7Guh3/view?usp=sharing>





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