

Department of Mechanical and Aerospace Engineering

**Analysing & Predicting Electricity Generation from Onshore Wind Energy  
using simulation software considering ground topography & land cover  
data – A case study of Gujrat, India**

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A thesis submitted in partial fulfilment for the requirement of the degree  
Master of Science in  
Sustainable Engineering: Renewable Energy Systems And The Environment

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## ABSTRACT

In the current energy market, wind energy is becoming a more significant factor in the shift to low-carbon energy systems. As a result, modelling and simulation of wind energy systems have attracted a lot of research interest. Numerous modelling tools, such as HOMER Pro, energyPRO, EnergyPLAN, WAsP, windPRO and WindStation, are available for wind energy assessments. Inputs needed by each tool vary depending on the simulation being run. As a result, they need a distinct modelling strategy to produce the necessary results. Each tool also sets a set of assumptions for the simulation. The outcomes of the defined inputs vary in relation to the tool as a result of this variance. There aren't many inputs needed for programmes like HOMER Pro, energyPRO, and EnergyPLAN. They execute simplified modelling based on a limited number of inputs and presumptions made by the tool. In contrast, tools like WAsP, windPRO and WindStation contain a wide range of factors throughout the simulation and produce results that are the most similar to the actual situation

By simulating a variety of simplified and sophisticated modelling tools, this thesis aims to evaluate the accuracy of various wind resource modelling methods for wind energy-producing systems. A literature review is the first phase, and it comprises the inputs, outputs, presumptions, and modelling techniques for each tool. In the methodology section, every software simulation was done separately. Two locations in the west part of India, close to Bhuj, Gujarat, were also selected for the simulation. Once the simulations are done successfully then the simulation results from several software programmes were addressed. And in the final section, all the findings are summarised and it is demonstrated how several software programmes can be used in concert to produce the best and most accurate results possible for the feasibility study of any wind farm project.

**Key words:** Renewable energy, Non-Renewable Energy, Fossil Fuels, Wind Energy, Gujrat, India, Terrain analysis, CFD, WAsP, windPRO, HOMER Pro, Modelling tools, Energy Production, Wake effect, Power curve, Wind Turbines

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## LIST OF SYMBOLS

GW - Gigawatt

GWh/Yr - Gigawatt hour per year

MWh – Megawatts hour

MW - Megawatt(s)

mm - Millimeters

m - Meter

m/s - Meters per second

Kg/m<sup>3</sup> - Kilograms per cubic meter

kW - Kilowatts

N/m<sup>2</sup> - Newton per meter square

## ACRONYMS

MNRE - Ministry of New and Renewable Energy

CUF - Capacity Utilization Factor

NIWE - National Institute of Wind Energy

C-WET - Centre for Wind Energy Technology

ABL - Above Ground Level

WAsP - Wind Atlas Analysis and Application Program

OWC - Observed Wind Climate

WTG - Wind Turbine Generator

RES - Renewable Energy Sources

RET - Renewable Energy Technology

NDC - National Determined Contribution

GDP - Gross Domestic Product

CFD - Computational Fluid Dynamics

HOMER - Hybrid Optimization Model for Electrical Renewable

STP - Standard Temperature & Pressure

AEP - Annual Energy Production

GHG - Greenhouse Gases

DEM - Digital Elevation Model

NPV - Net Present Value

IRR - Internal Rate of Return

# 1 INTRODUCTION

## 1.1 Problem Definition

The energy dilemma has grown in importance due to fast industrialization and economic expansion for sustainable development. Conventional sources of energy like fossil fuels are scarce on the earth and will inevitably run out in the future. Governments of different countries are working to combat this problem by supporting the usage of various renewable energy sources (RESs) in place of fossil fuels, which is what is causing the global warming that is currently impacting human society and is the outcome of aggressive fossil fuel usage. With 62 per cent of all new power generation capacity added between 2009 and 2018, Non-conventional sources of energy have become a crucial component of the energy and development strategy across the world. Onshore wind energy, which now accounts for 24% of all renewable energy capacity, is the dominant non-hydro renewable technology. Between now and 2030, the capacity of renewable energy sources, including wind, must rise four times faster than this in order to provide for climate protection and sustainable development.

Rapid industrialisation and extensive fossil fuel use have harmed our ecology and are now the primary cause of global warming. Attention should be paid to the unsustainable climate since it threatens the existence of all living things, including people, animals, and plants. Due to the rising energy demand, natural resources have been under strain, which has resulted in the traditional transition from resource generation to resource exploitation. The Indian market has seen significant economic growth during the previous ten years. [1]

Conventional sources are inadequate sources of energy that are quickly running out, and they will soon be extinct. We are quickly reaching an energy crisis because the majority of energy is produced by fossil fuels. The most significant discovery of the decade is the paradigm shift toward renewable energy technology (RET). In addition to being good for the environment, putting more of an emphasis on renewable energy-based power generation will assure energy security and availability. [1]

During the Paris Agreement for the period between 2021 to 2030, the Goals defined by India are: “Reducing GDP's emissions intensity by 33 to 35 percent by 2030 as compared to 2005 levels and total installed capacity should have 40% installation for renewable energy generation by 2030 with the aid of technology transfer and low-cost international financing”. [2]



India is on the right path to meet the Paris agreement goals. Currently, India has an installed capacity of 93 GW from non-conventional sources (excluding large hydro) and in the last 7 years we have seen a significant increase of 2.5 times i.e. from 40 GW to 93 GW, while installed solar energy capacity increased by 5 times and Wind energy capacity increased from 21 GW in 2014 to 60 GW in 2021, and renewable energy proportion in total energy generation increased from 5.5% to 11% of total energy generated as shown in Figure 1. India is now ranked 4<sup>th</sup> in terms of renewable energy capacity, 4<sup>th</sup> in wind energy, and 5<sup>th</sup> in solar energy across the world. [2]

Year	Installed RE Capacity (in GW)	% Share of RE in total Installed Capacity	Generation from Renewable Sources (in BU)	Total Generation from all sources (in BU)	% Share of RE in Generation
2014-15	39.55	14.36	61.78	1110.18	5.56
2015-16	46.58	15.23	65.78	1172.98	5.60
2016-17	57.90	17.68	81.54	1241.38	6.56
2017-18	69.77	20.24	101.83	1303.37	7.81
2018-19	78.31	21.95	126.76	1375.96	9.21
2019-20	87.07	23.52	138.32	1390.93	9.95
2020-21	92.54	24.53	111.92	1017.81	11.00
	(Up to Jan, 2021)	(Up to Jan, 2021)	(Up to Dec, 2020)	(Up to Dec, 2020)	(Up to Dec, 2020)

Figure 1 India's Renewable Sector (Adopted from Annual report 2020-21 of MNRE [2])

One of the main reasons behind the exponential rise in renewable energy is renewable energy prices have dropped dramatically in the recent six years as shown in Figure 2. Solar tariffs have fallen sharply since April 2014, from Rs. 6.47 per kilowatt-hour in 2013-14 to Rs. 1.99 per kilowatt-hour in Dec 2020. A similar drop is observed for wind energy where it reduces from Rs. 5.92 per kilowatt-hour in 2013-14 to Rs. 3.00 per kilowatt-hour in December 2020 when the procurement methodology was changed from feed-in Tariffs to bidding in 2017. [2]

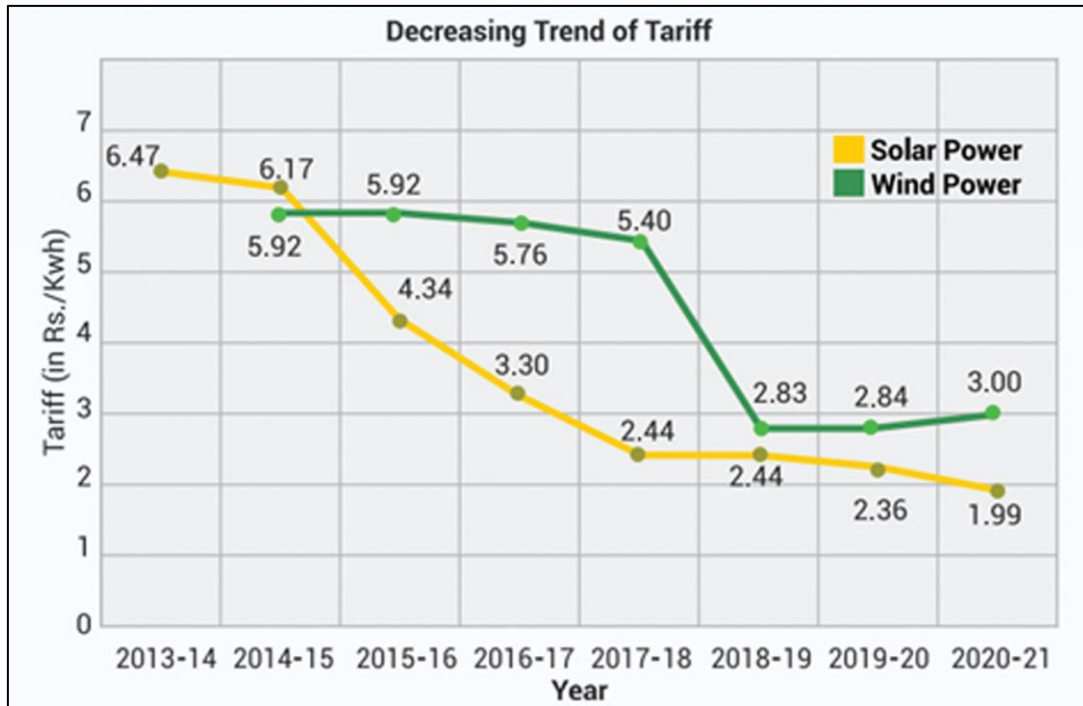


Figure 2 Solar & wind energy tariff trend (Adopted from annual report 2020-21 of MNRE [2])

The domestic wind energy market in India, which has shown consistent expansion, is the industry's driving force. As a result of the wind industry's expansion, there is now a robust environment, project operating capabilities, and a manufacturing hub that produces about 10,000 megawatts annually. “The nation has the fourth largest installed wind capacity in the world, with a total installed capacity of 38.62 GW (as of December 31, 2020), and 64.64 billion units were produced from wind power in 2019–20”. [2]

To achieve such expansion, a thorough evaluation of the capacity that is available to accomplish this objective in a way that is both economical and socially acceptable is necessary. Resource evaluations for renewable energy are currently a hot topic of research due to the global push toward more sustainable energy systems. Researchers have given this subject a lot of attention over the past few decades, which has led to significant methodological breakthroughs and more precise resource estimations. This includes advancements in real-time wind and climate data, accurate terrain study using open-source data for height contour and roughness, and availability of the technical specifications of turbines. [3]

According to the most recent study, “the country's gross wind power potential is 302.25 GW and 695.50 GW at 100 m and 120 m agl, respectively” [4]. The majority of this potential is concentrated in seven windy states, as shown in Table 1 below.

Table 1 Wind energy potential across India (Adopted from annual report 2020-21 of MNRE [2])

Sr. No	State	Wind Power Potential at 100 m agl in (GW)	Wind Power Potential at 120 m agl (GW)
1	Andhra Pradesh	44.23	74.9
2	Gujarat	84.43	142.56
3	Karnataka	55.86	124.15
4	Madhya Pradesh	10.48	15.4
5	Maharashtra	45.39	98.21
6	Rajasthan	18.77	127.75
7	Tamil Nadu	33.8	68.75
	Total (7 windy States)	292.97	651.72
	Other States	9.28	43.78
	All India Total	302.25	695.5

The wind atlas can be found at <https://niwe.res.in/index.php> on the NIWE website. Figure 3 and Figure 4 show the wind potential at 100 m and 120 m above ground level, respectively. Figure 3 shows that at 100 m agl, most states have wind CUF less than 18, and only a few states have CUF greater than 18, which can be used for wind energy generation, particularly in two states, Gujarat and Tamil Nadu, where CUF is greater than 25, which is excellent for wind energy generation. Similarly in Figure 4, as the agl rises, CUF rises, and CUF rises to more than 40 in a few regions of Gujarat and Tamilnadu.

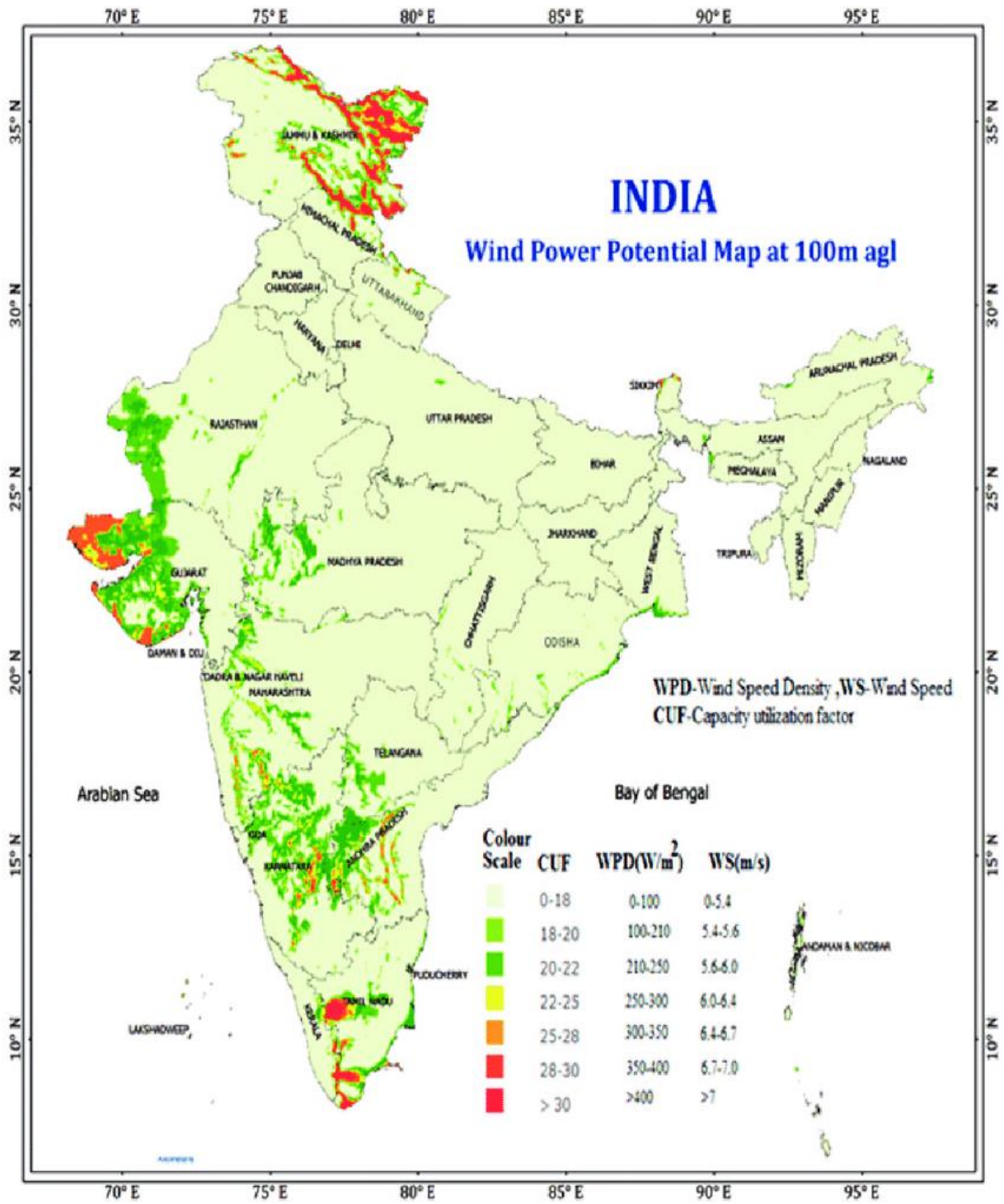


Figure 3 Wind potential map at 100 metres agl (Adopted from India's Wind Potential Atlas [4])

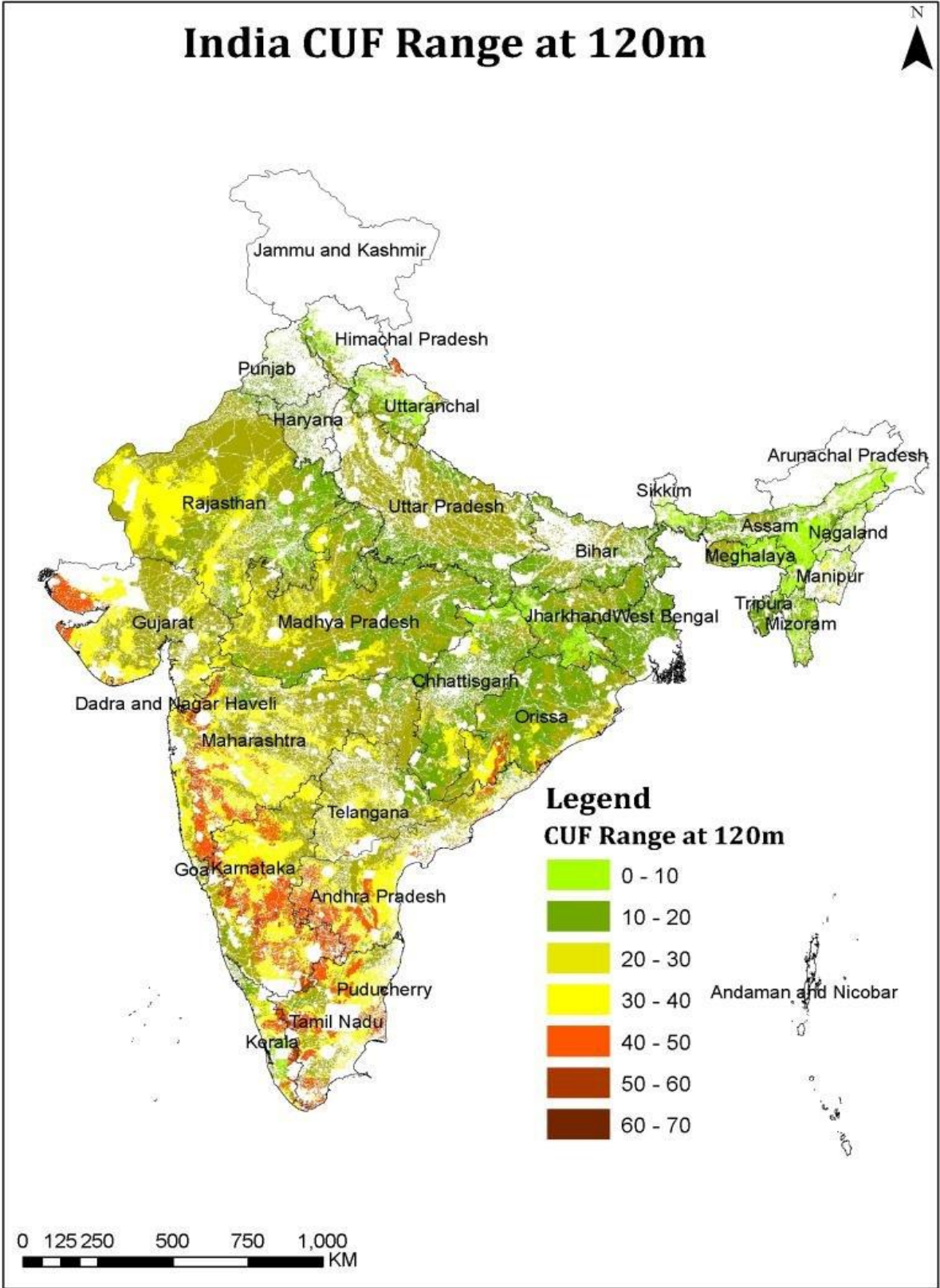


Figure 4 Wind potential map at 120 meter agl (Adopted from India's Wind Potential Atlas [4])



Before choosing possible locations, it is very important and necessary to do a proper assessment of wind energy because wind varies because of height contour and roughness of the terrain varies from site to site. The Ministry has built 890 meteorological stations across the country through the NIWE and issued wind potential maps at 50, 80, 100, and 120 meters above ground level (NIWE). As a result, wind energy analysis is critical for achieving the goal of net zero carbon energy. This gets us to the area of our project where we discuss the project's goal and objectives.

## **1.2 Aim**

To analyse & predict electricity generation from onshore wind energy using various tools to model and simulate while considering ground topography & land cover data taking the western part of India (Gujrat) as a case study.

It is complemented by detailed objectives:

- To study the modelling and simulation results of wind energy generation using different software and to analyse how the output is getting affected because of the ground topology.
- Comparing detailed simulation results from different tools and suggesting recommendations for the Installing of Turbines and direction of turbine installation.

## **1.3 Methodology Overview And Structure**

A review of the literature consulted in order to complete this study is included in Section 2. The study starts with a thorough investigation of the onshore wind energy capacity in India's major regions. In addition to information regarding the location we chose as a case study, Section 2.1 provides an overview of wind energy potential in the state of Gujrat, India. Section 2.2 gives an overview of each modelling tool, including its advantages and disadvantages. Specific parameters for each tool were also clarified in this section. The particular inputs necessary for each tool, as well as the results recovered after the simulation, are described in Section 2.2. For simulation, each wind resource modelling method necessitates a set of assumptions and parameters. They also rely on a set of pre-programmed mathematical equations to achieve their objectives. Section 2.3 delves deeper into those equations and calculations.

The project's methodology is covered in Section 3 of the report, where Section 3.1 describes the processes and presumptions to be used while doing wind energy assessments in different software. The following sections, Sections 3.2 and 3.3, demonstrate the simulation approach used for Site 1 and Site 2 in Gujrat, respectively, and suggest the topographical and wind data are taken into account for the simulation at specific sites.

Section 4 discusses the simulation results produced by various software and how those results vary depending on the assumptions or parameters modified in various software. For site 1 in Gujrat, the results of simulation using windPRO, WAsP, and HOMER Pro will be discussed in Section 4.1, and for site 2 in Gujrat, the findings produced using various wind energy assessment tools will be discussed in Section 4.2.

Section 5 is the Discussion, which talks about the conclusion, final remarks based on the case study, challenges faced and a few recommendations for the future.

## 2 LITERATURE REVIEW

This section discusses the wind potential in various locations of India, how to more correctly evaluate wind strength, and various laws put in place by the Indian government to promote wind energy. Then, for an accurate assessment of wind energy, a full summary of the site location chosen as a case study is supplied. This section also explains the exact inputs needed for each tool, as well as the outputs obtained after the simulation and the assumptions that must be made. This section briefly explains the strengths and weaknesses of each tool. To provide the desired results, each wind resource modelling tool employs a set of pre-determined mathematical equations. These equations and calculations are explained in this article.

### 2.1 Wind Analysis in India And Various Methods To Measure The Wind Strength

In order to draw in investors, the Indian government is putting a lot of effort into policy development in the wind energy industry. “The policy framework for India's first offshore wind development has been developed and made public by the Indian government in association with the National Institute of Wind Energy (NIWE). Chennai is home to the National Institute of Wind Energy, formerly the Centre for Wind Energy Technology (C-WET), which serves as a research hub for the whole Indian wind energy industry”.[5]

By providing tax and financial benefits like Accelerated Depreciation and concessionary custom duty exemption on specified parts of wind energy generators, the government is promoting private sector involvement in wind power projects across the country. Furthermore, wind projects that were finished before March 31, 2017, were eligible for the Generation Based Incentive (GBI) Scheme.[6]

The following steps have been taken to encourage the development of wind power across the nation apart from the aforementioned financial and other incentives:

- Technical support from Chennai's NIWE, including evaluation of wind resource potential and location identification.
- To encourage the sale of wind energy across state borders, interstate transmission costs and losses have been eliminated for wind and solar projects that are finished before March 2022.



- Making the bidding process more transparent, which includes standardising the procedure and clarifying the roles and responsibilities of various stakeholders, proper guidelines are published by the government for purchasing & selling to the grid. These Guidelines are intended to make it simpler for Distribution Licensees to purchase wind energy at fair pricing.

## 2.2 Overview of Case Study Location

Gujarat has a lot of onshore and offshore wind energy potential in India. According to prior studies, Gujarat has the biggest wind energy potential of all Indian states, with an estimated 85GW at 100m agl and 140GW at 120m agl, as shown in Table 1. So, for the case study in India, two sites were chosen near Bhuj town and Runn of Kutch, both of which are located in Gujarat, India (on the west coast of the country), as shown in Figure 5



Figure 5 Image taken from Google Earth Pro

### 2.2.1 Study Case 1 - Location 1 (Bhuj Gujrat)

As indicated in Figure 6, the case study location is close to Bhuj city, which is approximately 10 kilometres south of Bhuj city. And the coordinates for the site centre are:

Center (Lat, Long): 23.147937°, 69.650574° (Easting 566609, Northing 2560041)

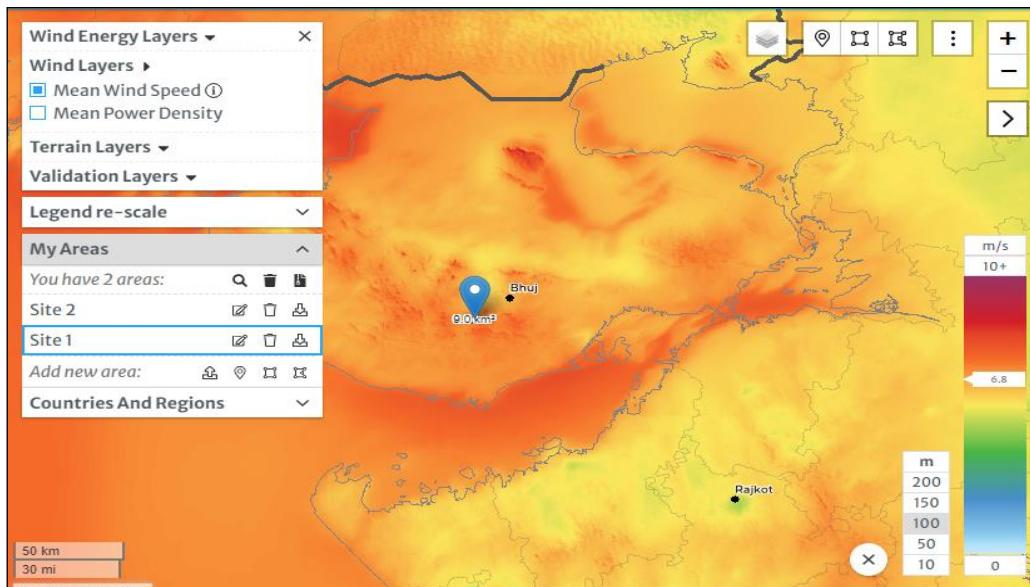


Figure 6 Image captured from Global Wind Atlas

### 2.2.2 Site Location 2 ( Rann of Kutch, Gujrat)

The case study location 2 is in Rann of Kutch, which is about 80 kilometres north of Bhuj city, as illustrated in Figure 7. And the coordinates for the site centre are:

Center (Lat, Long): 23.918481°, 69.868241° (Easting 588368, Northing 2645473)

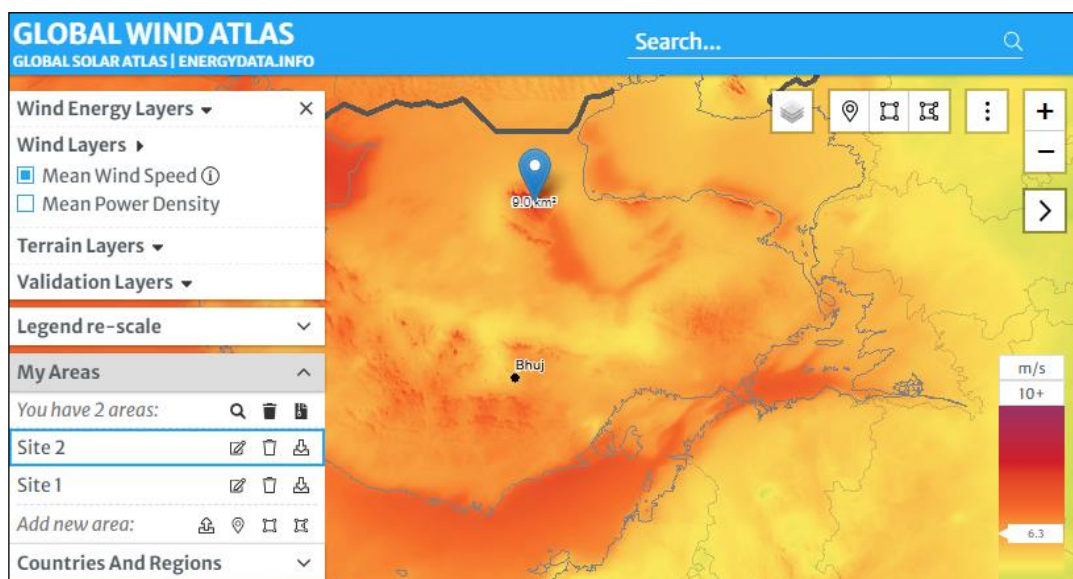


Figure 7 Image captured from Global Wind Atlas

## 2.3 Overview of Different Wind Assessment Software

### 2.3.1 WAsP

“In 1987, the Department of Wind Energy at the Technical University of Denmark created the first version of the numerical model known as WAsP (Wind Atlas Analysis and Application Program)”. It was developed as a supplement to the European Wind Atlas analysis. This programme forecasts wind resources, wind conditions, and energy output from wind farms. For pre-construction and operational evaluations of wind farms, WAsP is an essential instrument. When used properly, it enables the user to pick an appropriate location for new development or capacity increase. These results are based either on generalised wind conditions derived from the outputs of mesoscale models or wind data from nearby meteo stations.[7]

WAsP simulation tool runs the analysis on the assumption that the analyzed region's wind velocity data follows the 2-parameter Weibull distribution. The regional wind atlas statistics are calculated by the WAsP simulation program by analyzing four different input data in its sub-models[8]. “A comprehensive terrain flow model, a roughness change model, a sheltering obstacle model, a model for wind turbine wake, and a model for the site's normal atmospheric stability conditions are all included in the programme. This package also contains a Climate Analyst for making wind-climatological inputs, a Map Editor for constructing topographical inputs, and a Turbine Editor for creating wind turbine inputs for WAsP. The principles of WAsP and how to use wind atlas are covered in the European Wind Atlas” [9].

“The WAsP simulation software is composed of four Microsoft loader files: WAsP Climate Analyst, WAsP Map Editor, and WAsP Program. The WAsP Turbine Editor has also been built as part of the WAsP placement programme” [9]. A few physical designs are needed to characterize wind flow across various terrains and near shelter obstacles. The documentation is delivered through online help files. The WAsP simulation programme is compatible with Windows 7, XP, and Vista. In WAsP, the so-called wind map methodology is used, and it is easily recognised as seen in Figure 8.



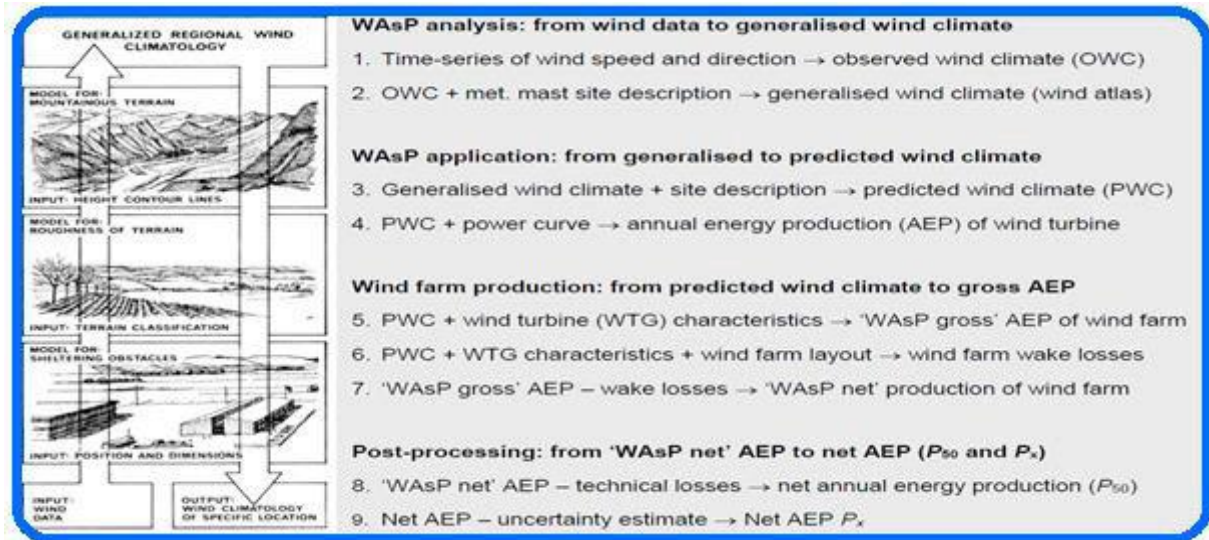


Figure 8 WAsP's Wind Methodology (Adopted from Simulation Framework for Wind Energy [8])

#### Advantages of WAsP tool:

- It is a linear numerical model that is based on the physical concepts of flows in the atmospheric boundary layer and is capable of simulating complex topographical conditions.
- The program can describe wind flow over a variety of terrains, as well as near shielding obstructions and at specific spots.
- WAsP estimates the anticipated power loss in wind farms caused by a decrease in upwind turbine wake speed.

#### Dis-advantages of the WAsP tool:

- When calculating power density, WAsP utilises an air density of 1.225 kg/m<sup>3</sup>. It is possible to determine the power generation for this standard air density by using one of the sample power curves.
- Any modifications made to the map in the WAsP Map Editor are not immediately visible in WAsP; instead, the map must be saved and reloaded to take effect.
- For actual installations, getting a site-specific power curve from the manufacturer is highly advised.

### 2.3.2 windPRO

The industry's top software package for wind farm project design and planning is called windPRO. Wind data analysis, energy yield calculations, uncertainty quantification, site appropriateness evaluations, and environmental effect calculations and visualisations are all covered by windPRO. Additionally, extensive post-construction analysis of production data is possible using windPRO. All aspects of the development and planning of wind farm projects are covered by windPRO, which is modular-based and includes, as shown in Figure 9, “wind data analysis, wind resource mapping, micro-siting, site suitability analyses, energy production estimation, layout optimization, environmental impact calculations, visualisations, and electrical and economic calculations” [10].

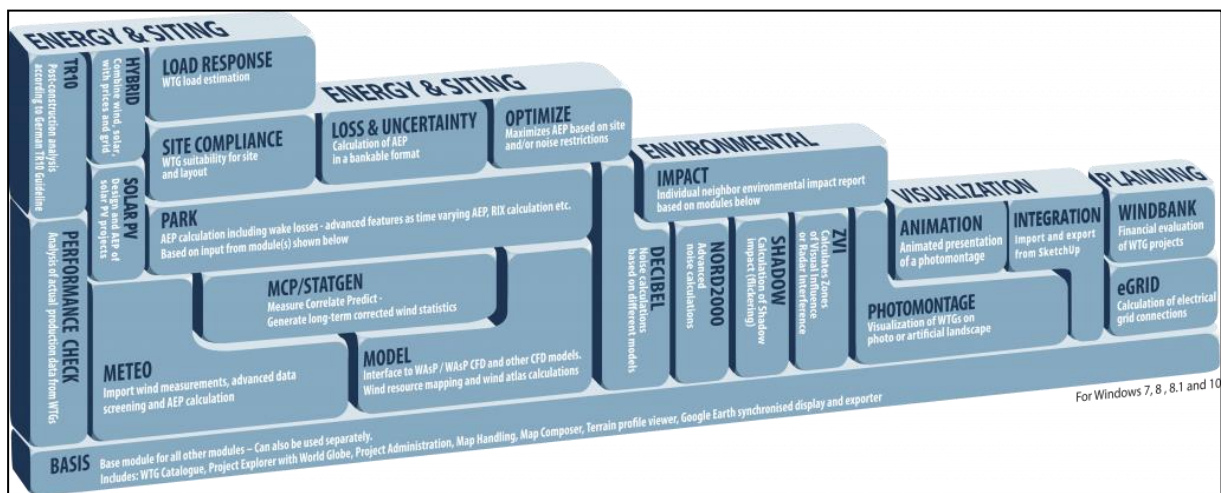


Figure 9 windPRO Modules

#### Advantages of windPRO

- Easy to download precise online data for terrain (orography & roughness data).
- Wind climate data is available to download from various meteo stations across the world.
- Easy interface and acceptance of different online data and software.
- Various methods available for wind analysis and energy analysis

#### Disadvantages of windPRO

- Require WAsP software in addition to windPRO to generate power curves and to predict wind energy assessment.

### 2.3.3 HOMER Pro

HOMER Pro (Hybrid optimization model for electrical renewables) is a modelling tool for evaluating and modelling wind resources for various energy mixes, renewable energy resources, and other fuel sources. “HOMER Pro was created in 1993 by Mistaya Engineering in Canada for the National Renewable Energy Laboratory (NREL) in the United States. Generators, solar PV, wind turbines, hydropower, biomass, storage capacity, and batteries are just a few of the items that might be evaluated” [11]. It also estimates the overall cost of setting up and maintaining the system over its useful life. The tool is helpful since it compares several design options based on their technical and financial benefits. There are several choices, including different component sizes, components that will be added to the system, and cost functions of system components. Options for system design are evaluated with the help of HOMER Pro's optimization and sensitivity analysis techniques [12]. “Capital, operation, replacement and maintenance, fuel, and interest are all factored into the system cost calculations” [13].

The following are some of the benefits of using the HOMER Pro tool [14]:

- HOMER Pro is simple to use and navigate (open source).
- It is capable of processing data on an hourly basis.
- It gives the user graphical and tabular results.
- It can take into account grid purchases or sales based on user demand.
- Simulating takes very little time.
- Bus voltage fluctuations are not taken into account.

The following are some of the tool's drawbacks:

- It solely takes imperial units into account.
- It is not possible to import time series data as a daily average.
- It does not have analytic capabilities in a thermal system.

### 2.3.4 WindStation

WindStation is a program that simulates turbulent flow over complex topography numerically. It uses raster landscape descriptions, wind readings, and atmospheric stability as input data. The nonlinear fluid dynamics equations are solved, with Coriolis effects taken into account. Three general-purpose turbulence models and a fourth model with a particular formulation for air flows are available. With capabilities like automated alignment with free stream direction and nesting, domain and meshing allow a lot of versatility[15].

Due to the layering technique that is built in, observed wind climate or meteo station data can be used to simulate. WindStation is used for performing wind energy assessment, especially where the terrain is complicated and may cause a lot of difference between meteo station and turbine site. This is achieved by including information about the topography and its roughness in addition to the meteo station wind data. Windstation is also used to simulate how products and people move through buildings in cities. Additionally, particular evaluations of the urban climate, such as computations for air pollution and dispersion, can be performed using WindStation. The batch-run features allow for the setup and calculation of numerous projects, including climatology calculations for statistical analysis. There are postprocessing tools and data export options for visualisation. [16].

### 2.3.5 energyPRO

energyPRO is used for simulating and analysing big energy projects that utilise both electrical and thermal energy (process heat, hot water, and cooling). Energy projects such as industrial cogeneration systems that provide both electricity and steam [17] such as “district heating cogeneration plants with gas engines, boilers, and thermal storage, cogeneration facilities with absorption chilling (trigeneration), biogas-fueled CHP plants with a biogas store, and biomass cogeneration plants” are all examples of energy projects for which energyPRO is frequently used for techno-economic analysis [18]. It can be used to mimic any kind of energy plant because of its adaptable and all-encompassing architecture. A user-friendly interface is also utilised to conduct in-depth technical and financial studies of ongoing and planned energy projects, providing the user with a comprehensive picture of the project [19].

The graphic representation of the simulated operation that is incorporated in it provides a high-level overview and detailed explanation of the continuous changes in the load profile or energy system. energyPRO creates a thorough financial plan for the project that covers operation costs,

monthly cash flow, profit and loss statements, balance sheets, and other crucial investment indicators like NPV, IRR, and payback period. With the aid of the software, a user can compute and create a report for the emissions produced by the project under consideration (CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, and so on). Using set power prices or spot market rates, energyPRO enables daily operation optimization. The optimization is based on the size restriction of heat and fuel storage [20].

### 2.3.6 EnergyPLAN

Since 1999, the EnergyPLAN model has been regularly improved and expanded. “It is a user-friendly tool that is designed as a series of tab sheets and is programmed in Delphi Pascal. EnergyPLAN had previously been used to simulate a 100% renewable energy system for Denmark”. In terms of technology and pricing ranges, the user defines the input. The main goal of the EnergyPLAN model is to examine the energy, environmental, and economic consequences of various energy plans. Every national energy system has three important areas: electricity, heat, and transportation, which are all taken into account by EnergyPLAN. As renewable energy sources such as wind power become more widespread in energy systems, flexibility will become increasingly critical [21].

One of the most accessible ways to give flexibility is to integrate the electricity, heat, and transportation sectors utilizing technologies such as combined heat and power (CHP) plants, heat pumps, electric vehicles, and hydrogen. As a result, depending on the study's objectives, this could be a crucial factor to consider. Instead of modelling one 'optimal' solution based on pre-defined parameters, the main goal is to define a range of viable options that can be compared to one another. EnergyPLAN is a deterministic tool that uses user-defined inputs and outputs to optimize the operation of an energy system [22].

The following are some of the benefits of using the EnergyPLAN tool :

- It provides hourly analysis in great depth.
- EnergyPLAN's results can be used for both technical and economic analyses.
- It's open-source and simple to use. It has a worldwide user base.

The following are the tool's drawbacks:

- The time horizon is only one year long.
- This tool's simulation cannot be done over an extended period.



- It does not calculate the amount of CO<sub>2</sub> emitted directly. Furthermore, it produces no direct CO<sub>2</sub> emissions.

## **2.4 Requirements And Outcomes of Different Wind Resources Modelling Tools Used**

### **2.4.1 WAsP**

The following are the inputs needed to run simulations using WAsP software for wind energy evaluation [9]:

- Predictor location (meteorological station)
- Wind turbine site or met station
- Current weather conditions
- Hourly wind data
- Topography information
- Turbine height
- Obstacle near the Turbine site

Simulations are done based on the above-listed inputs to assess the following details in outputs as listed below [23]:

- Mean Wind speed at the wtg site
- Turbine installation direction
- Annual energy production
- wake effect and losses

### **2.4.2 windPRO**

The following are the inputs needed to run simulations using windPRO software for wind energy evaluation:

- Terrain elevation
- Terrain roughness
- Meteorological (meteo) stations
- Wind turbine generator make and model

Simulations are done based on the above-listed inputs to assess the following details in outputs as listed below:

- Mean Wind speed at the wtg site
- Turbine installation direction
- Annual energy production
- Wake effect and losses
- Power Curve
- Impact of hills and obstacles

### **2.4.3 HOMER Pro**

The following are the inputs needed to run simulations using for wind energy evaluation:

- wind data of the area
- Load for the chosen facility
- Number and type of Wind turbines
- Storage system to store surplus energy
- Capital investment and operation and maintenance cost

Simulations are done based on the above-listed inputs to assess the following details in outputs as listed below:

- Energy generated
- Battery storage system charging & discharging cycle
- Cost of energy generation
- Payback period

## **2.5 Equation And Calculation behind Wind Resources Modelling Tools Used**

### **2.5.1 WAsP**

The predicted power loss in wind farms as a result of the downdraft caused by upwind turbine wakes is modelled by WAsP. For wind farm analyses, this attribute is crucial. Very little power will be generated if a turbine is placed in an area with little wind, and wake effects from installing a turbine close to another one can dramatically reduce production at one of the sites. [7].

To calculate wake effects and their impacts on power production, WAsP uses the Park model. The Park model is a quick computational model that simplifies some of its estimates. The programme WAsP employs the Park model to determine wake effects and their influence on power production.

The wind turbine's susceptibility to fatigue will also be impacted by increased turbulence. The rotor blades will be particularly harmed by this. This aspect needs to be considered as well when undertaking micro-siting exercises. The crucial point to keep in mind is that other than a modest fall in production due to increased turbulence, there won't be any direct effects on energy generation. The lifespan of a particular turbine is impacted by increased turbulence. The fatigue life of crucial components like blades is determined by the accumulated damage brought on by stress cycling on various components. It is important to quantify and take into account the fatigue damage this effect causes. Another thing to think about is how best to use the land. According to studies, particularly in low to moderate wind regimes, tightly packed wind farms have higher array losses. The research of decreasing array impacts through proper geometric machine structure is known as micro-siting of wind turbines. There aren't any clear-cut rules to follow in practice. The following is the definition of array efficiency:

$$\text{Array efficiency} = \frac{E_{farm}}{E_{free}} * 100$$

Where  $E_{farm}$  = Actual turbine output

$E_{free}$  = Turbine output with no impact from other wind turbines

The following factors affect the effectiveness of an array:

- Average wind speeds and main wind directions according to the amount of land that is available.
- The relationship between turbine design and turbulence intensity (TI)
- The land's shape, orography, roughness, and orientation concerning the wind farm.
- The anticipated number of turbines or the Megawatt capacity.
- Projected annual average wind farm output in MWh
- Legal limitations on the usage of adjacent lands.

If a place has difficult, rocky terrain or extremely difficult air conditions, the accuracy of WAsP software may not be dependable [24]. The overall grid layout's orography and site ruggedness index ( $\Delta RIX$ ) are analysed by WAsP. A project's trouble spots may be found using the corresponding performance indicator (RIX). "The fractional extent of the surrounding terrain that is steeper than a critical slope and lies inside the working range of the WAsP flow model is referred to as  $\Delta RIX$ . The fractional difference (%) between the predicted and reference locations is what is referred to as  $\Delta RIX$ " [25].

There is a formula to express the relationship between  $\Delta RIX$  and the estimation error of wind speeds:

$$U_m = U_p / \exp(\alpha \Delta RIX)$$

Where,  $U_m$  = error in wind speed prediction

$U_p$  = wind speed at turbine site at particular hub height

$\alpha$  = constant

By taking into account orography and roughness, WAsP extrapolates wind climatic data inside a region using the linear atmospheric model. The Navier-Stokes equations' linear components are used in this model to calculate the wind speed at various places [7].

There are two different types of terrain analysis members used in WAsP simulations: IBZ and CFD. The IBZ terrain analysis is equivalent to the traditional WAsP models: the linearized BZ flow model and the roughness change model based on internal boundary layer theory. Since WAsP's debut in 1987, these models have served as the foundation for the programme. EllipSys' CFD function is compatible with the CFD terrain analysis. In order to set up the CFD computations, this member will arrange the calculation tiles to cover every site and submit a request for the CFD cluster [26].

In order to learn about the elevation (orography) and land cover (roughness) parameters of a terrain, WAsP uses vector maps. The terrain analysis component that determines which models are used to analyse the flow has maps as its offspring. Maps and TAs can be found across the workspace hierarchy, although often each project has its map. Different maps are frequently used for the locations of the meteo stations and the predictions. Bitmap image files that can serve as map underlays are referred to as spatial images in WAsP. In addition to being able to attach many kinds to the same vector map, they can be positioned anywhere in the hierarchy. There may be surrounding impediments that provide shelter for meteo stations and (less

frequently) turbine sites. An obstacle group is a term used to describe a collection of shielding barriers that can be connected to one or more places. Reference sites help calculate a wind farm power curve, which represents a wind farm's output as a function of wind speed and direction at the reference site. Reference sites are comparable to turbine sites in that they forecast the local wind climate [27].

Seven factors can be used to define the atmosphere's condition, and they are all location- and time-dependent. The seven equations that are typically employed to explain these seven variables are: "the equation of state, the first rule of thermodynamics, the continuity equations for mass and substance, and three parts of Newton's second law". The relevant equations can be integrated with specific initial and boundary conditions to create a mathematical model of the atmosphere. In order to produce an estimate with an acceptable level of accuracy, the models solve these equations numerically marching through time, "using the rates of change of the variables over time, substituting a ratio of finite differences for the derivative, and computing the changes of the variables over a predetermined time interval as many times as necessary" [28].

It should be highlighted that there will be several issues with arranging the layout of wind farms. The layouts are often chosen based on the row and column space. Numerous scientific and managerial difficulties are associated with the micro-siting of wind turbines. The issue of whether simplified thumb rules can be developed so that the authorities in charge of approving wind farms can use them without having to consult topic experts again cannot be easily resolved. Some fundamental guidelines can still be developed to maximise the utilisation of the land and resources. The land is more expensive to buy in windy places [29].

### **2.5.2 windPRO**

The base used to enter all data into the programme is called windPRO, and the solver, WASP, is in charge of simulating wind or other forms of energy and creating resource maps. By taking into account orography and roughness, windPRO extrapolates wind climatic data inside a region using the linear atmospheric model. The Navier-Stokes equations' linear components are used in this model to calculate the wind speed at various places [30].

Based on height contour and roughness data, windPRO's numerous methods for wind analysis can determine mean wind speed and direction. The measure-correlate-predict (MCP) method is one technique. The capabilities listed below are part of the MCP module for windPRO and

allow for the completion of a thorough MCP analysis in a matter of hours: Long-term data: NCEP / NCAR data extraction:

- Measure using filtered time series data load
- Using correlation analysis to extract concurrent data
- predict using linear regression, the matrix approach, the Weibull Scale, and the Wind Index.
- Wind data are generated by STATGEN directly from the MCP result.

The regression model is used to compute the long-term corrected meteorological data (transfer function). After transferring all of the data from the long-term reference series, a Monte-Carlo simulation method is used to determine the residuals. The end product is a "fabricated" time series that shows a long-term adjusted wind distribution.

To calculate the long-term distribution using the Weibull Scale MCP, you must first search for the relevant Weibull distributions and then calculate the adjustment table. The Weibull Scale method is an extremely straightforward empirical technique that performs "linear manipulation on the Weibull form and scale parameters ( $A,k$ ) as well as modifications to the frequency distribution" [30].

The matrix approach in windPRO uses joint distributions fitted on the matrix of wind speed bins and wind direction bins to simulate changes in wind speed and direction. To move wind directions and speeds to the turbine site from the meteo station, a set of non-linear transfer functions are computed using the parallel period of recorded wind data.

Utilizing actual power curves for the wind turbine, the Wind Index MCP technique in windPRO allows users to calculate the wind indexes. Additionally, a general power curve built on a squared-truncated wind speed technique could be selected. The MCP adjustment is applied to the estimated WTG energy yield when the wind indices are calculated, i.e. by multiplying the production estimate by a correction factor depending on the difference in the wind index from the estimated long-term site data to the estimated short-term site data estimate. Using the findings from MCP, Wind analysis is conducted using the STATGEN approach based on the aforementioned methods [30].

The PARK technique is the approach utilised by the WAsP software that we covered in section 2.5.1. , is another way to perform wind analysis and energy assessment. Figure 10 shows how windPRO performed the wind energy assessment using WAsP in the background [31].

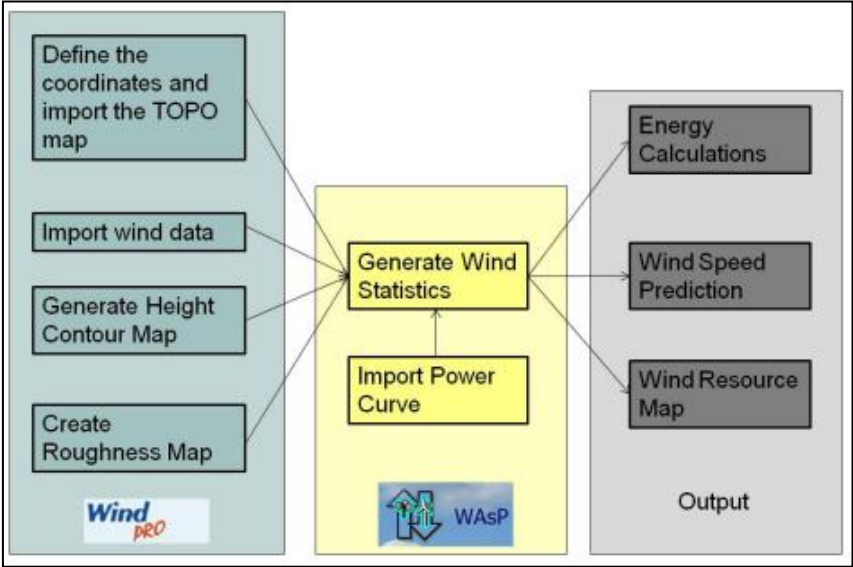


Figure 10 windPRO and WAsP Integration

**2.5.3 HOMER Pro**

The resources data (Solar, Temperature, Wind) used by HOMER Pro can be selected by location, and they are obtained from NASA Surface Meteorology. The power output of the wind turbine is calculated by HOMER Pro in three steps, one for each time step.

- Wind Speed Estimation

The Weibull probability distribution was used to calculate the most likely wind speed at various places using maximum and minimum data. If the probability density function for a random variable x is provided as in Equation, then the variable has a Weibull distribution [32].

$$f(x; \alpha, \theta) = \begin{cases} \frac{\alpha}{\theta^\alpha} \cdot x^{\alpha-1} \cdot \exp[-(x/\theta)^\alpha] & x \geq 0 \\ 0 & x < 0 \end{cases}$$

The parameters  $\alpha$  and  $\theta$  are estimated with experimental data. Depending on their values, the equation for the probability density function of Rayleigh distribution is produced as shown below:

$$f(x; \sigma^2) = \frac{x}{\sigma^2} \cdot \exp(-x^2/2\sigma^2) \quad x > 0$$

Using the user's inputs on the Wind Resource page, HOMER Pro calculates the wind speed at the wind turbine hub height for each time step. HOMER Pro determines the wind speed at the hub height by using the logarithmic law:

$$U_{hub} = U_{anem} * \frac{\ln\left(\frac{Z_{hub}}{Z_0}\right)}{\ln\left(\frac{Z_{anem}}{Z_0}\right)}$$

Where,

$U_{hub}$  = the wind speed at the hub height of the wind turbine [m/s]

$U_{anem}$  = the wind speed at anemometer height [m/s]

$Z_{hub}$  = the hub height of the wind turbine [m]

$Z_{anem}$  = the anemometer height [m]

$Z_0$  = the surface roughness length [m]

In order to determine the anticipated power production at that wind speed under typical temperature and pressure circumstances, HOMER Pro analyses the wind turbine's power curve after determining the wind speed at hub height. "Each wind turbine has a very unique power performance curve since the output power of a wind turbine significantly varies with wind speed. A power curve aids in predicting wind energy without understanding the precise technical details of the components of the wind turbine generating system" [33]. The power curve shows the relationship between wind speed and hub height in terms of electrical power output. The lowest speed at which the turbine generates useful power is known as the cut-in speed ( $u_c$ ). The rated speed is the wind speed at which the electrical generator's maximum output power, or rated power, is reached ( $u_r$ ). Usually, the cut-out ( $u_s$ ) is restricted by technical design and safety standards. According to Figure 11, it is the highest wind speed at which a turbine may produce power.



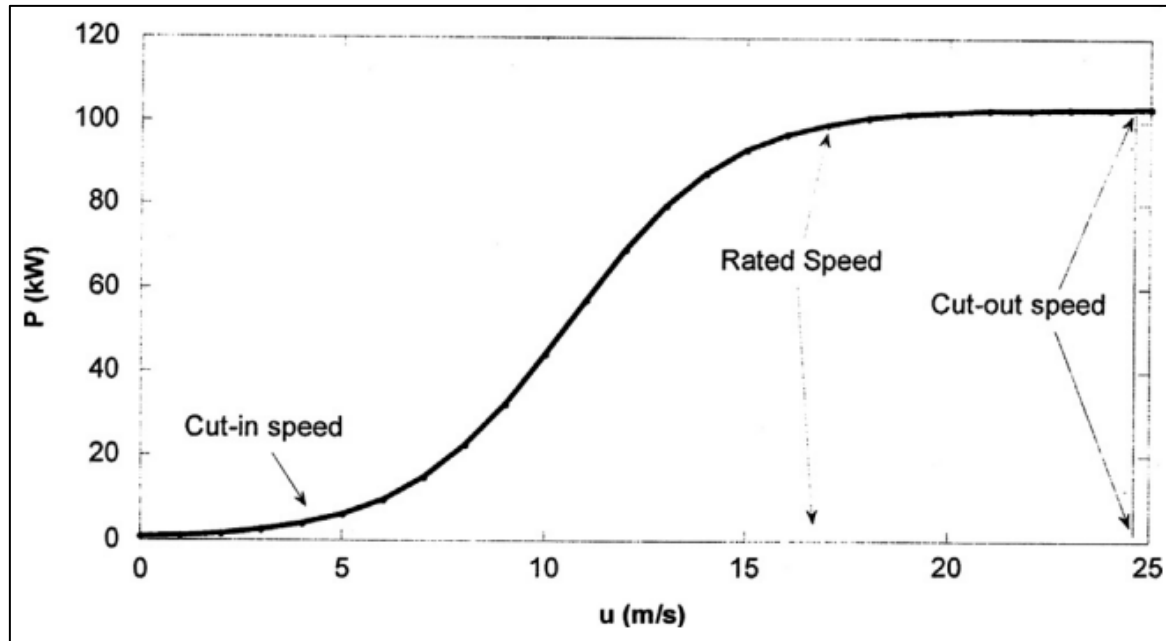


Figure 11 Wind Turbine Power Curve

“A power curve is frequently used to represent the performance of wind turbines under standard temperature and pressure (STP) conditions. As shown in the equation below, HOMER Pro multiplies the power value anticipated by the power curve by the air density ratio in order to adjust to real-world conditions” [34]:

$$P_{WTG} = \left( \frac{\rho}{\rho_0} \right) * P_{WTG,STP}$$

Where,

$P_{WTG}$  = the wind turbine power output [kW]

$P_{WTG,STP}$  = the wind turbine power output at standard temperature and pressure [kW]

$\rho$  = the actual air density [kg/m<sup>3</sup>]

$\rho_0$  = the air density at standard temperature and pressure (1.225 kg/m<sup>3</sup>)

## 2.6 Factors To Be Considered for Calculating Wind Speed at The Site

Wind speed and direction at the exact turbine site are different to the wind speed and direction measured at the meteo station. There are various factors which impact wind speed and direction but two very important factors are the Wake effect and Topography.

### 2.6.1 Wake Effect

The wake effect is the change in wind speed due to wind turbines on each other when turbines are placed closer to one another. To calculate the wake effect park model is used. The Park model is a quick and short computational model that simplifies some of its estimates. According

to the programme, the speed behind the turbine rotor would initially decrease. An empirical wake-decay constant and the thrust coefficient curve of the turbine will be used to compute this speed reduction. By ignoring some data from the flow field near a turbine rotor and assuming that the wakes spread out linearly with distance, the computation is made easier. The wake cross sections of the turbines upstream are superimposed when there are many wakes, as seen in Figure 12. The anticipated wind speed for a downwind turbine is calculated using the free stream wind speed with the fewest wake effects. Next, the wake effects-induced downwind wind speed deficit is calculated using:

$$\delta V_{01} = U_0(1 - \sqrt{1 - C_t}) \left( \frac{D_0}{D_0 + 2kX_{01}} \right)^2 \frac{A_{overlap}}{A_1^{(R)}}$$

Where,  $U_0$  = Undisturbed wind speed at the upwind turbine  
 $D_0$  = rotor diameter  
 $k$  = wake coefficient

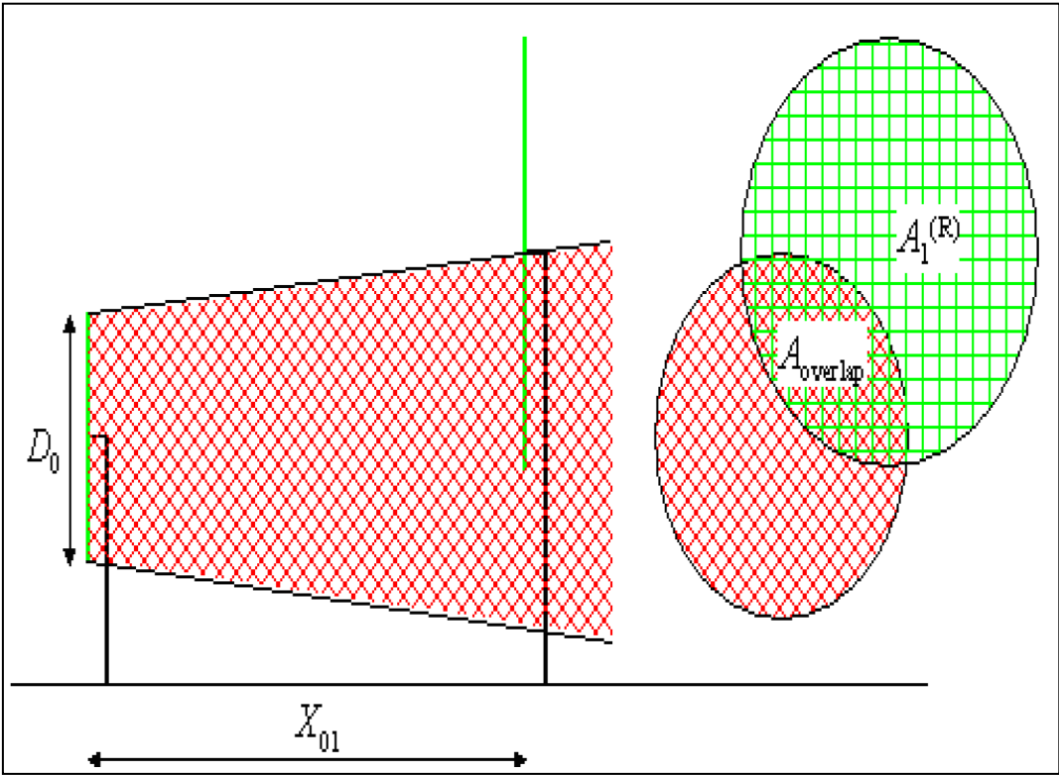


Figure 12 Illustration of How Wake Effect Is Calculated At Turbine Output Using The Park Model

Because of the wake effect, it becomes vital to position the turbines so that their function at each site is hindered by other turbines the least and won't significantly interfere with nearby turbines on their own [23]. When a turbine is built in a small area, the wind conditions in the immediate area will change. Two significant effects have been found. The first is a reduction in wind speed in front of the rotor as shown in Figure 13. The other is that the wind field is

made more turbulent by the rotor activity. The wind power generated by the machines in the "wake" of the machines in front will be reduced as a result of both of these factors.

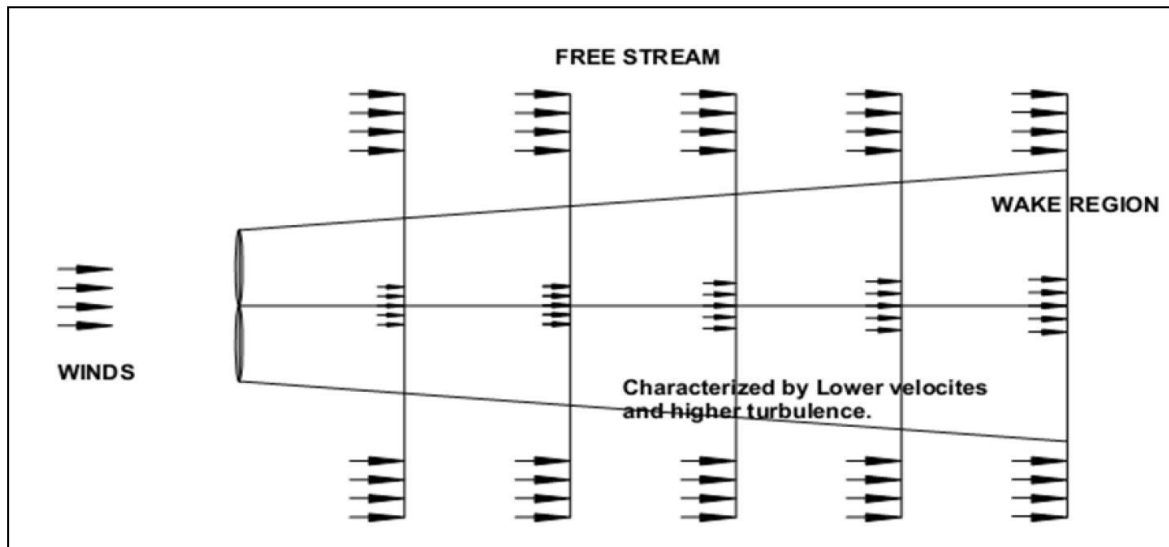


Figure 13 Wake Effect on Wind Turbine

## 2.6.2 Topography

In wind energy assessments, it is crucial to take into account how the orography, topography, and surface roughness may affect the results. The findings of the wind speed measurements are influenced by the surrounding topography and the general weather system, which typically has an influence radius of several hundred kilometres. An accurate description of the station and its surroundings should take into account the influence of local structures, sheltering obstacles, open spaces, woods, water bodies, and terrain elevation changes, all of which have an impact on wind speed and, by extension, wind energy [35]. Because there is less friction and pressure gradient when the turbine is located at a higher altitude than the meteorological station, the wind speed at the site will be higher than at the station. Similar to how wind speed is higher near the open sea than on level terrain.

Due to the intricacy of the surrounding areas, the accuracy of the wind speed data is significantly decreased. When completing a wind energy assessment, it is crucial to employ accurate orography and roughness data in modelling software.

### 3 Methodology

#### 3.1 Steps For Simulation on Each Tool Separately

##### 3.1.1 WAsP

This section will cover the step-by-step process for running the simulation. The workspace hierarchy window first needs to be created before it appears on the screen. Projects are always included in the workspace hierarchy, which is shown in Figure 14 and contains all the elements needed to do a wind evaluation including a new project named “Example” then under the same tree it contains generalised wind climate, terrain data and wind turbine site and wind turbine generator. The complete work hierarchy is discussed in detail below.

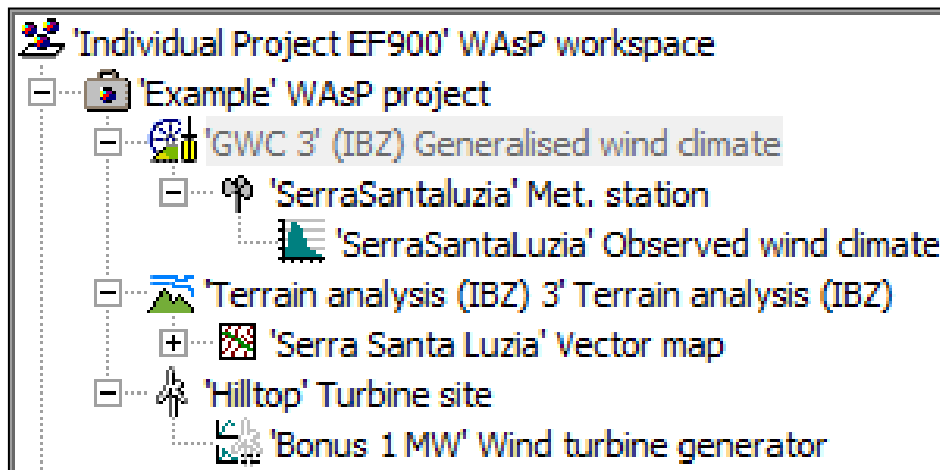


Figure 14 WAsP Workspace Hierarchy

First and foremost, any project requires that we supply a generalised wind climate for the area where the turbine will be erected. Generalized wind climate provides information on the wind speed at different hub heights and different directions, and the wind climate files can be acquired from several websites, including ERA and EMD, or we can choose the closest accessible weather station to the location of the proposed wind turbine. The next step is to define the meteo station, which enables us to locate the data collection point on a related map and, in turn, provides us with information about the local wind climate. However, we may input wind data directly from the worldwide wind atlas, a product created exclusively by the WAsP, and data can be linked. Using the global wind atlas also saves us from having to provide coordinated and observed wind climate files separately for each met station. Besides that, it has the drawback that the wind data in the global wind atlas is derived from simulations of mesoscale time-series models over ten years, which does make it less certain than actual data from

meteorological masts, but it is unquestionably still useful and frequently used for estimating preliminary energy yields.

The next stage is to include topography detail (orography and roughness data) and to obtain the vector map once the weather information has been submitted to the system. There are numerous open DEM platforms from which we can acquire kml/kmz files to obtain orography and roughness data. Then, as WAsP only accepts .map format files as vector maps for the orography and roughness data, we may upload those files to the WAsP map editor and transform them into .map files. We can alter the landscape data if necessary in the WAsP map editor as well. However, one drawback or challenge that typically arises when uploading kml/kmz files in MAP editor is that it does not permit the import of files that feature complex terrain and in that case, you cannot modify or convert them into .map format that is accepted by WAsP software.

Thus, windPro software can be used to extract the height contour and roughness details of the terrain to solve the problem of acquiring terrain data and uploading it in a WAsP compliant format. For the site centre, windPRO enables the download of height contour and roughness details from multiple web sources. Under windPRO section 3.1.2, the specific processes to download the height contour and roughness data files are described. The downloaded data will then be converted using the WAsP programme into a format that is compatible with WAsP, namely the .map format. Additionally, we can avoid using the WAsP map editor by directly importing the downloaded data into the WAsP software. Then, as illustrated in Figure 14, we will import the files into WAsP under the IBZ hierarchy of terrain analysis. According to Figure 15 for the map projection set, the zone is set to 42 and the datum is WGS 1984.

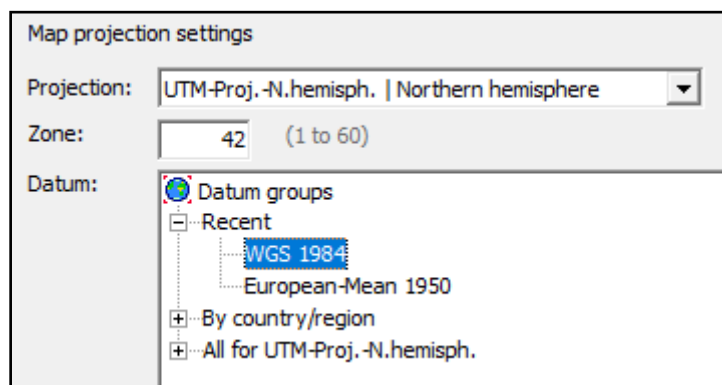


Figure 15 Map Projection of Wind Turbine Site

Once the Weather details and Terrain details of the site are added to the software. The spatial view of the location is generated and depicted in Figure 16 with x and y coordinates suggesting latitude and longitude as per UTM coordinate system. The places with either an uphill or a

downward slope are marked by red colour lines. Forests that will impede the path of the wind are indicated by green lines. The goal is to locate the areas with predominant wind and place the turbine which seems suitable or has more red contours as shown in Figure 16.

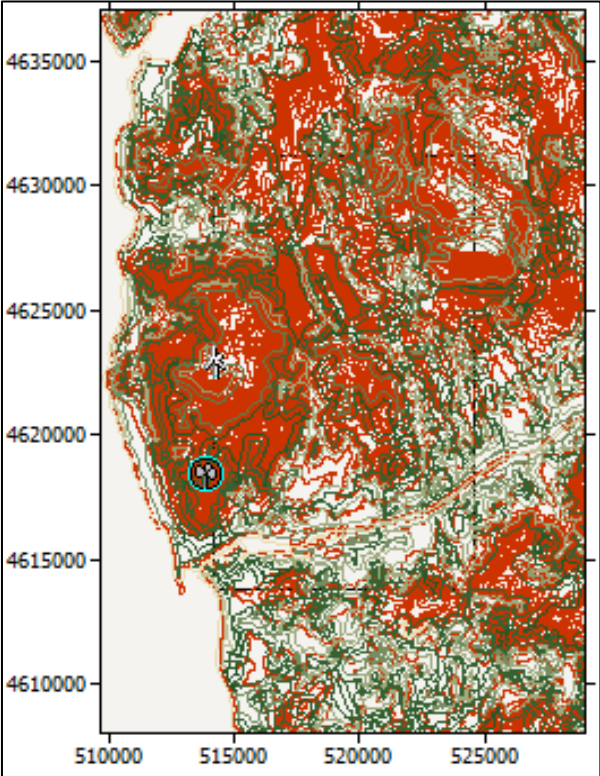


Figure 16 Spatial Image of The Site Showing Turbine Site, Height Contour & Roughness

On the hilltop, a turbine facility has been built. The turbine's hub height is assumed to be 100 metres. Now, as illustrated in Figure 16, the turbine may be seen in a spatial view at the specified coordinates. The chosen turbine has a rated power capacity of 1 MW and other details of the wind turbine generator are shown in Table 2. The power curve of the selected wind turbines is depicted in Figure 17 below. When the rated wind speed is 14.6 m/s, it states that each turbine may produce a maximum output of 984 kW. The cut-in and cut-off wind speeds are, respectively, 4.0 m/s and 25 m/s.

Table 2 Specification of Wind Turbine

Manufacturer	Rating (MW)	Rotor Diameter (m)	Control System	Hub Height (m)
Bonus Energy	1	54.2	Pitch	100

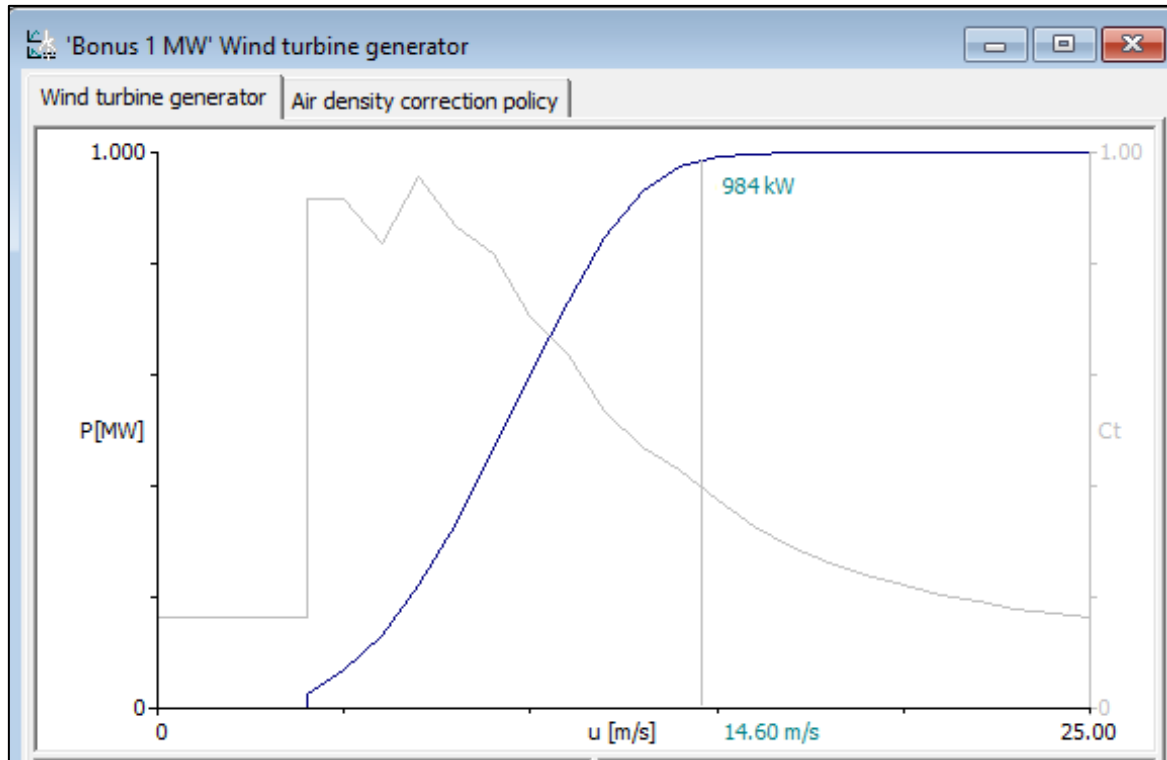


Figure 17 Power Curve of Selected Wind Turbine

Now the wtg has been selected and placed at the site, We will be simulating to calculate wind speed at the site and AEP taking meteo station wind data as reference and considering the terrain data and wake effect.

### 3.1.2 windPRO

The following stages or processes must be followed to do a wind energy assessment using windPRO. First, a new project or new project with a wizard must be created. When a new project is formed, all the weather and terrain information for the site location must be manually imported or downloaded, as opposed to when a new project is created using the wizard, when all the information is obtained automatically. As illustrated in Figure 18, we will define project attributes and site coordinates once the new project has been created.



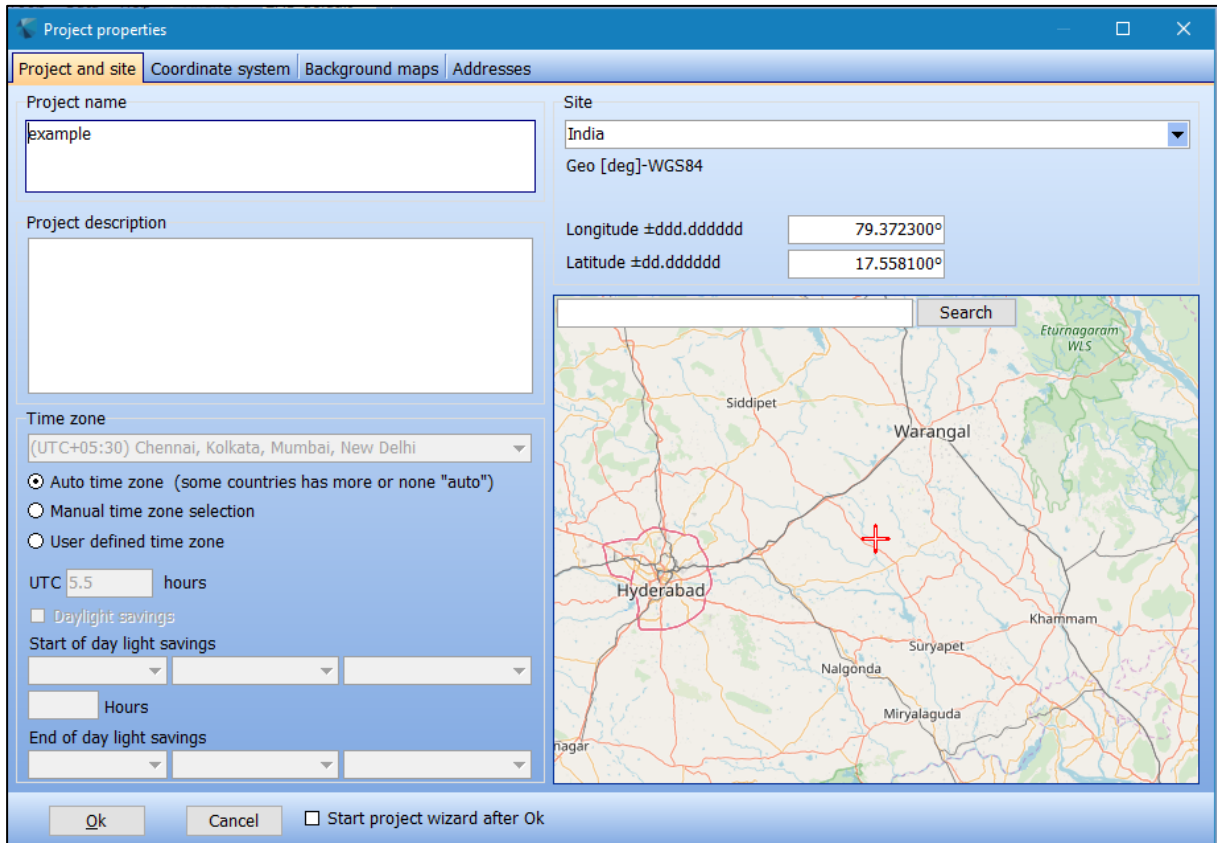


Figure 18 Project Properties in windPRO

After we've updated the project properties and site information, we'll create a new layer for the height contour, insert line data inside of it, and then define the specifics of that line data by either importing the downloaded file, if available, or by using the online data tab, as shown in Figure 19.

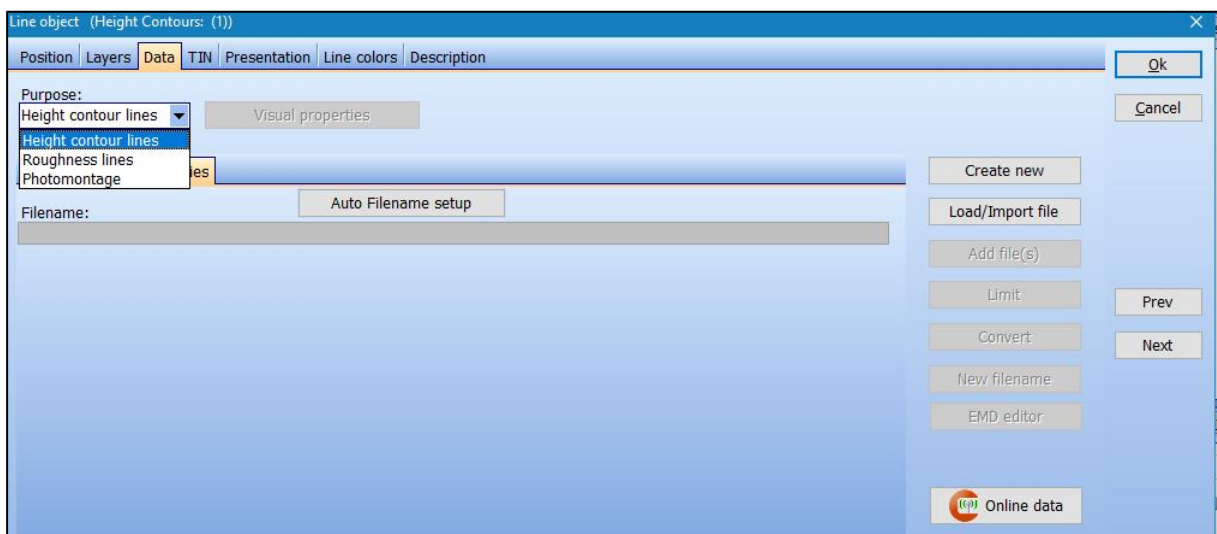


Figure 19 Line Object for Height Contour And Roughness



Next, we will define online data. As seen in Figure 20. , we have taken into account SRTM: Shuttle DTM 3 arc-second in this report.

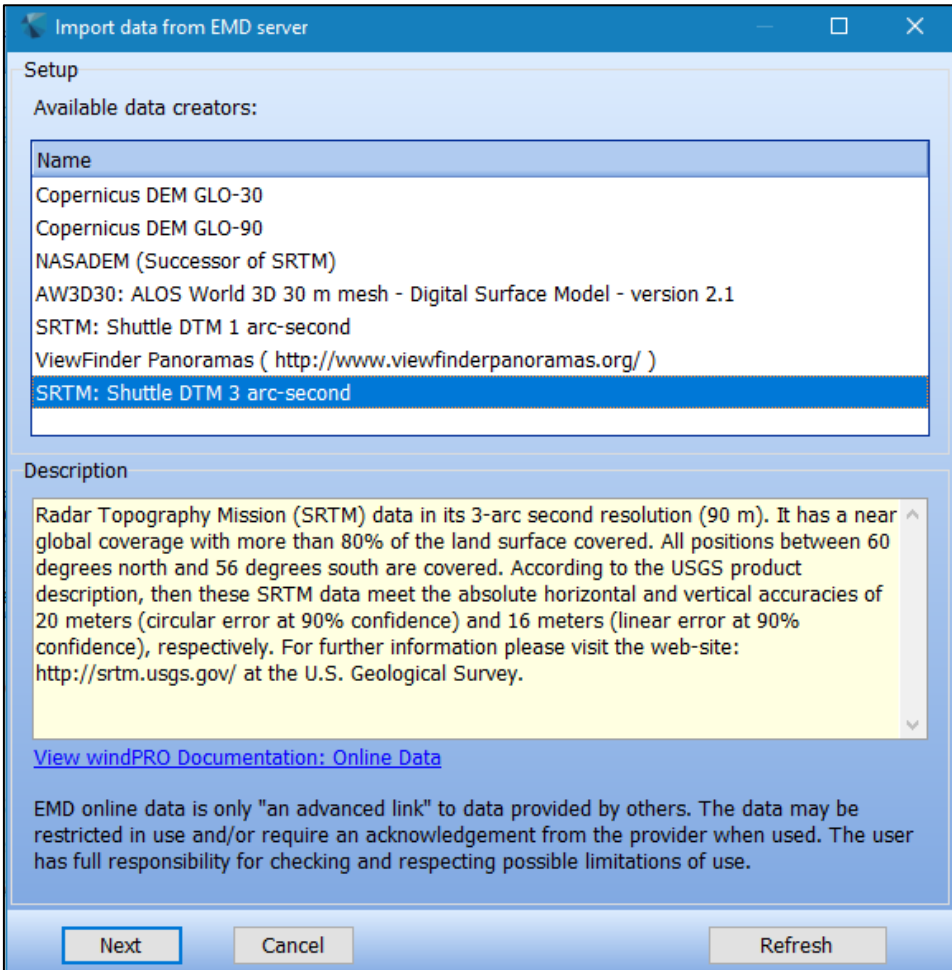


Figure 20 Various Online Data Sources

The area for which we must download the height contour data must then be determined. 7km by 7km is the bare minimum needed. Therefore, the 30km by 30km height contour region examined in this report is given in Figure 21.

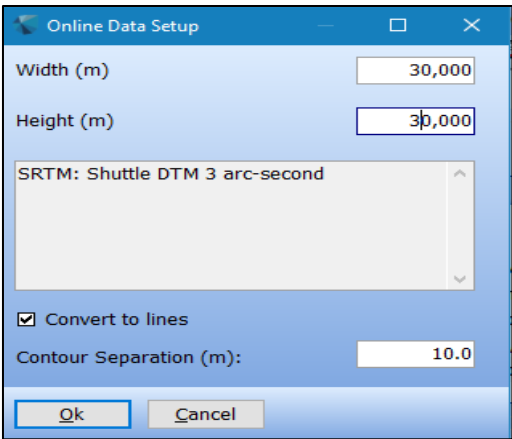


Figure 21 Online Data Settings

Similar to height contour data, we can download roughness data as well, with the exception that the minimum size requirement for roughness lines is now 20 km by 20 km. Therefore, the roughness lines area considered for simulations in this report is 60 km by 60 km.

After downloading the height contour and roughness data. We can convert those files to the map format that WAsP supports. We can import terrain analysis input files for further computation and wind energy assessment in WAsP by using the feature listed below.

After updating the topography data in the new project, we will now add a new layer for wind data. You can get wind climate data files from a variety of internet sources, particularly by choosing the meteo station that is closest to the site's centre. The location of the turbine is chosen along with the model of the wind turbine generator to be used for wind energy assessment after the wind data and topography data are provided in the model. To select the best area or most suitable place to install the turbine, we will use the resource calculation (RESGEN) method which performs wind analysis and shows approximate wind speed at all places in the selected area with a resolution as low as 10 m. And then changes the spatial image with different colours based on the wind speed. This step helps us to find a few good places to install wind turbines and perform a detailed study for those particular places.

There are several methods for wind analysis and energy assessment at the exact place where the Turbine is to be installed taking the reference data of the selected meteo station, and in this report, either the RESGEN, STATGEN or PARK energy calculation method is used to run the simulation and carry out the computation. STATGEN uses MCP in the background to generate wind statistics while the park method uses WAsP as a background tool for wind analysis and calculating annual energy production (AEP). The model's site data is inserted to start the calculation, and from there we must choose the model and method to be utilised for calculating the wind speed and energy, as illustrated in Figure 22.

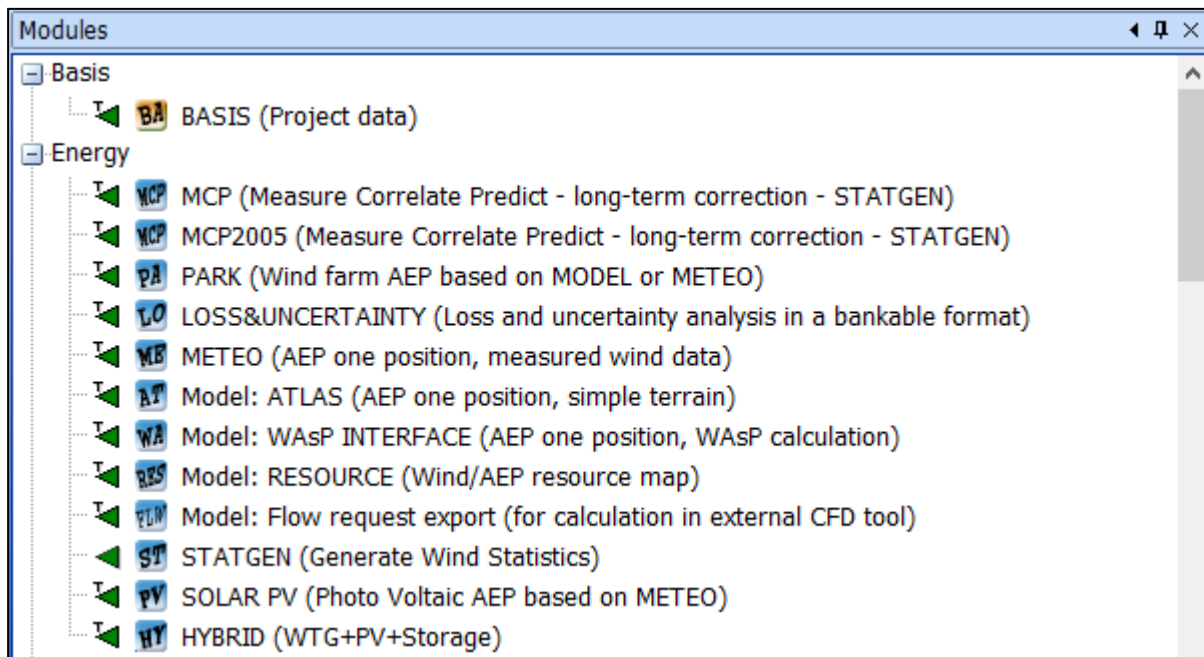


Figure 22 Various Modules for Energy Calculation

Depending on the calculation method that was used, Simulations are run, and the reports are generated.

### 3.1.3 HOMER Pro

HOMER Pro is highly generalised software that may be used to estimate annual energy production using the generalised wind data available. The outcome is unaffected by the location of the turbines at a given location, as was covered in prior sections. Additionally, when calculating AEP, the orography and roughness statistics are not taken into account. To calculate AEP from the wind turbine following steps are to be followed. We must first specify the location of the turbine's site or the area where we intend to put WTG. Then, for the specific area, we must add wind data, which can be imported using a time series data file, a library file downloaded from one of the many online wind data sources, or directly from the internet using information from a NASA prediction of world energy resource database for last 30 years. The next step is to choose the appropriate wind turbine from the library when the site and wind data have been updated.

Now that all the information about wind turbines is available in HOMER Pro, we will add some electrical load. Since we are only checking the annual energy production in this case, we can choose between residential and community load using the generalised load profiles that are already present in HOMERPRO. The energy storage system, which enables us to save excess

energy and use it during the peak hour, will then be added. Therefore, we can choose a Li-ion battery from the several choices offered in the library.

Once the entire energy system, which consists of the energy generation component, the WTG, the electrical load, and the energy storage system in the form of a Li-ion battery, is added. Following that, a calculation is made, and a report is produced.

### 3.2 Simulation By Different Modelling Software for Location 1

#### 3.2.1 WAsP

Based on the procedure and steps discussed in section 3.1.1 to model and perform the simulation. In this section we would be performing the simulation at site 1 as discussed in section 2.2.1, Firstly we have created a new project named “Site 1 Gujrat” and in the hierarchy under the project, generalised wind climate data is imported using global wind atlas as depicted in Figure 23. Wind climate data is directly integrated into the WAsP from the Global Wind Atlas. And it shows wind speed at different heights, Weibull distribution and wind speed in different directions.

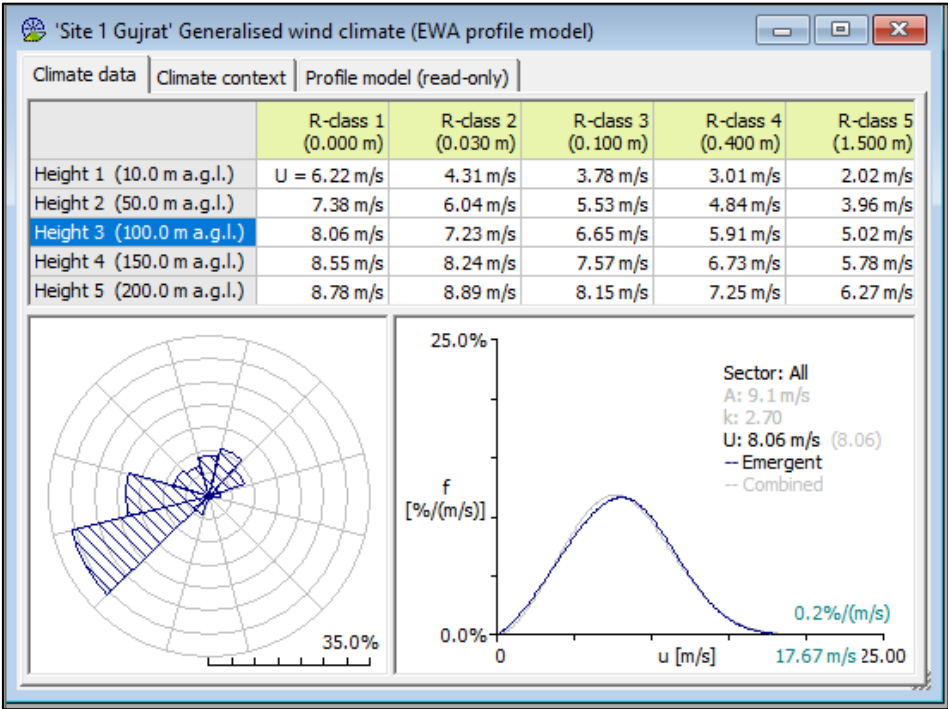


Figure 23 Wind Climate at Site 1 Gujrat

After the wind data is defined, Terrain data (Orography & roughness data) is defined by importing the .map file for height contour and the roughness data files as shown in Figure 26 under the workspace hierarchy. Here the vector maps for terrain analysis are generated using

the windPRO software as the WAsP map editor was not supporting the complex kml/kmz files as discussed in section 3.1.1.

After defining the wind climate and terrain data, the location of the wind turbine is chosen, and the turbines are then positioned in the spatial image with x & y coordinates defining latitude and longitude and the resolution of the height contour map is 90m as illustrated in Figure 24. In this case, we have selected 4 wind turbines to analyse the best place to install the wind turbine and also to understand the wake effect and losses due to it.

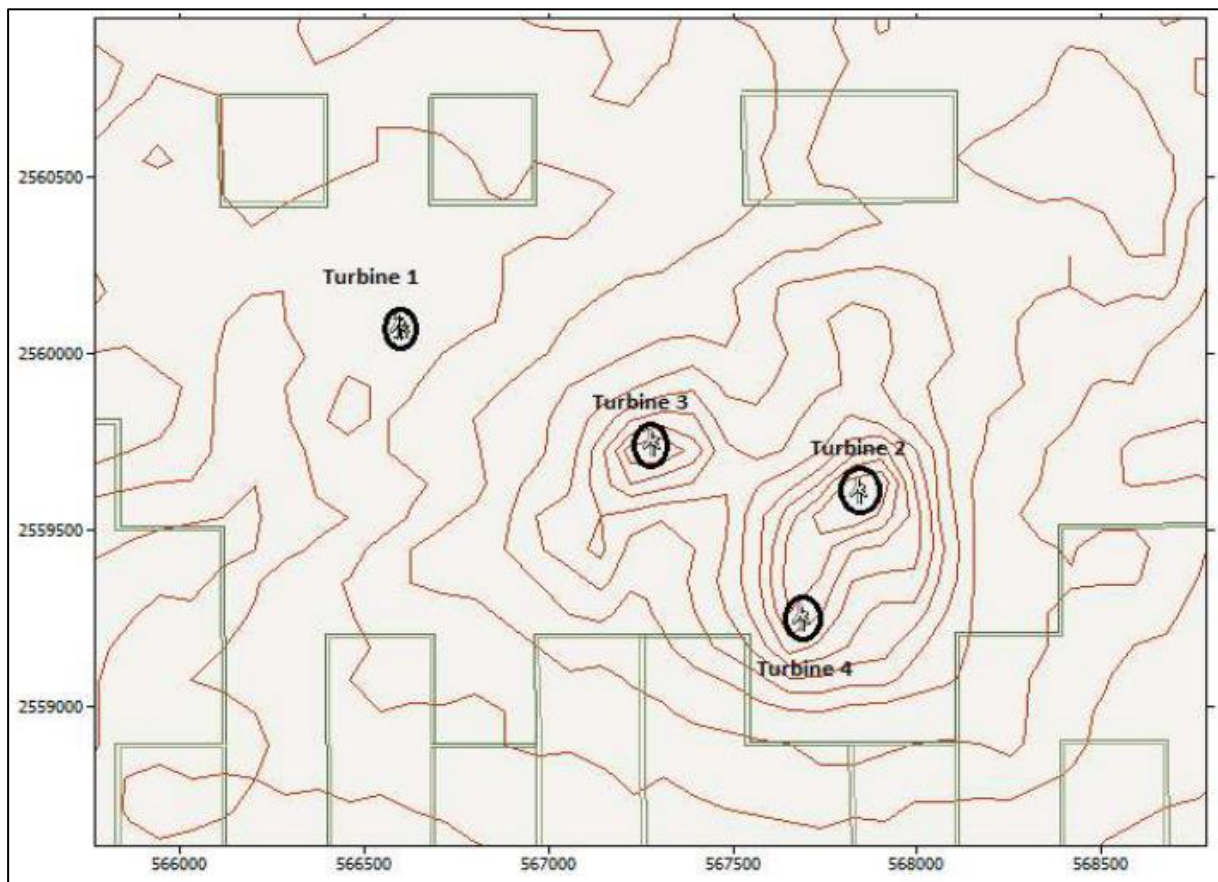


Figure 24 Spatial Image of The Site 1 With Turbine

Following that, a wind turbine generator is chosen; in this instance, the 2MW Vestas V90 model is selected, other specifications and power characteristics of the WTG are presented in Figure 25.

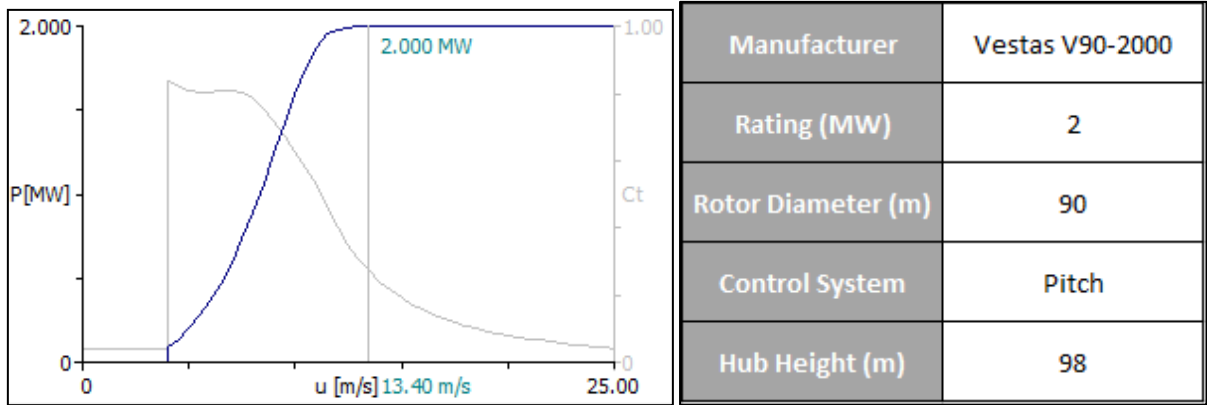


Figure 25 Power Curve Characteristics & Specification of Selected Turbine Generator

Now all the inputs are added under the Site 1 Project workspace hierarchy which includes wind data, terrain data and turbines as shown in Figure 26.

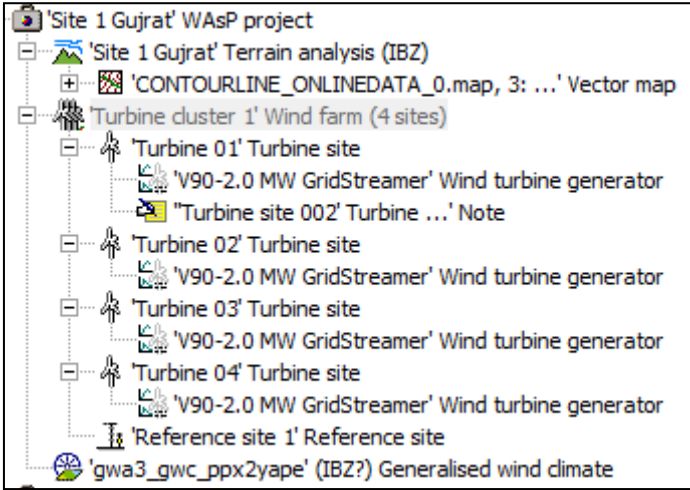


Figure 26 WASP Workspace Hierarchy Site 1

After that, the wind energy calculation will be done, and section 4.1.1 will analyse the results.

**3.2.2 windPRO**

The model and steps outlined in section 3.1.2 were used to carry out the simulation. We will be performing the simulation at Site 1 as stated in Section 2.2.1. To begin, we have created a new project called "Site 1 Gujrat." The site location and coordinate system for the simulation would then be determined. When the site centre is finalized, we will add height contour and roughness line layers. After that, we will use online data to import the terrain analysis files (orography and roughness data).

The next stage is to include wind data around the site centre when the topographical data in the windPRO model has been updated. Since EMD-WRF IND meteorological data is located closest to the site location in this instance, we chose online data and downloaded it. Once the



wind data is imported for the site location, we can observe that the wind is stronger in the WSW direction (west-southwest) and also the Weibull distribution of wind speed at all heights from all directions is depicted in Figure 27.

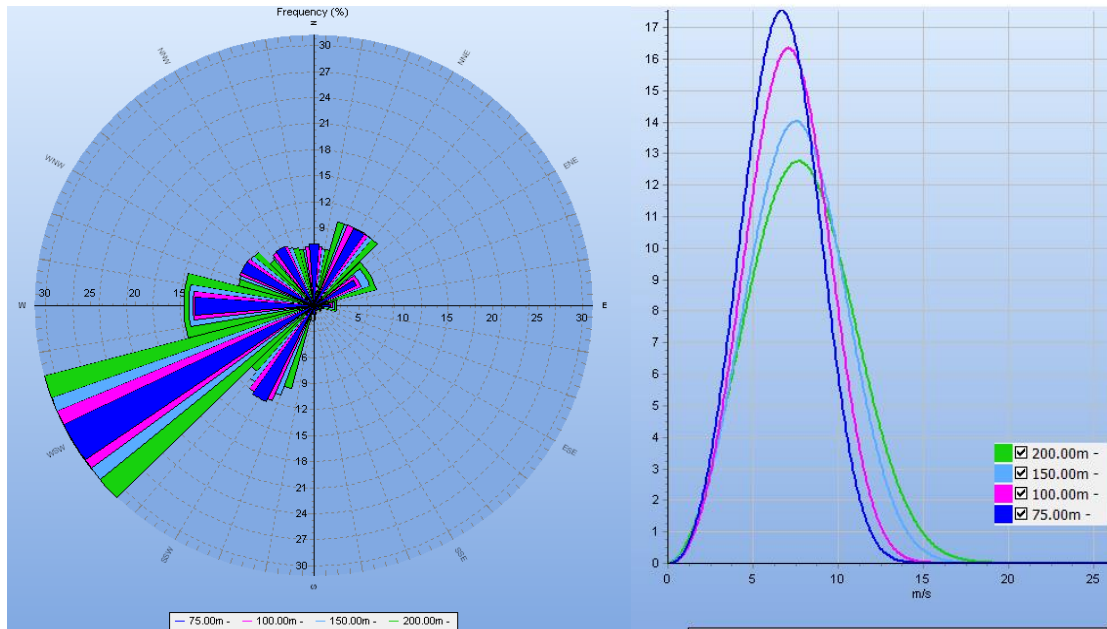


Figure 27 Rose View & Weibull Distribution

Following the inclusion of all relevant topography and wind data in the model, a wind turbine generator is chosen from among the many models on the market. A hub height of 100 metres is taken into account in this simulation while using the Vestas V90 model. In the aforementioned part, we used the same wind turbine generator that was chosen for the WAsP software simulation, and the specifications for the turbine generators are displayed in Figure 25. And we have selected 4 wind turbines are different locations nearby to each other as shown in Figure 28 to analyse which place is best suited in the location to generate max output.

Once all the input required for modelling is added to the software, a topography image is generated for the area using google earth as illustrated in Figure 28, which shows 4 wind turbines, meteo station location, height contours of the area and wind speed at a different location.



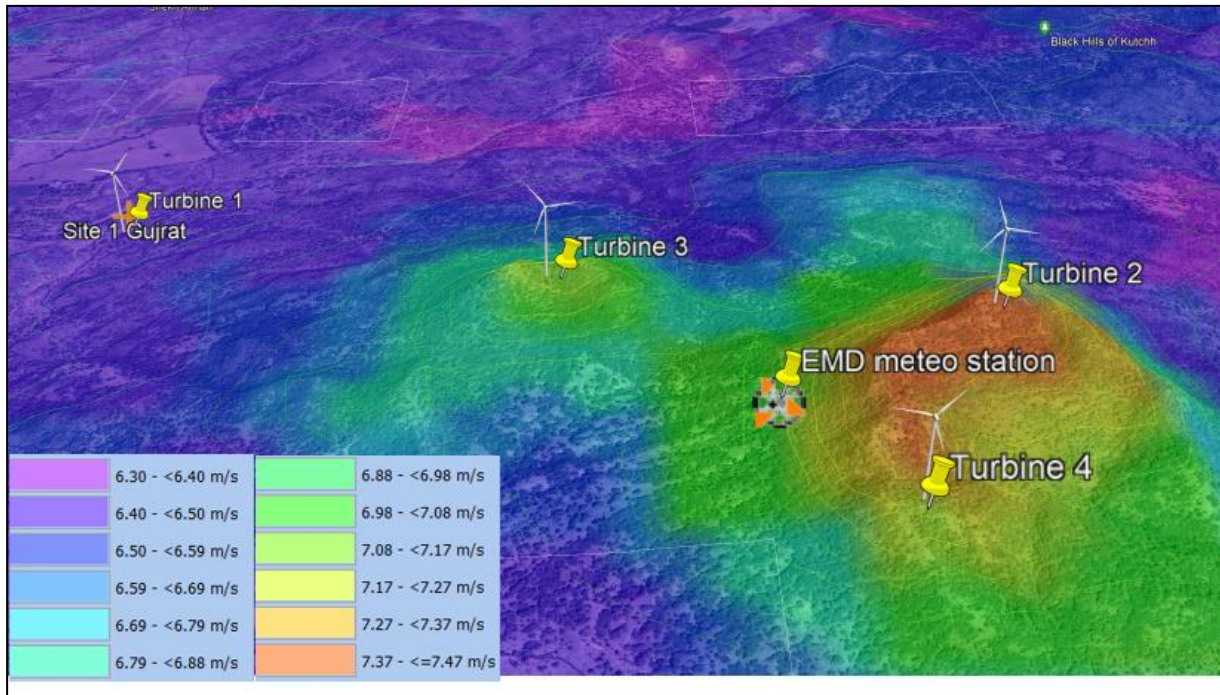


Figure 28 Spatial Image of Site 1 Gujrat

All of the input needed to complete the calculation is currently available and updated in the project. As a result, we shall execute the calculation for the study of wind energy. To do the calculation, we must first enter the site's data and choose a model from the available selection of wind energy calculation models in Figure 22. Now windPRO model is currently prepared to conduct the simulation and produce the output data. Figure 29 displays the entire list of objects added to prepare the project for simulation. In addition to the x and y coordinates for each object added to the model. Also, we can see various layers of height contour, roughness, turbines, wind data, and site data.

Description	Locked	Longitude ±dc	Latitude ±dd.d	Z	Type	System label	User	Result (most rec)	Layers
EMD-WRF India_N23.142_E	<input type="checkbox"/>	69.660000°	23.142000°	258.5	Meteorolo		42	3.86 m/s @ 10.0	Climate data
Height Contours: CONTOUF	<input type="checkbox"/>	69.650660°	23.147898°		Line Objec		36		height contour
Roughness Lines: ROUGHNI	<input type="checkbox"/>	69.650660°	23.147898°		Line Objec		37		Roughness
Site data: RESGEN (26)	<input type="checkbox"/>	69.659972°	23.142017°	258.0	Site Data		76		Existing Turbines
Site data: STATGEN (24)	<input type="checkbox"/>	69.660000°	23.142000°	258.5	Site Data		74		Existing Turbines
Site data: WASP (12)	<input type="checkbox"/>	69.660000°	23.142000°	258.5	Site Data		54		Existing Turbines
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.650574°	23.147937°	200.0	New WTG		38	Site : 4,857 MWh/y;	2 Layer 2
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.662762°	23.143675°	290.0	New WTG		62	6,659 MWh/y;	3 Layer 2
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.657269°	23.144938°	270.0	New WTG		63	6,285 MWh/y;	3 Layer 2
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.661217°	23.140439°	269.3	New WTG		64	6,498 MWh/y;	3 Layer 2

Figure 29 windPRO Site 1 Gujrat Object List

Now, calculations are made using windPRO for site 1 in Gujrat, and section 4.1.2 discusses the outcomes of the simulation.

### 3.2.3 HOMER Pro

The method discussed in section 3.1.3 will be used to model a wind turbine for site 1 in Gujarat in this section. First, we chose the location where we wanted to put the turbine, using WASP or windPRO to get the coordinates of the site's centre. Then in WASP and windPRO, the wind turbine model is chosen. The VESTAS V90 model was chosen, but the HOMERpro library did not have that model. As a result, we chose the Leitwind LTW90 WTG model with the same rating and hub height and other turbine specifications listed in Table 3. LTW90 model also has a nearly identical power curve to the Vestas V90 model, as shown in Figure 30.

Table 3 HOMER Pro Wind Turbine Specification

Manufacturer	Rating (MW)	Rotor Diameter (m)	Control System	Hub Height (m)
Leitwind LTW90	2	90	Pitch	98

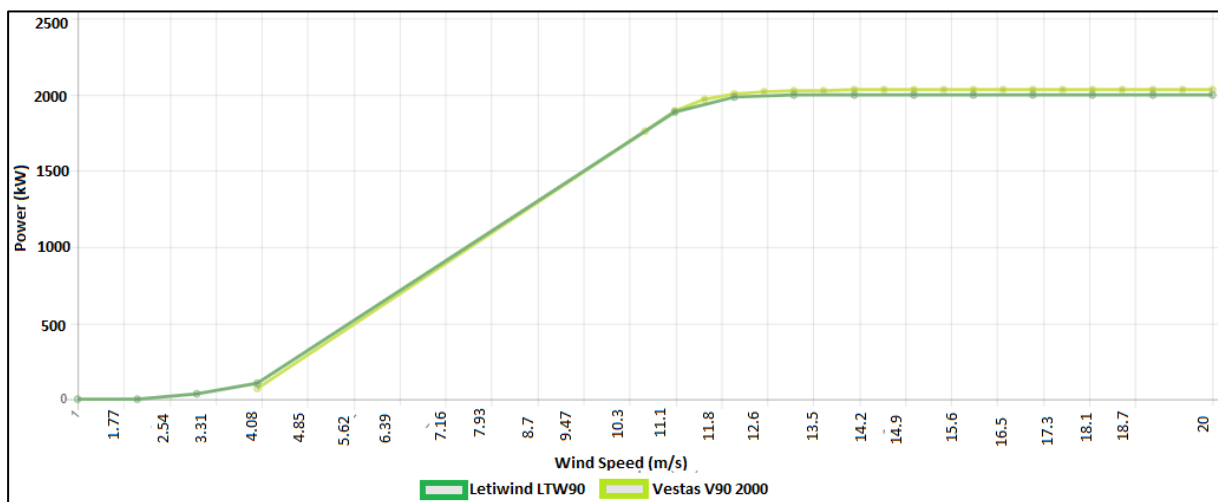


Figure 30 Power Curve Comparison

Once the wind turbine is added, Wind data is added from the internet which uses the NASA database which shows the monthly and annual average wind speed in the location. The next step is to add an electrical load to perform the simulation so we have added a generalised electrical load for the residential area and additionally, a 1 MW lithium-ion battery is selected. The complete energy system schematic is shown in Figure 31

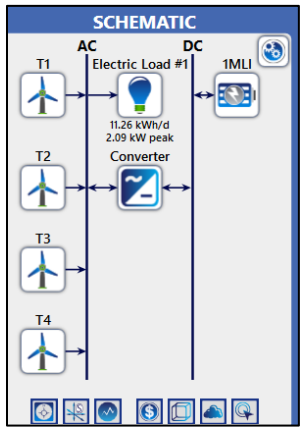


Figure 31 Energy System Schematic

Now the calculation is run and a report is generated which is discussed in section 4.1.3

### 3.3 Simulation By Different Modelling Software for Location 2

#### 3.3.1 WAsP

Similar to section 3.2.1, Now we will be modelling for the simulations to be performed at Site 2 Gujrat as described in 2.2.2 which is around 100 km away from site 1. First, we will be creating a new project named “Site 2 Gujrat” and in the hierarchy under the project, generalised wind climate data is imported using a global wind atlas as depicted in Figure 32. Wind climate data is directly integrated into the WAsP from the Global Wind Atlas. The generalised wind climate tells wind speed at different hub heights and from different directions and Weibull distribution at the meteo station in the nearby vicinity to the actual site.

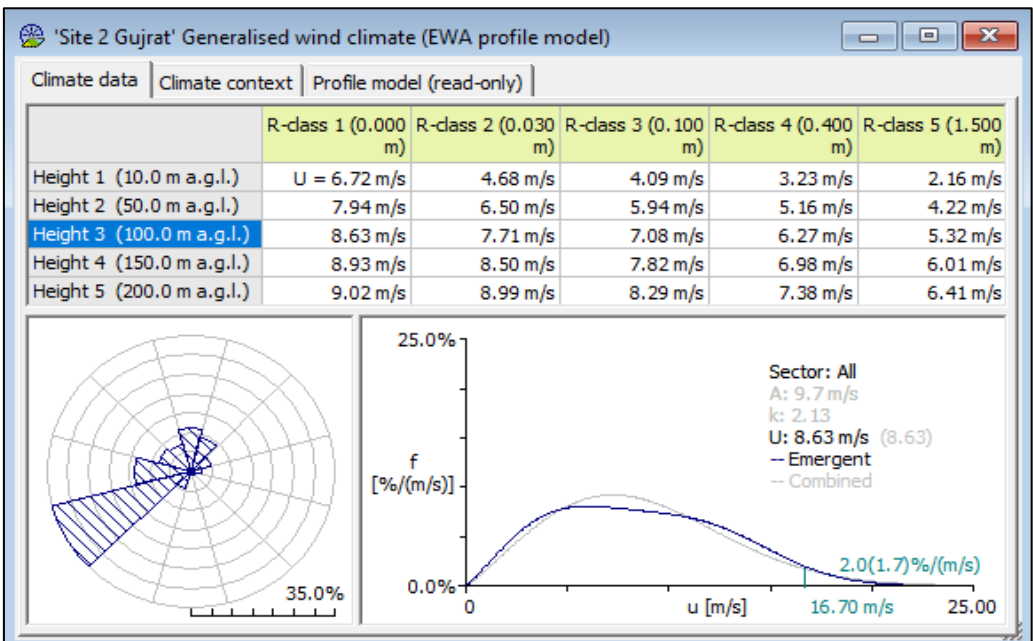


Figure 32 Wind Climate At Site 2 Gujrat



After the wind data is defined, Terrain data (Orography & roughness data) is defined by importing the .map file for height contour and the roughness data files which are downloaded using the windPRO software.

After defining the wind climate and terrain data the location of the wind turbine is chosen, and in this case study, we have selected 4 wind turbines at different locations. Now with terrain data, wind data and turbine site are decided, the spatial image is generated for the area as illustrated in Figure 33 where x & y coordinates define latitude and longitude and the resolution of the height contour map is 90m. And the wind turbine model selected is the same as Site 1 i.e. Vestas V90 with specification and power curve shown in Figure 25.

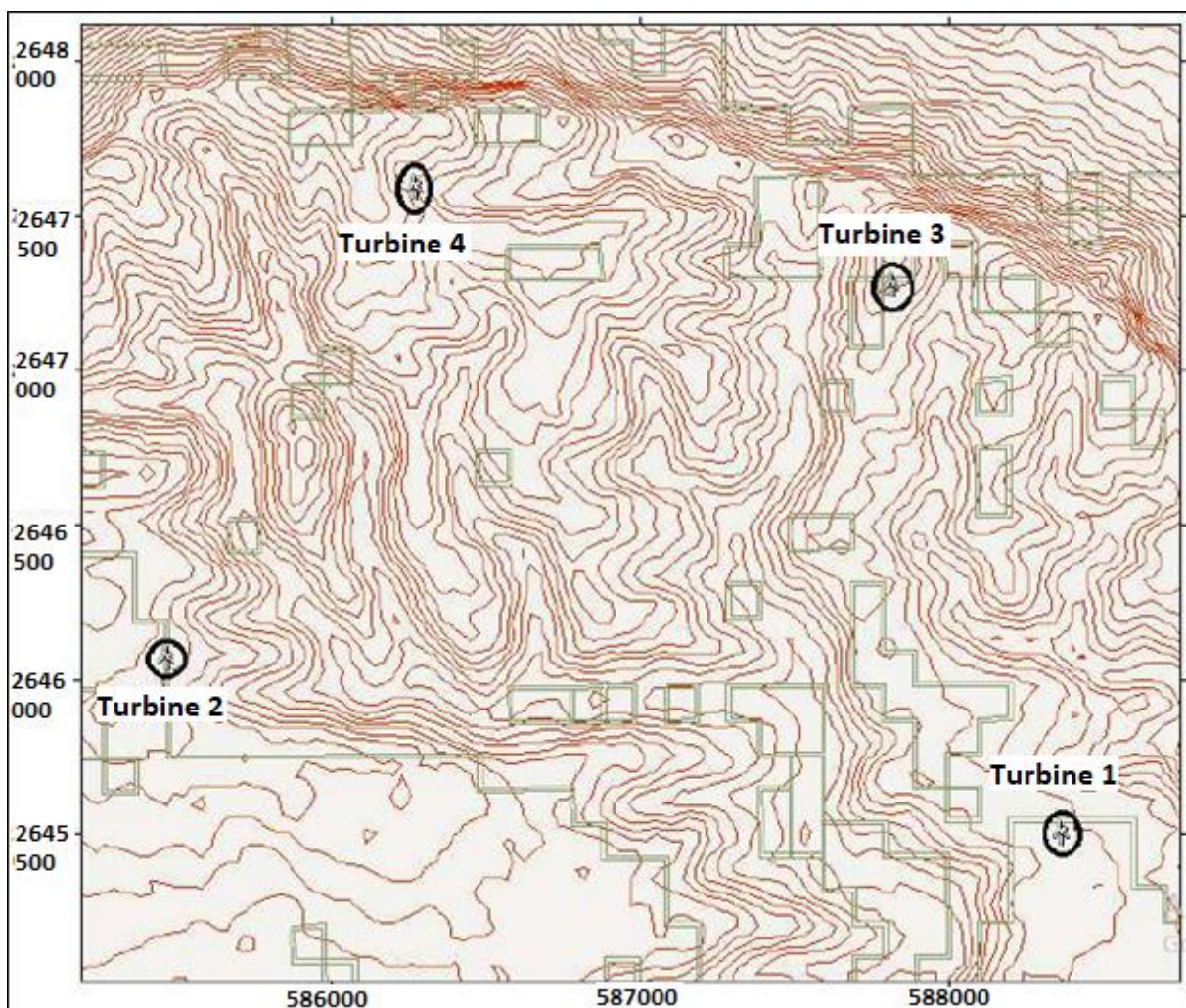


Figure 33 Spatial Image of The Site 2 With Turbine

Now all the inputs are added under the Site 1 Project workspace hierarchy which includes wind data, terrain data and Turbine as shown in Figure 34

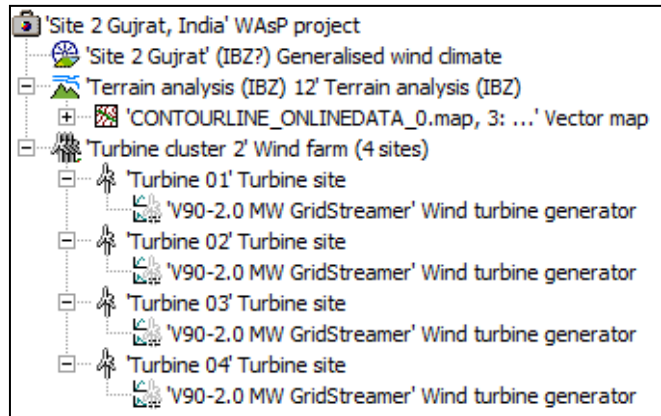


Figure 34 WASP Workspace Hierarchy Site 2

After that, the wind energy calculation will be done, and section 4.2.1 will analyse the results.

### 3.3.2 windPRO

The model and steps outlined in section 3.1.2 were used to carry out the simulation. We will be performing the simulation at Site 2 as stated in Section 2.2.2. First, we have created a new project called "Site 2 Gujrat". All the steps are followed similar to the modelling procedure discussed for Site 1 except few changes i.e. for height contour we have used SRTM: Shuttle DTM 1 arc-second instead of SRTM: Shuttle DTM 3 arc-second and for the roughness lines we have selected Copernicus global land service instead of Globcover 2009 as shown in Figure 35.

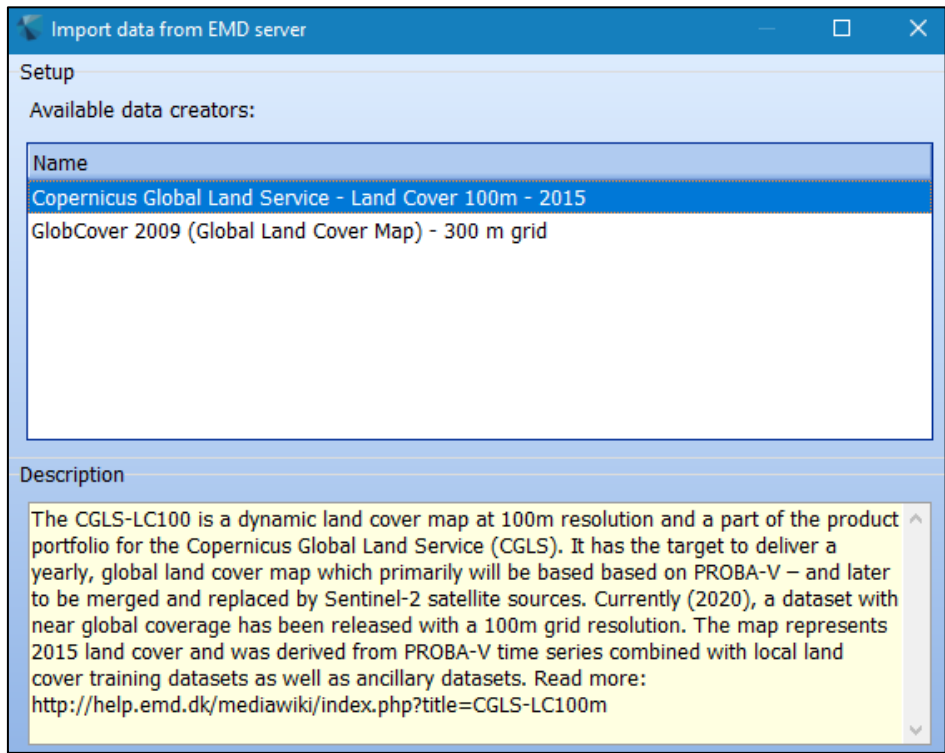


Figure 35 Roughness Line

And once height contour and roughness data. The next stage is to include wind data around the site centre when the topographical data in the windPRO model has been updated. Since EMD-WRF IND meteorological data is located closest to the site location in this instance, we chose online data and downloaded it. Once the wind data is imported for the site location, we can observe that the wind is stronger in the WSW direction (west-southwest) and that the Weibull distribution of wind speed at all heights from all directions is depicted in Figure 36.

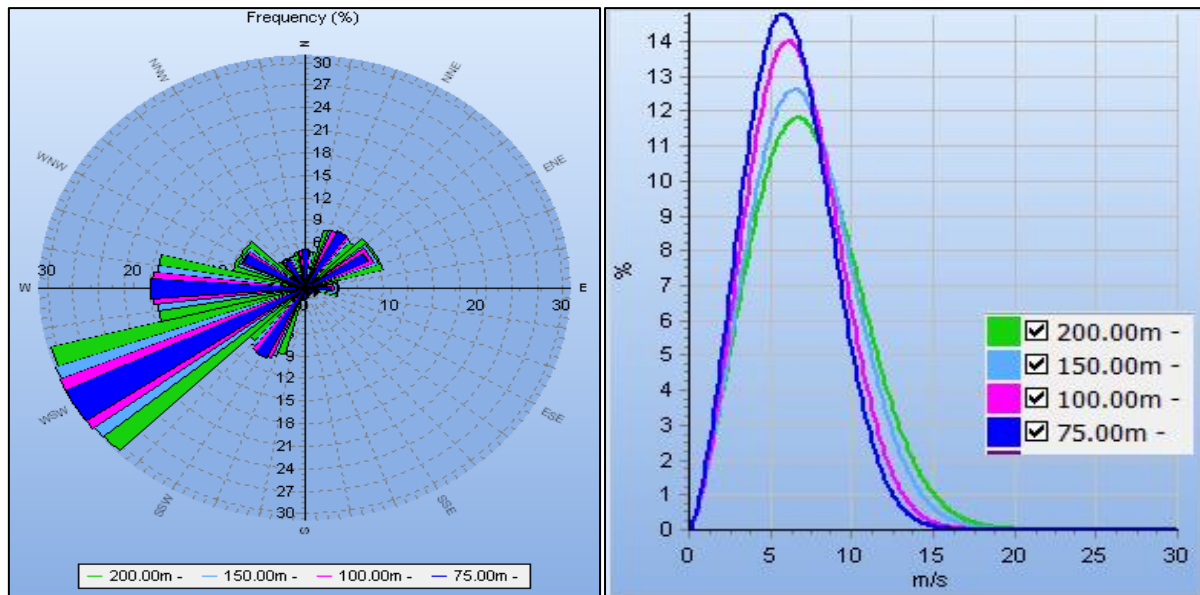


Figure 36 Rose View & Weibull Distribution

Following the inclusion of all relevant topography and wind data in the model, a wind turbine generator is chosen from among the many models on the market. A hub height of 100 metres is taken into account in this simulation while using the four Vestas V90 models. In the aforementioned part, we used the same wind turbine generator that was chosen for the WAsP software simulation, and the specifications for the turbine generators are displayed in Figure 25.

Now all the required input is available in the software, a topographic image is generated for the area using google earth as illustrated in Figure 37, which shows 4 wind turbines, meteo station location, height contours and wind speed at different locations.



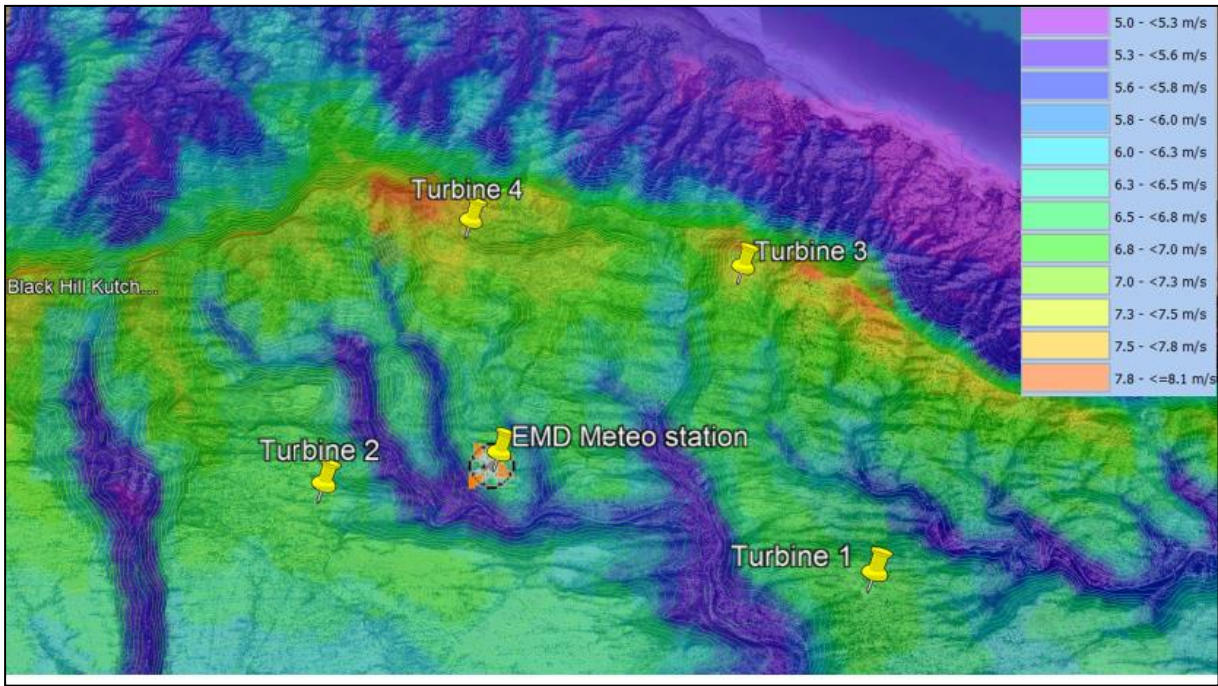


Figure 37 Spatial Image of Site 2 Gujrat

To do the calculation, we must first enter the site's data and choose a model from the available selection of wind energy calculation models in Figure 22. Now windPRO model is currently prepared to conduct the simulation and produce the output data. Figure 38 displays the entire list of objects added to prepare the project for simulation. In addition to the x and y coordinates for each object added to the model. Also, we can see various layers of height contour, roughness, turbines, wind data, and site data.

Description	Locked	Longitude ±dc	Latitude ±dd.d	Z	Type	System label	User	Result (most rec)	Layers
EMD-WRF India_N23.925_E	<input type="checkbox"/>	69.849000°	23.925000°	300.0	Meteorolo	21		3.93 m/s @ 10.0	Climate
Height Contours: CONTOUF	<input type="checkbox"/>	69.868241°	23.918481°		Line Objec	1			Height Contour
Site data: RESGEN (13)	<input type="checkbox"/>	69.849000°	23.925000°	300.0	Site Data	25			Climate
Site data: STATGEN (10)	<input type="checkbox"/>	69.849000°	23.925000°	300.0	Site Data	22			Climate
Site data: WASP (11)	<input type="checkbox"/>	69.849000°	23.925000°	300.0	Site Data	23			Climate
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.868241°	23.918481°	270.0	New WTG	3		5,667 MWh/y; 2	New Turbines
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.839830°	23.923738°	330.6	New WTG	7		5,454 MWh/y; 2	New Turbines
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.863005°	23.934486°	326.5	New WTG	8		6,716 MWh/y; 3	New Turbines
VESTAS V90 2000 90.0 !O!	<input type="checkbox"/>	69.847813°	23.937467°	373.3	New WTG	9		6,731 MWh/y; 3	New Turbines

Figure 38 windPRO Site 2 Gujrat Object List

Now, calculations are made using windPRO for site 2 in Gujrat, and section 4.2.2 discusses the outcomes of the simulation.



### 3.3.3 HOMER Pro

In this section, HOMERPRO modelling and calculation are discussed for site 2 Gujrat. So firstly we have selected the location by putting the coordinates similar to the site centre we have marked for windPRO and WAsP. Then we installed 4 wind turbines and the wind turbine model selected is similar to the model we have selected for Site 1 calculation in HOMERPRO as discussed in section 3.2.3. Then wind data is added which is downloaded from the internet using the NASA database. And then similar to site 1 we have selected a generalised electrical load with a residential profile and a battery of 1MW.

Once all the data is available and modelling is done, we will run the calculation and a report is generated. The results of the simulations are discussed in section 4.2.3

## 4 RESULTS

This section should address the results of various software at both the site location and discusses how they vary from the other software.

### 4.1 Case Study 1

#### 4.1.1 WAsP

Based on the simulations performed in WAsP, The calculation is carried out after choosing "Calculate the AEP, anticipated wind climate, site effects, and delta-RIX for site 1 Gujrat" by right-clicking on the turbine site option. The output reports show the energy generated by all the 4 wtg as shown in Table 4.

Table 4 WAsP Site 1 Results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Meteo station wind Speed [m/s]	mean wind Speed at the site [m/s]	Net AEP [GWh]	Wake loss [%]
Turbine 01	(566600, 2560045)	V90-2.0 MW	197	7.1	6.7	5.5	0.0
Turbine 02	(567850, 2559579)		290		7.7	7.1	3.7
Turbine 03	(567287, 2559716)		270		7.4	6.8	0.6
Turbine 04	(567693, 2559220)		269		7.5	6.9	2.4

As per the site results, we can find that all turbines are placed at different coordinates and different heights with Turbine 01 being at a minimum height of 197 m while turbine 02 is at the top of the hill and is 100 m above turbine 1 while other two turbines are also located at higher altitude as compared to turbine 01. And as we discussed earlier wind speed will increase over the hill because of less obstruction we can notice the same in the simulation results and accordingly the annual energy production got increases by 30% if we move the turbine location from turbine 01 to turbine 02. And also the wind speed increases by 15% as compared to turbine 01 and if we compare wind speed at meteo station to the particular turbine site we can see a significant increase of 10% for turbine 02 while we can notice for turbine 01 it reduces by 6%. And one more important parameter which we notice is the wake effect and how the position of turbines causes wake loss. We can notice turbine which comes first from the direction wind is

approaching i.e. turbine 01 faces 0 wake loss, turbine 03 which comes the next faces 0.6% of wake loss and after turbine 02 which is on the hill but falls after turbine 01 and turbine 03 faces maximum wake loss of around 4%.

While comparing the AEP for all the turbines, Turbine 02 is generating a maximum output of 7.1 GWh. Thus we have generated the Weibull distribution and the wind direction graph which also shows the wake effect in red colour and also suggests from which direction we are facing wake losses as shown in Figure 39.

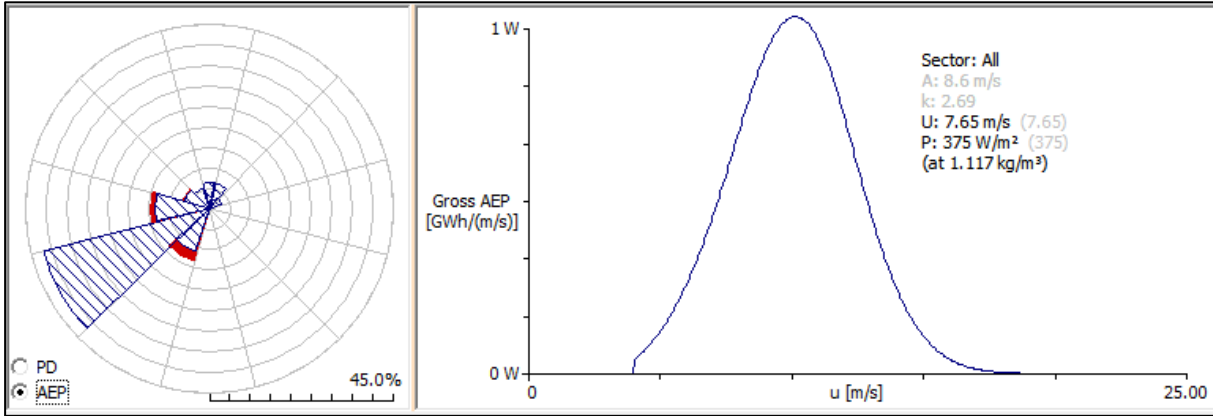


Figure 39 Wind Direction and Power Curve

For a detailed output report for simulation please refer to Appendix 1

**4.1.2 windPRO**

In windPRO, the calculation is done using the PARK technique, which runs the simulation and calculates energy using WASP in the background. The report created based on the simulation includes various sections, which are listed in Figure 40.

PARK:	
	Main Result
	Production Analysis
	Power Curve Analysis
	Terrain
	Wind Data Analysis
	Park power curve
	WTG distances
	Wind statistics info
	Map

Figure 40 Various Components of the Report

The report's main results section discusses the wake model, mean wind speed, annual energy produced by each wind turbine, and the total amount of energy produced by the wind farm (applicable if more than 1 wind turbine is installed) as shown in Table 5.

Table 5 windPRO PARK Method Site 1 Results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Meteo station wind Speed [m/s]	Mean Wind Speed at the site [m/s]	Net AEP [GWh]	Wake loss [%]
Turbine 01	(566600, 2560045)	V90-2.0 MW	197	7.1	6.4	4.9	0
Turbine 02	(567850, 2559579)		290		7.5	6.7	5.2
Turbine 03	(567287, 2559716)		270		7.2	6.3	1.3
Turbine 04	(567693, 2559220)		269		7.3	6.5	3

As per the site results, we can find that turbines are placed at 4 different coordinates which are similar to the turbine location we have selected for the WAsP software simulation, And noticed in this case also Turbine 02 is generating a maximum output of 6.7 GWh even after facing the maximum wake loss of approx 5% at a mean speed of 7.5 m/s which is higher than the wind speed of 7.1 m/s measured at meteo station. And if compare to turbine 01 which generated minimum annual energy, Turbine 02 generated 36% higher AEP and wind speed is also 18% higher. Thus it shows how much role terrain plays in wind energy assessment.

The report's next part, titled "Production Analysis," discusses how hills and other impediments affect energy generation in different directions and provide examples. Following this, the paper discusses power curve analysis, which depicts power, efficiency, and energy at various wind speeds and how it changes as a result of fluctuation in wind speed. The files used to store the orography and roughness data utilised during simulation are described in the report's following section. The report's following part, "Wind Data Analysis," illustrates how the reference and current sites differ by comparing Weibull distribution, energy rose, mean wind speed, and frequency (%) of the current site to the reference site, as seen in Figure 41. We can notice at the turbine wind speed is more and also denser as compared to the reference site where it is having more radiated. While if we talk about distribution, Current site Weibull distribution mostly follows reference site data.

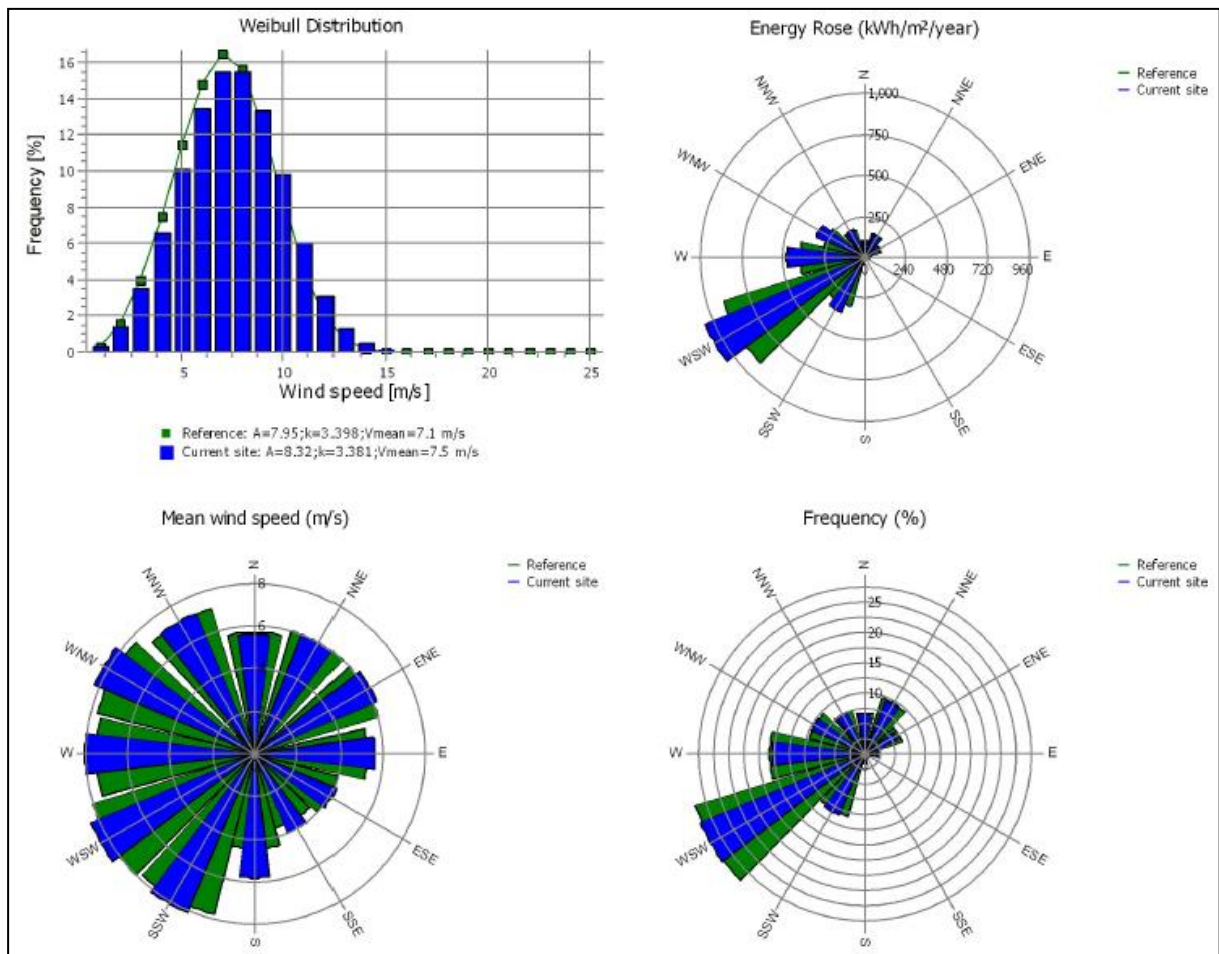


Figure 41 Wind Data Analysis In windPRO

The report also includes sections on the park power curve, WTG distances, information on wind statistics, and a map. For a full analysis of the report produced by windPRO based on calculations made, see appendix 2.

As already discussed, windPRO uses WAsP as a background tool to calculate AEP. Thus the result of windPRO software is almost equal to the site results generated by calculation in WAsP software. The little variance is due to the different methods used by windPRO and WAsP for wind analysis.

### 4.1.3 HOMER Pro

HOMER Pro calculations are very generalised as they don't consider any effects due to terrain data and also all wind turbines are considered at the same above sea level and same hub height. Also, it doesn't allow to allocate a different location for a different wind turbine in one wind farm or one area. And even though HOMER allows the option for considering wake loss but it doesn't calculate by default, we can enter wake loss values if we are already aware of the wake loss based on different turbine locations and using the output of windPRO and WAsP. So based

on that the results are generated and they show that all the wind turbines are generating the same output power i.e. approx. 5 GWh over a year, wind speed of 6.3 m/s i.e. same speed for all turbines as shown in below-attached Table 6 with a capacity factor of 28.3%.

Table 6 HOMER Pro site results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	mean wind Speed at the site [m/s]	Net AEP [GWh]
Turbine 01	(566609, 2560041)	LTW90-2.0 MW	-	6.3	5.0
Turbine 02	(566609, 2560041)		-	6.3	5.0
Turbine 03	(566609, 2560041)		-	6.3	5.0
Turbine 04	(566609, 2560041)		-	6.3	5.0

We may notice HOMER Pro doesn't give very accurate results for wind analysis and annual energy production, but it is very much helpful for doing other studies like cost analysis, integration of different energy sources, grid purchase power and impact on the grid because of renewable energy sources etc. As shown in below attached Figure 42 below where HOMER performs simulation for 15 different possible scenarios like only 1 turbine is working along with grid supply and battery storage, in another scenario it considers 2 turbines are working and in one scenario it considers all the 4 turbines are running. Based on all the scenario results, HOMER suggests the impact on the grid for all the scenarios and which scenario gives reducing grid purchase and is economically best fit for the energy system.

Architecture										Cost			System		T1		T2	
T1	T2	T3	T4	1MLI	Converter (kW)	Dispatch	NPC (\$)	COE (\$)	Operating cost (\$/yr)	Initial capital (\$)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost (\$)	Production (kWh/yr)	O&M Cost (\$)	Capital Cost (\$)	Production (kWh/yr)	
1				1	1.23	CC	\$1.07M	\$20.17	\$28,660	\$700,379	100	0	10.0	4,966,238	0			
	1			1	1.23	CC	\$1.07M	\$20.17	\$28,660	\$700,379	100	0				10.0	4,966,238	
		1		1	1.23	CC	\$1.07M	\$20.17	\$28,660	\$700,379	100	0						
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earlier i.e. windPRO and WAsP doesn't generate a time series curve for the wind energy generated by the turbine, they just provide annual energy production. But time series plot is very much when planning to integrate wind turbines or wind farms into the existing electrical system infrastructure. Because time series plots tell us at what time of the year and at what time of the day we are getting more energy from the wind turbine and during which period of the day we may need to purchase power from the grid and also time series plots help in modelling battery storage system and demand side management.

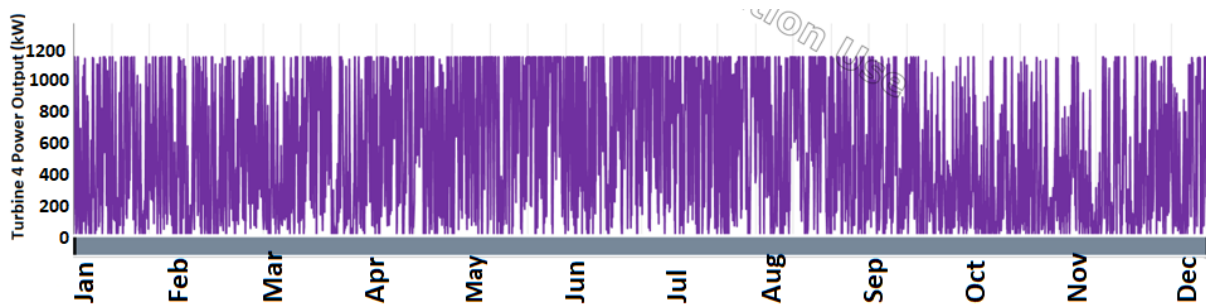


Figure 43 Time Series Plot for 1 year

According to the time series curve, it is evident that more wind energy will be produced throughout the summer, specifically between March and September, as opposed to the months of October to February. And taking into account India's load demand, we require more energy in the summer for air cooling in the home and less energy in the winter because air conditioning is not needed. As a result, the time series curve becomes crucial for designing energy systems that integrate various energy sources and storage devices.

For a detailed report for site 1 using HOMER Pro, refer to Appendix 3

#### 4.1.4 Annual Energy Production and wind speed comparison for Site 1

In this section, we have compared the annual energy production and wind speed for all 4 wind turbines based on the simulation results from windPRO, WAsP and HOMER Pro. From the graph, as shown in Figure 44 we can notice there is a slight difference between the wind speed measured by windPRO and WAsP because of different wind climate data considered by them while doing simulations and accordingly we can annual energy production also varies in the same proportion for windPRO and WAsP for all the 4 turbines. And we can notice for HOMER Pro results it is the flat line for all the turbines.

As opposed to other tools like windPRO and WAsP, HOMER pro results consistently underpredict and are less accurate. Therefore, we can conclude that the output suggested by HOMER Pro can be regarded as the minimum value that can be used for performing coast



analysis because it will show the worst-case scenario, but when we are modelling the infrastructure of an energy system, we need to take into consideration the results that are the highest of all the software because that helps us to define the rating of electrical equipment and to make the system safe. Also, we can notice windPRO and WAsP results for turbine 02 are 40% higher as compared to HOMER Pro which suggests that to meet the load demand we need 10 turbines while to generate the same results using HOMER Pro we may need to install 14 turbines which has a big cost impact because we need extra 4 turbines, additional construction work, more electrical equipments and if we have installed an energy storage system based on HOMER Pro results then many times we may need to waste energy generated because the energy generated will be more than expected and storage system can't accommodate.

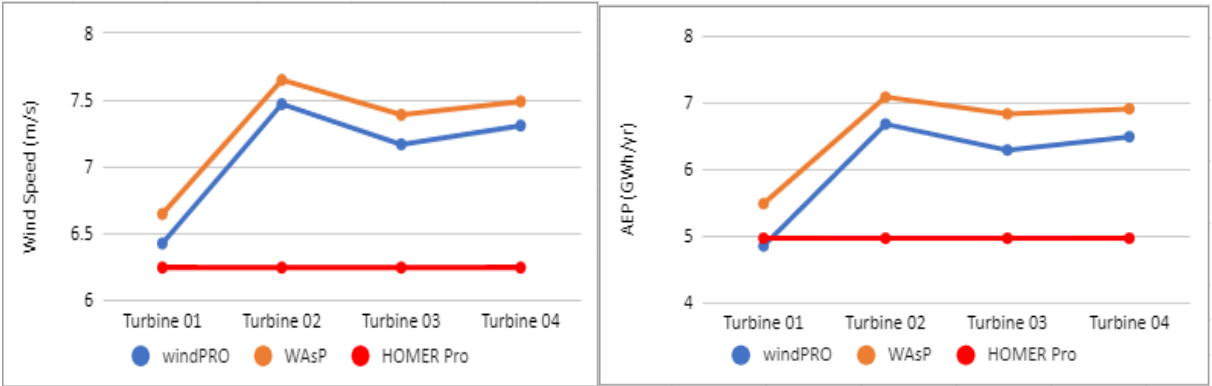


Figure 44 Wind Speed and AEP Comparison For Site 1 From Different Software

## 4.2 Case Study 2

### 4.2.1 WAsP

Similar to section 4.1.1, Now the results are discussed for the wind energy calculation performed for site 2 in Gujrat. The calculation is carried out after choosing "Calculate the AEP, anticipated wind climate, site effects, and delta-RIX for site 2 Gujrat" by right-clicking on the turbine site option. The output reports show the energy generated by all the 4 wtg as shown in Table 7.

Table 7 WAsP Site 2 Results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Meteo station wind Speed [m/s]	Mean wind Speed at the site [m/s]	Net AEP [GWh]	Wake loss [%]
Turbine 01	(588368, 2645473)	V90-2.0 MW	271	6.5	6.9	6.4	0.2
Turbine 02	(585472, 2646037)		331		6.7	5.8	0.2
Turbine 03	(587824, 2647242)		326		7.2	7.2	0.3
Turbine 04	(586276, 2647562)		373		7.5	7.4	0.2

As per the site results, we can find that all turbines are placed at different coordinates and different heights with Turbine 01 being at a minimum height of 271 m while turbine 04 is at the top of the hill and is 100 m above turbine 1 while other two turbines i.e. 02 & 03 are also located at higher altitude as compared to turbine 01. And as we discussed earlier wind speed will increase over the hill because of less obstruction we can notice the same in the simulation results and accordingly the annual energy production got increases by 15% if we move the turbine location from turbine 01 to turbine 04. And also the wind speed increases by 9% as compared to turbine 01 and if we compare wind speed at meteo station to the particular turbine site we can see a significant increase of 15% for turbine 04. Also, we can notice there is not much difference in the output for turbine 03 and turbine 04 even though there is a 50 m height difference between them because turbine 03 is placed in an open area without much obstruction. And one more important parameter which we notice is the wake effect and how the position of turbines causes wake loss. We can notice unlike site 1 in the above section, site 2 where turbines are placed far away from each other doesn't see much wake effect.

While comparing the AEP for all the turbines, Turbine 04 is generating a maximum output of 7.4 GWh. Thus we have generated the Weibull distribution and the wind direction graph which also shows the wake effect in red colour and also suggests from which direction we are facing wake losses as shown in Figure 45.

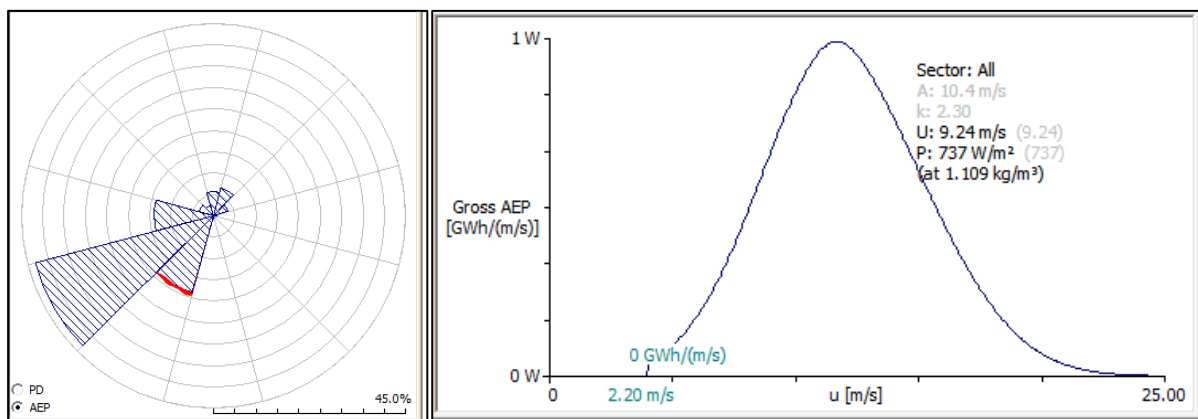


Figure 45 Wind Direction and Power Curve

For a detailed output report please refer to appendix 4

### 4.2.2 windPRO

Similar to section 4.1.2, The report's main results section discusses the wake effect, mean wind speed and annual energy produced by each wind turbine, and the total amount of energy as shown in Table 8.

Table 8 windPRO Site 2 Results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Meteo station wind Speed [m/s]	mean wind Speed at the site [m/s]	Net AEP [GWh]	Wake loss [%]
Turbine 01	(588368, 2645473)	V90-2.0 MW	270	6.5	6.7	5.7	0.3
Turbine 02	(585472, 2646037)		331		6.6	5.5	0.3
Turbine 03	(587824, 2647242)		327		7.2	6.6	0.9
Turbine 04	(586276, 2647562)		373		7.3	6.7	0.5

As per the site results, we can find that the turbines are placed at 4 different coordinates which are similar to the turbine location we have selected for the WAsP software simulation, And noticed in this case also Turbine 04 is generating a maximum output of 6.7 GWh at a mean speed of 7.3 m/s which is 12% higher than the wind speed measured at meteo station. And if compare to turbine 01 which generated minimum annual energy, Turbine 04 generated 18% higher AEP and wind speed is also 9% higher. And the wake loss is very less i.e. less than 1% for all the wind turbines because turbines are placed more away from each other as compared to site 1.

The report's following part, "Wind Data Analysis," illustrates how the reference and current turbine sites differ by comparing Weibull distribution, energy rose, mean wind speed, and frequency (%) of the current site to the reference site, as seen in Figure 46. We can notice at the turbine wind speed is more and also denser as compared to the reference site where it is having more radiated. while if we talk about distribution, Current site Weibull distribution mostly follows reference site data at higher wind speed but deviates from reference site at lower wind speed. Also, Weibull distribution suggests means peed for the reference site is 6.0 m/s while for the turbine 02 location mean wind speed is 7.3 m/s.

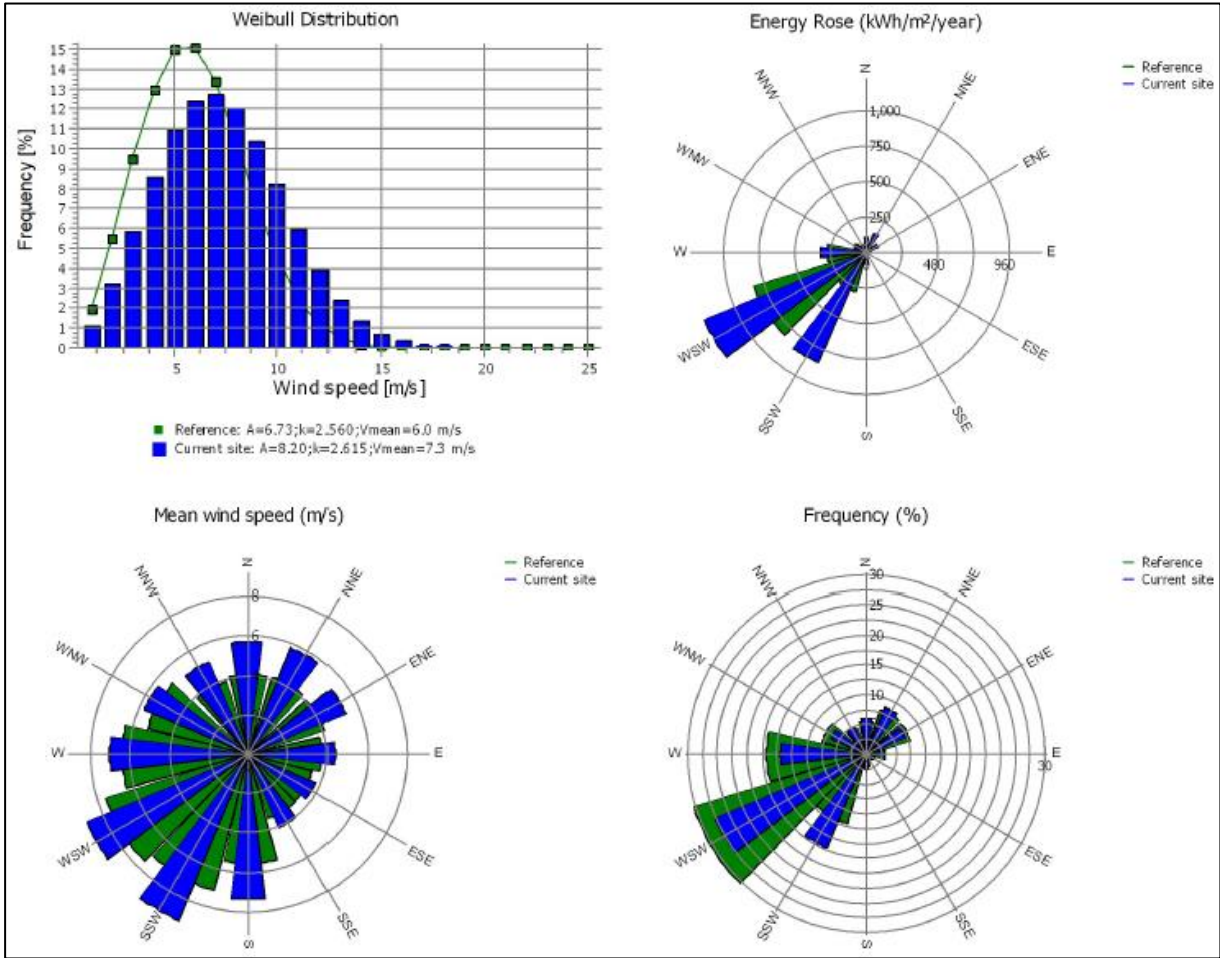


Figure 46 Wind Data Analysis In windPRO

The report also includes sections on the park power curve, WTG distances, information on wind statistics, and a map. For a full analysis of the report produced by windPRO based on calculations made, see appendix 5.

### 4.2.3 HOMER Pro

As discussed above, HOMER Pro calculations are very generalised as they don't consider any effects due to terrain data, wake effect and also all wind turbines are considered at the same above sea level and same hub height. So based on that the results are generated and they show that all the wind turbines are generating the same output power i.e. 4.8 GWh over a year, wind speed of 6.4 m/s i.e. same speed for all turbines as shown in the below-attached Table 9.

Table 9 HOMER Pro Results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Meteo station wind Speed [m/s]	Mean wind Speed at the site [m/s]	Net AEP [GWh]
Turbine 01	(588368, 2645473)	LTW90-2.0 MW	-	6.4	6.4	4.8
Turbine 02	(588368, 2645473)		-	6.4	6.4	4.8
Turbine 03	(588368, 2645473)		-	6.4	6.4	4.8
Turbine 04	(588368, 2645473)		-	6.4	6.4	4.8

We may notice HOMER Pro doesn't give very accurate results for wind analysis and annual energy production, but it is very much helpful for doing other studies like cost analysis, integration of different energy sources, grid purchase power and impact on the grid because of renewable energy sources etc which are discussed in above section 4.1.3

For a detailed report please find the attached report in appendix 6.

### 4.2.4 Annual Energy Production and wind speed comparison for Site 2

In this section, we have compared the annual energy production and wind speed for all 4 wind turbines based on the simulation results from windPRO, WAsP and HOMER Pro. From the graph, as shown in Figure 47 we can notice there is a slight difference between the wind speed measured by windPRO and WAsP because of different wind climate data considered by them while doing simulations and accordingly we can annual energy production also varies in the same proportion for windPRO and WAsP for all the 4 turbines. And we can notice for HOMER Pro results it is the flat line for all the turbines.

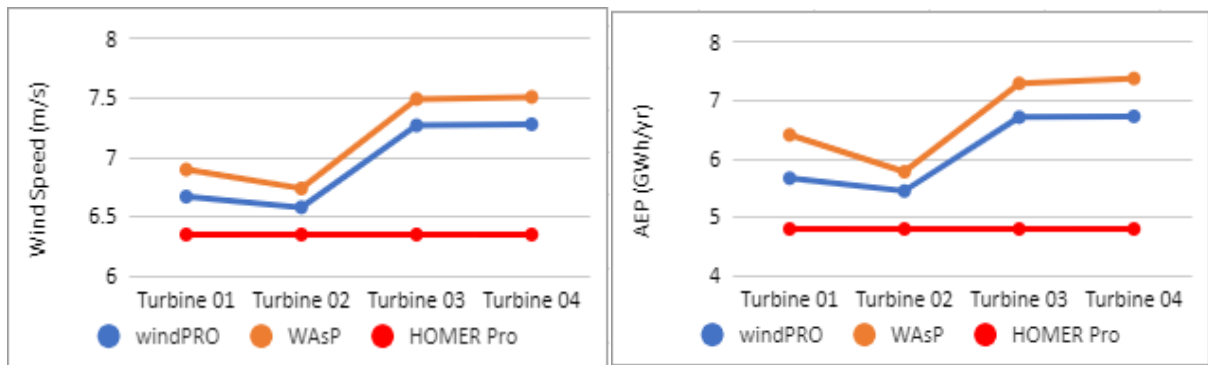


Figure 47 Wind Speed and AEP Comparison For Site 2 From Different Software

As opposed to other tools like windPRO and WAsP, HOMER pro results consistently underpredict and are less accurate for this case i.e. site 2 also. we can notice WAsP results for turbine 04 are 50% higher as compared to HOMER Pro which suggests we will end up installing more wind turbines to generate the same results using HOMER Pro we may need to install 15 turbines which have a big cost impact because we need extra turbines, additional construction work, more electrical equipments and if we have installed an energy storage system based on HOMER Pro results then many times we may need to waste energy generated because the energy generated will be more than expected and storage system can't accommodate.

## 5 FINAL REMARKS

In this section, we will be discussing the finding of our simulation results, then discuss the challenges faced while performing simulations and then some future recommendations.

### 5.1 Conclusion

This brief section summarises various topics discussed in the report. The report evaluates the wind energy potential of two sites in Gujrat that are 80 kilometres apart using three modelling programmes: WAsP, windPRO, and HOMERPro. Each of the three software programmes in use has advantages and disadvantages. None of the tools works well on its own or can provide us with reliable findings that allow us to decide whether or not it is technically and financially possible to erect a wind turbine at a specific place.

If we talk about terrain analysis, With the use of windPRO software, we can easily download the topography (orography and roughness) data for the area and let the user select data creator from various providers available. While the WAsP lacks this level of versatility, the .map file needed can be created with the WAsP map editor. However, the complicated digital elevation model files kml/kmz files downloaded from different web portals are not supported by the WAsP map editor. Therefore, WAsP lacks a variety of possibilities for incorporating internet-based landscape data. As a result, windPRO assists us in obtaining the data so that it may be transformed into a .map format that is compatible with WAsP. While the third simulation tool HOMER Pro, unlike windPRO and WAsP does not account for topographical data while doing simulations, which is a significant shortcoming.

Another important parameter is wind and climate data, windPRO allows us to search for all meteorological stations in the turbine area and then choose the one that is closest to the wind turbine site to import wind data. As a result, windPRO is very helpful and user-friendly. If we are speaking about WAsP, it also gives us the option to import the wind climate file from the meteo station, but it does not provide the option to import directly through the internet; instead, it requires the wind data file to be downloaded from the internet separately. Another simple option in WAsP is to use a generalised wind climate, which is less accurate. Following WAsP, HOMER Pro likewise has drawbacks; either it makes use of NASA's world energy wind data or you have to look online for various meteo station files.



When extrapolating the wind data from the meteo station and performing wind analysis at turbine locations, windPRO gives us the option to calculate using different methods like STATGEN, RESGEN, and the park technique, and the outcomes of the three methods can be compared to validate the wind analysis. WAsP solely uses the park technique to extrapolate and calculate the wind speed at the turbine site. While HOMER Pro use the meteo station wind speed for the computation of the wind turbine site but does not extrapolate for the turbine site.

Next, We'll talk about the AEP forecast. In contrast to HOMER Pro, which uses the turbine power curve and generalised wind speed to calculate annual energy production, windPRO and WAsP both use the park technique, which considers the wind speed at the site rather than the wind speed at the meteorological station as well as the influence of the terrain and the wake effect.

HOMER Pro is a great tool for understanding the impact on the grid, figuring out the contribution of renewable energy, analysing load demand, and figuring out the amount of required battery storage for a variety of additional benefits like peak shaving and lowering grid import during peak periods when a wind farm is implemented and integrated with the existing infrastructure. Moreover, to perform a cost analysis and select the most economically sensible choice. In windPRO or WAsP, none of the aforementioned analyses can be performed.

Based on the discussion above, it is clear that all software has some strengths and some weaknesses. Therefore, it is advised to apply all three applications simultaneously to obtain a good and thorough study in order to improve wind energy evaluation.

## **5.2 Limitations of This Study Report**

A few limitations to this study are as mentioned below:

- Terrain data considered in windPRO and WAsP
- Wind and climate data are different in windPRO and WAsP and that makes a slight difference in the results generated using the same PARK method.
- Load assumption and wind data assumptions considered for HOMER Pro software
- Limited access because of license issues for HOMERPRo and windPRO software.

### 5.3 Direction For Future Investigations

- To conduct further research on the approaches and key considerations to be made when utilising all three software simultaneously, to develop an interface platform that enables the integration of various software or the use of one software's output as an input for another, and to carry out the next stage of the wind energy assessment.
- To obtain precise wind data from the meteorological stations and use the same file in several software programmes to better comprehend and compare the outcomes.
- For upcoming research, wind station software that is specifically designed for wind analysis can be utilised, and the results can be compared with windPRO and WAsP.

## 6 REFERENCES

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## 7 APPENDIX

Appendix 1 – WAsP report for calculation performed at site 1 Gujrat.

Appendix 2 – windPRO report for calculation performed at site 1 Gujrat.

Appendix 3 – HOMER Pro report for calculation performed at site 1 Gujrat.

Appendix 4 – WAsP report for calculation performed at site 2 Gujrat.

Appendix 5 – windPRO report for calculation performed at site 2 Gujrat.

Appendix 6 – HOMER Pro report for calculation performed at site 2 Gujrat.

# Appendix 1

## WAsP Report for Calculation Performed At Site 1 Gujrat

# 'Site 1 Gujrat' WAsP project report

Produced on 28-07-2022 at 08:45:08 by licenced user: Aayush Choudhary using WAsP Version: 12.07.0056

## Report Contents

[1. WAsP project parameters](#)

[2. Generalised wind climate](#)

[3. Wind farms](#)

[3.1 Turbine cluster 1](#)

## 1. Project Parameters

### WAsP project parameters

All of the WAsP project parameters have default values.

## 2. Generalised wind climate 'GWA3 download for 23.14418, 69.65666'

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### Reference conditions

Number of roughness lengths	5
Number of heights	5
Number of sectors	12
Roughness lengths	0.000 m; 0.030 m; 0.100 m; 0.400 m; 1.500 m
Heights a.g.l	10 m; 50 m; 100 m; 150 m; 200 m

### Climate context

The generalised wind climate is located at 23.14°N 69.66°E

### Barometric reference information

Mean temperature	27.12 °
Ref. altitude for temperature a.s.l	108.3 m
Mean pressure	99,639 Pa
Ref. altitude for pressure a.s.l	106.3 m
Relative humidity	53.68935 %

### GWC profile model for 'GWA3 download for 23.14418, 69.65666'

Not using geostrophic wind shear model

Using the classic WAsP profile model, with:

- Rms heat flux over land: 100.00 (the default)
- Rms heat flux over water: 30.00 (the default)
- Offset heat flux over land (classic): -40.00 (the default)
- Offset heat flux over water (classic): -8.00 (the default)
- Factor in height of boundary layer over land: 1.00 (the default)
- Factor in height of boundary layer over water: 1.00 (the default)
- Power law in decay of the stability induced perturbation of wind profile: 1.50 (the default)

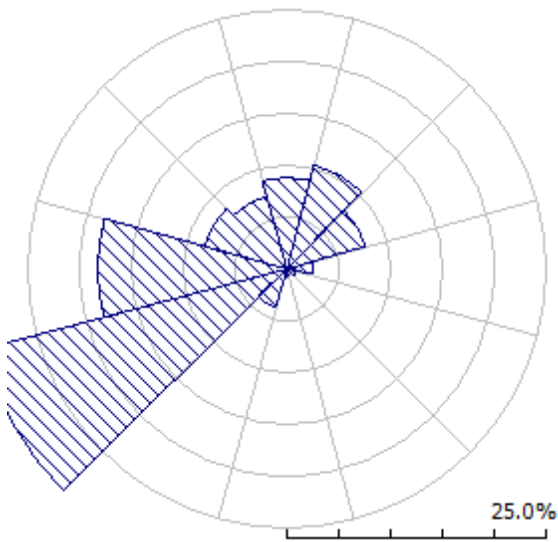
### Generalised wind climate summary



		Roughness length 0.000 m	Roughness length 0.030 m	Roughness length 0.100 m	Roughness length 0.400 m	Roughness length 1.500 m
Height 10.0 m	Weibull A [m/s]	7.09	4.95	4.34	3.42	2.30
	Weibull k	2.25	1.93	1.98	2.01	2.11
	Mean speed U [m/s]	6.28	4.39	3.84	3.03	2.04
Height 50.0 m	Weibull A [m/s]	8.40	6.94	6.35	5.50	4.50
	Weibull k	2.42	2.31	2.32	2.31	2.39
	Mean speed U [m/s]	7.45	6.15	5.62	4.87	3.99
Height 100.0 m	Weibull A [m/s]	9.15	8.27	7.60	6.69	5.68
	Weibull k	2.63	2.76	2.72	2.66	2.70
	Mean speed U [m/s]	8.13	7.36	6.76	5.95	5.05
Height 150.0 m	Weibull A [m/s]	9.75	9.33	8.56	7.64	6.56
	Weibull k	2.46	2.72	2.68	2.71	2.65
	Mean speed U [m/s]	8.64	8.30	7.61	6.80	5.83
Height 200.0 m	Weibull A [m/s]	9.99	10.06	9.23	8.22	7.10
	Weibull k	2.37	2.59	2.57	2.55	2.50
	Mean speed U [m/s]	8.86	8.93	8.19	7.29	6.30

## Detailed descriptions

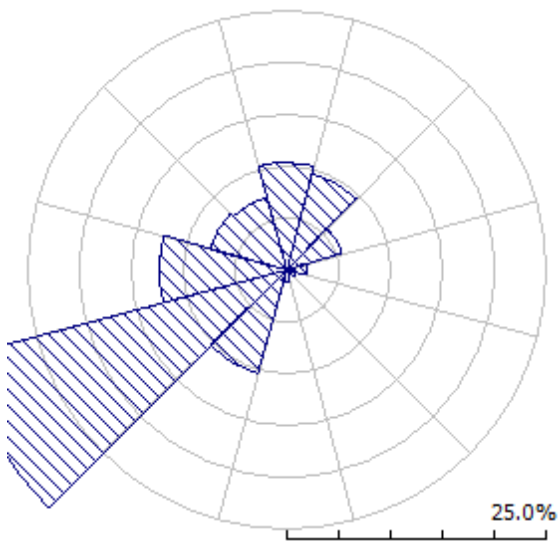
### Roughness length 0.000 m



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	5.9	6.2	6.1	4.9	3.4	3.3	5.0	7.1	8.5	7.5	6.6	6.0
	k	2.07	2.05	1.81	1.60	1.82	1.47	1.47	3.21	2.85	2.79	2.21	1.81
	U [m/s]	5.22	5.45	5.44	4.39	3.00	3.01	4.55	6.37	7.55	6.70	5.85	5.32
Height 50.0 m	A [m/s]	7.0	7.3	7.3	5.8	4.0	4.0	6.0	8.4	10.0	8.9	7.8	7.1
	k	2.26	2.24	1.97	1.74	1.99	1.61	1.60	3.50	3.12	3.05	2.40	1.97
	U [m/s]	6.19	6.47	6.46	5.21	3.56	3.57	5.40	7.55	8.95	7.94	6.94	6.31
Height 100.0 m	A [m/s]	7.6	8.0	8.0	6.4	4.4	4.4	6.6	9.1	10.9	9.7	8.5	7.8
	k	2.48	2.46	2.17	1.91	2.19	1.76	1.75	3.84	3.43	3.35	2.64	2.17

m	k U [m/s]	6.76	7.06	7.04	5.68	3.89	3.90	5.89	8.24	9.77	8.67	7.58	6.88
Height 150.0 m	A [m/s]	7.6	8.4	8.6	7.3	4.3	4.3	6.5	9.6	11.7	10.5	9.1	7.9
	k U [m/s]	2.11	2.32	2.03	1.83	1.45	1.64	1.55	3.35	3.45	3.08	2.38	1.85
Height 200.0 m	A [m/s]	6.77	7.48	7.65	6.45	3.88	3.88	5.82	8.58	10.48	9.38	8.06	7.03
	k U [m/s]	7.5	8.4	8.7	7.3	4.7	4.3	6.5	9.7	12.2	10.9	9.1	7.7
Freq. [%]	A [m/s]	2.04	2.11	1.96	1.81	1.25	1.67	1.47	3.05	3.53	2.93	2.21	1.75
	k U [m/s]	6.66	7.48	7.72	6.52	4.40	3.80	5.84	8.64	10.97	9.75	8.05	6.90
		8.9	10.3	7.8	2.5	1.0	0.6	0.8	3.9	30.3	18.3	8.3	7.3

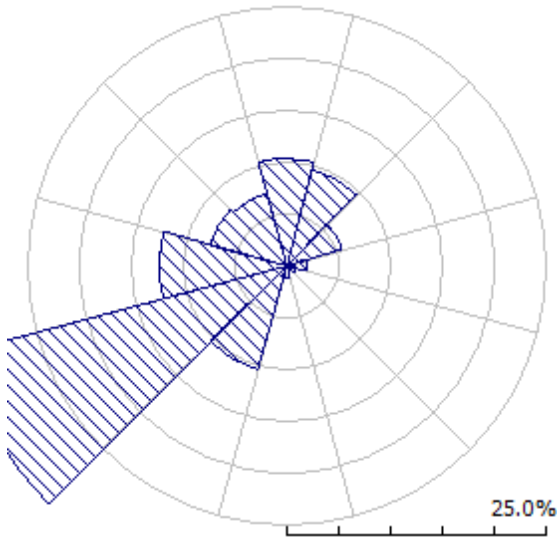
### Roughness length 0.030 m



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	4.2	4.4	3.9	2.8	2.3	2.1	3.9	5.6	5.9	5.0	4.4	3.9
	k U [m/s]	1.71	1.76	1.37	1.15	1.38	1.13	1.41	2.53	2.50	2.26	1.57	1.48
Height 50.0 m	A [m/s]	3.73	3.94	3.54	2.71	2.13	2.03	3.58	5.00	5.21	4.40	3.92	3.55
	k U [m/s]	5.9	6.2	5.6	4.2	3.3	3.1	5.6	7.8	8.2	6.9	6.2	5.6
Height 100.0 m	A [m/s]	2.09	2.14	1.67	1.40	1.69	1.38	1.72	3.09	3.06	2.76	1.92	1.81
	k U [m/s]	5.23	5.52	4.96	3.79	2.98	2.84	5.02	7.00	7.30	6.16	5.49	4.98
Height 150.0 m	A [m/s]	7.1	7.4	6.7	5.1	4.0	3.8	6.8	9.3	9.7	8.2	7.4	6.7
	k U [m/s]	2.58	2.64	2.06	1.72	2.08	1.69	2.13	3.82	3.79	3.42	2.38	2.24
Height 200.0 m	A [m/s]	6.26	6.61	5.94	4.54	3.57	3.40	6.01	8.38	8.73	7.37	6.57	5.96
	k U [m/s]	7.7	8.2	7.9	5.8	4.3	4.2	7.2	10.4	10.9	9.6	8.4	7.2
Height 150.0 m	A [m/s]	2.40	2.40	2.17	1.59	2.15	1.81	1.94	3.94	3.74	3.70	2.38	2.10
	k U [m/s]	6.79	7.28	7.04	5.18	3.84	3.76	6.41	9.40	9.87	8.68	7.45	6.37
Height 200.0 m	A [m/s]	8.0	8.7	8.5	6.3	4.4	4.3	7.5	11.3	12.0	10.3	8.9	7.4
	k U [m/s]	2.32	2.30	2.09	1.55	1.75	1.62	1.79	4.15	3.64	3.22	2.26	2.04
		7.11	7.74	7.50	5.68	3.93	3.86	6.69	10.22	10.84	9.25	7.91	6.56

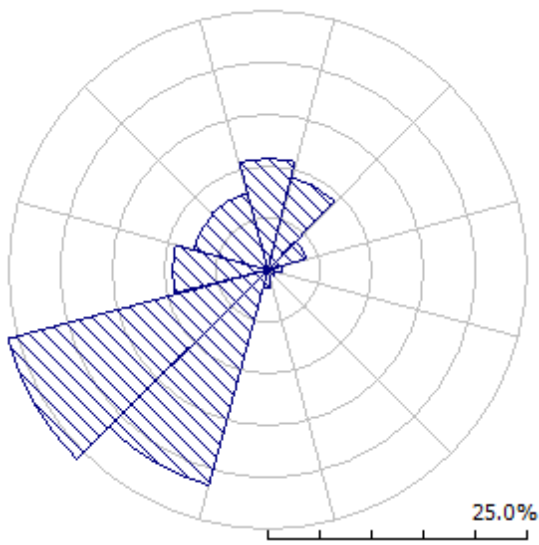
U [m/s]													
Freq. [%]	10.3	9.6	5.7	1.9	0.9	0.5	1.1	10.4	32.4	12.3	7.7	7.3	

**Roughness length 0.100 m**



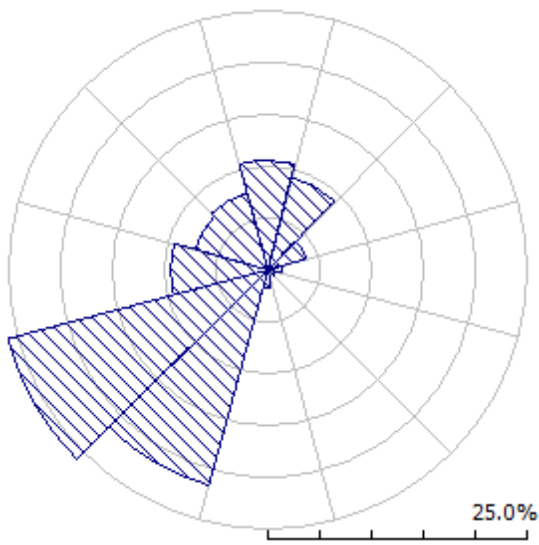
		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	3.7	3.8	3.4	2.5	1.9	2.0	3.4	4.9	5.1	4.4	3.8	3.5
	k U [m/s]	1.77 3.28	1.71 3.40	1.42 3.11	1.19 2.38	1.30 1.79	1.26 1.87	1.44 3.11	2.63 4.39	2.60 4.56	2.34 3.86	1.62 3.44	1.53 3.12
	U [m/s]												
Height 50.0 m	A [m/s]	5.4	5.6	5.1	3.8	2.9	3.0	5.1	7.2	7.5	6.3	5.7	5.1
	k U [m/s]	2.11 4.79	2.04 4.98	1.69 4.56	1.41 3.48	1.54 2.62	1.50 2.74	1.72 4.55	3.14 6.42	3.10 6.68	2.79 5.64	1.94 5.03	1.83 4.56
	U [m/s]												
Height 100.0 m	A [m/s]	6.5	6.7	6.2	4.7	3.5	3.7	6.2	8.5	8.9	7.6	6.8	6.2
	k U [m/s]	2.54 5.76	2.45 5.98	2.04 5.48	1.70 4.19	1.87 3.15	1.81 3.29	2.07 5.47	3.79 7.71	3.74 8.02	3.37 6.78	2.35 6.04	2.20 5.48
	U [m/s]												
Height 150.0 m	A [m/s]	7.0	7.5	7.2	5.3	3.8	3.8	6.6	9.5	10.0	8.8	7.7	6.6
	k U [m/s]	2.38 6.24	2.37 6.69	2.07 6.40	1.58 4.76	1.92 3.37	1.70 3.43	1.90 5.83	3.92 8.64	3.70 9.06	3.67 7.97	2.35 6.84	2.08 5.86
	U [m/s]												
Height 200.0 m	A [m/s]	7.4	8.0	7.8	5.8	4.1	4.0	6.8	10.3	11.0	9.5	8.2	6.8
	k U [m/s]	2.29 6.53	2.28 7.10	2.07 6.90	1.54 5.22	1.79 3.65	1.62 3.59	1.75 6.06	4.08 9.38	3.61 9.94	3.19 8.49	2.24 7.26	2.03 6.03
	U [m/s]												
Freq. [%]	10.3	9.7	5.6	1.9	0.9	0.5	1.1	10.3	32.4	12.3	7.7	7.3	

**Roughness length 0.400 m**



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	2.9	3.1	2.6	1.7	1.6	2.1	3.1	4.1	3.8	3.3	3.0	2.8
	k [m/s]	1.82	1.72	1.49	1.14	1.42	1.30	1.97	2.54	2.56	2.12	1.59	1.69
	U [m/s]	2.61	2.73	2.33	1.62	1.48	1.95	2.75	3.65	3.39	2.90	2.65	2.49
Height 50.0 m	A [m/s]	4.7	4.9	4.2	2.8	2.7	3.5	5.0	6.6	6.1	5.2	4.8	4.5
	k [m/s]	2.13	2.02	1.74	1.33	1.66	1.52	2.30	2.98	2.99	2.48	1.86	1.98
	U [m/s]	4.19	4.38	3.73	2.61	2.37	3.13	4.42	5.87	5.45	4.65	4.25	4.01
Height 100.0 m	A [m/s]	5.8	6.0	5.1	3.5	3.3	4.3	6.1	8.0	7.4	6.4	5.9	5.5
	k [m/s]	2.50	2.37	2.05	1.56	1.95	1.78	2.71	3.51	3.53	2.92	2.19	2.32
	U [m/s]	5.11	5.35	4.56	3.19	2.89	3.82	5.40	7.16	6.65	5.68	5.19	4.89
Height 150.0 m	A [m/s]	6.6	6.9	5.9	4.1	3.5	4.6	6.8	9.1	8.5	7.4	6.5	5.8
	k [m/s]	2.57	2.29	2.02	1.47	2.05	1.78	2.74	3.79	3.97	2.86	2.14	2.10
	U [m/s]	5.82	6.12	5.25	3.72	3.09	4.09	6.05	8.18	7.74	6.62	5.79	5.18
Height 200.0 m	A [m/s]	6.9	7.4	6.5	4.5	3.6	4.7	7.2	9.9	9.3	7.9	6.9	6.0
	k [m/s]	2.46	2.24	1.97	1.40	1.90	1.64	2.49	3.85	3.45	2.64	1.99	2.00
	U [m/s]	6.14	6.51	5.74	4.07	3.17	4.16	6.43	8.96	8.37	7.02	6.09	5.28
Freq. [%]	10.7	9.1	3.8	1.4	0.8	0.6	1.8	21.5	25.9	9.3	7.4	7.7	

**Roughness length 1.500 m**



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	2.0	2.1	1.8	1.2	1.1	1.4	2.1	2.8	2.6	2.2	2.0	1.9
	k [m/s]	1.91	1.80	1.63	1.19	1.60	1.35	2.06	2.66	2.67	2.30	1.66	1.78
	U [m/s]	1.75	1.83	1.59	1.10	1.01	1.31	1.85	2.45	2.27	1.96	1.77	1.67
Height 50.0 m	A [m/s]	3.9	4.1	3.5	2.3	2.2	2.8	4.1	5.4	5.0	4.3	3.9	3.7
	k [m/s]	2.20	2.08	1.88	1.37	1.84	1.55	2.38	3.08	3.08	2.66	1.92	2.05
	U [m/s]	3.43	3.59	3.11	2.15	1.99	2.56	3.63	4.80	4.46	3.85	3.46	3.27
Height 100.0 m	A [m/s]	4.9	5.1	4.4	3.0	2.8	3.6	5.2	6.7	6.3	5.5	4.9	4.7
	k [m/s]	2.53	2.39	2.17	1.58	2.12	1.79	2.75	3.55	3.56	3.07	2.21	2.37
	U [m/s]	4.34	4.54	3.93	2.72	2.52	3.24	4.59	6.07	5.64	4.87	4.38	4.14
Height 150.0 m	A [m/s]	5.6	5.9	5.1	3.6	2.9	4.0	5.9	7.8	7.3	6.3	5.6	5.0
	k [m/s]	2.49	2.25	1.98	1.46	1.88	1.76	2.71	3.73	3.68	2.79	2.17	2.11
	U [m/s]	4.99	5.26	4.52	3.23	2.58	3.54	5.23	7.02	6.62	5.64	5.00	4.45
Height 200.0 m	A [m/s]	6.0	6.4	5.6	3.8	3.1	4.0	6.3	8.6	8.1	6.8	5.9	5.1
	k [m/s]	2.41	2.20	1.94	1.37	1.85	1.60	2.47	3.78	3.35	2.62	1.94	1.95
	U [m/s]	5.31	5.63	4.98	3.52	2.74	3.60	5.58	7.74	7.26	6.00	5.20	4.53
Freq. [%]	10.6	9.1	3.8	1.4	0.8	0.6	1.8	21.5	25.9	9.4	7.4	7.7	

### 3. Wind farms

[back to top](#)

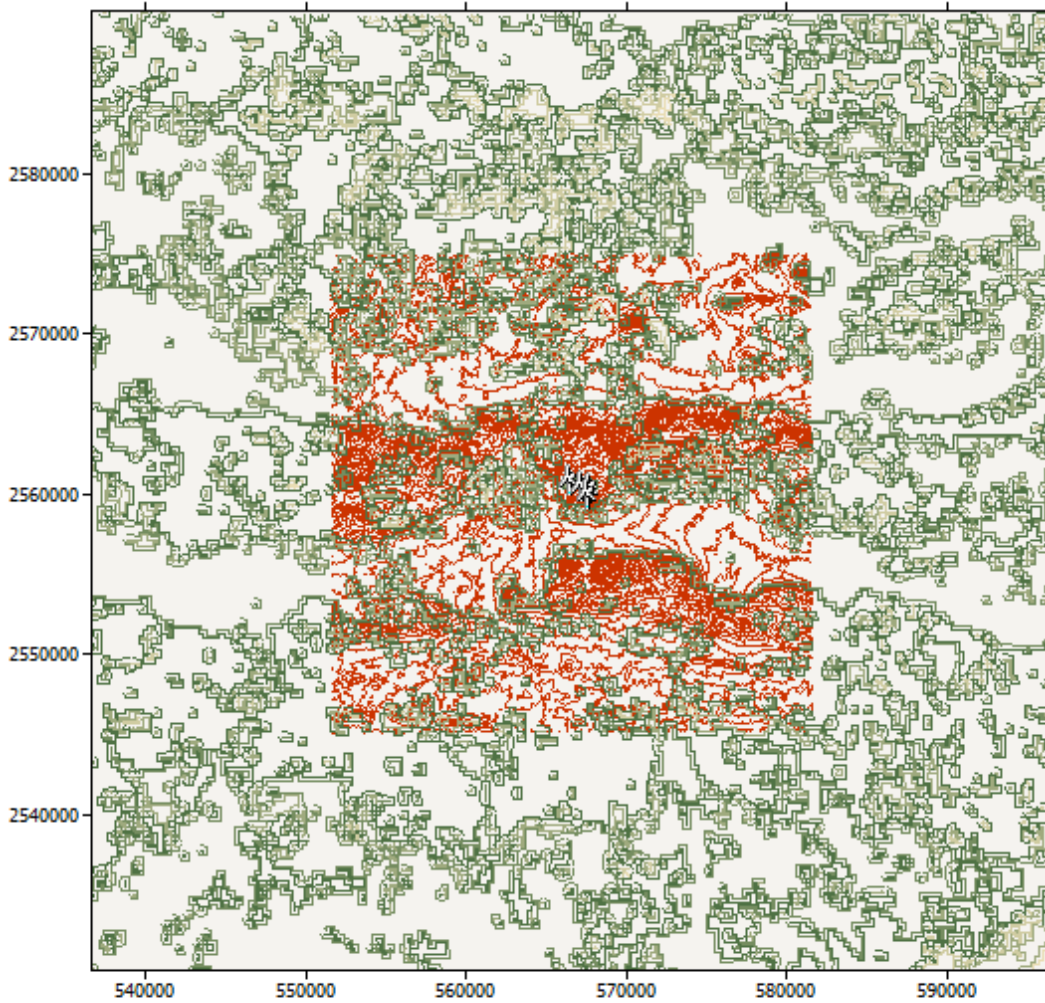
#### [3.1 Turbine cluster 1](#)

### 3.1 Wind farm: 'Turbine cluster 1'

#### Site information

Site count	4
Uniform hub height a.g.l	No

The Wind farm lies in a map called 'CONTOURLINE\_ONLINEDATA\_0.map, 3: 42: 10: 0, UTM (north)-WGS84 Zone: 42, optimized'.



## Summary results

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	26.312	6.578	5.486	7.085
Gross AEP [GWh]	26.798	6.700	5.487	7.356
Wake loss [%]	1.81	-	-	-

## Site results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m <sup>3</sup> ]	Net AEP [GWh]	Wake loss [%]
Turbine 01	(566600, 2560045)	V90-2.0 MW GridStreamer	196.9	100.0	1.127	5.486	0.03
Turbine 02	(567850, 2559579)	V90-2.0 MW GridStreamer	290.0	100.0	1.117	7.085	3.68
Turbine 03	(567287, 2559716)	V90-2.0 MW GridStreamer	270.0	100.0	1.119	6.833	0.59
Turbine 04	(567693, 2559220)	V90-2.0 MW GridStreamer	269.3	100.0	1.120	6.909	2.44

## Site wind climates

Site	Location [m]	H [m]	A [m/s]	k	U [m/s]	E [W/m <sup>2</sup> ]	RIX [%]	dRIX [%]
Turbine 01	(566600, 2560045)	100.0	7.5	2.66	6.65	250	0.1	N/A
Turbine 02	(567850, 2559579)	100.0	8.6	2.69	7.65	375	1.3	N/A
Turbine 03	(567287, 2559716)	100.0	8.3	2.71	7.39	338	0.5	N/A
Turbine 04	(567693, 2559220)	100.0	8.4	2.65	7.49	356	0.4	N/A

---



# Appendix 2

## windPRO Report for Calculation

### Performed At Site 1 Gujrat

Project:

Site 1 Gujrat with wizard

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Aayush / aayush.choudhary.2021@uni.strath.ac.uk

Calculated:

26-07-2022 01:15/3.5.584

## PARK - Main Result

Wake Model N.O. Jensen (RISØ/EMD)

Calculation performed in UTM (north)-WGS84 Zone: 42  
At the site centre the difference between grid north and true north is: 0.3°

Power curve correction method  
New windPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>  
Air density calculation method  
Height dependent, temperature from climate station  
Station: DWARKA V3 2014  
Base temperature: 25.7 °C at 11.0 m  
Base pressure: 1013.3 hPa at 0.0 m  
Air density for Site center in key hub height: 200.0 m + 100.0 m = 1.148 kg/m<sup>3</sup> -> 93.7 % of Std  
Relative humidity: 0.0 %

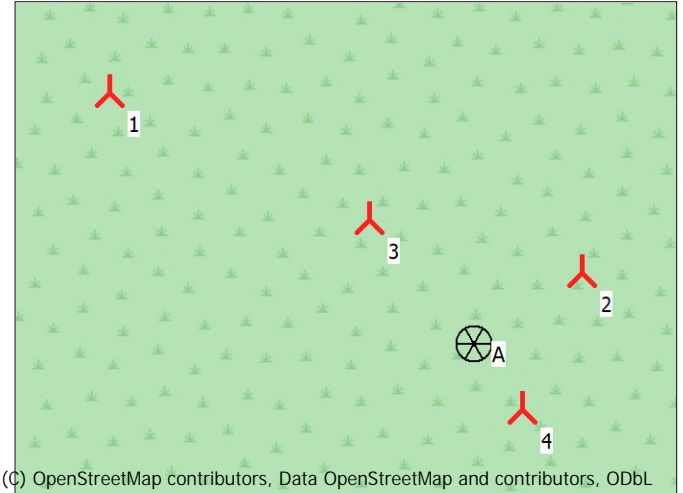
Wake Model Parameters  
Wake decay constant 0.075 DTU default onshore

Omnidirectional displacement height from objects

Wake calculation settings  
Angle [°] Wind speed [m/s]  
start end step start end step  
0.5 360.0 1.0 0.5 30.5 1.0

Wind statistics IN EMD-WRF India\_N23.142\_E069.66 (3) - 100.00 m.wws

WASP version WASP 12 Version 12.07.0056



### Key results for height 100.0 m above ground level

Terrain UTM (north)-WGS84 Zone: 42

Easting	Northing	Name of wind distribution	Type	Wind energy [kWh/m <sup>2</sup> ]	Mean wind speed [m/s]	Equivalent roughness
A 567,568	2,559,392	Site data: WASP (12)	WASP (WASP 12 Version 12.07.0056)	2,335	7.1	1.1

### Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10.0% [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Wake loss [%]	Specific results <sup>a)</sup>			Mean wind speed @hub height [m/s]
					Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	
Wind farm	24,298.3	21,868.5	24,945.7	2.6	31.2	5,467.1	2,734	7.1

<sup>a)</sup> Based on Result-10.0%

### Calculated Annual Energy for each of 4 new WTGs with total 8.0 MW rated power

Links	WTG type Valid	Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy			Free mean wind speed [m/s]	
									Result [MWh/y]	Result-10.0% [MWh/y]	Wake loss [%]		
1	A	Yes	VESTAS	V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	4,856.6	4,371	0.0	6.43
2	A	Yes	VESTAS	V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	6,658.9	5,993	5.2	7.47
3	A	Yes	VESTAS	V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	6,284.8	5,656	1.3	7.17
4	A	Yes	VESTAS	V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	6,498.1	5,848	3.0	7.31

### WTG siting

UTM (north)-WGS84 Zone: 42

Easting	Northing	Z [m]	Row data/Description
1 New	566,600	2,560,045	200.0 VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (1)
2 New	567,850	2,559,579	290.0 VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (3)
3 New	567,287	2,559,716	270.0 VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (5)
4 New	567,693	2,559,220	269.3 VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (6)

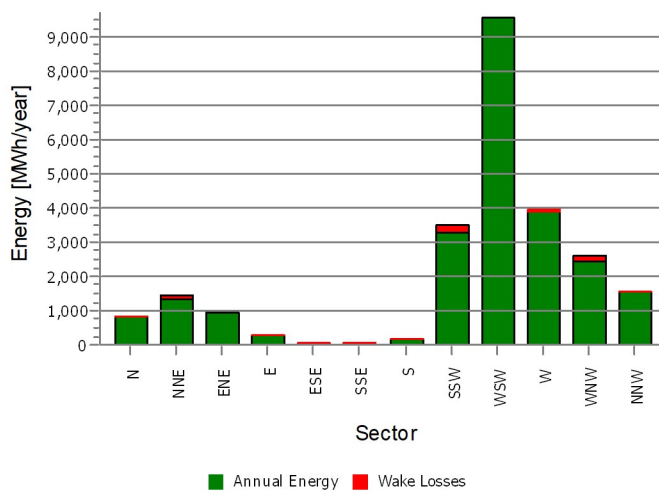
## PARK - Production Analysis

WTG: All new WTGs, Air density varies with WTG position 1.139 kg/m<sup>3</sup> - 1.148 kg/m<sup>3</sup>

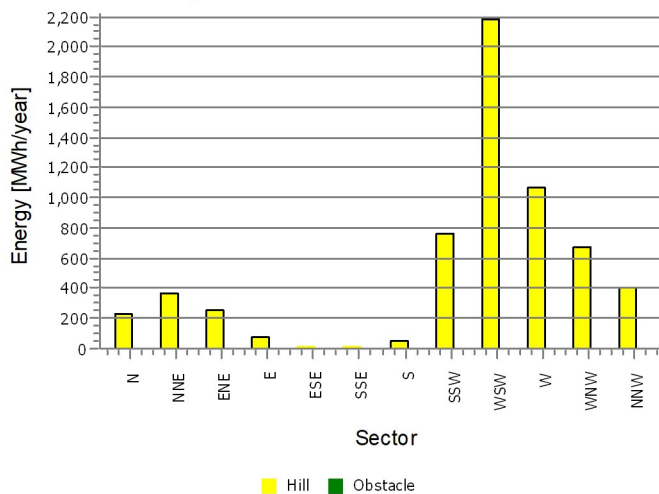
### Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	636.5	1,052.6	702.8	195.3	32.9	23.3	137.6	2,723.0	7,355.4	2,892.5	1,922.0	1,177.8	18,851.6
+ Increase due to hills	[MWh]	223.2	372.8	257.5	81.4	14.8	10.1	46.3	760.9	2,183.7	1,072.2	670.1	401.3	6,094.1
-Decrease due to wake losses	[MWh]	8.4	101.9	0.0	6.8	3.1	1.3	2.3	187.8	0.0	109.5	176.2	50.0	647.4
Resulting energy	[MWh]	851.2	1,323.5	960.2	269.8	44.6	32.1	181.5	3,296.0	9,539.1	3,855.2	2,415.9	1,529.1	24,298.3
Specific energy	[kWh/m <sup>2</sup> ]													955
Specific energy	[kWh/kW]													3,037
Increase due to hills	[%]	35.1	35.4	36.6	41.7	45.1	43.3	33.6	27.9	29.7	37.1	34.9	34.1	32.33
Decrease due to wake losses	[%]	1.0	7.1	0.0	2.5	6.4	4.0	1.3	5.4	0.0	2.8	6.8	3.2	2.60
Utilization	[%]	41.1	39.4	41.5	39.6	36.4	37.4	38.8	38.2	40.4	41.2	38.7	40.5	40.0
Operational	[Hours/year]	573	810	497	189	66	51	118	984	2,525	1,225	770	615	8,423
Full Load Equivalent	[Hours/year]	106	165	120	34	6	4	23	412	1,192	482	302	191	3,037

Energy vs. sector



Impact of hills and obstacles vs. sector



## PARK - Power Curve Analysis

WTG: 1 - VESTAS V90 2000 90.0 !O!, Hub height: 100.0 m

Name: Level 0 - - Mode 0 - 07-2009  
Source: Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type	Generator type	Specific power kW/m <sup>2</sup>
09-07-2009	EMD	23-08-2004	20-10-2009	25.0	Pitch	User defined	Variable	0.31

Curves based on Document no. 0004-6207 V01 dated 2009-07-09.  
Please contact Vestas for information on latest power curve.

HP curve comparison - Note: For standard air density

Vmean [m/s]	5	6	7	8	9	10
HP value Pitch, variable speed (2013) [MWh]	3,248	4,971	6,649	8,153	9,427	10,451
VESTAS V90 2000 90.0 !O! Level 0 - - Mode 0 - 07-2009 [MWh]	3,202	4,904	6,568	8,064	9,331	10,343
Check value [%]	1	1	1	1	1	1

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.  
For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see the windPRO manual.  
The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.  
Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

### Power curve

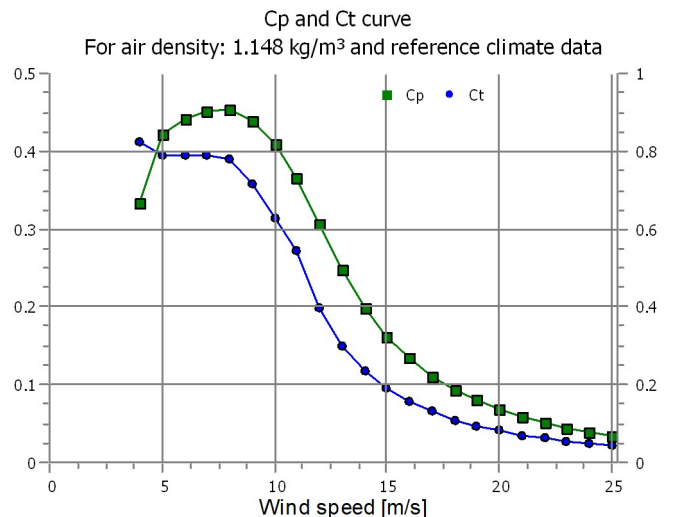
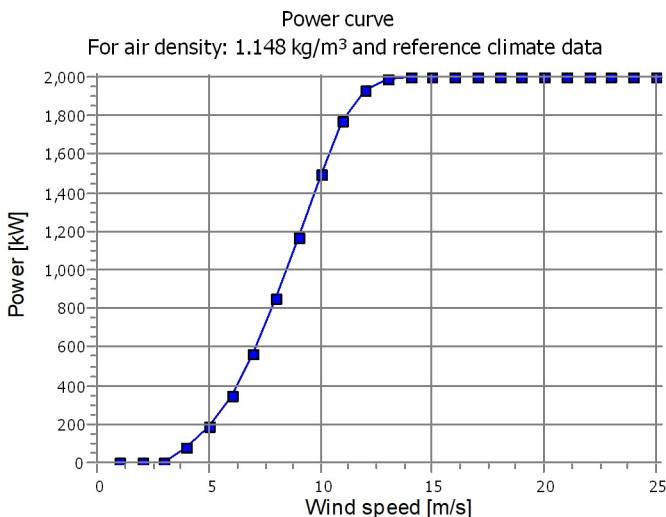
Original data, Air density: 1.225 kg/m<sup>3</sup>

Wind speed [m/s]	Power [kW]	Cp	Wind speed [m/s]	Ct curve
4.0	88.0	0.35	4.0	0.82
5.0	205.0	0.42	5.0	0.79
6.0	371.0	0.44	6.0	0.79
7.0	601.0	0.45	7.0	0.79
8.0	901.0	0.45	8.0	0.78
9.0	1,243.0	0.44	9.0	0.72
10.0	1,591.0	0.41	10.0	0.63
11.0	1,876.0	0.36	11.0	0.54
12.0	1,979.0	0.29	12.0	0.40
13.0	1,999.0	0.23	13.0	0.30
14.0	2,000.0	0.19	14.0	0.24
15.0	2,000.0	0.15	15.0	0.19
16.0	2,000.0	0.13	16.0	0.16
17.0	2,000.0	0.10	17.0	0.13
18.0	2,000.0	0.09	18.0	0.11
19.0	2,000.0	0.07	19.0	0.09
20.0	2,000.0	0.06	20.0	0.08
21.0	2,000.0	0.06	21.0	0.07
22.0	2,000.0	0.05	22.0	0.06
23.0	2,000.0	0.04	23.0	0.05
24.0	2,000.0	0.04	24.0	0.05
25.0	2,000.0	0.03	25.0	0.04

### Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1.148 kg/m<sup>3</sup> New windPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>

Wind speed [m/s]	Power [kW]	Cp	Interval [m/s]	Energy [MWh]	Acc. Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50- 1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50- 2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50- 3.50	6.6	6.6	0.1
4.0	77.7	0.33	3.50- 4.50	73.9	80.5	1.7
5.0	192.1	0.42	4.50- 5.50	248.4	328.9	6.8
6.0	349.1	0.44	5.50- 6.50	539.0	867.9	17.9
7.0	565.6	0.45	6.50- 7.50	890.7	1,758.5	36.2
8.0	847.7	0.45	7.50- 8.50	1,104.7	2,863.3	59.0
9.0	1,169.6	0.44	8.50- 9.50	993.2	3,856.5	79.4
10.0	1,496.1	0.41	9.50-10.50	629.6	4,486.1	92.4
11.0	1,775.4	0.37	10.50-11.50	275.1	4,761.2	98.0
12.0	1,933.6	0.31	11.50-12.50	79.5	4,840.6	99.7
13.0	1,988.8	0.25	12.50-13.50	14.2	4,854.8	100.0
14.0	1,999.4	0.20	13.50-14.50	1.6	4,856.4	100.0
15.0	2,000.0	0.16	14.50-15.50	0.1	4,856.6	100.0
16.0	2,000.0	0.13	15.50-16.50	0.0	4,856.6	100.0
17.0	2,000.0	0.11	16.50-17.50	0.0	4,856.6	100.0
18.0	2,000.0	0.09	17.50-18.50	0.0	4,856.6	100.0
19.0	2,000.0	0.08	18.50-19.50	0.0	4,856.6	100.0
20.0	2,000.0	0.07	19.50-20.50	0.0	4,856.6	100.0
21.0	2,000.0	0.06	20.50-21.50	0.0	4,856.6	100.0
22.0	2,000.0	0.05	21.50-22.50	0.0	4,856.6	100.0
23.0	2,000.0	0.04	22.50-23.50	0.0	4,856.6	100.0
24.0	2,000.0	0.04	23.50-24.50	0.0	4,856.6	100.0
25.0	2,000.0	0.04	24.50-25.50	0.0	4,856.6	100.0



Project:

Site 1 Gujrat with wizard

Licensed user:

TEST license

This license is only to be used for testing purposes

Aayush / aayush.choudhary.2021@uni.strath.ac.uk

Calculated:

26-07-2022 01:15/3.5.584

## PARK - Terrain

Site Data: A - Site data: WASP (12)

Obstacles:

0 Obstacles used

Roughness:

Terrain data files used in calculation:

C:\Users\Glitch\Documents\WindPRO Data\Projects\Site 1 Gujrat\ROUGHNESSLINE\_ONLINEDATA\_0.map

Min X: 536,757, Max X: 596,486, Min Y: 2,530,048, Max Y: 2,590,268, Width: 59,730 m, Height: 60,220 m

Orography:

Terrain data files used in calculation:

C:\Users\Glitch\Documents\WindPRO Data\Projects\Site 1 Gujrat\CONTOURLINE\_ONLINEDATA\_0.map

Min X: 551,663, Max X: 581,475, Min Y: 2,545,085, Max Y: 2,575,017, Width: 29,811 m, Height: 29,933 m

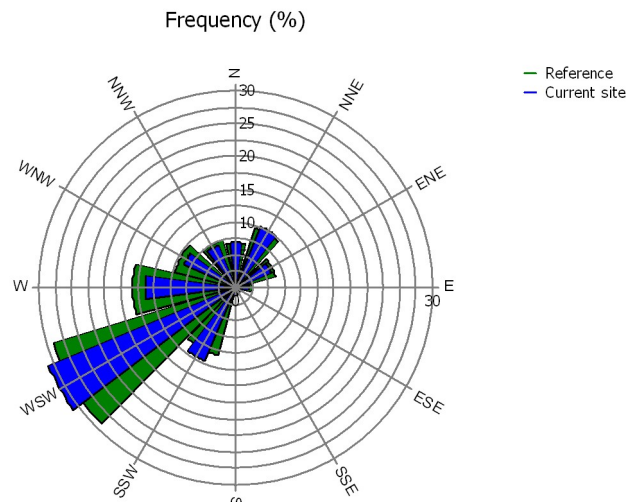
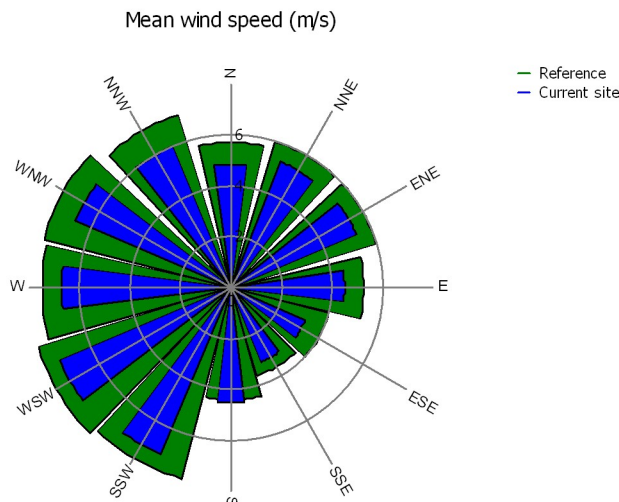
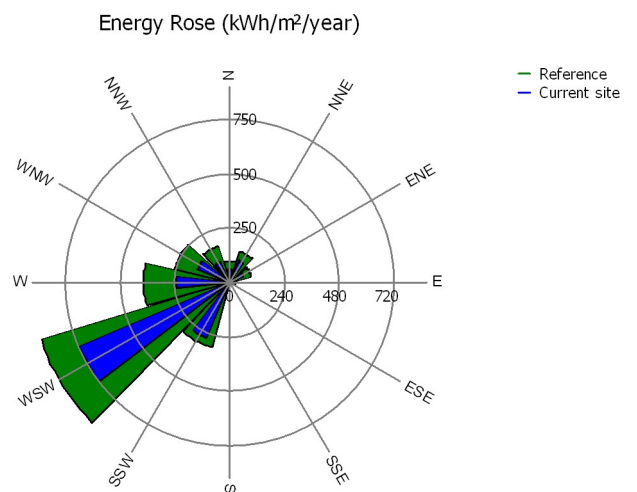
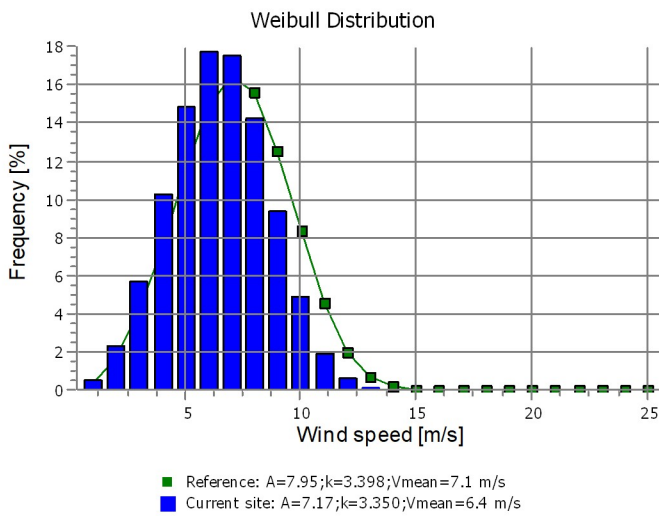
## PARK - Wind Data Analysis

Wind data: A - Site data: WASP (12); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 566,600 North: 2,560,045  
Site 1 Gujrat - VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (1)  
Wind statistics  
IN EMD-WRF India\_N23.142\_E069.66 (3) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	5.45	4.84	2.521	6.9	6.42	2.576	6.8
1 NNE	5.95	5.31	2.939	10.0	6.72	2.951	9.6
2 ENE	6.03	5.37	2.748	5.9	6.74	2.803	6.3
3 E	5.06	4.48	2.268	2.1	5.91	2.373	2.5
4 ESE	3.59	3.20	1.705	0.7	4.48	1.807	0.9
5 SSE	3.53	3.14	1.732	0.6	4.04	1.736	0.6
6 S	5.11	4.53	2.080	1.3	4.99	1.838	0.9
7 SSW	7.86	7.13	3.971	12.1	8.53	3.998	10.6
8 WSW	8.06	7.34	4.357	30.9	8.74	4.381	29.1
9 W	7.32	6.70	4.768	13.8	8.18	4.615	15.7
10 WNW	7.34	6.69	4.467	8.7	8.37	4.498	9.5
11 NNW	6.68	6.01	3.518	7.0	7.87	3.650	7.5
All	7.17	6.43	3.350	100.0	7.95	3.398	100.0





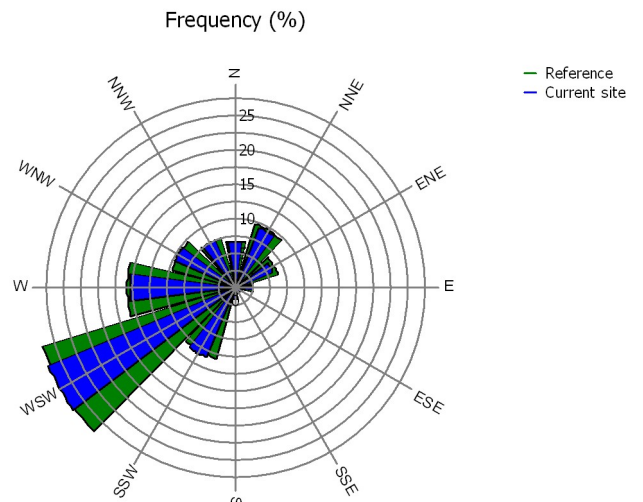
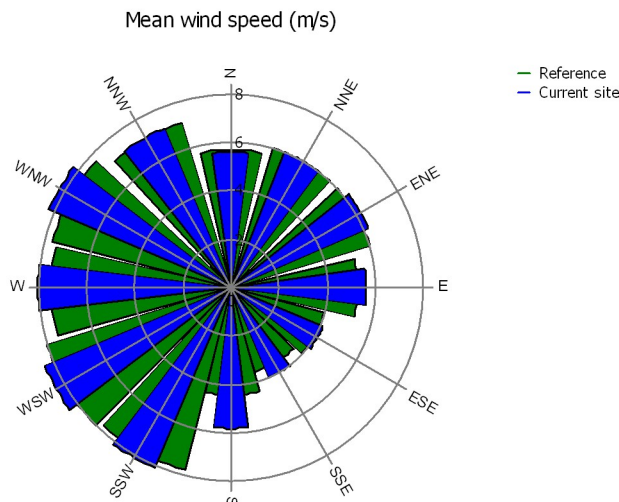
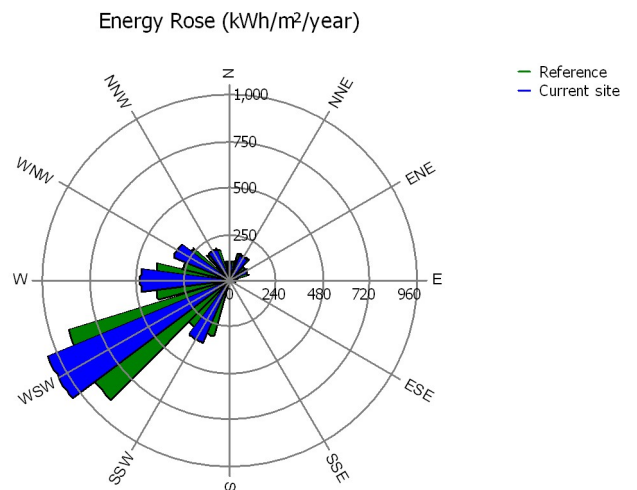
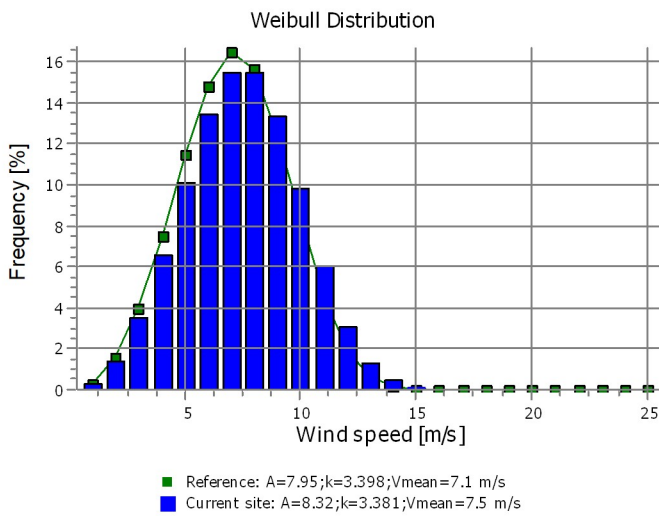
## PARK - Wind Data Analysis

Wind data: A - Site data: WASP (12); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 567,850 North: 2,559,579  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (3)  
Wind statistics  
IN EMD-WRF India\_N23.142\_E069.66 (3) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	6.31	5.60	2.502	6.7	6.42	2.576	6.8
1 NNE	6.72	6.00	2.955	9.3	6.72	2.951	9.6
2 ENE	6.96	6.20	2.768	5.9	6.74	2.803	6.3
3 E	6.32	5.60	2.334	2.4	5.91	2.373	2.5
4 ESE	4.63	4.13	1.725	0.8	4.48	1.807	0.9
5 SSE	4.50	4.01	1.744	0.6	4.04	1.736	0.6
6 S	6.55	5.80	2.252	1.6	4.99	1.838	0.9
7 SSW	8.92	8.08	3.982	10.9	8.53	3.998	10.6
8 WSW	9.18	8.36	4.354	29.3	8.74	4.381	29.1
9 W	8.77	8.02	4.713	15.4	8.18	4.615	15.7
10 WNW	8.99	8.20	4.432	9.6	8.37	4.498	9.5
11 NNW	7.95	7.14	3.408	7.5	7.87	3.650	7.5
All	8.32	7.47	3.381	100.0	7.95	3.398	100.0



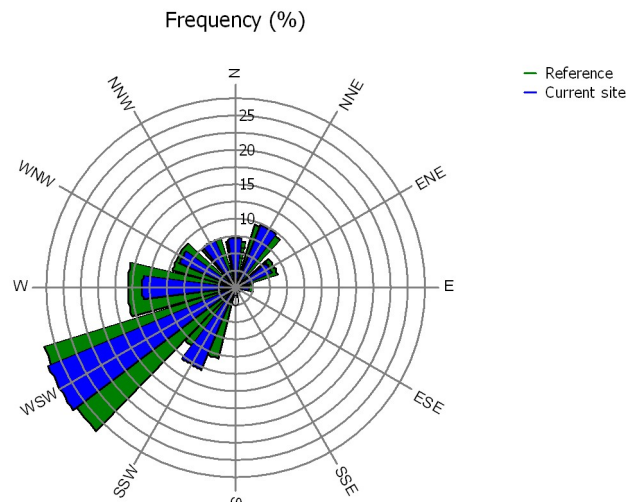
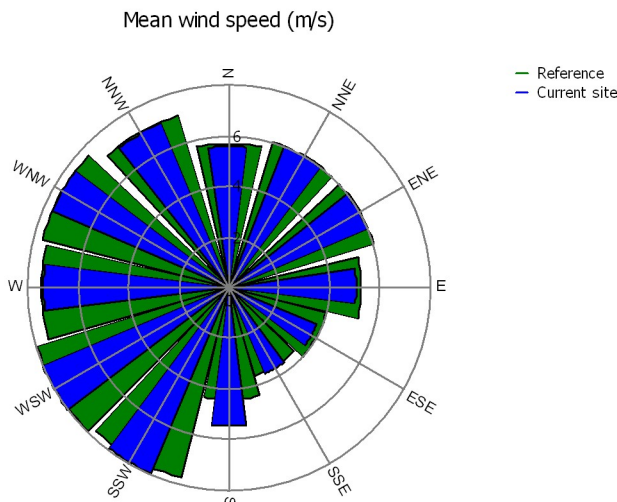
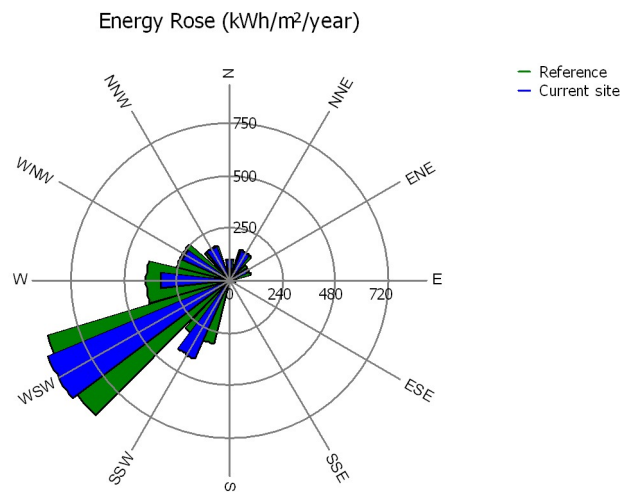
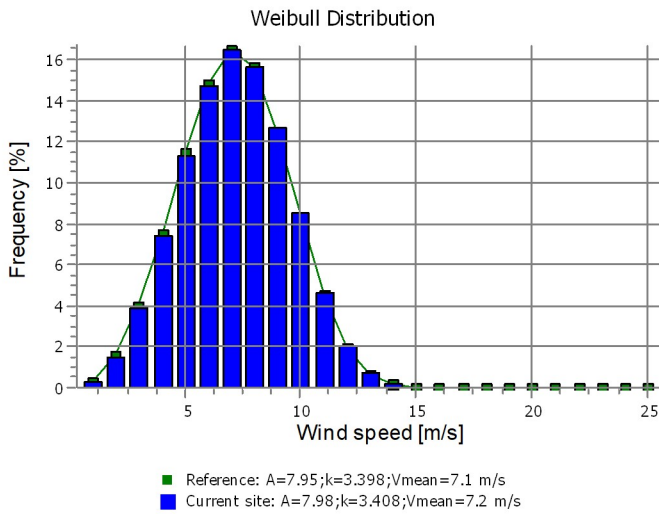
## PARK - Wind Data Analysis

Wind data: A - Site data: WASP (12); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 567,287 North: 2,559,716  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (5)  
Wind statistics  
IN EMD-WRF India\_N23.142\_E069.66 (3) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	6.30	5.59	2.510	7.2	6.42	2.576	6.8
1 NNE	6.71	5.99	2.951	9.8	6.72	2.951	9.6
2 ENE	6.72	5.98	2.756	5.7	6.74	2.803	6.3
3 E	5.69	5.04	2.287	2.1	5.91	2.373	2.5
4 ESE	4.23	3.77	1.721	0.8	4.48	1.807	0.9
5 SSE	4.14	3.69	1.729	0.6	4.04	1.736	0.6
6 S	6.17	5.46	2.053	1.4	4.99	1.838	0.9
7 SSW	8.77	7.95	4.018	12.9	8.53	3.998	10.6
8 WSW	8.80	8.01	4.361	29.6	8.74	4.381	29.1
9 W	8.07	7.39	4.779	13.6	8.18	4.615	15.7
10 WNW	8.38	7.64	4.471	9.0	8.37	4.498	9.5
11 NNW	7.81	7.03	3.541	7.5	7.87	3.650	7.5
All	7.98	7.17	3.408	100.0	7.95	3.398	100.0



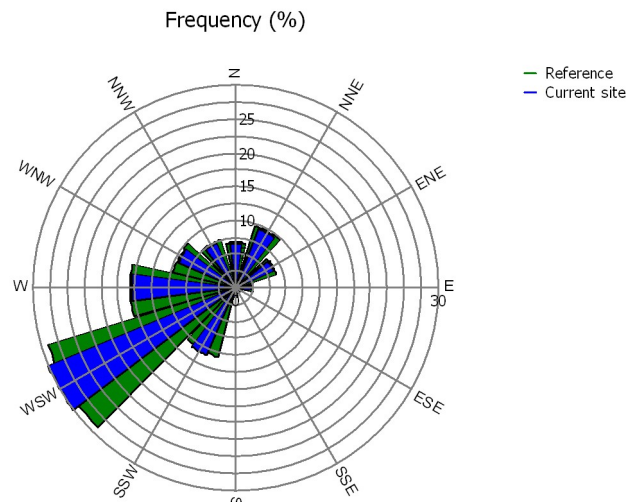
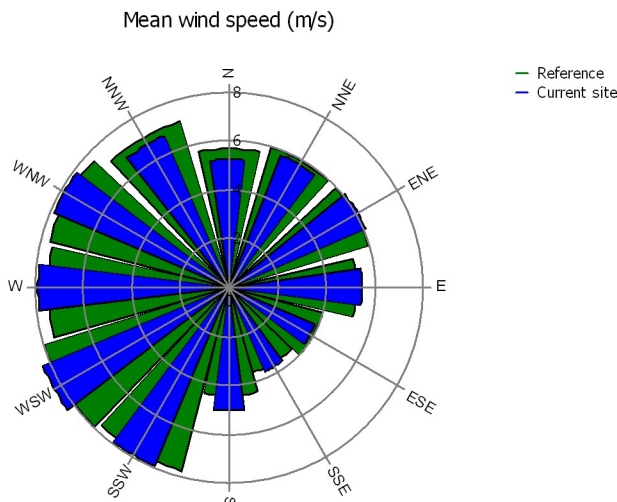
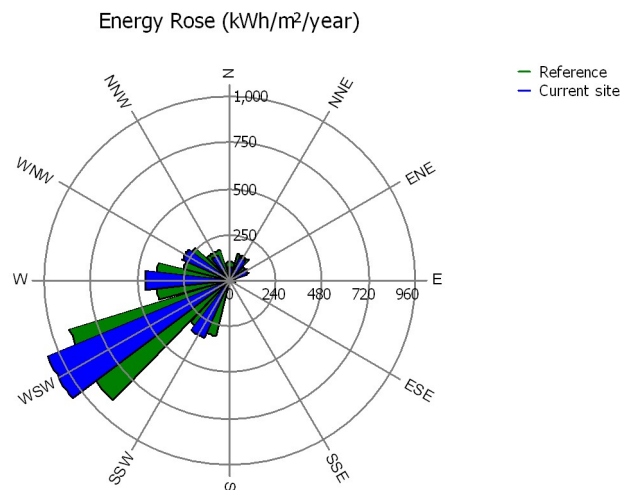
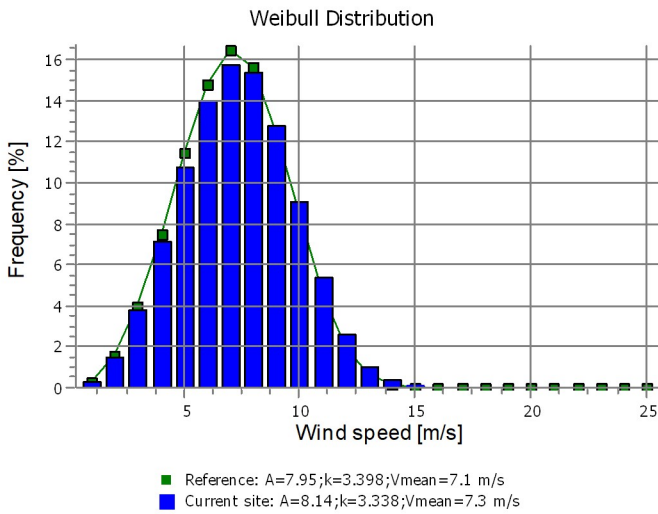
## PARK - Wind Data Analysis

Wind data: A - Site data: WASP (12); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 567,693 North: 2,559,220  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (6)  
Wind statistics  
IN EMD-WRF India\_N23.142\_E069.66 (3) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	5.91	5.25	2.494	6.5	6.42	2.576	6.8
1 NNE	6.52	5.82	2.947	9.4	6.72	2.951	9.6
2 ENE	6.88	6.12	2.775	6.2	6.74	2.803	6.3
3 E	6.19	5.48	2.318	2.4	5.91	2.373	2.5
4 ESE	4.30	3.84	1.705	0.8	4.48	1.807	0.9
5 SSE	4.17	3.71	1.736	0.6	4.04	1.736	0.6
6 S	5.69	5.04	2.158	1.3	4.99	1.838	0.9
7 SSW	8.72	7.90	3.971	10.9	8.53	3.998	10.6
8 WSW	9.12	8.31	4.354	30.1	8.74	4.381	29.1
9 W	8.62	7.88	4.725	15.4	8.18	4.615	15.7
10 WNW	8.64	7.87	4.393	9.3	8.37	4.498	9.5
11 NNW	7.52	6.76	3.447	7.2	7.87	3.650	7.5
All	8.14	7.31	3.338	100.0	7.95	3.398	100.0



## PARK - Park power curve

Wind speed [m/s]	Power														
	Free WTGs [kW]	Park WTGs [kW]	N [kW]	NNE [kW]	ENE [kW]	E [kW]	ESE [kW]	SSE [kW]	S [kW]	SSW [kW]	WSW [kW]	W [kW]	WNW [kW]	NNW [kW]	
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3.5	79	70	75	64	79	70	50	69	75	64	79	71	50	69	
4.5	536	509	527	471	536	511	471	505	527	471	536	511	470	505	
5.5	1,065	1,026	1,051	975	1,065	1,028	965	1,019	1,051	975	1,065	1,029	964	1,019	
6.5	1,802	1,739	1,780	1,657	1,802	1,742	1,643	1,729	1,780	1,657	1,802	1,745	1,641	1,729	
7.5	2,789	2,695	2,757	2,572	2,789	2,701	2,554	2,681	2,757	2,572	2,789	2,704	2,552	2,681	
8.5	4,000	3,881	3,961	3,721	4,000	3,888	3,705	3,863	3,961	3,721	4,000	3,891	3,702	3,863	
9.5	5,306	5,182	5,266	5,012	5,306	5,191	5,004	5,165	5,266	5,012	5,306	5,195	5,001	5,165	
10.5	6,555	6,446	6,521	6,293	6,555	6,455	6,297	6,432	6,521	6,293	6,555	6,457	6,293	6,432	
11.5	7,534	7,464	7,513	7,364	7,534	7,471	7,372	7,455	7,513	7,363	7,534	7,471	7,365	7,455	
12.5	7,905	7,884	7,898	7,855	7,905	7,885	7,855	7,881	7,898	7,855	7,905	7,886	7,853	7,881	
13.5	7,990	7,986	7,989	7,982	7,990	7,987	7,981	7,986	7,989	7,982	7,990	7,987	7,981	7,986	
14.5	8,000	7,999	7,999	7,999	8,000	7,999	7,999	7,999	7,999	7,999	8,000	7,999	7,999	7,999	
15.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
16.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
17.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
18.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
19.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
20.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
21.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
22.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
23.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
24.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

### Description:

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes wake losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in windPRO.

The park power curve can be used for:

1. Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
2. Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
3. Calculation of wind energy index based on the PARK production (see below).
4. Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in windPRO (PPV-model).

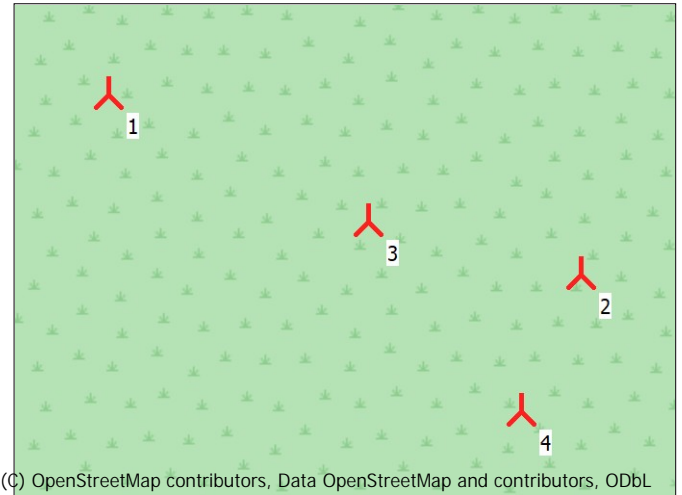
### Note:

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

## PARK - WTG distances

### WTG distances

	Z	Nearest WTG	Z	Horizontal distance	Distance in rotor diameters
	[m]		[m]	[m]	
1	200.0	3	270.0	762	8.5
2	290.0	4	269.3	392	4.4
3	270.0	2	290.0	579	6.4
4	269.3	2	290.0	392	4.4
Min	200.0		269.3	392	4.4
Max	290.0		290.0	762	8.5



Scale 1:20,000

 New WTG

Project:

Site 1 Gujrat with wizard

Licensed user:

TEST license

This license is only to be used for testing purposes

Aayush / aayush.choudhary.2021@uni.strath.ac.uk

Calculated:

26-07-2022 01:15/3.5.584

## PARK - Wind statistics info

### Main data for wind statistic

File	C:\Users\Glitch\Documents\WindPRO Data\Projects\Site 1 Gujrat\IN EMD-WRF India_N23.142_E069.66 (3) - 100.00 m.wvs
Name	EMD-WRF India_N23.142_E069.66 (3) - 100.00 m
Country	India
Source	USER
Mast coordinates	UTM (north)-WGS84 Zone: 42 East: 567,568 North: 2,559,392
Created	24-07-2022
Edited	25-07-2022
Sectors	12
WASP version	WASP 12 Version 12.07.0056
Coordinate system	UTM (north)-WGS84 Zone: 42
Displacement height	None

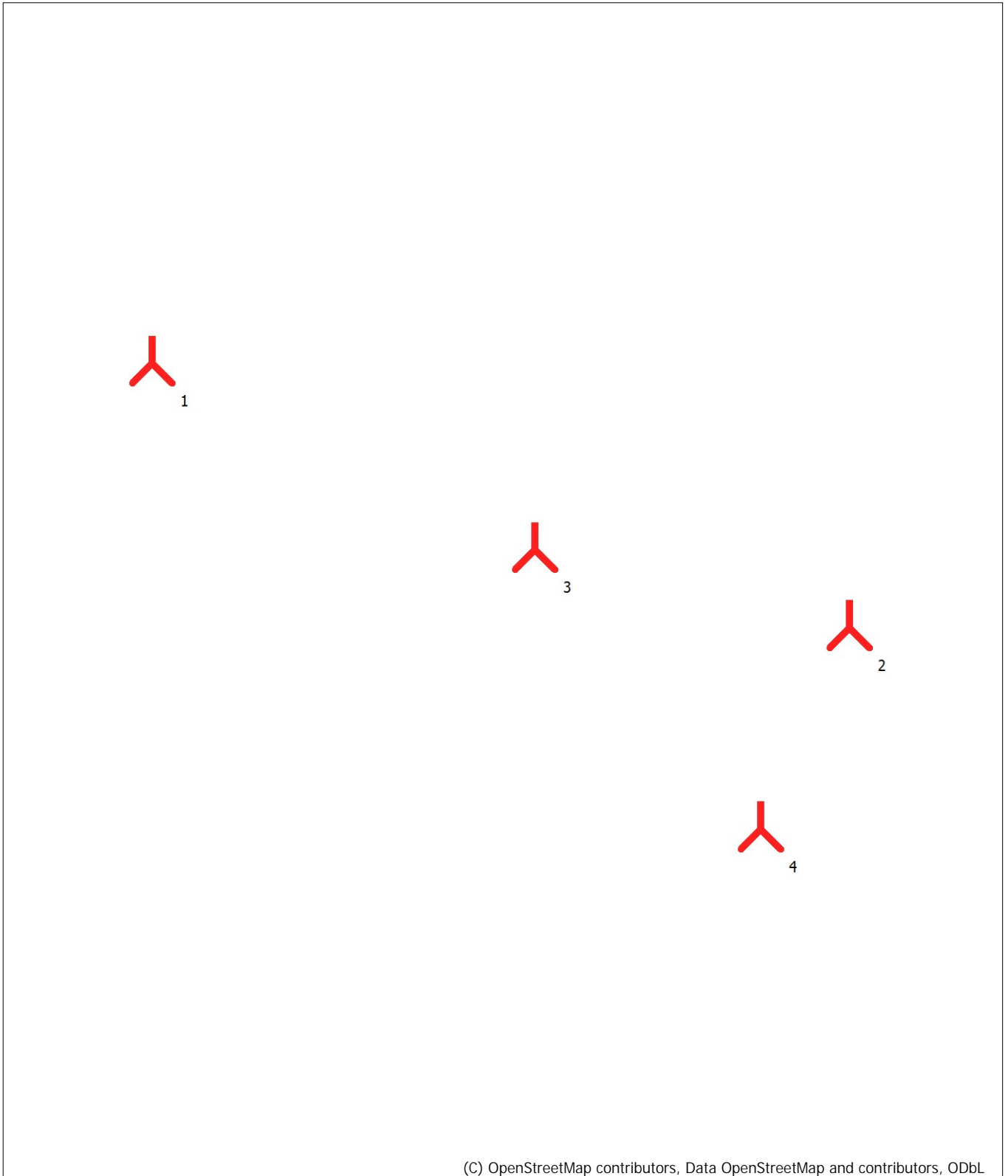
### Additional info for wind statistic

Source data	EMD-WRF India_N23.142_E069.66 (3)
Data from	01-01-1994
Data to	31-08-2019
Measurement length	307.9 Months
Recovery rate	100.0 %
Effective measurement length	307.9 Months

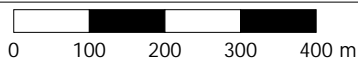
### Note

To get the most correct calculation results, wind statistics shall be calculated with the SAME model and model parameters, as currently chosen in calculation. For WASP versions before 10.0, the model is unchanged, but thereafter more model changes affecting the wind statistic is seen. Likewise WASP CFD should always use WASP CFD calculated wind statistics.

## PARK - Map



(C) OpenStreetMap contributors, Data OpenStreetMap and contributors, ODbL



Map: EMD OpenStreetMap , Print scale 1:10,000, Map center UTM (north)-WGS84 Zone: 42 East: 567,225 North: 2,559,633

 New WTG



# Appendix 3

## HOMER Pro Report for Calculation

### Performed At Site 1 Gujrat



**HOMER**  
Pro

## System Simulation Report



**File:** Site 1 Gujrat updated.homer

**Author:**

**Location:** 4MX2+56 Bharapar, Gujarat, India (23°8.9'N, 69°39.0'E)

**Total Net Present Cost:** \$1,070,906.00

**Levelized Cost of Energy (\$/kWh):** \$20.17

**Notes:** Site 1 Gujrat



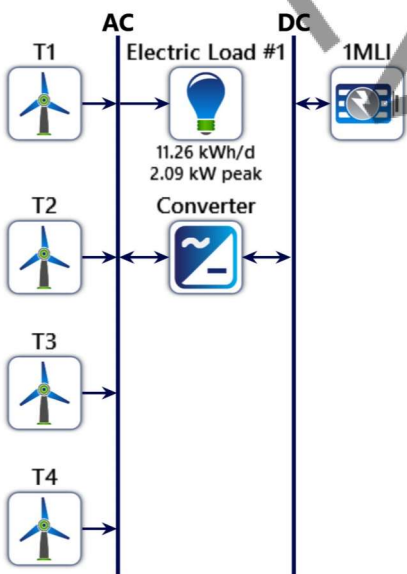
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Converter: System Converter	12
Compare Economics	13

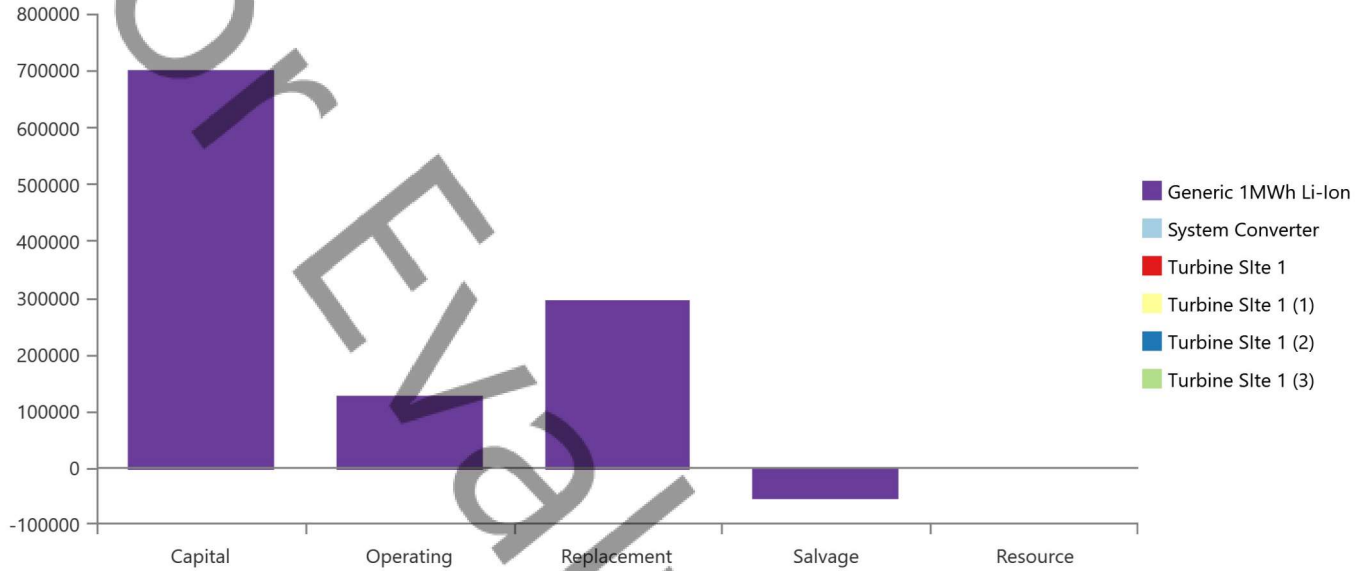
## System Architecture

Component	Name	Size	Unit
Storage	Generic 1MWh Li-Ion	1	strings
Wind turbine #1	Turbine SIt e 1	1	ea.
Wind turbine #2	Turbine SIt e 1 (1)	1	ea.
Wind turbine #3	Turbine SIt e 1 (2)	1	ea.
Wind turbine #4	Turbine SIt e 1 (3)	1	ea.
System converter	System Converter	1.23	kW
Dispatch strategy	HOMER Cycle Charging		

## Schematic



### Cost Summary



### Net Present Costs

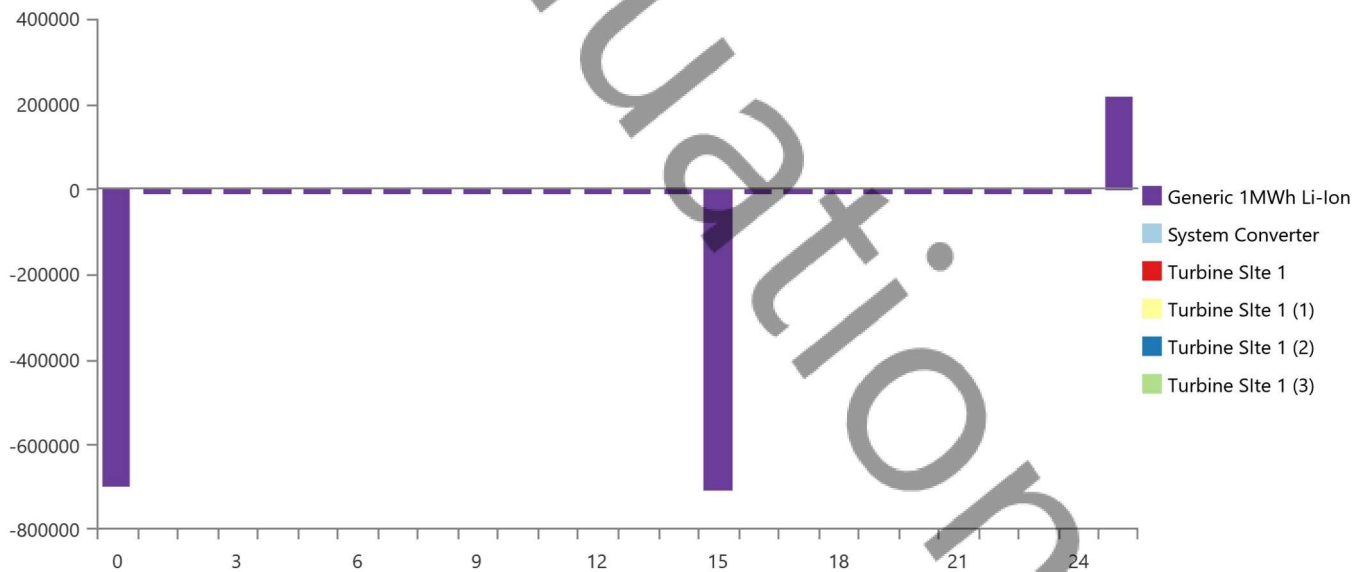
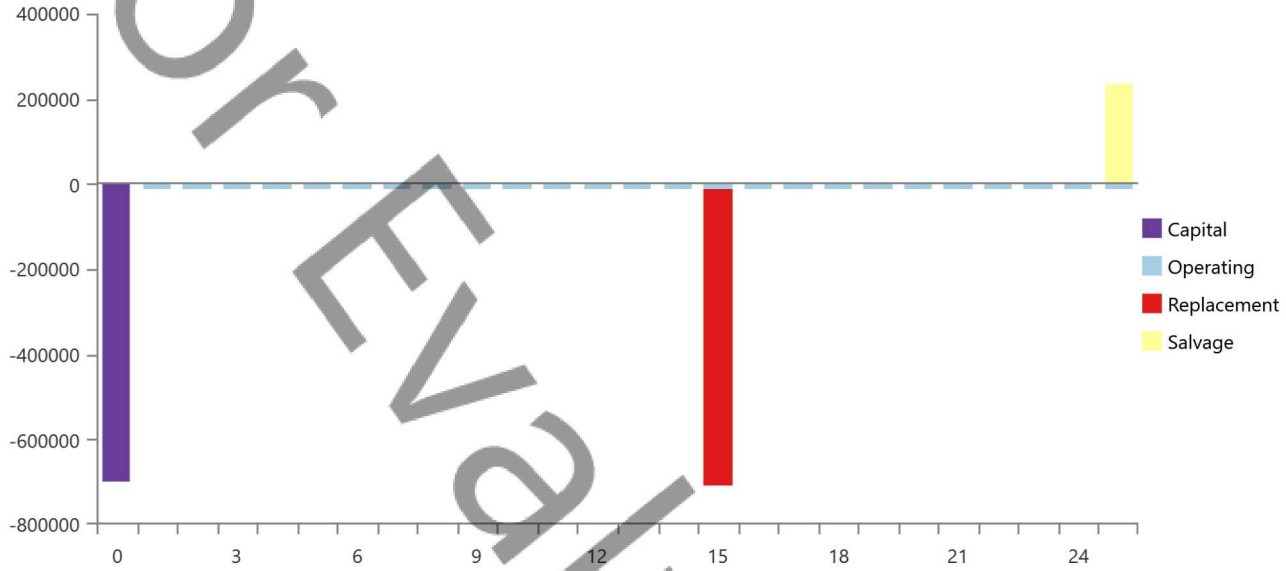
Name	Capital	Operating	Replacement	Salvage	Resource	Total
<b>Generic 1MWh Li-Ion</b>	\$700,000	\$129,275	\$296,992	-\$55,897	\$0.00	\$1.07M
<b>System Converter</b>	\$369.09	\$0.00	\$156.60	-\$29.47	\$0.00	\$496.22
<b>Turbine Site 1</b>	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
<b>Turbine Site 1 (1)</b>	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
<b>Turbine Site 1 (2)</b>	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
<b>Turbine Site 1 (3)</b>	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
<b>System</b>	\$700,409	\$129,275	\$297,148	-\$55,926	\$0.00	\$1.07M

### Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
<b>Generic 1MWh Li-Ion</b>	\$54,148	\$10,000	\$22,974	-\$4,324	\$0.00	\$82,798
<b>System Converter</b>	\$28.55	\$0.00	\$12.11	-\$2.28	\$0.00	\$38.38
<b>Turbine Site 1</b>	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
<b>Turbine Site 1 (1)</b>	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
<b>Turbine Site 1 (2)</b>	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
<b>Turbine Site 1 (3)</b>	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
<b>System</b>	\$54,180	\$10,000	\$22,986	-\$4,326	\$0.00	\$82,839



### Cash Flow



## Electrical Summary

### Excess and Unmet

Quantity	Value	Units
Excess Electricity	19,860,776	kWh/yr
Unmet Electric Load	2.15	kWh/yr
Capacity Shortage	3.88	kWh/yr

### Production Summary

Component	Production (kWh/yr)	Percent
Turbine Site 1	4,966,238	25.0
Turbine Site 1 (1)	4,966,238	25.0
Turbine Site 1 (2)	4,966,238	25.0
Turbine Site 1 (3)	4,966,238	25.0
Total	19,864,952	100

### Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	4,107	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	4,107	100



## Wind Turbine: Turbine Site 1

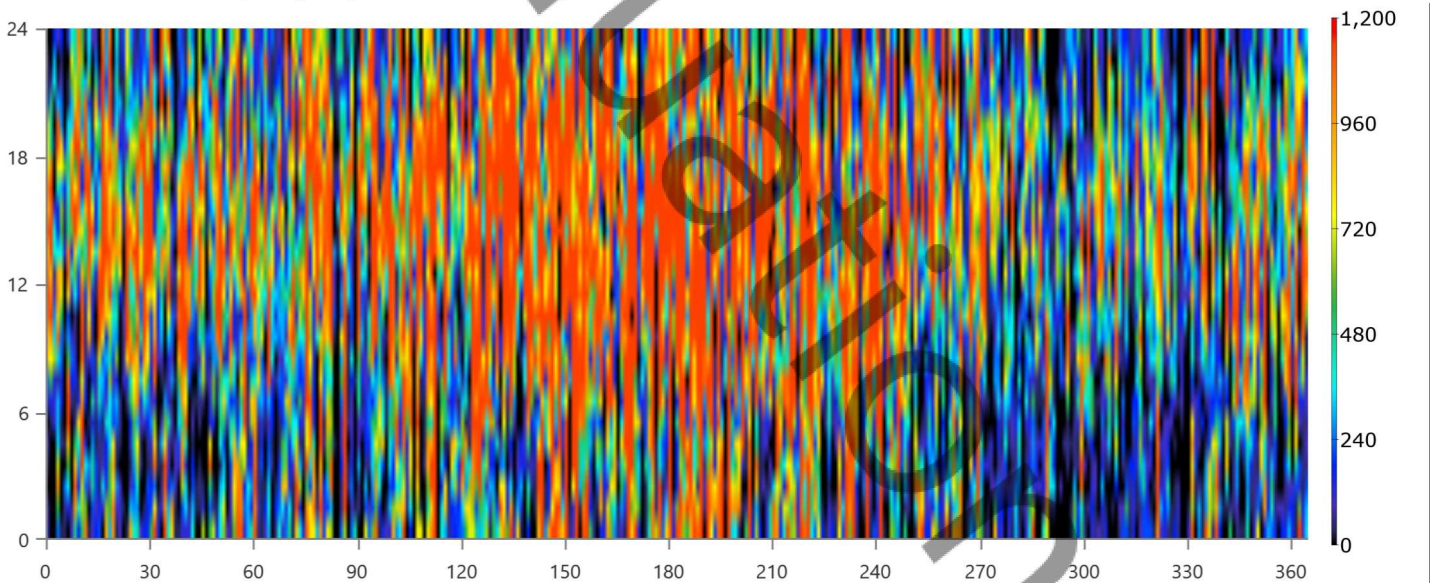
### Turbine Site 1 Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	120,859	%
Hours of Operation	7,981	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 1 Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	567	kW
Capacity Factor	28.3	%
Total Production	4,966,238	kWh/yr

### Turbine Site 1 Output (kW)



## Wind Turbine: Turbine Site 1 (1)

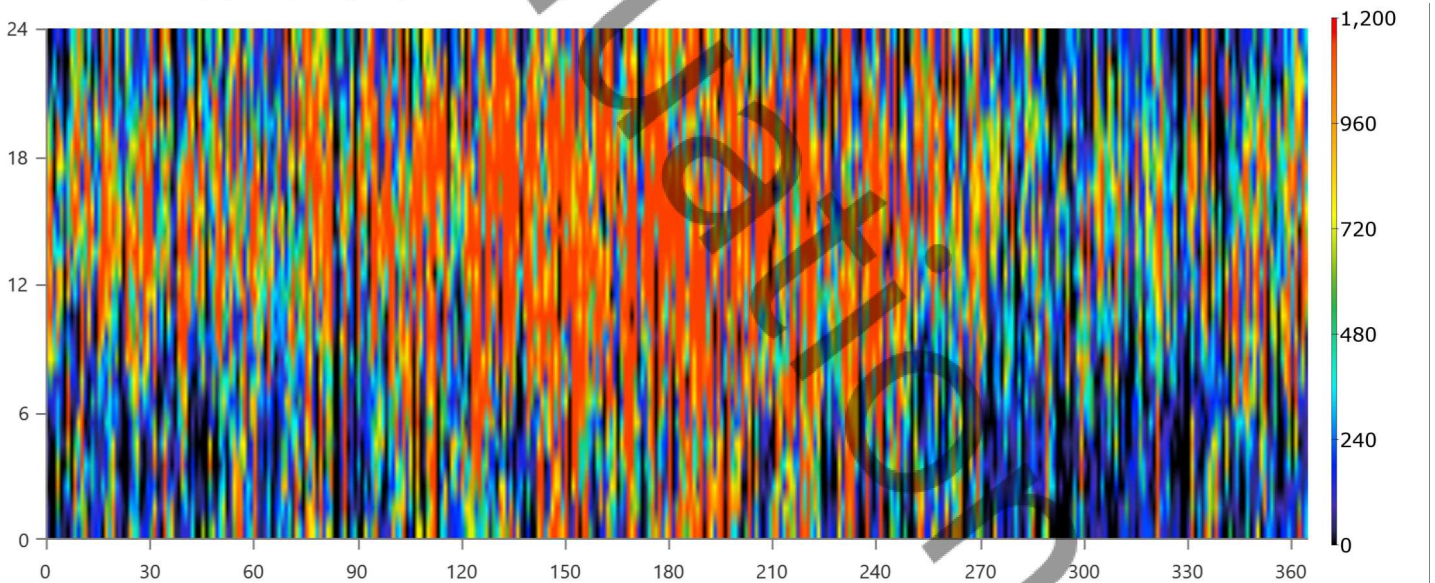
### Turbine Site 1 (1) Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	120,859	%
Hours of Operation	7,981	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 1 (1) Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	567	kW
Capacity Factor	28.3	%
Total Production	4,966,238	kWh/yr

### Turbine Site 1 (1) Output (kW)



## Wind Turbine: Turbine Site 1 (2)

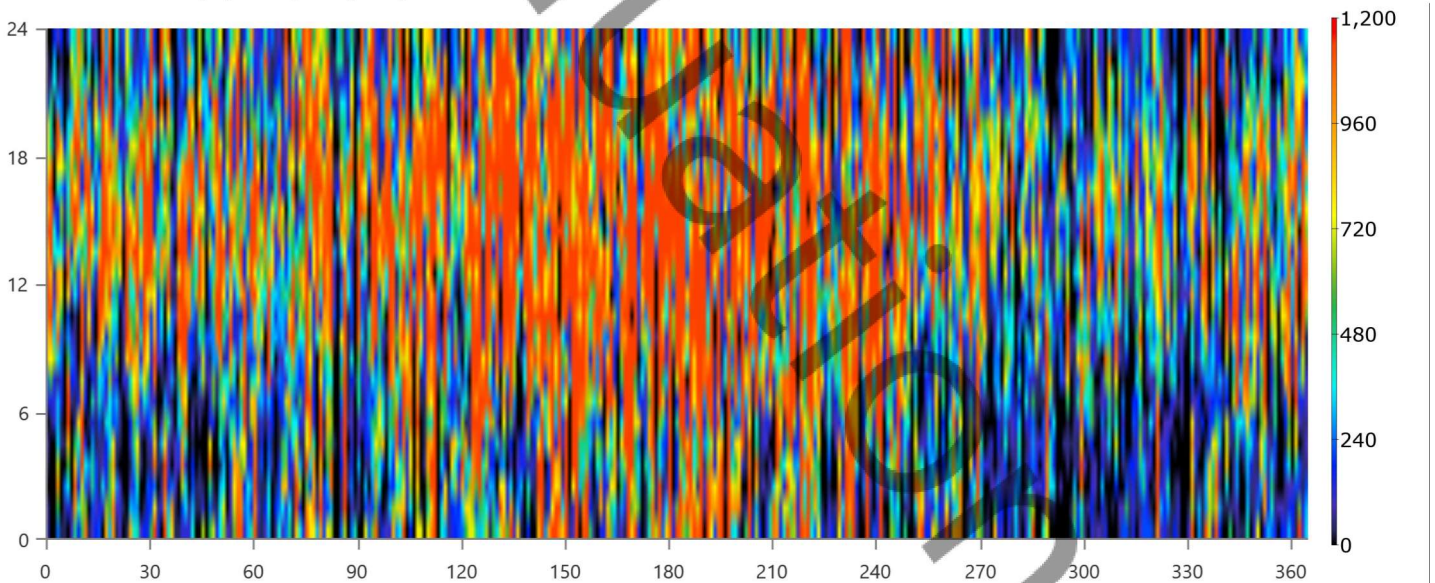
### Turbine Site 1 (2) Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	120,859	%
Hours of Operation	7,981	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 1 (2) Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	567	kW
Capacity Factor	28.3	%
Total Production	4,966,238	kWh/yr

### Turbine Site 1 (2) Output (kW)





## Wind Turbine: Turbine Site 1 (3)

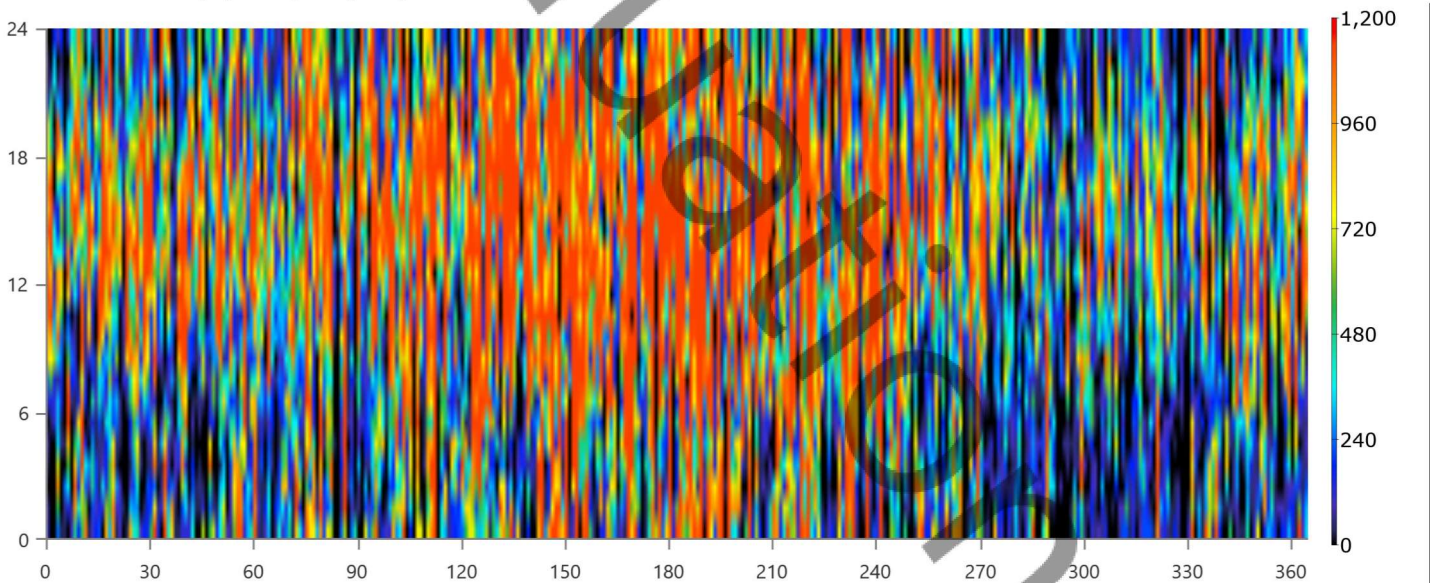
### Turbine Site 1 (3) Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	120,859	%
Hours of Operation	7,981	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 1 (3) Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	567	kW
Capacity Factor	28.3	%
Total Production	4,966,238	kWh/yr

### Turbine Site 1 (3) Output (kW)



## Storage: Generic 1MWh Li-Ion

### Generic 1MWh Li-Ion Properties

Quantity	Value	Units
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	600	V

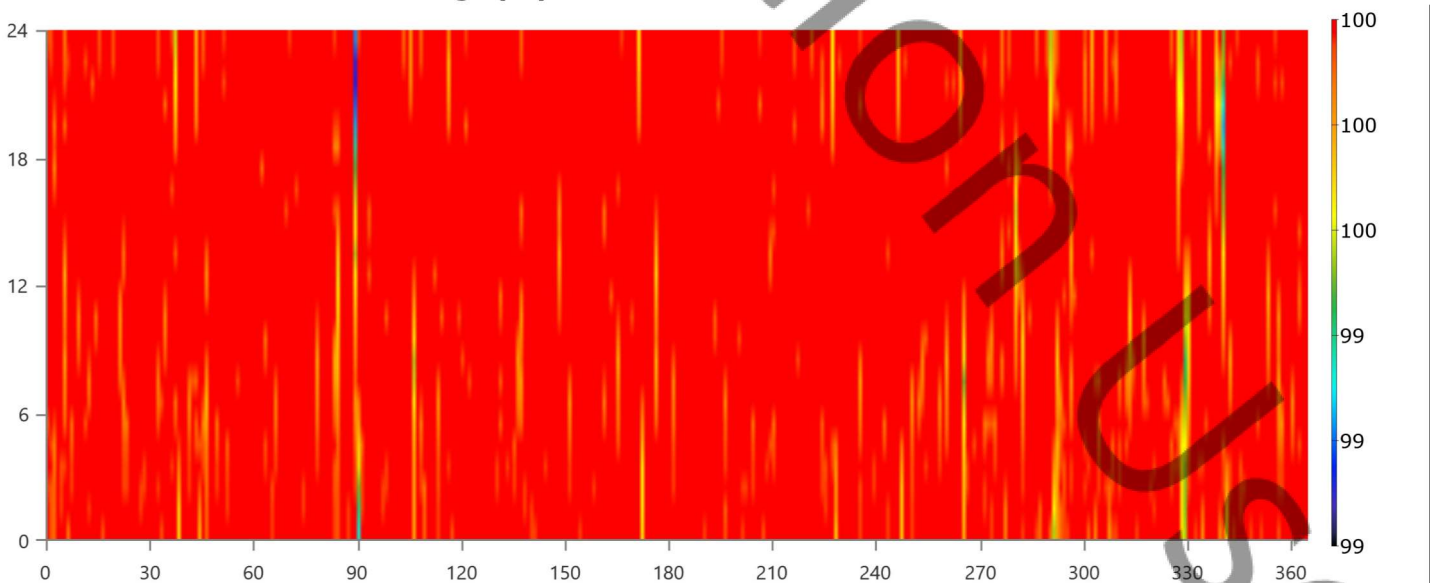
### Generic 1MWh Li-Ion Result Data

Quantity	Value	Units
Average Energy Cost	0	\$/kWh
Energy In	350	kWh/yr
Energy Out	315	kWh/yr
Storage Depletion	0	kWh/yr
Losses	35.0	kWh/yr
Annual Throughput	332	kWh/yr

### Generic 1MWh Li-Ion Statistics

Quantity	Value	Units
Autonomy	1,705	hr
Storage Wear Cost	0.246	\$/kWh
Nominal Capacity	1,000	kWh
Usable Nominal Capacity	800	kWh
Lifetime Throughput	4,987	kWh
Expected Life	15.0	yr

### Generic 1MWh Li-Ion State of Charge (%)



## Converter: System Converter

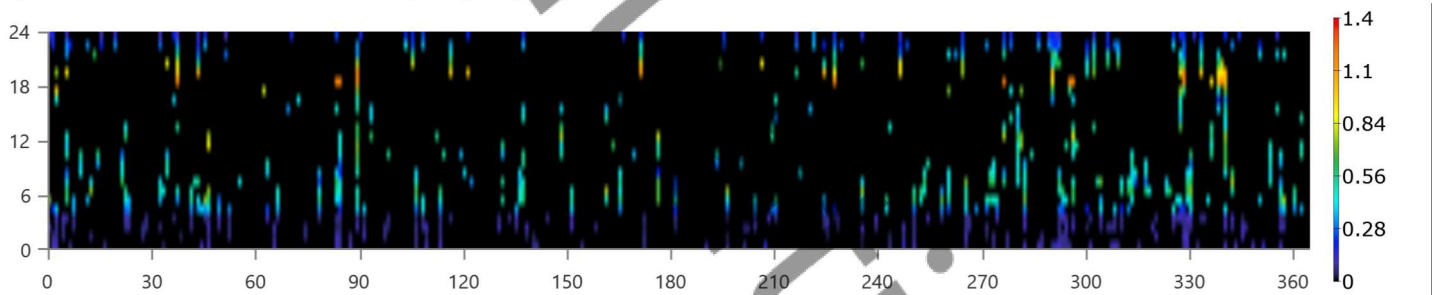
### System Converter Electrical Summary

Quantity	Value	Units
Hours of Operation	779	hrs/yr
Energy Out	300	kWh/yr
Energy In	315	kWh/yr
Losses	15.8	kWh/yr

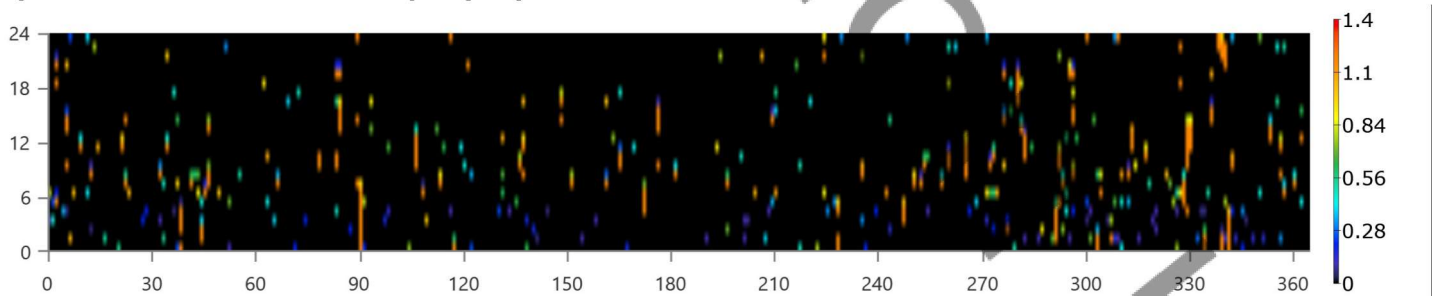
### System Converter Statistics

Quantity	Value	Units
Capacity	1.23	kW
Mean Output	0.0342	kW
Minimum Output	0	kW
Maximum Output	1.23	kW
Capacity Factor	2.78	%

### System Converter Inverter Output (kW)



### System Converter Rectifier Output (kW)





**Compare Economics**

IRR (%): **N/A**

Discounted payback (yr): **N/A**

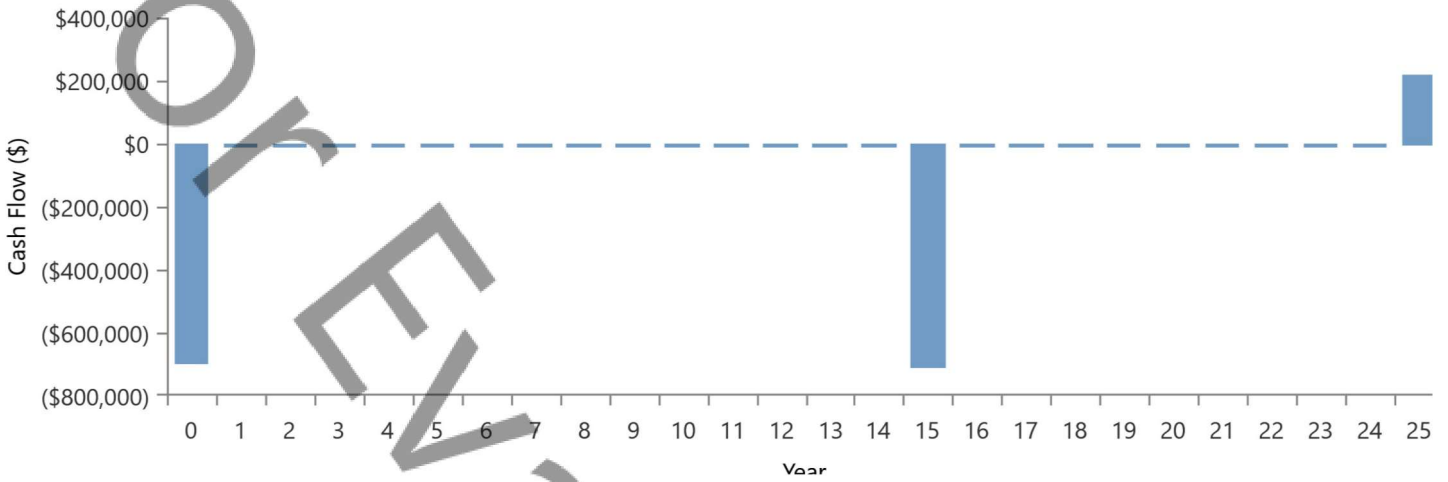
Simple payback (yr): **N/A**

	Base System	Proposed System
Net Present Cost	\$1.07M	\$1.07M
CAPEX	\$700,379	\$700,409
OPEX	\$28,660	\$28,660
LCOE (per kWh)	\$20.17	\$20.17
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

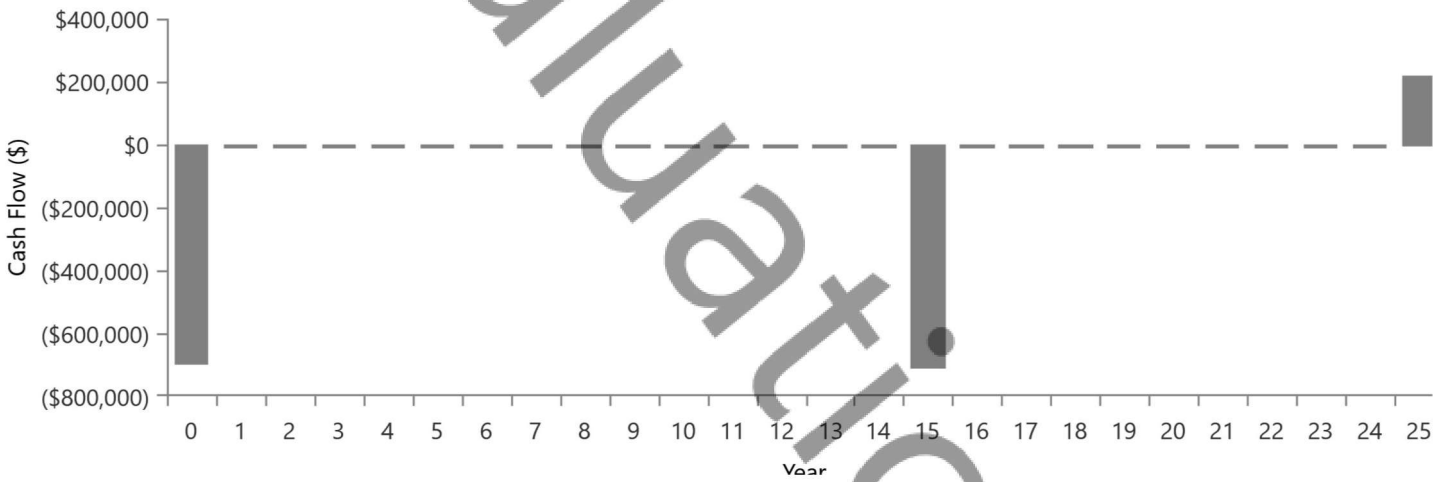




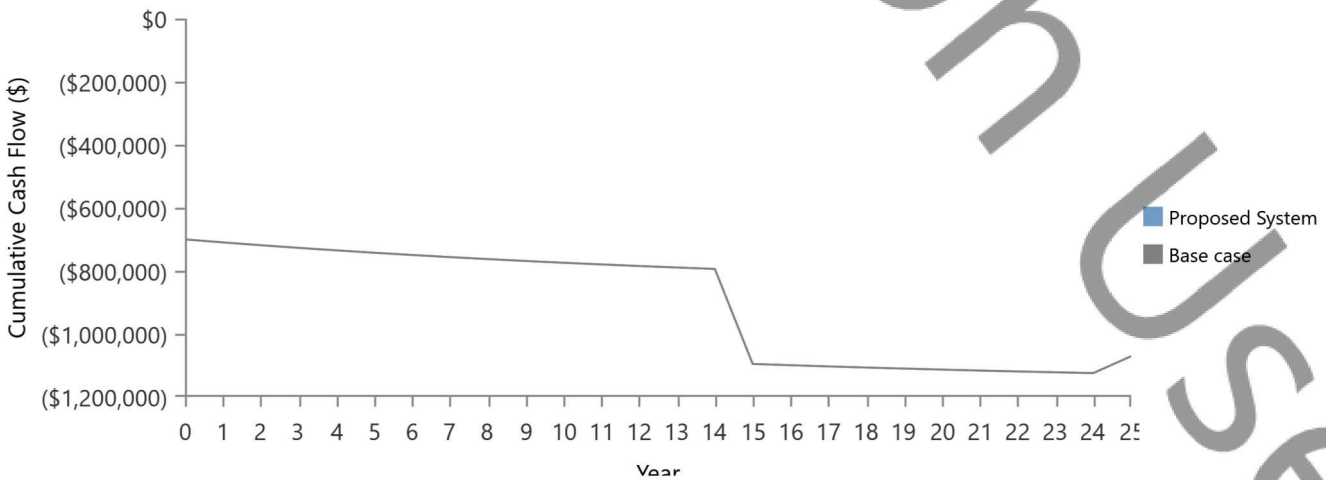
### Proposed Annual Nominal Cash Flows



### Base System Annual Nominal Cash Flows



### Cumulative Discounted Cash Flows



# Appendix 4

## WAsP Report for Calculation Performed At Site 2 Gujrat

# 'Site 2 Gujrat, India' WASP project report

Produced on 28-07-2022 at 08:43:33 by licenced user: Aayush Choudhary using WASP Version: 12.07.0056

## Report Contents

[1. WASP project parameters](#)

[2. Generalised wind climate](#)

[3. Wind farms](#)

[3.1 Turbine cluster 2](#)

## 1. Project Parameters

### WASP project parameters

All of the WASP project parameters have default values.

## 2. Generalised wind climate 'GWA3 download for 23.92800, 69.85409'

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### Reference conditions

Number of roughness lengths	5
Number of heights	5
Number of sectors	12
Roughness lengths	0.000 m; 0.030 m; 0.100 m; 0.400 m; 1.500 m
Heights a.g.l	10 m; 50 m; 100 m; 150 m; 200 m

### Climate context

The generalised wind climate is located at 23.93°N 69.85°E

### Barometric reference information

Mean temperature	27.84 °
Ref. altitude for temperature a.s.l	18.1 m
Mean pressure	100,640 Pa
Ref. altitude for pressure a.s.l	16.1 m
Relative humidity	50.51129 %

### GWC profile model for 'GWA3 download for 23.92800, 69.85409'

Not using geostrophic wind shear model

Using the classic WASP profile model, with:

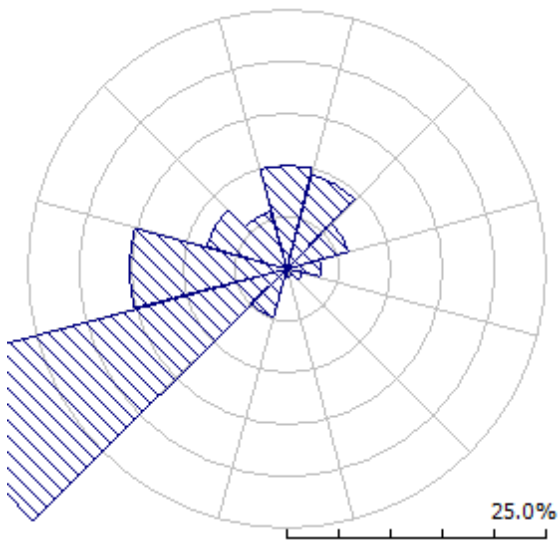
- Rms heat flux over land: 100.00 (the default)
- Rms heat flux over water: 30.00 (the default)
- Offset heat flux over land (classic): -40.00 (the default)
- Offset heat flux over water (classic): -8.00 (the default)
- Factor in height of boundary layer over land: 1.00 (the default)
- Factor in height of boundary layer over water: 1.00 (the default)
- Power law in decay of the stability induced perturbation of wind profile: 1.50 (the default)

### Generalised wind climate summary

		Roughness length 0.000 m	Roughness length 0.030 m	Roughness length 0.100 m	Roughness length 0.400 m	Roughness length 1.500 m
Height 10.0 m	Weibull A [m/s]	7.40	5.11	4.49	3.56	2.39
	Weibull k	1.94	1.71	1.75	1.81	1.88
	Mean speed U [m/s]	6.56	4.56	4.00	3.17	2.13
Height 50.0 m	Weibull A [m/s]	8.76	7.16	6.56	5.71	4.69
	Weibull k	2.04	1.94	1.96	2.00	2.05
	Mean speed U [m/s]	7.76	6.35	5.82	5.06	4.15
Height 100.0 m	Weibull A [m/s]	9.54	8.53	7.86	6.96	5.92
	Weibull k	2.15	2.20	2.19	2.19	2.22
	Mean speed U [m/s]	8.45	7.56	6.96	6.16	5.24
Height 150.0 m	Weibull A [m/s]	9.98	9.50	8.77	7.78	6.69
	Weibull k	2.12	2.29	2.30	2.27	2.25
	Mean speed U [m/s]	8.84	8.41	7.77	6.90	5.93
Height 200.0 m	Weibull A [m/s]	10.13	10.12	9.33	8.31	7.18
	Weibull k	2.08	2.25	2.25	2.23	2.21
	Mean speed U [m/s]	8.98	8.97	8.26	7.36	6.36

## Detailed descriptions

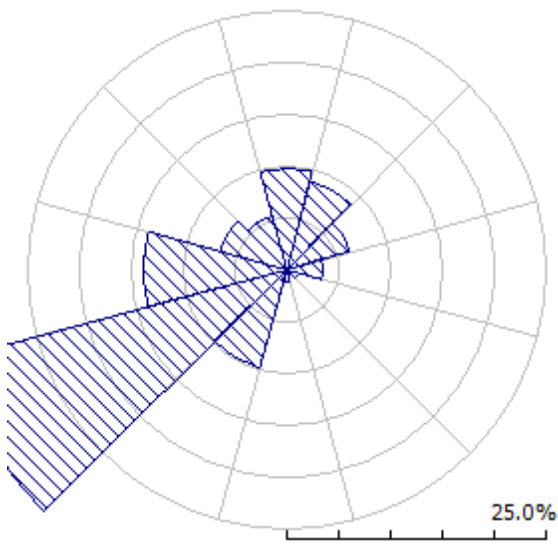
### Roughness length 0.000 m



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	4.4	4.8	5.1	3.9	3.6	3.5	4.6	8.0	9.7	9.3	6.7	4.5
	k	1.80	1.78	1.79	1.58	1.62	1.50	1.43	2.22	3.02	2.75	1.93	1.65
	U [m/s]	3.90	4.28	4.52	3.47	3.19	3.13	4.21	7.08	8.62	8.30	5.93	4.05
Height 50.0 m	A [m/s]	5.2	5.7	6.0	4.6	4.2	4.2	5.6	9.5	11.4	11.0	7.9	5.4
	k	1.94	1.92	1.93	1.71	1.76	1.63	1.54	2.38	3.25	2.96	2.10	1.79
	U [m/s]	4.62	5.07	5.36	4.11	3.78	3.71	5.00	8.39	10.18	9.80	7.03	4.80
Height 100.0 m	A [m/s]	5.7	6.2	6.6	5.1	4.6	4.6	6.1	10.3	12.3	11.9	8.7	5.9
	k	2.12	2.08	2.09	1.86	1.92	1.78	1.67	2.56	3.53	3.21	2.28	1.94

m	k U [m/s]	5.04	5.53	5.85	4.49	4.12	4.05	5.45	9.15	11.06	10.65	7.67	5.24
Height 150.0 m	A [m/s]	6.1	7.0	7.3	5.7	5.0	4.4	5.7	9.6	12.8	12.4	9.2	6.3
	k U [m/s]	2.04	2.21	1.99	1.83	1.82	1.59	1.50	1.96	3.38	3.00	2.22	1.92
Height 200.0 m	A [m/s]	5.42	6.21	6.49	5.03	4.45	3.93	5.18	8.56	11.47	11.06	8.14	5.57
	k U [m/s]	6.2	7.2	7.7	5.9	5.2	4.1	5.4	8.7	13.1	12.5	9.2	6.4
Freq. [%]	A [m/s]	1.95	2.08	2.03	1.72	1.75	1.46	1.39	1.69	3.47	2.76	2.17	1.94
	k U [m/s]	5.48	6.40	6.86	5.22	4.60	3.70	4.88	7.73	11.80	11.09	8.18	5.63
		10.0	9.3	6.2	3.2	1.6	0.7	0.8	4.8	34.5	15.1	8.0	5.7

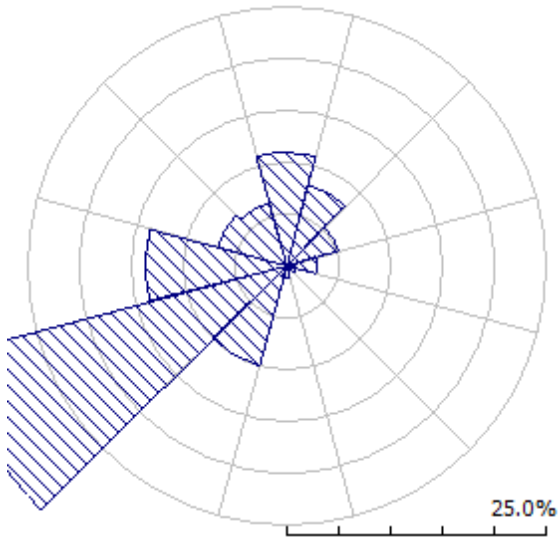
### Roughness length 0.030 m



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	3.0	3.3	3.5	2.7	2.3	2.5	3.8	5.6	6.9	6.2	4.2	2.9
	k U [m/s]	1.46	1.50	1.47	1.32	1.35	1.22	1.33	1.88	2.64	2.10	1.47	1.38
	k U [m/s]	2.71	2.99	3.13	2.49	2.14	2.35	3.45	5.00	6.15	5.46	3.78	2.66
Height 50.0 m	A [m/s]	4.3	4.7	4.9	3.9	3.4	3.6	5.4	7.9	9.5	8.6	6.0	4.2
	k U [m/s]	1.76	1.79	1.76	1.59	1.64	1.47	1.62	2.27	3.15	2.53	1.77	1.66
	k U [m/s]	3.80	4.20	4.39	3.49	3.00	3.30	4.84	6.98	8.51	7.61	5.30	3.72
Height 100.0 m	A [m/s]	5.1	5.7	5.9	4.7	4.1	4.4	6.5	9.4	11.1	10.1	7.2	5.0
	k U [m/s]	2.14	2.14	2.10	1.94	2.02	1.80	1.97	2.78	3.78	3.08	2.13	2.02
	k U [m/s]	4.54	5.02	5.25	4.18	3.60	3.94	5.79	8.34	10.07	9.07	6.34	4.45
Height 150.0 m	A [m/s]	5.9	6.7	7.1	5.5	4.4	4.5	6.8	10.1	12.2	11.3	8.2	5.6
	k U [m/s]	2.23	2.32	2.24	2.04	1.83	1.67	1.83	2.72	3.91	3.20	2.38	2.04
	k U [m/s]	5.20	5.91	6.28	4.87	3.93	3.99	6.01	8.97	11.05	10.10	7.27	4.96
Height 200.0 m	A [m/s]	6.3	7.4	7.9	6.0	4.7	4.4	6.8	10.5	13.0	12.0	8.6	6.0
	k	2.14	2.32	2.28	1.96	1.73	1.54	1.66	2.54	3.79	3.00	2.29	2.02
		5.54	6.52	6.97	5.30	4.19	3.97	6.07	9.32	11.79	10.71	7.63	5.29

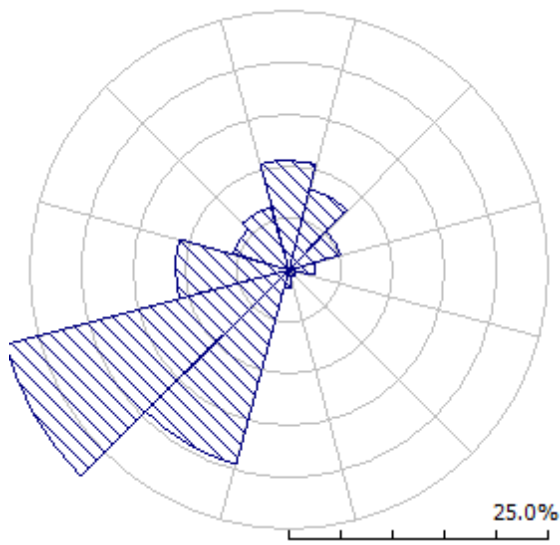
U [m/s]													
Freq. [%]	9.9	8.8	6.3	3.4	1.1	0.7	1.1	9.9	32.9	13.9	6.7	5.4	

**Roughness length 0.100 m**



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	2.7	3.1	3.0	2.4	2.0	2.3	3.3	5.0	6.0	5.4	3.6	2.5
	k U [m/s]	1.56 2.43	1.61 2.76	1.42 2.69	1.37 2.20	1.31 1.87	1.31 2.12	1.38 3.04	1.98 4.40	2.67 5.34	2.19 4.79	1.53 3.28	1.39 2.25
	U [m/s]												
Height 50.0 m	A [m/s]	4.0	4.5	4.4	3.6	3.0	3.4	5.0	7.2	8.6	7.9	5.4	3.7
	k U [m/s]	1.84 3.55	1.88 4.04	1.66 3.94	1.61 3.22	1.55 2.73	1.54 3.10	1.63 4.45	2.35 6.42	3.12 7.74	2.58 6.98	1.79 4.80	1.64 3.29
	U [m/s]												
Height 100.0 m	A [m/s]	4.8	5.5	5.3	4.4	3.7	4.2	6.0	8.6	10.2	9.4	6.5	4.5
	k U [m/s]	2.20 4.27	2.21 4.85	1.94 4.74	1.90 3.87	1.87 3.29	1.84 3.73	1.95 5.34	2.81 7.70	3.67 9.22	3.06 8.36	2.11 5.77	1.94 3.95
	U [m/s]												
Height 150.0 m	A [m/s]	5.5	6.4	6.5	5.1	4.1	4.2	6.3	9.3	11.3	10.4	7.4	5.1
	k U [m/s]	2.25 4.87	2.38 5.68	2.23 5.78	1.99 4.56	1.84 3.68	1.69 3.74	1.82 5.58	2.69 8.24	3.96 10.20	3.15 9.29	2.28 6.54	2.06 4.49
	U [m/s]												
Height 200.0 m	A [m/s]	6.0	7.0	7.2	5.7	4.4	4.1	6.3	9.6	12.0	11.1	7.8	5.3
	k U [m/s]	2.27 5.32	2.39 6.23	2.19 6.37	1.99 5.04	1.73 3.90	1.54 3.72	1.65 5.63	2.51 8.55	3.73 10.81	2.97 9.87	2.25 6.92	1.96 4.70
	U [m/s]												
Freq. [%]	10.9	8.1	5.2	2.8	1.0	0.6	1.1	9.9	33.4	13.6	7.0	6.3	

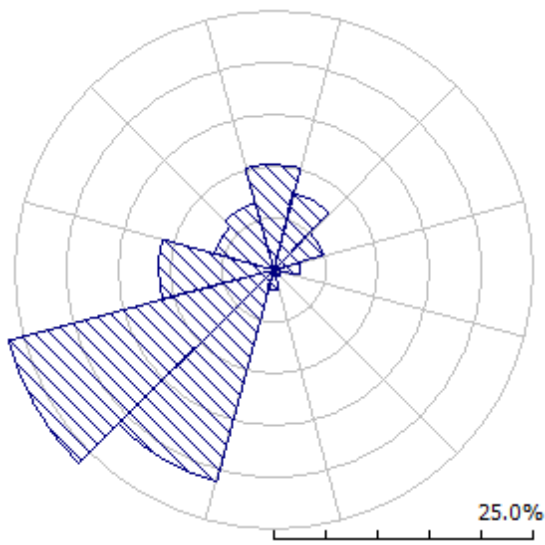
**Roughness length 0.400 m**



		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	2.2	2.5	2.2	1.9	1.5	1.9	2.8	4.3	4.8	3.9	2.5	2.0
	k [m/s]	1.60	1.64	1.46	1.45	1.30	1.34	1.44	2.47	2.84	1.99	1.53	1.51
	U [m/s]	1.95	2.19	2.02	1.68	1.39	1.79	2.53	3.79	4.32	3.44	2.26	1.80
Height 50.0 m	A [m/s]	3.5	4.0	3.6	3.0	2.5	3.2	4.6	6.8	7.7	6.2	4.1	3.2
	k [m/s]	1.85	1.87	1.67	1.68	1.51	1.55	1.68	2.87	3.24	2.32	1.76	1.75
	U [m/s]	3.13	3.52	3.24	2.71	2.23	2.87	4.07	6.08	6.87	5.53	3.63	2.89
Height 100.0 m	A [m/s]	4.3	4.9	4.5	3.7	3.1	3.9	5.6	8.3	9.2	7.6	5.0	4.0
	k [m/s]	2.14	2.15	1.93	1.96	1.77	1.80	1.97	3.36	3.72	2.71	2.03	2.03
	U [m/s]	3.83	4.30	3.96	3.30	2.73	3.51	4.97	7.42	8.31	6.75	4.43	3.53
Height 150.0 m	A [m/s]	5.0	5.8	5.4	4.3	3.4	4.1	5.9	9.1	10.2	8.4	5.7	4.5
	k [m/s]	2.28	2.35	2.07	1.96	1.83	1.72	1.87	3.20	3.85	2.85	2.13	2.05
	U [m/s]	4.46	5.12	4.78	3.82	2.99	3.63	5.28	8.13	9.20	7.53	5.01	3.98
Height 200.0 m	A [m/s]	5.4	6.4	6.0	4.7	3.5	3.9	6.2	9.7	10.8	8.9	6.1	4.7
	k [m/s]	2.19	2.39	2.11	1.90	1.72	1.54	1.74	3.04	3.66	2.72	2.17	1.95
	U [m/s]	4.82	5.66	5.35	4.13	3.08	3.55	5.50	8.65	9.78	7.93	5.39	4.16
Freq. [%]	10.5	8.0	5.2	2.5	0.8	0.7	1.8	19.4	28.1	11.0	5.6	6.4	

**Roughness length 1.500 m**





		Sec. 1 0°	Sec. 2 30°	Sec. 3 60°	Sec. 4 90°	Sec. 5 120°	Sec. 6 150°	Sec. 7 180°	Sec. 8 210°	Sec. 9 240°	Sec. 10 270°	Sec. 11 300°	Sec. 12 330°
Height 10.0 m	A [m/s]	1.5	1.7	1.5	1.3	1.0	1.4	1.9	2.9	3.2	2.6	1.7	1.3
	k [m/s]	1.67	1.76	1.57	1.53	1.38	1.45	1.50	2.69	2.88	2.07	1.59	1.60
	U [m/s]	1.32	1.51	1.39	1.15	0.95	1.23	1.70	2.62	2.85	2.30	1.49	1.19
Height 50.0 m	A [m/s]	2.9	3.3	3.1	2.5	2.1	2.7	3.7	5.7	6.2	5.1	3.3	2.6
	k [m/s]	1.91	1.99	1.78	1.75	1.59	1.65	1.72	3.08	3.26	2.38	1.80	1.82
	U [m/s]	2.59	2.96	2.72	2.25	1.87	2.40	3.34	5.13	5.54	4.50	2.92	2.33
Height 100.0 m	A [m/s]	3.7	4.2	3.9	3.2	2.7	3.4	4.8	7.2	7.7	6.4	4.2	3.3
	k [m/s]	2.17	2.24	2.01	2.00	1.83	1.87	1.97	3.52	3.69	2.73	2.04	2.07
	U [m/s]	3.28	3.75	3.44	2.85	2.37	3.04	4.23	6.48	6.97	5.69	3.70	2.95
Height 150.0 m	A [m/s]	4.4	5.1	4.8	3.8	2.9	3.5	5.1	8.0	8.7	7.2	4.7	3.8
	k [m/s]	2.26	2.41	2.14	1.94	1.80	1.70	1.83	3.22	3.72	2.74	2.03	1.96
	U [m/s]	3.87	4.52	4.23	3.33	2.61	3.14	4.56	7.15	7.84	6.41	4.21	3.33
Height 200.0 m	A [m/s]	4.8	5.6	5.3	4.2	3.0	3.4	5.3	8.5	9.3	7.7	5.1	4.0
	k [m/s]	2.23	2.42	2.08	1.95	1.69	1.49	1.69	2.99	3.52	2.68	2.03	1.88
	U [m/s]	4.25	5.00	4.69	3.68	2.69	3.07	4.76	7.62	8.38	6.85	4.53	3.52
Freq. [%]	10.2	7.7	5.1	2.4	0.8	0.7	1.8	21.1	26.4	11.1	5.9	6.8	

### 3. Wind farms

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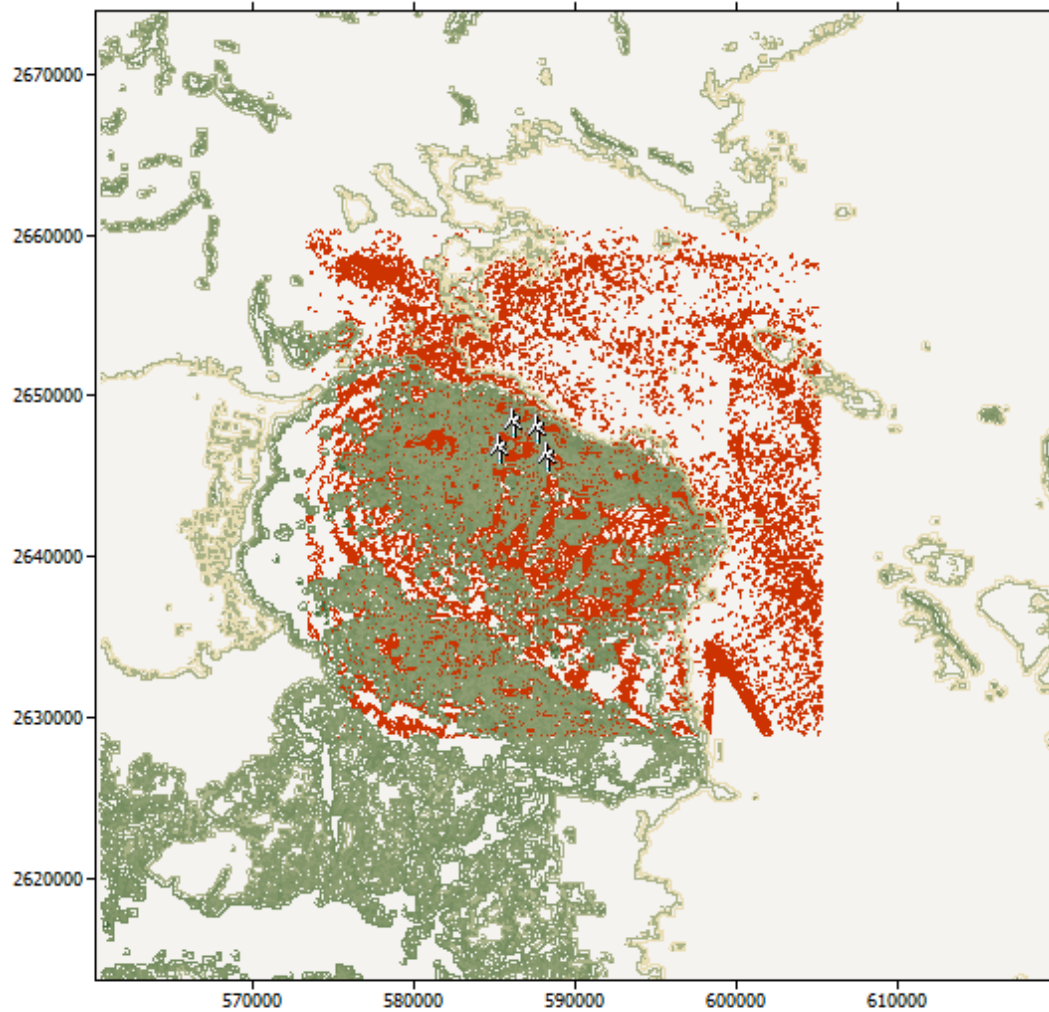
#### [3.1 Turbine cluster 2](#)

### 3.1 Wind farm: 'Turbine cluster 2'

#### Site information

Site count	4
Uniform hub height a.g.l	No

The Wind farm lies in a map called 'CONTOURLINE\_ONLINEDATA\_0.map, 3: 42: 10: 0, UTM (north)-WGS84 Zone: 42, optimized'.



## Summary results

Parameter	Total	Average	Minimum	Maximum
Net AEP [GWh]	26.623	7.079	6.394	7.628
Gross AEP [GWh]	26.921	7.096	6.408	7.661
Wake loss [%]	0.22	-	-	-

## Site results

Site	Location [m]	Turbine	Elevation [m] a.s.l.	Height [m] a.g.l.	Air density [kg/m <sup>3</sup> ]	Net AEP [GWh]	Wake loss [%]
Turbine 01	(588368, 2645473)	V90-2.0 MW GridStreamer	271.1	100.0	1.119	6.353	0.17
Turbine 02	(585472, 2646037)	V90-2.0 MW GridStreamer	330.6	100.0	1.113	5.756	0.16
Turbine 03	(587824, 2647242)	V90-2.0 MW GridStreamer	326.4	100.0	1.114	7.118	0.34
Turbine 04	(586276, 2647562)	V90-2.0 MW GridStreamer	373.3	100.0	1.109	7.396	0.18

## Site wind climates

Site	Location [m]	H [m]	A [m/s]	k	U [m/s]	E [W/m <sup>2</sup> ]	RIX [%]	dRIX [%]
Turbine 01	(588368, 2645473)	100.0	9.6	2.21	6.875	594	6.3	N/A
Turbine 02	(585472, 2646037)	100.0	9.4	2.21	6.724	563	11.7	N/A
Turbine 03	(587824, 2647242)	100.0	10.4	2.31	7.188	738	9.9	N/A
Turbine 04	(586276, 2647562)	100.0	10.4	2.30	7.532	737	12.1	N/A

---

# Appendix 5

## windPRO Report for Calculation

### Performed At Site 2 Gujrat

## PARK - Main Result

Calculation: PARK Site 2

Wake Model N.O. Jensen (RISØ/EMD)

Calculation performed in UTM (north)-WGS84 Zone: 42  
At the site centre the difference between grid north and true north is: 0.4°

Power curve correction method  
New windPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>  
Air density calculation method  
Height dependent, temperature from climate station  
Station: BADIN V3 2014  
Base temperature: 26.7 °C at 11.0 m  
Base pressure: 1013.3 hPa at 0.0 m  
Air density for Site center in key hub height: 270.0 m + 100.0 m = 1.137 kg/m<sup>3</sup> -> 92.8 % of Std  
Relative humidity: 0.0 %

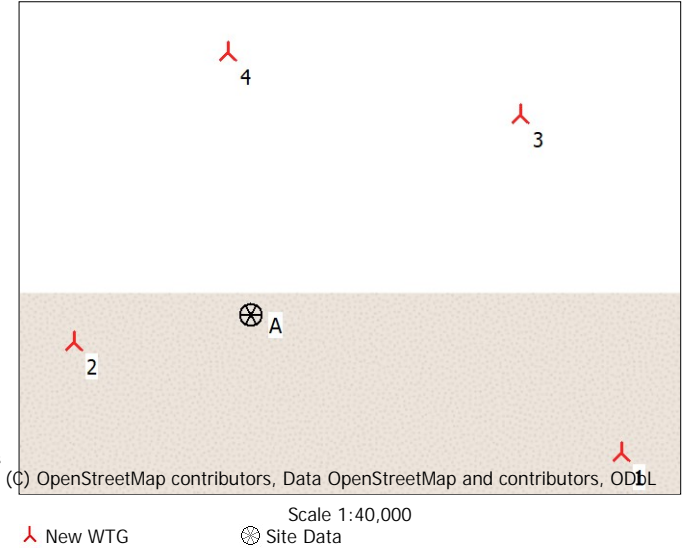
Wake Model Parameters  
Wake decay constant 0.075 DTU default onshore

Omnidirectional displacement height from objects

Wake calculation settings  
Angle [°] Wind speed [m/s]  
start end step start end step  
0.5 360.0 1.0 0.5 30.5 1.0

Wind statistics IN EMD-WRF India\_N23.925\_E069.849 (9) - 100.00 m.wvs

WASP version WASP 12 Version 12.07.0056



### Key results for height 100.0 m above ground level

Terrain UTM (north)-WGS84 Zone: 42

Easting	Northing	Name of wind distribution	Type	Wind energy [kWh/m <sup>2</sup> ]	Mean wind speed [m/s]	Equivalent roughness
A 586,405	2,646,183	Site data: WASP (11)	WASP (WASP 12 Version 12.07.0056)	2,015	6.5	0.1

### Calculated Annual Energy for Wind Farm

WTG combination	Result PARK [MWh/y]	Result-10.0% [MWh/y]	GROSS (no loss) Free WTGs [MWh/y]	Wake loss [%]	Specific results <sup>a)</sup>			
					Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	24,568.6	22,111.8	24,700.6	0.5	31.5	5,527.9	2,764	7.0

<sup>a)</sup> Based on Result-10.0%

### Calculated Annual Energy for each of 4 new WTGs with total 8.0 MW rated power

Links	Valid	WTG type Manufact.	Type-generator	Power, rated [kW]	Rotor diameter [m]	Hub height [m]	Power curve Creator	Name	Annual Energy			
									Result [MWh/y]	Result-10.0% [MWh/y]	Wake loss [%]	Free mean wind speed [m/s]
1	A	Yes	VESTAS V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	5,667.2	5,101	0.3	6.67
2	A	Yes	VESTAS V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	5,454.1	4,909	0.3	6.58
3	A	Yes	VESTAS V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	6,716.2	6,045	0.9	7.27
4	A	Yes	VESTAS V90-2,000	2,000	90.0	100.0	EMD	Level 0 - - Mode 0 - 07-2009	6,731.1	6,058	0.5	7.28

### WTG siting

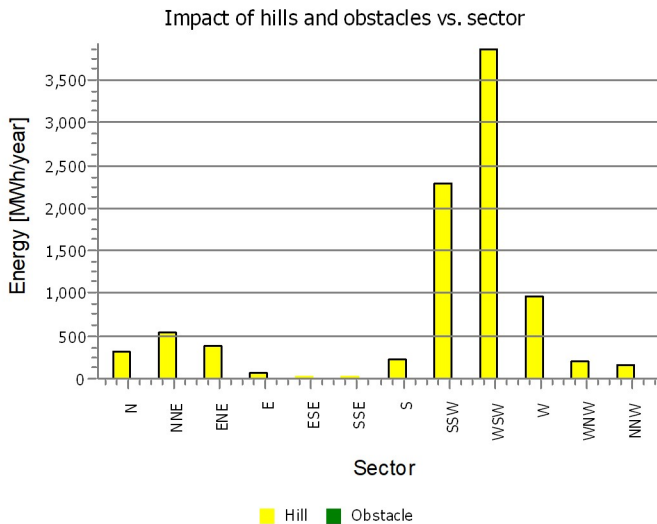
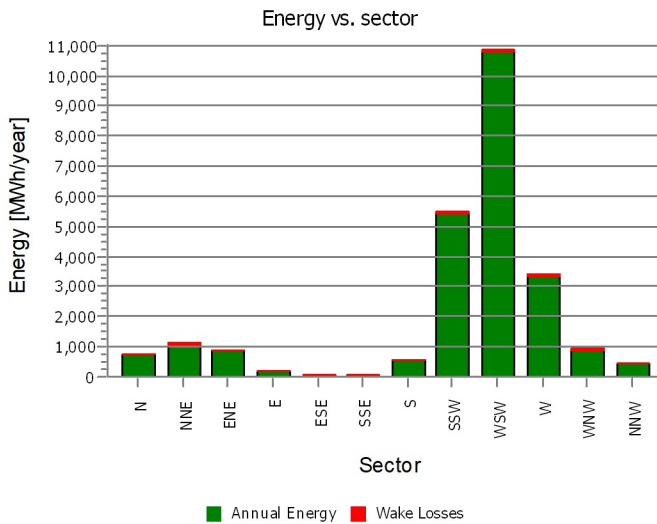
UTM (north)-WGS84 Zone: 42

	Easting	Northing	Z [m]	Row data/Description
1 New	588,368	2,645,473	270.0	VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (1)
2 New	585,472	2,646,037	330.6	VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (2)
3 New	587,824	2,647,242	326.5	VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (3)
4 New	586,276	2,647,562	373.3	VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (4)

## PARK - Production Analysis

Calculation: PARK Site 2WTG: All new WTGs, Air density varies with WTG position 1.126 kg/m<sup>3</sup> - 1.137 kg/m<sup>3</sup>  
Directional Analysis

Sector		0 N	1 NNE	2 ENE	3 E	4 ESE	5 SSE	6 S	7 SSW	8 WSW	9 W	10 WNW	11 NNW	Total
Roughness based energy	[MWh]	421.4	584.7	489.3	145.2	42.5	40.4	342.8	3,167.1	6,999.9	2,438.6	705.5	287.2	15,664.7
+ Increase due to hills	[MWh]	310.1	527.4	370.9	72.5	15.4	21.4	227.4	2,295.7	3,857.2	971.3	210.3	156.4	9,035.9
-Decrease due to wake losses	[MWh]	1.4	8.3	4.5	3.4	0.4	0.6	1.1	32.9	31.9	39.9	4.7	2.6	131.9
Resulting energy	[MWh]	730.1	1,103.8	855.8	214.2	57.5	61.1	569.1	5,429.9	10,825.3	3,369.9	911.1	440.9	24,568.6
Specific energy	[kWh/m <sup>2</sup> ]													965
Specific energy	[kWh/kW]													3,071
Increase due to hills	[%]	73.6	90.2	75.8	49.9	36.2	52.8	66.3	72.5	55.1	39.8	29.8	54.4	57.68
Decrease due to wake losses	[%]	0.2	0.7	0.5	1.6	0.7	1.0	0.2	0.6	0.3	1.2	0.5	0.6	0.53
Utilization	[%]	37.3	39.6	41.1	39.9	38.5	37.3	35.5	35.4	37.1	42.3	41.6	39.3	37.8
Operational	[Hours/year]	448	656	614	264	103	75	202	1,215	2,367	1,219	542	362	8,068
Full Load Equivalent	[Hours/year]	91	138	107	27	7	8	71	679	1,353	421	114	55	3,071



## PARK - Power Curve Analysis

Calculation: PARK Site 2WTG: 1 - VESTAS V90 2000 90.0 IO!, Hub height: 100.0 m

Name: Level 0 - - Mode 0 - 07-2009  
Source: Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type	Generator type	Specific power kW/m <sup>2</sup>
09-07-2009	EMD	23-08-2004	20-10-2009	25.0	Pitch	User defined	Variable	0.31

Curves based on Document no. 0004-6207 V01 dated 2009-07-09.  
Please contact Vestas for information on latest power curve.

HP curve comparison - Note: For standard air density

Vmean [m/s]	5	6	7	8	9	10
HP value Pitch, variable speed (2013) [MWh]	3,248	4,971	6,649	8,153	9,427	10,451
VESTAS V90 2000 90.0 IO! Level 0 - - Mode 0 - 07-2009 [MWh]	3,202	4,904	6,568	8,064	9,331	10,343
Check value [%]	1	1	1	1	1	1

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m<sup>2</sup>) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.  
For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see the windPRO manual.  
The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.  
Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.

### Power curve

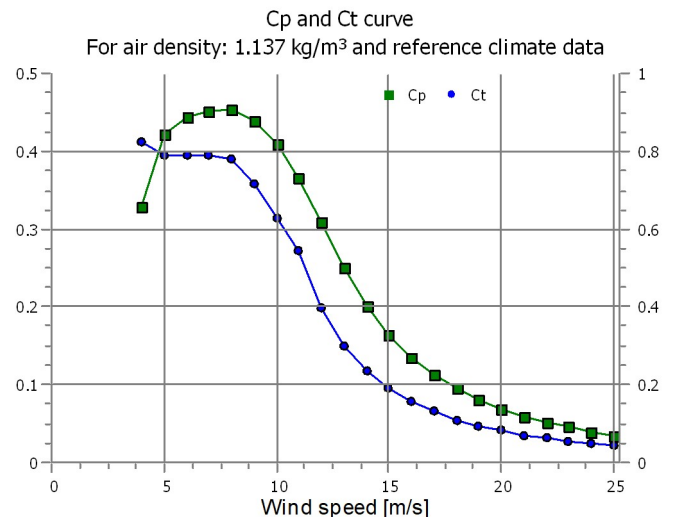
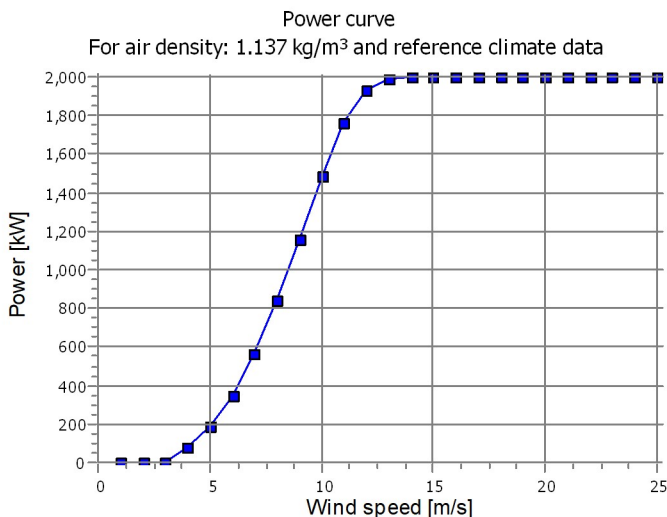
Original data, Air density: 1.225 kg/m<sup>3</sup>

Wind speed [m/s]	Power [kW]	Cp	Wind speed [m/s]	Ct curve
4.0	88.0	0.35	4.0	0.82
5.0	205.0	0.42	5.0	0.79
6.0	371.0	0.44	6.0	0.79
7.0	601.0	0.45	7.0	0.79
8.0	901.0	0.45	8.0	0.78
9.0	1,243.0	0.44	9.0	0.72
10.0	1,591.0	0.41	10.0	0.63
11.0	1,876.0	0.36	11.0	0.54
12.0	1,979.0	0.29	12.0	0.40
13.0	1,999.0	0.23	13.0	0.30
14.0	2,000.0	0.19	14.0	0.24
15.0	2,000.0	0.15	15.0	0.19
16.0	2,000.0	0.13	16.0	0.16
17.0	2,000.0	0.10	17.0	0.13
18.0	2,000.0	0.09	18.0	0.11
19.0	2,000.0	0.07	19.0	0.09
20.0	2,000.0	0.06	20.0	0.08
21.0	2,000.0	0.06	21.0	0.07
22.0	2,000.0	0.05	22.0	0.06
23.0	2,000.0	0.04	23.0	0.05
24.0	2,000.0	0.04	24.0	0.05
25.0	2,000.0	0.03	25.0	0.04

### Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1.137 kg/m<sup>3</sup> New windPRO method (adjusted IEC method, improved to match turbine control) <RECOMMENDED>

Wind speed [m/s]	Power [kW]	Cp	Interval [m/s]	Energy [MWh]	Acc. Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50- 1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50- 2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50- 3.50	7.0	7.0	0.1
4.0	76.2	0.33	3.50- 4.50	67.8	74.9	1.3
5.0	190.2	0.42	4.50- 5.50	199.9	274.8	4.8
6.0	345.8	0.44	5.50- 6.50	391.6	666.4	11.8
7.0	560.3	0.45	6.50- 7.50	638.9	1,305.2	23.0
8.0	839.7	0.45	7.50- 8.50	881.4	2,186.6	38.6
9.0	1,158.9	0.44	8.50- 9.50	1,014.8	3,201.5	56.5
10.0	1,482.6	0.41	9.50-10.50	962.8	4,164.2	73.5
11.0	1,761.5	0.37	10.50-11.50	742.2	4,906.5	86.6
12.0	1,927.3	0.31	11.50-12.50	450.6	5,357.1	94.5
13.0	1,987.3	0.25	12.50-13.50	209.5	5,566.6	98.2
14.0	1,999.4	0.20	13.50-14.50	75.0	5,641.6	99.5
15.0	2,000.0	0.16	14.50-15.50	20.5	5,662.1	99.9
16.0	2,000.0	0.13	15.50-16.50	4.3	5,666.4	100.0
17.0	2,000.0	0.11	16.50-17.50	0.7	5,667.1	100.0
18.0	2,000.0	0.09	17.50-18.50	0.1	5,667.2	100.0
19.0	2,000.0	0.08	18.50-19.50	0.0	5,667.2	100.0
20.0	2,000.0	0.07	19.50-20.50	0.0	5,667.2	100.0
21.0	2,000.0	0.06	20.50-21.50	0.0	5,667.2	100.0
22.0	2,000.0	0.05	21.50-22.50	0.0	5,667.2	100.0
23.0	2,000.0	0.05	22.50-23.50	0.0	5,667.2	100.0
24.0	2,000.0	0.04	23.50-24.50	0.0	5,667.2	100.0
25.0	2,000.0	0.04	24.50-25.50	0.0	5,667.2	100.0





Project:  
Site 2 Gujrat, India

Licensed user:  
TEST license  
This license is only to be used for testing purposes

Aayush / aayush.choudhary.2021@uni.strath.ac.uk  
Calculated:  
26-07-2022 14:15/3.5.584

## PARK - Terrain

Calculation: PARK Site 2Site Data: A - Site data: WAsP (11)

### Obstacles:

0 Obstacles used

### Roughness:

Terrain data files used in calculation:

C:\Users\Glitch\Documents\WindPRO Data\Projects\Site 2 Gujrat, India\Maps\ROUGHNESSLINE\_ONLINEDATA\_0\_Coopernicus.map  
Min X: 560,615, Max X: 619,597, Min Y: 2,613,404, Max Y: 2,674,106, Width: 58,982 m, Height: 60,702 m

### Orography:

Terrain data files used in calculation:

C:\Users\Glitch\Documents\WindPRO Data\Projects\Site 2 Gujrat, India\Maps\CONTOURLINE\_ONLINEDATA\_0.map  
Min X: 573,449, Max X: 605,147, Min Y: 2,628,795, Max Y: 2,660,518, Width: 31,698 m, Height: 31,723 m

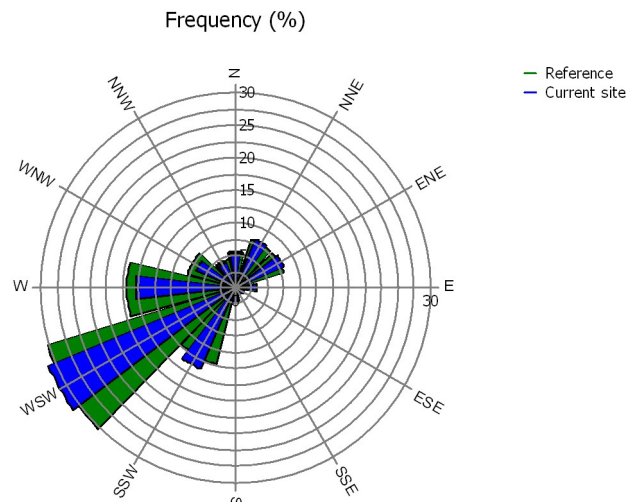
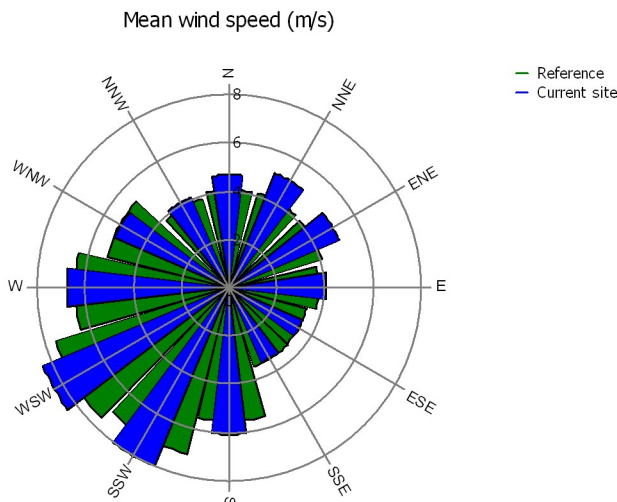
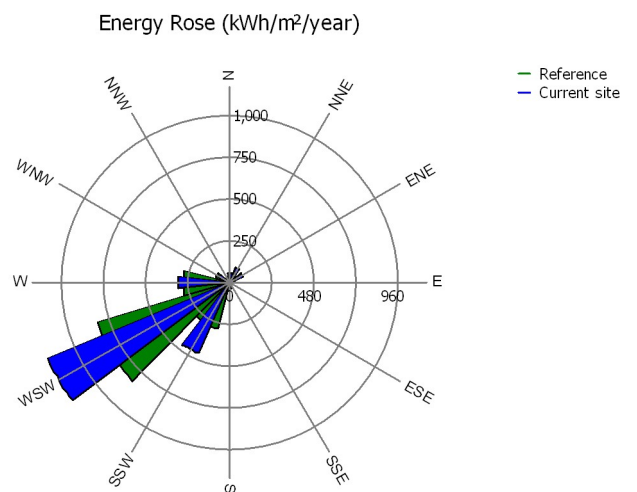
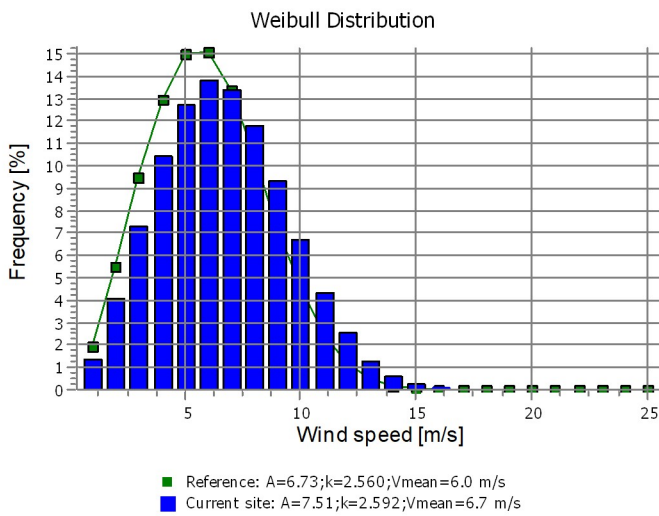
## PARK - Wind Data Analysis

Calculation: PARK Site 2Wind data: A - Site data: WASP (11); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 588,368 North: 2,645,473  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (1)  
Wind statistics  
IN EMD-WRF India\_N23.925\_E069.849 (9) - 100.00 m.wvs

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	5.28	4.68	1.943	5.2	4.60	2.025	5.5
1 NNE	5.78	5.12	2.248	8.0	4.63	2.416	7.8
2 ENE	5.62	4.98	2.400	8.1	4.57	2.525	7.7
3 E	4.61	4.08	2.318	3.3	4.22	2.396	3.2
4 ESE	3.79	3.36	1.896	1.3	3.78	1.889	1.4
5 SSE	3.75	3.38	1.529	0.9	3.79	1.537	1.0
6 S	6.87	6.09	2.408	2.4	6.26	2.268	2.1
7 SSW	8.91	8.02	3.592	13.6	7.88	3.572	12.1
8 WSW	9.28	8.41	4.057	31.2	8.34	4.174	30.3
9 W	7.47	6.76	3.869	15.3	7.08	4.049	16.7
10 WNW	5.86	5.21	2.670	6.7	5.92	2.686	7.7
11 NNW	4.58	4.06	1.943	4.1	4.34	1.924	4.5
All	7.51	6.67	2.592	100.0	6.73	2.560	100.0



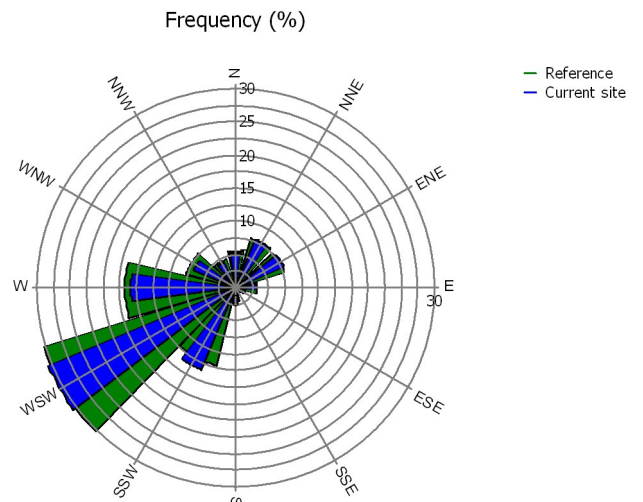
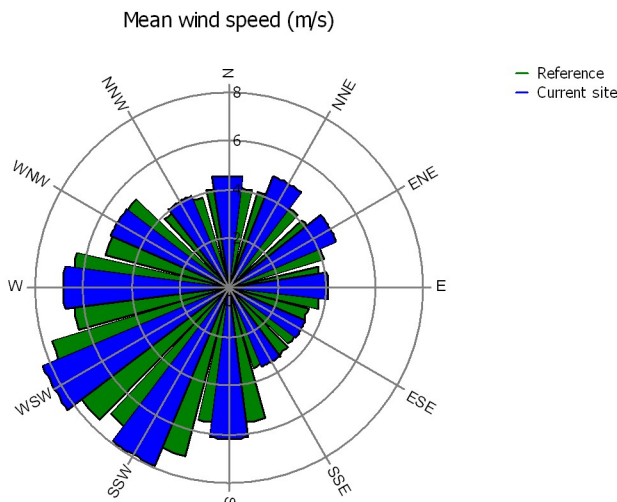
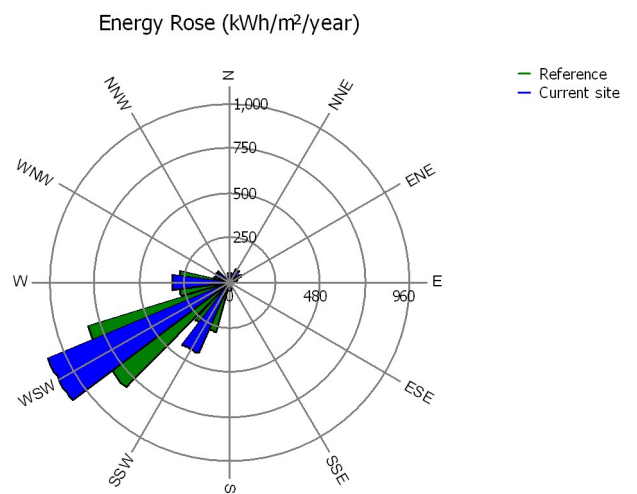
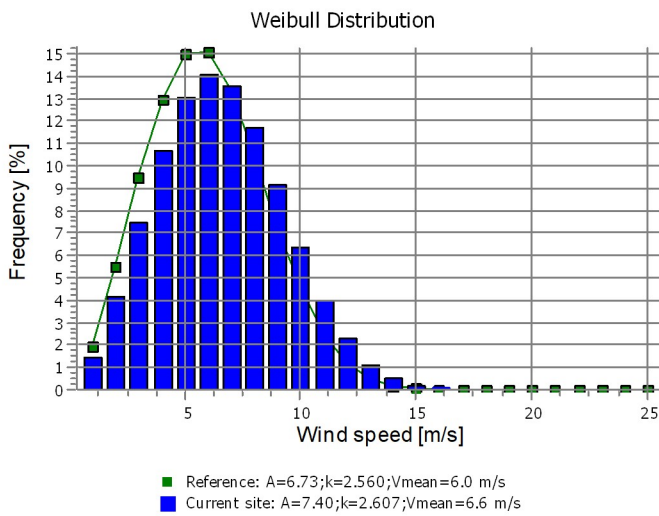
## PARK - Wind Data Analysis

Calculation: PARK Site 2Wind data: A - Site data: WASP (11); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 585,472 North: 2,646,037  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (2)  
Wind statistics  
IN EMD-WRF India\_N23.925\_E069.849 (9) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	5.15	4.56	1.971	5.3	4.60	2.025	5.5
1 NNE	5.52	4.89	2.287	7.9	4.63	2.416	7.8
2 ENE	5.41	4.79	2.412	7.9	4.57	2.525	7.7
3 E	4.58	4.06	2.342	3.3	4.22	2.396	3.2
4 ESE	3.85	3.42	1.889	1.3	3.78	1.889	1.4
5 SSE	3.88	3.49	1.533	0.9	3.79	1.537	1.0
6 S	6.95	6.16	2.455	2.4	6.26	2.268	2.1
7 SSW	8.74	7.87	3.607	13.5	7.88	3.572	12.1
8 WSW	9.13	8.29	4.088	30.6	8.34	4.174	30.3
9 W	7.52	6.80	3.893	15.8	7.08	4.049	16.7
10 WNW	5.97	5.30	2.666	6.9	5.92	2.686	7.7
11 NNW	4.57	4.05	1.928	4.2	4.34	1.924	4.5
All	7.40	6.58	2.607	100.0	6.73	2.560	100.0



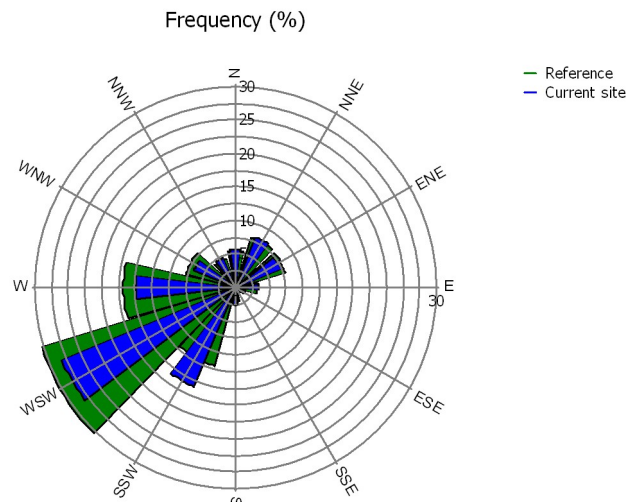
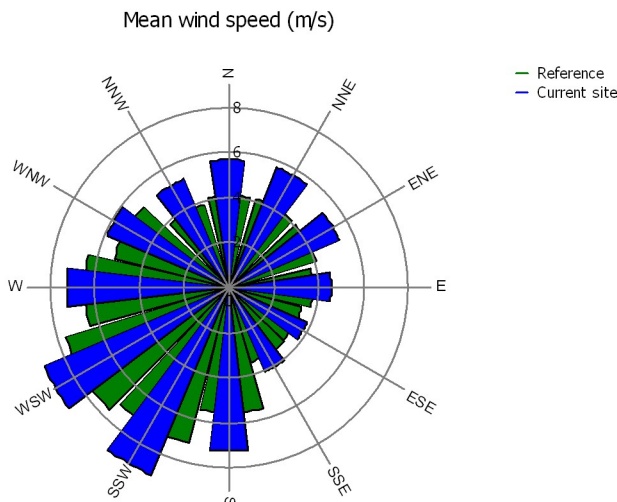
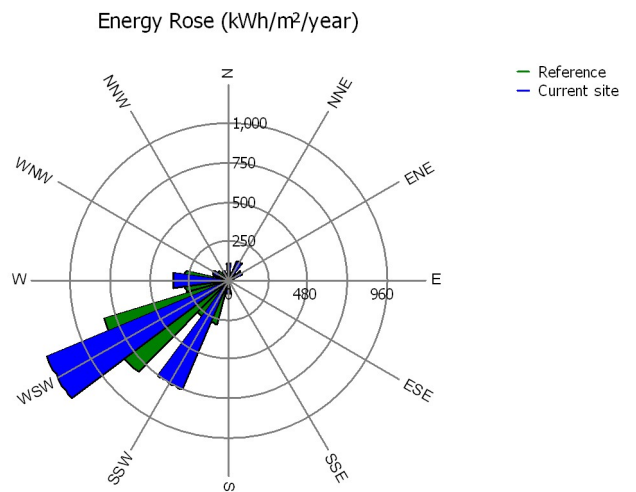
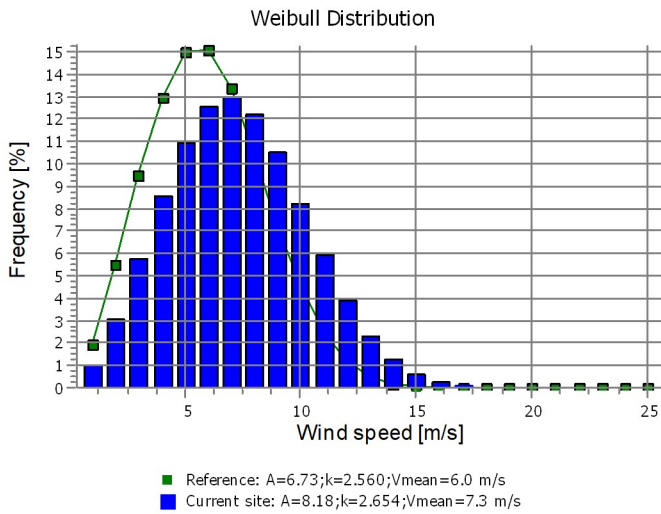
## PARK - Wind Data Analysis

Calculation: PARK Site 2Wind data: A - Site data: WASP (11); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 587,824 North: 2,647,242  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (3)  
Wind statistics  
IN EMD-WRF India\_N23.925\_E069.849 (9) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	6.37	5.65	1.939	5.7	4.60	2.025	5.5
1 NNE	6.47	5.73	2.268	8.1	4.63	2.416	7.8
2 ENE	6.03	5.34	2.365	7.3	4.57	2.525	7.7
3 E	5.13	4.54	2.326	3.3	4.22	2.396	3.2
4 ESE	4.29	3.81	1.900	1.3	3.78	1.889	1.4
5 SSE	4.49	4.04	1.557	1.0	3.79	1.537	1.0
6 S	8.16	7.24	2.404	2.6	6.26	2.268	2.1
7 SSW	9.94	8.97	3.713	16.0	7.88	3.572	12.1
8 WSW	9.82	8.91	4.064	28.1	8.34	4.174	30.3
9 W	7.97	7.22	4.002	14.9	7.08	4.049	16.7
10 WNW	6.64	5.90	2.670	6.8	5.92	2.686	7.7
11 NNW	5.87	5.20	2.029	4.8	4.34	1.924	4.5
All	8.18	7.27	2.654	100.0	6.73	2.560	100.0



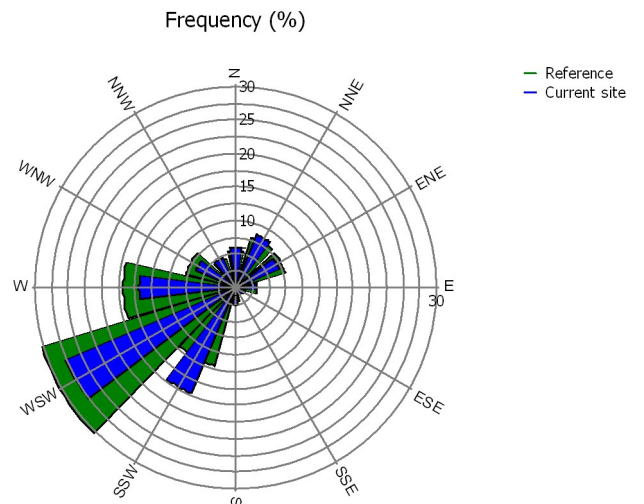
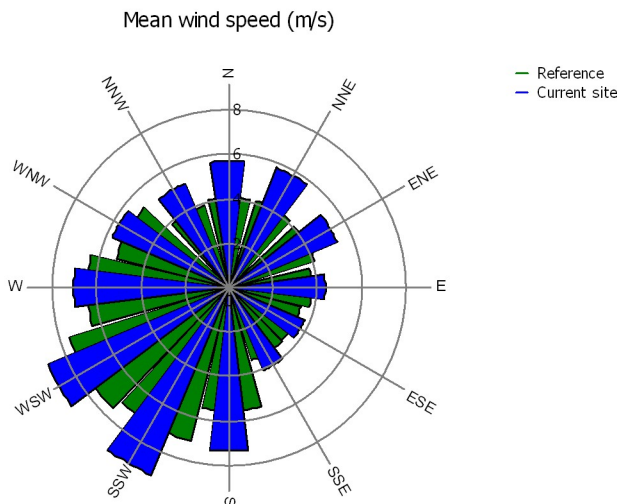
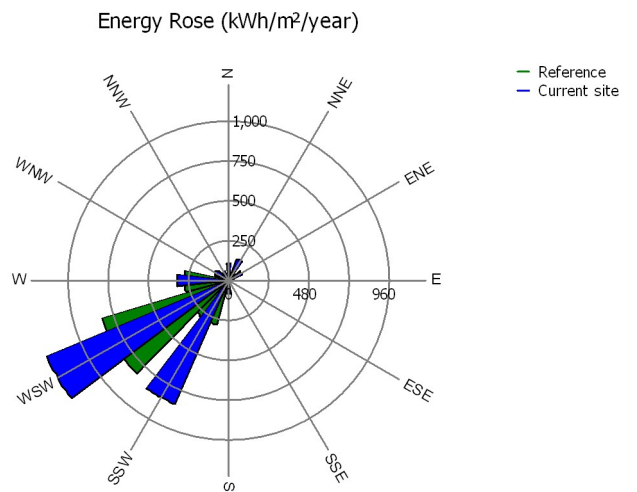
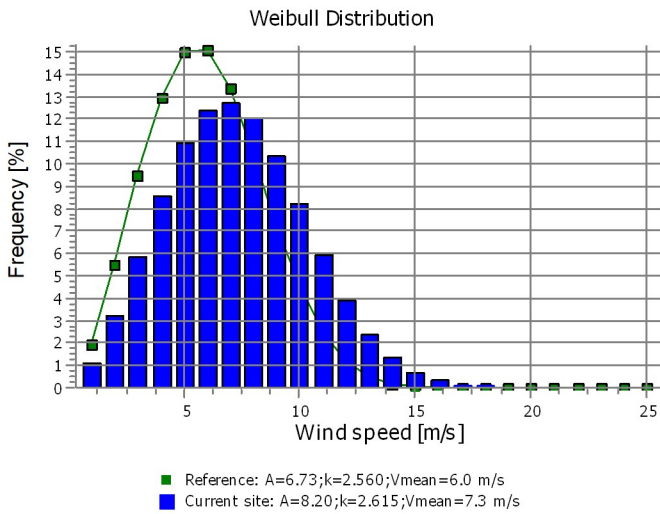
## PARK - Wind Data Analysis

Calculation: PARK Site 2Wind data: A - Site data: WASP (11); Hub height: 100.0

Site coordinates  
UTM (north)-WGS84 Zone: 42  
East: 586,276 North: 2,647,562  
VESTAS V90 2000 90.0 !O! hub: 100.0 m (TOT: 145.0 m) (4)  
Wind statistics  
IN EMD-WRF India\_N23.925\_E069.849 (9) - 100.00 m.wws

### Weibull Data

Sector	Current site			Frequency [%]	Reference: Roughness class 1		
	A- parameter [m/s]	Wind speed [m/s]	k- parameter		A- parameter [m/s]	k- parameter	Frequency [%]
0 N	6.43	5.70	1.947	5.9	4.60	2.025	5.5
1 NNE	6.57	5.82	2.283	8.5	4.63	2.416	7.8
2 ENE	5.98	5.30	2.373	7.1	4.57	2.525	7.7
3 E	4.92	4.36	2.334	3.2	4.22	2.396	3.2
4 ESE	4.17	3.70	1.893	1.2	3.78	1.889	1.4
5 SSE	4.48	4.03	1.561	1.0	3.79	1.537	1.0
6 S	8.31	7.37	2.393	2.6	6.26	2.268	2.1
7 SSW	10.13	9.14	3.732	17.1	7.88	3.572	12.1
8 WSW	9.83	8.91	4.014	27.5	8.34	4.174	30.3
9 W	7.77	7.04	3.990	14.4	7.08	4.049	16.7
10 WNW	6.48	5.76	2.670	6.5	5.92	2.686	7.7
11 NNW	5.76	5.10	2.053	4.8	4.34	1.924	4.5
All	8.20	7.28	2.615	100.0	6.73	2.560	100.0



## PARK - Park power curve

Calculation: PARK Site 2

Wind speed [m/s]	Power														
	Free WTGs [kW]	Park WTGs [kW]	N [kW]	NNE [kW]	ENE [kW]	E [kW]	ESE [kW]	SSE [kW]	S [kW]	SSW [kW]	WSW [kW]	W [kW]	WNW [kW]	NNW [kW]	
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
3.5	74	69	72	68	70	66	70	69	72	68	70	66	70	69	
4.5	529	523	527	522	525	519	525	523	527	522	525	519	525	523	
5.5	1,053	1,043	1,050	1,041	1,046	1,037	1,047	1,043	1,050	1,041	1,046	1,037	1,047	1,043	
6.5	1,782	1,766	1,777	1,762	1,771	1,755	1,772	1,765	1,777	1,762	1,771	1,755	1,772	1,765	
7.5	2,760	2,736	2,752	2,730	2,743	2,720	2,744	2,734	2,752	2,730	2,743	2,720	2,744	2,734	
8.5	3,962	3,934	3,953	3,927	3,943	3,916	3,944	3,932	3,953	3,927	3,943	3,916	3,943	3,932	
9.5	5,260	5,233	5,251	5,227	5,242	5,215	5,242	5,232	5,251	5,227	5,241	5,215	5,242	5,232	
10.5	6,507	6,486	6,500	6,481	6,493	6,472	6,493	6,485	6,500	6,480	6,493	6,472	6,494	6,486	
11.5	7,510	7,495	7,505	7,491	7,500	7,484	7,500	7,494	7,505	7,490	7,500	7,487	7,501	7,497	
12.5	7,880	7,875	7,878	7,874	7,877	7,872	7,877	7,875	7,878	7,874	7,877	7,872	7,877	7,875	
13.5	7,984	7,983	7,984	7,983	7,983	7,983	7,983	7,983	7,984	7,983	7,983	7,983	7,983	7,983	
14.5	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	7,999	
15.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
16.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
17.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
18.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
19.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
20.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
21.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
22.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
23.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
24.5	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	8,000	
25.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
26.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
27.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
28.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
29.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

### Description:

The park power curve is similar to a WTG power curve, meaning that when a given wind speed appears in front of the park with same speed in the entire wind farm area (before influence from the park), the output from the park can be found in the park power curve. Another way to say this: The park power curve includes wake losses, but do NOT include terrain given variations in the wind speed over the park area.

Measuring a park power curve is not as simple as measuring a WTG power curve due to the fact that the park power curve depends on the wind direction and that the same wind speed normally will not appear for the entire park area at the same time (only in very flat non-complex terrain). The idea with this version of the park power curve is not to use it for validation based on measurements. This would require at least 2 measurement masts at two sides of the park, unless only a few direction sectors should be tested, AND non complex terrain (normally only useable off shore). Another park power curve version for complex terrain is available in windPRO.

The park power curve can be used for:

- Forecast systems, based on more rough (approximated) wind data, the park power curve would be an efficient way to make the connection from wind speed (and direction) to power.
- Construction of duration curves, telling how often a given power output will appear, the park power curve can be used together with the average wind distribution for the Wind farm area in hub height. The average wind distribution can eventually be obtained based on the Weibull parameters for each WTG position. These are found at print menu: >Result to file< in the >Park result< which can be saved to file or copied to clipboard and pasted in Excel.
- Calculation of wind energy index based on the PARK production (see below).
- Estimation of the expected PARK production for an existing wind farm based on wind measurements at minimum 2 measurement masts at two sides of wind farm. The masts must be used for obtaining the free wind speed. The free wind speed is used in the simulation of expected energy production with the PARK power curve. This procedure will only work suitable in non complex terrains. For complex terrain another park power curve calculation is available in windPRO (PPV-model).

### Note:

From the >Result to file< the >Wind Speeds Inside Wind farm< is also available. These can (e.g. via Excel) be used for extracting the wake induced reductions in measured wind speed.

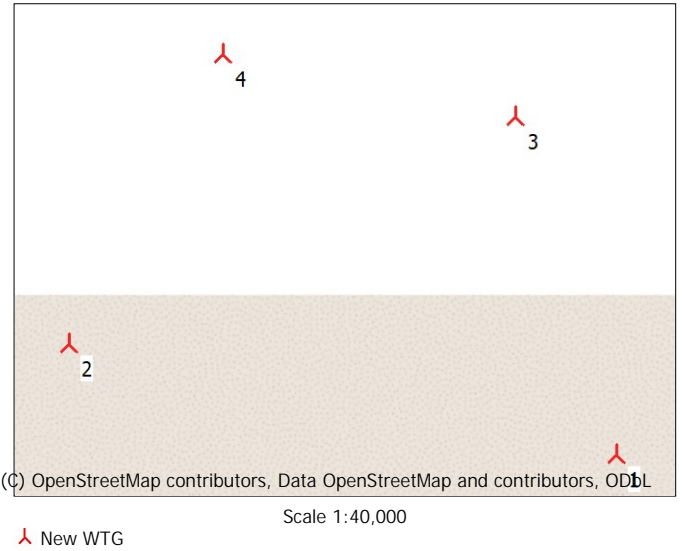


## PARK - WTG distances

Calculation: PARK Site 2

### WTG distances

	Z	Nearest WTG	Z	Horizontal distance	Distance in rotor diameters
	[m]		[m]	[m]	
1	270.0	3	326.5	1,850	20.6
2	330.6	4	373.3	1,724	19.2
3	326.5	4	373.3	1,581	17.6
4	373.3	3	326.5	1,581	17.6
Min	270.0		326.5	1,581	17.6
Max	373.3		373.3	1,850	20.6





Project:  
Site 2 Gujrat, India

Licensed user:  
TEST license  
This license is only to be used for testing purposes

Aayush / aayush.choudhary.2021@uni.strath.ac.uk  
Calculated:  
26-07-2022 14:15/3.5.584

## PARK - Wind statistics info

Calculation: PARK Site 2

### Main data for wind statistic

File	C:\Users\Glitch\Documents\WindPRO Data\Projects\Site 2 Gujrat, India\IN EMD-WRF India_N23.925_E069.849 (9) - 100.00 m.wws
Name	EMD-WRF India_N23.925_E069.849 (9) - 100.00 m
Country	India
Source	USER
Mast coordinates	UTM (north)-WGS84 Zone: 42 East: 586,405 North: 2,646,183
Created	26-07-2022
Edited	26-07-2022
Sectors	12
WAsP version	WAsP 12 Version 12.07.0056
Coordinate system	UTM (north)-WGS84 Zone: 42
Displacement height	None

### Additional info for wind statistic

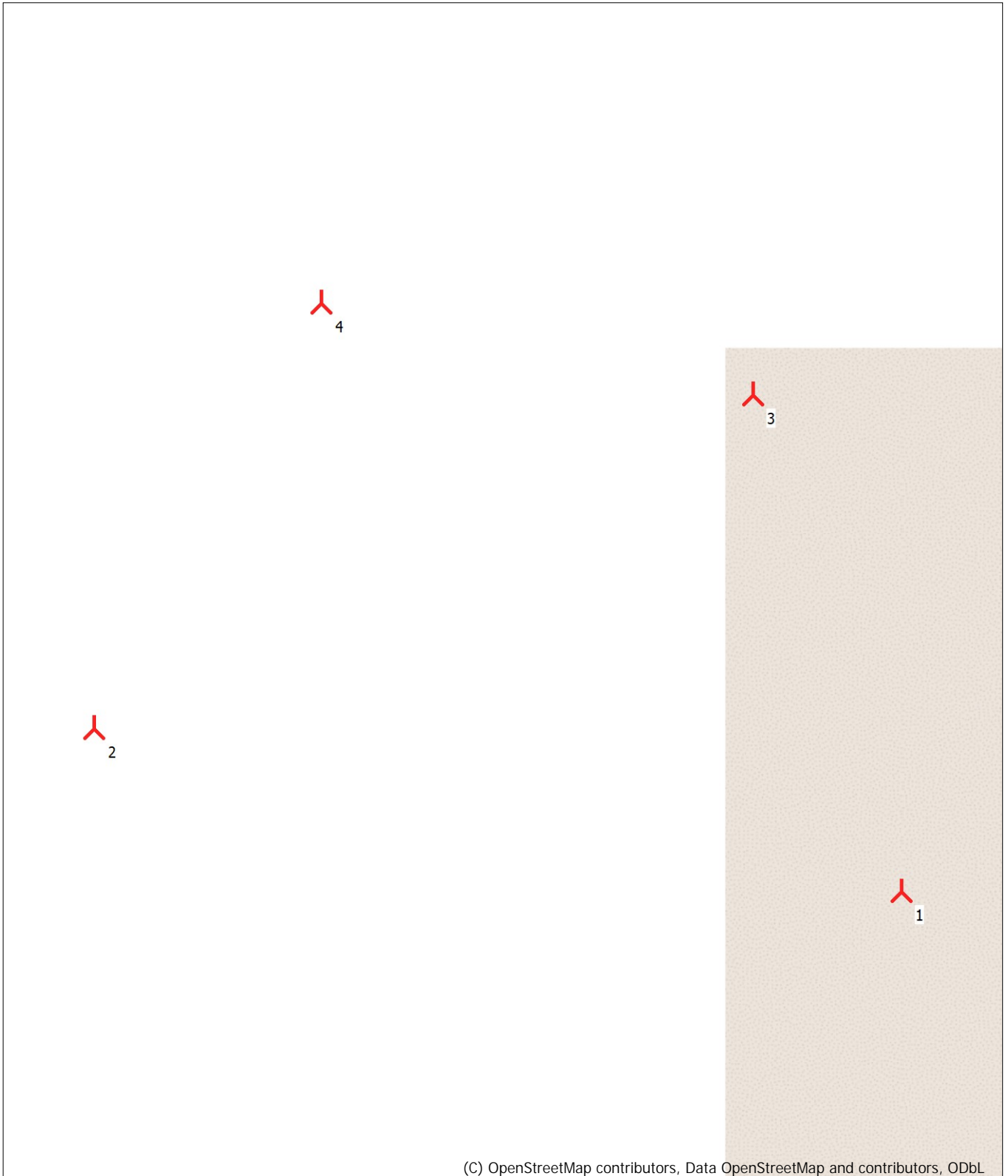
Source data	EMD-WRF India_N23.925_E069.849 (9)
Data from	01-01-1994
Data to	31-08-2019
Measurement length	307.9 Months
Recovery rate	100.0 %
Effective measurement length	307.9 Months

### Note

To get the most correct calculation results, wind statistics shall be calculated with the SAME model and model parameters, as currently chosen in calculation. For WAsP versions before 10.0, the model is unchanged, but thereafter more model changes affecting the wind statistic is seen. Likewise WAsP CFD should always use WAsP CFD calculated wind statistics.

## PARK - Map

Calculation: PARK Site 2



(C) OpenStreetMap contributors, Data OpenStreetMap and contributors, ODbL

0 250 500 750 1000m

Map: EMD OpenStreetMap , Print scale 1:20,000, Map center UTM (north)-WGS84 Zone: 42 East: 586,920 North: 2,646,518

 New WTG

# Appendix 6

## HOMER Pro Report for Calculation

### Performed At Site 2 Gujrat



**HOMER**  
Pro

## System Simulation Report



**File:** Site 2 Gujrat.homer

**Author:**

**Location:** WV99+97 Ratadiya, Gujarat, India (23°55.1'N, 69°52.1'E)

**Total Net Present Cost:** \$674.27

**Levelized Cost of Energy (\$/kWh):** \$0.0127

**Notes:** Site 2 Gujrat



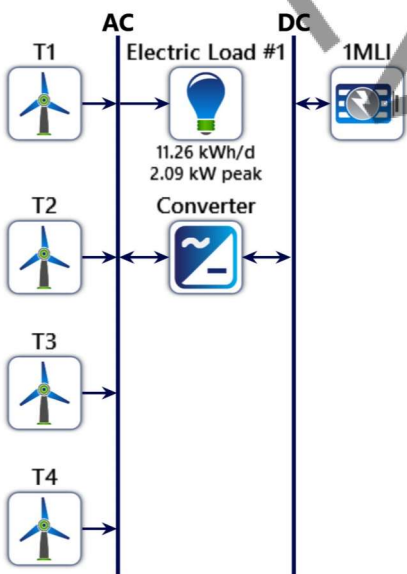
## Table of Contents

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Wind Turbine: Turbine Site 2 (1)	8
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Storage: Generic 1MWh Li-Ion	11
Converter: System Converter	12
Compare Economics	13

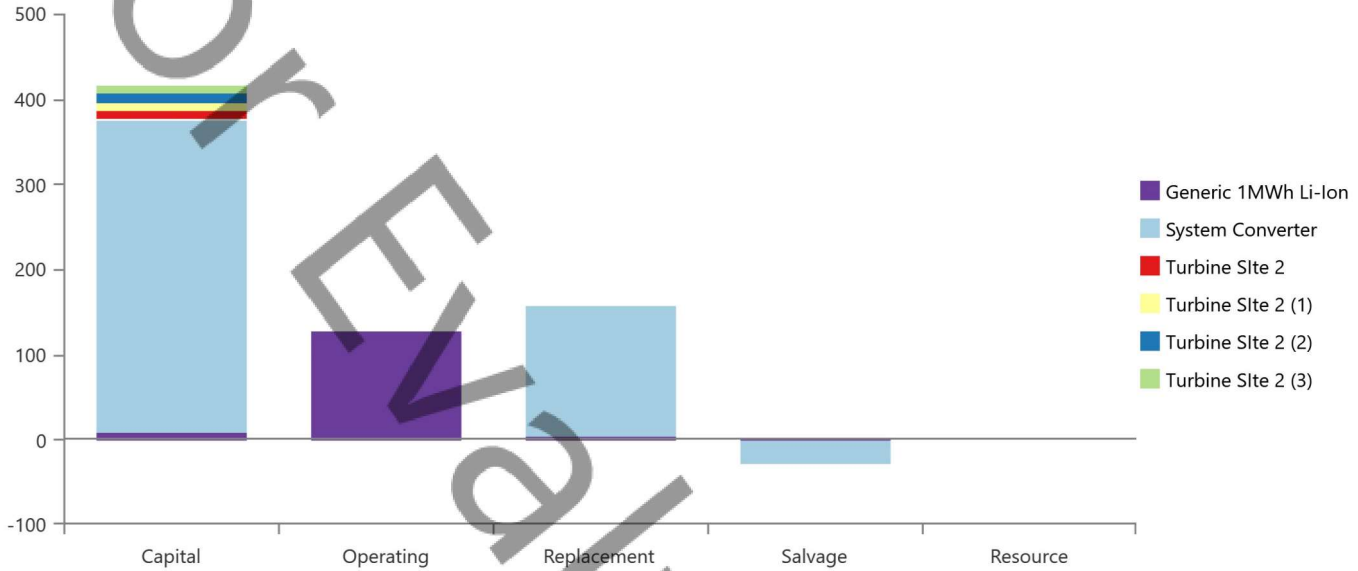
## System Architecture

Component	Name	Size	Unit
Storage	Generic 1MWh Li-Ion	1	strings
Wind turbine #1	Turbine SItE 2	1	ea.
Wind turbine #2	Turbine SItE 2 (1)	1	ea.
Wind turbine #3	Turbine SItE 2 (2)	1	ea.
Wind turbine #4	Turbine SItE 2 (3)	1	ea.
System converter	System Converter	1.22	kW
Dispatch strategy	HOMER Cycle Charging		

## Schematic



### Cost Summary



### Net Present Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 1MWh Li-Ion	\$10.00	\$129.28	\$4.24	-\$0.799	\$0.00	\$142.72
System Converter	\$365.63	\$0.00	\$155.13	-\$29.20	\$0.00	\$491.55
Turbine Site 2	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
Turbine Site 2 (1)	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
Turbine Site 2 (2)	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
Turbine Site 2 (3)	\$10.00	\$0.00	\$0.00	\$0.00	\$0.00	\$10.00
<b>System</b>	<b>\$415.63</b>	<b>\$129.28</b>	<b>\$159.37</b>	<b>-\$29.99</b>	<b>\$0.00</b>	<b>\$674.27</b>

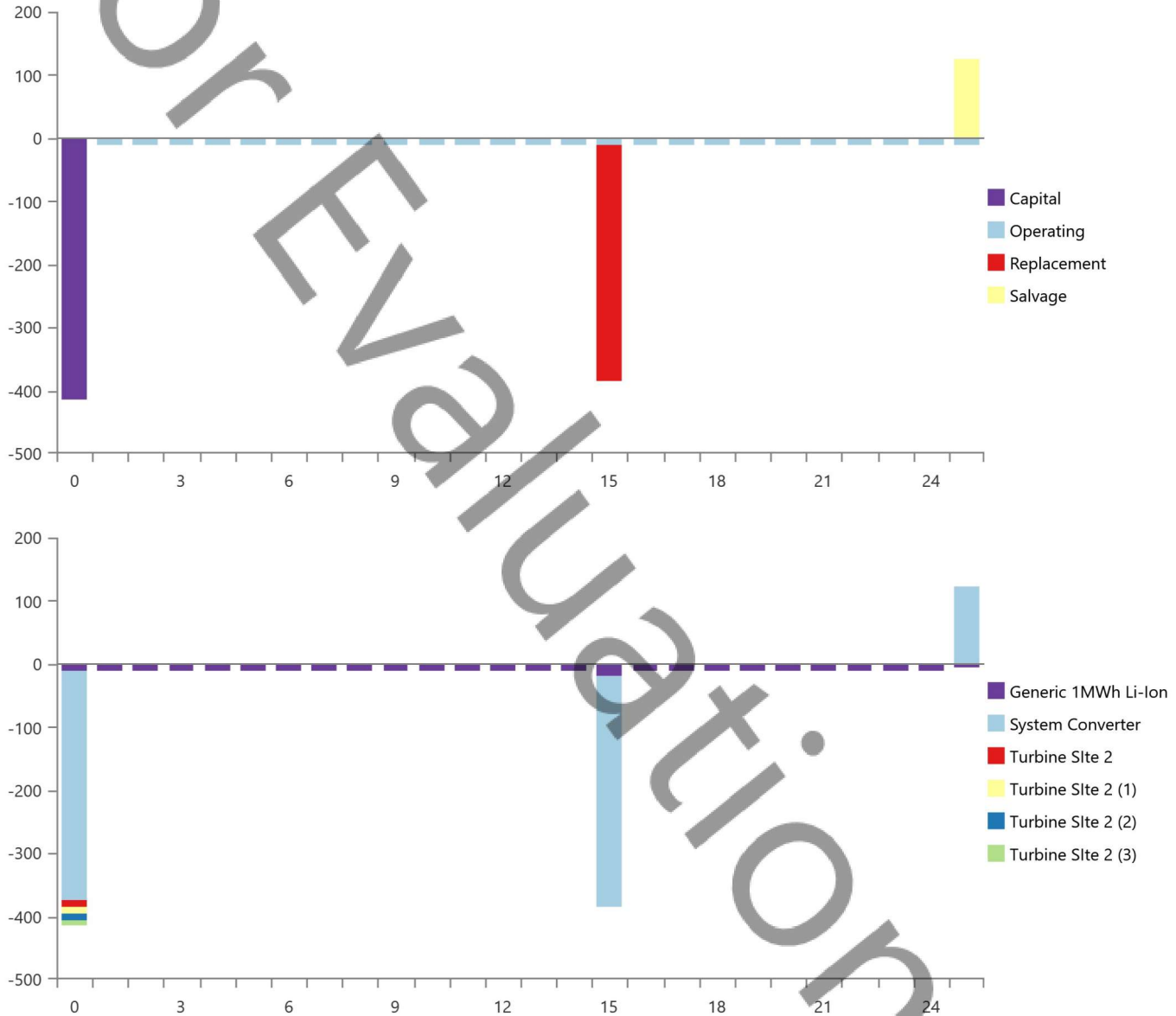
### Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 1MWh Li-Ion	\$0.774	\$10.00	\$0.328	-\$0.0618	\$0.00	\$11.04
System Converter	\$28.28	\$0.00	\$12.00	-\$2.26	\$0.00	\$38.02
Turbine Site 2	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
Turbine Site 2 (1)	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
Turbine Site 2 (2)	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
Turbine Site 2 (3)	\$0.774	\$0.00	\$0.00	\$0.00	\$0.00	\$0.774
<b>System</b>	<b>\$32.15</b>	<b>\$10.00</b>	<b>\$12.33</b>	<b>-\$2.32</b>	<b>\$0.00</b>	<b>\$52.16</b>





### Cash Flow



## Electrical Summary

### Excess and Unmet

Quantity	Value	Units
Excess Electricity	19,318,292	kWh/yr
Unmet Electric Load	2.29	kWh/yr
Capacity Shortage	4.07	kWh/yr

### Production Summary

Component	Production (kWh/yr)	Percent
Turbine Site 2	4,830,617	25.0
Turbine Site 2 (1)	4,830,617	25.0
Turbine Site 2 (2)	4,830,617	25.0
Turbine Site 2 (3)	4,830,617	25.0
<b>Total</b>	<b>19,322,470</b>	<b>100</b>

### Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	4,107	100
DC Primary Load	0	0
Deferrable Load	0	0
<b>Total</b>	<b>4,107</b>	<b>100</b>

## Wind Turbine: Turbine Site 2

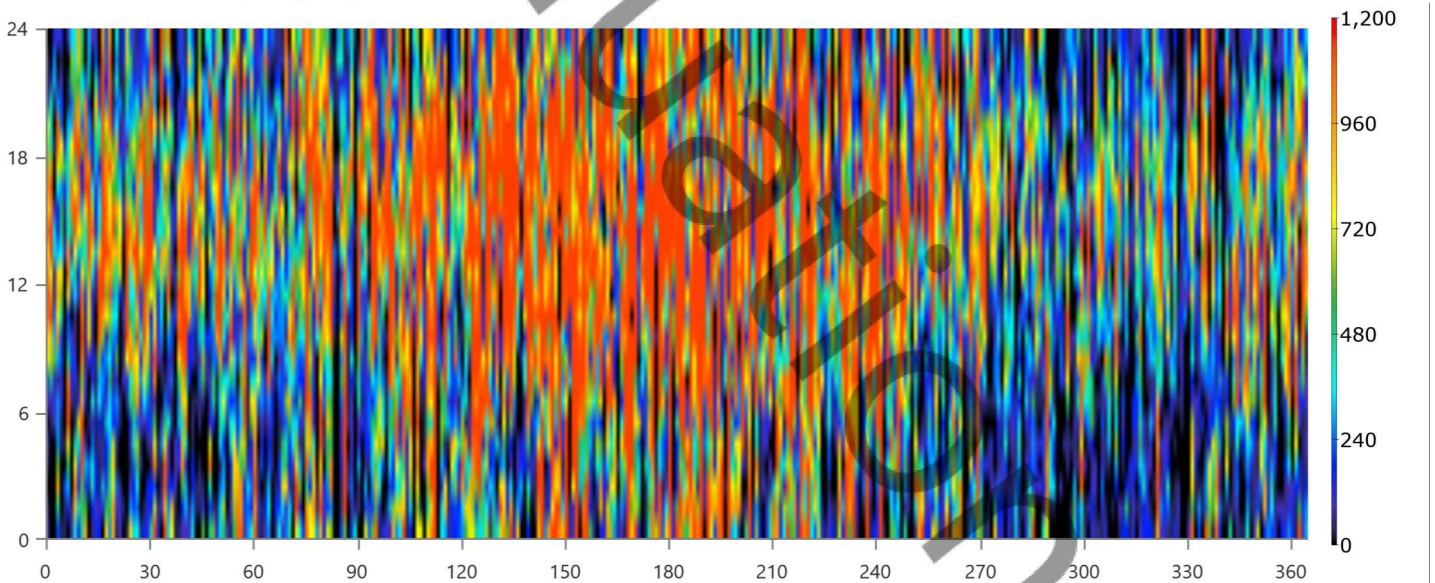
### Turbine Site 2 Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	117,558	%
Hours of Operation	7,962	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 2 Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	551	kW
Capacity Factor	27.6	%
Total Production	4,830,617	kWh/yr

### Turbine Site 2 Output (kW)



## Wind Turbine: Turbine Site 2 (1)

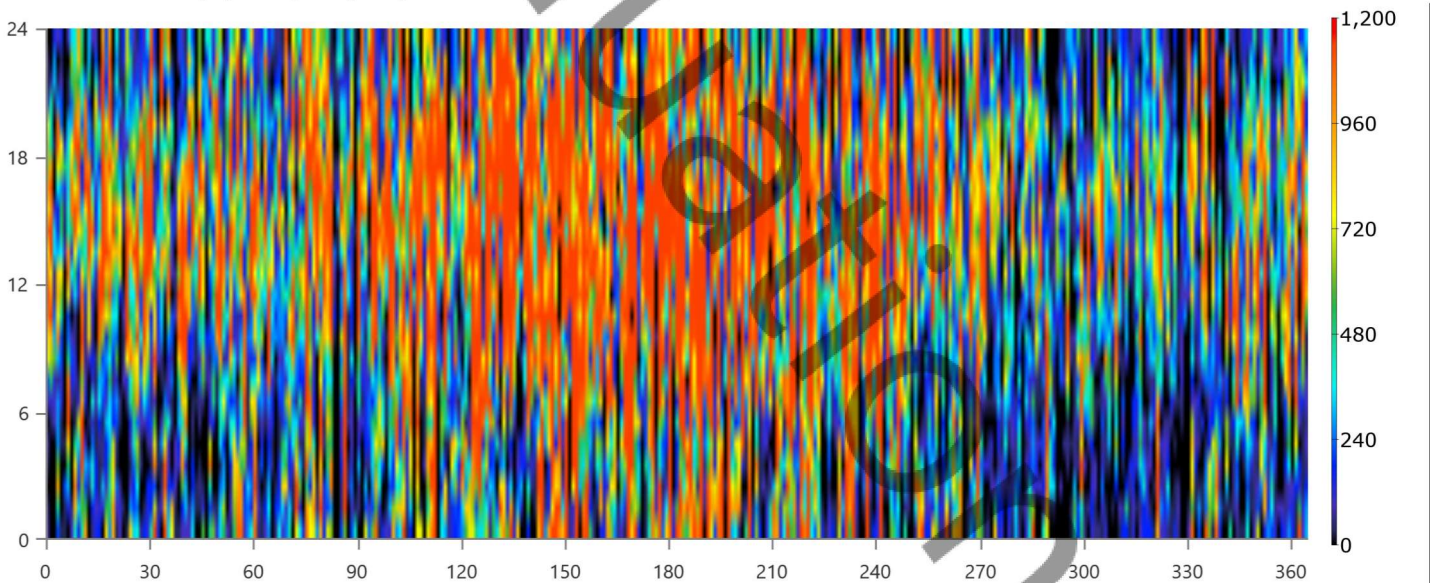
### Turbine Site 2 (1) Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	117,558	%
Hours of Operation	7,962	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 2 (1) Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	551	kW
Capacity Factor	27.6	%
Total Production	4,830,617	kWh/yr

### Turbine Site 2 (1) Output (kW)





## Wind Turbine: Turbine Site 2 (2)

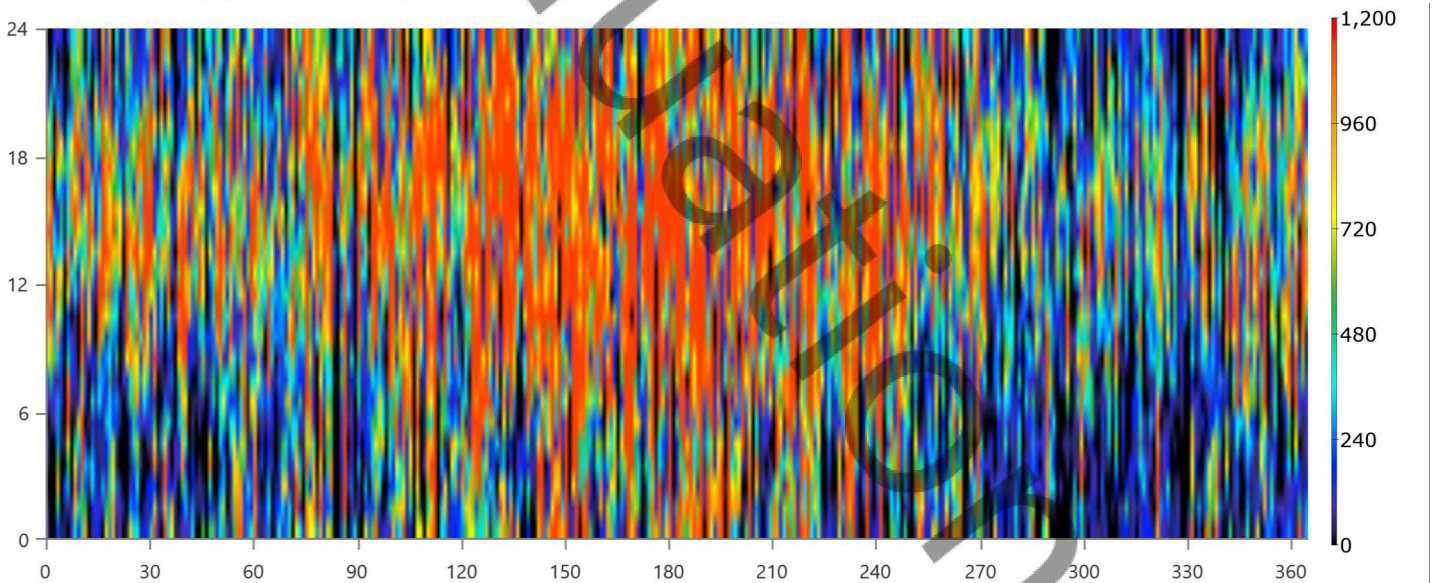
### Turbine Site 2 (2) Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	117,558	%
Hours of Operation	7,962	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 2 (2) Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	551	kW
Capacity Factor	27.6	%
Total Production	4,830,617	kWh/yr

### Turbine Site 2 (2) Output (kW)



## Wind Turbine: Turbine Site 2 (3)

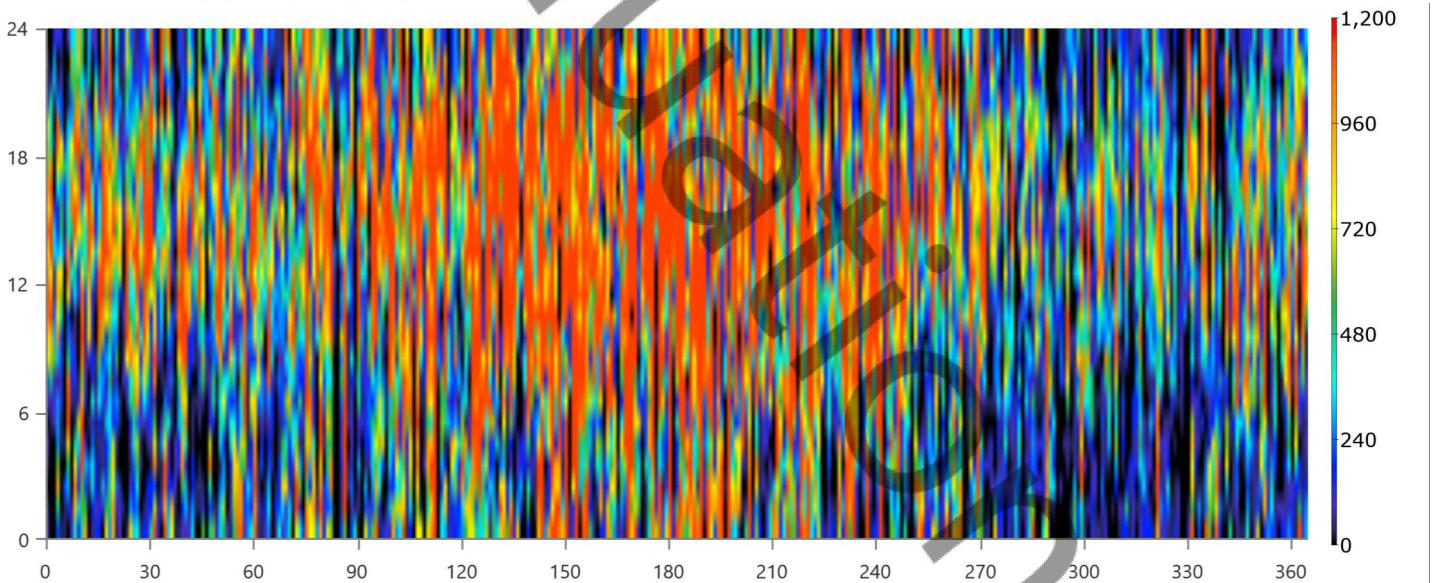
### Turbine Site 2 (3) Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,177	kW
Wind Penetration	117,558	%
Hours of Operation	7,962	hrs/yr
Levelized Cost	0	\$/kWh

### Turbine Site 2 (3) Statistics

Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	551	kW
Capacity Factor	27.6	%
Total Production	4,830,617	kWh/yr

### Turbine Site 2 (3) Output (kW)



## Storage: Generic 1MWh Li-Ion

### Generic 1MWh Li-Ion Properties

Quantity	Value	Units
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	600	V

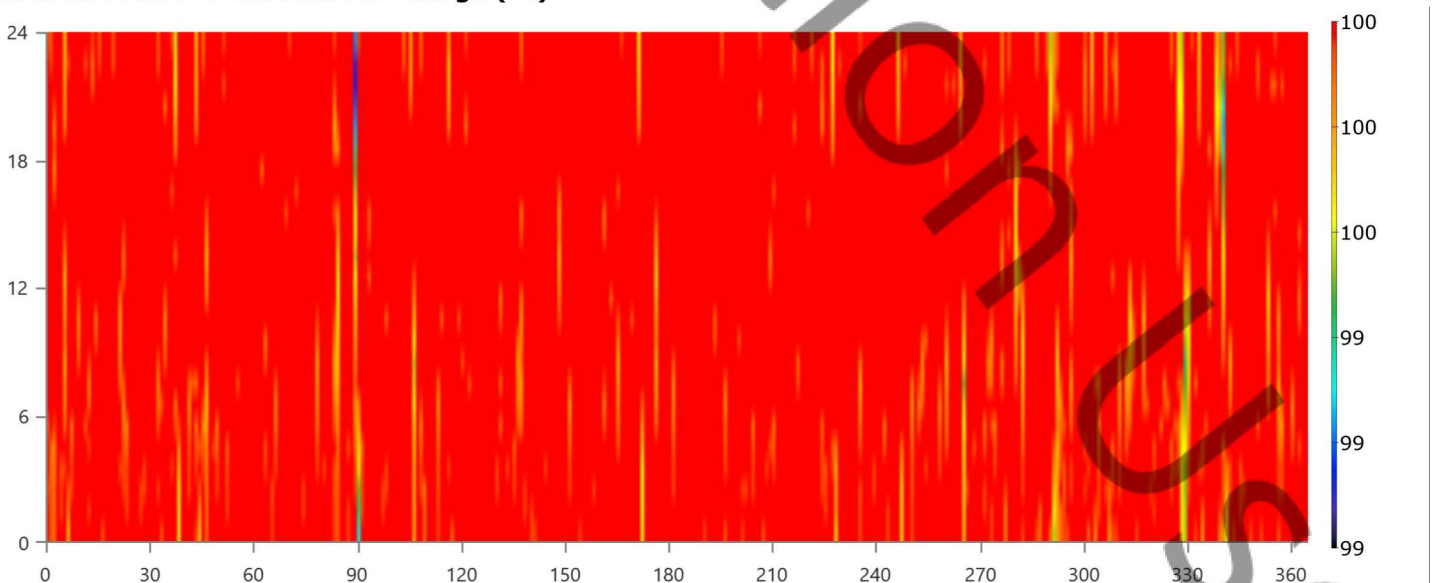
### Generic 1MWh Li-Ion Result Data

Quantity	Value	Units
Average Energy Cost	0	\$/kWh
Energy In	358	kWh/yr
Energy Out	322	kWh/yr
Storage Depletion	0	kWh/yr
Losses	35.8	kWh/yr
Annual Throughput	340	kWh/yr

### Generic 1MWh Li-Ion Statistics

Quantity	Value	Units
Autonomy	1,705	hr
Storage Wear Cost	0.00000400	\$/kWh
Nominal Capacity	1,000	kWh
Usable Nominal Capacity	800	kWh
Lifetime Throughput	5,097	kWh
Expected Life	15.0	yr

### Generic 1MWh Li-Ion State of Charge (%)





## Converter: System Converter

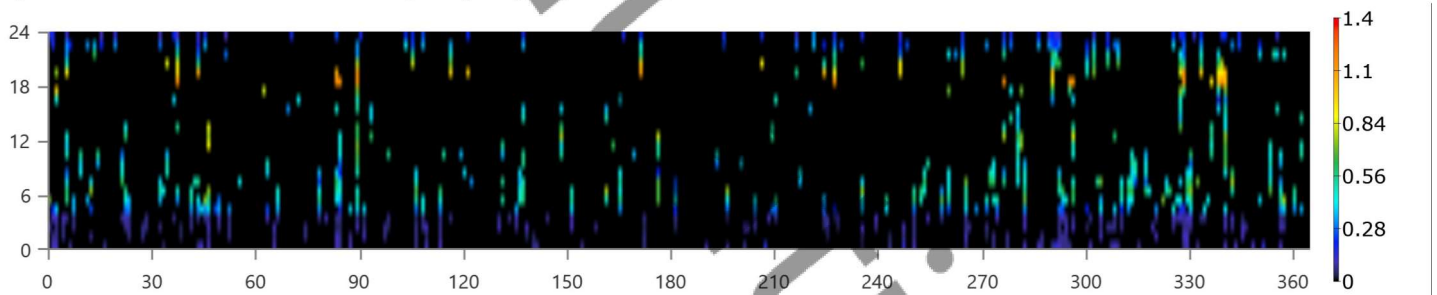
### System Converter Electrical Summary

Quantity	Value	Units
Hours of Operation	798	hrs/yr
Energy Out	306	kWh/yr
Energy In	322	kWh/yr
Losses	16.1	kWh/yr

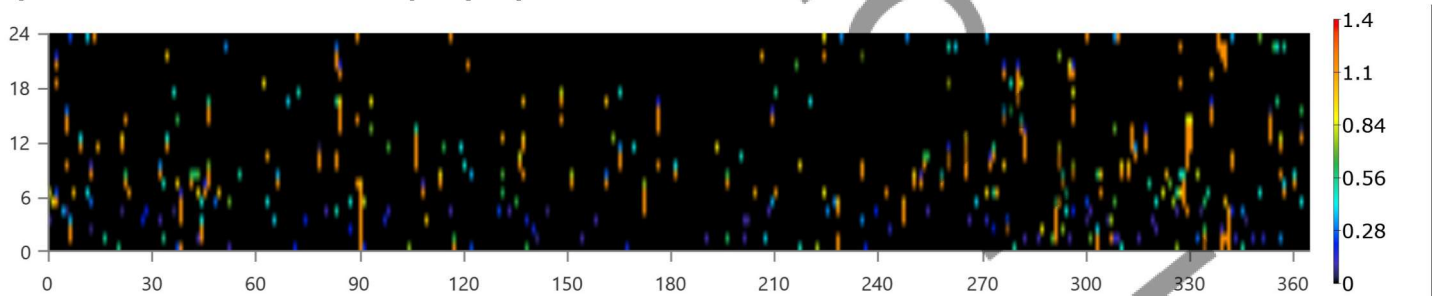
### System Converter Statistics

Quantity	Value	Units
Capacity	1.22	kW
Mean Output	0.0350	kW
Minimum Output	0	kW
Maximum Output	1.22	kW
Capacity Factor	2.87	%

### System Converter Inverter Output (kW)



### System Converter Rectifier Output (kW)





### Compare Economics

IRR (%): **N/A**

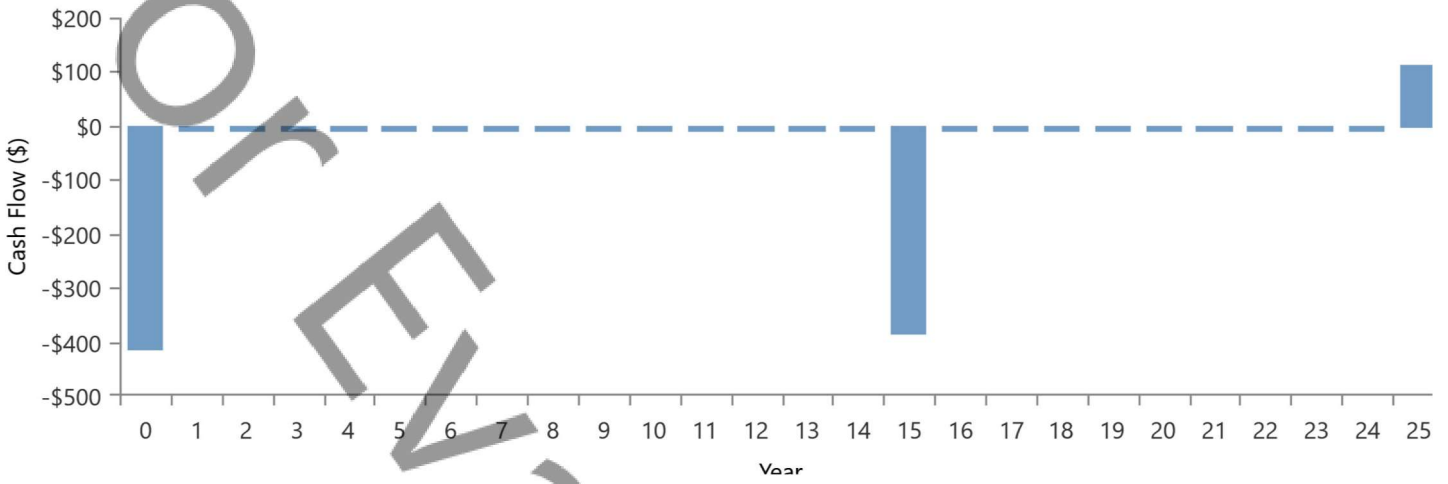
Discounted payback (yr): **N/A**

Simple payback (yr): **N/A**

	Base System	Proposed System
Net Present Cost	\$644.27	\$674.27
CAPEX	\$385.63	\$415.63
OPEX	\$20.01	\$20.01
LCOE (per kWh)	\$0.0121	\$0.0127
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0



### Proposed Annual Nominal Cash Flows



### Base System Annual Nominal Cash Flows



### Cumulative Discounted Cash Flows

