STUDY ON THE ECONOMICS OF REPOWERING A WINDFARM

By

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Further, I certify that the work is based on the investigation made, data collected and analysed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of MBA.

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Executive Summary

Repowering is the process of replacing an older wind turbine machines which are now beyond manufacturers' warranty periods with recent units that are quieter, consistent and capable of producing more electricity efficiently. This procedure allow us to replace older WTGs before they come to the end of their operational life within a timeframe. There is no doubt that re-powering is a major and growing market that will help India to achieve its renewable energy targets.

It will explain the technical, economical & recent renewable power policy aspects of the wind farms in India. This process is the outcome of progressively increasing demand for non - conventional energies helped by the great potential available of wind energy in the India. The wind pocket chosen in this work were set up before 1998 and they are now obsolete WTGs with low power.

The main reasons which set off the concept of repowering in India are acute power shortages and inefficient utilization of potential windy areas. There are many windfarm sites across the country which have attained an age of 15-20 years and possess old, underperforming wind turbines. Also, many sites in India with very good wind resources are underutilized as older, low rated wind turbines were installed in these sites during the earlier days of the industry and performance of these turbines has been below par. Over the years, the wind industry has seen significant improvement in design feature. The unit rating is now varying between 1500 kW to 2500 kW.

Therefore it is natural to explore the option of replacing these with modern high capacity wind turbine technology that could offer better returns and more power than before. The generation from modern windfarms shall aid in meeting the demand-supply gap of electricity.

In the national interest and also in the interest of the project proponents, there is a need of repowering from various viewpoints such as i.e. advanced wind turbine technologies & its considerable benefits, land utilization per megawatt of installed capacity, meeting electricity need and achieving national targets for CO2 emissions.

The aim of this work is to investigate the potential to repower existing first-generation turbines capacity less than 500 kW to deliver more efficient, reliable, environment friendly and economic 2100 kW wind turbines site.

CHAPTER 1

Introduction

The complete aim of the project is to support sustainable growth of electricity generation from wind power through repowering concept in India. Therefore it is desired to initially carry out a study on repowering scenarios considering a region which possesses first generation WTGs. In this study, Vankusavade windfarm in Maharashtra has been selected as the region of interest where maximum WTGs are below 500KW. The outcome of this study would help to gain complete understanding of optimal utilization of land, wind resource & Environmental protection at existing wind-farm in Vankusavade site in Maharashtra by disposition of modern higher capacity wind turbine generators. Also this process will extend the service life, increases its power and performance of WTGs.

The main reasons which set off the concept of repowering in India are acute power shortages and inefficient utilization of potential windy areas. There are many windfarm sites across the country which have attained an age of 15-20 years and possess old, underperforming wind turbines.

Also, many sites in India with very good wind resources are underutilized as older, low rated wind turbines were installed before 15 to 20 years ago. Over the years, the wind industry has seen significant improvement in design feature. Therefore it is natural to explore the option of replacing these with modern high capacity wind turbine technology that could offer better returns and more power than before. The generation from present windfarms shall aid in meeting the demand-supply gap of electricity.

Objective of the Study

An attempt has been made in the present work to study the economics of repowering a wind farm by replacing the existing wind turbines with the new turbine of the current state of art technology. The energy generation of the existing turbine is recorded where as that of the repowered turbine is calculated based on the wind assessment techniques using the actual data of the wind recorded in the controller of the turbine. The energy generation, present worth and the revenues of the existing wind turbines and the repowered wind turbines are compared. The rate of returns, net present value on the investment is calculated for the repowered wind turbines to be installed to compare the feasibility of the project considering a discount rate of 10% per annum. Also reviewed the Power Evacuation, Transmission & Distribution Infrastructure, Power Purchase Agreement, Power Financing, Policy support for wind Energy like Tax Exemption, Accelerated Depreciation, Tariff Structure, Subsidies, Generation Based Incentive (GBI) etc. and finally the benefits of renewable energy CDM and GHG.

Overview

As of 31st March 2015 the installed capacity of wind power in India was 23,447 MW, mainly spread across South, West and North regions. Wind power accounts nearly 8.5% of India's total installed power generation capacity and generated 28,214 million Kwh (MU) in the fiscal year 2014-15 which is nearly 2.6% of total electricity generation. The capacity utilisation factor is nearly 15 % in the fiscal year 2014-15. 70% of wind generation is during the five months duration from May to September coinciding with South West monsoon duration. The state wise wind turbine installed capacity are as under:

Sr. No.	List of States	Capacity (MW) as of 31st March 2015
1	Tamil Nadu	7455.2
2	Gujarat	3645.4
3	Maharashtra	4450.8
4	Rajasthan	3307.2
5	Karnataka	2638.4
6	Andhra Pradesh	1031.4
7	Madhya Pradesh	879.7
8	Kerala	35.1
9	Others	4.3
	Total	**23447.5**

Table 1: State wise installed wind power.

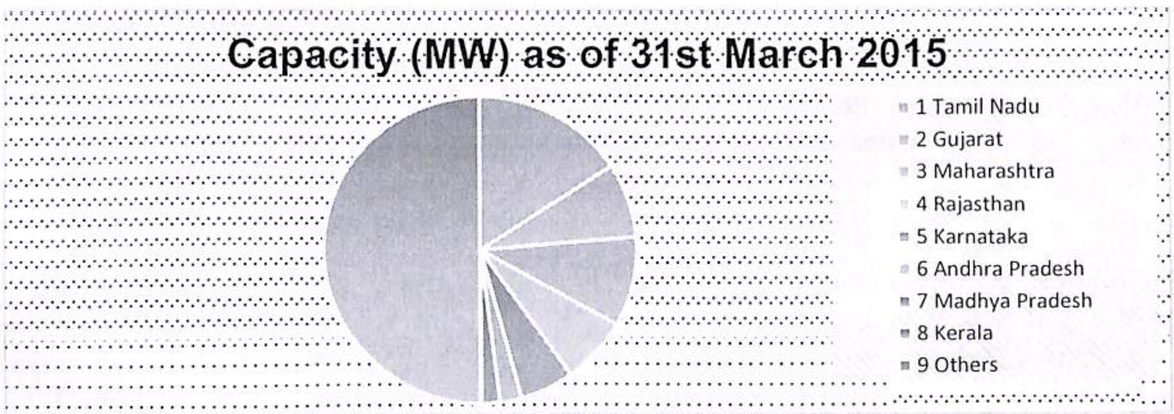


Figure 1: India's total Installed Wind Power capacity as of 31.03.2015. (Source: MNRE).

Maharashtra is one of the prominent states considering the installation of wind power projects second to Tamil Nadu in India. As on 30.09.2014, installed capacity of wind energy is 4167.26 MW.

Repowering means replacing small, old turbines with new, more powerful and more efficient ones. Wind turbine have an expected service life of 20 years, but the technology has developed so much over the past two decades that wind turbines can seem outdated even though they are still running. For instance in 1990 the average turbine newly installed in India was capacity of less than 500kW; by 2015, it is around 2.10 MW. Large turbines with taller towers are making better use of wind and they are running at higher capacity. The energy yield of modern wind turbines has thus been growing faster than their rated capacity. As a result it will be possible to produce even more power within a given plot of land if old turbines are replaced by larger – and more efficient new ones.

The replacement of old and inefficient turbines by the new and more efficient ones in an attempt to increase not only the installed capacity but also the power generation can be referred to as the classical definition of repowering. There are several methods in which this replacement can happen, but generally the increase in installed capacities for most repowered projects around the world is typically below 25%, although the net power generation can go up by more than 300% given the higher hub heights and the higher turbine efficiencies.

Approximately 25% of turbines in India have wind turbine generators (WTGs) with rating less than 500 kW and Maharashtra being the state with Third highest number of old generation turbines. The state has the best wind energy sites, some of which includes Vankusavade, Satara, Amberi, Chakla, Chalkewadi, Dhalgaon, Thoseghar & Vijaydurga etc. in Maharashtra.

Methods of Repowering: The old wind farm can be repowered by following ways:

- 1-to-1 up-scaling of solitary wind turbines
- 2-to-1 replacement, replacement of two smaller wind turbines by one large wind turbine.
- Clustering of wind turbines in a farm, e.g. replacement of 20 solitary wind turbines by clustering 6-10 wind turbines at one location.
- 1-to-1 replacement of wind turbines with similar rates but with newer machines.
- 1-to-1 up-scaling of wind farms.

Here we have we have selected Vankusavade in Maharashtra as the region of interest (RoI). The basis for selecting this region lies in the fact that it holds first generation WTGs, which have completed an age of 15-20 years. Viability of project on these sites will be more feasible due to availability of long term operation data which is one of the most reliable source for energy estimation. As the old sites are having very good wind potential, returns on investment will also be high for these site.

For repowering a windfarm need to carry out analysis of repowering potential in Vankusavade, Maharashtra region which covers the following scope of work:

- Wind Resource Assessment by applying process of Local Effects, Wind Shear, Wind Assessment, Preliminary Area Identification, Area Wind Resource Evaluation & Micro siting etc.
- Sensitivity Analysis
- Grid & Power evacuation Augmentation.
- Review of Old & New Central and State Policies and regulation.
- Applicable policies like PPAs, permission, approvals and policy support for new repowered wind farm.
- Disposal of Old Wind Turbine.
- Certifications and Incentives like Income Tax Exemptions, Accelerated Depreciation, and applicable tariff, Renewable Energy Certificates, Subsidies and Generation based incentives & C-WET certification.

Site Name:	Vankusavade
Village:	Vankusavade
District:	Satara
State:	Maharashtra
Assignment Type:	1. Potential Capacity Estimation and Sensitivity Analysis. 2. Proposal of new Model. 3. Existing Policies and regulation. 4. Aspect of Policy Changes. 5. Sub-Station and Grid Review 6. Barriers and Possible solutions
Existing WTGs:	Model S33/350 KW (Total 51 WTGs)
Region of Interest:	15.3 Sq. Km
Met Mast Height:	50m, 80m & 90m
Nearest Railway Station:	Satara
Nearest Airport:	Pune
Latitude:	17° 27′ 14″ N
Longitude:	73° 49′ 58″ E

Table 2: Project Parameters.

Vankuswade Wind Park is a wind farm located on a high mountain plateau at 1,150 m above the Koyana Reservoir, around 40 km from the town of Satara, Satara District in Maharashtra, this site is located on one variable and rugged terrain with a length of approximately 29 Km and it is a Asia's one of the largest Wind Farm. Total

556 WTGs of 350 KW are installed and commissioned here and there are various turbines owners for these WTGs. A 220/33kV sub-station is also constructed at this site with a capacity of 150 MVA transformer for power evacuation.

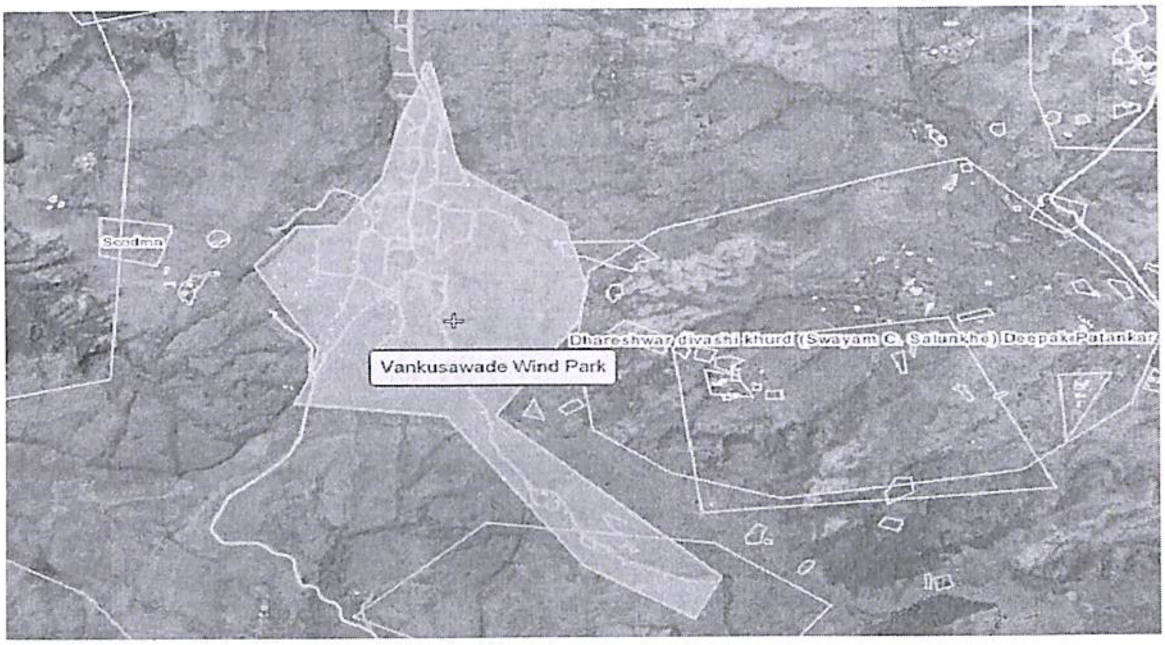


Figure 2: Satellite Map of Vankuswade Wind Park (Source: Google map)

Background

1.1 Current Energy Scenario in India:

India's installed generation capacity has reached 276.78 GW at the mid of September 2015, the Ministry of Power noted in its year-end review. The thermal power capacity continues to hold a major share with almost two-thirds of the capacity. Coal-based power projects alone constitute over 60.80% of the total installed capacity. Renewable energy holds a share of 13.20% while the share of large-hydro power projects is about 15.20%.

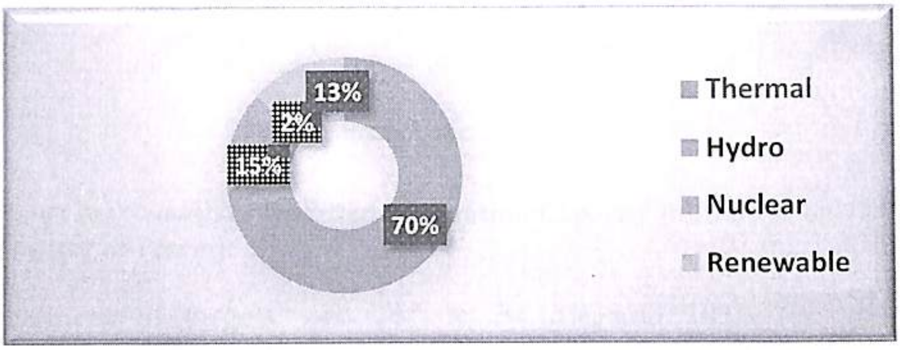


Figure 3: India's Installed Generation Capacity of Power in % age as of 19-09-2015. (Source: Ministry of Power).

The electricity generation target for the year 2015-2016 was fixed as 1137.5 Billion Unit (BU). i.e. growth of around 8.47% over actual generation of 1048.673 for the previous year (2014-2015). The generation during (2014-15) was 1048.673 BU as compared to 967.150 BU generated during April- March 2014, representing a growth of about 8.43%.

Around 40,781 MW capacity has already been added during the eleventh plan which is nearly double the capacity added in the entire Tenth Plan, according to Indian government sources of power. According to these sources, the last four years have seen rapid strides in capacity addition and the installed capacity has gone up from approximately 1,32,000 MW in March 2007 to over 1,81, 000 MW in July 2011 with an unprecedented growth of 37%. Highlighting the strong participation by the private sector, the government sources indicate that the private sector would contribute to nearly 36% of the capacity addition in the 11th Plan and over 50% of the capacity addition proposed for the 12th Plan. Further, a total grid interactive renewable power generation capacity of around 24,503.45 MW has been set up in the country which is about 12.15% of the total power generation installed capacity from all sources, according to a release by the Ministry of New and Renewable Energy.

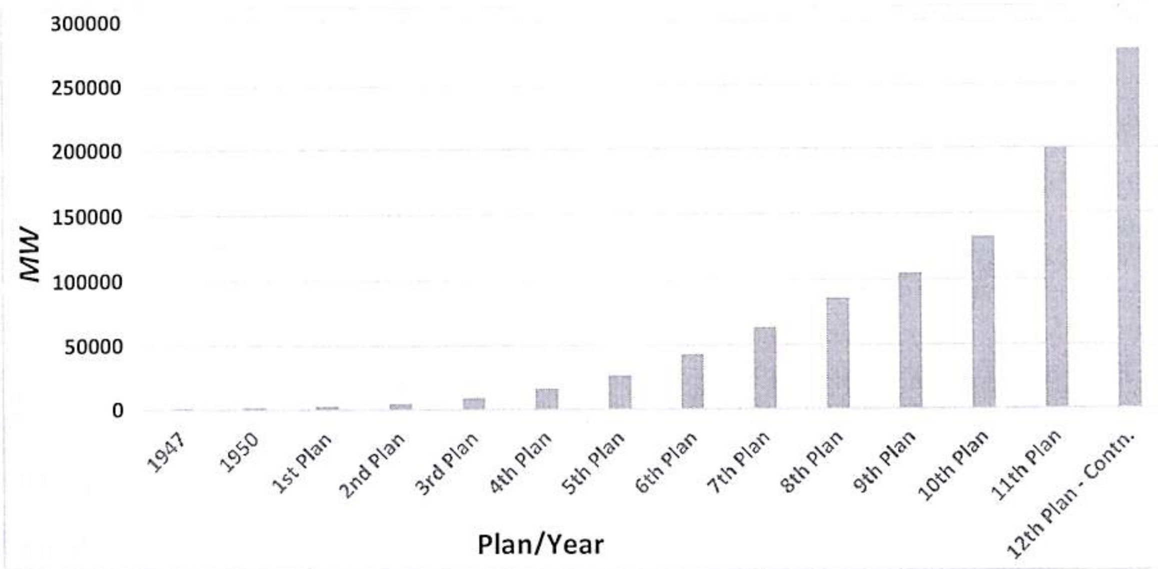


Figure 4: Plan/Year Growth of Installed Generation Capacity in India as on 30.09.2015 (Source: Ministry of Power)

The achievement of targets was 76.68%, 84.15% and 108% for generation of renewable energy during the last 3 years i.e. 2012-13, 2013-14 and 2014-15 respectively. The short-falls during 2012-13 and 2013-14 were under primarily Wind Power and Small Hydro Power Program due to discontinuation of Accelerated Depreciation (AD) benefit and generation based incentive (GBI) under the Wind Power Sector and delay in obtaining forest area clearances and court cases in some of the states under Small Hydro Sector. With the restoration of AD benefit, generation based Incentives, etc. have resulted in overachievement of target during 2014-15. According to MNRE, in terms of wind energy India ranks 5th position and in terms of solar energy india holds 11th in the world. The current renewable energy portfolio stands at 36.47 GW out of a total of 276.78 GW of installed power capacity.

Sector	MW	% age
State Sector	96,015.00	34.7%
Central Sector	74,171.00	26.8%
Private Sector	106,597.00	38.5%
Total	**276,783.00**	

Table 3: Total Installed Capacities (by Sector) as of 30-09-2015. *(Source: Ministry of Power).*

Fuel	MW	%age
Coal	168,208.00	60.8%
Gas	23,333.00	8.4%
Oil	994.00	0.4%
Hydro (Renewable)	41,997.00	15.2%
Nuclear	5,780.00	2.1%
RES (MNRE)	36,471.00	13.2%
Total	**276,783.00**	

Table 4: Total Installed Capacities as of 30-09-2015. (Source: Ministry of Power).

The Minister further stated that the an estimated potential of 897 GW has been identified from various renewable energy sources in the country which includes 749 GW from solar, 103 GW from wind, 25 GW from bio-energy and 20 GW from small hydro power. MNRE has proposed grid power of 175 GW from various renewable energy sources by the year 2022. This includes 100 GW from solar, 60 GW from wind, 10 GW from bio-power and 5 GW from small hydro power. Solar technologies possess the highest potential when it comes to off-grid energy generation. These include solar water heating systems, home lighting systems comprising solar lanterns, solar cooking systems, solar pumps and small power generating systems. Under the solar mission, The Indian Government has revised the National Solar Mission target of Grid Connected Solar Power projects from 20,000 MW by 2022 to 1,00,000 MW by 2022. The revised National Solar Mission is under implementation. The Minister stated that the it is planned to achieve the revised target of 1,00,000 MW by setting up Distributed Rooftop Solar Projects and Medium & Large Scale Solar Projects.

1.2 Need for energy efficiency in India:

There are five specific reasons for which India needs to promote energy efficiency. These include: increasing energy requirement; increasing threat of climate change and other environmental considerations; energy security; lack of other supply options; and huge scope for energy efficiency measures. India also faces some additional problems like other developing countries in energy sector. With increase in demand for conventional energy sources leading to increase in their price over the last two decades, the cost of electricity generation is increasing. There are, of course, some new and renewable sources of energy that have become prominent recently and have become the focus of world's attention. However, these are at a very nascent stage and will take a long time to fully meet growing energy demand. Moreover, in India and other developing countries per unit cost of electricity generation from such sources appears to be much higher than the conventional sources and also the required technology is, at the moment, beyond the means of common consumers.

1.3 Challenges for Setting up of New Power Plants:

Productions of energy by thermal power plants are associated with many environmental problems. For example, coal power plants have local effects such as air pollution particularly nitrogen oxide and sulfur oxide. These also have medium distance effects such as acid rain along with long-range and long-term climate change impacts such as global warming from the emission of carbon dioxide and other 'greenhouse gases'. Nuclear plants have their own environmental consequences related to the handling of nuclear materials and the disposal of radioactive waste. For example, some radioisotopes have half-lives of thousands of years and need to be stored in geologically stable locations. To save our environment, it is all the more necessary to adopt energy conservation measures.

Purpose of the Study

The main purpose of study is to support the sustainable electricity generation from wind through repowering and optimal utilization of land & wind resource to fill the demand supply gap of power. Also this study will set off the concept of repowering in India are acute power shortages and inefficient utilization of potential windy areas. There are four reason which is triggering the indication of repowering:

- Many States are facing power shortages and also host to sites with good wind power potential which is not being utilised efficiently and is currently loaded with old and inefficient wind turbines. Repowering with more powerful turbines will add the additional power to these states and in Maharashtra State Vankusavade windfarm have second highest low rating wind turbines which is about to completion their life.

- Large areas are occupied by more than 8,500 small rating turbines (<500 kW capacity), manufactured by suppliers that have long since disappeared from the Indian market. This leads to lapses in operations & maintenance (O&M), which in turn increases a machine's down time and reduces revenue. In addition, maintenance costs tend to be higher for aging WTGs. If we

- Breakdown of critical components badly affects machine availability and O&M cost for smaller capacity machines.

- Old wind turbines were often installed at maximum hub-heights of 30 to 40 meters and occupy land on good resource sites. However, these sites could benefit from modern turbines extracting energy from the much higher wind power density at high hub heights.

- Modern wind turbine extracting energy from higher wind power density at high hub height.

- Purpose of the study to identify the high potential site where the low capacity old turbines are installed and provide the solution of repowering by optimum usage of available land.

- Estimation and comparison of Gross and Net PLF at P50 of existing all turbines as well as Gross & Net PLF at P75 to check the improvement in Revenue Generation.

- Sensitivity analysis is to be carried out which will highlight the impact of varying the main parameters that affect the project IRR calculations.

- To analyse the existing power evacuation system, Transmission and distribution system of Vankusavade site and provide the proper solutions.

- Identify implications of PPA, Turbine Ownership & Scraping of old wind turbines etc. and suggest the feasible solutions for these challenges.

- Also this study will highlights on the different types of benefits offered by Indian government to promote the renewable energy sources.

CHAPTER 2

Literature Review

Wind Energy Scenario

Wind Energy is the fastest growing renewable energy sector in the country. With a cumulative installed capacity of over 23,439.26 MW, wind power currently accounts for almost 70% of the total installed capacity in the renewable energy sector. About 2,090 MW of new wind power capacity has been added during the last financial year 2014- 2015 so far. The 12th Five Year Plan proposals envisage around 15,000 MW of grid-interactive renewable power capacity addition from wind energy alone.

The Indian government has been at the forefront of providing the necessary policy support and a facilitative regulatory ecosystem for the fast and orderly growth of the sector. We are equally conscious of the challenges and difficulties being faced by the sector. The target of 15% of total power capacity through renewable for India by 2020 envisaged under the National Action Plan on Climate Change cannot be achieved without a substantial contribution of wind energy.

1.1 Status of Wind Energy In India

Electricity shortages are common, and over 40% of the population they do not have access to modern energy services. India's electricity demand is projected to more than triple between 2005 and 2030. In the recently released National Electricity Plan 2012 the Central Electricity Authority projected the need for 350-360 GW of total generation capacity by 2022. Despite major capacity additions over recent decades, power supply struggles to keep up with demand. As of September 2015, renewable energy accounted for 13.2 percent of total installed capacity, up from 3 percent in 1995. Wind power accounts for about 70 percent of this installed capacity. By the end of March 2015, wind power installations in India had reached more than 23.44 GW.

Under the New Policies Scenario of the World Energy Outlook 2014, total power capacity in India would reach 779 GW in 2035. To reach 779 GW in 2035, capacity must grow at a CAGR of 5.9 percent, or over 20 GW per year from 2009 through 2035. The largest addition per year up to now was nearly 21.14 GW during fiscal year 2014-2015; this scale of expansion could pose a challenge for the government without a significant role for renewables. During fiscal year 2014-2015 wind energy alone delivered over 2GW to India's new installed capacity.

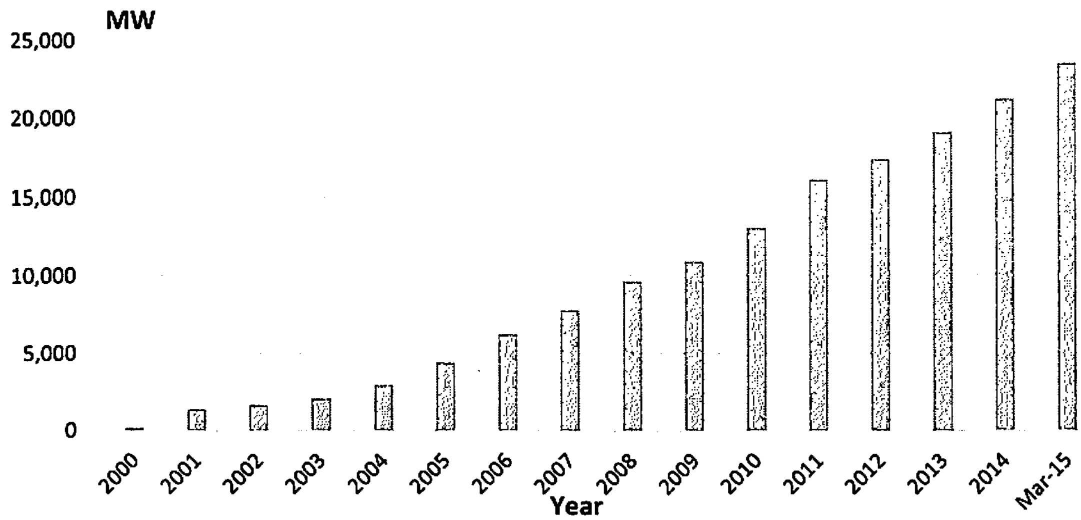


Figure 5: Cumulative wind Installation (MW) as on 31-03-2015 (Source from GWEC)

Global demand for wind turbines has increased dramatically in recent years, and demand for wind turbines has out stripped industry supply. In this turbine limited environment, those developers that have access to new turbines will dedicate those turbines to the most profitable wind projects in their pipeline. This dynamic potentially introduces another consideration – the opportunity cost of new turbines – into the repowering decision. In other words, the choice facing an existing wind project owner may not simply be between continuing to operate the existing facility or repowering. Instead, the choice may really be between continuing to operate the existing facility and using the new turbines for a new Green projects or repowering and thereby foregoing the opportunity to use the new turbines elsewhere.

In such a case, a repowered facility must not only overcome the expected profitability (NPV) of the continued operations of the existing facility, but must also overcome the expected profitability (NPV) of a new Green project. In an environment in which owners of Wind Turbines earn normal profits, assumed here at 10 percent, this additional complication in this instance, using a discount rate of 10 percent, would have an NPV of 0, so no additional NPV would need to be recovered by the repowered project, and the results presented previously would not change. However, profits of above 10 percent for Green projects may be possible. In this instance, the NPV at a 10 percent discount rate would be positive and, arguably, would need to be recovered by the repowered project.

Many of the Wind Turbines are aging, these turbines are aging and often inefficient compared to the current wind turbine technology. Repowering of these turbines could result in a moderate amount of additional renewable energy delivered to the grid. Other potential benefits of Wind farm repowering include reduced aesthetic concerns, potentially lower costs than new wind power or "Green Projects" and improved turbine technology that better supports the state's electrical grid. Below figure depicts the physical reality that, as of the end of 2015, most of India's existing wind turbines are old and of dramatically different scale than the present industry standards. At the end of 2011, the greatest concentration of wind turbines and capacity deployed in the country were in 55-500 kW size range, 5-10 times smaller in the capacity terms than the current state of art technology.

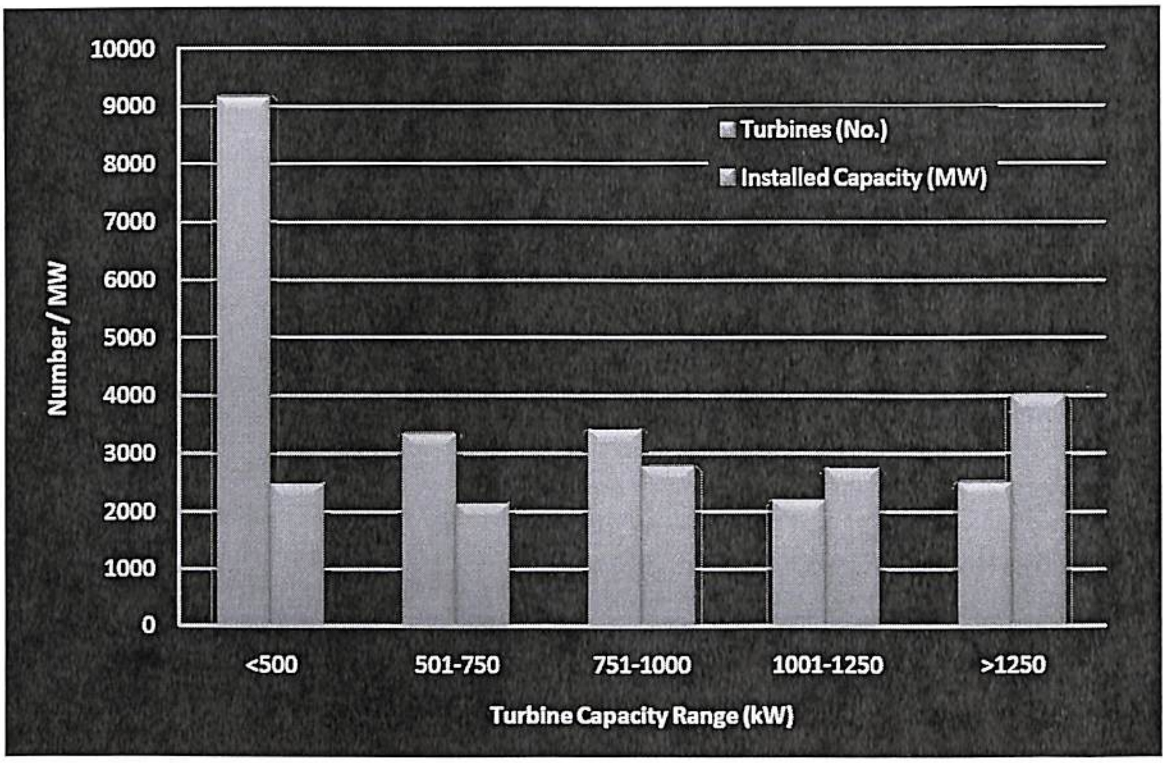


Figure 6: Number and Capacity of Wind Turbine in India (Source: Directory, Indian Wind Power 2011, 11th edition)

Economic, legislative, regulatory, institutional and financial considerations all have a Direct bearing on the repowering decisions and a variety of barriers have contributed
to the relatively slow rate of Wind Turbine replacement in India.

1.2 Renewable Energy in the 12th five year Plan [2012-2017]

Historically, wind energy has met and often exceeded the targets set for it under both the 10th Plan (2002-2007) and 11th Plan (2007-2012) periods. During the 10th Plan period the target set was of 1,500 M W whereas the actual installations were 5,427 MW. Similarly during the 11th Plan period the revised target was for 9,000 MW and the actual installations were much higher at 10,260 MW.

The report of the sub-group for wind power development appointed by the Ministry of New and Renewable Energy to develop the approach paper for the 12th Plan period (April 2012 to March 2017) fixed a reference target of 15,000 M W in new capacity additions, and an aspirational target of 25,000 MW. Importantly the report recommends the continuation of the Generation Based Incentive scheme during the 12th Plan period. The report also prioritized the issue of transmission, which was a weak link in the value chain until now. A joint working group of the MNRE, the Ministry of Power, the Central Electricity Authority and the Power Grid Corporation of India is looking at this issue.
However, for India to reach its potential and to boost the necessary investment in renewable energy it will be essential to introduce comprehensive, stable and long-term support policies, carefully designed to ensure that they operate in harmony with existing state level mechanisms so as to avoid reducing their effectiveness.

1.3 Estimated Wind Power Potential in India

Wind power installable potential of the country has been estimated with reference to Indian Wind Atlas and insitu measurements. On a conservative consideration, a fraction of 2% land availability for all states except Himalayan states, Northeastern states and Andaman Nicobar Islands has been assumed for energy estimation. In Himalayan states, Northeastern states and Andaman & Nicobar Islands, it is assumed as 0.5%. However the potential would change as per the real land availability in each state. Over the past year other research organizations have estimated wind potential using differing models for mapping the wind resource9. In one such study conducted by the Lawrence Berkeley National Laboratory, assuming a turbine density of 9 MW/km2, the total wind potential in India with a minimum capacity factor of 20 percent ranges from 2,006 GW at 80-meter hub-height to 3,121 GW at 120-meter hub-height.

These research studies need ground level validation through long-term wind measurements at 80 and 120-meter hub height. Nevertheless their findings may have a significant impact on India's renewable energy strategy as it attempts to cope with a substantial and chronic shortage of electricity.

1.4 Offshore Wind Energy

India has a long coastline of over 7500 Km. In April 2012, the Ministry for New and Renewable Energy constituted an Offshore Wind Energy Steering Committee13 under the chairmanship of the Secretary, MNRE, to drive offshore wind power development in India in a planned manner.

The Government is looking to prepare a time-bound action plan for development of offshore wind energy, especially in the coastal states of Andhra Pradesh, Gujarat, Maharashtra, Odisha, Kerala, Karnataka, West Bengal and Tamil Nadu. A policy and guidelines for offshore wind are likely to be announced by the Ministry of New and Renewable Energy in the near future.

1.5 Repowering Potential in India

Commercial wind power generation in India began in 1986. Many of the older low-capacity (< 500 kW) wind turbines installed more than 15 to 20 years ago occupy some of the best wind sites in India. These turbines need to be replaced with more efficient, larger capacity machines. One of the immediate benefits after repowering the old wind turbines is that more electricity can be generated from the same site. A study on repowering potential conducted by WISE for the Ministry of New and Renewable Energy estimated India's current repowering potential at approximately 2,760 MW.

The concept of repowering projects is new and the potential of such projects has so far remained untapped in the country. Actually repowering is a proven concept. Countries like Germany and Denmark have extensively repowered their old installed wind farms to bring the fleet to contemporary technology standards. We see a need for implementing repowering at a wider scale in our country. Repowering has lot of merits, it can be undertaken on the existing wind farm boundary, it does away with the hassle of land acquisition, and uses large amount of existing infrastructure. With given resources and replacing old wind turbines with advanced and contemporary wind turbines, we can generate more power, capacity wise and close to triple the electricity generation from these sites.

India has immense repowering potential with existing wind capacity 4 GW coming from installations 10 years or older, and turbines with less than 500kW ratings, which are installed on rich wind sites. Some States in India such as Tamil Nadu, Gujarat, Maharashtra, Karnataka etc., have the potential. Strong policy support and incentives from Central & State governments will see faster repowering of these farms. More private wind developers will evince interest in taking up projects under repowering scheme, which will lead to overall growth of the sector.

Advantages of Repowering

Repowering has several advantages that can be broadly categorised into four main categories as listed below.

- Efficient utilization of premium wind resource rich sites. Increasing the energy yield by several times from current levels.
- Higher Plant Load Factors (PLF).
- Maintenance (O&M) costs of the new turbines are much lower than the previous ones.
- Modern wind turbines make integration with the grid easier.

- Achieving better LCOE for the repowered farm.
- Reduction of the ratio of land area to per MW of installed capacity.
- Increase in the opportunities of the states to achieve Renewable Purchase Obligation (RPO) targets, and thereby the national targets in National Action Plan on Climate Change (NAPCC).
- Increase in the number of issued Renewable Energy Certificates (RECs).
- Increase the visual appeal of the farm.
- Lowering the incidents of the collision of birds.
- Quality of landscape also improve as number of turbines is much less per unit area.
- New turbines also produce lesser noise.

However due to a lack of policy guidelines and incentives for repowering, concerns are raised on a number of subjects including disposal of old machines, fragmented land ownership in existing wind farms, clarity on the feed-in tariff offered to newly repowered projects and constrained evacuation of the extra power generated.

1.6 Power Evacuation Facility

India's transmission network has a two-tier structure: interstate grids that are managed by the Power Grid Corporation of India (PGCIL) and the local grids are managed by the State Transmission Utilities. India still needs to establish an interlinked and unified grid through integration of its local, regional and national grids. Often inadequate and weak grids act as a barrier to smoother integration of power generation from renewables. India's power transmission system is divided into five regional grids: northern, northeastern, eastern, southern and western regions. Since August 2006, four regional grids have been fully integrated with the exception of the southern grid that is to be synchronized with these grids by 2014. The variability of wind power can create problems for the traditional grids in maintaining a supply and demand balance. Most of the wind farms in India are located in remote areas that are quite far away from load centres. Due to a weak transmission and distribution network, it is difficult to transmit the power from wind farms to the load dispatch centres. This is one of the key constraints for the future of wind power development in the country. In the past, with vertically integrated utilities, a single organisation was responsible for the planning and operation of networks and giving access to generators, and therefore the technical requirements did not have to be particularly clearly defined or codified. Now, with increased ownership separation between grid operators and power generators the need for defining the technical requirements governing the relationship between them becomes essential. Renewable energy generation further complicates the process of evacuation and dispatch.

1.7 Grid Integration

Power Evacuation studies for conventional power plants, are generally conducted as stipulated in Central Electricity Authority's "Manual on Transmission Planning Criteria" for annual system peak load and light load conditions for maximum Hydro / Thermal generation scenarios. Evacuation studies would be analysed for various scenarios to examine the ability of the various elements of network to carry the power during peak hours without network congestion and voltage violations including under contingency conditions stipulated in the relevant grid codes. System studies also examine whether voltage excursions are within limits particularly during light load hours and help to suggest measures to keep the voltages within acceptable limits. However, renewable energy projects like wind are generally located in remote locations from load centres. The local sub-station loads near the wind farm sites are also likely to be low during peak wind season. In such a scenario the entire wind generation may have to be transported to the nearest major grid sub-station for further absorption in the grid and this ability of the network has to be checked in the evacuation studies of wind to avoid backing down of wind generation. Annual system peak loads generally occur in summer months (may be due to high agriculture and industrial/commercial loads) and system peak loads during peak wind generation period may be around 60 to 90% of system annual peak demand. The corresponding minimum loads during peak wind season will also be low and may occur in night hours when wind generation may also hit the peak. Therefore, load flow studies have been simulated for minimum system demand during peak wind season along with local light loads for developing reliable wind power evacuation system.

1.8 Transmission Planning Process

Lack of adequate power evacuation capacity in the state grids is a major concern in transmission planning. Unless the transmission capacity planning process incorporates a long term vision of planned wind power additions and involves wind sector players at the planning stage, bottlenecks related to evacuation capacity are expected to remain. The remedy is more procedural than technical and requires administrative will rather than advanced technical understanding. The Ministry of Power (MOP) has recently constituted a committee chaired by the Joint Secretary of the MOP to work on accelerated development of RE through legislative and policy changes. One of the suggestions to streamline transmission planning for renewable energy is to have a separate sub-division in the Central Electricity Authority (CEA) and across all the state utilities for transmission planning of all renewable energy power plants.

India's local distribution systems are weak and would require substantial augmentation or laying of parallel power evacuation infrastructure, which will invariably add not only to the costs but also to construction time. The issue is further complicated by stipulations related to cost sharing of building this additional infrastructure. It is especially true for state-owned utilities (DISCOMs) that are severely cash-strapped. Another major concern is that of forced power outage (curtailment) due to a weak local grid, which results in substantial generation loss for the investor.

Moreover, difficulties related to institutional learning, ground level data and lack of extensive experience in grid integration of higher volumes of renewable energy and comprehensive power evacuation planning are adding to the delay. For utilities that are accustomed to the conventional model of centralized power generation, these issues are likely to linger for some more years.

In India, previous regulations under the electricity grid code (IEGC) did not allow renewables based power to connect to the inter-state transmission network, resulting in interconnection of wind power projects to a weak State transmission or distribution network leading to forced outage of generation, especially during the peak wind season. The need to allow power evacuation at higher voltages in the inter-state grid of the Central transmission utility is critical for the

Growth of the sector. The CERC recently allowed projects with capacities of over 50 MW to connect directly to the central transmission network subject to scheduling requirements37. This allowance has addressed one long-standing concern of investors by reducing the threat of curtailment.

1.9 Renewable Energy Law

One of the critical requirements for India is to develop and adopt an integrated energy framework that has a long-term vision, a time-bound plan and an implementing mandate that supports India's efforts for achieving clean, secure and universal energy access for its people. Today, most countries with advanced levels of wind power development have this framework in place, usually in the form of a renewable energy law. Such a framework, if adopted, can help to address not only the concerns of investors in relation to volatile policy environment and market risks but also deliver indigenous power supply free from the fuel price risk associated with fossil fuels.

Recently the Energy Coordination Committee under the Prime Minister's Office has decided to support the enactment of a Renewable Energy Law. Subsequently, a national level technical working committee for a Renewable Energy Law was constituted by MNRE.

1.10 Regulatory & Energy Policy Incentives for Wind

Over the next decade, India will have to invest in options that not only provide energy security but also provide cost effective tools for eradicating energy poverty across the board. India, as part of its obligations to the United Nations climate convention (UNFCCC), released a National Action Plan on Climate Change (NAPCC) in June 2008 that laid out the government's vision for a sustainable and clean energy future. The NAPCC outlined its implementation strategy through the establishment of eight national missions. Two of these missions were energy related, namely the National Solar Mission and the National Mission for Enhanced Energy Efficiency. In its present state the NAPCC does not have a mission dedicated to wind power.

The NAPCC stipulates that a dynamic minimum renewable purchase target of 5% (of total grid purchase) may be prescribed in 2009-2010 and this should increase by 1% each year for a period of 10 years. That would mean that by 2020, India should be procuring 15% of its power from renewable energy sources. To achieve such targets there is a clear need for comprehensive and long-term planning both at the federal and state levels. Current policy and regulatory incentives for wind power development are listed below.

1.11 Policy Support to Wind Energy

Central Electricity Regulatory Commission in its order dated 16/09/2009 introduced its regulations and tariff orders for procuring wind power into the grid; for control period from 16/09/2009 to 31/03/2012. The tariff structure consisting of fixed cost components: Return on Equity, Interest on loan Capital, Depreciation, Interest on Working Capital and Operation & Maintenance Expenses.

➢ **Accelerated Depreciation**

The main incentive for wind power projects in the past, was accelerated depreciation. This tax benefit allows projects to deduct upto 80% of value of wind power equipment during first year of project operation. Investors are given tax benefits upto 10 years. Wind Power producers receiving accelerated depreciation benefits must register with and provide generation data to IREDA and are not eligible to receive more recent Generation Based incentives.

➢ **Indirect Tax Benefits**

This includes concessions on excise duty and reduction in customs duty for wind power equipment. Wind powered electricity generators and water pumping wind mills, aero-generators and battery chargers are except from excise duties. Indirect tax benefits for manufacturers of specific energy parts vary from 5-25% depending upon the component.

➢ **Central-level Generation-based Incentives**

Offered by the central government since June 2008 and administered by IREDA, the GBI for wind is available for independent power producers with a minimum installed capacity of 5 MW for projects commissioned on or before 31/03/2012. As of December 2009, the GBI is set at INR 0.50/kWh (USD 0.01/kWh) of grid- connected electricity for a minimum of 4 years and a maximum of 10 years, up to a maximum of INR 6.2 million (USD 140,000) per MW. The scheme will deploy a total of INR 3.8

billion (USD 81 million) until 2012 and aims to incentivize capacity additions of 4,000 MW. Wind power producers receiving a GBI must register with and provide generation data to IREDA. The GBI is offered in addition to SERC's state preferential renewable energy tariffs. However, IPPs using GBIs cannot also take advantage of accelerated depreciation benefits. The GBI program will be reviewed at the end of the Eleventh Plan and revised as deemed appropriate. As of December 2011, 58 projects had been registered under this scheme with over 288.8 MW commissioned.

1.12 CDM Benefits to Wind Energy

The Clean Development Mechanism (CDM) was one of three mechanisms established by the Kyoto Protocol in 1997 to meet the Climate Convention objective of stabilizing greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The other two mechanisms are Emissions Trading and Joint Implementation, both of which are not applicable to developing countries. The CDM has two objectives; first to assist non-Annex I parties in achieving sustainable development and in contributing to the ultimate objective of the Climate Convention, and the second to assist Annex I parties with commitments under the Protocol in reducing greenhouse gas emissions to comply with their reduction targets.

Six main GHGs are covered by the Kyoto: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs); perfluorocarbons (PFCs); and sulphur hexafluoride (SF6). The Protocol allows Annex I countries the option of meeting the target through reductions in the emission of one or more of these GHGs. Some activities in the land-use change and forestry sector, such as afforestation and reforestation, that absorb carbon dioxide from the atmosphere, are also included in the Protocol.

It is intended that through emission reduction projects, the CDM would stimulate international investment and provide the essential resources for cleaner economic growth in developing countries.

Negotiations continued after Kyoto to develop the guidelines and modalities for implementing the CDM. The Marrakesh Accord of 2001 includes the guidelines for implementing the CDM and the other two mechanisms. The CDM provides opportunity to Annex I countries, including their private sector companies to reduce emissions in developing countries and then count these reductions towards their reduction commitments.

Private Participation in Power Sector

The Indian Power Sector was opened with much fanfare to private participation in 1991 to hasten the increase in generating capacity and to improve the system efficiency as well.

However, although several plants are under construction, till early 1999, generation had commenced at private plants totalling less than 2,000 MW. In contrast, some state undertakings have completed their projects even earlier than scheduled.

Independent power producers (IPPs) claim that their progress has been hindered by problems such as litigation, financial arrangements, and obtaining clearances and fuel supply agreements. On the other hand, the State Electricity Boards have been burdened by power purchase agreements (PPAs) that favour the IPPs with such clauses as availability payment irrespective of plant utilization, tariffs reflecting high capital costs and returns on equity, etc.

The process of inviting private participation in the power sector and the problems experienced seem to have spurred on the restructuring of the power sector, including the formation of Central and State Electricity Regulatory Commissions. However, some important problems have not been addressed. Additions to the generation capacity without corresponding improvement of the transmission and distribution facilities are likely to further undermine the system efficiency. What is more, issues like the reduction of "commercial losses" appear to have been ignored. Most importantly, investment in infrastructure has been a state responsibility because the intrinsically long gestation coupled with the relatively low returns from serving all categories of consumers have rendered such projects commercially unprofitable. Whether or not private participation can take on such tasks is to be seen.

A new policy of opening electricity generation to private participation was announced by the Central government in October 1991. Then, in May-June 1992, a high-level team consisting of the Union Cabinet Secretary, Power Secretary and Finance Secretary visited the USA, Europe, and Japan, to invite foreign private sector participation in the power sector. Foreign companies returned the visit to India and found the electricity establishment offering concessions and incentives that were hitherto unheard of in the power sector business.

Reasons for inviting private sector participation

In 1990, the situation facing the energy sector in India was roughly as follows. The central government - the conventional source for funding power projects -- was believed to have reached its limit as far as funding was concerned. The Indian electricity sector had virtually no surpluses to make available for investment. The World Bank had stated in 1989 that requests from the electricity sector of developing countries added up to $100 billion per year. In response, only about $20 billion was available from multilateral sources, leaving a gap of about more than $80 billion.1 Hence, it was suggested that the only possible source of funds was the private sector and, in view of the fact that the Indian capital market did not appear to be able to make a significant contribution, that the foreign private sector should be welcomed.

It was also hoped that there would be a side-benefit regarding the unacceptably low system efficiency of the state electricity boards. This efficiency would be improved through the oft-claimed better management and higher technical performance of the private sector.

India has a good potential for renewable energy power (Biomass, Wind, Solar, Small Hydro) of about 84,776 MW, of which wind power potential is estimated as 45,195 MW and Biomass power potential is estimated as 24,581 MW, small hydropower upto 25 MW is estimated as 15,000 MW. Energy from the solar photovoltaic systems is estimated at 50MW/km2. Most of these potential is tapped by government sector as well as the power sector. To tap the higher potential available from these sources, the government is promoting the private sector to come forward and invest in the development of renewable energy power projects by providing them some financial incentives and other regulatory supports. Private sector has come forward and contributed much in the development of these sectors.

Public Private Partnership:

The Indian power sector has garnered significant interest from private players. The share of the private sector in power generating capacity has increased from 13 per cent in FY 2006-07 to 33 per cent as on Jan 2015. India's total generating capacity is around 255 GW, of which, the private sector accounts for the almost 36 per cent. Going forward, the private sector is likely to account for a major share of the additional capacity and investments (almost 50 per cent); wherein, PPP is likely to be the preferred route for such ventures.

The Central Government has introduced the DBFOT framework for development of generation projects through private sector participation. MoP has put up a framework in place in for promoting private sector participation allowing private players to develop transmission infrastructure though a tariff based competitive bidding framework. With the advent of private sector participation in transmission, JVs are being formed with Central & state transmission utilities. In addition, many states in India have adopted the Distribution Franchisee route. A PPP policy framework is being devised with Coal India Limited to increase coal production and to reduce dependency on imported coal.

Power is one of the key sectors attracting FDI inflows into India. FDI inflows into the sector increased from a mere USD 87 million in FY-06 to USD 1,066 million in FY-14 and USD 486 million during April 14 to October 14. The sector accounted for 4.1 per cent of the total inflows in FY-14. The cumulative FDI inflows into the sector in April 2000 October 2014 were USD-9.4 billion.

The High Level Committee on Infrastructure Financing projects an investment of Rs. 9.1 lacs crore in Electricity, and, Rs. 1.7 lacs crore in Renewable Energy sector during the 12th FYP, of which, approximately 50% is to be met through the private sector participation, while, balance through Central and State Governments.

Policy Environment:

- Enactment of Electricity Act 2003 and National Tariff Policy 2006 leading to a more liberal framework for power sector across the value chain and increasing investment through competitive bidding;
- Development of UMPPs, i.e. large scale projects, through tariff based competitive bidding;
- Launch of R-APDRP with the purpose of reducing AT&T losses up to 15 per cent by upgradation of transmission and distribution network. Sanctioned projects of more than USD 5.8 billion;
- 100% FDI allowed under the automatic route except atomic energy;
- During FY-13, the Government liberalized FDI policy for Power Trading Exchanges;
- Foreign investment in power exchanges registered under the CERC Regulations 2010 allowed

Factors critical to success of study

Currently, neither the states nor the central government provides dedicated policy support or incentives to encourage Indian wind power developers or investors to repower their old projects. However, there are some challenges to be addressed before a comprehensive repowering attempt in India. Few of the key challenges are listed below:

- **Turbine Ownership:** Process of repowering reduces the number of turbines and one-to-one replacement of turbines may not be possible. Due to reduction in number of turbines there are chances that owner of turbines they may not be ready for repowering proposal. Thus turbine ownership issue needs to be handle carefully.

- **Single wind Turbine Repowering:** There are several single wind mill owners in India due to the AD-based investors/developers. An individual requiring repowering of a single WTG at the same location needs to obtain clearance from the consenting authority from the State/Centre with regards to the effect of such repowering to the neighbouring wind turbines/wind farms. While replacement of same capacity WTG of modern technology would mean not a great increase in Annual Energy Production (AEP), use of higher capacity instead would need policy for intercropping.

- **Land Ownership:** Another critical factor behind repowering at existing windfarm is land ownership. Multiple owners of wind farm land may create obstacle for repowering projects.

- **Power Purchase Agreement:** For existing turbines power purchase agreement were signed with the State Electricity Boards for 10 to 20 years and the particular electricity board may not be ready in discontinuing or revising the power purchase agreement before its specified time period.

- **Power Evacuation Infrastructure:** There are chances that current substation and transmission facilities may be designed to support present generation capacity and for repowering project we may have to augment the existing substation and transmission facilities as repowering project will inject the more power than existing system.

- **De-erection & Erection Cost:** Before moving forward for repowering projects the additional costs incurred during the de erection of old turbine and erection of higher technology turbines need to be accessed.

- **Old turbine disposal:** The disposal of old turbines are the crucial factor which is seen as a challenges for repowering projects. There are various options such as scrapping, buy-back by the government or manufacturer, or export. Local capacity may need to be developed to overcome from this issue.

- **Incentives:** One of the primary barriers to repowering is the lack of economic incentive to replace the older turbines. To compensate for additional cost of repowering, appropriate incentives schemes are necessary to attract financers. To encourage repowering, financial incentives need to be extended by government.

- **Policy package:** A new policy package should be developed which would cover additional project cost and add-on tariff by the State Electricity Regulatory Commissions (SERCs) and include a repowering incentive (on the lines of the recently introduced generation-based incentive scheme by MNRE).

Summary

India is the 3rd largest annual wind power market in the world, and provides great business opportunities for both domestic and foreign investors. The Indian wind power sector experienced record annual growth in 2014 with the addition of more than 2 GW of new installations. Diverse incentives supported by a long-term policy and regulatory framework at the central and state levels have played a crucial role in achieving this goal. Wind power is now increasingly accepted as a major complementary energy source for securing a sustainable and clean energy future for India.

Wind Energy has been the fastest growing renewable energy sector in the country. With a cumulative installed capacity of over 23,439 MW, wind power currently accounts for almost 70 percent of the total installed capacity in the renewable energy sector. About 2,090 MW of new wind power capacity has been added during the last financial year 2014- 2015 alone which is the highest in a year, so far. The 12th Five Year Plan proposals envisage around 15,000 MW of grid-interactive renewable power capacity addition from wind energy alone.

The Indian Government has been at the forefront of providing the necessary policy support and a facilitative regulatory ecosystem for the fast and orderly growth of the sector. We are equally conscious of the challenges and difficulties being faced by the sector. We are, however, confident that the potential of the sector is enormous. The target of 15 percent of total power capacity through renewable for India by 2020 envisaged under the National Action Plan on Climate Change cannot be achieved without a substantial contribution of wind energy.

Since the 1980s the Government has taken various initiatives for developing the country's vast indigenous renewable energy resources. This includes the National Action Plan on Climate Change (NAPCC), and the current 12th five-year plan, which set long-term targets, that help in evolving a better investment environment for the wind sector. But this effort would have been in vain, without the positive and proactive role of the Ministry of New and Renewable Energy and the electricity sector regulators. Their role in the development of wind power in India is undeniable and important. We look forward to working closely with all relevant stakeholders and supporting the Government towards achieving the goals set under the NAPCC and the 12th five-year plan. Our top priority is to support the development of a comprehensive renewable energy law and stable regulatory environment for wind power in India.

CHAPTER 3

Research Design, Methodology and Plan

There are number of process are available for investigating the wind resource assessment for a given sites. The preferred approach will depend on your wind energy program objectives and on previous experience with wind resource assessment. These approaches can be categorized as three basic scales or stages of wind resource assessment: preliminary area identification, area wind resource evaluation, and micrositing.

3.1 The Wind:

The earth receives around 1.7×1014 kW of power from the sun in the form of solar radiation. This radiation heats up the atmospheric air. The intensity of this heating will be more at the equator (0° latitude) as the sun is directly overhead. Air around the poles gets less warm, as the angle at which the radiation reaches the surface is more acute. The density of air decreases with increase in temperature. Thus, lighter air from the equator rises up into the atmosphere to a certain altitude and then spreads around. This causes a pressure drop around this region, which attracts the cooler air from the poles to the equator. This movement of air causes the wind. Thus, the wind is generated due to the pressure gradient resulting from the uneven heating of earth's surface by the sun. As the very driving force causing this movement is derived from the sun, wind energy is basically an indirect form of solar energy. One to two per cent of the total solar radiation reaching the earth's surface is converted to wind energy in this way. The wind described above, which is driven by the temperature difference, is called the geostrophic wind, or more commonly the global wind. Global winds, which are not affected by the earth surface, are found at higher altitudes. The rotation of earth leads to another phenomenon near its surface called the Coriolis Effect. Due to the Coriolis Effect, the straight movement of air mass from the high pressure region to the low pressure region is diverted as shown in fig 2.2 Under the influence of Coriolis forces, the air move almost parallel to the isobars. Thus, in the northern hemisphere, wind tends to rotate clockwise where as in the southern hemisphere the motion is in the anti-clockwise direction.

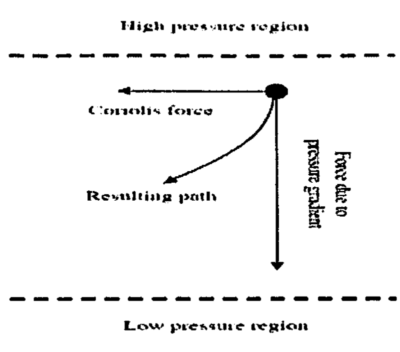


Figure 7: Wind Direction affected by Coriolis force

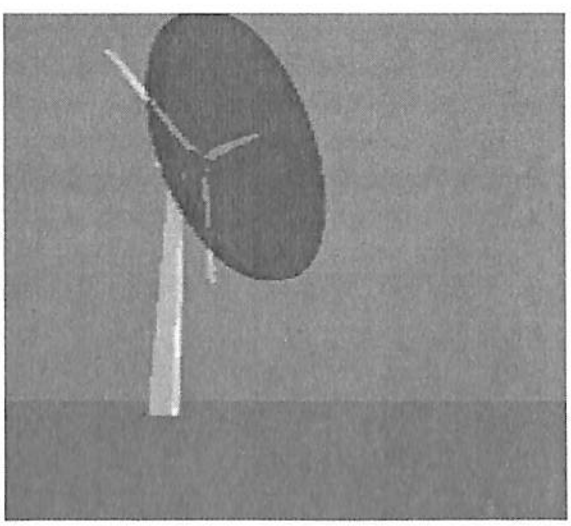
3.1 The Coriolis Force:

Since the globe is rotating, any movement on the Northern hemisphere is diverted to the right, if we look at it from our own position on the ground. (In the southern hemisphere it is bent to the left). This apparent bending force is known as the Coriolis force. (Named after the French mathematician Gustave Gaspard Coriolis 1792-1843). It may not be obvious to you that a particle moving on the northern hemisphere will be bending towards the right.

The Coriolis force is a visible phenomenon. Railroad tracks wear out faster on one side than the other. River beds are dug deeper on one side than the other. (Which side depends on which hemisphere we are in: In the Northern hemisphere moving particles are bent towards the right). In the Northern hemisphere the wind tends to rotate counter clockwise (as seen from above) as it approaches a low pressure area. In the Southern hemisphere the wind rotates clockwise around low pressure areas. On the next page we shall see how the Coriolis force affects the wind directions on the globe.

3.3 Energy In The Wind:

A wind turbine obtains its power input by converting the force of the wind into a torque (turning force) acting on the rotor blades. The amount of energy which the wind transfers to the rotor depends on the density of the air, the rotor area, and the wind speed. The cartoon shows how a cylindrical slice of air 1 metre thick moves through the 2,300 m2 rotor of a typical 1,000 kilowatt wind turbine. With a 54 metre rotor diameter each cylinder actually weighs 2.8 tonnes, i.e. 2,300 times 1.225 kilogrammes.



Density of Air:

The kinetic energy of a moving body is proportional to its mass (or weight). The kinetic energy in the wind thus depends on the density of the air, i.e. its mass per unit of volume. In other words, the "heavier" the air, the more energy is received by the turbine. At normal atmospheric pressure and at 15° Celsius air weighs some 1.225 kilogrammes per cubic metre, but the density decreases slightly with increasing humidity. Also, the air is denser when it is cold than when it is warm. At high altitudes, (in mountains) the air pressure is lower, and the air is less dense.

Rotor Area:

A typical 1,000 kW wind turbine has a rotor diameter of 54 metres, i.e. a rotor area of some 2,300 square metres. The rotor area determines how much energy a wind turbine is able to harvest from the wind. Since the rotor area increases with the square of the rotor diameter, a turbine which is twice as large will receive 2 2 = 2 x 2 = four times as much energy.

3.4 Wind Deflection:

The image on the previous page on the energy in the wind is a bit simplified. In reality, a wind turbine will deflect the wind, even before the wind reaches the rotor plane. This means that we will never be able to capture all of the energy in the wind using a wind turbine. We will discuss this later, when we get to Betz' Law. In the image above we have the wind coming from the right, and we use a device to capture part of the kinetic energy in the wind. (In this case we use a three bladed rotor, but it could be some other mechanical device).

3.5 Wind Speed and Energy:

The wind speed is extremely important for the amount of energy a wind turbine can convert to electricity: The energy content of the wind varies with the cube (the third power) of the average wind speed, e.g. if the wind speed is twice as high it contains 2 3 = 2 x 2 x 2 = eight times as much energy. In the case of the wind turbine we use the energy from braking the wind, and if we double the wind speed, we get twice as many slices of wind moving through the rotor every second, and each of those slices contains four times as much energy, as we learned from the example of braking a car.

The graph shows that at a wind speed of 8 metres per second we get a power (amount of energy per second) of 314 Watts per square metre exposed to the wind (the wind is coming from a direction perpendicular to the swept rotor area).

At 16 m/s we get eight times as much power, i.e. 2509 W/m2. The table in the Reference Manual section gives you the power per square metre exposed to the wind for different wind speeds.

The power of the wind passing perpendicularly through a circular area is:

P = 1/2 ρ v3 π r2

Where P = the power of the wind measured in W (Watt). ρ= (rho) = the density of dry air = 1.225 measured in kg/m 3 (kilogrammes per cubic metre, at average atmospheric pressure at sea level at 15° C). v = the velocity of the wind measured in m/s (metres per second). π= (pi) = 3.1415926535...
r = the radius (i.e. half the diameter) of the rotor measured in m (metres).

3.6 Local Effects:

Changes in velocity and direction of wind near the surface, say up to 100 m above the ground, is more important as far as energy conversion is concerned. In this region, the wind pattern is further influenced by several local factors. Land and sea breezes are examples for the local wind effects. During the day time, land gets heated faster than the sea surface. As a result, the air near the land rises, forming a low pressure region. This attracts cool air to the land from the sea. This is called the sea breeze. During night time, the process gets reversed as cooling is faster on land. Thus wind blows from the land to the sea, which is called the land breeze. In mountain valleys, the air above the surface gets heated and rises up along the slopes during the day time. This is replaced by the cool air, resulting in the valley winds. During the night, the flow is from the mountain to the valley which is known as the mountain wind. Quite often, this phenomenon may create very strong air currents, developing powerful wind. Wind shear, turbulence and acceleration over the ridges are some other examples for local wind effects.

3.7 Wind Shear:

The flow of air above the ground is retarded by frictional resistance offered by the earth surface (boundary layer effect). This resistance may be caused by the roughness of the ground itself or due to vegetations, buildings and other structures present over the ground. For example, a typical vertical wind profile at a site is shown in Fig. 3.2. Theoretically, the velocity of wind right over the ground surface should be zero. Velocity increases with height upto a certain elevation. The velocity increases noticeably upto 20 m, above which the surface influence is rather feeble.

It is common practice to use a power law model to estimate wind speeds at one location based on measurements taken at a different elevation. The power law model assumes wind speeds at different heights are related by the equation,

$$r_h = r_{h_0} \frac{h}{h_0}$$

Where *h* is the turbine height, *h0* is a height for which the wind speed is known, *vh* and *vho* are the wind speeds at these heights, and *a* is a wind shear exponent, between 0 and 1, which is greater for sites with stronger wind shear. The rate at which the velocity increases with height depends on the roughness of the terrain. Presence of dense vegetations like plantations, forests, and bushes slows down the wind considerably. Level and smooth terrains do not have much effect on the wind speed. The surface roughness of a terrain is usually represented by the roughness class or roughness height. The roughness height of a surface may be close to zero (surface of the seạ) or even as high as 2 (town centers). Some typical values are 0.005 for flat and smooth terrains, 0.025-0.1 for open grass lands, 0.2 to 0.3 for row crops, 0.5 to 1 for orchards and shrubs and 1to 2 for forests, town centers etc.

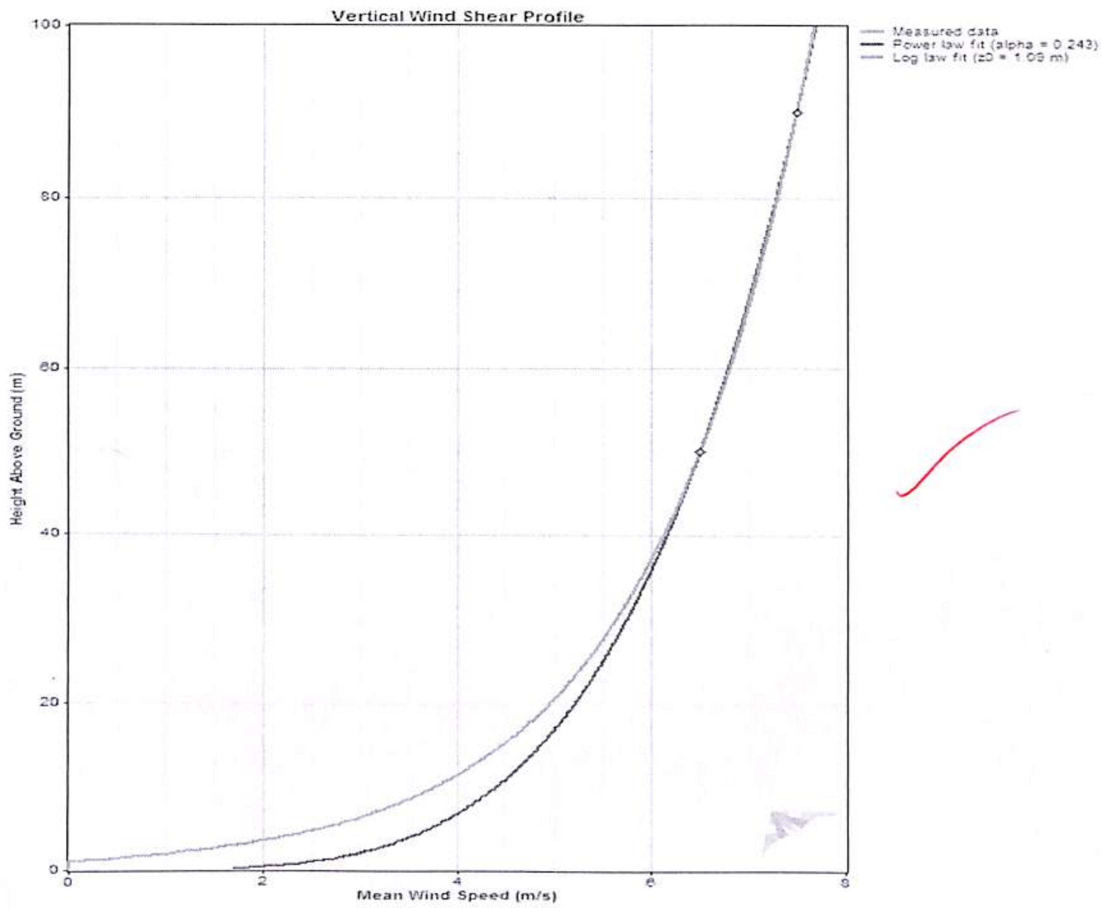


Figure 8: Variation of Wind Velocity with height

The above graph represents the mean wind speed in m/s at different level of heights. including the hub height at 50 m & 90m and at both the height wind velocity is different. At 90 m of height wind speed is more compared to 50m height.

Roughness height is an important factor to be considered in the design of wind energy plants. Suppose we have a wind turbine of 30 m diameter and 40 m tower height, installed over the terrain described in Fig. 3.2. The tip of the blade, in its lower position, would be 25 m above the ground. Similarly, at the extreme upper position, the blade tip is 55 m above the ground. As we see, the wind velocities at these heights are different. Thus, the forces acting on the blades as well as the power available would significantly vary during the rotation of the blades. This effect can be minimized by increasing the tower height. The wind data available at meteorological stations might have been collected from different sensor heights. In most of the cases, the data are logged at 10 m as per recommendations of the World Meteorological Organization (WMO). In wind energy calculations, we are concerned with the velocity available at the rotor height. The data collected at any heights can be extrapolated to other heights on the basis of the roughness height of the terrain.

Data Sources

- **Modern-Era Retrospective Analysis for Research and Applications (MERRA):** MERRA, which was developed by the National Aeronautics and Space Administration (NASA), utilizes a variety of observing systems which have been assimilated into a global three-dimensional grid by numerical atmospheric models at a horizontal resolution of 1/2° latitude and 2/3° longitude. The Modern-Era Retrospective Analysis for Research and Applications (MERRA) was undertaken by NASA's Global Modeling and Assimilation Office with two primary objectives: to place observations from NASA's Earth Observing System satellites into a climate context and to improve upon the hydrologic cycle represented in earlier generations of reanalyses. Focusing on the satellite era, from 1979 to the present, MERRA has achieved its goals with significant improvements in precipitation and water vapor climatology. Here, a brief overview of the system and some aspects of its performance, including quality assessment diagnostics from innovation and residual statistics is given.

- **ERA-Interim (ERA-I):** ERA-I, which was developed by the European Centre for Medium-Range Weather Forecasts (ECMWF), utilizes a variety of observing systems which have been assimilated into a global three-dimensional grid by numerical atmospheric models at a spectral resolution of T255, or an approximate horizontal resolution of 79 km. ECMWF is both a research institute and a 24/7 operational service, producing and disseminating numerical weather predictions to its Member States. This data is fully available to the national meteorological services in the Member States. The Centre also offers a catalogue of forecast data that can be purchased by businesses worldwide and other commercial customers. The supercomputer facility (and associated data archive) at ECMWF is one of the largest of its type in Europe and Member States can use 25% of its capacity for their own purposes. The organisation was established in 1975 and now employs around 280 staff from more than 30 countries. ECMWF is one of the six members of the Co-ordinated Organisations, which also include the North Atlantic Treaty Organisation (NATO), the Council of Europe (CoE), the European Space Agency (ESA), the Organisation for Economic Co-operation and Development (OECD), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

- **Climate Forecast System Reanalysis (CFSR):** CFSR, which was developed by the National Centers for Environmental Prediction (NCEP), is a global atmosphere-ocean-land-sea ice system that produces hourly and 6-hourly outputs at a horizontal resolution of 1/2° latitude and 1/2° longitude. CFSR extends through 2010, while an operational version of CFSR has been employed beginning in 2011.

Research Design

Wind Assessment:

A wind resource assessment program is similar to other technical projects. It requires planning and coordination and is constrained by budget and schedule limitations. Before wind turbines can be installed, a siting study needs to be undertaken to determine where to locate them. The major objective of a siting study is to locate a wind turbine (or turbines) such that cost of energy is maximized. Several approaches are available when investigating the wind resource within a given land area. These approaches can be categorized as three basic scales or stages of wind resource assessment: preliminary area identification, area wind resource evaluation, and Micrositing. The scope of a siting study can have a very wide range, which could include everything from wind prospecting for suitable turbine sites over a wide geographical area to considering the placement of a single wind turbine on a site or of multiple wind turbines in a wind farm.

A. Preliminary Area Identification:

This process screens a relatively large region for suitable wind resource areas based on information such as airport wind data, topography, flagged trees, and other indicators. At this stage new wind measurement sites can be selected. Areas with high average wind speeds within the region of interest are identified using a wind resource atlas and any other available wind data. The characteristics of turbine types or designs under consideration are used to establish the minimum useful wind speed for each type. Potential windy sites within the region are identified where the installation of one or more wind turbines appears to be practical from engineering and public acceptance standpoints. If the nature of the terrain in the region is such that there is significant variation within it, then a detailed analysis is required to identify the best areas. At this stage, topographical considerations, ecological observations, and computer modeling may be used to evaluate the wind resource. Geologic, social, and cultural issues are also considered.

B. Area Wind Resource Evaluation:

This stage applies to wind measurement programs to characterize the wind resource in a defined area or set of areas where wind power development is being considered. In this phase, each potential site is ranked according to its economic potential, and the most viable sites are examined for any environmental impact, public acceptance, safety, and operational problems that would adversely affect their suitability as a wind turbine site. Once the best sites are selected, a preliminary measurement program may be required. At this point, the measurements should include wind shear and turbulence in addition to wind speed and prevailing wind directions. The most common objectives of this scale of wind measurement are to:

- Determine or verify whether sufficient wind resources exist within the area to justify further site-specific investigations.
- Compare areas to distinguish relative development potential.
- Obtain representative data for estimating the performance and/or the economic viability of selected wind turbines.
- Screen for potential wind turbine installation sites.

C. Micrositing:

The smallest scale, or third stage, of wind resource assessment is micrositing. Its main objective is to quantify the small-scale variability of the wind resource over the terrain of interest. Ultimately, micrositing is used to position one or more wind turbines on land to maximize the overall energy output of the wind plant.

The most critical factor influencing the power developed by a wind energy conversion system is the wind velocity. Due to the cubic relationship between velocity and power, even a small variation in the wind speed may result in significant change in power. For example, an increase in the wind speed by 10 per cent may enhance the productivity of the turbine by over 33 per cent. As the wind velocity and thus the power vary from place to place, the first step in planning a wind energy project is to identify a suitable site, having strong and impressive wind spectra. Wind is stochastic in nature. Speed and direction of wind at a location vary randomly with time. Apart from the daily and seasonal variations, the wind pattern may change from year to year, even to the extent of 10 to 30 per cent. Hence, the behaviour of the wind at a prospective site should be properly analyzed and understood. Realizing the nature of wind is important for a designer, as he can design his turbine and its components in tune with the wind characteristics expected at the site. Similarly, a developer can assess the energy that could be generated from his project, if the wind regime characteristics are known. Average wind velocity gives us a preliminary indication on a site's wind energy potential. A location having good average wind speed - say for example with a minimum of 7 m/s - is expected to be suitable for wind

electric generation. However, for a detailed planning, apart from the average strength of the wind spectra, its distribution is also important. Statistical models are being successfully used for defining the distribution of wind velocity in a regime, over a given period of time. Once the wind velocity and its distribution at a prospective site are available, we can proceed further with the assessment of the energy potential. Similarly, for the safe structural design, possibilities of extremely high wind at the site should be identified. Statistical models commonly used for wind resource analysis are described, indicating their application in wind energy conversion. The discussions are further extended to the derivation of methods and indices for assessing the energy potential of a given wind regime.

Once a site is chosen, or possibly as part of the final site evaluation, the exact location of the turbines and their energy production needs to be determined. This may be able to be done with computer programs that can model the wind field and the various aerodynamic interactions between turbines that affect energy capture. The more complex the terrain, and the less the available data from nearby sites, the less accurate these models are. A site in complex terrain may require detailed measurements at numerous locations to determine the local wind field for micrositing decisions.

D. Estimating the Wind Resource:

There are a number of possible approaches to determining the long-term wind resource at candidate sites. Each of these has advantages and disadvantages and, thus, might be used at different stages of the siting process, depending on the information needed. These methods include (1) ecological methods, (2) the use of wind atlas data, (3) computer modeling. Some of the methods presented here can also be used for more general estimates of wind resource.

E. Ecological Methods:

Vegetation deformed by high average winds can be used both to estimate the average annual wind speed and to compare sites, even when no wind data are available. These methods are most useful during initial site selection and in geographic areas with very little available wind data. This technique works best in three regions coastal regions, in river valleys and in mountainous terrain. Ecological indicators are especially useful in remote mountainous terrain not only because there is usually little wind data there, but also because the winds are highly variable over small areas and are difficult to characterize. Among the many effects of wind on plant growth, the effects of wind on trees are the most useful for the wind prospecting phases of siting. Trees have two advantages - height and a long lifetime in which to gather evidence. Research work has produced numerous potential indices relating tree deformation to long-term average wind speeds. Three of the more common ones are the Griggs-Putnam index for conifers, The Griggs-Putnam index applies to conifers and defines eight classes of tree deformation ranging from no effect (class 0) to the predominance of lateral growth in which the tree takes the form of a shrub (class VII).

The intensity and nature of this deformation depends on the strength of wind. This method is specifically suitable to judge the wind in valleys, coasts and mountain terrains. Deformations of trees due to wind effect are classified by Putnam. There are four types of deformations under Putnam's classification. They are brushing, flagging, throwing and carpeting. Wind brushing refers to the leeward bending of branches and twigs of the trees. Brushing may clearly be observed when the trees are off their leaves. This is an indication for light wind, which is not useful for wind energy conversion. In flagging, the branches are stretched out to leeward, with possible stripping of upwind branches. The range of wind speeds corresponding to the flagging effect is of interest for energy conversion. In wind throwing, the main trunk and branches of the tree lean away from the coming wind. This indicates the presence of stronger wind. Under clipping, the lead branches of the tree are suppressed from growing to its normal height due to strong wind. With extreme winds the trees are clipped even at a very low height, this is termed as wind carpeting.

Index	Top View of Tree	Side View of Tree	Description	Average Wind Speed
0			No Deformity	No Significant Wind
I			Brushing and Slight Flagging	11-14 kph 7-9 mph 3-4 m/s
II			Slight Flagging	14-18 kph 9-11 mph 4-5 m/s
III			Moderate Flagging	18-21 kph 11-13 mph 5-6 m/s
IV			Complete Flagging	21-26 kph 13-16 mph 6-7 m/s
V			Partial Throwing	24-29 kph 15-18 mph 7-8 m/s
VII			Complete Throwing	26-34 kph 16-21 mph 8-9 m/s
VIII			Carpeting	35+ kph 22+ mph 10+ m/s

F. Using Wind Atlas Data:

Wind atlas data (or other archived data) from nearby sites may be able to be used to determine local long-term wind conditions. The effects of surface roughness, topography and nearby obstacles could have been removed from the data in order to have data that represent the basic surface flow patterns. The atlas also includes a description of a procedure to use these data to estimate the long-term resource at a specific site. The procedure starts with the selection of appropriate comparison sites and includes formulas for corrections to the Weibull parameters to account for surface roughness effects, upwind structures, and changes in elevation. The basic procedure involves determining the estimated Weibull parameters for the wind at the site. These parameters, in conjunction with the wind direction distribution information, can be used to determine the annual long-term wind speed and wind speed distribution. If a turbine has been selected, then these data can be used to estimate turbine power production. WAsP has become part of a much larger framework of wind atlas methodologies, which also encompasses mesoscale modelling and satellite imagery analysis. in order to be able to assess the wind resources of diverse geographical regions where abundant high-quality, long-term measurement data does not exist and where important flow features may be due to regional-scale topography. Figure 4 is a schematic presentation of the entire framework.

Mesoscale	**Pre-processing** Wind classes Terrain elevation Terrain roughness Input specifications Model setup	**Modelling** Mesoscale model; e.g. KAMM, WRF, MC2, MM5 or similar.	**Post-processing** Predicted wind climate Regional wind climate Predicted wind resource for selected terrain site coordinates	**Numerical WA** Mesoscale maps Database of results WAsP *.LIB files Uncertainties Parameters
Measurements	**Met. stations** Siting Design Construction Installation Operation	**Wind data** Data collection Quality control Wind database Wind statistics Observed wind climate	**Verification** Meso- and microscale results vs. measured data Adjust model and model parameters to fit data Satellite imagery (offshore sites only)	**Applications** Best practices Courses and training Microscale flow model Wind farm wake model ⇒ **Wind farm AEP**
Microscale	**Pre-processing** Wind speed distributions Wind direction distribution Terrain elevation Terrain roughness Sheltering obstacles	**Modelling** Microscale model: Linearised, e.g. WAsP, MS-Micro or similar. Non-linear, e.g. CFD (Computational Fluid Dynamics).	**Post-processing** Regional wind climate Predicted wind climate Predicted wind resource for selected terrain site coordinates	**Observational WA** Microscale maps Database of results WAsP *.LIB files Uncertainties Parameters

Table 5 : Overview of state-of-the-art wind atlas methodologies.

Wind resource assessment based on mesoscale modelling, a numerical wind atlas, can provide reliable data for physical planning on national, regional or local scales, as well as data for wind farm siting, project development, wind farm layout design and micro-siting of wind turbines. Bankable estimates of the power production from prospective wind farms require additional on-site wind measurements for one or several years.

The present course notes thus describe mainly the 'grey', 'green' and 'yellow' parts of the diagram above, i.e. what is referred to as the observational wind atlas methodology.

G. Computer Modelling:

There are now computer modelling programs that can be used to estimate the local wind field and to optimize turbine layout in a wind farm. A current challenge for the wind energy industry is the prediction of the wind resource in complex terrain. There is interest in placing wind turbines in hilly and mountainous areas, due to the potentially high speed-up in certain areas, leading to a locally high wind resource. Currently missing, however, is a flow model that is both accurate in complex terrain, and simple and computationally cheap enough to be used on a commercial scale on personal computers. Programs to model the local long-term wind field at a site use topographical information and long-term upper-level meteorological data and/or nearby surface level wind data. The more nearby data that are available and the more smooth the terrain is, the more accurate these predictions are. Numerous such programs are commercially available.

WAsP is one of the computer program to determine the wind resource at a site. WAsP was developed, as part of the international effort to provide a tool to use the data in the atlas. The Wind Atlas Analysis and Application Program (WAsP) was developed at Risø National Laboratory, Roskilde, Denmark, in the late 1980s. It is a widely used commercial PC-based tool to estimate wind resources at a potential wind turbine site, given a set of wind climatology measurements taken at a nearby meteorological mast and information about the local terrain. The current WAsP model for flow over orography is very quick, and accurate in flat to mildly undulating terrain, and has been used commercially with no inconsiderable success for two decades. However, it performs poorly when applied to complex orography, slopes steeper than about 30% lead to flows that violate its basic assumptions, especially in terms of flow separation, and thus discrepancies arise between the predicted and actual flow perturbations, most notably the speed-up WAsP includes the effects of the atmospheric stability, surface roughness, obstacles and topography at the site in the determination of the site-specific wind conditions. The modeling uses a simple fluid flow model that includes mass and momentum conservation to determine the flow field at the site, based on the nearby reference sites. One advantage of WAsP is that it determines local wind field using a polar coordinate grid centered on the site. This provides a high resolution around the site, allowing the wind field for a complete wind farm to be predicted. Another advantage is that it does not require on-site measurements. It also works at any height and location. Disadvantages are that the method may give inexact results in complex terrain and that it does not include thermally driven effects such as sea breezes. The Risø Atmospheric Mixed Spectral Integration Model (RAMSIM) is a microscale, linearized flow model of a new type, developed to calculate the flow field over terrain comprising steep slopes, as an eventual replacement for the current WAsP orography model.

RAMSIM is governed by the Reynolds-Averaged Navier-Stokes and *E-ε* closure equations, expressed in general curvilinear coordinates. A terrain-following coordinate system is created, not by using a numerical grid generator, but rather based on a simple *analytical* expression, which can then be "built into" the model equations. The many factors that arise in the equations due to the coordinate transformation can therefore be replaced by analytical expressions. The equations are then linearized by a perturbation expansion, of which only the zero- and first-order terms are retained. The zero-order equations simply describe logarithmic wind flow over flat terrain of roughness *z0*.

The first-order equations, representing the spatial correction due to the presence of orography, are Fourier-transformed analytically in the two horizontal dimensions. After some differentiations, algebraic eliminations, and other manipulations, the firstorder equations are turned into a set of ordinary differential equations (ODEs) with *z* as the independent variable.

H. Economics of Repowering:

The cost factor is an important parameter while investing for repowering the wind farm. The present worth of an existing turbine, the de-erection cost, installation & commissioning cost of the new turbine of a higher capacity has to be estimated to check the feasibility of repowering project.

- **Net Present Value:**

A fundamental principle of finance and economics is that the present value of future cash flows is what counts when making decisions based on value. The Net Present Value technique applies this idea to the analysis of projects. Net Present Value (NPV), defined as the present value of a project's cash inflow minus the present value of its costs. In the net present value technique, we calculate the present value of each of project's cash flows and add them together. The result is the net present value of the project. A project's NPV can be represented by the following equation:

$$NPV = C_0 + \frac{C_1}{(1+r)^1} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_n}{(1+r)^n}$$

where Cn = nth Cash flow at time tn

r = Discount Rate

The NPV decision rule says that the firms should invest in those projects when the sum of the present values of future cash inflows exceeds the initial project outlay.

- **Internal Rate of Return**

The internal rate of return (IRR) is the most commonly used performance measure in private equity. The IRR does not indicate how much money a fund has made, but how time-efficient the fund has invested, that is, the shorter the investment period for a profitable investment, the higher the IRR. The IRR is the value of the discount rate that makes the net present value of all cash flows zero. The IRR tells the exact rate of return that will be earned on the original investment. Therefore the IRR is an extremely useful quantity to know when evaluating a potential investment project. It can be represented by the following equation:

$$\sum_{t=0}^{n} \frac{C^n}{(1+IRR)^n} = 0$$

- **Payback Period:**

Payback period in capital budgeting refers to the period of time required for the return on an investment to repay the sum of the original investment. Payback period intuitively measures how long something takes to pay for initial investment. All else being equal, shorter payback periods are preferable to longer payback periods. The payback method measures the time it will take to recover the total funds invested in a project. It shows the time required for the total cash inflows to equal the total cash outflows. The payback period is usually expressed in years and is calculated as follows:

$$\text{Payback Period} = \frac{\text{Amount of Initial investment}}{\text{Annual net Cash Inflows}}$$

Payback method ignores the time value of money which understates the true payback Payback method ignores the time value of money which understates the true payback period. To incorporate the time value of money, Discounted Payback Period (DPP) method is used. The discounted payback period is a variation of the payback method that considers the time value of money. It can be calculated as follows:

$$\text{Discounted Payback Period} = \frac{\text{Amount of initial investment}}{\text{Annual Discounted Net Cash Inflows}}$$

- **Problem Statement:**

In the present situation there is a demand for energy, associated with the rising cost of energy and environmental problems are the matter of concern. It is necessary to limit the cost of the energy generation with the available resource of land on which wind turbines are already installed. The installed turbines are of a lower capacity which can be replaced with a higher capacity model as per the state of art technology. Repowering deals with the replacement of the first generation small capacity wind turbines with the turbines of the modern state of art technology. The replacement of the older turbines with the modern megawatt (MW) and multi megawatt turbines will increase the generation capacity as well as increase in the capacity of the wind farm with the available Land / Area. Though the generation capacity from the renewable sources is still in initial stage and the cost per unit energy generation from the renewable sources is very high compared to non renewable sources, the capacity addition in the presently operating wind farm will reduce the cost per unit of the energy generated.

Data Analysis Procedures

The periods of record considered for each modeled dataset for this analysis begin in January 2010. This was done to limit the risk of longer-term trends that can impact these datasets, while still giving the most significant benefit of using a long-term reference. Each modeled dataset can be interpolated to the exact location of a meteorological mast. For this analysis, the model output for the four nearest grid cells were interpolated to the location of Vankusavade.

Linear regression equations were established using concurrent daily mean wind speeds at Vankusavade and each potential reference. The strongest correlation was found with the MERRA ((ERA-I) and (CFSR).

In an effort to determine the most accurate climate adjustment for the project, several factors were considered alongside the linear correlation coefficients. It presents the respective time series of annual mean wind speeds from the reanalysis datasets between 2010 and 2014. This plot was created to determine whether any abrupt changes or significant trends in mean wind speed occurred during the reference periods of record. A discontinuity or abnormal trend in modeled data could indicate a change in the source data or the analytical techniques used to estimate the wind speed. Either of these conditions would call into question the validity of the climatological adjustment.

Additionally, a series of multiple linear regressions were performed using the potential references. This technique is often useful for striking a compromise between two or more reference datasets, with the weight given to each dataset in the regression being influenced by the quality of its relationship with the target site and its degree of statistical independence from the other potential references.

After considering correlation coefficients, trends, and multiple linear regression results, CFSR, ERA-I and MERRA were selected to estimate the long-term mean wind speed at Vankusavade. The long-term mean wind speed at Vankusavade 90m was calculated as 7.509 m/s and The long-term mean wind speed at Vankusavade at 50.0 was calculated as 6.508 m/s. A scatterplot showing the relationship between the observed daily mean wind speeds at Vankusavade and those predicted using the reference datasets is contained in below figure.

The wind data analysis and calculation of the observed wind climate may conveniently be done using the WAsP Climate Analyst. Whether the wind data are measured by the organisation carrying out the analysis or by a third party, a number of data characteristics must be known, such as: the data file structure, time stamp definition, data resolution (discretisation), calm thresholds, and any flag values used for calms and missing data. This information may be collected by filling out a WAsP Data Description Form; in the subsequent analysis all input values in the Climate Analyst protocol (import filter) editor should correspond to the data specifications.

This Step utilizes existing data from state wind resource maps, nearby publically available wind resource data, and other weather measurement sites to make rough projections about the financial of project. Initial assessment of the site is fairly simple in most states with publically available high resolution wind resource data.

Based on Collected data need to check the Wind Turbine Generators Details and Power curve of machines are below:

Model	S33 - 350 kW	S97 - 2100 kW
POWER		
Rated power:	350 kW	2100 kW
Cut-in wind speed:	3.5 m/s	3.5 m/s
Rated wind speed:	14 m/s	11 m/s
Cut-out wind speed:	25 m/s	20 m/s
Survival wind speed:	67 m/s	60 m/s
ROTOR		
Diameter:	33.4 m	97 m
Swept area:	876.1 m2	7386 m2
Number of blades:	3	3
Power density 1:	399.5 W/m2	284.3 W/m2
Power density 2:	2.5 m2/kW	3.5 m2/kW
GEAR BOX		
Type:	Spur	Spur
Stages:	3	3
Ratio:	1:32	
GENERATOR		
Type:	Asynchronus	Asynchronus
Number:	1.0	1.0
Speed, max:	1.006 U/min	
Voltage:	400 V	690 V
Grid connection:	Thyristor	DFIG
Grid frequency:	50 Hz	50/60 Hz
TOWER		
Hub height:	50/60/70 m	80/90/100 m
Type:	Lattice	Tubular
Corrosion protection:	Galvanized	Painted

Table 6: 350 Kw & 2100kw Machine Details.

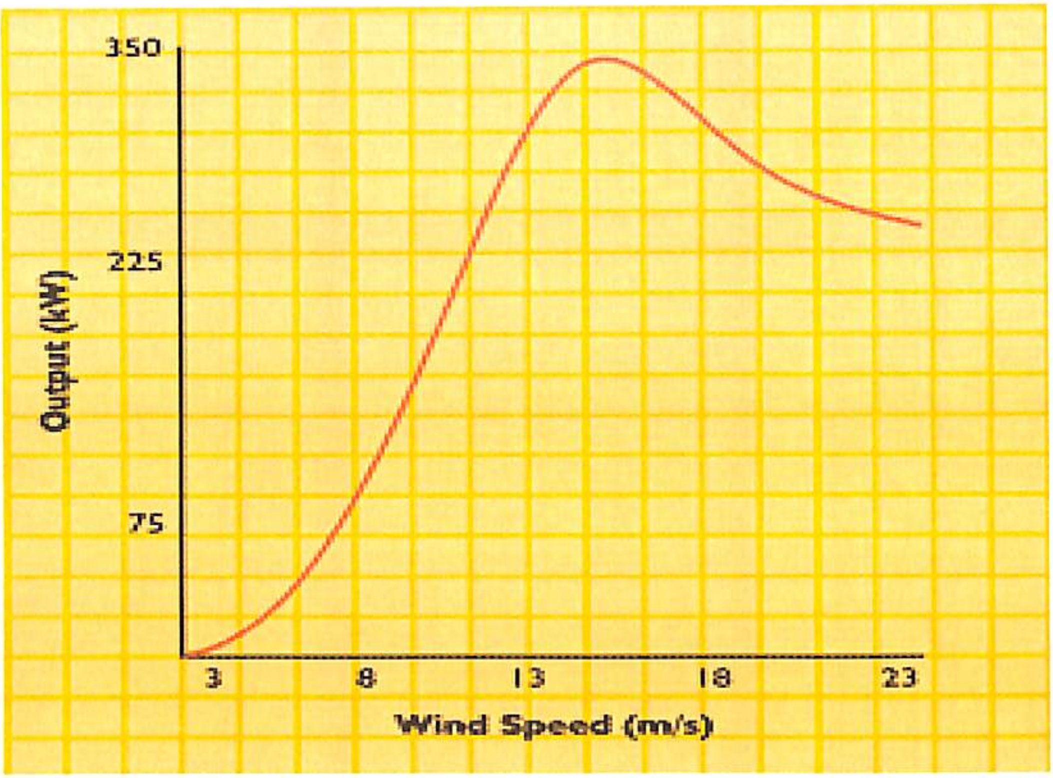


Figure 9: Power Curve of 350 kW Machine

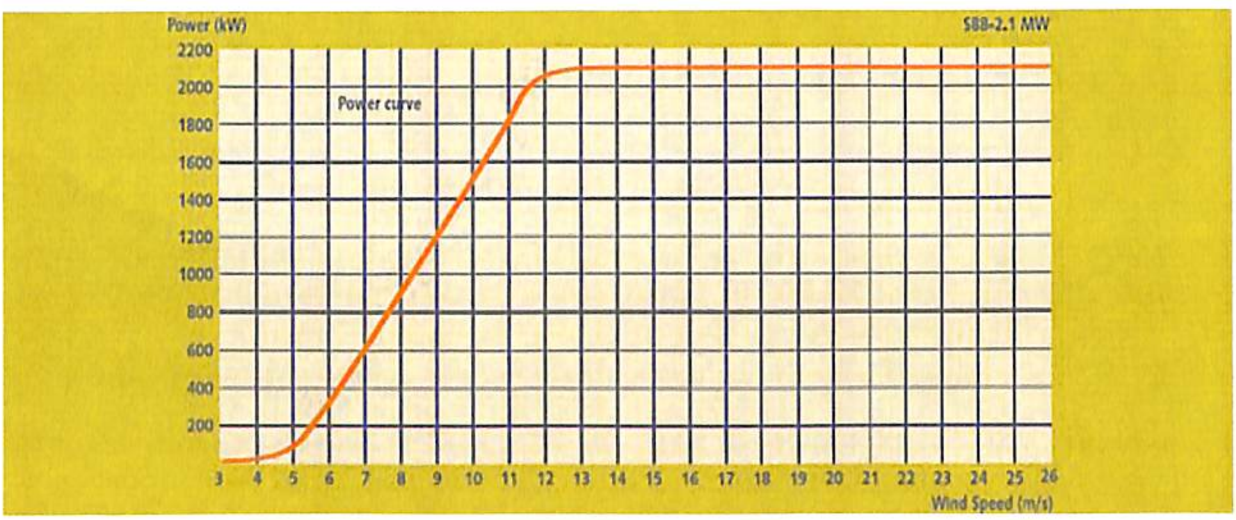


Figure 10: Power Curve of 2100 kW Machine

WAsP predictions are based on the observed wind climate at the met. station site; i.e. time-series data of measured wind speeds and directions over one or several years that have been binned into intervals of wind direction (the wind rose) and wind speed (the histograms). Therefore, the quality of the measurement data has direct implications for the quality of the WAsP predictions of wind climate and annual energy production. In short, the wind data must be accurate, representative and reliable.

The wind data analysis and calculation of the observed wind climate may conveniently be done using the WAsP Climate Analyst. Whether the wind data are measured by the organisation carrying out the analysis or by a third party, a number of data characteristics must be known, such as: the data file structure, time stamp definition, data resolution (discretisation), calm thresholds, and any flag values used for calms and missing data. This information may be collected by filling out a WAsP Data Description Form; in the subsequent analysis all input values in the Climate Analyst protocol (import filter) editor should correspond to the data specifications.

The observed wind climate (OWC) should represent as closely as possible the long-term wind climate at anemometer height at the position of the meteorological mast. Therefore, an integer number of full years must be used when calculating the OWC, in order to avoid any seasonal bias. For the same reason, the data recovery rate must be quite high (> 90-95%) and any missing observations should preferably be distributed randomly over the entire period.

Wind data series from prospective wind farm sites rarely cover more than one or a few full years, so they must be evaluated within context of the long-term wind climate, in order to avoid any long-term or climatological bias. Comparisons to near-by, long-term meteorological stations or to long-term modelled data for the area can be made using simple (or complicated) measure-correlate-predict (MCP) techniques.

WAsP uses Weibull distributions to represent the sector-wise wind speed distributions and the emergent distribution for the total distribution. The difference between the fitted (and emergent) and the observed wind speed distributions should therefore be small: less than about 1% for mean power density (which is used for the Weibull fitting) and less than a few per cent for mean wind speed.

The topographical inputs to WAsP are given in the vector map, which can contain height contour lines, roughness change lines and lines with no attributes (say the border of the wind farm site). In addition, nearby sheltering obstacles may be specified in a separate obstacle group member and shown on the map.

Map coordinates and elevations must be specified in meters and given in a Cartesian map coordinate system. The map projection and datum should be specified in the Map Editor so this information is embedded in the map file. All metric coordinates used in the WAsP workspace should of course refer to the same map coordinate system. Obstacle distances and dimensions must likewise be given in meters.

The Map Editor can do the transformation from one map coordinate system to another; the Geo-projection utility program in the Tools menu can transform single points, lists of points and lists of points given in an ASCII data file.

The elevation map contains the *height contours* of the terrain. These may be digitised directly from a scanned paper map - as described in the Map Editor Help facility - or may be obtained from a database of previously digitised height contours, established by e.g. the Survey and Cadastre of a country or region. Alternatively, they can also be generated from gridded or random spot height data using contouring software.

The elevation map should extend at least several (2-3) times the horizontal scale of significant orographic features from any site – met. mast, reference site, turbine site or resource grid point. This is typically 5-10 km. A widely cited rule for the minimum extent of the map is max($100\times h$, 10 km); this is usually sufficient for the elevation map.

The accuracy and detail of the elevation map are most critical close to the site(s), therefore it is recommended to add spot heights within the wind farm site and close to the met. mast(s); one may also interpolate extra contours if necessary. The contour interval should be small (≤ 10 m) close to calculation sites, whereas the contour interval can be larger further away from the calculation sites (≥ 10 m).

Non-rectangular maps (circular, elliptic, irregular) are allowed and sometimes preferred in order to reduce the number of points in the map, while at the same time retaining model calculation accuracy.

The final elevation map should be checked for outliers and errors by checking the range of elevations in the map. An elevation map generated from a gridded data set could also be compared to a scanned paper map of the same area.

WAsP analysis is the transformation of the wind climate observed at a met. Station to the generalised (also called regional) wind climate, the wind atlas member in WAsP.

The wind atlas may be dynamic, as shown in Figure 13 with an open book, or static, if the wind atlas data set is simply a previously calculated data file. The dynamic wind atlas may contain a map, which is then specific to the met. Station site. The met. Station can contain an obstacle group, which is then specific to the met. Mast. The map and obstacle group should of course correspond to the conditions in the time period when the wind measurements were taken.

A wind farm consists of a number of wind turbines, which may be arranged in turbine site groups. The wake model is invoked automatically for the wind turbines in a wind farm; however, two or more 1st level wind farms in the WAsP hierarchy do not interact. So, all the wind turbines that should be part of a given wake calculation must be in the same (1st level) wind farm.

The wind resource grid corresponds to a regular grid of wind turbines, but no wake calculations are done. The results for each site corresponds to the free-stream or gross values. Remember, that the map requirements mentioned above should be fulfilled for all the sites in a resource grid.

Date/Time	Anem 90m	Anem 50m	Vane 50m	Temp	Pressure
01-01-2010 00:00	9.171	7.951	84.2	14.9	938
01-01-2010 01:00	9.44	8.184	88.1	15.2	939
01-01-2010 02:00	9.126	7.912	91.8	17.6	939
01-01-2010 03:00	8.409	7.29	97.6	21.5	940
01-01-2010 04:00	8.887	7.704	107.8	25.3	940
01-01-2010 05:00	8.529	7.394	117.4	28.1	940
-	-	-	-	-	-
-	-	-	-	-	-
27-09-2011 00:00	3.51	3.043	288.7	19.6	937
27-09-2011 01:00	3.301	2.862	286.3	20	938
27-09-2011 02:00	3.406	2.952	283.5	21.8	938
27-09-2011 03:00	3.6	3.121	282.6	24.3	939
27-09-2011 04:00	3.645	3.159	275.6	28.3	939
27-09-2011 05:00	4.212	3.652	264.5	29.6	938
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
09-03-2012 18:00	8.409	7.29	332.6	16.7	935
09-03-2012 19:00	7.812	6.772	342.9	15.7	934
09-03-2012 20:00	7.707	6.682	353.9	14.8	933
09-03-2012 21:00	7.767	6.733	3.8	14.1	933
09-03-2012 22:00	7.827	6.785	14.5	13.4	933
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
25-10-2013 01:00	8.245	7.148	24.8	19.7	935
25-10-2013 02:00	7.588	6.578	24.5	21.3	936
25-10-2013 03:00	7.05	6.112	26.9	22.9	936
25-10-2013 04:00	7.214	6.254	28.7	24.7	936
25-10-2013 05:00	7.334	6.358	26.7	26.4	936
25-10-2013 06:00	7.229	6.267	18	27.9	935
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
31-12-2014 14:00	5.96	5.167	296.9	18.8	936
31-12-2014 15:00	5.482	4.752	310.2	18.6	936
31-12-2014 16:00	5.243	4.545	323.2	18.3	936
31-12-2014 17:00	5.138	4.454	331.9	17.9	936
31-12-2014 18:00	5.198	4.506	336.6	17.7	935

Table 7: Time Series data of Vankuswade for the period of 2010-2014 (Source: MERA, ERA-I etc.)

Month	2010	2011	2012	2013	2014	Average@50m
Jan	4.78	4.73	5.57	4.57	4.73	4.88
Feb	4.89	4.78	5.56	5.18	5.63	5.21
Mar	5.78	5.77	5.96	5.74	5.11	5.67
Apr	5.84	4.84	6.15	5.90	5.15	5.57
May	7.08	6.42	7.46	7.15	5.21	6.66
Jun	7.58	9.91	8.37	9.63	8.33	8.77
Jul	10.19	9.33	10.23	11.58	11.38	10.54
Aug	8.70	8.98	9.89	9.17	8.12	8.97
Sep	6.27	7.24	7.73	5.86	6.83	6.78
Oct	4.86	4.63	4.98	5.08	4.19	4.75
Nov	4.76	6.20	4.34	4.63	5.42	5.07
Dec	4.92	5.67	5.12	4.91	4.98	5.12
Average at 50m	**6.32**	**6.55**	**6.79**	**6.63**	**6.26**	**6.51**

Table 8: Average Monthly Wind Speed of Vankuswade at 50m Height (Source: MERA, ERA-I etc.)

Month	2010	2011	2012	2013	2014	Average
Jan	5.52	5.46	6.42	5.27	5.46	5.63
Feb	5.64	5.51	6.41	5.98	6.5	6.01
Mar	6.66	6.65	6.88	6.62	5.89	6.54
Apr	6.74	5.58	7.09	6.8	5.94	6.43
May	8.17	7.41	8.6	8.25	6.01	7.69
Jun	8.74	11.44	9.66	11.11	9.61	10.11
Jul	11.76	10.76	11.8	13.36	13.12	12.16
Aug	10.04	10.36	11.41	10.57	9.36	10.35
Sep	7.23	8.35	8.92	6.76	7.87	7.83
Oct	5.61	5.34	5.74	5.86	4.83	5.48
Nov	5.49	7.16	5.01	5.34	6.25	5.85
Dec	5.67	6.54	5.9	5.66	5.75	5.9
Average	**7.29**	**7.56**	**7.83**	**7.65**	**7.22**	**7.51**

Table 9: Average Monthly Wind Speed of Vankuswade at 90m Height (Source: MERA, ERA-I etc.)

Wind data are useful in the early stage of the siting process. These data represent records of actual wind conditions, so they must be evaluated before the windiest areas of a particular region are sought. Unfortunately, most historical wind data were not collected for wind energy assessment purposes. Thus the results often represent the mean conditions near population centers in relatively flat terrain or low elevation areas. Their primary benefit to the analyst, therefore, is to provide a general description of the wind resource within the analysis area, not to pinpoint the windiest locales.

Month	2010	2011	2012	2013	2014	Average
Jan	21.44	19.64	20.28	22.12	20.44	20.78
Feb	23.40	22.84	26.09	26.65	22.00	24.21
Mar	29.79	29.22	29.20	30.25	27.86	29.26
Apr	33.24	29.72	32.63	31.62	31.96	31.83
May	31.16	28.81	31.21	30.80	29.92	30.38
Jun	26.14	25.29	27.44	24.94	26.96	26.15
Jul	23.90	24.10	24.05	23.26	24.31	23.92
Aug	23.74	23.45	23.68	23.18	23.69	23.55
Sep	23.93	23.52	23.59	23.83	23.76	23.73
Oct	23.86	23.74	23.55	23.53	23.64	23.66
Nov	22.96	22.39	21.90	21.97	21.70	22.18
Dec	19.89	20.41	20.68	18.75	19.30	19.80
Average	**25.29**	**24.43**	**25.34**	**25.06**	**24.63**	**24.95**

Table 10: Monthly Average Temperature at Vankusavade Site.

Month	2010	2011	2012	2013	2014	Average
Jan	939.84	937.71	938.14	938.97	939.55	938.84
Feb	938.51	937.12	936.69	937.90	937.70	937.58
Mar	937.62	936.27	936.49	937.13	937.72	937.05
Apr	935.89	935.32	935.29	935.16	936.35	935.60
May	933.33	934.82	934.50	934.02	934.94	934.32
Jun	932.90	932.00	932.70	931.67	932.49	932.35
Jul	932.44	931.95	931.99	931.77	932.74	932.18
Aug	932.61	932.25	933.43	933.38	933.44	933.02
Sep	934.04	933.91	934.58	933.87	934.89	934.26
Oct	934.65	936.55	937.07	936.01	937.65	936.39
Nov	936.39	937.89	937.46	938.13	938.73	937.72
Dec	936.23	937.98	938.12	938.55	938.94	937.96
Average	**935.35**	**935.30**	**935.54**	**935.54**	**936.26**	**935.60**

Table 11: Monthly average pressure at Vankusavade Site.

Site-Specific measurements using anemometers are considered from most reliable estimates of the wind resources for a project. However, they can be quite costly and require from one to several years to complete. Other methods also exist where large scale computer weather models are created to extrapolate wind conditions at a specific site from historical data. Many times these computer models of a site's wind resource can be less expensive than taking meteorological readings for a year or more. As scientists and lending institutions are beginning to understand weather modeling and the wind industry better this method of resource assessment is becoming more accepted by lenders, but sometimes they may require a combination of site specific meteorological measurements coupled with computer models from long-term weather data for validation of conditions at the site.

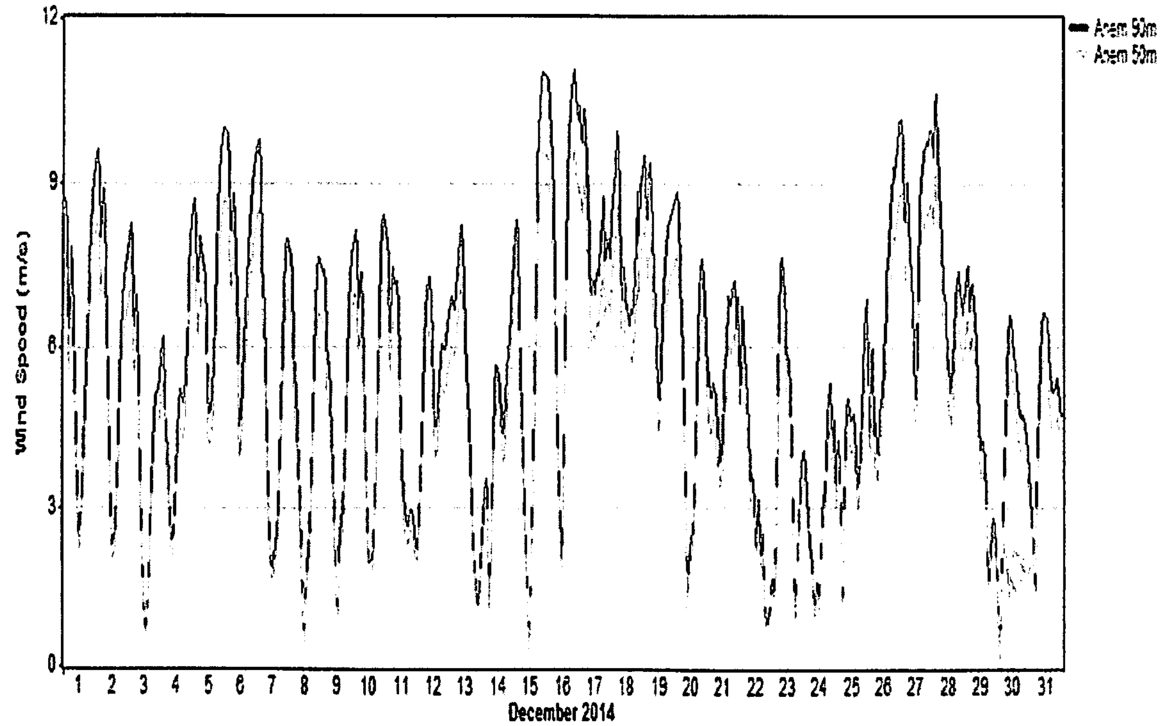


Figure 11: Wind Speed Graph at 50m and 90m height.

Wind speed data are the most important indicator of a site's wind energy resource. Multiple measurement heights are encouraged for determining a site's wind shear characteristics, conducting turbine performance simulations at several turbine hub heights, and for backup. For accurate measurement of wind speed at different level sensors are placed to record the wind. Here there are five anemometers are used to record the data. Five anemometers are positions are 2 Nos. at 90m height, 2 at 70 meter of height & 1 at 50 meter of height.

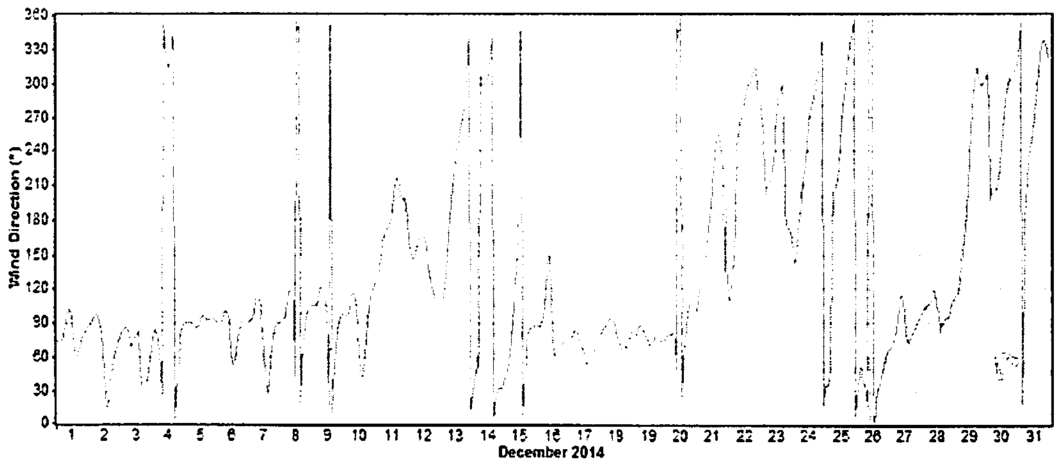


Figure 12: Wind Direction graph at 50m and 90m height.

To define the prevailing wind direction(s), wind vanes should be installed at all significant monitoring levels. Wind direction frequency information is important for identifying preferred terrain shapes and orientations and for optimizing the layout of wind turbines within a wind farm.

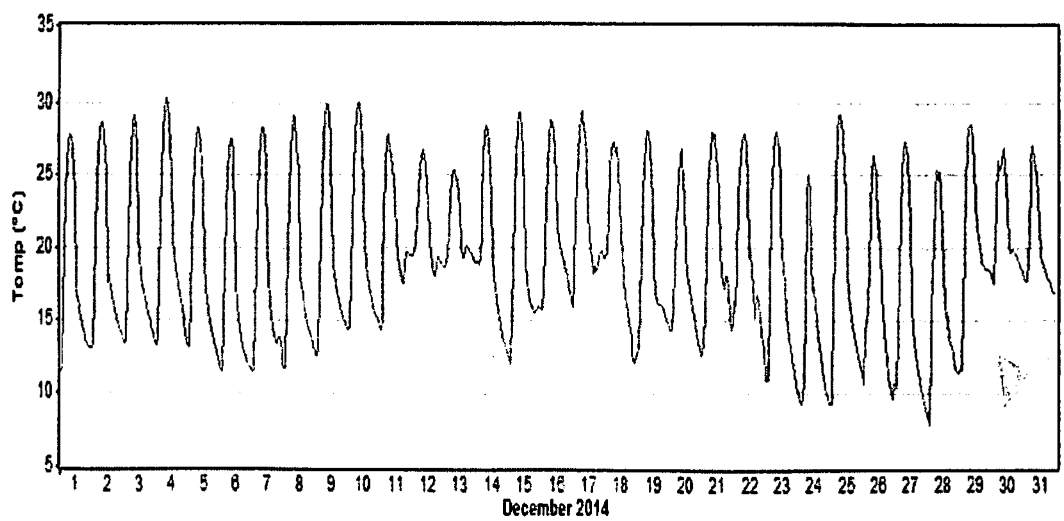


Figure 13: Temperature graph

Air temperature is an important descriptor of a wind farm's operating environment and is normally measured either near ground level (2 to 3 m), or near hub height. In most locations the average near ground level air temperature will be within 1°C of the average at hub height. It is also used to calculate air density, a variable required to estimate the wind power density and a wind turbine's power output.

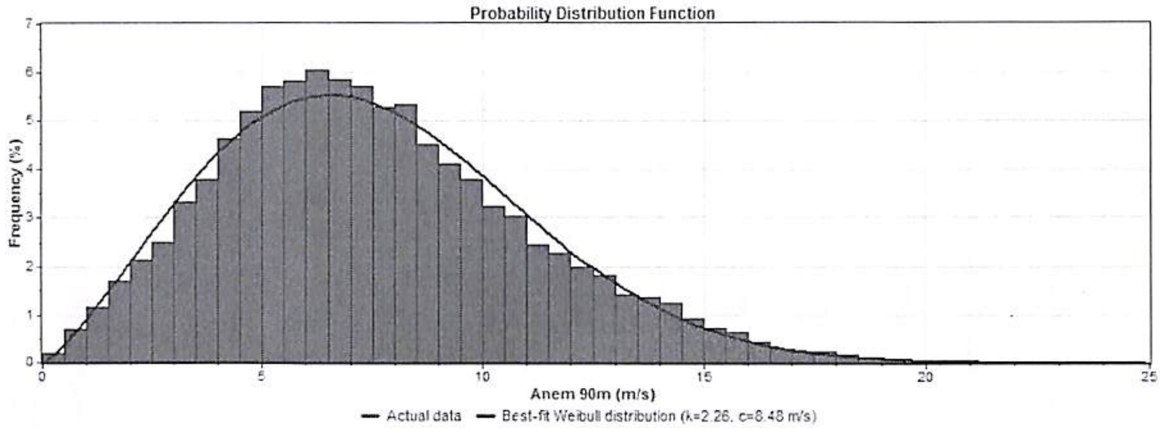


Figure 14: Frequency v/s Anemometer graph at 90m height.

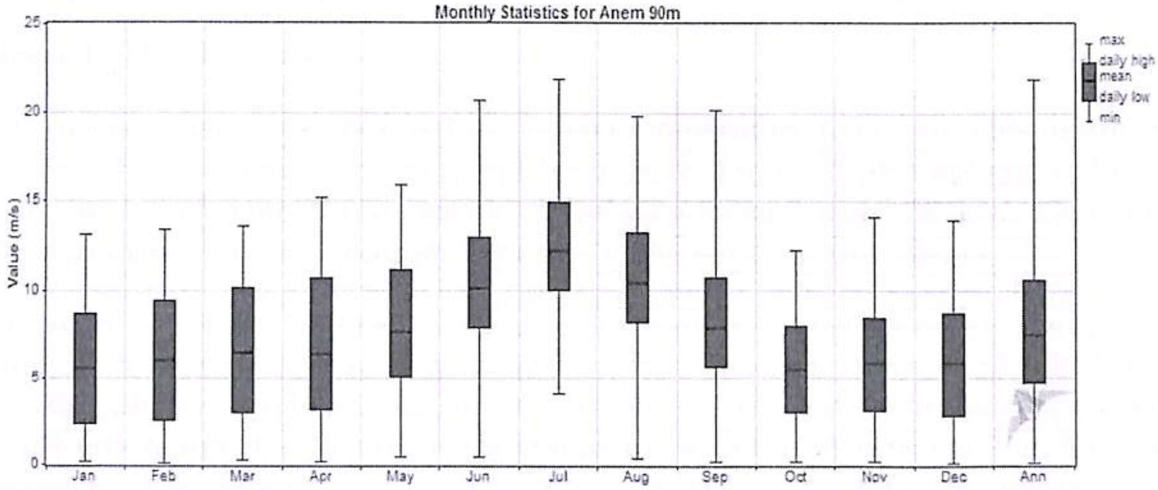


Figure 15: Monthly Statics for anemometer at 90m height.

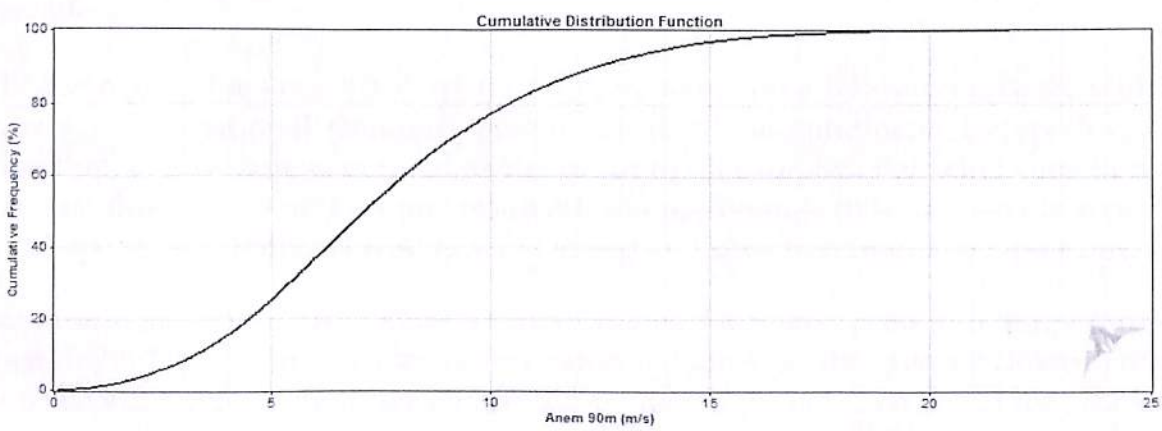


Figure 16 : Cumulative Distribution function graph at 90m height

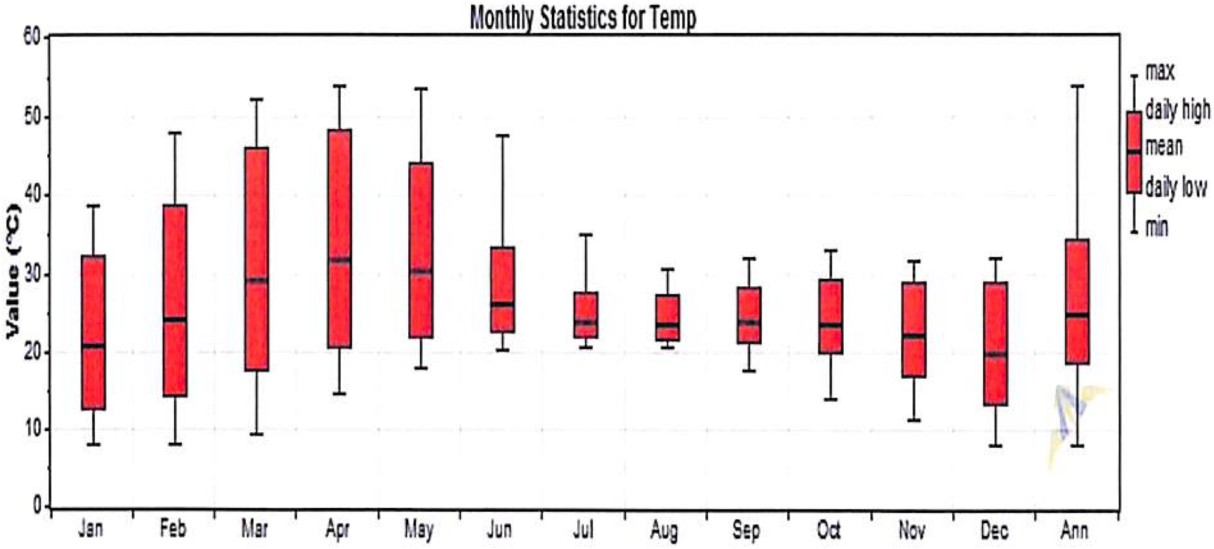


Figure 17: Monthly statics of Temperature.

This measurement, also referred to as delta temperature (ΔT), provides information about turbulence and historically has been used to indicate atmospheric stability. A matched set of temperature sensors should be located near the lower and upper measurement levels without interfering with the wind measurements.

Barometric pressure is used with air temperature to determine air density. It is difficult to measure accurately in windy environments because of the dynamic pressures induced when wind flows across an instrument enclosure. An indoor or office environment is a preferred setting for a pressure sensor. Therefore, most resource assessment programs do not measure barometric pressure and instead use data taken by a regional National Weather Service station that is then adjusted for elevation.

The average value are calculated for all parameters on a ten-minute basis, which is now the international standard period for wind measurement. Except for wind direction, the average is defined as the mean of all samples. For wind direction, the average should be a unit vector (resultant) value. Average data are used in reporting wind speed variability, as well as wind speed and direction frequency distributions.

Maximum and minimum values are determined for wind speed and temperature at least daily. The maximum (minimum) value is defined as the greatest (lowest) one or two second reading observed within the preferred period. The coincident direction corresponding to the maximum (minimum) wind speed should also be recorded.

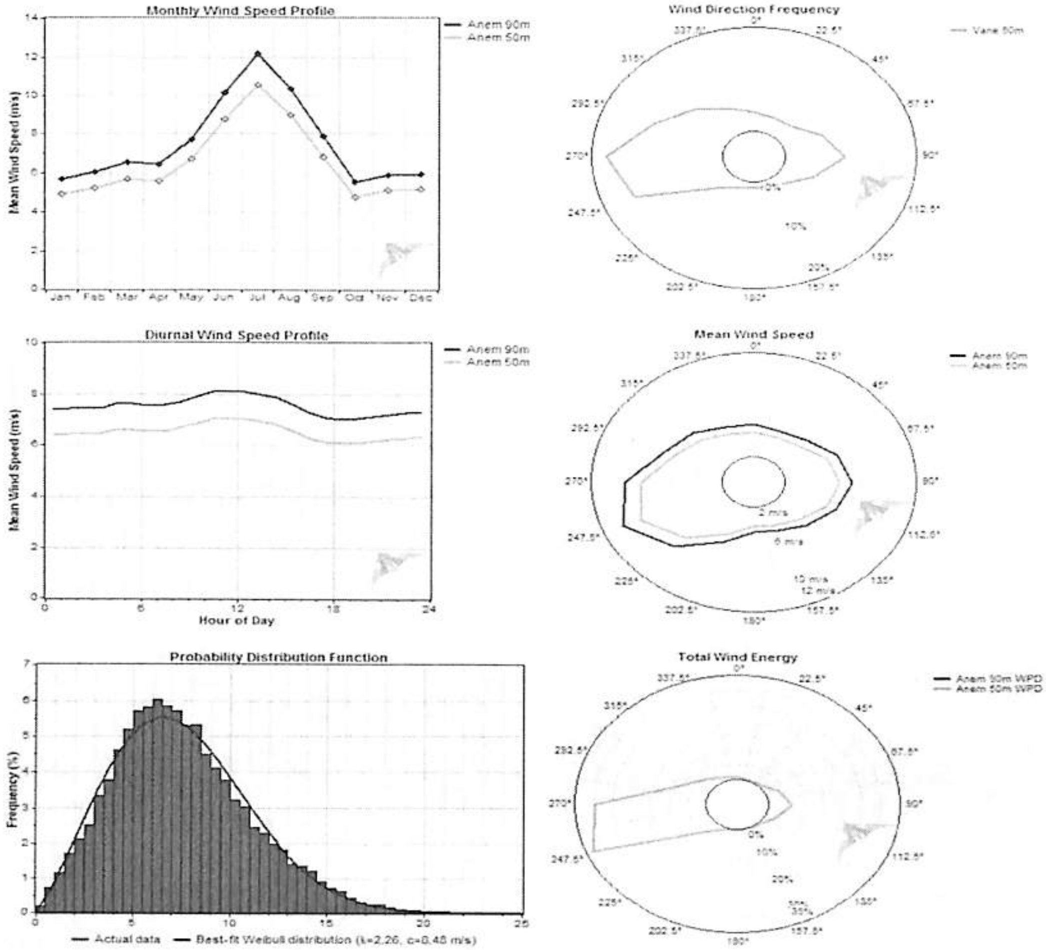


Figure 18: Wind Speed and Direction Graph.

A wind vane is used to measure wind direction. The most familiar type uses a fin connected to a vertical shaft. The vane constantly seeks a position of force equilibrium by aligning itself into the wind. Most wind vanes use a potentiometer type transducer that outputs an electrical signal relative to the position of the vane. This electrical signal is transmitted via wire to a data logger and relates the vane's position to a known reference point (usually true north). Therefore, the alignment (or orientation) of the wind vane to a specified reference point is important.

The data logger provides a known voltage across the entire potentiometer element and measures the voltage where the wiper arm contacts a conductive element. The ratio between these two voltages determines the position of the wind vane. This signal is interpreted by the data logger system, which uses the ratio (a known multiplier) and the offset (a known correction for any misalignment to the standard reference point) to calculate the actual wind direction. Electrically the linear potentiometer element does not cover a full 360°. This "open" area is the deadband of the wind vane. When the wiper arm is in this area, the output signal is random. Some manufacturers compensate for the deadband in their data logger software to prevent random signals. Therefore, the deadband area should not be aligned into or near the prevailing wind direction.

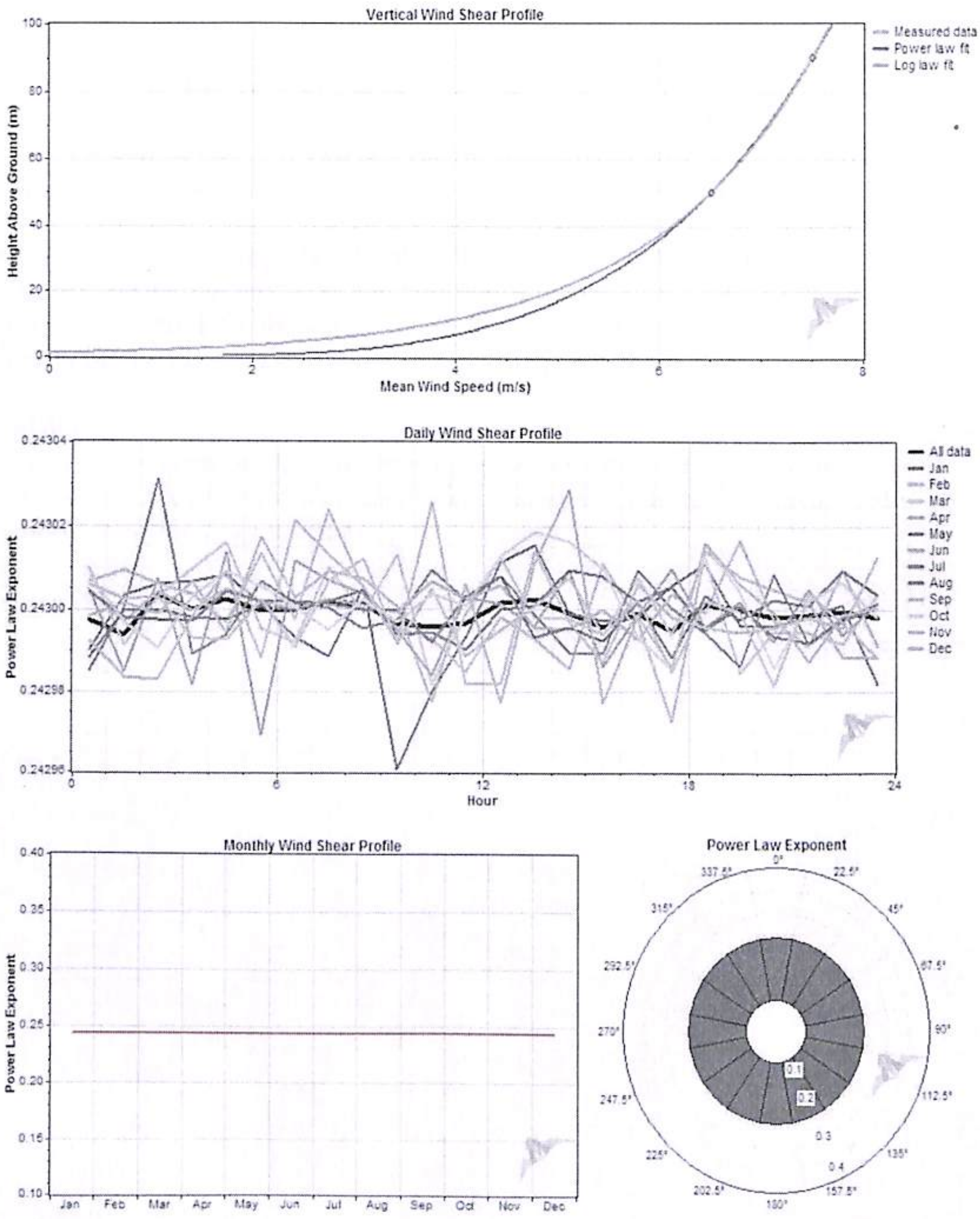


Figure 19 : Wind Shear Graph for 50m & 90m height.

The wind-climatological input to WAsP is given in the observed wind climate, which contains the wind direction distribution (wind rose) and the sector-wise distributions of mean wind speed (histograms). The observed wind climate file should also contain the wind speed sensor (anemometer) height above ground level in metres and the geographical coordinates of the mast site: latitude and longitude. The latitude is used by WAsP to calculate the Coriolis parameter.

The difference between a WAsP prediction and the correct value is the modelling error. In general, the correct value is not known exactly, even when predicting another cup anemometer or a wind turbine, where the wind speed or production data are known. This is because these numbers are also determined with some uncertainty. However, they may be close estimates of the correct value.

Therefore, the modelling uncertainty should be estimated. The uncertainty is an estimate of the likely limits to the modelling error, and it is composed of all the uncertainties related to the entire modelling procedure. The different uncertainty factors tend to be random in nature and are often not correlated.

In addition, the modelling results may be biased. The biases represent any systematic deviations of the modelling result from the correct value. The biases should also be estimated and possibly corrected for where the 'mean value' could correspond to a WAsP prediction.

CHAPTER 4

Findings and Analysis

In the present work an attempt is made to find out the comparison between the total energy generation of the lower capacity Wind Turbine in the existing site and the higher capacity Wind Turbine which can be installed in the same site. The actual generation is recorded in the controller of the lower capacity Wind Turbine and the wind data recorded in the controller is used to calculate the estimated energy generation of the Repowered Wind Turbine. The Pressure is recorded in the Data Logger of the nearby met mast installed in the existing site.

The Anemometers, Wind Vanes, Temperature Sensor & Pressure sensor is mounted on the met mast at a specific height above the ground level. The met masts are installed in the sites which are to be assessed for the feasibility check to install the Wind Turbine Generators. A suitable point is marked and the met mast is installed. The wind speed, wind direction, temperature and pressure are recorded in the Data Logger which is powered by means of a Solar Panel (135W) and a battery.

A typical ambient air temperature sensor is composed of three parts: the transducer, an interface device, and a radiation shield. The transducer contains a material element (usually nickel or platinum) with a relationship between its resistance and temperature. Thermistors, resistance thermal detectors (RTDs), and semiconductors are common element types recommended for use. The resistance value is measured by the data logger (or an interface device), which uses a known equation to calculate the actual air temperature. The transducer is housed within a radiation shield to protect it from direct solar radiation. A common radiation shield is the Gill type, multi-layer, passive shield.

The propeller anemometer is especially suited for measuring the vertical wind component. It consists of a propeller mounted on a fixed vertical arm. The sensor requires a transducer that can electrically relate both the rotational direction (indicative of upward or downward motion) and the speed of the propeller. This signal is usually a polarized DC voltage that is interpreted by the data logging system (or interface device). The polarity indicates rotational direction; the magnitude indicates rotational speed. The data logger then uses a known multiplier and offset to calculate the actual vertical wind speed.

Data loggers (or data recorders) come in a variety of types and have evolved from simple strip chart recorders to integrated electronic on-board cards for personal computers. Many manufacturers offer complete data logging systems that include peripheral storage and data transfer devices.

Figure 20: Wind Mast & Temperature Sensors.

Equipment Used	Specification
Anemometer	Range: 0.3 to 50m/s Accuracy : +/- 0.2 m/s
Wind Vane	Range: 0 to 360° Accuracy: +/- 1°
Temperature Sensor	NRG 110S Range: -40° C to 52.5° C Accuracy: +/- 1.11° C
Barometric Pressure Sensor	NRG BP20 Range: 15 kPa to 115 kPa Accuracy: +/- 1.5 kPa

Every electronic data logger has some type of operating software that includes a small internal data buffer to temporarily store incremental (e.g., once per second) data. Internal algorithms use this buffer to calculate and record the desired data parameters. The data values are stored in one of two memory formats. Some data loggers have a fixed internal program that cannot be altered; others are user-interactive and can be programmed for a specific task. This program, and the data buffer, are usually stored in volatile memory. Their drawback is that they need a continuous power source to retain data. Data loggers that incorporate the use of internal backup batteries or use non-volatile memory are available. They are preferred because data cannot be lost due to low battery voltage.

Descriptive Statistics

The actual generation details are recorded from the controller of the Wind Turbine and the temperature & pressure details are taken from the Data Logger. Also the wind speed and the wind direction details are recorded and are used for the calculation of the estimated energy generation of the repowered turbine.

1 anemometer and 1 wind vane is placed at a height of 90m & 50m respectively. The readings of the wind speed and the wind direction are recorded at an interval of 10 minutes. The temperature sensor and pressure sensor are mounted at a height of 65m. The readings of the temperature and the pressure are also recorded at an interval of 10 minutes.

The data is measured in the data logger with a sampling interval of 2s, and recorded at a fixed average interval of 10 min. Each data interval is time stamped. The data logger is mounted inside the metal shelter box and is powered by Solar PV – Battery. It also has an internal battery for the real time clock backed with the leap year correction. The storage medium is 16 MB Multimedia Card (MMC) and the maximum data storage is 664 days.

Remote transfer requires a telecommunication system to link the in-field data logger to the central computer. The communications system may incorporate direct wire cabling, modems, phone lines, cellular phone equipment, or RF telemetry equipment, or some combination thereof. An advantage of this method is that you can retrieve and inspect data more frequently than you can conduct site visits. This allows you to promptly identify and resolve site problems. Disadvantages include the cost and time required to purchase and install the equipment. This may prove worthwhile in the long term if data monitoring problems can be spotted early and quickly remedied.

There are two basic remote data retrieval types: those that require the user to initiate the communications (call out) and others that contact the central computer via the link (phone home), both at prescribed intervals. The first type requires you to oversee the telecommunication operation. You initiate communications to the in-field data logger, download the data, verify data transfer, and erase the logger memory. Some call-out data logger models are compatible with computer-based terminal emulation software packages with batch calling features. Batch calling automates the data transfer process by initiating the modem's dialing sequence at a prescribed interval to sequence through the various monitoring sites. Batch programs can also be written to include data verification routines. You should consult with data logger manufacturers to determine compatibility of their equipment with this beneficial feature.

The phone home type data logger automatically calls the central computer to transfer data. A single personal computer can communicate with a larger number of sites in the call out mode compared to the phone home mode. In the latter case, enough time must be allotted for each call to account for a normal data transfer time and several retries for unsuccessful transfer attempts.

Cellular phone data loggers are gaining popularity today for their ease of use and reasonable cost. You need to determine the minimum signal strength requirements of the data logger and relate that to actual field testing when researching this type of system. A portable phone can be used at the proposed site to determine the signal strength and the cellular company. Locations that experience weak signal strengths may be improved by selecting an antenna with higher gain. Guidelines for establishing a cellular account are usually provided by the data logger supplier. Work closely with your supplier and cellular telephone company to resolve any questions before you begin to monitor. To avoid conflicts with local or regional cellular network use, you should schedule data transfers during off-peak hours. This often has an economic advantage, as many cellular networks offer discounts for volume off-peak usage. In addition, the ability to perform frequent data transfer will maximize your data recovery.

The outcome values from the methods indicate that the repowering a windfarm is feasible with a significant addition in the energy generation as compared to the old turbines, the investment is considerably high but the return on investment and the payback period is less.

The present section deals with the methodology of the data measurement. The data recorded is taken from the data logger and used for calculating the energy output of the new higher capacity wind turbine. We have recorded the wind data for a period of 1 year (Jan '10 to Jan '15) and tabulated the results. Next chapter deals with the results and discussions for the wind variation and the economics of repowering a windfarm with the existing turbines.

CHAPTER 5

Interpretation of Results

The recorded parameters of the wind are downloaded from the data logger. The parameters are the wind speed, wind direction, temperature and pressure. The data along with the time stamp is as given in the below table.

Date/Time	Anem 90m	Anem 50m	Vane 50m	Temp	Pressure
01-01-2010 00:00	9.171	7.951	84.2	14.9	938
01-01-2010 01:00	9.44	8.184	88.1	15.2	939
01-01-2010 02:00	9.126	7.912	91.8	17.6	939
01-01-2010 03:00	8.409	7.29	97.6	21.5	940
01-01-2010 04:00	8.887	7.704	107.8	25.3	940
-	-	-	-	-	-
-	-	-	-	-	-
27-09-2011 00:00	3.51	3.043	288.7	19.6	937
27-09-2011 01:00	3.301	2.862	286.3	20	938
27-09-2011 02:00	3.406	2.952	283.5	21.8	938
27-09-2011 03:00	3.6	3.121	282.6	24.3	939
27-09-2011 04:00	3.645	3.159	275.6	28.3	939
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
09-03-2012 18:00	8.409	7.29	332.6	16.7	935
09-03-2012 19:00	7.812	6.772	342.9	15.7	934
09-03-2012 20:00	7.707	6.682	353.9	14.8	933
09-03-2012 21:00	7.767	6.733	3.8	14.1	933
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
25-10-2013 01:00	8.245	7.148	24.8	19.7	935
25-10-2013 02:00	7.588	6.578	24.5	21.3	936
25-10-2013 03:00	7.05	6.112	26.9	22.9	936
25-10-2013 04:00	7.214	6.254	28.7	24.7	936
25-10-2013 05:00	7.334	6.358	26.7	26.4	936
25-10-2013 06:00	7.229	6.267	18	27.9	935
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
31-12-2014 14:00	5.96	5.167	296.9	18.8	936
31-12-2014 15:00	5.482	4.752	310.2	18.6	936
31-12-2014 16:00	5.243	4.545	323.2	18.3	936
31-12-2014 17:00	5.138	4.454	331.9	17.9	936
31-12-2014 18:00	5.198	4.506	336.6	17.7	935

Table 12: Wind data sample for 4 years

The sampling rate of the wind parameter measurement is 10 sec, and the average data

Recording interval is 10 minutes. In the above table the data is considered for a period Of 1 year (Jan - 2010 to Dec - 2014).

After the data is downloaded, the graph of the variation in the wind speeds is plotted which is as shown below.

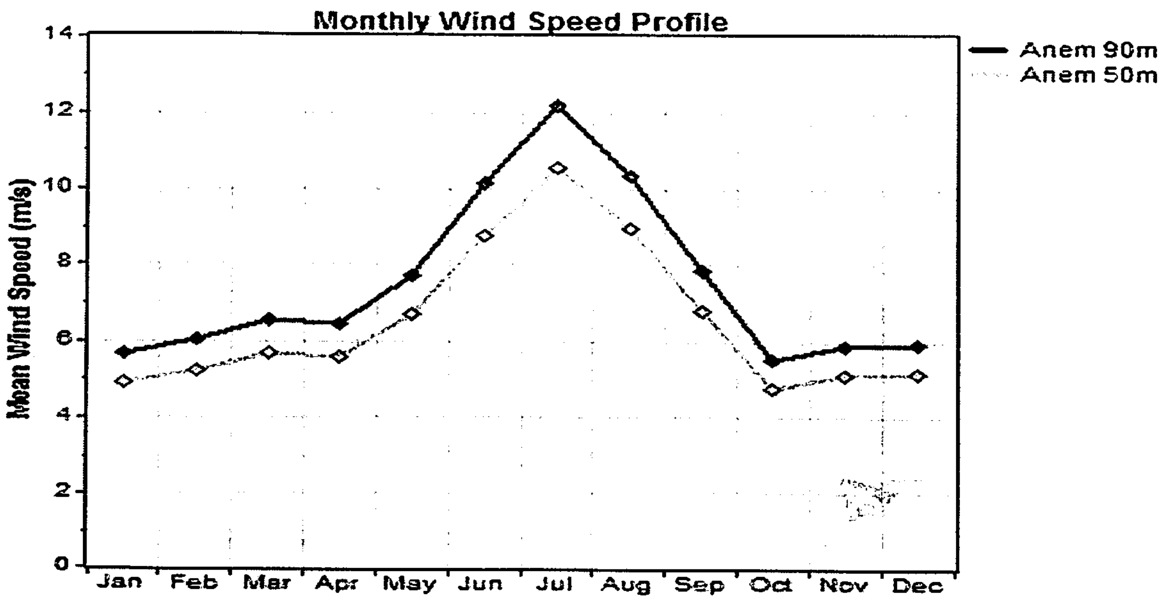


Figure 21: Wind Variation over a period of 1 year (Monthly Average)

From the average monthly wind variation, it is observed that the months May - Sept is the high wind season & Oct - Apr is the low wind season. The daily average variations in the temperature & pressure is also shown in the below graphs.

Based on the wind data recorded, a frequency distribution power output from the turbine is calculated.

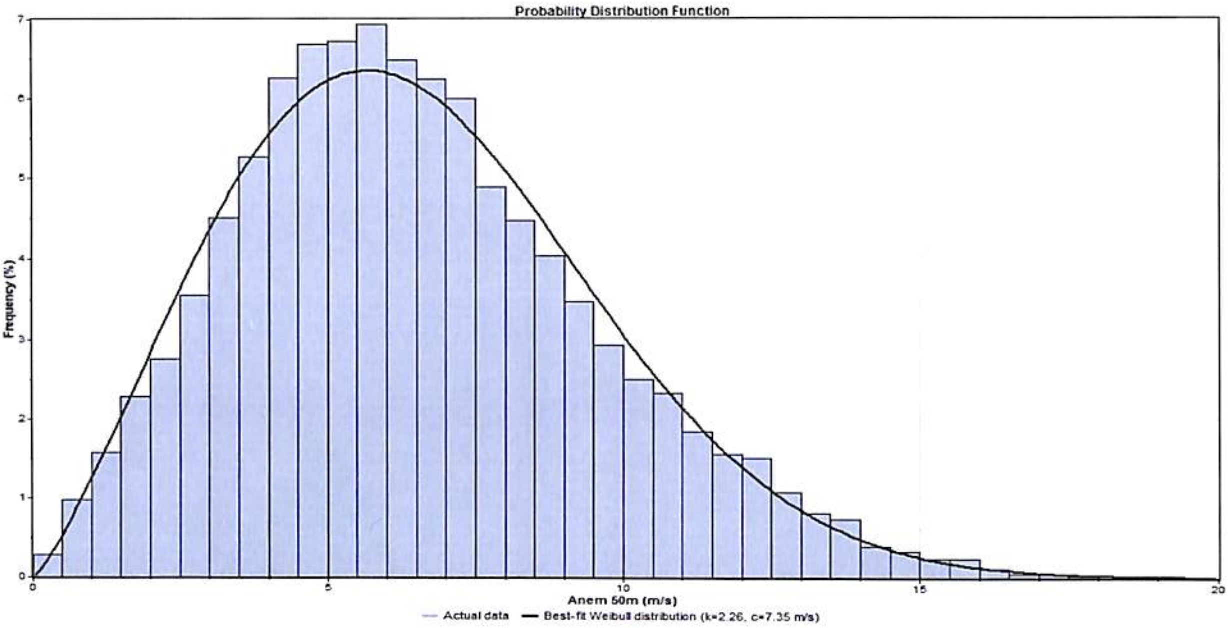


Figure 22: Frequency vs Anemometer distribution graph of Vankusavade site at 50m height.

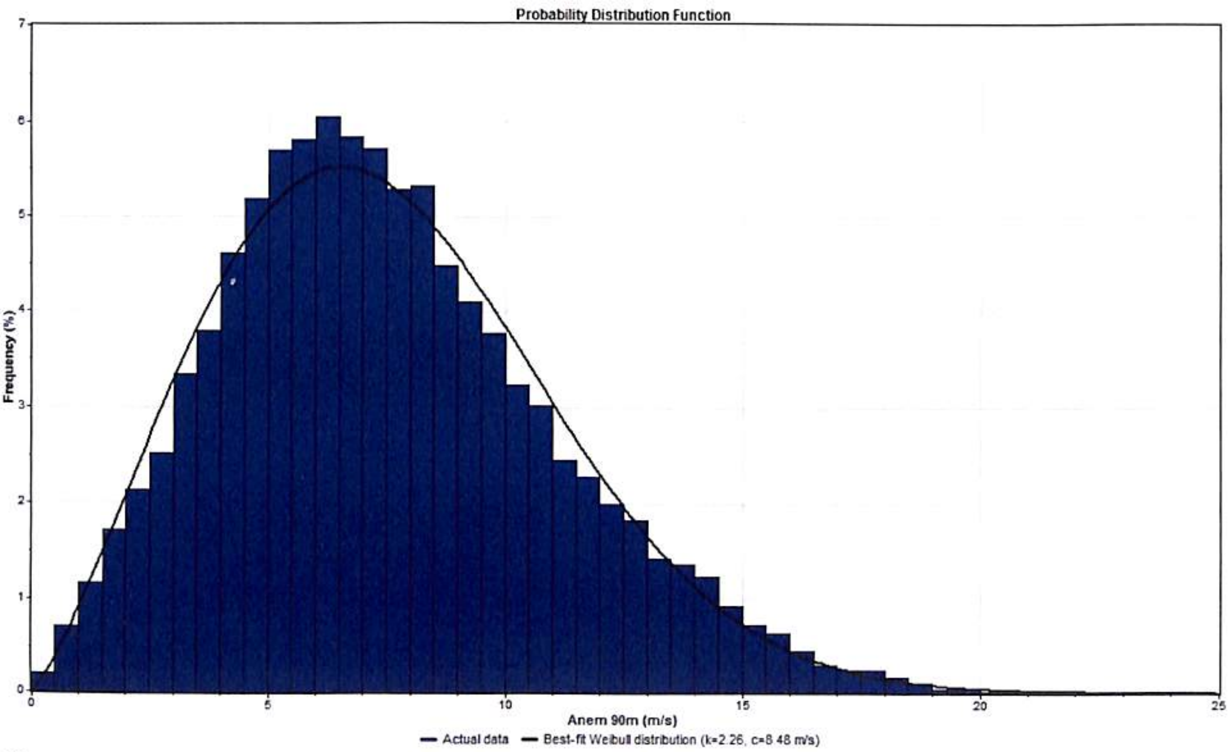


Figure 23: Frequency vs Anemometer distribution graph of Vankusavade site at 90 m height.

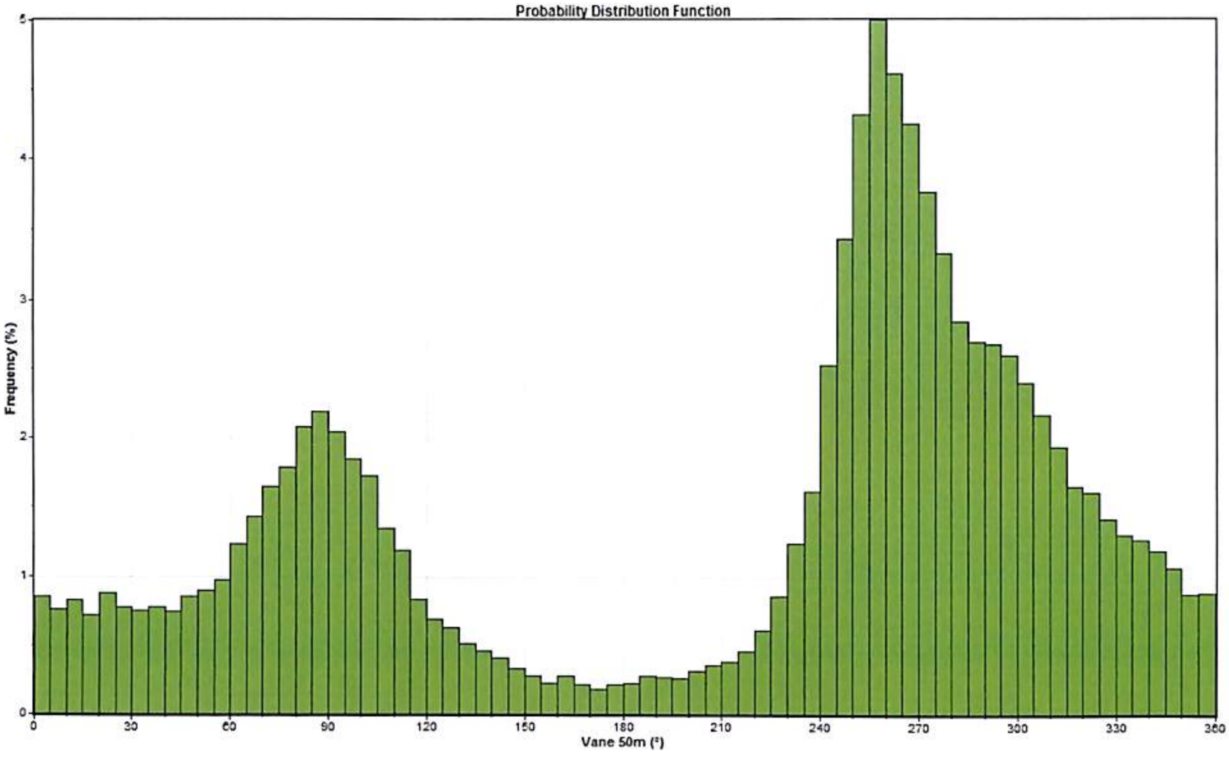


Figure 24: Frequency vs Wind Vane distribution graph of Vankusavade site at 50m height.

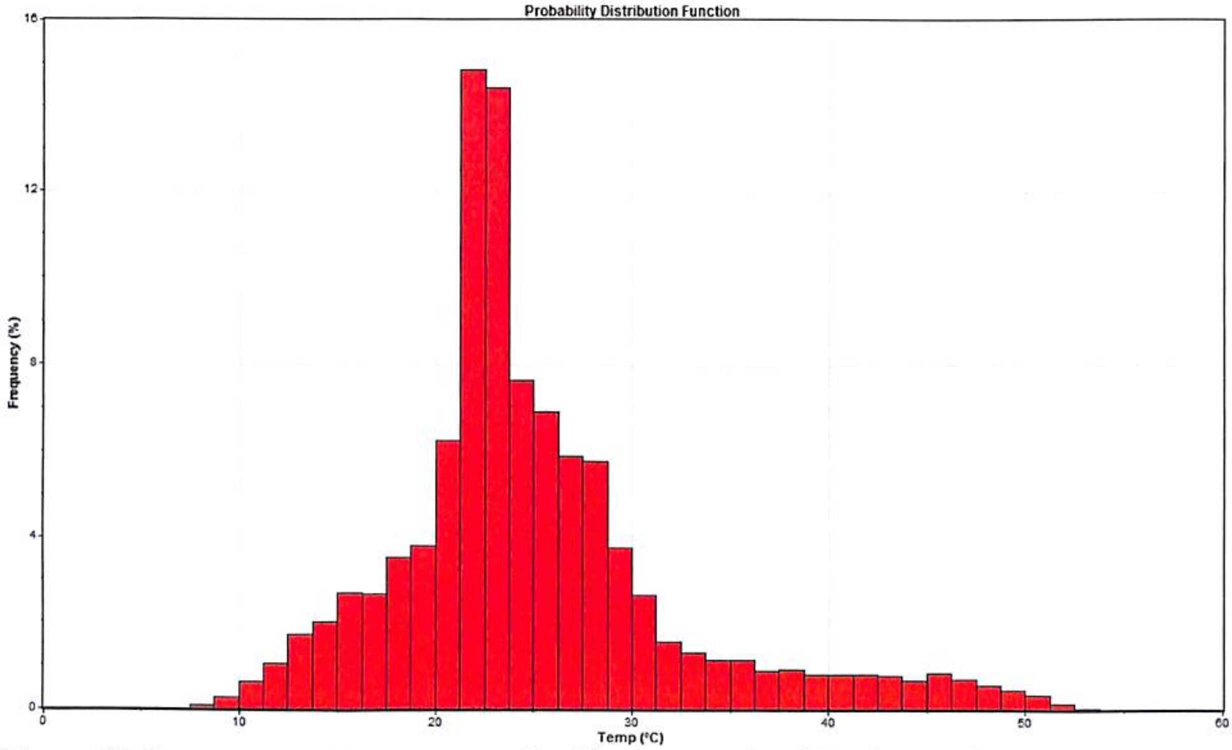


Figure 25: Frequency vs Temperature distribution graph of Vankusavade site.

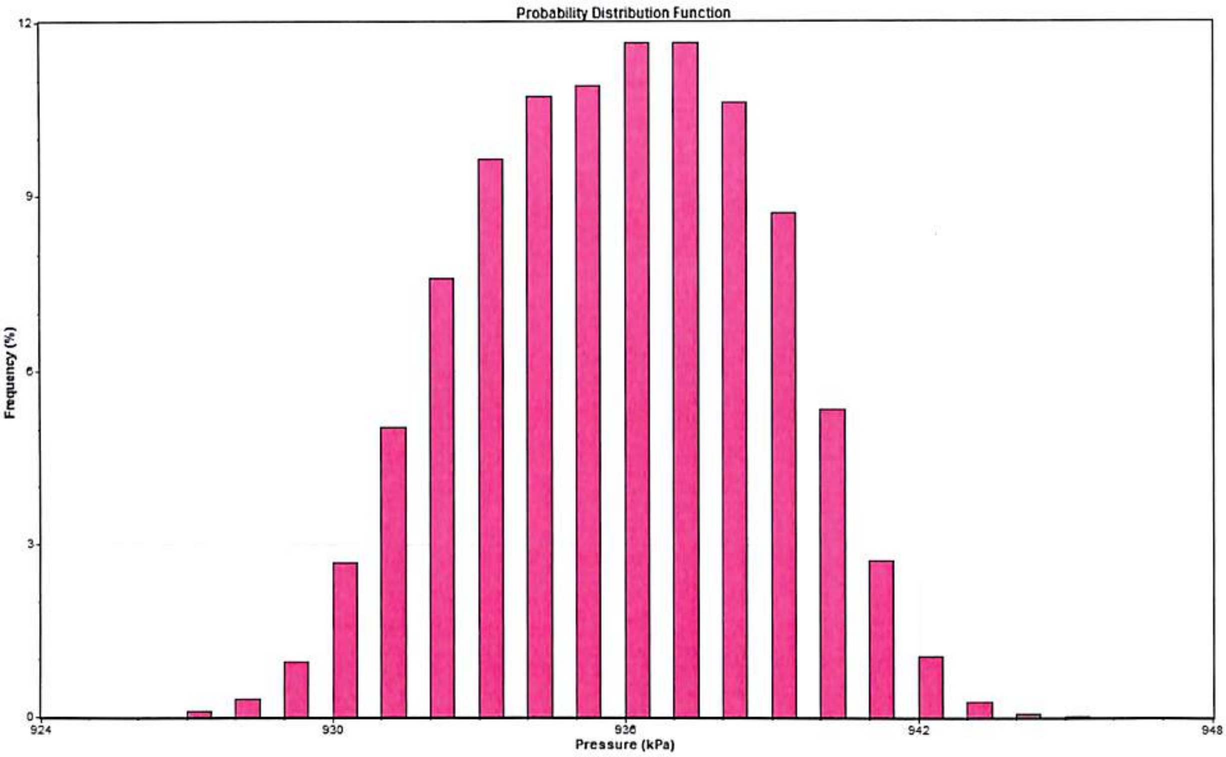


Figure 26: Frequency vs. Pressure distribution graph of Vankusavade site.

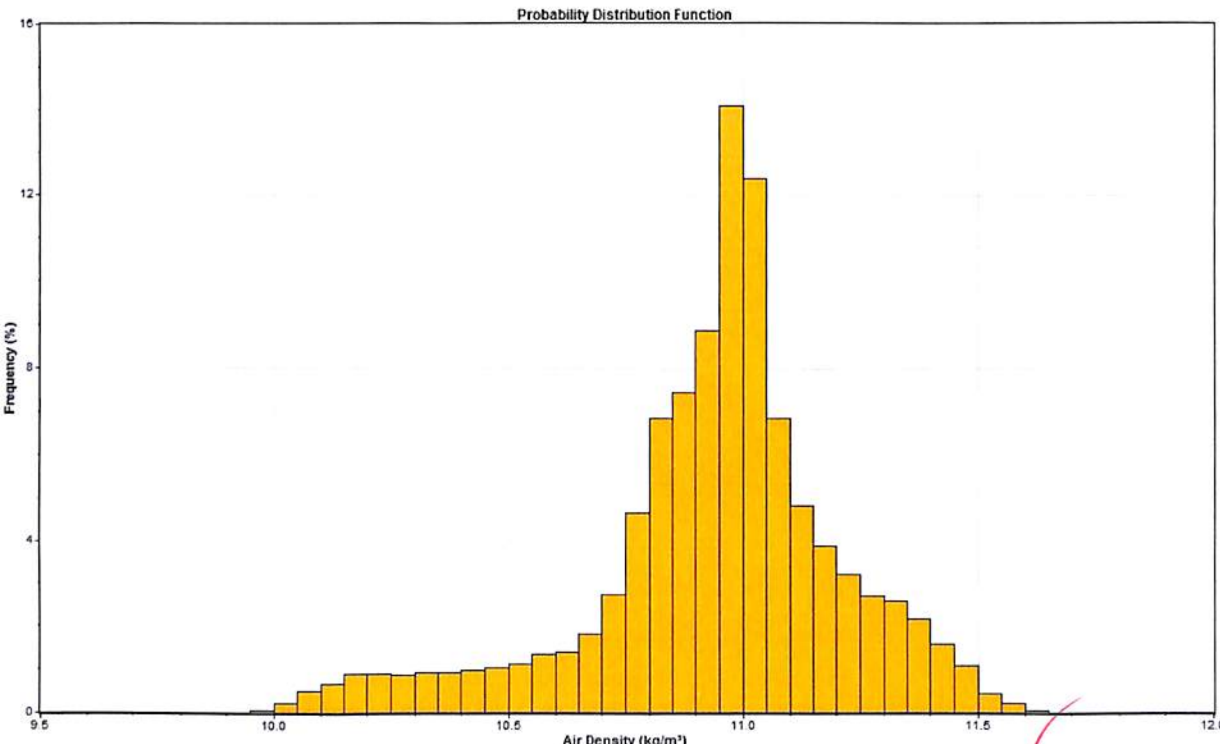
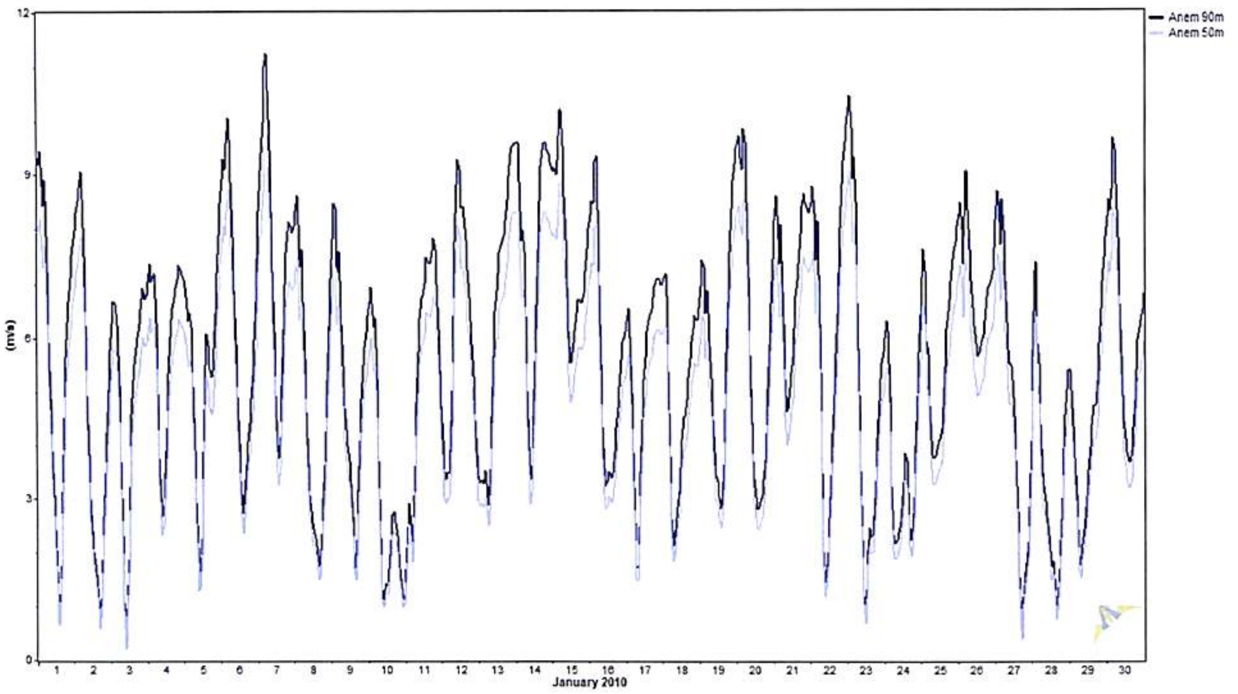


Figure 27: Frequency vs. Air Density graph of Vankusavade site.



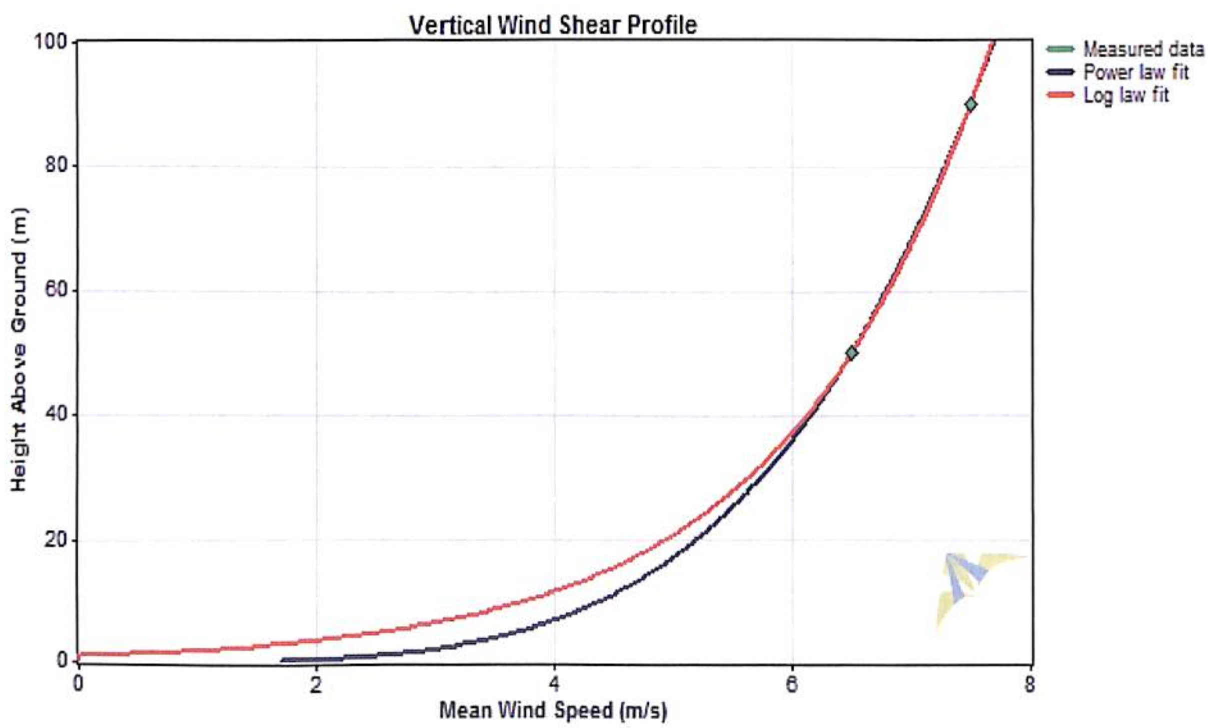


Figure 28: Mean wind speed graph above ground level of Vankusavade site.

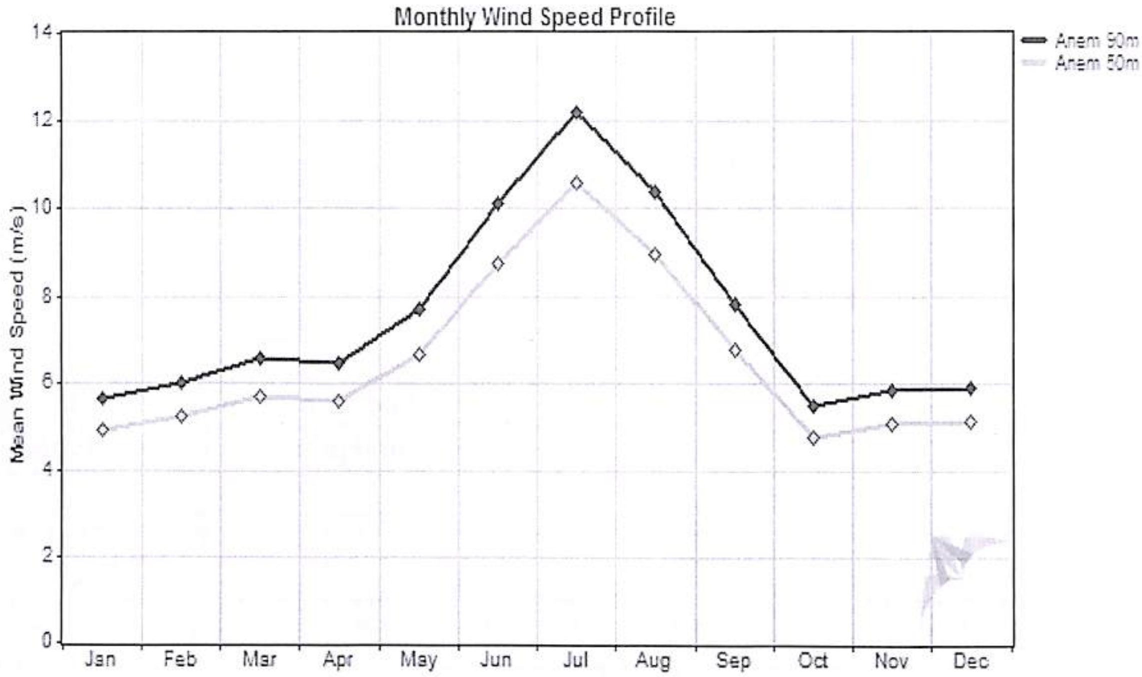


Figure 29: Monthly wind speed graph of Vankusavade site.

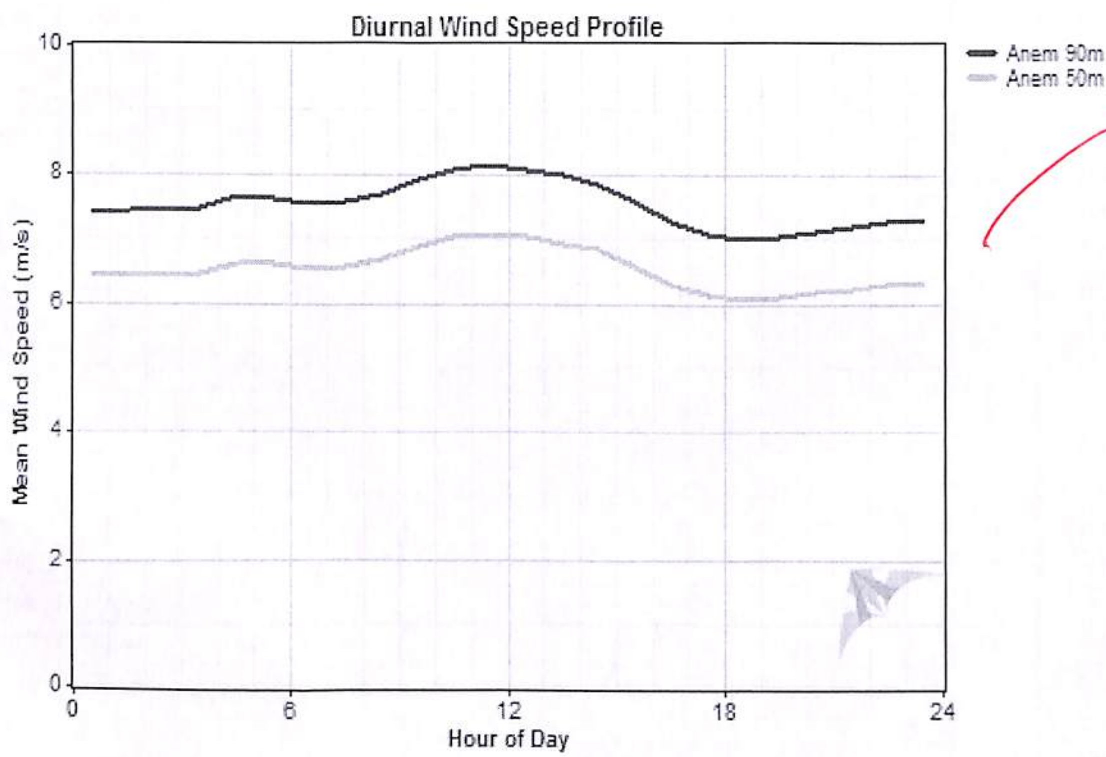


Figure 30: Hourly wind Speed graph of Vankusavade site.

The total Energy estimate is calculated for 350 kW of machine using the above mast raw data with the help of WaSP software.

Energy Capture Summary

Project :	Vankuswade
Wind turbine type :	S33_50 m Hub Height
Turbine Capacity :	350 KW
Hub height :	50 m
Number of turbines :	50 WTGs
Site capacity :	17.5 MW
Est. annual net energy production:	267 Lac units
Est. annual net energy production / WTG:	5.33 Lac units

Loc. No.	Turbine Co-ordinate (m)			Wind Speed (m/s)	Gross Gen. (Lac)	Corrections					P(50) (Lac Unit)	P(75) (Lac Unit)	PLF P(50)	PLF P(75)
	Easting	Northing	Elevation			Wake Loss (%)	OCF	MA	GA	TL				
1	379880	1937459	1122	6.8	7.5	1	3%	97%	97%	3%	7	6	22%	21%
2	379858	1937351	1121	6.8	7.4	2	3%	97%	97%	3%	6	6	21%	20%
3	379824	1937253	1121	6.7	7.2	3	3%	97%	97%	3%	6	6	20%	19%
4	379793	1937151	1122	6.6	7.1	7	3%	97%	97%	3%	6	6	19%	18%
5	379782	1937046	1124	6.6	7.0	12	3%	97%	97%	3%	5	5	18%	17%
6	379970	1937049	1118	6.7	7.3	13	3%	97%	97%	3%	6	5	18%	17%
7	379785	1936898	1123	6.6	6.9	14	3%	97%	97%	3%	5	5	17%	16%
8	379540	1937083	1119	6.2	6.0	5	3%	97%	97%	3%	5	5	17%	16%
9	379533	1936970	1120	6.3	6.3	6	3%	97%	97%	3%	5	5	17%	16%
10	379545	1936860	1120	6.4	6.6	7	3%	97%	97%	3%	5	5	18%	17%
11	379545	1936760	1118	6.5	6.7	6	3%	97%	97%	3%	6	5	18%	17%
12	379527	1936657	1113	6.4	6.6	6	3%	97%	97%	3%	5	5	18%	17%
13	380027	1936956	1116	6.6	7.1	13	3%	97%	97%	3%	5	5	18%	17%
14	379836	1936812	1120	6.5	6.8	16	3%	97%	97%	3%	5	5	16%	16%
15	380091	1936863	1116	6.6	7.0	14	3%	97%	97%	3%	5	5	17%	17%
16	379880	1936714	1120	6.5	6.8	15	3%	97%	97%	3%	5	5	17%	16%
17	379919	1936624	1123	6.6	6.9	17	3%	97%	97%	3%	5	5	16%	16%
18	380119	1936773	1116	6.6	7.1	14	3%	97%	97%	3%	5	5	17%	17%
19	380159	1936676	1118	6.7	7.2	15	3%	97%	97%	3%	5	5	18%	17%
20	380143	1936579	1122	6.7	7.2	17	3%	97%	97%	3%	5	5	17%	17%
21	379499	1936553	1108	6.3	6.4	7	3%	97%	97%	3%	5	5	17%	16%
22	379688	1936547	1123	6.6	7.1	17	3%	97%	97%	3%	5	5	17%	16%
23	379713	1936475	1125	6.7	7.1	17	3%	97%	97%	3%	5	5	17%	16%
24	379764	1936375	1125	6.6	7.1	18	3%	97%	97%	3%	5	5	17%	16%
25	379511	1936425	1107	6.4	6.5	8	3%	97%	97%	3%	5	5	17%	16%
26	379557	1936338	1111	6.5	6.8	10	3%	97%	97%	3%	5	5	18%	17%

27	379912	1936515	1125	6.6	6.9	20	3%	97%	97%	3%	5	5	16%	15%
28	379956	1936429	1125	6.6	6.9	20	3%	97%	97%	3%	5	5	16%	15%
29	379982	1936325	1125	6.6	6.9	19	3%	97%	97%	3%	5	5	16%	15%
30	380205	1936481	1119	6.6	6.9	17	3%	97%	97%	3%	5	5	17%	16%
31	380262	1936386	1116	6.5	6.7	15	3%	97%	97%	3%	5	5	16%	16%
32	380311	1936294	1116	6.5	6.7	15	3%	97%	97%	3%	5	5	16%	16%
33	379781	1936269	1123	6.6	7.0	17	3%	97%	97%	3%	5	5	17%	16%
34	379791	1936168	1120	6.6	6.9	17	3%	97%	97%	3%	5	5	17%	16%
35	380019	1936226	1125	6.6	6.9	19	3%	97%	97%	3%	5	5	16%	15%
36	380042	1936127	1123	6.5	6.8	18	3%	97%	97%	3%	5	5	16%	15%
37	379559	1936229	1106	6.5	6.7	8	3%	97%	97%	3%	5	5	18%	17%
38	379587	1936101	1106	6.6	6.8	8	3%	97%	97%	3%	6	5	18%	17%
39	379584	1936003	1098	6.5	6.6	7	3%	97%	97%	3%	5	5	18%	17%
40	379805	1936066	1115	6.5	6.7	16	3%	97%	97%	3%	5	5	16%	15%
41	379811	1935959	1104	6.4	6.4	12	3%	97%	97%	3%	5	5	16%	15%
42	380034	1936017	1122	6.5	6.8	15	3%	97%	97%	3%	5	5	17%	16%
43	380059	1935922	1118	6.5	6.8	12	3%	97%	97%	3%	5	5	17%	16%
44	380097	1935831	1109	6.5	6.7	8	3%	97%	97%	3%	5	5	18%	17%
45	380339	1936188	1119	6.5	6.7	13	3%	97%	97%	3%	5	5	17%	16%
46	380344	1936074	1125	6.5	6.7	13	3%	97%	97%	3%	5	5	17%	16%
47	380352	1935972	1125	6.5	6.7	12	3%	97%	97%	3%	5	5	17%	16%
48	380368	1935847	1122	6.5	6.7	9	3%	97%	97%	3%	5	5	18%	17%
49	380392	1935745	1122	6.5	6.8	6	3%	97%	97%	3%	6	5	18%	18%
50	380389	1935643	1121	6.6	6.9	4	3%	97%	97%	3%	6	6	19%	18%
				6.54	342	11.95	3%	97%	97%	.03	5.33	5.08	17.4%	16.6%

		PLF
5.33	Lac/WTG/Year	17.4%
5.08	Lac/WTG/Year	16.6%
4.85	Lac/WTG/Year	15.8%

MA : Machine Availability

GA : Grid Availability

TL : Transmission Loss

AVF : Annual Wind Variation Factor

OCF : Other Correction Factors

Table 13: Energy Estimate (PLF) for 350kW machines

Before assessment of wind energy the micrositting of site is done and the result found reduction in locations. The number of locations reduced from 50 locations of 350kW machine to 18 locations of 2100kW machines.

Energy Capture Summary

Project :	Vankuswade
Wind turbine type :	S97 _ 90m Hub Height
Turbine Capacity :	2100 KW
Hub height :	90 m
Number of turbines :	18 WTGs
Site capacity :	37.8 MW
Est. annual net energy production:	1092 Lac units
Est. annual net energy production / WTG:	60.67 Lac units

Loc. No.	Turbine Co-ordinate (m)			Wind Speed (m/s)	Gross Gen. (Lac)	Corrections					P(50) (Lac units)	P(75) (Lac Units)	PLF P(50)	PLF P(75)
	Easting	Northing	Elevation			Wake Loss (%)	OCF	MA	GA	TL				
VAN01	379880	1937503	1122	7.8	82	2	5%	97%	97%	3%	70	67	38%	36%
VAN02	379871	1937303	1121	7.7	82	6	5%	97%	97%	3%	67	63	36%	35%
VAN03	379923	1937117	1120	7.7	81	11	5%	97%	97%	3%	62	59	34%	32%
VAN04	380042	1936933	1116	7.6	79	14	5%	97%	97%	3%	59	56	32%	30%
VAN05	380152	1936757	1116	7.6	79	14	5%	97%	97%	3%	59	56	32%	31%
VAN06	380173	1936565	1121	7.6	79	13	5%	97%	97%	3%	60	57	33%	31%
VAN07	380269	1936378	1116	7.5	76	13	5%	97%	97%	3%	58	55	31%	30%
VAN08	380342	1936194	1118	7.5	76	12	5%	97%	97%	3%	58	55	32%	30%
VAN09	380382	1936004	1125	7.5	76	10	5%	97%	97%	3%	60	57	32%	31%
VAN10	380373	1935814	1122	7.5	77	8	5%	97%	97%	3%	61	58	33%	32%
VAN11	380372	1935616	1119	7.6	78	5	5%	97%	97%	3%	64	61	35%	33%
VAN12	379733	1935998	1106	7.5	76	12	5%	97%	97%	3%	58	55	31%	30%
VAN13	379619	1936154	1110	7.5	78	10	5%	97%	97%	3%	61	58	33%	31%
VAN14	379580	1936348	1115	7.5	78	10	5%	97%	97%	3%	61	58	33%	31%
VAN15	379517	1936532	1110	7.4	75	8	5%	97%	97%	3%	60	57	33%	31%
VAN16	379557	1936746	1118	7.5	76	10	5%	97%	97%	3%	60	57	32%	31%
VAN17	379532	1936929	1120	7.4	75	11	5%	97%	97%	3%	58	55	31%	30%
VAN18	379420	1937118	1116	7.1	71	7	5%	97%	97%	3%	57	54	31%	30%
				7.53	1394	9.70	5%	97%	97%	3%	60.67	57.75	33%	31.4%

		PLF
60.67	lac/WTG/Year	33.0%
57.75	lac/WTG/Year	31.4%
55.13	lac/WTG/Year	30.0%

MA : Machine Availability Factor **GA :** Grid Availability; Factors
TL : Transmission Loss

AVF : Annual Wind Variation
OCF : Other Correction

Table 14: Energy Estimates (PLF) for 2100kW machines after micrositting.

The frequency distribution of the wind is calculated and the power output of the turbine for a particular wind speed is calculated. The total hours wind availability and the corresponding power output is summarized and the annual estimated generation is calculated.

Comparison of Results with Assumptions (Hypotheses)

In this section, a feasibility of replacing the old Wind turbines with the new turbines is checked. A detailed report of the existing project and the repowering project is summarized. The initial investment, present worth, internal rate of returns and the payback period of the investment done is calculated based on the estimated generation from the recorded wind speeds and the density of atmospheric air. The discount rate considered for calculating the NPV is 10%. The below tables show the estimated, actual project cost and financing for the existing project and the repowering project. It also shows the performance for the remaining project life of the existing windfarm.

Input Variable	Estimated	Actual (Jan '14)	Remaining Project
Project Size (MW)	17.5	17.5	17.5
Discount Rate	10%		10%
Original Installed Cost (Lacs)	8,249.99	8,284.41	-
Generation (Lacs)	254.00	267.00	-
Initial O&M expense (Lacs/Year/WTG)	4.00	4.00	5.20
O&M Escalation rate/Year (%)	5.00	5.00	5.00
Capacity Factor (%)	26.09	26.09	26.09
Project Life (Years)	20	12	-
Power Sales Price	Rs. 2.82	Rs. 2.82 (Annual escalation of Rs. 0.11/year up to 8 years)	Rs. 2.52
Payback	8th Year	8th Year	-

Table 15: Existing Project Cost, Performance & Financing.

Input Variable	Estimated
Project Size (MW)	37.8
Discount Rate (%)	10
Original Installation Cost (Lacs/Year/WTG)	19,893.96
Average Generation of 18 WTGs (Lacs)	57.75
Initial O&M Expense (Lacs/Year/WTG)	21
O&M escalation rate/year	5%
Capacity Factor (%)	22.83
Project Life (Years)	20
Power Sales Price (Rs.)	5.37
Estimated Payback (Year)	6th

Table 16: Repowering Project Cost, Performance & Financing

The actual generation data is recorded in the controller of the turbine. The total average generation of each of the turbine is compared with the new turbine. The below table shows the comparison between the generation details,

Comparison of Generation between Existing & Re-powered Project

Existing Project	Actual Generation per WTG (Avg.)	5.33 Lacs units/Year
	Actual Generation of 50 WTG's at P75	267 Lacs unit/Year
	Capacity Factor	26.09%
	Rotor Swept Area	876.1 m2
Repowering Project	Estimated Generation per WTG (Avg.)	60.67 Lacs Unit/Year
	Estimated Generation of 18 WTG's at P75	1092 Lacs unit/Year
	Capacity Factor	22.83%
	Rotor Swept Area	7386 m2

Table 17: Comparison between Existing & Repowering Project.

For repowering a windfarm the initial investment is high, though the present worth of the existing wind turbine should be considered, it is almost equivalent to the de-erection cost of the turbines and its transportation. So the present worth, de-erection & mobilization cost of the wind turbines are not considered in checking the feasibility of repowering the windfarm.

The rotor diameter of the existing 350kW WTG is 32m and that of 2100kW WTG is 90m. The power is proportional to the swept area of the rotor, doubling the radius will quadruple the power. In the above table there is an estimated generation of 1092 lacs units / year from the repowered turbine, which is almost 75.54% extra than the available actual generation.

As per the Income tax act, the renewable energy (Wind Generated Electricity) comes under the accelerated depreciation, Eg: If the asset is of Rs. 100.00, the tax is levied on Rs. 80.00 for the first year, 80% of remaining (Rs. 20.00) i.e. Rs. 16.00 for second year, 80% of remaining (Rs. 4.00) i.e. Rs. 3.20 for the third year. So within the period of 5 years, there will not be any tax liability on the asset.

The study identifies key challenges which are likely to come in repowering project in Vankusavade region. Following are the key challenges and possible solutions to each:

(Rs. in Lacss)

A.	**Cost of the Project**	**Rate/WTG**	**Total**
	Land	30	1320
	Wind Turbine Generator	657.45	28927.8
	Tower	176.8	7779.2
	Transformer	16.75	737
	Civil Works	57.35	2523.4
	Electrical Items & Supplies	42.39	1865.16
	Statutory Fee & other charges	3.15	138.6
	Erection & Commissioning	28.68	1261.92
	Power Evacuation	92.65	4076.6
	Total	1105.22	48629.68
	Cost per MW		526.295
B.	**Means of Finance**		
	Promoters Contribution	25%	12157.42
	Borrowings	75%	36472.26
	Total	100%	48629.68
C.	**Terms of Borrowings :**		
	Assumptions made -		
	Rate of Interest	12.00%	
D.	**Inflows :**		
	Estimations based -	42.00 Lacs	
	Annual Unit Generation per WTG	Rs. 5.37	
E.	**Outflows :**		
	Insurance	1.5	
	Operation & Maintenance		
	From 3rd year	21	
	Annual Escalation	5%	

Table 18: Statement showing parameters of 37.8 MW project.

The above table shows the total project cost of 18 WTG's of 2100kW. The project cost includes procurement of land on lease/purchase for 20 years, Supply items of WTG, Tower, Transformer and Electrical Items, the Statutory payments to be made to the respective Renewable Agency of the particular state nodal agency for Installation and Power Evacuation, Erection & Commissioning of the WTG. The means of finance is assumed as 25% promoter's contribution and 75% borrowings from the market with the rate of interest of 12% per annum.

(Rs. In lacs)

Year	Annual Average Gen.	Total No. of M/C.	Creditable Units Gen. in Lac.	Selling Rate Rs./Unit	Power Income Rs. Lac.	O & M	Ins.	Int.	Total Cost	Profit
1	58	18	1,039	5	5,577	-	27	5,021	5,048	529
2	58	18	1,039	5	5,577	-	27	4,425	4,452	1,125
3	58	18	1,039	5	5,577	378	27	3,744	4,149	1,428
4	58	18	1,039	5	5,577	397	27	3,064	3,488	2,090
5	58	18	1,039	5	5,577	417	27	2,383	2,827	2,751
6	58	18	1,039	5	5,577	438	27	1,702	2,167	3,411
7	58	18	1,039	5	5,577	459	27	1,021	1,508	4,070
8	58	18	1,039	5	5,577	482	27	340	850	4,727
9	58	18	1,039	5	5,577	507	27		534	5,044
10	58	18	1,039	5	5,577	532	27		559	5,018
11	58	18	1,039	5	5,577	558	27		585	4,992
12	58	18	1,039	5	5,577	586	27		613	4,964
13	58	18	1,039	5	5,577	616	27		643	4,935
14	58	18	1,039	5	5,577	647	27		674	4,904
15	58	18	1,039	5	5,577	679	27		706	4,871
16	58	18	1,039	5	5,577	713	27		740	4,838
17	58	18	1,039	5	5,577	748	27		775	4,802
18	58	18	1,039	5	5,577	786	27		813	4,764
19	58	18	1,039	5	5,577	825	27		852	4,725
20	58	18	1,039	5	5,577	866	27		893	4,684
TOTAL			**20,772**		**111,546**				**32,875**	

Table 19: Statement showing income from Power Generation & Taxation

The above table shows the income generated from the power sale to the electricity board and the other expenses. The total creditable generation of 18 WTG's are 1092 Lac units, considering an average annual generation of 57.75 Lac units per WTG. The selling price is decided by the state electricity boards, the current prevailing rate per unit is Rs. 5.37. The O&M cost for the initial 2 years is free after which the cost is Rs.

21 Lacs / WTG per year with an escalation rate of 5% per year. The insurance cost per WTG is Rs.1.5 Lacs. The interest on the borrowings is calculated at the rate of 14% till complete repayment is done. The profit is calculated after the deduction of the expenses and the tax on the borrowings.

Year	Outflow	Inflow	Discount factor	Discounted inflow	Cumulative inflow
1	(532.06)	-	1.00	-	-
2	(1,596.17)	-	0.91	-	-
3	-	353.91	0.83	428.23	428.23
4	-	473.65	0.75	630.43	1,058.65
5	-	449.84	0.68	658.61	1,717.26
6	-	446.87	0.62	719.68	2,436.95
7	-	443.89	0.56	786.38	3,223.33
8	-	482.43	0.51	940.12	4,163.45
9	-	478.34	0.47	1,025.36	5,188.81
10	-	446.31	0.42	1,052.37	6,241.18
11	-	430.73	0.39	1,117.21	7,358.39
12	-	427.80	0.35	1,220.55	8,578.94
13	-	424.71	0.32	1,332.93	9,911.87
14	-	421.48	0.29	1,455.05	11,366.92
15	-	401.94	0.26	1,526.36	12,893.28
16	-	398.37	0.24	1,664.09	14,557.37
17	-	394.62	0.22	1,813.28	16,370.65
18	-	390.69	0.20	1,974.72	18,345.37
19	-	386.56	0.18	2,149.22	20,494.59
20	-	382.22	0.16	2,337.61	22,832.19
21	-	377.66	0.15	2,540.72	25,372.91
22	-	372.88	0.14	2,759.40	28,132.31
23	-	367.86	0.12	2,994.45	31,126.76
24	-	362.58	0.11	3,246.68	34,373.44
25	-	357.05	0.10	3,516.81	37,890.25
Total	**(2,128.23)**	**9,472.37**		**37,890.25**	
		Payback period			**5.43 Years**
		IRR			**30.80%**

Table 20: Statement showing Discounted Payback Period & IRR of Project.

The above tables show the payback period of the project and the internal rate of returns of the project. The payback period used is the discounted payback period method. The payback period is placed at 5.43 year and rate of return is 30.80%.

Table arrived after considering the parameters for state Maharashtra, Free Operation & Maintenance period of 2 years, Tariff plan Rs. 5.37, percentage of debt funding 0.7 and SCOD till 31.03.2017, soft cost in case of assumption 1, EPC per turbine cost Rs. 11.05 Crores for 2.10 MW capacity of turbine, Debtor Revenue 90 days and generation based incentives is for 90 days, Service tax considered as current prevailing rate at 14.00% and tax depreciation considered 7.69%.

New PPAs:

For sale to EB projects, many if not most of the projects are under the old PPA rates and in case the projects are to be set up by dismantling of old WTGs, for financial viability of the projects, we recommends that State Electricity Board should allow developers to sell power under current FiT (Feed in Tariff) rates. It is possible State Electricity Board will not be willing to come out of such PPAs where they are buying power at much cheaper rate than that of current tariff. Few of the existing project proponents may be having PPA with private consumers (industrial/ commercial at the indexed tariff), who will not be willing to come out of the existing short term PPA because of power deficiency in the state. But since the Third-party sale rates are very high, PPAs should be allowed to lapse after giving a notice of 6 months which will give the existing power buyers to find new sellers.

Possible Solution: There should also be a provision of "Right of First Refusal to Purchase" to the existing group of captive PPA holders to buy power from the repowered projects at competitive rates. In this case the existing power purchaser should have the right to opt the electricity generated from repowered project at the price determined by state regulatory body and if existing purchaser refuse to opt then only power producer may opt to go for other option of sale of electricity. This way interest of existing power purchaser will not be harmed. In another option each repowered project must be considered as a new project in terms of PPA rates and the existing PPA must be lapsed with a notice period of 6 to 12 months.

Turbine and Project Ownership:

Multiple owners of windfarm land may create complications for repowering projects. The wind turbines are being maintained by different agencies and OEMs. Repowering will reduce the number of turbines and there may not be one-to-one replacement. Thus, the issue of ownership needs to be handled carefully.

Possible Solution: It is necessary identify and engage concerned stakeholders such as owners of the wind-farms, OEMs, project developers, financial institutions, regulatory bodies, nodal agencies, land owners, O&M agencies etc. to arrive at a workable business model. All existing stakeholders willing to re-power, can be made partners in a Special Purpose Vehicle (SPV) and profits can be shared in the ratio of equity shareholding in the SPV.

Disposal of Wind Turbine:

The disposal of old WTGs is a crucial factor which is seen as a challenge for repowering projects.

Possible Solution: There are various options such as scrapping, buy-back by the government or manufacturer. Local capacity may need to be developed. But most of the turbines may be too old and in unusable condition and can be just sold as scrap to be scavenged for usable spare parts and copper and other expensive metals.

Incentives:

One of the primary barriers to re-powering is the general lack of economic incentive to replace the older WTGs. In order to compensate for the additional cost of repowering, appropriate incentives are necessary. To encourage repowering, financial incentives need to be extended by Government. The following are some of the incentives which can be which could boost repowering in the country:

- Need of easy financing for repowering projects from financial institution such as IREDA etc.
- Concession on custom duty on certain components of WTGs or excise duty exemption;
- Need of extended tax holidays to encourage the re-powering of project;
- IPPs (Independent Power Producers) and FDI (Foreign Direct Investment) need to be encouraged by government; and
- Old project owners needs to be given freedom to choose alternate option for sale of power i.e. REC Mechanism, third party sale etc.

Policy Package:

A new policy package should be developed which would cover additional project cost and add-on tariff by the State Electricity Regulatory Commissions (SERCs) and include a repowering incentive (on the lines of the recently introduced generation-based incentive scheme by Ministry of New and Renewable Energy (MNRE)). Such additional funds even for a period of 5-6 years can be helpful in meeting the initial interest portion of the debt obtained. Following are few of policy package which should be provided by government:

- For successful repowering of wind project minimum feed-in tariff need to be declared by state government for repowering project for financial feasibility;
- Policy package should include reduction of wheeling and banking charges from re-powering projects;

- Government need to mandate for absorption of complete energy generated by repowered project;
- Repowering need to be mandated for all projects which are generating low PLF considering the wind potential at sites; and
- Government may relax micrositing criteria for wind site from 5Dx7D concept to 3Dx5D concept for better utilization of land.

C-WET certification:

The wind regime at Vankusavade Pass is suitable for Class IIIA / IIA turbines and in certain cases even Class IB turbines can be used. But most of the current WTGs sold in India are suitable for low wind sites i.e. class IIIA/IIIB and manufacturers have higher class turbines (class I/II) in their portfolio have stopped manufacturing such turbines due to lack of demand and/or their C-WET certifications have lapsed. C-WET needs to allow fast-track revival of type certificates for manufacturing of higher class turbines of limited numbers for such re powering Projects.

CHAPTER 6

Conclusions

- Based on the frequency delivery of the wind speed, the estimated generation of S97_90M Hub Height of 2100 kW WTG may 57.67 Lacs units per year.

- Repowering the windfarm will lead to an extra energy capacity addition in the same area, capacity may increase to almost 4-5 times the present capacity of the windfarm.

- The existing wind farms can be repowered in optimized way for the higher energy generation with the available area / land.

- The study results clearly indicate that there is enough scope for the repowering the windfarms.

- The initial investment will be high, the payback period of the repowering project can be in the 5.43 year and the IRR will be approx. 30.80%.

- The outcome of this modelling exercise is wind speed m.e.s.o maps at 920 to 1100 m.a.s.l, capacity estimation of repowering and annual energy assessment.

- The m.e.s.o map assessment model validation with measurement of wind speed data. The validation will be carried out primarily based on NCEP/NCAR reanalysis Project data, annual mean wind speed from NIWE Measurement data.

- The average mean annual wind speed at 90m height will be assessed approx. 7.53 m/s.

- The potential capacity of the Region of Interest shall be assessed considering the trade-off between performance of wind turbines and land utilization. Shall be used spacing criterion of 3D x 5D, the capacity/km² and will be estimated to 2.10 MW. The total potential capacity in Region of Interest shall be estimated.

- **Power Evacuation System:** Load flow study to be analysed the situation of current power evacuation & solution for improvement in infrastructure for additional load post repowering.

- **Disposal of Wind Turbine:** The disposal of old WTGs is a crucial factor seen as a challenges for repowering projects. Scrapping of WTGs appears to be a practical option as most of the turbines may be too old and in unusable condition and can be just sold as scrap to be scavenged for usable spare parts and copper and other expensive metals.

- **Incentives:** To encourage repowering in the national interest, extra incentive or probably extra GBI may be considered.

- **Policy Package:** A new policy package should be developed which would cover additional project cost and add-on tariff by EB and include a repowering incentive (on the lines of the recently introduced. generation-based incentive scheme by MNRE). The additional decommissioning costs for old turbines (such as transport charges) need to be assessed.

Scope for Future Work

- Wind can be assessed using computer modelling methods. Window grapher can be used to assess the wind flow over the complex contours.

- Accurate assessment of wind flow over complex regions can be done through CFD simulation to estimate the accurate output of the wind turbine.

- Energy generation can be further improved by 8-10% to this windfarm if we perform the wind resource assessment and install the 120 meters height of wind turbine generators.

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