Investigation of Wind Energy Potential in Asia-Pacific Region: Thailand, South Korea and Bangladesh Perspectives

Khandaker Dahirul Islam

A Thesis Submitted in Fulfillment of the Requirement for the Degree of Doctor of Philosophy in Sustainable Energy Management

Prince of Songkla University

2021

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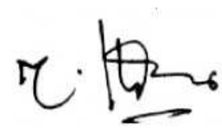

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Academic Year 2020

ABSTRACT

This dissertation simply deeply focuses on the wind energy analysis in Thailand, South Korea and Bangladesh, a small but not a least part of the Asia-Pacific Region in terms of energy issues through statistical wind data interpretations, building wind energy atlas as well as launching machine learning modeling for the sake of training and testing sample wind data for the selection of the suitable methods and algorithms. In order for the statistical analysis of the wind data, the areas have been chosen based on the data availability. Wind data statistical analysis were done as per the rule of internationally recognized standard like IEC 61400-12-1. Following the standard, a part of the research, this dissertation analyzes the prospects and possibilities of wind energy from the engineering point of view in Hoenggyeong do and Mal do two of the small Islands of the Jeollabuk province of the Republic of Korea. As wind resource is a prominent sector of renewable energy of Korea in the recent era having lots of wind flow in a varying speed all around the year, this research attempts to analyze the 10-minutes averaged real wind speed and direction data of the proposed Islands with a view to identify the possibilities of building up offshore wind farm in the near future.

In terms of the research work regarding Thailand, satellite data from NOAA has been retrieved from its own FTP server from which wind speed and direction data were used for analysis. Wind data of hourly averaged available for every day basis, i.e. the downloaded

file was one for every single day. Finally, wind maps were created using some mathematical tool most prominent for wind energy analysis. This was indeed used in ArcMap through raster calculator. As an annexure of the thesis for validation work, machine learning was introduced for training and testing a sample wind data of Thailand recorded at 10 m above ground level (AGL) which was interpolated to get wind speed at different heights like 20 m, 15 m or 30 m AGL using regression method.

As a part of the research, this work investigates coastal wind resource of Bangladesh through time-series measured (1-year: 2017) and predicted (2000-2017) wind data analysis as per IEC 61400-12-1. Building high resolution mesoscale (resolution: 3000 m) and microscale (resolution: 200 m) wind resource maps at 60 m, 80 m and 100 m above ground level (AGL) as a part of weather research and forecasting (WRF) through MERRA2/NASA global reanalysis climate database have also been applied in this research. Simulated (i.e. predicted) wind speed data have been validated through a number statistical tests by the use of measured wind speed of seven coastal area of the country. Using computational fluid dynamics MC2/MS-Micro wind flow modeling along with measured wind data interpretation, a number of test WTGs (wind turbine generators) with the range of 1-3.3 MW of capacity have been employed for gaining sufficient idea of available energy that may be produced in these micro-sites. The research concerns with the mitigation of the carbon as a global point of view of energy when carbon issue is one of the most crying bargaining points at present. Results show that, 1 MW WTG at 60 m AGL in each site can produce a total of 2.79 GWh (AEP of 1.72 GWh and 1.08 GWh respectively) of energy in one year (reducing 1781.69 Ton of CO_2/year), 3.30 MW WTG at 80 m AGL can reduce 12098.54 Ton CO_2/year by producing a total of 18.99 GWh (AEP of 10.81 GWh and 8.19 GWh respectively) and 1.6 MW WTG at 100 m AGL can produce a total of 11.04 GWh (AEP of 6.22 GWh and 4.83 GWh respectively) of energy reducing 7035.03 Ton CO_2/year. In addition to the wind energy analysis in a number of ways, this dissertation analyzes the wind turbine noise generated from a 5 kW test wind turbine generator (WTG) with hub height, rotor diameter, cut-in and rated speed of 15m, 4m, 3 m/s and 12 m/s respectively according to IEC 61400-11 (acoustic noise) standard. It discusses the realistic and comparable performances of small WTG that sets its own characteristics in terms of power and acoustic performances. Standard set by American Wind Energy Association (AWEA 2009) has also been incorporated together with IEC 61400-11. For the measurements of noise level, the averaging period has been considered to be 10-second as per AWEA 2009. The study attempts to analyze time-series noise data recorded at different distance from the WTG for finding Noise (dB)-Frequency (Hz), RPM-Volt and Noise-RPM relationship. The analysis has been done with the help of wind speed histogram bin each of size 1 m/s which estimates that, RPM ranges between 0 - 170, overall noise ranges between 45.17 (dB) - 48.78 (dB) and background noise ranges between 33.2 (dB) - 65.6 (dB). The relationship between the noises coming from WTG with background noise demonstrates for the deeper understanding that the environmental hazard created by WTG noise is likely to demand for analysis which can never be ignored.

The thesis, as a part of doctoral activities was basically meant for learning, thinking, realizing the current global energy issues through creating and implementing wind maps from satellite remote sensing wind data along with statistical analysis of wind data, validating the maps with real met station data along with launching machine learning for wind data test with a view to be a part of creating a sustainable world.

Keywords: *Wind energy, wind map, statistical analysis, machine learning, WTG noise analysis, sustainability, carbon footprint, Asia-Pacific region.*

ACKNOWLEDGEMENTS

All thanks goes to my Lord Almighty Allah, for the first kind, for He has accepted me being here in the Energy Systems Laboratory of the Faculty of Environmental Management, Prince of Songkhla University, Hat Yai, Thailand for the sake of accomplishment of my Doctoral dissertation titled as *Investigation of Wind Energy Potential in Asia-Pacific Region: Thailand, South Korea and Bangladesh Perspectives.*

This work was supported by the Graduate School (research grant of Interdisciplinary Graduate School (IGS)), Department of Mechanical Engineering of the Faculty of Engineering, Energy Systems Laboratory of the Faculty of Environmental Management, Prince of Songkla University, Hat Yai-90112, Songkhla, Thailand and Space Research Laboratory, GISTDA, Ministry of Energy, Kingdom of Thailand. As a result, I first of all would like to thank Dr. Kuaanan Techato, Dean of the Faculty of Environmental Management, Prince of Songkla University for yielding fantastic opportunity for me of my research, who I think is the man of inspiration. My gratitude goes to my honorable adviser Dr. Thanansak Theppaya along with co-adviser Dr. Juntakan Taweekun without who my dissertation and research articles would not have been advanced in many ways.

Deep regards goes to Dr. Tanita Suepa of GISTDA, Chonburi, Thailand, who always had time for me to listen to my issues with great cordiality and patience, then guided me throughout my working about building wind map for Thailand. She always concerned about me regarding gaining cartography expertise, lending me her books, showing me novel paths to learn new things. I truly owe to her.

I am also grateful to all the respected teachers who in any way taught me many things in the arena of energy and the outside, especially Dr. Wattana Ratismith of Energy Systems Laboratory, PSU, Hat Yai, Thailand. All the students at the Sustainable Energy Management program deserve compliments like the way my gratitude without any doubt goes for Ms. Paweenrat Na Phatthalung, one of the most active officers to my opinion of the Faculty of Environmental Management at PSU Hatyai campus who took care for all of my administrative and academic concerns during my staying and my absence here in the campus. And I must have to add the name of Ms. Sutawan Sathianwiriya, another active-most officer of the faculty who always supported me during my time therein.

Later, I will take the opportunity to thank all who supported, motivated and guided me in any measurable way during this study period in terms of learning recent techniques of energy, especially wind energy, cartography, big data analysis and machine learning.

May the memory of the path of this intellectual activity remain for long.

Ameen.

Thank you very much.

Khandaker Dahirul Islam

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LIST OF ABBREVIATIONS

Acronyms	Elaboration
AD	Anno Domini
AEDP	Alternative Energy Development Plan
AEP	Annual Energy Production
AGL	Above Ground Level
APAC	Asia-Pacific
BAU	Business as Usual
BC	Before Christ
BCAS	Bangladesh Centre for Advanced Studies
BMD	Bangladesh Meteorological Department
BPDB	Bangladesh Power Development Board
CAB	Consumers Association of Bangladesh
CF	Capacity Factor
CO_2	Carbon di-oxide
CSOs	Civil society organizations
CWEA	Chinese Renewable Energy Association
DAU	Dynamic As Usual
DEDE	Department of Alternative Energy Development and Efficiency
DEM	Digital Elevation Model
EM	Empirical Method
EPF	Energy Pattern Factor
EPPO	Energy Policy and Planning Office
ERC	Energy Regulatory Commission
ESI	Electricity Supply Industry

ETSU	Energy Technology & Services Unit
EVM	Eddy Viscosity Model
EWEA	European Renewable Energy Association
FES	Friedrich-Ebert-Stiftung
FiTs	Feed-in-Tariffs
FY	Fiscal Year
GHG	Green House Gas
GIS	Geographical Information System
GM	Graphical Method
GOB	Government of Bangladesh
GW	Giga Watt
GWEC	Global Wind Energy Council
HAWT	Horizontal Axis Wind Turbine
ICS	Improved Cook Stove
IRENA	International Renewable Energy Association
kW	Kilo Watt
kWh	One kilowatt-hour. This is a measure of electrical energy equivalent to 10 100-watt light bulbs running for one hour
LCOE	Levelized Cost of Energy
LG	Life is Good
LGED	Local Government Engineering Department
LNG	Liquefied Natural Gas
MAE	Mean Absolute Error
MBE	Mean Bias Error
MERRA	Modern Era Retrospective-analysis for Research and Applications
MLM	Maximum Likelihood Method
MOE	Ministry of Energy
M/P	Measured vs. Predicted

MPEMR	Ministry of Power, Energy and Mineral Resource
MW	Mega Watt
NASA	National Aeronautics and Space Administration
NCCC	National Board of Climate Change Policy
NEA	National Energy Administration
NEPC	National Energy Policy Council
NGO	Non-Government Organization
NOAA	National Oceanic and Atmospheric Administration
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
P&E	Power and Energy
PDF	Probability Distribution Function
PEA	Provincial Electricity Authority
PPP	Public-Private Partnership
PWC	Predicted Wind Climate
R & D	Research and Development
RMSE	Root Mean Square Error
SDG	Sustainable Development Goal
SO2	Sulphur di-oxide
SOEs	State Owned Enterprises
SRTM	Shuttle Radar Topography Mission
TIEP	Thailand Integrated Energy Plan
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
USA	United States of America
VAWT	Vertical Axis Wind Turbine
WAsP	Wind Atlas Analysis and Application Program
WE	Wind Energy

WECS	Wind Energy Conversion Systems
WEST	Wind Energy Statistical Tool
WFDO	Wind Farm Design and Optimization
WTG	Wind Turbine Generator
WWII	Second World War

Chapter 1

Introduction

1.1. BACKGROUND

Sustainable energy is the function of utilizing energy such that fulfills the demand of the present without trading off the capacity of future ages to meet their very own demands [1] [2]. The terms sustainable energy and sustainable power source are some of the time utilized reciprocally. Sustainable power source innovations are fundamental supporters of reasonable energy as they for the most part add to world energy security, decreasing reliance on petroleum product assets and giving chances to relieving ozone depleting substances [3]. Worldwide, there is a needs as far as energy utilization in a feasible manner is thought of and considered as perhaps the best challenge in the present century. About a billion of individuals ailing in getting to power alongside around 3 billion of individuals having customary fuel sources, for example, wood and creature fertilizer for cooking shows that executions of economic energy idea is still far approach. As the sorting out standard for supportability is practical advancement, which incorporates the four interconnected spaces: environment, financial matters, legislative issues and culture. [4][5], an integrated societal concern globally in limiting global warming to the prescribed level will need to describe a rapid pursuing of methods of producing electricity that will cause less harm to the environment. Wind energy is one of those energy sources that helps to shift the conventional energy sources towards adopting more sustainable sources of energy. But building sustainable globe requires stronger government and regional policies.

Giving reasonable energy is generally seen as probably the best challenge confronting humankind in the 21st century, both regarding addressing the requirements of the present and as far as impacts on who and what is to come [6] [7]. In consideration to sustainable development as far as the energy supply system is considered, wind energy potential assessment, wind mapping and wind farm design are crucial as well as important area to work within the context of current global warming situation.

Attention to the Kyoto Protocol 1997 for energy saving programs worldwide with the attempt to manipulate environment-friendly technologies i.e. sustainable energy sources is now a very crucial talk and thought.

In this context, wind energy endeavors along with other renewable energy generation are increasing. Perhaps in the future, it has to be needed to find some more alternative sources of energy as well like wind and solar energy.

Wind is by far most brisk entity in nature as well as unpredicted too. But a proper site selection might be very much effective in building wind farms. When the decrease of emissions of CO_2 and other poisonous elements is a great concern, there are few sources to be found in nature like wind. As a result, developing wind energy sector more creative and more functional is now is one of the major challenges in the energy sector on earth. At an international level wind as an energy carrier is one of the major sources to be dealt with for getting a pathway towards a future sustainable energy society.

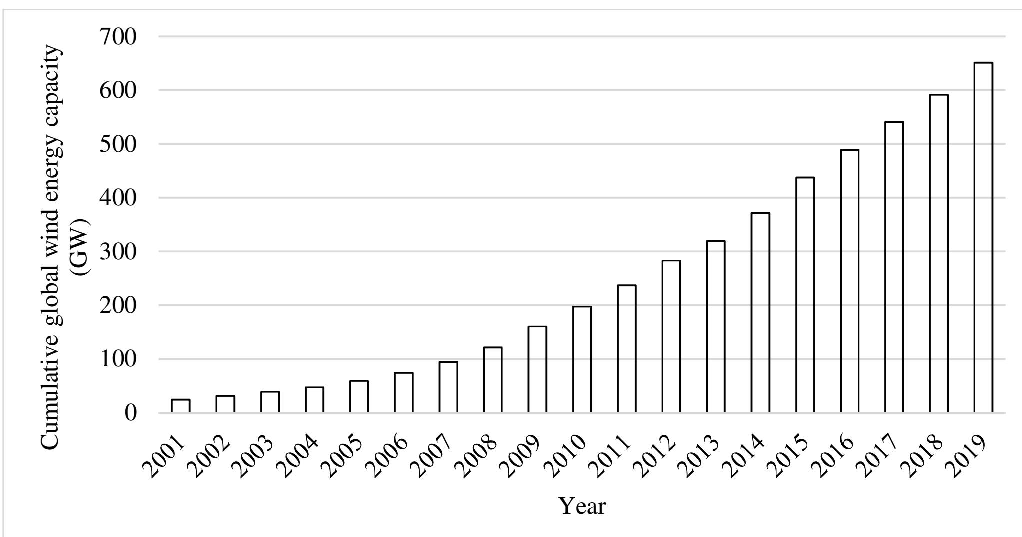


Figure 1.1. Global historical wind energy capacity from 2001 to 2019 [8].

To the nature, it is very much expected to contribute both to the reduction of air pollution along with CO_2-reduction. With this, it is also expected to get energy supply stability. This research might be one of many steps that intend to help in the future development of the scientific endeavors of wind energy which is looking forward to having wind energy sites with ultimate potentiality, an error-free and reliable wind map, pre-selecting wind sites efforts, wind survey in coastal and offshore regions etc. will have been undertaken from different angles so that a proper diagnosis of the wind energy potential of the sites or the regions can be possible. The importance of the economic issue along with enormous environmental pollution problem associated with the use of oil will amplified over time in the name of development of renewable energy resources will gain huge magnitude and acceptability due to their sustainability, inexhaustibility and ecological awareness [9].

1.2. WIND ENERGY (WE) PERSPECTIVES

As the first law of thermodynamics states, mathematically, energy cannot be produced or destroyed, but can be converted to other form of energy, wind energy is one among those few sources in the field of green energy that can be changed to electrical or mechanical form of energy without hampering the environment or with a very little hazard.

The conversion of wind energy into other form of energy is not a new technology though, modern wind energy converted to electrical energy is a relatively young (about 30 years) but rapidly expanding power source with an historical evidence that, over the past decade global installed capacity has increased from 2.5 Gigawatts (GW) in 1992 to almost 75 GW at the end of 2006, at an annual growth rate of near 30% [10]. It has overcome its childhood stage through many ups and downs in the history of time. Now it is working at its more matured phase on a global basis. Due to the increase in its capacity every year, the researchers are getting more interest in working in this sector. Following sections will describe the wind energy state of the art in different point of views, its trends and progress in global and regional manners.

1.2.1. Wind Energy Globally

Wind energy estimation depends on the characteristics of a particular wind site. The topography of a large region where the site resides is also very much important to understand the wind energy potential.

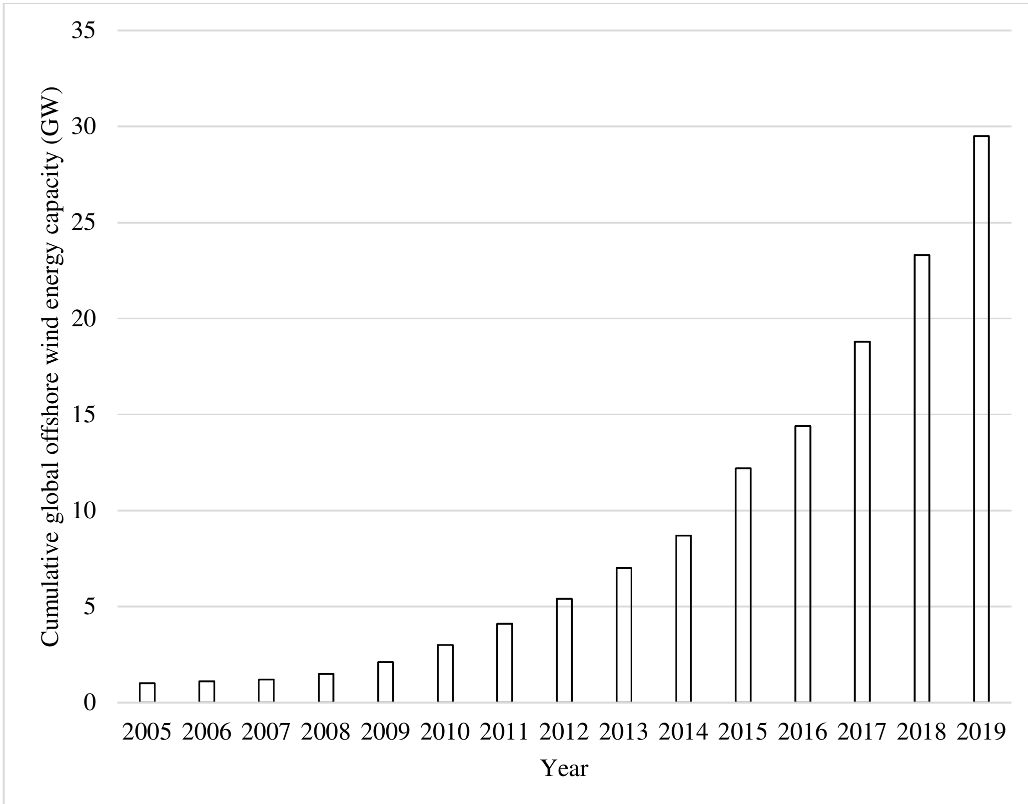


Figure 1.2. Global cumulative offshore capacity (GW) [11].

All the possibilities of building a wind farm do not ensure it to be possibly a future farm. Energy policy and regulatory functions are very much important to launch energy production from wind. As of the end of 2016, the worldwide total cumulative installed electricity generation capacity from wind power amounted to 486,790 MW, an increase of 12.5% compared to the previous year [12]. This scenario has revealed the pace of wind energy growth which already has become a promising energy sector throughout the globe. Wind energy can be extracted using wind turbines. In order to understand wind energy from wind turbine, it needs to go through some very complex work that demands the knowledge of wind energy density, wind speed zone, wind energy potential, wind class, and most importantly wind energy policy and regulations of the respective region.

Wind energy nowadays is one of the most promising and growing fields in energy sector. Several countries have achieved relatively high levels of wind power penetration, such as 39% of stationary electricity production in Denmark, 18%

in Portugal, 16% in Spain, 14% in Ireland and 9% in Germany in 2010 [13] reveals that the future power sector will have to be dependent significantly on wind energy. It is estimated that, wind power could be supplying up to 19 percent of the world's electricity and avoiding over three billion tons of CO_2 a year by 2030 [14]. As the coming world is going to face the ultimate scarcity of fossil-fuel, it needs to explore for alternate source of power in a way that it can be able to meet the future needs. Renewable energy sector is to be the power substitute when environmental impacts are a great concern throughout the world.

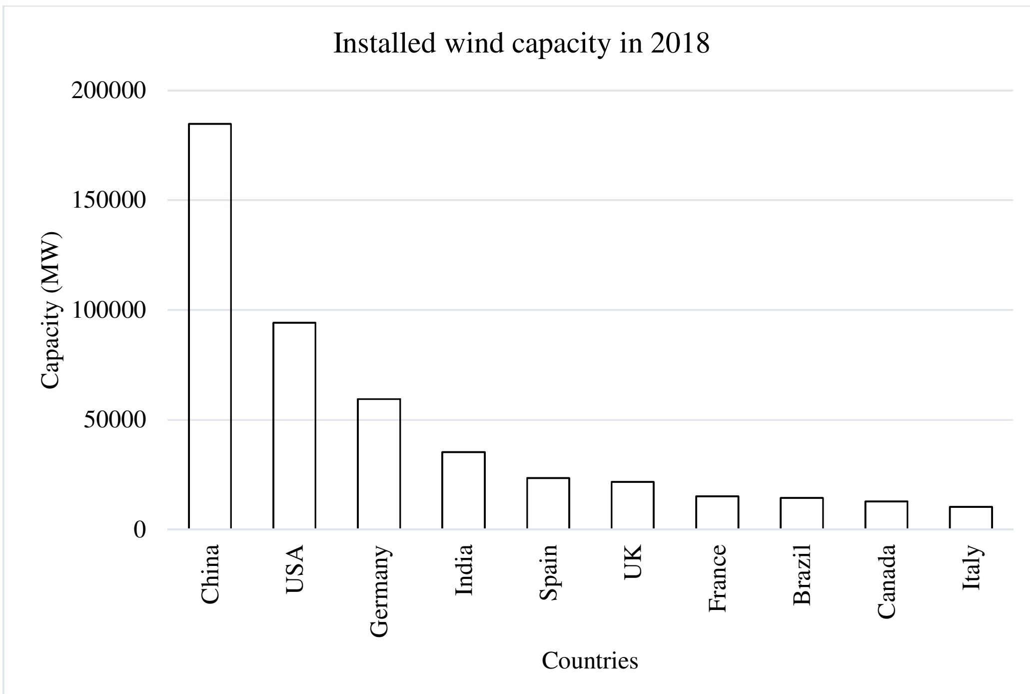


Figure 1.3. Country ranking in wind energy installed capacity in 2018 [15].

The statistics reveals that, countries like Denmark, Germany, US and so on are the leaders of wind power technologies [16][17][18]. Due to the prominence of energy usage, the globe has been recently grown with a novel thinking of how to cope with meeting future energy demands. A decent, differentiated, and eco-friendly energy framework is the objective for the entire world to check issues related with non-renewable energy source energy frameworks, which is the fundamental driver of the stressing environmental change [19]. Other than this, ongoing increments in the expense of petroleum derivatives have resuscitated the enthusiasm for current abuse of energy from wind power [20]. So as to get the greatest advantages from wind, detailed and itemized information on wind characteristics and distribution are important as well as urgent parameters to choose ideal wind energy conversion system to enhance energy yield and to minimize power generation cost [21]. Wind assets are only from time to time predictable and fluctuate with time, season of the year, height over the ground, type of landscape, and from year to year, consequently ought to be explored cautiously and thoroughly [22].

Wind energy is an ultimate source of green and clean energy that is well proven in applying to national grid, and even some sort of stand-alone off-grid connections [23]. Higher wind speeds are available offshore compared to on land, so offshore wind power's electricity generation is higher per amount of capacity installed [24]. The offshore area usually shows greater wind energy potential than most other terrestrial locations [25]. In wind turbine design and site planning, the probability distribution of short-term wind speed becomes critically important in estimating energy production [26]. Figure 132 shows the recent global cumulative offshore wind energy capacity as indicated by EWEA for the year 1998 to 2010 [27] and GWEC for the year 2011 to 2016 [28][29][30].

1.2.2. Wind Energy in Asia-Pacific (Projected Countries)

With having 4.4 billion people, the Asia and the Pacific region together share a large, diverse and dynamic region of the globe. The region accounts for more than half of global energy consumption holding the world's largest energy consumer to very small island economies. These islands are the most vulnerable to the impact of global climate change. But among the total energy consumption, 85% of the consumption are from fossil fuels. Though the region is responsible for a great majority of energy consumption, yet one tenth of its total population lack access to electricity. But this region had proved to have the largest potentiality comparing to other part of the world. With this vast energy potential, significant research have been conducted in this region too that helped gaining much knowledge and expertise on renewables for the researchers in this area.

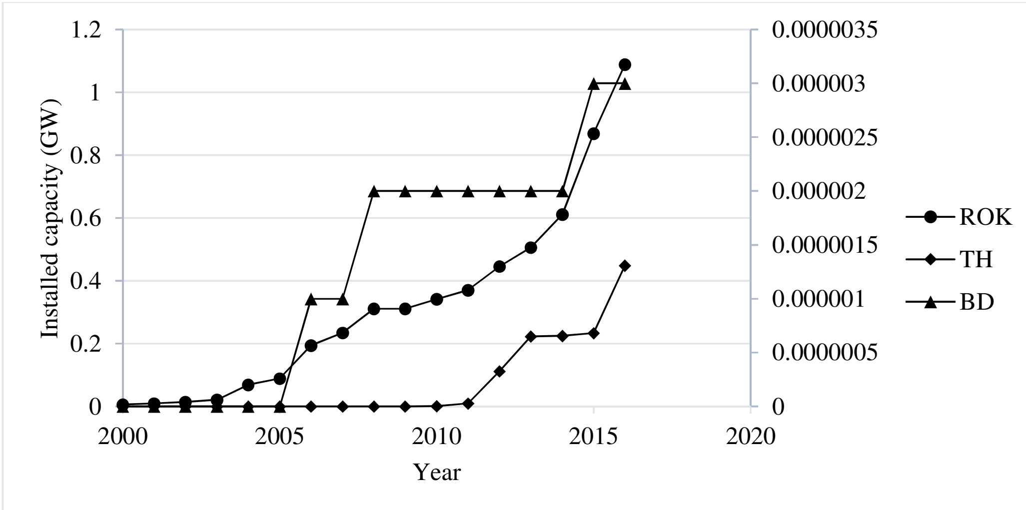


Figure 1.4. Trends of wind energy installed capacity for the projected countries (Bangladesh in secondary axis) [31].

If a comparison can be made among the three projected countries, it can be seen in Figure 1.4 that, South Korea has got a significant rise in wind energy project installation followed by Thailand. But in case of Bangladesh, there no big endeavors over time in R & D (research and development) in wind energy.

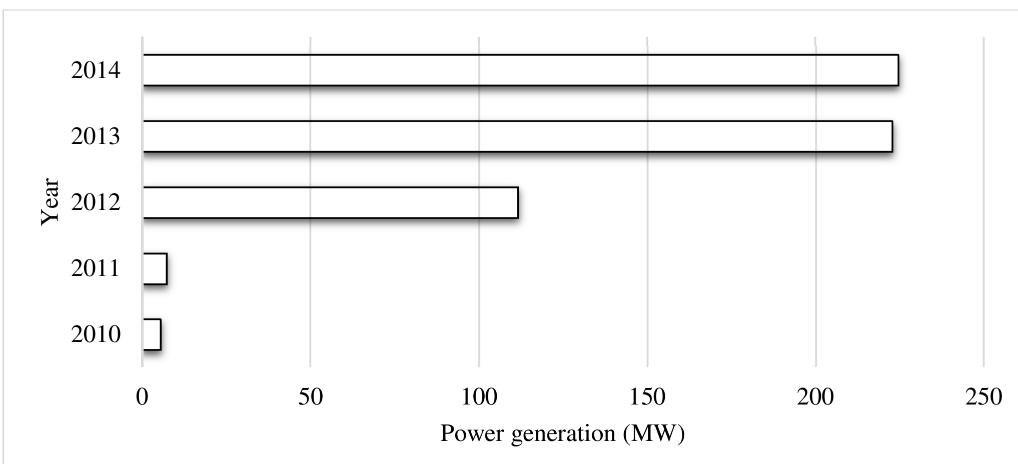


Figure 1.5. Power generation from wind energy (MW) in Thailand.

As far as the wind energy is considered, the market experts in the same field opine that Asia Pacific will lead global wind turbine market along with the global wind energy share in near future.

1.2.2.1. *Thailand WE scenario*

The total installed capacity of commercial wind energy in Thailand was 915 MW in early 2019. Thailand's Alternative Energy Development Plan (AEDP) envisages 1,485 MW by 2036 [32] whereas wind power in Thailand amounted to an installed production capacity of 224.5 MW as of the end of 2014 [33].

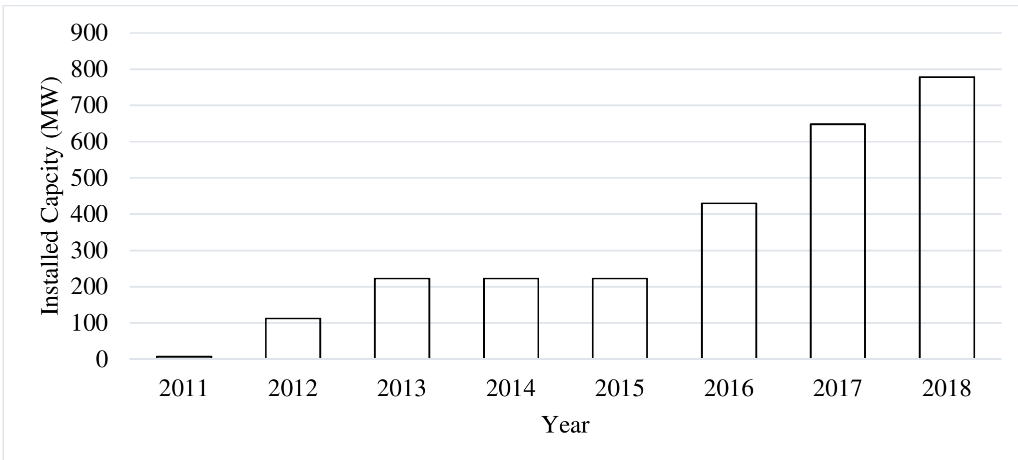


Figure 1.6. Installed wind power capacity (MW) in Thailand [34].

This difference implies the quick development in wind energy research in the country. Figure 1.5 shows the rapid growth of the production of wind energy in Thailand [35]. Figure 1.6 shows the installed capacity of the country.

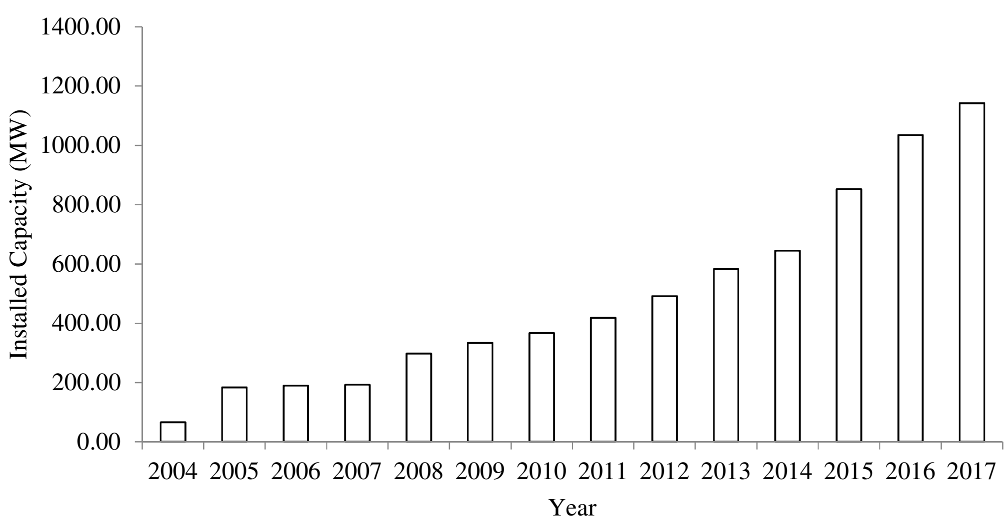


Figure 1.7. Historical installed wind energy capacity in South Korea.

Though Thailand started wind energy production in the early of this decade, Thai investigations on wind energy were accomplished in the mid-1980s by specialists in the same sector at the Asian Institute of Technology and at the Meteorological Department of the Thai Ministry of Communications [36].

1.2.2.2. *Wind Prospect in Republic of Korea*

The Republic of Korea, commonly known as South Korea is in a region with wide coastal plains in the west and south [37]. South Korea's first commercial offshore wind farm was setup at Geumdeung-ri on Jeju Island.

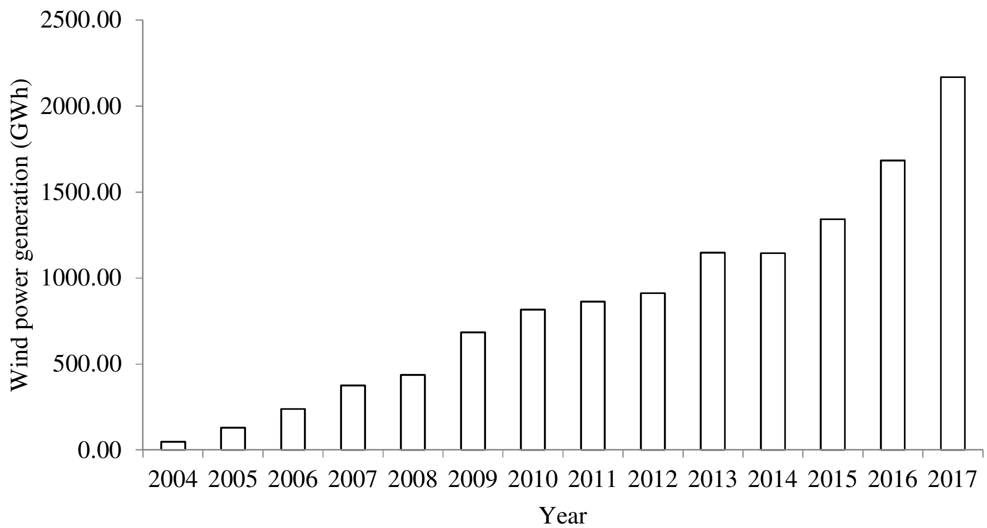


Figure 1.8. Historical wind energy generation in South Korea.

The farm was comprised of 10 wind turbines each of 3 MW of capacity. As of 2017 wind power capacity of the country was around 1150 MW. Wind energy share of total electricity consumption is significantly small and is far below 0,1%. As a result, the government of planned to invest $8.2 billion into offshore wind farms which may help increasing the total electricity share up to the capacity of 2.5 GW by 2019. Before 2004, South Korea didn't have much research in wind energy capacity estimation. In 2004, the total estimated capacity of wind energy was 22.5 MW [38]. Figure 1.8 discloses the wind power potential of the countryas of 2017.

South Korea has a late start in wind power investments compared to other nations in the area such as China, with 42 GW of onshore and offshore wind combined, compared to only 278 MW with the country [39]. There are significant amount of works that have been carried out to estimate the potential of wind energy in the country.

1.2.2.3. *Bangladesh Wind Situation*

Bangladesh situated between 20.34º - 26.38º N and 88.01º - 92.41º E having 724 km long coast line with a number of islands in the Bay of Bengal to the south of the country. Strong south-westerly wind is available in the summer and a moderately north-easterly wind blows in winter in Bangladesh.

Table 1.1. Electricity capacity (MW) of Bangladesh from wind energy in 2018. (Source: IRENA (2019), Renewable Energy Statistics 2019, the International Renewable Energy Agency, Abu Dhabi.)

Country/area	*Indicator*	*Technology*	*2018*
Bangladesh	Electricity capacity (MW)	Wind	3

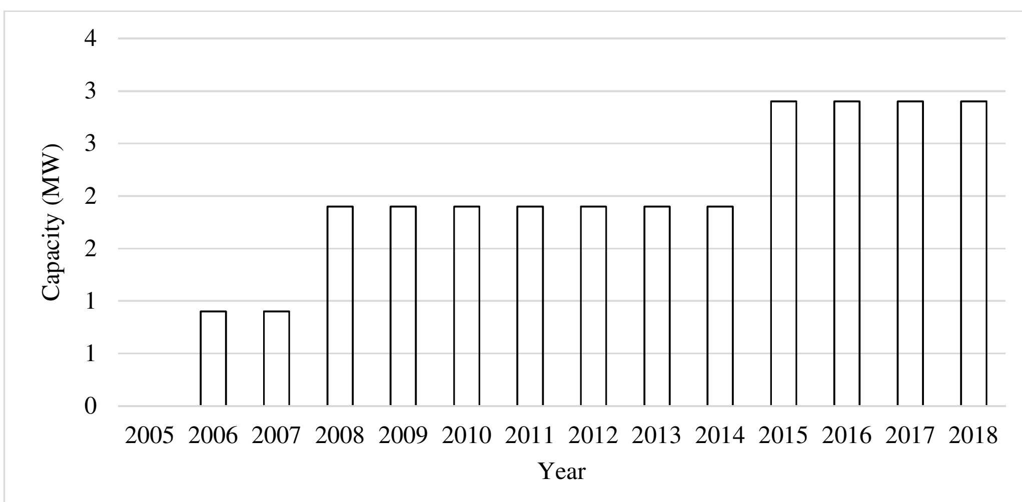


Figure 1.9. Wind energy capacity of Bangladesh by year [40].

Long term wind flows on an average between 3 - 4.5 m/s for summer and monsoon seasons (from the months of March to October) and 1.7 - 2.3 m/s for remaining of the year. Due to low wind in comparison to the countries suitable for large scale wind energy generation, Bangladesh didn't have the capacity so far in the sector. Table 1.1 shows the wind energy capacity for both offshore and onshore area for the year 2018. Bangladesh is industrially a low developed country. As a result, the country is not that much ahead of economic development. Industrially lagging is due to its scarcity and usage of electric power. Bangladesh Government (GoB) has taken a vision for providing electricity for all the citizen by 2020.

The coverage of electricity today stands at around only 32% of the total population makes as one of the lowest in the world with having a large unsatisfied demand for energy growing by 10% annually. The per-capita production of energy is additionally essentially low with 158 kWh/year (FY 2005) (Ministry of Power, Energy and Mineral Resources, GoB and National Energy Policy Bangladesh). Step by step wind energy investigation in Bangladesh isn't growing up or dismally gradually. Various inadequate exploration for little wind instances and wind-solar oriented hybrid frameworks have been introduced so far by Grameen Shakti, and Local Government Engineering Department [41]. Figure 7609345 shows the yearly wind energy capacity. This covers both offshore and onshore wind energy in the country which identifies that how meagre is the wind energy application.

Today's globe, when suffering from sufficient power crisis with the increasing rate of environmental threats, there needs to setup more and more alternative sources to be found out, so that the crisis and threats can be mitigated. Wind power as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, and uses little land [42]. There needs to employ wind as the source of power for the countries where it is suitable. For the necessity of providing all the people a green energy, wind power becomes an ideal one and is a proven way to produce electricity significantly cheaper than the conventional power sources. Wind is an inexpensive source of electricity, competitive with or in many places cheaper than coal or gas plants [43] [44]. Energy supply is a major problem for all classes in Bangladesh. The energy consumption rate is 208 kWh/capita, which is the lowest in the world. Bangladesh Meteorological Department (BMD) stations located many places around the country measure winds at lower height (10 meters from ground level), and it has been found that BMD data gives low values due to the obstacle effect by trees and buildings close to the met stations [45].

For fossil fuel becoming more expensive and difficult to explore, the alternative solution of energy source is the demand of the time. As the resources are limited, it has to be thought of how to devise ways in power solution which would help great, and more efficiently so that the future generation doesn't face power criseswhich will invoke the concept of sustainable energy generation. As the agriculture plays the vital role of the economy in the third world, it is a must to know how they are using electricity in the farming production. As the coming world is going to face the ultimate scarcity of fossil-fuel, we have to search for alternate source of power. There could be no alternate way except for we need to utilize environmentally friendly power source to address the issues. Circuitous energy utilized in agribusiness, including upstream usage from data sources like manures, pesticides and water siphons and downstream use for preparing, and dispersion, surpasses on-farm use for fuel and makes cultivates especially powerless against price spikes [46].

So, it is renewable energy that would be the power substitute when environmental impacts are a great concern throughout the world.Some studies in wind energy show that the wind observing stations of Bangladesh Meteorological Department (BMD) mostly setup in unsuitable areas measure low wind speed near the ground level at height of around 10 m from which wind forecast for the seacoast and coastal islands are not possible which have been identified to have many good sites with prospective wind speed [47] [48].

1.3. WIND ENERGY AND SUSTAINABILITY

Today, wind is one of the fastest growing renewable energy technologies [49] along with the sources of energy available on earth. Wind produces energy with its speed, the value of which and the direction is controlled by some atmospheric parameters like temperature, humidity and the difference of air pressure. When the term sustainability comes to mind, the most notable thing is to consider the carbon footprint. Today's world, something sustainable means it is less responsible for emitting carbon byproducts. For wind energy, the production mechanism is that, the carbon footprint is very low. If the production cycle of the various parts of wind turbines are ignored, only the energy comes from wind is complexly clean and reliable. The following points will demonstrate wind energy to be one of sustainable energy sources.

1) The cost of wind energy is very low
2) The energy is sourced locally
3) Wind energy is crucial to helping spur economic growth
4) Wind is an infinite energy source
5) The impact on the environment is very small
6) Wind farms are very effective in saving carbon dioxide.

But one thing is of great concern regarding wind energy that the stability and security of this energy source is very low in terms of Asian region. It is found that only 20%-30% of the total time of a year can be harvested for real energy generation in Asia. Also when capacity factor is talked about, its range is between 20 and 40%, with values in especially desirable locations at the upper end of the range. Many factors such as wind speed variation and generator size influence the capacity factor.

Electrical power created from wind can be exceptionally factor at a few distinctive timescales: hourly, daily, monthly or seasonally. In any case, wind is consistently in steady supply some place, making it reliable in terms of energy stability since it will never lapse or get wiped out. Yearly variation likewise exists, however isn't so huge. Like other power sources, wind energy must have to be well scheduled. Wind power control techniques should be utilized, yet consistency of wind plant yield stays low for momentary or short-term operation. Since instantaneous power generation and utilization of energy must stay in equilibrium in order to keep up the power grid to be stable, this inconstancy can display considerable challenges to consolidate a large share of wind power into a matrix framework (grid system).

With the rising proportion of wind power in the power system, fluctuations and drop of wind power will have obvious negative impacts on that area where the grid connections are weak. Wind energy to be conducive to security and stability, it needs to study and develop the measure the safe and stable operation of the system.

The word 'sustainability' means quality of being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged [50]. It refers to something to be able to last or to be able to continue for a long time or to have the ability to be maintained at a certain rate or level. When the word is used in refer to available resources, the meaning of the word becomes 'without becoming depleted or destroyed'. When it is said that the resources or the energy are sustainable, it first comes to mind that, the usage of that resource will not hamper the earth's environment the way conventional resources or energy sources are doing. There is no such thing as a sustainable use of a non-renewable resource, since any positive rate of exploitation will eventually lead to the exhaustion of earth's finite stock [51]. The globe as a whole have reached to an agreement that, it's the time to save the earth by reducing the limitless usage of fossil-based resources.

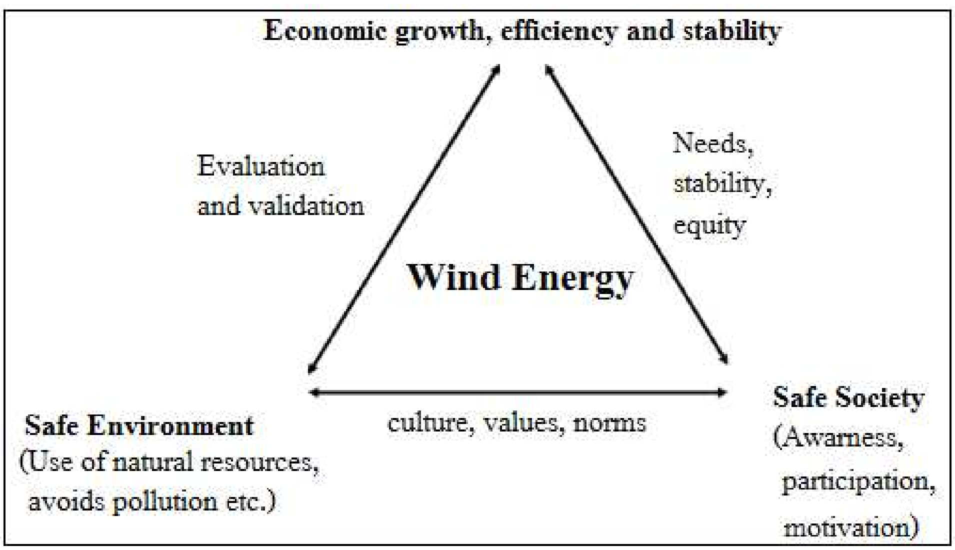


Figure 1.10. Wind energy and sustainable development.

In this context, wind energy has been emerged as one of the prime area towards maintaining sustainability throughout the globe. The research in wind energy will require big data which engages both meteorological data and satellite simulated retrospective data for the completion of the validation process, which appears to be the most important part of a research. The whole actions taken in wind energy research will follow the road to sustainable development through the steps shown in figure 1. Research in wind energy analysis and wind mapping with big data which could be hold by remote sensing technologies with the help of GIS which maximize the opportunity to identify the potential of a specific area/site for understanding the wind characteristics will help the earth for ensuring sustainable development in the following ways. This can be demonstrated and can be related with the 5 (five) P's strategies (People, Planet, Prosperity, Peace and Partnership) SDG (sustainable development goal) has taken. The 17 UN Sustainable Development Goals give a worldwide arrangement for a sustainable future, both monetarily and environmentally [52].

1) Wind power projects will yield job opportunities (green job). As far as per kWh of energy production is concerned, wind energy creates more jobs than fossil/coal-based energy production.
2) Wind generate electricity through the avoidance of carbon emission thus takes part in reducing emission of CO_2.
3) SO_2 is a byproduct of burning fossil fuels. SO_2 in the atmosphere react with other chemicals and it form acidic compounds. Power through wind emits no SO_2 thus takes part in reducing SO_2 emissions.
4) Depletion of natural resources is not the act of wind energy sector. Wind energy is green. It is renewed every day as the changes occur every moment on earth (through heating and cooling).
5) The energy generated by wind turbines is able to balance the energy and also is able to mitigate the excessive usage of fossil-based resources.

The vision to build sustainable development can be setup by making one question: What it needs to think the world will be like after twenty years, or in 2050 or any stipulated future time? If the answer can be found, it is possible to set the vision for sustainable development throughout the world. Now is the Decade of Sustainable Energy for All (2014-2024) as designated by the UN. As a part of sustainable development programs, the renewable energy (wind energy in particular) researchers will favor talking about this specific area as far as sustainable energy is concerned by visualizing the energy objectives in compatible with what is defined by the UN:

1) To guarantee all inclusive admittance to current energy administrations,
2) To twofold the pace of progress in energy effectiveness,
3) To twofold the portion of environmentally friendly power in the worldwide energy mix.

In a nutshell, big climatic data analysis (wind speed. direction, temperature, humidity etc.) as well as wind mapping endeavors by some well-known software like ArcGIS, WAsP etc. in research will create new ways and opportunities economic development, social development and environmental protection for future generations as SDG by United Nations specifications. Taking part in global sustainable development movements in a way that the energy transition might be suitable for making the globe a “Green Globe”, the vision should work for the advancement of green technology, restoration of the degraded eco-systems, building carbon-free social development, assurance of energy security and employment of clean energy technology. To realize this vision, the mandates given by the UN along with other local and global NGOs, government and inter-governmental body should be well understood and practiced well, and the people of this arena should be committed to operatively pursuing in this kind of global realization. Two future scenario can be envisaged:

1) The DAU scenario: The future world will be more crowded. Villages will be destroyed to build an urban world. People will live in concrete forests. This is a proposition towards the concept of dynamic as usual (DAU). The people, the economy, life support, the nature, community and society will be under some threatening questions, under some infallible situation.
2) The sustainable development scenario: It needs to visualize the future world in such a way that the people all over the globe are able to live at peace. But the assurance of it can only be achieved through knowing and realizing how to adapt to the impacts of the present and future climate change through the reduction of GHGs. Climate change mitigation, energy security and air pollution- these all three are directly related to the use of

energy. Upon caring for the usage of renewable energy resources, the globe has the only chance to be safe in terms of the sustainable environment.

Sustainable development activities will be at the forefront in all sector of research in terms of renewable energy, and there are still numerous, innovative and feasible pathways. It's the time to fix the vision in making sustainable development through sustainable energy solutions.

1.4. MOTIVATION

In consideration to sustainable development in energy supply system, wind energy potential assessment, wind mapping and wind farm design are crucial as well as important area to work within the context of current global warming situation. Attention to the Kyoto Protocol 1997 for energy saving programs worldwide with the attempt to manipulate environment-friendly technologies is now a very crucial talk and thought. In this term, wind energy endeavors along with other renewable energy generation are increasing. Perhaps in the future, it has to be needed to find some more alternative sources of energy as well.

Wind is by far most brisk entity in nature as well as unpredicted too. But a proper site selection might be very much effective in building wind farms. When the decrease of emissions of CO_2 and other poisonous elements is a great concern, there are few sources to be found in nature like wind. As a result, developing wind energy sector more creative and more functional is now is one of the major challenges in the energy sector on earth. At an international level, wind as an energy carrier is one of the major sources to be dealt with for getting a pathway towards a future sustainable energy society.

To the nature, it is very much expected to contribute both to the reduction of air pollution along with CO_2-reduction. With this, it is also expected to get energy supply stability. This research might be one of many steps that intend to help in the future development of the scientific endeavors of wind energy.

1.5. RESEARCH PROBLEM

The prime focus of the research is to analyze and to understand the wind characteristics globally and regionally emphasizing on building wind resource maps for low speed wind. The research would follow in making wind atlas for the better understanding the wind situation of the region.

1.6. OBJECTIVES

This is the legal and logical plans of action which will help the researcher for gathering knowledge in the context of continuous improvement in the related field to work for the benefits of society and mankind in local and global manner. In order to meet the need of power from the wind in the present and future days for building a sustainable environment, the current wind energy research has the following objectives:

1) To identify the wind characteristics in three Asia and Pacific countries. The countries are, Thailand, South Korea and Bangladesh.
2) To analyze the wind power potential in the projected regions/countries.
3) To build-up wind resource atlas for selected areas/sites.
4) To forecast wind which can help utilities and grid operators better foresee the production level and make it simpler to fulfill purchasers' power need for energy and dependability.

The objective of this research deals with acquiring the actual and retrospective data needed for the subsequent statistical analysis and validation work which will help gaining sufficient knowledge in the specific sector that will improve the role of the researcher to the society as a whole.

1.7. STUDY GOALS

The goals for this graduate research education are:

1) Gaining in-depth knowledge and understanding of the national and international approaches of the specialized area of wind energy issues that

covers wind energy potential assessment, demands and supply strategy, wind energy plans, RRA, collaboration, renewable energy forecast, wind turbine and farm optimization, turbine noise with environment issues etc. which are responsible for wind energy stability, prosperity and sustainability.

2) Gaining deeper knowledge within a particular specialized area of wind energy, and gain insight into literature, research methods and a good handle on current topics within the field.
3) Gaining practical experience in the research of wind energy potential assessment and wind site simulation (micro-siting) along with WFDO (wind farm design and optimization).
4) Gaining thorough experience in critical and scientific research on renewable energy and energy policy problems which will create a base and opportunity for the preparation of continuous activity in energy sector both within and outside the academia.

1.8. RESEARCH QUESTIONS

Based on the objectives and aims of the research above, the following research questions may be formulated:

1) How wind data are collected?
2) What are the ways wind data can be helpful for analysis?
3) What tools are used to analyze wind data?
4) Considering economic and financial perspective, is it viable to launch wind turbine or building wind farms in the projected sites?
5) What are the barriers?
6) What are the impacts of risk considerations regarding wind energy source?
7) What are the technical and environmental barriers in implementing wind energy standard, policy and regulatory framework?
8) What are the social and cultural effects that are related to sustainable livelihood while focusing wind energy as a potential source of power generation?

9) How much does the existing international standards for renewable energy integrate the national needs?
10) Does the existing wind energy policy consider the site specific or site suitable criteria for promotion, generation and distribution of power?
11) How much capabilities the policy of the respective region, such as AEDP, has achieved in terms of the regulations given by IRENA?

For future analysis in terms of broader sense of energy and environment, the following questions can be thought of:

1) What are the policies and incentives that will be taken in order to drive the utility-scale wind energy both regionally and globally?
2) How will the different forms of wind energy development projects can affect the ecology of the environment?
3) How will wind power development affect the local residents in terms of habits, livelihood, behaviors and cultures?
4) Will the opinions of the residents and information gaps be well addressed?
5) How are decisions being made in the solar energy siting process?
6) What changes that may take place and improvements that may cause can be adopted to more effectively in wind energy facilities with occurring minimal ecological impact?

1.9. PURPOSE AND SCOPE OF THE RESEARCH

The purposes of this research are

1. To suffice as much as knowledge and wisdom in energy sector (as a whole) so as to contribute to society both in local and global manner in terms of sustainable development.
2. To create opportunity to work both within academic enclosure and outside.

The proposed area has plenty of renewable energy resources especially wind energy which is found suitable for energy production in different parts of the region. Since wind energy has not been sufficiently exploited, the energy demand is not satisfied from the existing power supply system, there are lots of work can be done in this sector such as to work more to identify the potential areas as well as to work with energy policy to build a sustainable energy production culture.

As the goal of this research is to present a series of qualitative and quantitative analyses in wind energy sector that together can be able to provide a framework for the conducive and evaluated proposed utility-scale wind energy prospects in both regional and global basis. In order to ensure proper wind energy generation along with the conservation of ecosystems, the scopes of the study are like following:

1) A ‘do nothing’ alternative
2) There are still sufficiently exploited area for wind energy generation
3) Wind energy resources yielding opportunity to investigate
4) A varying type, size and capacity of analysis can be done in this sector
5) Both offshore and onshore wind energy prospects are huge.
6) Available technologies and its continuous development are prevailing.
7) Local and global policy analysis can be made up due having the lack of inconsistency and implementation.

The gap among wind site exploration, funding, culture, environment and policy implementation etc. has instigated the researchers throughout the world from different aspects to work more on this sector which yielded the door of great prospect for both the community and the researchers. The deployment of wind energy extraction systems requires reliable data collected for the farms to be built-up for a particular area, and for policy makers and thinkers a great way to find suitable opportunity to match the wind technologies with those policies.

1.10. LIMITATIONS OF THE STUDY

Wind energy shares a ton practically speaking with solar energy regarding consistency. Despite the fact that the current research tends to qualify as an inexhaustible asset for future research, wind speed fluctuation can be a major frustration to analyze data with integrity undertaking just to wind up with proper validation. As wind is difficult to model as it is quite unpredictable for its speed and direction changing quickly, the reliability analysis will face big challenge. While a satisfactory adjustment of energy analysis requires the integration of wind energy comes from the proper error analysis, the requirement for holding wind power output is firmly associated with the exactly selected validation methods, which is tough to identify. As an example, the tail part of the probability density function (pdf) can stand as the difficult area to forecast.

At times, for holding the wind data there is seen that a lot gust wind data are there should be "unloaded" or "spilled." This extra-ordinary wind data causes the test turbine to dump because of its mechanical restrictions. Some of the time, electrical output from the data analysis is too low to even consider devouring the entirety of the wind power. The exchangeable terms "wind dumping" or "wind spilling" creates these circumstances.

Wind energy comes with its own very sensitive environmental impacts and big costs which cannot be associated with this research for its broadness of analysis though it is a heavily related issue in terms of sustainable development.

In addition to these kinds of anomalies, difficulties in selection of right data source, data integrity, reduction of data sets, lack of precise training etc. may diminish the pace of research. Moreover the societal and cultural issues might have some extent of sensitivity in terms of when research relating to environment is concerned. In contrast to it, no indicated bound for current wind energy study that might influence the validity of the study. The researcher will follow all the possible methodologies to perform.

1.11. STRUCTURE OF THE THESIS

This research proposal is divided into seven chapters:

- Chapter One: This chapter will give the introductory overviews of wind energy research highlighting some background information.
- Chapter Two: This chapter will go for literature review by keeping a look on contemporary and historical wind energy research.
- Chapter Three: This chapter describes the prospected area for wind energy analysis. In addition, this section provides the overview of the methods of wind energy potential analysis that are hold by the contemporary research

in this field from global and regional perspectives. It describes wind mapping methods used or to be used in this research, including WAsP and ArcGIS software, introduction to the data sources that are used for analysis, the wind mapping procedure, and validation analysis. In addition to it, the chapter will discuss about wind turbine noise analysis and environment issues related to turbine noise.

- Chapter Four: Chapter five will discuss about the challenges and possible gaps of wind energy research.
- Chapter Five: This section will give an overview of the expected results of the future research hold by this proposal.
- Chapter Six: It summarizes the overall discussion.

Chapter 2

Literature Reviews

2.1. INTRODUCTION

Wind energy is considered to be sustainable from an environmental point of view, where sustainable is defined as meeting society's current needs without harming future generations. Because of the fuel being free, wind energy provides the ultimate in energy independence and it becomes denoted as clean and renewable. Wind energy analysis is complex, not easy to understand. Ding et. al. [53] presents a couple of nonparametric data analytic methods for the researchers relevant to wind energy applications with real life example for demonstration in a usable and understandable way.

The climate of the earth varies on many different factors in both spatial and temporal scales. Change in the temperature of the atmosphere also causes the pattern of the wind flow to be changed. A felicitous modern era of sustainable energy, more specifically wind energy is dawning and many researches and practical applications have already been done. Keeping with the pace of the current research activities in wind energy from different corners, more efforts are to be made with time series data for wind speed, wind direction and temperature of atmosphere in order to correlate and to understand the wind resource analysis of a particular region. One of the most important areas in climate research is to understand and predict changes in regional climatic characteristics [54]. In the same way wind energy resource analysis demands all relative climatic data analysis in time-series manners. Wind data analysis and precise wind energy potential appraisal is basic for appropriate and productive advancement of wind power application which is profoundly site-dependent.

2.2. WE HISTORY: RESEARCH, DEVELOPMENTS AND TRENDS

2.2.1. Ancient ages

The Babylonian ruler Hammurabi wanted to utilize wind control for his ambitious water system venture in the seventeenth century BC (before Christ) [55].

Saint of Alexandria (Heron) in first-century Roman Egypt portrayed what gives off an impression of being a wind-driven wheel to control a machine [56][57]

Another early case of a wind-driven wheel was the prayer wheel, which is accepted to have been first utilized in Tibet and China, however there is vulnerability over the date of its first appearance, which could've been either around 400, the seventh century [58] or later [59].

2.2.2. Middle Ages

Wind-controlled machines used to granulate grain and siphon water, the windmill and wind siphon, were created in what are presently Iran, Afghanistan and Pakistan by the ninth century [60][61] . The primary useful windmills were being utilized in Sistan, an area in Iran and flanking Afghanistan, in any occasion by the tenth century and conceivably as exactly on schedule as the mid-to-late seventh century which were level windmills, and had long vertical drive shafts with six to twelve rectangular sails canvassed in reed tangling or fabric [62]. These windmills were utilized to siphon water, and in the grist processing and sugarcane enterprises [63].

The utilization of windmills got broad over the Middle East and Central Asia, and later spread to China and India [64]. Vertical windmills were later utilized broadly in Northwestern Europe to crush flour starting during the 1180s, and numerous models still exist [65]. By 1000 AD, windmills were utilized to siphon seawater for salt-production in China and Sicily. The first windmill in Europe appear in sources dating to the twelfth century regarding a windmill dates from 1185, in Weedley, Yorkshire, though different earlier yet less emphatically dated twelfth-century European sources implying windmills have moreover been shown [66].

While it is every so often contended that crusaders may have been animated by windmills in the Middle East, this is unrealistic since the European vertical windmills were of basically surprising arrangement in contrast with the even windmills of Afghanistan. Lynn White Jr., a genius in middle age European advancement, verifies that the European windmill was a "self-governing turn of events;" asserted it is outlandish that the Afghanistan-style windmill had spread as far west as the Levant during the Crusader time span [67]. In medieval England rights to water-power objections were regularly restricted to decency and pastorate, so wind power was a huge resource for another middle class [68].

2.2.3. Eighteenth century

Windmills were utilized to siphon water for salt making on the island of Bermuda, and on Cape Cod during the American unrest [69].

In Mykonos and in different islands of Greece windmills were utilized to plant flour and stayed being used until the mid-twentieth century [70]. A considerable lot of them are currently renovated to be occupied [71].

2.2.4. Nineteenth century

The first wind turbine utilized for the generation of power was worked in Scotland in July 1887 by Prof James Blyth of Anderson's College, Glasgow, and Blyth's 10 meters high, fabric cruised wind turbine was introduced in the nursery of his vacation bungalow at Marykirk in Kincardineshire and was utilized to charge gatherers created by the Frenchman Camille Alphonse Faure, to control the lighting in the cabin [72], subsequently making it the primary house on the planet to have its power provided by wind control [73]. Blyth offered the surplus power to the individuals of Marykirk for lighting the central avenue, in any case, they turned down the idea as they suspected power seemed to be "crafted by the fallen angel" [72].

In spite of the fact that he later assembled a breeze turbine to supply crisis capacity to the neighborhood Lunatic Asylum, Infirmary and Dispensary of Montrose, the innovation never truly got on as the innovation was not viewed as financially practical [72]. In the mean time in 1850, United States Wind Engine Company was set up. Over the Atlantic, in Cleveland, Ohio a bigger and vigorously built machine was structured and developed in the winter of 1887–1888 by Charles F. Brush [74]. This was worked by his building organization at his home and worked from 1888 until 1900 [75]. The machine fell into neglect after 1900 when power got accessible from Cleveland's focal stations, and was deserted in 1908 [76]. A piece previously, in 1890, the breeze control in USA was utilized for siphoning water and power, and in 1893, for windmill, steel edges were concocted.

In 1891 Danish researcher, Poul la Cour, built a wind turbine to create power, which was utilized to deliver hydrogen [72] by electrolysis to be put away for use in tests and to light the Askov High School. He later tackled the issue of creating an unfaltering inventory of intensity by developing a controller, the Kratostate, and in

1895 changed over his windmill into a model electrical power plant that was utilized to light the town of Askov [77]. In the American Midwest somewhere in the range of 1850 and 1900, an enormous number of little windmills, maybe 6,000,000, were introduced on ranches to work water system siphons [78].

2.2.5. Twentieth century

Some historical facts can be cited here.

1941: Biggest Local Power Utility using Turbine during WWII

1978: President Signed Public Utility Regulatory Policies Act of 1978

1978: Wind turbine manufacturer named Vestas in Denmark produced its first wind turbine.

1980: First Large Wind Farms are installed

1980: The levelized cost of wind energy is now $0.38/kWh (kilowatt hour) in the United States.

1991: Denmark constructed the first offshore wind farm in the world.

1998: China-based Goldwind is formed to manufacture wind turbines.

2014: Over 240,000 commercial-sized wind turbines in the year 2014 were in production in the world, producing 4% of the world's electricity [79][80].

2.2.6. Twenty first century

2.2.6.1. Trends in twenty first century

Historically twenty first century faces the utmost development in wind energy technologies. Following are some of the trend regarding US wind energy along with some related issues.

2005: 226 wind farms are online in the US, providing enough power for up to 2.20 million homes.

2008: 20% increased by 2030. Department of Energy in The United States published a report on 20% Wind Energy by 2030.

2008: The installed capacity of United States of America reaches to 25.40 gigawatts.

2008: Nearly 2000 wind farms are in operation across the UK, producing enough electricity for over 1.50 million British homes.

2010: China passes US to become the country with the most cumulative installed wind power capacity in the world. Charts of new and cumulative wind power capacity by country [81].

2011: Japan plans a multiple-unit floating wind farm (6 wind turbines, each with 2 megawatts of capacity). By 2020, Japan intends to have up to 80 floating wind turbines off its coast near Fukushima [81].

2012: U.S. Installed Capacity Reaches 60 gigawatts. The amount of wind energy produced in the United States reaches the point of being able to power 15 million homes.

2013: First Grid-Connected Wind Turbine in offshore areas in the U.S.

As the twenty first century started, petroleum product was still generally modest, and the business in wind control industry started extending at a powerful development pace of about 25% every year, driven by the prepared accessibility of huge wind assets, and falling expenses because of improved innovation and wind ranch the executives [82].

Mechanical developments, empowered by progresses in PC supported building [83], keep on driving new improvements in the utilization of wind control [84][85].

By 2015, the biggest wind turbine were 8 megawatts limit Vestas V164 for seaward use. By 2014, more than 240,000 business estimated wind turbines were working on the planet, delivering 4% of the world's power [86][87]. Absolute introduced limit surpassed 336 gigawatt in 2014 with China, the U.S., Germany, Spain and Italy driving in establishments.

2016: First Commercial Offshore Wind Farm was built in US.

2018: U.S. Introduced Capacity Surpasses 96 Gigawatts. The wind energy introduced in the United States is sufficient to control more than 28 million homes [88].

2.2.6.2. Floating wind turbine innovation

Offshore wind power started to extend past fixed-base, shallow-water turbines starting late in the primary decade of the 2000s. The world's first operational profound water huge limit drifting wind turbine, Hywind, got operational in the North Sea off Norway in late 2009 [89][90] at an expense of somewhere in the range of 400 million kroner (around US$62 million) to assemble and convey [91].

These drifting turbines are an altogether different development innovation closer to gliding oil fixes rather than conventional fixed-base, shallow-water monopile establishments that are utilized in the other enormous offshore wind farms to date. By late 2011, Japan reported designs to manufacture a different unit skimming wind farm, with six 2 megawatts turbines, off the Fukushima bank of upper east Japan where the 2011 wave and atomic catastrophe has made a shortage of electric power [92]. After the assessment stage is finished in 2016, Japan intends to work upwards of 80 drifting wind turbines off Fukushima by 2020 [92] at an expense of some 10 - 20 billion Yen [93].

2.2.6.3. Airborne turbines

Airborne wind energy frameworks use airfoils or turbines bolstered noticeable all around by lightness or by streamlined lift. The reason for existing is to dispense with the cost of tower development, and permit extraction of wind energy from steadier, quicker, twists higher in the environment. So far no framework scale plants have been developed. Many structure ideas have been exhibited [94][95][96].

2.3. RESEARCH SCENARIO IN PROJECTED COUNTRIES

This section discusses the research activities taken place the Thailand, South Korea and Bangladesh which inspired this author to work in this region.

2.3.1. Thailand Wind Energy Research

Terry [97] identified the potential for wind-power generated electricity in Thailand by means of a wide-ranging literature survey. The requirement for improved low wind speed turbine execution for Thai applications is featured in this paper by comparing at the yield of industrially accessible wind turbines for Thai wind.

Unchai et. al. [98] worked on the hourly measured wind speed data for years 2008-2010 at 10 meter, 30 meter and 40 meter height for Ubon Ratchathani province in kingdom of Thailand. They have statically analyzed to determine the potential of wind power generation with the help of Parameters of Weibull distribution which have been assessed for yearly and monthly basis utilizing two strategies; the graphical method and the another strategy, assigned in this paper as approximated method, which relies upon the standard deviation and normal wind speed.

Chana et. al. [99] stated in their work to emphasize the capacity factor of WTG to be around 20% will be economically viable.

Glassbrook et. al. [100] had their study to assess the environmental implications and economic feasibility of small wind turbines.

Kittikorn [101] had his research on statistical information of wind data and power curves of wind turbines for the sake of establishment of annual energy production and capacity factor of WTG with the help of several case studies in the northern region of Thailand for the analysis on wind speed and wind direction measurement at 40 meters from ground level for seven meteorological stations.

Chana et. al. [102] worked on the assessment of onshore wind energy potential in Thailand. They used Regional Atmospheric Modeling System (RAMS) with a 9 kilometers resolution with an area of 1,150 kilometers /1,750 kilometers wind resource atlas at the height of 120 meters on the basis of the NCEP reanalysis database for the three year period from 2009 to 2011.

Major et. al. [103] measured the potential for wind energy generated electricity in Thailand by means of vast literature survey which shows the proposed application at a university campus that was considered as a case study to identify that wind energy is unlikely to be economically competitive comparing to grid-connected electrical power.

Tanate et. al. [104] worked as an investigator of wind energy at Chiang Mai Province, Thailand by taking real wind data from the weather station at Chiang Mai International Airport somewhere in the range of 2001 and 2006 which was dissected to acquire the potential energy produced by a Vertical Axis Wind Turbine (VAWT).

Sakkarin et. al. [105] had a critical review of the current status of wind energy in Thailand, including future plans for using wind energy in place of fossil fuels – oil, natural gas, and coal - to generate electricity.

2.3.2. Republic of Korea Wind Energy Research

South Korea declared its course of action to diminish its ozone harming substance emanations by 30% by 2020 by passing on sustainable energy framework, especially within wind energy frameworks [106]. In spite of the fact that a little country in size, this nation is the 10th greatest energy shopper on the planet. Being the seventh greatest carbon dioxide producer as far as worldwide energy utilization in the recent years, South Korean government as of now taking more activities to improve energy security and diminish ozone harming substance emanations. So as to construct a sustainable society, the nation is in a full speed of exploring the expected locales for wind energy generation.

Oh et. al. [107] worked on the identification of the design parameters of the demo-farm including seasonal and diurnal changes in wind speed and surface roughness as well as wind/energy rose with estimating long-term wind potential by using MCP (Measure-Correlate-Predict) techniques to clarify the design basis and to determine the wind turbine class in accordance with IEC 61400.

Kim et. al. [108] worked on the evaluation by the comparison of the offshore, onshore, and Island wind data recorded from meteorological tower.

Ali et. al. [109] estimated wind energy related parameters such as AEP (annual energy production), CF (capacity factor), LCOE (levelized cost of electricity), and NPV (net present value) for some sites, using five different wind turbines manufactured in South Korea.

Kim et. al. [110] worked on wind data analysis on South Korea in showing the capacity factors of wind energy which was found to be 23% along with identification of wind energy status of the country.

Ko et. al. [111] worked on annual wind data in 2014 at six locations are collected and analyzed in order to review optimal candidate site for offshore wind farm in the Western Seas of Korea. Observed wind data is fitted to Rayleigh and Weibull distribution and annual energy production is estimated according to wind frequency.

Mohammed et. al. [112] examined about the chances and difficulties of wind energy in South Korea by finding the most encouraging answers for accomplish the objectives of sustainable development, energy security, and environmental protections that are liable for strengthening the part of environmentally friendly power in electricity generation.

2.3.3. Bangladesh Wind Energy Research

In Bangladesh, systematic wind speed study has been made in a very small scale. Bangladesh Meteorological Department (BMD) is the sole government organization meant for climate and weather forecasting. So far as the research has been done from the data provided by BMD, it is insufficient for the determination of wind energy potential throughout the country. Historically, in early 80's, there had been a research with time series meteorological data for 30 years from a number stations controlled by BMD throughout the country were considered. It was found in that research that, wind speeds in some part of Chittagong district and Cox's Bazar district were the promising area to work on wind energy with an extension of the coastal area in the same part of the country.

Some measurements were made by F. Rahman in some coastal areas followed by a year's measurement in Patenga (Chittagong) at a height of 20 meters in 1995, where it was found that wind speed is higher than the values obtained by the meteorological department that led to a year-long systematic wind speed study at seven coastal sites in 1996-97 at a height of 25 meters by Bangladesh Centre for Advanced Studies (BCAS), in collaboration with Local Government and Engineering Department (LGED) and Energy Technology & Services Unit (ETSU), UK which was financially supported by the British Government [113].

The BCAS study first made an analysis of available meteorological data and established the following worthwhile information:

Kibria et. al. [114] investigated on previously collected wind data for wind resources measurement in Bangladesh and by analyzing this data, they were to predict the wind energy if they are sufficient commercial wind power generation.

Amin [115] has the analysis on previously collected data to measure wind energy potential at different areas of Bangladesh. They observed the feasibility to setup wind farms in different regions in professional level for the production of electricity. The irrigation of the farming related to wind farm are also described briefly. Working principle and design criteria for the installation of wind farm have also been discussed here in this paper.

Azmi [116] in her work analyzed the wind energy economics for the coastal area of Bangladesh.

Safiullah et. al. [117] considered the previous studies on energy conversion efficiency and economic condition of Bangladesh. They worked on vertical type three blade wind turbine to investigate its performance in rural areas.

Hossain et. al. [118] works on the renewable energy resources in Bangladesh and the percentage comparison of wind energy feasibility especially on the parameters like average speed vs. time duration, speed vs. location as well providing the information obstacle to implement of wind energy in Bangladesh. They relate their works with government policies and future plan and found that wind speed in some regions are good enough for the pumping water for irrigation and also for generation of electricity.

Safiullah et. al. [119] present the examination with a mean to process the capability of wind energy in Bangladesh as a type of manageability to relieve the energy emergencies. They dealt with the wind speed at six seaside zones: Patenga, Cox's Bazar, Teknaf, Char Fassion, Kuakata and Kutubdia at Bay of Bengal of Bangladesh. In this work, a close to shore wind farm has been considered at these areas.

Alam et. al. [120] analyzed wind speed data for Kuakata, Sitakunda and Kutubdia from January to December, 2006 to determine the potential for wind power generation where the variation of wind speed and direction with year, month and time of the day have been studied for proper selection of wind turbines based on Weibull Parameters.

Azad et. al. [121] had comprehensive study with the observation on wind regions considering 20 different areas including come of the hilly areas in the south of Bangladesh. They worked on the data over longer period of time.

Islam et. al. [122] did their analysis based on a 2-parameter Weibull PDF method, where wind characteristics and assessment of wind energy potential has been analyzed using the wind speed data of the period 2002-2011 at 10 m height of Cox's Bazar, the longest sea-beach located at the southeast of Bangladesh.

2.4. WIND RESOURCE MAP

The current research deals with building wind energy maps from NOAA online database for some coastal area of Bangladesh along with western and north-eastern region of Thailand. For Bangladesh, firstly mesoscale maps will have been built for a better understanding of the characteristics of wind in a vast area (a big domain of a grid in a map). Mesoscale and microscale modeling can be explained from the map as shown in table 5.1 by the identification of their distinction.

Table 2. 1. Mesoscale and microscale map explained.

Mesoscale map	*Microscale map*
Solve velocity, temperature and many factors. Usually weak mass conservation. Coarse grid resolution (a few kilometers to 500 meters). Ignore local effects (hill).	Solve velocity and pressure, sometimes temperature. Have a high grid resolution (a few meters) Detailed ground roughness models and forest. Computationally expensive. Ignore a lot of atmospheric phenomena Usually use idealized wind profile.

A wind map both mesoscale and microscale map contains time-series data with frequency distribution of it that includes wind speed and wind direction data in a particular region. In general, a wind map contains hourly averages wind speed data at an internationally standard height (10 meter) over a longer periods. But most recognized timely data are considered to be of 10 minutes averaged data other than hourly averaged data. That's why averaging time, height and period for analyzing the wind data may be different due to the difference in demand. Among many applications like climate analysis, rainfall forecasting, pollution monitoring, a wind map is mostly applicable and important for the analysis of wind energy potential which eases the identification of a particular site planned to be building a wind farm. The top wind power producing countries in the globe like the USA, Germany, China etc. have done due to the extensive use of the many years wind data and building wind maps of the respective country. Wind energy continued its dynamic growth worldwide in the year 2006 [123] till now. Research and development in this sector gives a way to mitigate the global scarcity of power as well as reducing carbonization.

Wind power installed capacity is 59,322 megawatt for the whole world at the end of 2005 [124].

Once the wind atlas will be built, it can be of great values to a number of variety of stakeholders like the academic researchers, private and public developers, investors etc. in terms of wind resource mapping techniques, Microscale and Mesoscale mapping procedure, proper utilization of data sources, wind mapping process development, wind energy life cycle analysis and validation analysis of wind energy potential measurement and wind farm development. There is a possibility that the atlas might be used for many applications including:

1) Atlas can be used together with wind energy resource development hold by national or regional energy plans.
2) Potentially suitable sites can be identified for wind energy project development.
3) Wind resource assessment analysis can be furthered with a view towards continuous development that includes site measurements, monitoring, control etc.
4) Atlas might be used as a resource for wind farm design and optimization (WFDO).
5) Micro or macro-level wind energy goals can be setup for wind resource development at a regional, national or provincial level.

2.4.1 Wind Resource Mapping Research in Thailand

Wind power potential analysis throughout the country and continuous development in this sector in Thailand will create opportunity to build an accurate wind map. In order to substitute fossil-based energy sources, Thailand foresees the significance of wind power in a very quick pace. This motivation brings forth the country to develop its alternative energy sources to a level that the goal of mitigating fossil-based power. The Department of Alternative Energy Development and Efficiency of Thailand under the Ministry of Energy, or DEDE, has concentrated on the estimation of wind energy potential since 1975, and as of now, they have various 70 wind speed and direction estimation stations, 23 of which have been arrangement at the height of 90 meters and the rest of 47 at the height of 40 meters. They intend to update all the current measuring stations to the height of 90 meters [125].

Jompob et. al. [126] had their work on building offshore wind resource map of the Gulf of Thailand having the objective of identifying the potential areas for grid connected offshore wind power development. Coupled numerical mesoscale atmospheric model and a microscale wind flow model, along with long-term global reanalysis climate data were used in their research to generate high resolution (200 meters) wind resource maps at different heights like 40 meters, 80 meters, 100 meters, and 120 meters above sea level.

Figure 2.1. Map of the Republic of Korea. [122].

Jompob et. al. [123] developed a high resolution (200 m) wind resource map for Nakhon Si Thammarat and Songkhla provinces in southern Thailand using combined mesoscale, MC2, and microscale, Ms Micro modeling techniques. These high resolution wind maps were validated with observed mean wind speeds from 10 meteorological stations located along the coastlines of the territory.

Janjai et. al. [124] evaluated the wind energy potential of Thailand by using an atmospheric mesoscale model and a Geographic Information System (GIS) approach. They validated their works with some statistical testing methods. The model they developed can measure the mean yearly wind speeds at 100 meter AGL and results were presented as a wind resource map which was incorporated into GIS application.

Kasemsan et. al. [125] worked on wind energy map on Thailand for large scale wind turbine to show the prediction and performance. The results they generated suggested a strong sensitivity of the measured technical potential of turbine technology with a suitability of low-wind-speed turbines for wind situations in Thailand.

2.4.2 Wind Mapping in South Korea

South Korea like Thailand, which is not a stranger to renewable energy, more specifically wind energy.

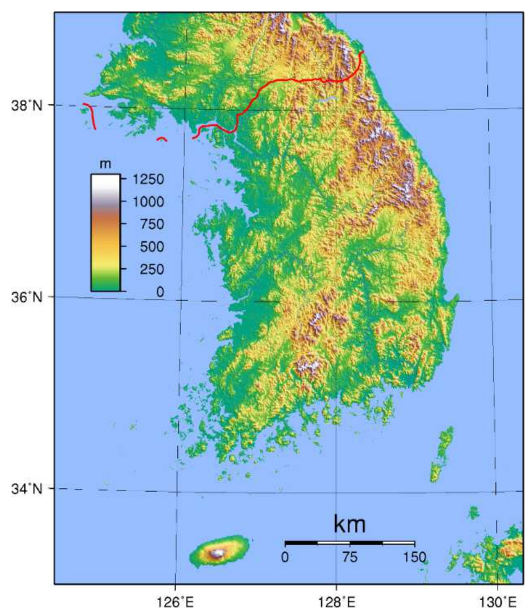


Figure 2.2. Topographic map of the Korean peninsula [126].

Though the country has 19 wind farms currently in production, there are significant number of farms are on the process of establishment. Wind energy potential assessment are being going on a pace all through the country. Some very well-known global companies like Samsung, LG, Hyundai, Daewoo etc. are entrusting renewable energy technologies within the country.

Hyun-Goo Kimet. al. [127] worked on South Korea wind resource map in order to estimate inland wind resource potential in order to mitigate the environmental regulation needed to attain the national dissemination target of wind power and determine the most suitable level of the incentive policy. South Korea is hilly and mountainous, with wide coastal plains in the west and south [128]. According to the characteristics of the terrain, the wind resource is mainly generated from offshore areas. A small portion of wind energy emerges out of the mountainous region in the eastern part of the country.

Korea didn't not constitute a high-resolution wind energy atlas for a long time. Korean Wind Energy Industry Association provided data made a wind map for the country which was actually not in the proper functioning as another highly interactive wind resource map produced by 3Tier of Vaisala energy. Later on Korean Institute of Energy Research built wind resource map of the country

2.4.3 Wind Map endeavors in Bangladesh

Bangladesh is so far not well equipped in terms of both technology and device with wind power potential analysis and generation. Analysis of wind data at some height by CWET India suggests that wind energy resource of Bangladesh is not good enough for grid connected wind farms (LGED). Wind energy has also made some inroads but its potential is mainly in coastal areas, and offshore islands with strong wind regimes. These coastal settings offer good opportunities for wind-powered pumping and electricity generation. Presently there are 2 megawatts of installed wind turbines at Feni and Kutubdia. An NGO named Grameen Shakti (GS) in Bangladesh installed 4 hybrid power stations which are the combination of wind turbine and diesel generator in four cyclone shelters of Grameen Bank of which 3 are 1.5 kilowatts and one is 10 kilowatts. Several wind resource assessment program under the name of WERM, SWERA, WRAP of BPDB are going in the country. Some previous studies can be considered for the understanding that, the small wind turbines can be installed in the coastal regions of the country [129]. Wind speed of some places in Bangladesh like

Cox's Bazar, Noakhali, Moheshkhali, Patenga and Kuakata has been measured in by the computerized anemometers.

As in Bangladesh, there is not so recognized wind map so far, it needs more research building wind resource map especially in the coastal and offshore area of the country. Previously wind map was made manually as there were no computation opportunities with the help of advanced technologies. But still in the past time some researchers from Bangladesh had endeavors in making maps. In a low economy country like Bangladesh, where a great many number of people are devoid of electricity, it needs more venture to investigate renewable power sources. Several organizations have been actively working on renewable energy alternatives for rural areas of Bangladesh [130][131][132] [133]. Assessment of wind energy resources and installation of wind energy conversion systems (WECS) in Bangladesh has long been hindered due to lack of reliable wind speed data. There is no reported wind map of Bangladesh which could be relied upon and used for wind energy assessment [132][133]. But research was done in an ongoing process to assess the suitable areas in the country, so that wind might be a solution for the endless scarcity of power in Bangladesh. For wind resource and geographical analysis of Bangladesh, the elevation map in figure 3 was built [133]. Several wind map of Bangladesh from NOAA database can be shown here for the understanding of the research related to wind resource assessment in the country [133].

Wind speed statistical distribution along with wind map for Bangladesh research has been established here and operated a comprehensive study for wind-monitoring in ten different meteorological stations all over Bangladesh. A database of high-qualityand reliable wind measurements now exists, and new information on turbulence intensity, gust wind speeds, lull wind speeds, atmospheric pressure has been obtained [134]. Wind energy potential measurement in Bangladesh will suffice only if a proper investigation of wind characteristics can be made so that furthering the research work may get continuity.

Khan et. al. [135] in their paper, presented a wind map which incorporates several microscale features, such as terrain roughness, elevation etc. with a mesoscale model, and also several meso-maps were obtained from global databases and a suitable model was chosen and modified for a 30 meters elevation through the collection of ground data from various sources for height and land condition adjustments based on local knowledge and GIS information.

2.5. WIND FARM DESIGN AND OPTIMIZATION

By the term WFDO problem, it identifies a set of advanced planning and approaches which are needed to take the performance of wind farms that may be comprised of a number of individual Wind Turbines Generators (WTGs) up to thousands of WTGs to an extreme level [136]. But the approaches for wind farm planning, design and optimization have been proven to be complex not only because of its multifaceted technological applications, but also for the numerous environments which they have to cope with. The number, size and intricacy of wind energy farms have been consistently expanding in the course of recent years as result of the aspiring objective of delivering a large share of energy from the wind [137][138][139]. Various numerical approaches used to solve the WFDO problem becomes more complex due to their modeling criteria, solution methods, limitations, and most importantly the applicability of a particular wind site. As a result, algorithms are numerous, and it's a never ending process to devise new algorithms, so that the objective functions can be met at a maximum level. Among many other factors, building a suitable wake model for a wind site is one of the most core subjects coined by the researchers.

There are many simple approach for wake modeling such as Jensen's linear expansion model as well as sophisticated models such as Ainslie's eddy viscosity model (EVM) and Crespo's UPMWAKE model. Although UPMWAKE model is regarded as an elaborate computation method with great capability for velocity fields and particularly turbulence intensity in wakes, it is unsuitable for application to an optimal design stage [140]. Researchers are continuously trying to mitigate the kinetic energy deficits taken place in the wake region. But, wind is so fickle that a perfect model build up for all types of wind site is proved to be impossible so far.

2.6. NOISE AND ENVIRONMENT ISSUES OF WTG

This section will discuss about small wind turbine noise. Small wind turbines in general are used for a variety of applications. This includes power supply for off-grid or on-grid residence, offshore establishments, schools, clinics, telecommunication towers etc. Small WTG are suitable for that requires energy but there is no electric grid for connection and supply. Hybrid solar oriented and wind powered units are progressively being utilized for traffic signage, especially in provincial areas, as they maintain a strategic distance from the need to lay long links from the closest mains association point [141]. The U.S. Division of Energy's National Renewable Energy Laboratory (NREL) characterizes little wind turbines as those littler than or equivalent to 100 kilowatts [142].

Performance measurement of wind turbine is one of the core subject to work with. In order to do it, a number of atmospheric parameters are also used for the better understanding of the turbine. Salih [143] worked on the simulation models are used to study the performance of small power systems based on different weather parameters and the results are extracted using Matlab software program for analyzing the performance of wind turbines where different parameters are shown to be responsible for affecting the performance of wind turbines which are: the wind speed air density, air pressure, temperature and the length of blades for wind generators.

However, noise is also an issue of performance of turbines where design is also a factor to be considered. As WTG emits noise, and the relationship between noise and environment is well-known, it needs to justify the noise emitted from the WTG to the extent of how much it is responsible for the hazard of environment. A recent peer-reviewed research of National Wind Coordinating Committee in USA discovered proof of the passing of bird and bat crashes with wind turbines and because of changes in pneumatic force brought about by the turning turbines, just as from territory disturbance with an end that these effects are generally low and don't represent a danger to animal groups populaces [144]. Keeping wind turbines un-moving during seasons of low wind could diminish bat passing by the greater part without essentially influencing power generation [145]. In any case, this sort of effects vary from one site to another, consequently proper examination, exploration and observing frameworks are needed for each wind farm or turbine specifically.

As far as the public health hazards are concerned, noise emitted is associated with wind turbines in operation. Turbine noise mostly of which is aerodynamic noise that is caused by the movement of turbine blades through the air accompanied by a certain level though very small, of mechanical noise generated by the turbine itself depend on design of turbine and wind speed. The more the wind speed, the more is the noise. A few group living near wind farms have griped about sound and vibration issues, yet industry and government-supported investigations in Canada and Australia have discovered that these issues don't unfavorably affect public health [146]. Innovative advances, for example, minimizing blade surface imperfections flaws and utilizing sound-spongy materials can diminish wind turbine noise [147].

Another issue is global warming though it is sought that WTG is not responsible for global warming. But if the life-cycle of a WTG is analyzed, it is found that, in some stage of its production like raw material handling etc. there is a certain amount of global warming caused by WTG too. Thus, assessment of life-cycle a global warming emissions of WTG is worth investigation. Some related evaluation of life cycle global warming emissions like natural gas used power are somewhere in the range of 0.60 and 2.00 pounds of carbon dioxide equivalent each kilowatt-hour and assessments for coal-produced power are 1.40 and 3.60 pounds of carbon dioxide equivalent each kilowatt-hour [148]. Assessments of total global warming emissions rely upon various components, including wind speed, percent of time the wind is blowing, and the material arrangement of the wind turbine [149].

One of the most complain against WTG is shadow flicker which can take place under some certain lighting conditions. There are a number of works have been found regarding this issue. The annoyance caused by shadow flicker can be minimized with careful siting, planting trees or installing window awnings, or curtailing wind turbine operations when certain lighting conditions exist [150].

2.7. WIND CHARACTERISTICS

Though wind power generated form wind is proportional to the cubic wind speed, but when it is all about to consider a specific site for a future wind energy generation field, it is very important to have the detailed knowledge of the site-specific wind characteristics along with the proper wind speed measurement. Characterizing wind is a very sensitive task since a minute error in wind speed analysis can have significant effects on the energy yield. Following are the site-specific wind characteristics:

- *Average wind speed.*
- *Frequency distribution of wind speed.* This topic has been discussed in chapter three.
- *Probability distribution of wind speed.* This topic has been discussed in chapter three.
- *Distribution of wind direction.* Wind direction can be distributed with wind speed in a frequency table. Both wind direction and wind speed are arranged by the method of bins. In the table, the frequency of wind speed can be shown as per every wind direction.
- *Analysis of distribution* in hourly, daily, monthly, seasonal and annual basis.
- *Turbulence.* In contrast to laminar flow of fluid (e.g. wind) that takes place fluid flows with no disruption, turbulence or turbulent flow is fluid motion characterized by chaotic changes in pressure and flow velocity [151].
- *Patterns of Wind Speed.* Wind speed patterns can be understood as a form of wind speed spectrum. A high value of wind speed indicates a considerable change in wind speed over a particular time period. The peaks in the wind speed spectrum account for annual, seasonal and daily patterns as well as short-term turbulences. A striking phenomenon is the spectral gap between time periods of 10 minutes to 2 hours. Wind patterns are important not only for yield estimations, but also for forecasting of wind power output.

- *Wind shear.* Wind shear is an estimation characterized by the distinction in wind speed or bearing over a generally short separation in the environment. Wind shear is likewise alluded to as wind gradient. Climatic wind shear is regularly portrayed as either vertical or level wind shear. Vertical wind shear is an adjustment in wind speed or course with change in height while laminar wind shear is an adjustment in wind speed with change in lateral position for a given elevation [152].

As expressed before, wind shear alludes to the variety of wind over either flat or vertical separations. This term is one of the most ordinarily utilized term for plane pilots who for the most part respect noteworthy wind shear to be a level change in velocity of 30 knots (15 m/s) for light air ship, and close to 45 knots (23 m/s) for aircrafts at flight elevation [153]. Vertical speed changes more noteworthy than 4.90 knots (2.5 m/s) additionally qualify as huge wind shear for airplane. Low level breeze shear can influence air ship velocity during departure and arriving in heartbreaking ways, and aircraft pilots are prepared to stay away from all microburst wind shear (headwind misfortune more than 30 knots [15 m/s]) [154].

2.7.1. Geostrophic Wind

Wind under the influence of both the pressure gradient force and Coriolis force tends to move parallel to isobars in conditions where friction is low (1000 meters above the surface of the Earth) and isobars are straight. Winds of this type are usually called geostrophic winds [155].

The geostrophic wind is the hypothetical wind that would result from a right balance and harmony between the Coriolis power and the weight angle power. This state of wind balance is due to Coriolis and pressure gradient (The adjustment in pressure estimated over a given distance) is called geostrophic balance. The geostrophic wind disregards frictional impacts, which is normally a decent estimate for the concise scale quick stream in the mid-latitude mid-troposphere [156].

Coriolis force influences the moving air causing it to deflect to the right of its path. This deflection continues until the pressure gradient force and Coriolis force are opposite and in balance with each other. Geostrophic winds come about because pressure gradient force and Coriolis force come into balance after the air begins to move [155].

Ambient temperature variation in different places may cause due to the differential heating variance on the Earth's surface. Warm air grows up and brings lower air density and pressure, while the encompassing cooler air has a higher air density and pressure. Pressure gradient is defined by the distinction in gaseous pressure between two spots on earth. Wind usually gets generated this way from the driving force what have been derived from this pressure gradient. Depending on the pressure gradient value, the driving force increases, and thus strong wind starts to blow.

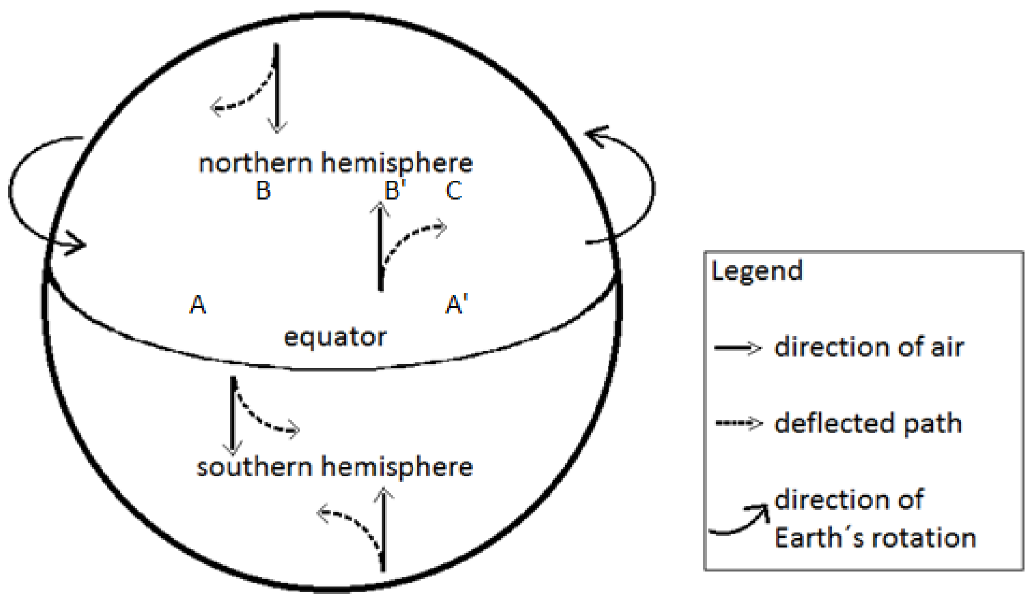


Figure 2.3. Deflection of a moving air mass on the Earth's surface [156].

In general, wind blows from high pressure to low pressure. In reality, besides air pressure, the Earth's rotation and the grounds friction also influence the wind direction. Relative to an observer in the northern hemisphere, a moving air mass will be deflected to the right due to the Earth’s rotation. Why would this happen?

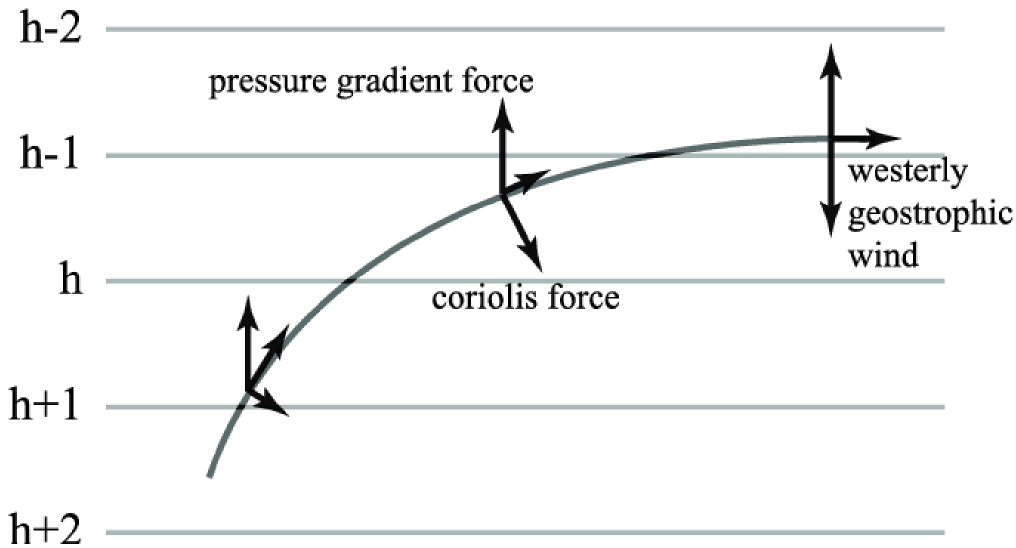


Figure 2.4. Schematic diagram of geostrophic wind formation [157].

As with the rotation of the Earth, air moves together with the surface of the Earth from west to east in the northern hemisphere. For example, an air parcel moving from A to B as shown in Figure 2.3, point A will move to position A' and the air mass will move to position C instead of B' with keeping pace to the Earth's rotation,.

This happens like that because, the moving speed of the earth at eastward direction is faster at A the speed of point B at higher latitude. As a result, the air mass will be glanced to the right in terms of the observer who is standing at point A'.

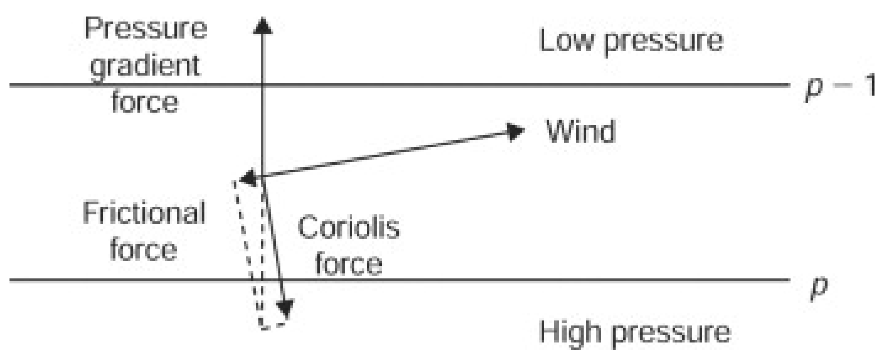


Figure 2.5. The balance between the pressure gradient force and the resultant (dotted line) of Coriolis force and frictional force [158].

Now it tends to be clarified the connection between the wind direction and direction of isobars on a climate diagram. Figure 2.3 shows an air mass moving from high pressure to low one under the pressure gradient force in the northern side of the equator. As the air mass begins to move, it is avoided to one side by the Coriolis power. The avoidance increments until the Coriolis power is adjusted by the pressure gradient force. Now, the wind will begin to blow corresponding to the isobars. At the point when this occurs, the wind is termed to as the "geostrophic wind". From Figure 2.4, a straightforward relationship can be seen between the wind direction and the pressure distribution in the northern side of the equator: in the event that an observer remain stands with his back towards the wind, the pressure to the left is lower than that to the right.

Figure 2.6. Horizontal Axes Wind Turbine [159].

In practical, as geostrophic wind is an optimal circumstance, it needs to consider the impact of the friction caused by air-ground mixing. At the point when it is seen that the pressure gradient force, frictional power and Coriolis power are in harmony, the direction of the wind will point at a little angle towards the low tension side as displayed in Figure 2.5. As the frictional force following up on an air parcel is more modest over the ocean than the land, geostrophic wind usually adjusts better with the real wind over the sea [160].

2.8. WIND TURBINE BASICS

A wind turbine, alternatively referred to as wind turbine generator (WTG) or wind energy converter, a great instance of modern technology working out for building sustainable development throughout the globe is a complex device that is used to convert the kinetic energy in wind into electrical energy. For sustainable development practice, power generation through wind turbine is proven to be one of the prominent technology.

One appraisal asserted that, starting at 2009, wind energy had the "most minimal relative greenhouse gas discharges, the least water utilization demands and the most ideal social effects contrasted with photovoltaic, hydro, geothermal, coal and gas [161]. Prior to setup a wind turbine for electricity generation, there goes a very deep data analysis and assessment like power density analysis etc. for the area the turbine will be setup.

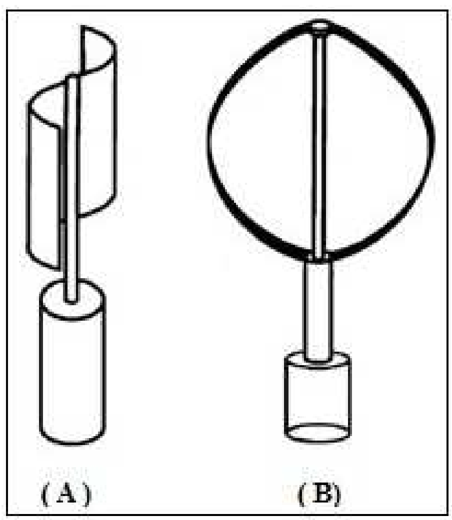


Figure 2.7. (A) Savonius rotor, (B) Darrieus turbine [162].

Notable that, Wind Power Density (WPD) is a quantitative measure of wind energy accessible at any area. It is the mean yearly power accessible per square meter of swept area of a turbine, and is determined for various statures over the ground. Computation of wind power density incorporates the impact of wind speed and air density [163].

2.8.1. Classification of WTG

In general, wind turbines are of two types: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). The two types of wind turbines have distinct advantages and disadvantages, which depend upon the physical characteristics of area in which they are used, and the needs of the operator. Though the history of wind wheel or windmill is referred to from remote past in the human history as stated in section 2.2, nowadays, Wind turbines with latest technologies are made in a wide scope of horizontal as well as vertical axis. Wind turbines can turn about either a level or an upward axis, the latter being both older and available [164]. They can likewise incorporate sharp edges, or be bladeless [165]. Design of a vertical wind turbine produces less energy and are more uncommon in real life use [166]. Wind turbines are again classified according to the wind speed they are designed for. These are from class I to class III, with giving A to C labels which refers to the turbulence intensity of the wind [167].

Table 2.2. Wind turbine class as per wind speed.

Class	*Wind speed (m/s)*	*Turbulence*
IA	10.00	16%
IB	10.00	14%
IC	10.00	12%
IIA	8.50	16%
IIB	8.50	14%
IIC	8.50	12%
IIIA	7.50	16%
IIIB	7.50	14%
IIIC	7.50	12%

While groups of horizontal axes wind turbines are our essential weapon in the war to diminish ozone harming substance outflows to spare the planet from the impacts of a worldwide temperature alteration, there are other intriguing wind turbine structures. Vertical axes wind turbines (VAWT) are available in an assortment of shapes and sizes. Vertical-axis wind turbines (or VAWTs) for which the main rotor shaft arranged vertically basically are of the types like, Darrieus, Giromill, Helical Blades, Cycloturbine and Savonius, though Giromill, Helical Blades and Cycloturbine can be attributed as the variation of the first kind, Darrieus. As a result, VAWT is mainly of two types: Darrieus and Savonius.

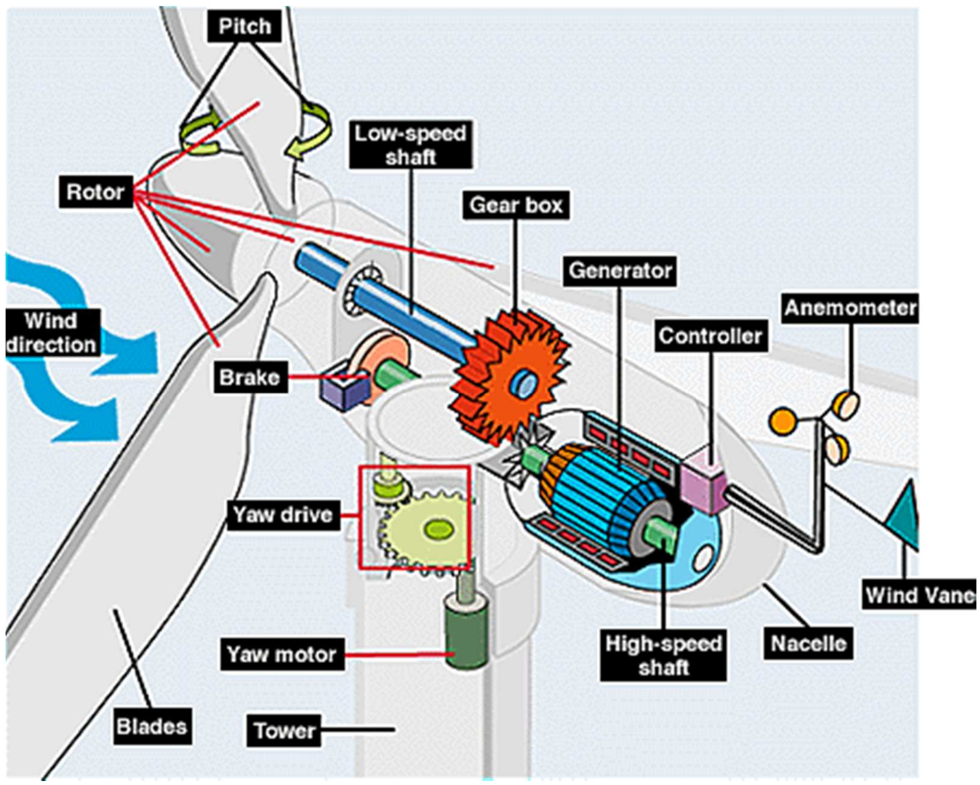


Figure 2.8. Components of a horizontal axes wind turbine [168].

Again according to the place where it is suitable to setup, wind turbines can be thought of as micro scale or small scale, medium scale and large scale wind turbines. Urban areas usually implement micro and small-scale systems. A significant number of micro or small scale wind turbine with a rated capacity of few kilowatts (literally 1.50-20.00 kilowatts) can be suitable to replace a medium or large scale wind turbine in an urban area to avoid nuisance in terms of environmental impacts. When compared to large scale wind turbines, small or micro scale wind turbines are those which have their rotor diameter ranging from 3 meters to 10 meters. Medium scale wind turbine can be defined as any wind turbine with less than 1 megawatt in capacity whereas large scale will be considered as those turbines having more than 1 megawatt of capacity.

2.8.2. Components of WTG

Wind turbines, like windmills, are mounted on a tower to capture the most wind energy [169]. This is because wind speed varies by height. For instance a wind current 100 meters above the ground dropped in speed by 10% when its height declined to 50 m [170]. This property is known as wind shear, where wind speed increases in speed with height, due to friction at the Earth's surface [171]. Wind Turbines have many complex internal parts, whose interconnection and distribution are illustrated by the figure 2.8.

Wind turbine is designed with a very careful way that balances cost, energy yield, and fatigue life. These elements are adjusted utilizing a very sophisticated computer program or software [172]. Wind turbines convert wind energy to electrical energy. A horizontal axis wind turbine can be partitioned into three parts alongside a large number of little parts joined to it:

- The rotor, which is roughly occupies 20% of the total wind turbine cost, incorporates the edges for changing over wind energy to low speed rotational energy.
- The generator, which is roughly 34% of the wind turbine cost, incorporates the electrical generator [173][174], the control gadgets, and no doubt a gearbox (e.g., planetary gear box) [175], customizable speed drive, or continuously variable transmission [176], part for changing the low-speed approaching revolution over to high velocity turn reasonable for producing power.
- The overall surrounding design, which is around 15% of the wind turbine cost, incorporates the tower and rotor yaw component [177].

A wind turbine generator is just in the same good as the whole of its parts. In any case, picking parts that work with insignificant support or fix needs is a big challenge in a wind farm. Nearly no matter what, turbines work under outrageous conditions that put these ground-breaking machines under significant pressure and wear. Engineers and manufacturers are continuously trying to improve the components of wind turbine for greater durability, reliability and performance. In order to get more improved turbine system, the components like slip rings, brushes, pitch controls, bearings etc. are most sensitive parts to update. Recent developments of these important turbine components are thus most prominent to cite.

2.8.3. New designs of WTG

Now the engineers have designed wind turbines with no blade. The thinking is to re-invent wind energy. They are much more concerned of the blades to be more dangerous for the environments: the noise, the lives of birds etc. A more new technology in wind turbine annexure is to using ultra capacitor. Ultra-capacitors, like all capacitors, have a high power density. What differentiates ultra-capacitors from their traditional counterparts, electrolytic capacitors, is their high energy density, allowing them to store a vast amount of energy in a small package. In general, the use of an ultra-capacitor in combination with a battery is an excellent way to increase the overall power density of the power source and decrease the strain on the battery. The most important facts about ultra-capacitors are these: functionality, lifespan, temperature range, cycling capability and price. There is a chance in future that, ultra-capacitors will offer a bright future for wind energy. Besides this, there are a number of peculiar innovations that have been devised for wind turbine such as, typhoon turbine, hybrid wind-hydro turbine, helium-filled floating wind turbines, wind tunnel tower, bird-friendly catching wind power etc.

Chapter 3

Methodology

3.1. INTRODUCTION

In order to decide a specific site to be a future wind farm, a vast and detailed investigation is necessary.

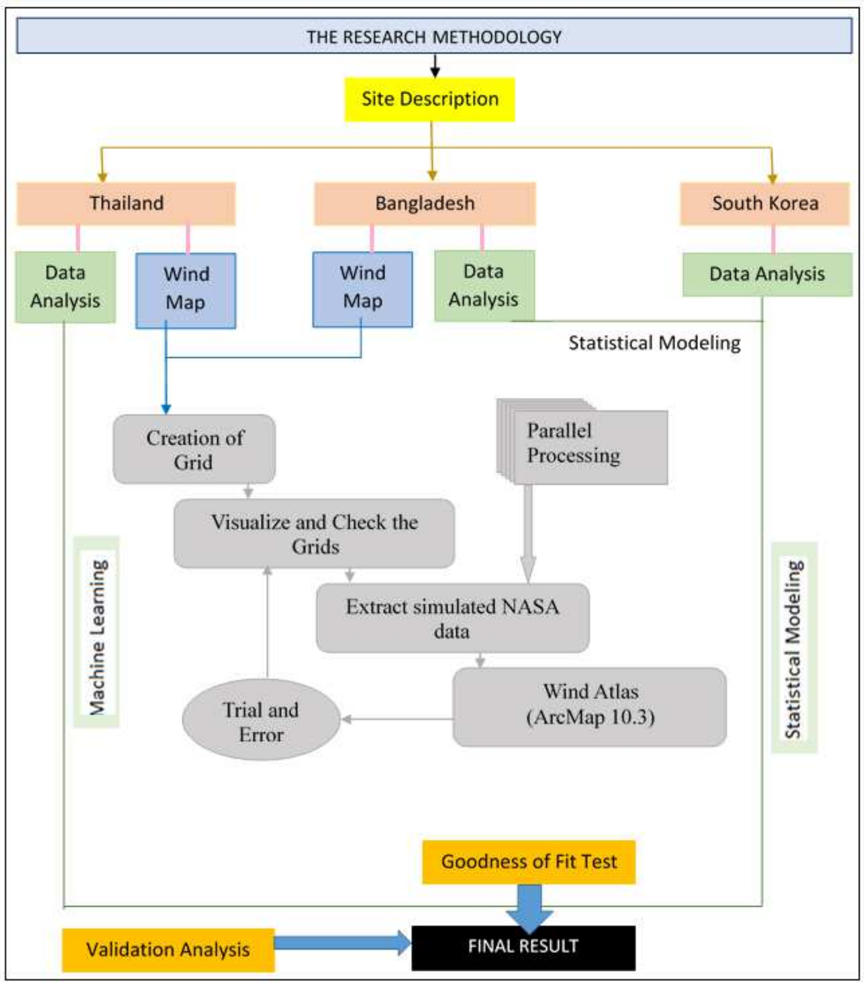


Figure 3.1. Flowchart of the methodology of the research.

This chapter will explain the wind energy analysis beginning from selection of sites to the mathematical modeling used for analysis starting with a flow chart describing the methodology showing in figure 3.1.

3.2. SITE DESCRIPTION

The Asia-Pacific region (APAC) is promoting sustainable development through road mapping the future with renewable energy by policy implementations, technology adaptations and proper investments. The rate is faster compared to the other part of the globe. As forecast, APAC will be the one that will lead the wind turbine market with an annual installation capacity of 33.14 GW by 2023, largely driven by the deployment of offshore wind, and this region has led the wind turbine market for the last couple of years with a total capacity of 138.20 GW between 2014 and 2018 [178]. This can be hoped that, this trend will continue in the future. This statistical phenomena has inspired this researcher to work within APAC region. The current research will cover both of some selected offshore and onshore area in three countries of APAC region: Thailand, South Korea and Bangladesh. The next sections will highlight the geographic facts regarding these countries.

3.2.1. Thailand

The following two regions of Thailand will be sought to have wind energy potential through depth analysis.

- Isaan (North-East region of Thailand)
- Western region

Table 3.1. Provinces of Northeastern region of Thailand.

Region	Province
Northeast Thailand	Amnat Charoen, Buriram, Chaiyaphum, Kalasin, KhonKaen, Loei, MahaSarakham, Mukdahan, NakhonPhanom, NakhonRatchasima, Nongbualamphu, Nongkhai, RoiEt, SakhonNakhon, Srisaket, Surin, UbonRatchathani, UdonThani, Yasothon.

Isaan comprises of twenty territories in the northeastern area of Thailand. Isaan is Thailand's biggest region in size, situated on the Khorat Plateau, flanked by the Mekong River (along the fringe with Laos) toward the north and east, by Cambodia toward the southeast and the Sankamphaeng Range south of Nakhon Ratchasima. Toward the west it is isolated from northern and focal Thailand by the Phetchabun Mountains. The twenty provinces are recorded in Table 3.1.

Western Thailand is a region of Thailand bordering Myanmar on the west, Southern Thailand on the south, and central Thailand on the east. This region includes the provinces shown in table 3.2. Figure 3.2 depicts the map of Thailand with the identification of northeast and western region of the country.

Figure 3.2. Map of Thailand [179].

Table 3.2. Provinces of Western region of Thailand.

Region	Province
Western Thailand	Kanchanaburi, Phetchaburi, Prachuap Khiri Khan, Ratchaburi, Tak

Geographic locations of the sites by region are shown in table 3.3 and table 3.4.

Table 3.3. Geographic location of the stations (with province names).

SN	Station/District	Province	Latitude	Longitude
01.	Buriram	Buriram	14.99° N	103.10° E
02.	Chaiyaphum	Chaiyaphum	15.80° N	102.03° E
03.	Chok Chai	NakhonRatchasima	14.74° N	102.16° E
04.	Kalasin	Kalasin	16.43° N	103.50° E
05.	KhonKaen	KhonKaen	16.43° N	102.82° E
06.	Loei	Loei	17.48° N	101.72° E
07.	MahaSarakham	MahaSarakham	16.01° N	103.16° E
08.	Mukdahan	Mukdahan	16.54° N	104.70° E
09.	NakhonPhanom	NakhonPhanom	17.39° N	104.76° E
10.	NakhonRatchasima	NakhonRatchasima	14.97° N	102.08° E
11.	Nang Rong	Buriram	14.63° N	102.79° E
12.	NongKhai	NongKhai	17.87° N	102.74° E
13.	Roi Et	Roi Et	16.05° N	103.65° E
14.	NakhonSakon	NakhonSakon	17.15° N	104.13° E
15.	Surin	Surin	14.88° N	103.49° E
16.	Tha Tum	Surin	15.32° N	103.67° E
17.	UbonRatchaThani	UbonRatchaThani	15.24° N	104.84° E
18.	UdonThani	UdonThani	17.36° N	102.81° E

Table 3.4. Geographic locations of the stations (with province names) that avail wind data for Western region.

SN	Station/District	Province	Latitude	Longitude
01.	Bhumibol Dam	Tak	17.24° N	098.97° E
02.	Hua Hin	PrachuapKhiri Khan	12.56° N	099.95° E
03.	Kanchanaburi	Kanchanaburi	14.10° N	099.41° E
03.	Mae Sot	Tak	16.71° N	098.57° E
05.	Petchaburi	Petchaburi	12.96° N	099.64° E
06.	PrachuapKhiri Khan	PrachuapKhiri Khan	11.79° N	099.79° E
07.	Tak	Tak	16.88° N	099.12° E
08.	Thong PhaPhum	Kanchanaburi	14.74° N	098.62° E
09.	Umphang	Tak	16.01° N	098.94° E

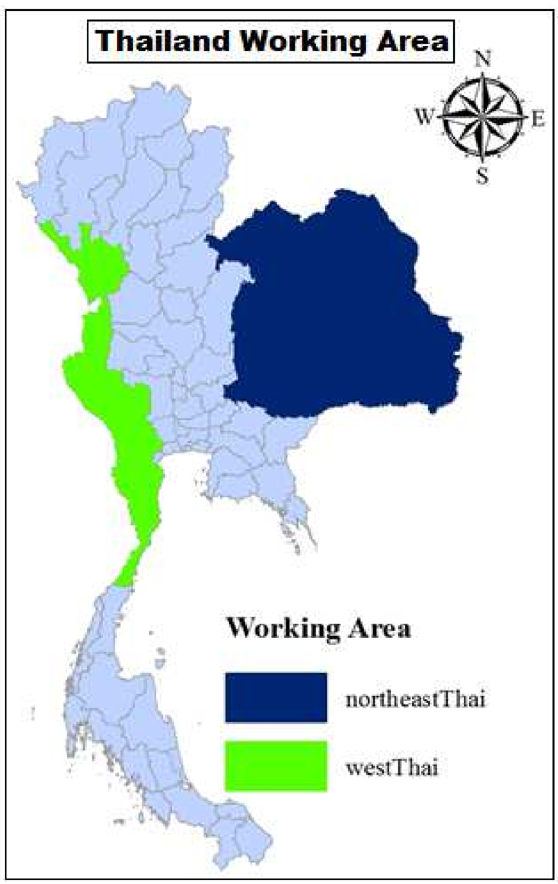


Figure 3.3. Thai Study Area**.**

The specific study area will be selected as per the data availability and the maps of the area might be acquired preferably from google map. It can be extracted from Arc Map using ArcGIS software either which demand prior knowledge to handle the software. The proposed chosen area cited above in Thailand shown in figure 3.1 will focus on estimating wind energy potential for Thailand through depth wind map analysis**.** As the north-east region of Thailand is equipped with Southeast Asia's largest wind farm, with generating capacity of 103.50 megawatts and costing 6.50 billion baht, starts operating in the province of Nakhon Ratchasima, there yields a big opportunity to vast and thorough analysis of the region in terms of identifying more wind potential within the region.

3.2.1.1. Thai Mapping Methodology

A wind map is simply a map with an exception that it contains some numerical values of wind speed, wind direction and wind power of a particular geographical area. Prior to building wind map, wind resource assessment studies are very important to conduct which holds three basic categories:

1) Preliminary Area Identification,
2) Area Wind Resource Evaluation and
3) Micro-siting

Wind mapping is a complex work. In the modern era computer tools are used to building maps which replaces manual system that was used before 1990s. Computerized mapping system has two primary goals:

(1) To produce a more consistent and detailed analysis of the wind resource
(2) To generate high-quality maps on a timely basis.

When using a suitable software is concerned, the following criteria regarding the software are discussed:

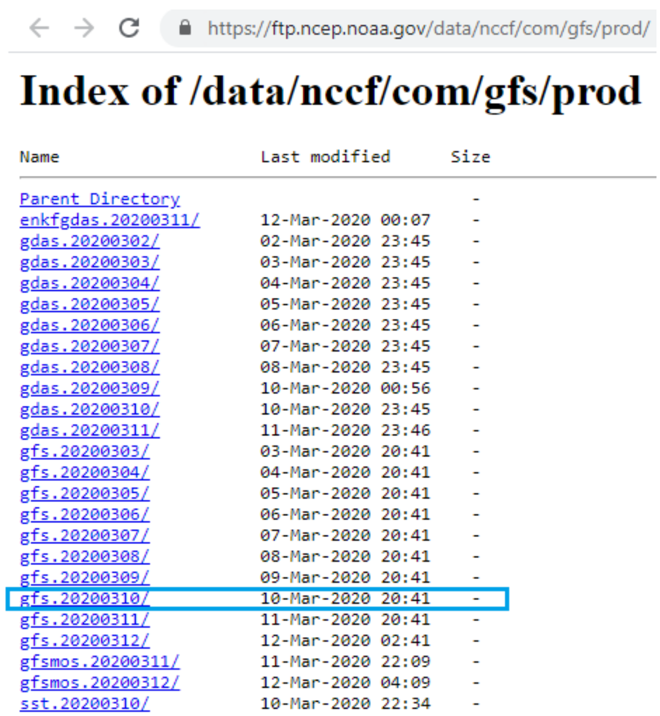
1) Models properties
2) Data criteria used by the model
3) Wind mapping process
4) Product of the mapping system

5) Limitations of the method

6) Error estimation from the input data

7) Validation of the model.

For validation analysis, all simulated and real data meet point should lie on $x = y$ line in a two-dimensional plot. Data will be reliable upon how much deviated they are from that line. There is no ideal case in research finding.


https://ftp.ncep.noaa.gov/data/nccf/com/gfs/prod/

Index of /data/nccf/com/gfs/prod

Name	Last modified	Size
Parent Directory		-
enkfgdas.20200311/	12-Mar-2020 00:07	-
gdas.20200302/	02-Mar-2020 23:45	-
gdas.20200303/	03-Mar-2020 23:45	-
gdas.20200304/	04-Mar-2020 23:45	-
gdas.20200305/	05-Mar-2020 23:45	-
gdas.20200306/	06-Mar-2020 23:45	-
gdas.20200307/	07-Mar-2020 23:45	-
gdas.20200308/	08-Mar-2020 23:45	-
gdas.20200309/	10-Mar-2020 00:56	-
gdas.20200310/	10-Mar-2020 23:45	-
gdas.20200311/	11-Mar-2020 23:46	-
gfs.20200303/	03-Mar-2020 20:41	-
gfs.20200304/	04-Mar-2020 20:41	-
gfs.20200305/	05-Mar-2020 20:41	-
gfs.20200306/	06-Mar-2020 20:41	-
gfs.20200307/	07-Mar-2020 20:41	-
gfs.20200308/	08-Mar-2020 20:41	-
gfs.20200309/	09-Mar-2020 20:41	-
gfs.20200310/	10-Mar-2020 20:41	-
gfs.20200311/	11-Mar-2020 20:41	-
gfs.20200312/	12-Mar-2020 02:41	-
gfsmos.20200311/	11-Mar-2020 22:09	-
gfsmos.20200312/	12-Mar-2020 04:09	-
sst.20200310/	10-Mar-2020 22:34	-

Figure 3.4. FTP server of NASA [180].

The mapping system is divided into three main components:

(1) The input data,

(2) The wind power calculations,

(3) The output section, which produces the final map.

It almost looks like the information process cycle: Input-Process-Output. The input data can be of two types: either it is simulated data from some online databases like MERRA database, or it may be the real met station data. In general, wind data from met stations are recorded at 10 m above ground level. The steps of wind mapping can be drawn like the diagram shown in figure 3.4. Roughness and topographic map can be built by Digital Elevation Model (DEM) database. The terrain data that will be used to divide the projected area into individual grid cells called domain, each having its own unique elevation value.

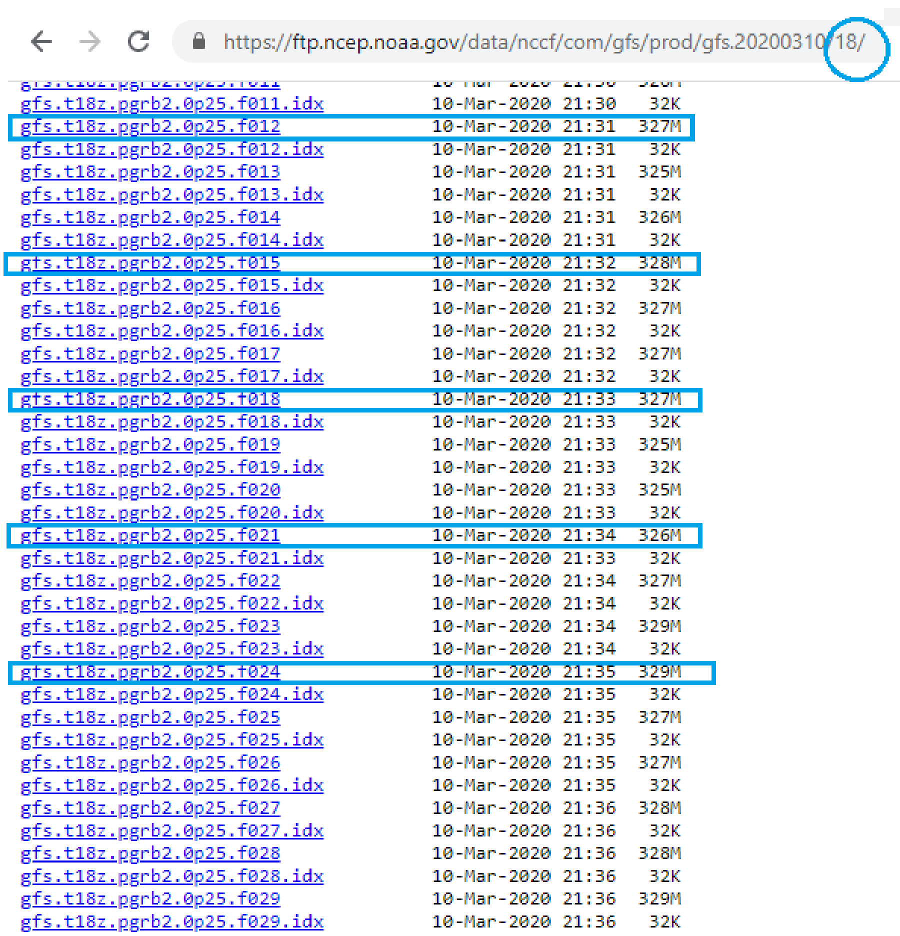


Figure 3.5. Selected files containing wind speed data [180].

Resolution of the map can be dependent on the necessity. As an example, 3 square km for mesoscale mapping and 200 square m for microscale mapping. Steps building wind speed and wind power map are

- Data Acquisition from Satellite
- Data Processing
- Data Analyzing
- Data manipulating for map in ArcMap

3.2.1.2. Data Acquisition from Satellite

This step utilizes NOAA weather and climate toolkit (WCT), an application that gives basic perception of climate and climatological information documented at NCDC. The Toolkit additionally gives admittance to climate and environment web administrations gave from NCDC and different associations. The Viewer gives devices to showing custom information overlay, Web Map Services (WMS), animations and basic filters.

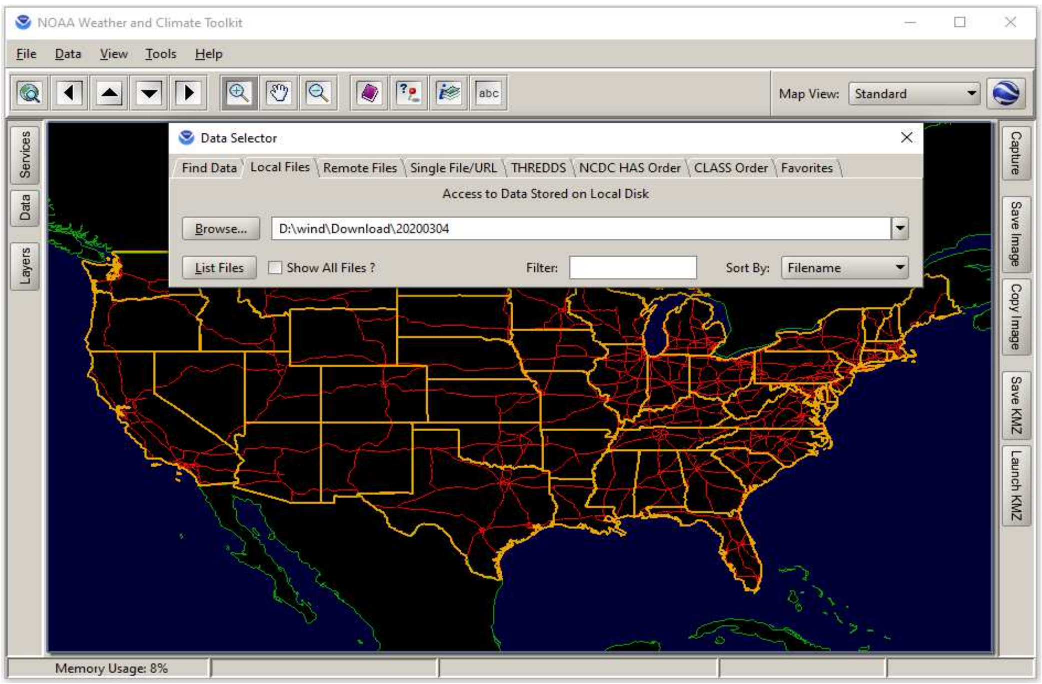


Figure 3.6. Weather and Climate Toolkit of NOAA [180].

The export of pictures and movies is given in various configurations. The Data Exporter takes into account information trade in both vector point/line/polygon and raster framework designs. Current information types uphold wind speed and direction data in grid format. To get to the data, the accompanying steps are required:

a) Open the site addressed as, http://www.ftp.ncep.noaa.gov/data/nccf/com/gfs/prod/
b) Download the .gfs files labelled as the latest date available. As an example, it is shown in figure 3.5.
c) Open the directory and select the folder named 18

d) Download the selected files as shown in figure 3.6.

e) Open wct.exe application as stated before.

f) From data selector, select the files downloaded in step d as shown in figure 3.7.

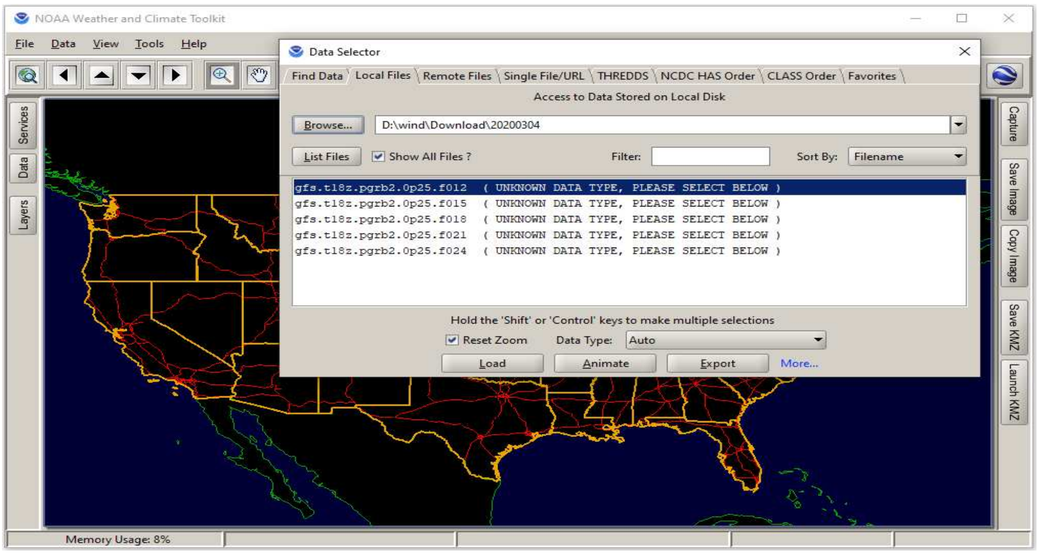


Figure 3.7. Files for obtainment of wind data [180].

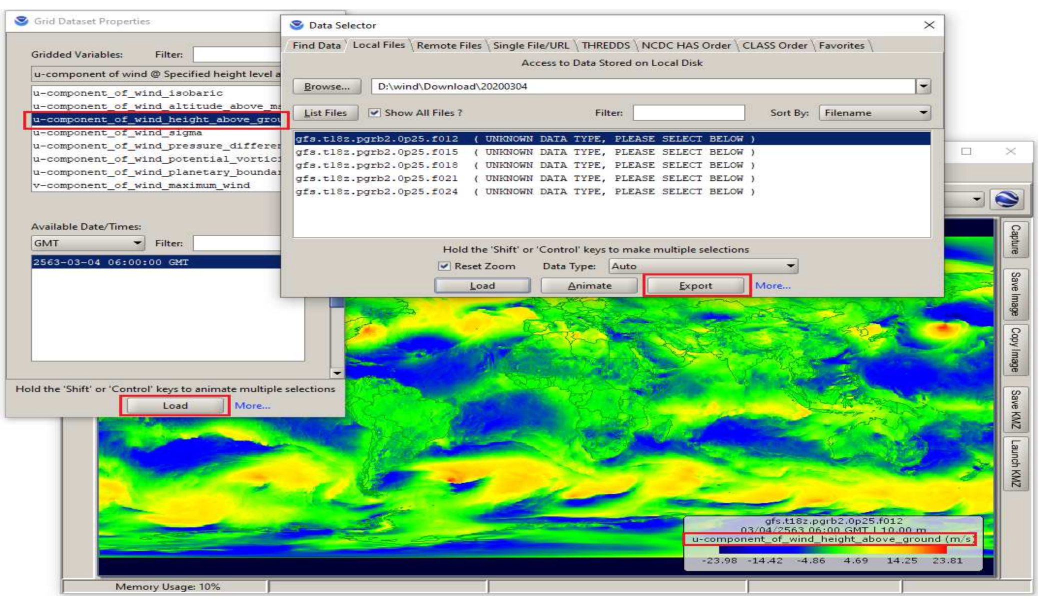


Figure 3.8. u-component and v-component of wind speed [180].

g) Select the file tagged f012 as shown in figure 3.6.

h) From grid dataset properties, scroll it down and select u-components of wind speed height above ground.

i) Load it and then click Export button as shown in figure 3.9.

j) Follow the Next button until the shape file for u-component is saved in the specified folder shown in figure 3.10.

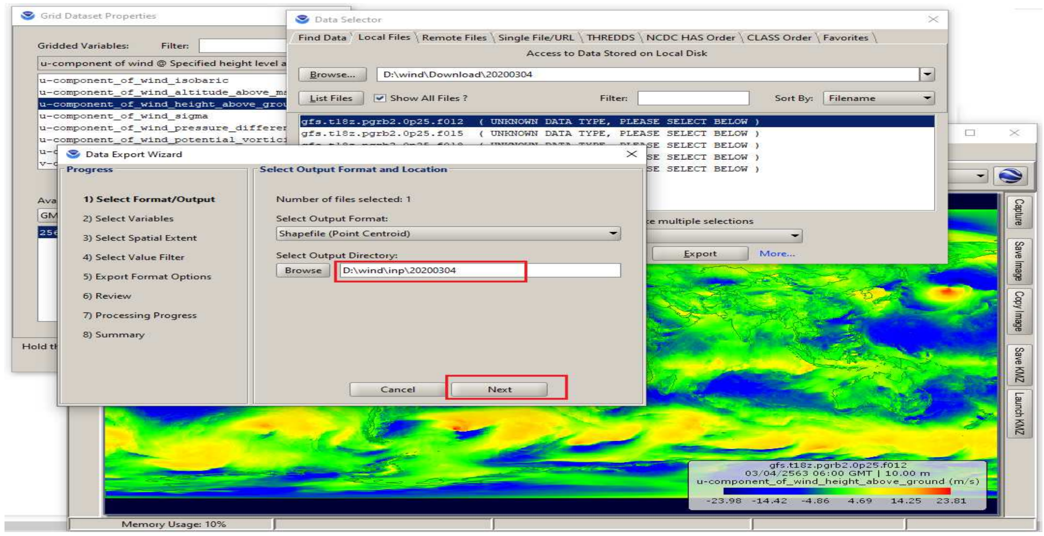


Figure 3.9. Saving the shape files in specified folder [180].

k) Follow the same procedure from h to i.

l) Now, we have the files like the above.

m) Now it needs to combine u-component and v-component of wind into a single shape file through python programming.

n) The output files from python looks like figure 3.11.

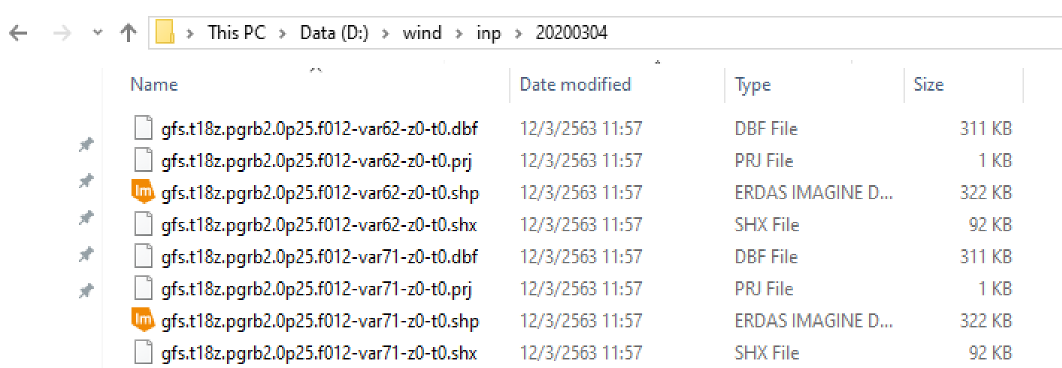


Figure 3.10. Selected folder for saving shape file of u-component and v-component of wind speed.

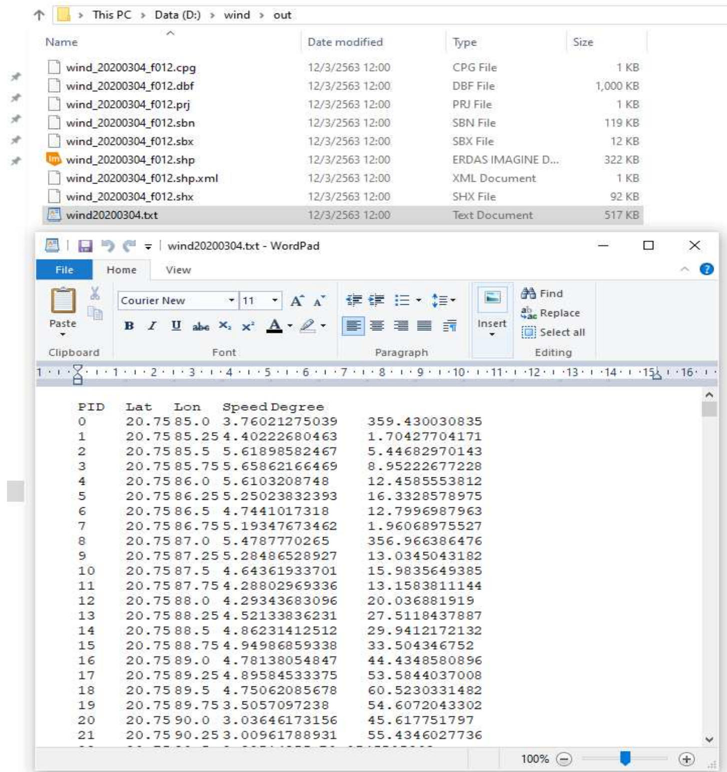


Figure 3.11. Final shape file that contains wind speed and wind direction data as a raster.

o) The same procedures will be applied for other files as indicated in figure 3.6.

p) Now, open the shape file shown in figure 3.13 in AcrMap 10.5.

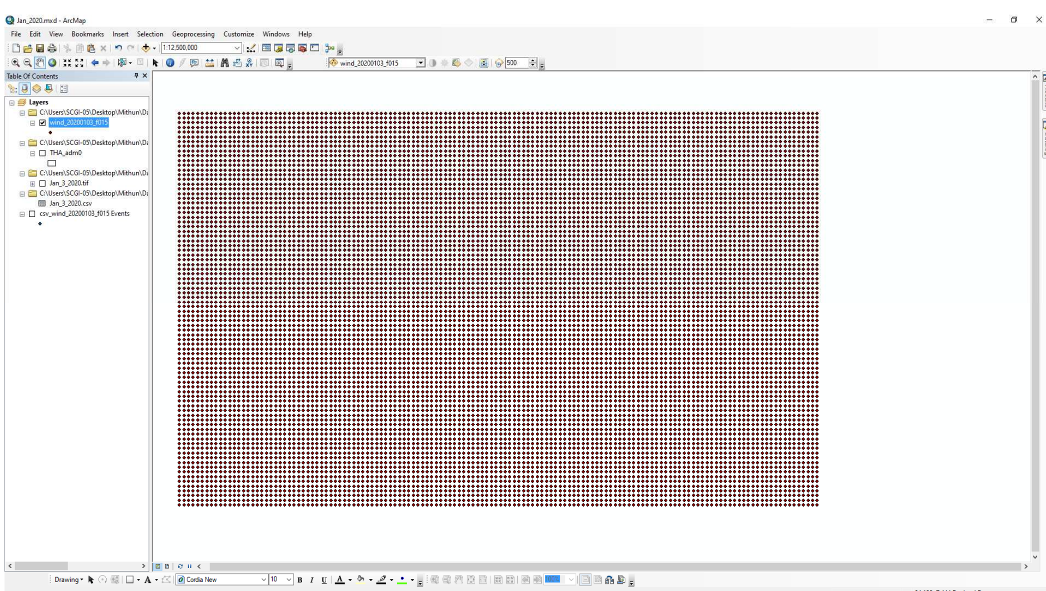


Figure 3.12. Shape file opened in ArcMap.

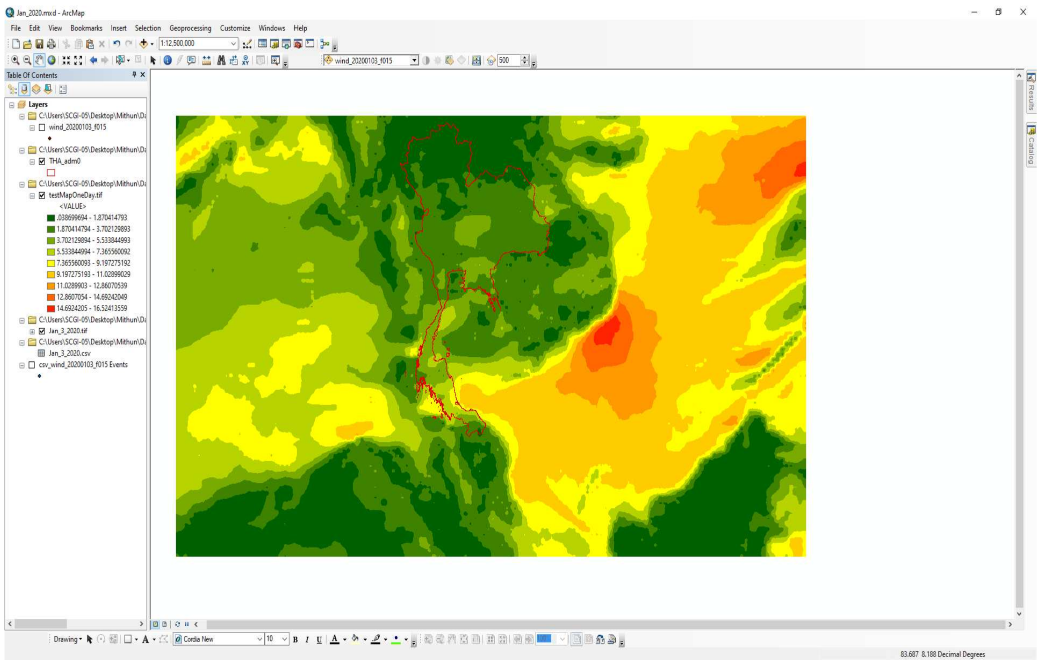


Figure 3.13. Image processing for wind resource map from the data shown in figure 3.11 and 3.12.

q) By operating inverse distance weighted technique in ArcMap, the wind speed map can be shown as in figure 3.14.

r) The satellite data that was downloaded gives shape file of every single day. As a result, if wind speed and wind power map for every day can be made, it is possible to build animation maps for both wind speed and wind power in order to understand the variation over a period of time of those.

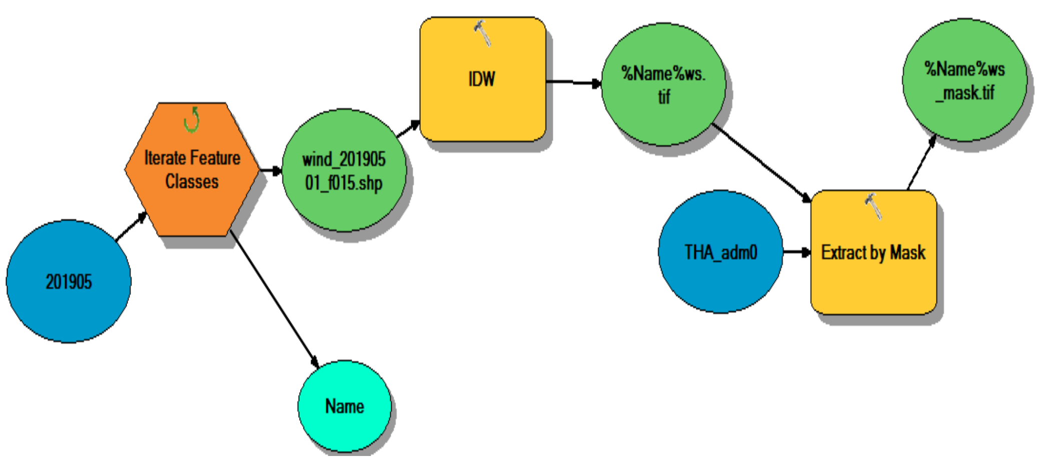


Figure 3.14. ArcMap model for wind mapping.

This is a very short way to interpret how we can use the related software stated above for building wind speed maps through the obtainment of data from satellite by the deployment of programming knowledge. Calculation of wind power from wind speed can render wind power maps as well.

3.2.1.3. ArcMap wind speed model

The model shown in figure 3.15 is built in or der to draw daily basis wind map in an iterative manner. As an example, if it needs to get one-month map, there will be say 31 map file for January, which will be run in iteration to get the map for the whole month.

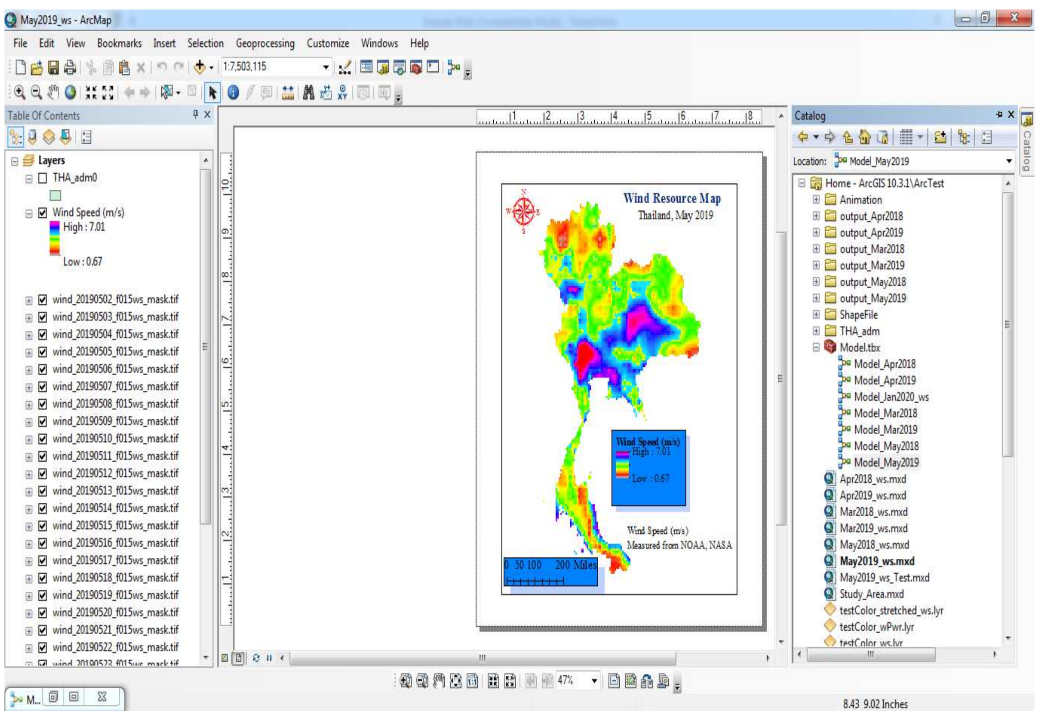


Figure 3.15. Processing for map building in ArcMap 10.5.

In order to calculate the wind energy generated from wind through a WTG demands the wind speed data from a particular level the WTG fits. As mentioned earlier, the wind data are recorded normally at 10 m AGL by an anemometer of meteorological stations. The WTG installed in a particular site has a defined hub height, typically from 30 m to 100 m. At this height, all the anemometers in the meteorological stations to be setup will be a very expensive task.

3.2.1.4. Power Estimation from PDF

Once the value of the Weibull parameters are gained, power estimation of the wind becomes easier. In engineering practice, the average wind turbine power $\hat{p}_w$ associated with the probability density function (pdf) of wind speed v is obtained from equation 1.

$$\hat{p}_w = \int_0^\infty p_w(v) f(v) dv \qquad (1)$$

Where $f(v)$ is the probability distribution function of wind speed v and $p_w(v)$ is the power output generated from a turbine describes power output versus wind speed. Now that it is being discussed about the power, normalized power can be of great values in order to estimate site-specific criteria of wind turbine. From the normative reference, in order to assess the quality of power and power performance measurement, IEC61400-12-1 gives sufficient guidelines. First step it needs to calculate the average of actual air density whether it needs to normalize data or not. This is to be considered only when the air density, air pressure and temperature data are available with wind data. As reference to IEC standard 61400-12-1 about data normalization, it doesn't need to normalize the wind speed data with two reference air density if the average actual air density in the range of 1.225±0.05.

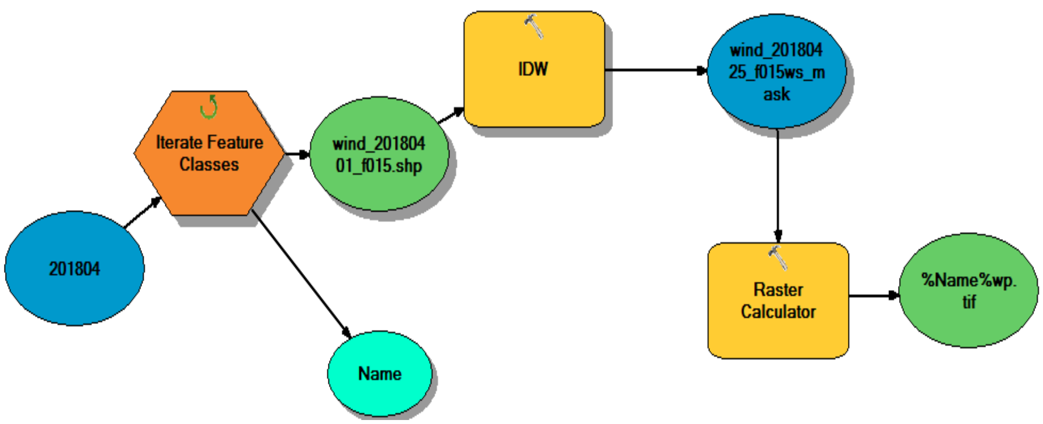


Figure 3.16. Wind power density model in ArcMap**.**

As per the standard, the data shall be collected once in every minute. Before handling the data, there needs to have a simple steps: data collection - data rejection - data correction. Power measure of wind speed can be written down as in equation 2.

$$P = \frac{1}{2}\rho A V^3 \tag{2}$$

In general, wind power analysis measures power density measured in w/m^2 unit which can be shown as in equation 3.

$$\frac{P}{A} = \frac{1}{2}\rho V^3 \tag{3}$$

In order to implement the mathematical model in ArcMap 10.3, the model shown in figure 3.16 is needed.

3.2.1.5. Contour Map

A contour map is essentially a guide map however is shown with contour lines (is a curve along which the capacity has a steady worth, so the curve joins the points of the same values [180][181]). As an example, a topographic map property of a particular region may be illustrated as a contour map, which will show the hills, mountains or any other elevation or the steepness or gentleness of the slopes.

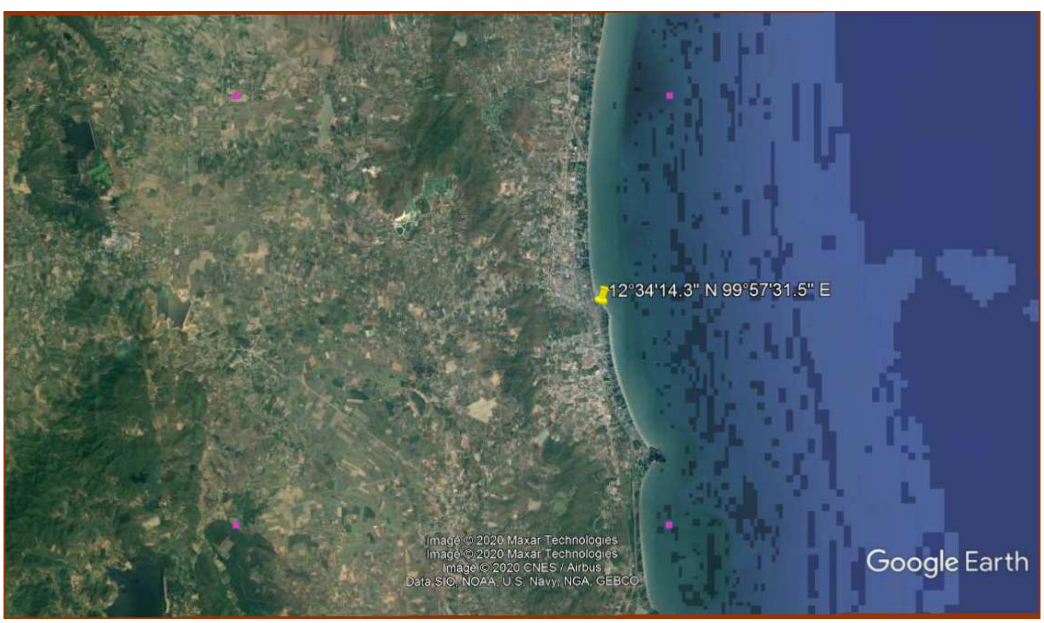


Figure 3.17. Google earth image for Pachuap region.

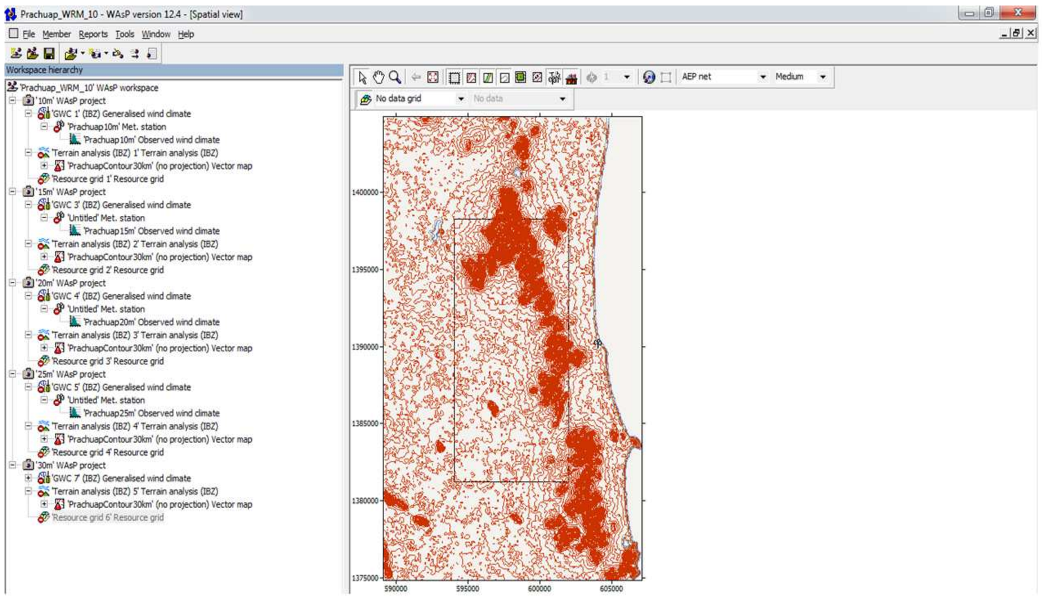


Figure 3.18. Contour mapping in WAsP 12.4.

Prachuap province in Thailand has been taken into consideration for building contour map. The google earth image of Prachuap is presented in figure 3.17. The contour lines are shown for Prachuap in figure 3.18.

3.2.2. South Korea

Offshore wind energy analysis of three Islands of South Korea will be conducted. The possible Islands as per the availability of the data are:

1) Phengyeong Island (Phengyeong Do)
2) Hongyeong Island (Hongyeong Do)
3) Mal Island (Mal Do)

Table 3.5 indicates the geographical information of the projected offshore sites of South Korea.

Table 3.5. Geographical Coordinates detail of Hoenggyeong Do and Mal Do Island, Republic of Korea.

Name of the site	*Country*	*Variables*	*Value*
Hoenggyeong Island	Jeollabuk Province, Republic of Korea	Latitude	35° 52'N
		Longitude	126°23'31" E
		Anemometer height	30 m
		Maximum elevation from sea level	3 m
Mal Island		Latitude	35° 50' 24" N
		Longitude	126° 22' 12"E
		Anemometer height	30 m
		Maximum elevation from sea level	3 m

Hongyeong Island is situated at 15 kilometers apart in the Yellow sea from Gunsan Wind Power Station of one of the tips of mainland Korea named Saemangeum in Jeollabuk province. The location of the island can be identified from the figure 3.3. Maldo is a small and very beautiful island, and yet a densely populated locality due to its importance in terms of tourism is situated on the southern-most tip of Republic of Korea. Table 3.6 below presents the wind energy potential in sea area of Jeollabuk Province of South Korea within which the projected Islands are situated.

Table 3.6. Sea potential of wind energy of Jeollabuk-do [183].

Sea potential (MW)				
Site name	Current Potential (GWh)	Developed so far (GWh)	Facilities capacity (GW)	Area (km^2)
Jeollabuk-do	80.75 (equivalent to 6943 Ton oil (TOE))	27,771	10.73	3,575

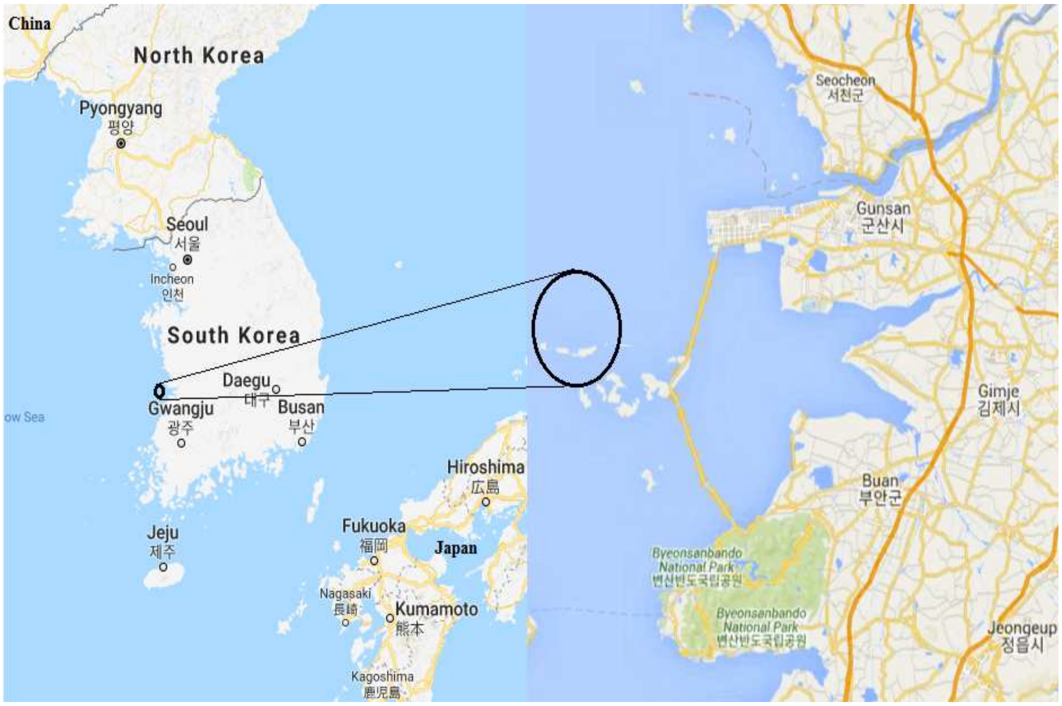


Figure 3.19. Hoenggyeong Island map [184].

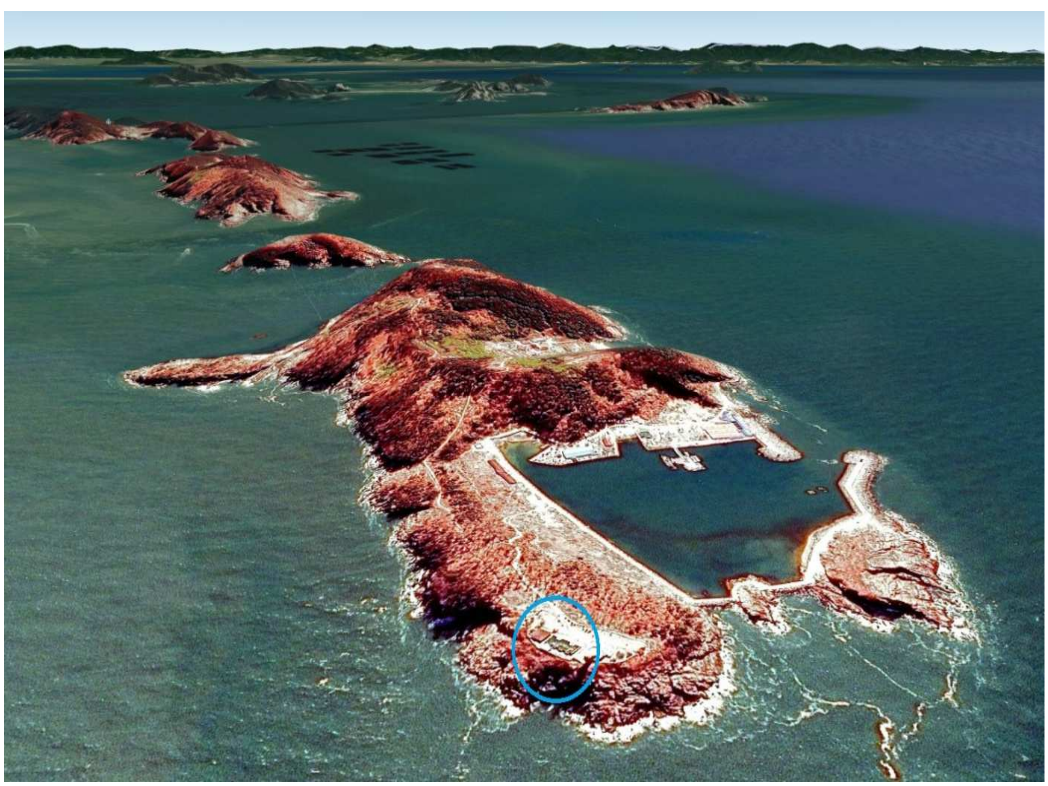


Figure 3.20. Maldo Island Map [185].

3.2.3. Bangladesh

This research would cover almost all wind potential areas especially in coastal areas as measured by Bangladesh Meteorological Department (BMD). Some of the potential wind areas in the coastal and offshore region in Bangladesh are Saint Martin's island, Sandweep Island, Hatia, Kutubdia, Feni, Kuakata, Potenga, and Mongla. Table 3.7 presents the coastal stations from where the met data at 10 m AGL have been collected. Besides this, four airport data is also regarded for analysis.

Table 3.7. Geographical coordinates of coastal area in Bangladesh.

Area/Station Name	Longitude	Latitude	Anemometer Height (m)
Charfashion	90.75° E	22.18° N	
Monpura	90.95° E	22.19° N	
Hatia	85.30° E	23.28° N	
Noakhali	91.10° E	22.82° N	10
Companigonj	91.26° E	22.82° N	
Sonagazi	91.39° E	22.84° N	
Sandweep	91.42° E	22.49° N	

3.3. RESEARCH DESIGN

The research would follow both qualitative and quantitative research design. Qualitative designs focus on credibility, transferability, dependability and conformability, where the later has very specific guidelines for reliability and validity. Following is the experimental setup that will be conducted:

1) Define the objectives and goals.
2) Collection of data according to the objectives and goals.
3) Arranging data.
4) Extensive literature survey
5) Defining tools and models for the analysis of the data.
6) Apply data to the suitable models as previously defined.
7) Validating the result.
8) Execution of the result
9) Searching for the advance research as an extension of the current study.

3.4. DATA COLLECTION TECHNIQUES

Wind energy varies with year, season and time of day, and the elevation above ground and form of terrain. Proper positioning of the turbine, in windy sites, away from large obstructions, improves the wind turbine performance. But in order to take a proper decision to setup turbines, the feasibilities of wind power in the areas must be established. The following ways are used to collect the wind data:

1) Wind speed and direction data measured by Meteorological Department of the respected countries at different heights (AGL-above ground level).
2) Data are recorded at different time-series manner. Though 10 minutes averaged data is internationally recommended and accepted.
3) 1-minute, 10-minutes, 1-hour, 3-hours averaged data are collected.
4) The recorded data are collected from the meteorological department. Though primarily, these data are stored in the field office from where exactly they were recorded (i.e. where the anemometers were setup.)
5) Documents review
6) Books and texts
7) Journals Information pertaining to the sites in terms of three projected countries is summarized below in table 3.8.

Table 3.8. Data types, site descriptions and the period of data for selected regions.

Country	Site/Region	Data types	Measurement dates/years	Site descriptions
Thailand	Northeast and Western region	Wind speed, wind direction, Temperature	2009-2018	Inland areas
South Korea	Some small Islands in Jeollabuk province	Wind speed, wind direction, temperature, pressure, air density, turbine noise, power, volts.	2017-2018	Islands facing yellow sea
Bangladesh	Coastal area	Wind speed, wind direction,	2000-2017	Flat land, and inland areas with trees, buildings etc.

Speed and direction data will be acquired from BMD under the Ministry of Defense. All data in the met stations are recorded at 10 m above ground level (AGL). BMD is the sole authority to suffice the data. Wind speed data at 10 m height will be converted to the wind speed of a required height using some suitable mathematical models. Generation of power now can now be predicted even at the height of 100-140 m from the sea level. For the wind data to build wind resource map, data will be acquired from MERRA online database operated by NASA.

The types of wind data can be interpreted as follows:

1) Wind speed data (m/s)
2) Wind direction data (degree)
3) Some other climactic data (if necessary)

Identification of ideal wind site for building farms depends on many criteria among which securing reliable data for analysis becomes one of the most important.

3.4.1. Data Types

The types of wind data can be interpreted as follows:

1) Wind speed data (m/s)
2) Wind direction data (degree)
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3.4.2. Data Source

Identification of ideal wind site for building farms depends on many criteria among which securing reliable data for analysis becomes one of the most important. The primary source of data is Bangladesh Meteorological Department and four airports of Bangladesh. The simulated data have been collected form MERRA2 online database.

3.5. MATERIALS AND METHODS

Specifically three things are going to be done for the current research:

1) Wind energy potential assessments
    - Northeastern and western region of Thailand
    - Offshore areas (some specified Island as stated in section 3.2.2) in South Korea.
2) Wind resource mapping (Bangladesh, northeastern and western region of Thailand)
3) Wind turbine noise analysis (for small scale wind turbine)
4) AEP (annual energy production) analysis of WTG
5) Economics of wind energy.

3.5.1. Potential Assessments Explained

In order to assess the wind profile characteristics and wind energy potential, following are the approaches the research that would be ensued:

- Collection of data from meteorological departments of the respective countries and other sources.
- Processing wind data using suitable software tools for the determination of:
    1) Hourly wind speed distribution,
    2) Daily wind speed distribution,
    3) Monthly wind speed distribution,
    4) Seasonal wind speed distribution,
    5) Sector-wise wind rose distribution
    6) Sector-wise frequency distribution by wind speed and wind direction.
    7) Probability and cumulative distribution,
    8) Identification of statistical parameter (Weibull shape and scale parameter k and C),
    9) Monthly and yearly wind power density analysis,

10) Using appropriate mathematical and engineering rules and formulas for the quantification of the research

- Analysis of the result according the research questions using suitable statistical distributions.

In order to calculate the wind energy generated from wind through a WTG demands the wind speed data from a particular level the WTG fits. As mentioned earlier, the wind data are recorded normally at 10 m AGL by an anemometer of a meteorological stations. The WTG installed in a particular site has a defined hub height, typically from 30 m to 100 m. At this height, all the anemometers in the meteorological stations to be setup will be a very expensive task. Consequently, as the wind speed varies in variation of the height, some mathematical functions are used to calculate wind speed at different height from the standard wind speed data (recorded 10 m AGL generally) like power law and logarithm law. The most frequently utilized equation to compute wind speed at various heights is the Hellmann power law that connects wind speed data at two different height for the accessible recorded data as presented by [186][187], is given in equation 4.

$$\alpha = \left(\frac{\ln(\frac{v_2}{v_1}}{\ln(\frac{z_1}{z_2}} \right) \tag{4}$$

Where α is power law index (PLI) which needs to determine for extrapolation of the wind speed values at different heights. Power law index α is calculated using equation 5:

$$\alpha = \frac{0.37 - 0.088 \ln(v_{ref})}{1 - 0.088 \ln\left(\frac{z_{ref}}{10}\right)} \tag{5}$$

Once the value of α is determined, any relevant and desired wind speed at a particular height can be measured by equation 6.

$$\frac{v_z}{v_{z_{ref}}} = \left(\frac{z}{z_{ref}}\right)^{\alpha} \tag{6}$$

Where, V_z = wind speed at height z, V_{Zref}= wind speed at reference height (Z_{ref}), Z = height above ground level, Z_{ref} = reference height.

Once more, the 1/7 power law, another strategy for taking the estimation of α= 0.14, has been demonstrated to give a decent guess for wind profile in the neutral atmospheric boundary layer, which has been consistently accepted as an incentive for open land [188][189][190].If only in case of having a neutral condition, the value of αequals 0.14 can be laid down for analysis. Other than neutral condition, the analysis doesn't produce expected outcome. Wind resources are seldom consistent and vary with time of the day, season of the year, height above the ground, type of terrain, and from year to year, hence should be investigated carefully and completely [191]. Mean wind speed and standard deviation have been estimates using equation 7 and equation 8.

$$v_m = \frac{1}{N}\left(\sum_{i=1}^{N} v_i\right) \tag{7}$$

$$\sigma = \left[\frac{1}{N-1}\left(\sum_{i=1}^{N}(v_i - v_m)^2\right)\right]^{\frac{1}{2}} \tag{8}$$

Where, v_m: mean wind speed, σ: standard deviation of the data, v_i: means hourly wind speed, N: number of measured hourly wind speed data. The wind speed at 10 meters from the ground needs to be converted to the wind speed at a desired height above the ground level using power law as stated before. The altitude from the ground is 40-70m or more is desired, where the wind speed is higher being applicable for power generation [192].

3.5.2. Determination of Probability Distribution

Weibull probability distribution function (PDF) has been generally applied as an instrument to survey the capability of wind energy by numerous specialists [193] which can be portrayed by two parameters k and c, the shape and the scale parameters respectively [194][195]. Weibull PDF will be used in this research for the reason that, this method is considered as the most perfect method for its simplistic approach with accuracy [196] and is used unanimously by researchers involved in wind speed analysis which has also extensively been used in wind energy analysis for many decades [197] because this PDF is proven to provide accurate and efficient estimation of energy output in terms of WECS.

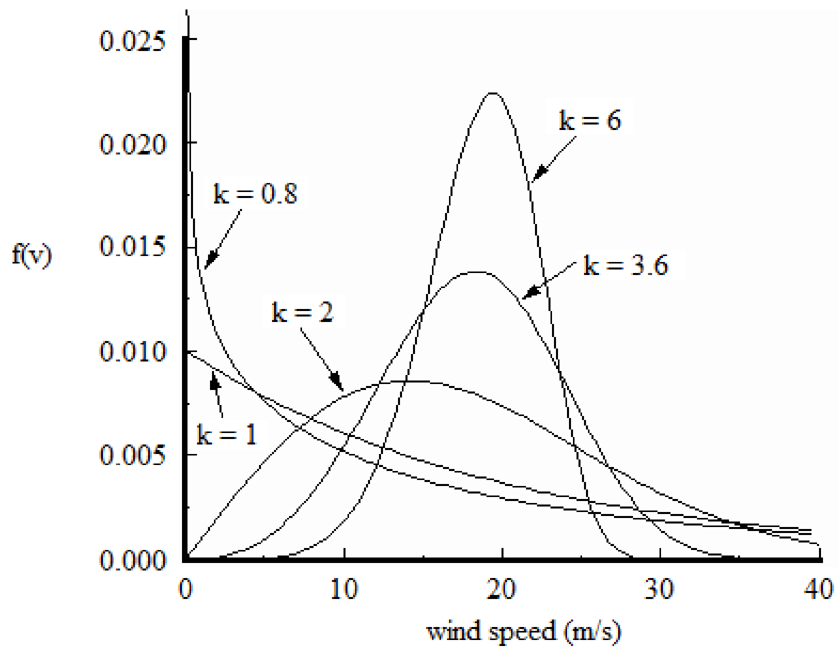


Figure 3.21. Weibull probability distribution with wind speed.

Weibull distribution can be characterized by its probability density function *f(v)* and cumulative distribution function *F(v)* as in equation 9 and equation 10 [174].

$$f(v) = \left(\frac{k}{c}\right).\left(\frac{v}{c}\right)^{k-1}.\exp\left(-\left(\frac{v}{c}\right)^{k}\right) \tag{9}$$

And, $$F(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \tag{10}$$

Where; $f(v)$ is the probability of observing wind velocity v_i, F(v) is the cumulative distribution function, c is the Weibull scale parameter (m/s) and k is the dimensionless Weibull shape parameter. There are many methods to estimate the vales of k and c.

The Weibull shape parameter, k, is also known as the Weibull slope. This is because the value of k can be thought of as the slope of the line in a probability plot. Different values of the shape parameter can have marked effects on the behavior of the distribution. In fact, some values of the shape parameter will cause the distribution equations to reduce to those of other distributions. For example, when $k = 1$, the PDF of the three-parameter Weibull reduces to that of the two-parameter exponential distribution. The parameter *k* is a pure number, *i.e.* it is dimensionless. Figure 3.6 shows the effect of different values of the shape parameter *k*, on the shape of the PDF. One can see that the shape of the PDF can take on a variety of forms based on the value of *k*.

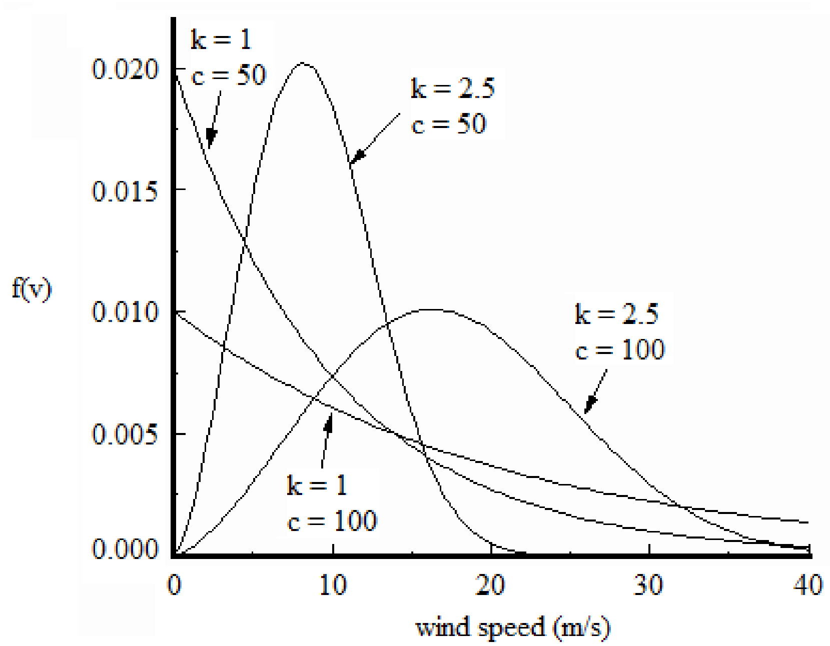


Figure 3.22. Weibull PDF with varying values of *C*.

A change in the scale parameter c has the same effect on the distribution as a change of the abscissa scale. Increasing the value of *c* while holding *k* constant has the effect of stretching out the PDF. Since the area under a PDF curve is a constant value of one, the "peak" of the PDF curve will also decrease with the increase of *c*, as indicated in figure 3.7.

There are a number of mathematical process the shape and scale parameters can be measured. Following are some sections some of those methods are discussed. From figure 4.2, the following propositions can be built up:

1) If C value is expanded while k is kept same, the distribution gets loosened up to one side and its height diminishes, while keeping up

its shape and area. Higher the k value, narrower is the frequency distribution.

2) If C value is diminished while k is kept same, the conveyance gets pushed in towards the left, and its height increases.
3) C has the same units as has time, speed etc. (e.g. hours, miles, cycles, actuations, etc.).

3.5.2.1. ***k and C Estimation Techniques***

Following are some mathematical modeling and methods that help identifying the values of shape and scale parameters for Weibull pdf and scale parameter for Rayleigh PDF.

3.5.2.1.1. ***Graphical Method***

This method interpolates wind speed data in a straight line using the concept of least squares regression. Equation (8) is converted to a logarithm form like equation 11.

$$\ln(-\ln(1-F(v)) = k.\ln(v) - k.\ln(c) \qquad (11)$$

Now, the shape and scale parameters of Weibull PDF are found by plotting $\ln(v)$ against $\ln(-\ln(1-F(v))$ where the shape parameter k is determined by the slope of the derived straight line and scale parameter from the relation: - *k. ln(c)* = *y-intercept*.

3.5.2.1.2. ***Empirical Method***

Shape and scale parameter *k* and C are measured in this method by the help of equation 12 and equation 13. C and *k* in this method are estimated from the mean wind speed (v_m) and standard deviation (σ) of wind data. The values of v_m and *k* help finding *c* from equation 13 once getting *k* from equation 12.

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \qquad (12)$$

$$c = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (13)$$

Where Γ is the standard Gamma function expressed as in equation 14.

$$\Gamma = \int_0^\infty t^{x-1} e^{-t} dt \tag{14}$$

Gamma function can be expressed as in equation 15.

$$\Gamma(x) = \sqrt{2\pi x}.x^{x-1}.e^{-x}.\left(1 + \frac{1}{12}x + \frac{1}{288}x^2 - \frac{139}{58140}x^3 + ...\right) \tag{15}$$

3.5.2.1.3. ***Energy Pattern Factor Method***

Average wind speed is used to estimate k and c is in this method. This method is simple to formulate, easy to implement and requires less computation. The method is defined by the equations 16 to equation 20.

$$E_{pf} = \frac{(v^3)_m}{(v_m)^3} \tag{16}$$

Where $(v^3)_m$ is denoted as the mean of the cubed wind speed, and can be mathematically written as in equation 17.

$$(v^3)_m = \frac{1}{N}\sum_{i=1}^{N} v_i^3 \tag{17}$$

And $(v_m)^3$ is the cube of mean wind speed. This can be shown as equation 18.

$$(v_m)^3 = \left(\frac{1}{N}\sum_{i=1}^{N} v_i\right)^3 \tag{18}$$

Here E_{pf} is called energy pattern factor. Once E_{pf} is calculated from equation 16, Weibull shape parameter k can be estimated as in equation 19

$$k = 1 + \frac{3.69}{(E_{pf})^2} \tag{19}$$

Once k is found, from the equation, scale parameter c can be measured from the following, as equation 20 shows.

$$v_m = c\Gamma\left(1+\frac{1}{k}\right) \tag{20}$$

Where, Γ is known as Gamma function as expressed in equation 14 and equation 15.

3.5.2.1.4. *Maximum Likelihood Method*

The Maximum Likelihood Estimation method (MLM) is a mathematical expression known as a likelihood function of the wind speed data in time series format.

$$k = \left[\frac{\sum_{i=1}^{N} v_1^k \ln(v_i)}{\sum_{i=1}^{n} v_i^k} - \frac{\sum_{i=1}^{n} \ln(v_i)}{n}\right]^{-1} \tag{21}$$

$$c = \left(\frac{1}{N}\left[\sum_{i=1}^{n} v_i^k\right]\right)^{\frac{1}{k}} \tag{22}$$

The MLM method was used by Costa Rocha *et al.* [198] quoting Stevens *et al.* [199] in their study for the estimation of parameters of the Weibull wind speed distribution for wind energy utilization purposes. The MLM method is solved through numerical iterations to determine the parameters of the Weibull distribution. The shape factor k and the scale factor c are estimated by equation 19 and equation 20.

3.5.3. Cumulative Frequency Distribution

Cumulative frequency is used to determine the number of observations that lie above (or below) a particular value in a data set. The cumulative frequency is calculated using a frequency distribution table, which can be constructed from stem and leaf plots or directly from the data. The cumulative frequency is calculated by adding each frequency from a frequency distribution table to the sum of its predecessors. The last value will always be equal to the total for all observations, since all frequencies will already have been added to the previous total [200]. Following figure is an interpretation for Weibull Function which can be derived from the integration of Weibull Probability Density Function. It is actually the cumulative of relative frequency of each wind velocity interval.

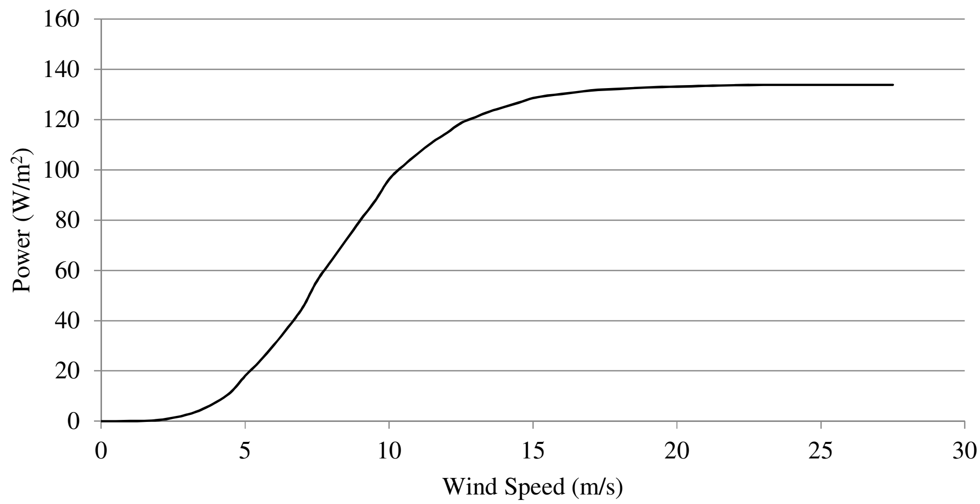


Figure 3.23. Example of cumulative frequency distribution.

Of course, the wind does not always blow and once in a while it howls. So the designer has to use statistics to describe the wind. We know that the wind speed cannot go below zero and it is very unlikely to be very high. One way to describe the wind is to use a "Rayleigh Distribution" which is a special case of the "Weibull Distribution." The Rayleigh distribution looks like this for an average wind speed of 4.50 m/s.

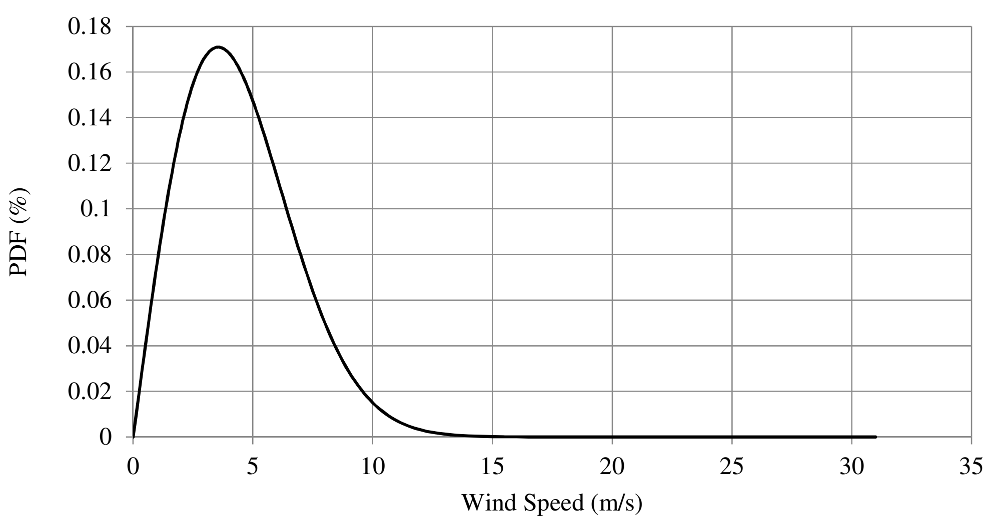


Figure 3.24. Rayleigh probability distribution function (PDF).

If you would like curves for other wind speeds, see the attached spreadsheet. One property of probability density functions is the area under the curve is equal to 1.00, or one could think of it as 100%. If one wants to find the probability of wind being between one speed and another, just measure the area under the curve between those speeds (http://www.calebengineering.com/how-much-wind.html). Cumulative distribution Function helps determine the probability of wind speed that might be measured or available at a particular time.

3.5.4. Rayleigh Probability Distribution Function

If shape parameter *c* is obtained from equation 20 by putting k = 2, then probability distribution functions for Rayleigh distribution can be found using equation 23.

$$v_m = c\Gamma\left(1+\frac{1}{2}\right) \tag{23}$$

Figure 3.9 describes the probability distribution and energy estimation using Raleigh PDF:

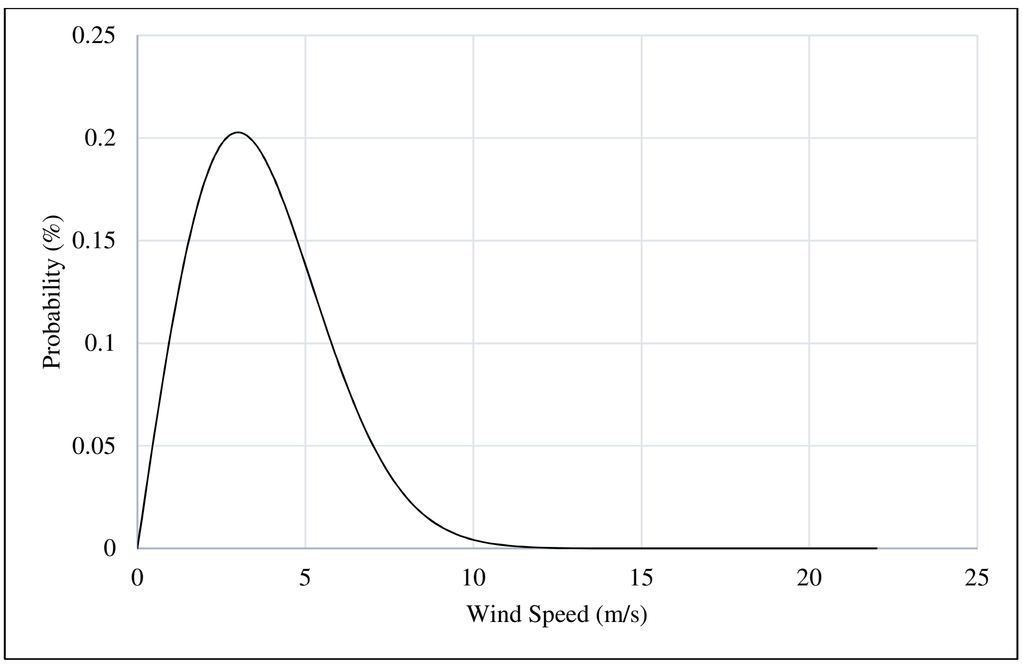


Figure 3.25. Raleigh PDF for frequency distribution.

This can be explained from the following. For the ease of explanation suppose Rayleigh distribution functions and Rayleigh cumulative distribution functions can be shown in the figure 3.26 and figure 3.27.

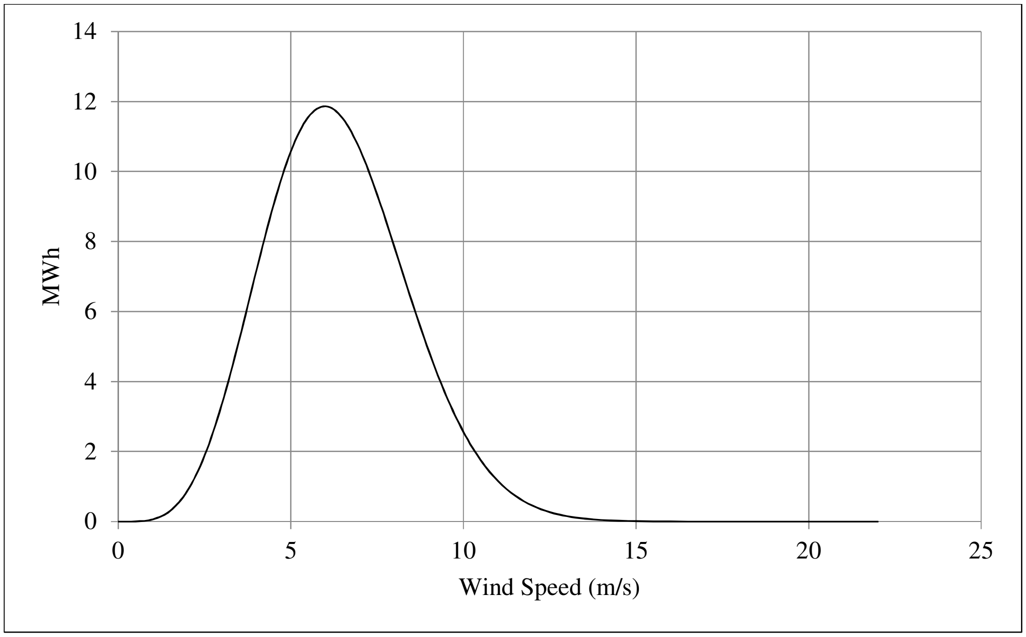


Figure 3.26. Raleigh PDF for energy estimation.

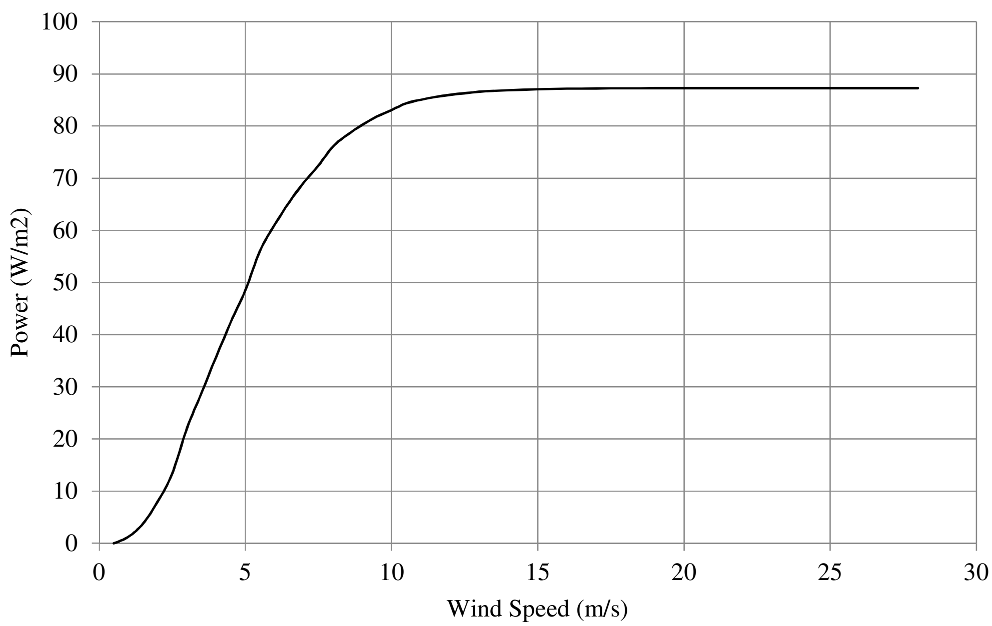


Figure 3.27. Rayleigh cumulative distribution function (CDF).

Measuring the area under the curve isn't always easy; to help out, the Rayleigh distribution can be expressed in the form of a "Cumulative Distribution" curve which gives the area under the density curve up to that speed. The cumulative distribution curve for an average wind speed of 4.50 m/s looks like figure 3.11. Using this curve, it is easy to see what the area is under the density function curve up to any wind speed. For instance, the area to the left of 6.00 m/s is about 0.75 or 75%. There is a 75% chance the wind will be less than 6.00 m/s.

3.5.5. Power Estimation from PDF

Once the value of the Weibull parameters are gained, power estimation of the wind becomes easier. In engineering practice, the average wind turbine power $\hat{p}_w$ associated with the probability density function (pdf) of wind speed v is obtained from equation 24.

$$\hat{p}_w = \int_0^\infty p_w(v) f(v) dv \qquad (24)$$

Where $f(v)$ is the probability distribution function of wind speed v and $p_w(v)$ is the power output generated from a turbine describes power output versus wind speed [201].

Now that it is being discussed about the power, normalized power can be of great values in order to estimate site-specific criteria of wind turbine. From the normative reference, in order to assess the quality of power and power performance measurement, IEC61400-12-1 gives sufficient guidelines. First step it needs to calculate the average of actual air density whether it needs to normalize data or not. This is to be considered only when the air density, air pressure and temperature data are available with wind data. As reference to IEC standard 61400-12-1 about data normalization, it doesn’t need to normalize the wind speed data with two reference air density if the average actual air density in the range of 1.225±0.05. As per the standard, the data shall be collected once in every minute. Before handling the data, there needs to have a simple steps:

data collection - data rejection - data correction.

The air density may be determined from measured air temperature and air pressure according to the equation 25.

$$\rho_{10\min} = \frac{B_{10\min}}{R_0 . T_{10\min}} \tag{25}$$

Where ρ_{10min}: derived 10 min averaged air density, B_{10min}: measured air pressure averaged over 10 min, T_{10min}: measured absolute air temperature averaged over 10 min, R_0: gas constant of dry air 287,05 J/(kg × K). When wind turbine with active power control is considered, the normalization procedure will be applied to the wind speed according to the following equation:

$$V_n = V_{10\min}\left(\frac{\rho_{10\min}}{\rho_0}\right)^{\frac{1}{3}} \tag{26}$$

Where V_n is the normalized wind speed; V_{10min} is the measured wind speed averaged over 10 min.

3.5.5.1. Determination of measured normalized power curve

Method of bins is usually exploited to get the measured power curve which is actually needed when normalized data sets are considered. The bin is of the size 0.5 m/s. Here shows the normalized wind speed along with the normalized power output when each wind speed bin as stated earlier is used in equation 27 and equation 28.

$$V_i = \frac{1}{N_i}\sum_{j=1}^{N_i} V_{n,i,j} \tag{27}$$

$$P_i = \frac{1}{N_i}\sum_{j=1}^{N_i} P_{n,i,j} \tag{28}$$

Where V_i: normalized and averaged wind speed in bin I, $V_{n,i,j}$: normalized wind speed of data set j in bin I, P_i: normalized and averaged power output in bin I, $P_{n,i,j}$: normalized power output of data set j in bin i; N_i: number of 10 min data sets in bin i. Power coefficient C_p of the wind turbine will be considered to test the results. Measured power curve is used to calculate C_p by equation 29.

$$C_p = \frac{P_i}{\frac{1}{2}\rho A V^3} \tag{29}$$

Where $C_{P,i}$: power coefficient in bin i, V_i : normalized and averaged wind speed in bin i, P_i: normalized and averaged power output in bin i, A: swept area of the wind turbine rotor, ρ_0: reference air density.

3.6. CALCULATION OF AEP

Selection of wind turbine is huge in examinations identified with wind energy feasibility, particularly in areas that have low wind speed [202]. Once the value of wind speed can be calculated from the hub height of the WTG, annual energy production (AEP) of the selected site becomes easy to compute. Standard AEP is calculated by applying the measured power curve to different wind velocity distributions of reference. A Rayleigh distribution similar to a Weibull distribution with a shape factor of 2 is used as the wind velocity distribution of reference as per IEC 61400-12-1. The factors needed to calculate AEP are:

1) Power curve of WTG
2) Capacity factor of WTG
3) Frequency of hours
4) Wind speed
5) Air density (standard or measured)
6) Weibull parameters

Power specified by the WTG manufacturers for every wind speed bin is multiplied by the respective hours like the following:

$$E = P * T$$

Where E=Energy in kWh, P = Power in kW and T =Time in hour. But mathematically power and AEP is calculated using the equation 30 and equation 31 for a pitch-regulated WTG.

$$P(v) = P_r \times \sum_{i=0}^{n} a_i v^i \tag{30}$$

$$AEP = P_r \int_{v_r}^{v_c} \left(\sum_{i=0}^{n} a_i v^i \right) f(v) dv + P_r \int_{v_r}^{v_c} f(v) dv \tag{31}$$

Where P_r is the wind turbine rated power, v_c is the cut-in wind speed, v_r is the rated wind speed, v_f is the cut-out wind speed, $\sum_{i=0}^{n} a_i v^i$ is the polynomial model and f (v) is the wind speed distribution. The wind turbines are generally divided into two categories: pitch-regulated WTG and stall-regulated WTG [203][204][205][206]. The total energy according to the bin is then summed up to get AEP. As efficiency of the WTG varies with the wind speeds as specified by the power curves, it is important to note that, power output of WTG varies almost with the cube of the wind speed. The k value (scale parameter of Weibull PDF) is equal to 2, which is usually denoted as Raleigh PDF and is normally specified by the manufacturers, and the C value (shape parameter of Weibull PDF) impact on the variation of AEP.

AEP can be measured also by the use of capacity factor of WTG which is in fact the ratio of the measured annual output from the turbine and the expected output for a year. Expected power output is a measure of the power derived from the WTG if it runs the full 8760 hours of the year at its rated power.

3.7. WIND TURBINE NOISE ANALYSIS

There are a number of mathematical equations available for modeling the noise emission and propagation from wind turbines [207]. The noise pressure level L_P at a distance R from a wind turbine, radiating noise at an intensity of L_W is given by equation 32.

$$L_P = L_W - 10\ log_{10}\ (2\pi\ R^2) - \alpha\ R \tag{32}$$

Where α is the sound absorption coefficient. For a given noise level of L_P, the sound power P_N expressed in W/m^2 can be approximated as in equation 33.

$$P_N = 10^{\left(\frac{L_P - 90}{10}\right)} \tag{33}$$

The research considers the background noise level caused by wind while estimating noise level of small WTG. When the background noise and wind turbine noise are at the same magnitude, the wind turbine noise gets lost in the background [208]. Typical background sound levels range from 35 dBA (quiet) to 50 dBA for urban setting [209]. AWEA attempts to measure the turbine noise level from equation 34.

$$WTNoiseLevel = L_{AWEA} + 10\log(4\pi 60^2) - 10\log(4\pi R^2) \tag{34}$$

After that, once the background noise has been acquired, the overall noise level is measured from equation 35.

$$OverallNoiseLevel = 10\log\left(10^{\frac{turbinenoiselevel}{10}} + 10^{\frac{backgroungnoiselevel}{10}}\right) \quad (35)$$

In order to assess the noise from a WTG and to get detailed result, time-series data are required for a number of operations in terms of different distances between the rotor hub and the sensor. The noise of WTG needs to correlate with wind speed which is measured at a height reference height of *z*. The standard measurement height is 10m. Practically WTG works in much higher altitude than standard measurement as wind speed increases with the increase in the height. Wind speed near the ground is lower due to many obstacles like forest, building, hills, vegetation etc. So it is impractical to commercialize WTG at lower level. That's why it needs to extrapolate the wind speed at the reference height z to a specific height as per some international standards with the help of mathematical equations like power law profile.

There are some related factors like frequency and magnitude that define the characteristics of noise. The magnitude of noise can be expressed either in terms of sound power level which indicates the acoustic power with which the noise is emitted from the source, and or sound pressure level that indicates the intensity of noise propagated experienced by the listener located at a given point [210]. Though to some extent, the noise propagated from the WTG is masked by the background noise created from trees, forests, buildings etc., the propagated WTG noise needs to estimate. Masking wind turbine noise has been studied with natural sounds and sound from road traffic [211].

3.8. WIND RESOURCE MAPPING

Numerical wind atlas analysis will be done for selecting suitable locations in the projected areas. The wind data will have been used to develop wind resource map using the Wind Atlas Analysis and Application Program (WAsP) and ArcGIS at different level shown in Table 12.The standard heights in a wind atlas are utilized to interpolate the wind climate (sector-wise Weibull A and k) to heights between these standard heights. The five default standard heights are [212] shown in table 3.9.

Table 3.9. Standard heights of a wind atlas.

Default standard heights [m]	10	25	50	100	200

WAsP model is a very suitable tool considers the elevation and the roughness length, besides utilizing linear components of Navier-Stokes equations to determine the wind speed at different sites [213]. WAsP can handle and produce different kinds of map files including:

- **Elevation map:** This can be extracted from Digital Elevation Model (DEM). DEM is in general digitized using ArcGIS or can be directly downloaded from SRTM data with different resolution like 1-arc second resolution (30 m) or 3-arc second resolution (90 m). Moreover, detailed information concerning the SRTM (Shuttle Radar Topography Mission by NASA, USA) data can be obtained from the United States Geological Survey website [214].
- **Roughness map:** Wind speed depends not only on atmospheric parameters, but also on formation of the land. Wind speed reduces or varies on many factors of roughness. Rougher is the land, the sudden variations the wind has. Forests, buildings, mountains along with other obstacles also impact on wind speed. In this context, roughness map is essential in understanding wind speed characteristics. Roughness map is a map that contains the value of land roughness length and class. Roughness line map can be built from the land-used image of topography map using software tools like WindPRO, WAsP etc. Roughly four types of roughness can be defined as follows though EMD international A/S has detected acutely the roughness class and length [212] as shown in Table 3.10.
    1) Roughness class 0: the soil is flat, such as the sea, the beach and the snow.
    2) Roughness class 1: open soil with non-farmed land, low vegetation and airports.
    3) Roughness class 2: agricultural areas with few buildings and few trees.

4) Roughness class 3: rough soil with many variations in soil inclination, forests and villages.

Table 3.10. EMD International defined roughness class and length.

Serial No.	*Area Type*	*Roughness Class*	*Roughness Length*
1.	Forest, City	3.00	0.40
2.	Closed farmland	2.50	0.20
3.	Partly closed farmland	2.50	0.10
4.	Nearly open farmland	1.50	0.05
5.	Open farmland	1.00	0.03
6.	Water	0.00	0.00

Google Earth Image: There are many kinds of imagery maps are available like topography map or extracted map. Google Earth can provide this kind. Topography map can be categorized into two types: 1) restricted topography which is more expensive and 2) unrestricted topography map.

WTG power curve: In general, power curves are provided by the WTG manufacturers that contains a graph of power expressed in Watt in terms of wind speed (bin). Again this data can be retrieved through WindPRO which provides the datasets of WTG power curves of WTG purchased from various manufacturers. Notable that, all types of WTG (small-scale, medium- scale and large-scale) power curves are available in WindPRO.

3.8.1. Mapping Methodology

A wind map is simply a map with an exception that it contains some numerical values of wind speed, wind direction and wind power of a particular geographical area. Prior to building wind map, wind resource assessment studies are very important to conduct which holds three basic categories [215]:

4) Preliminary Area Identification,
5) Area Wind Resource Evaluation and

6) Micro-siting

Wind mapping is a complex work. In the modern era computer tools are used to building maps which replaces manual system that was used before 1990s. Computerized mapping system has two primary goals:

- To produce a more consistent and detailed analysis of the wind resource
- To generate high-quality maps on a timely basis.

When using a suitable software is concerned, the following criteria regarding the software are discussed:

1. Models properties
2. Data criteria used by the model
3. Wind mapping process
4. Product of the mapping system
5. Limitations of the method
6. Error estimation from the input data
7. Validation of the model.

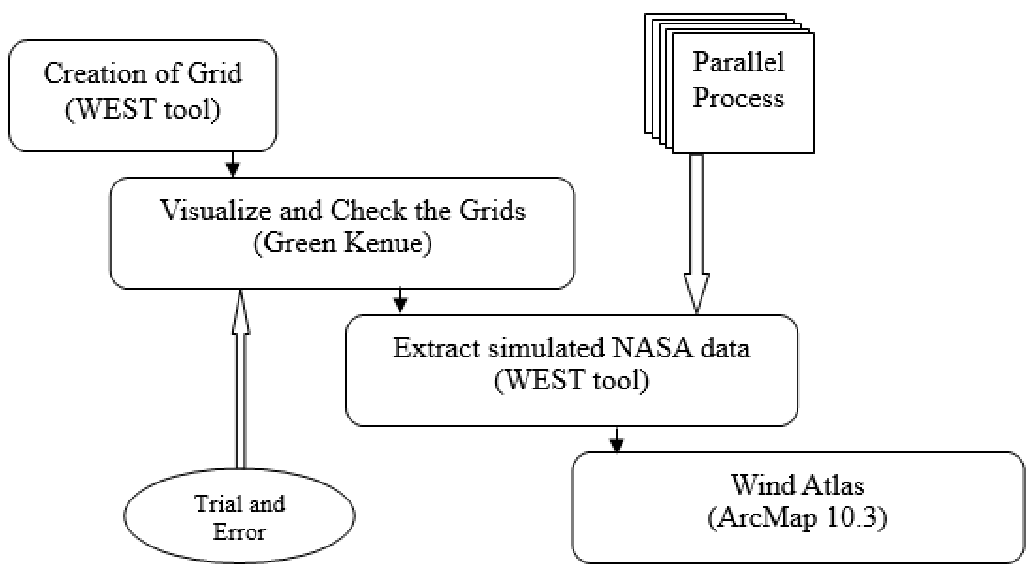


Figure 3.28. Simplified Steps of Building Atlas.

For validation analysis, all simulated and real data meet point should lie on $x = y$ line in a two-dimensional plot. Data will be reliable upon how much deviated they are from that line. There is no ideal case in research finding.

The mapping system is divided into three main components:

a. The input data,
b. The wind power calculations,
c. The output section, which produces the final map.

It almost looks like the information process cycle: Input-Process-Output. The input data can be of two types: either it is simulated data from some online databases like MERRA database, or it may be the real met station data. In general, wind data from met stations are recorded at 10 m above ground level. The steps of wind mapping can be drawn like the diagram shown in figure 3.12. Roughness and topographic map can be built by Digital Elevation Model (DEM) database. The terrain data that will be used to divide the projected area into individual grid cells called domain, each having its own unique elevation value. Resolution of the map can be dependent on the necessity. As an example, 3 square km for mesoscale mapping and 200 square m for microscale mapping.

3.9. WIND ENERGY ANALYSIS MODEL

This section will incorporate a very prominent wind energy software package named WAsP for the ease of analysis.

3.9.1. WAsP Tool

WAsP is a widely recognized computer application for wind speed and direction data analysis. The following sections would help understanding the tool for a proper application in the research.

3.9.2. WAsP Explained

WAsP (Wind Atlas Analysis and Application Program) is a computer program for anticipating and analyzing wind atmospheres, wind power, and power productions from wind turbines and wind farms (https://en.wikipedia.org/wiki/WAsP). The prediction of wind depends on wind information estimated at meteorological stations in a similar area. The program incorporates a complex terrain flow model, a roughness change model, a model for identifying and sheltering obstacles, and a wake model.

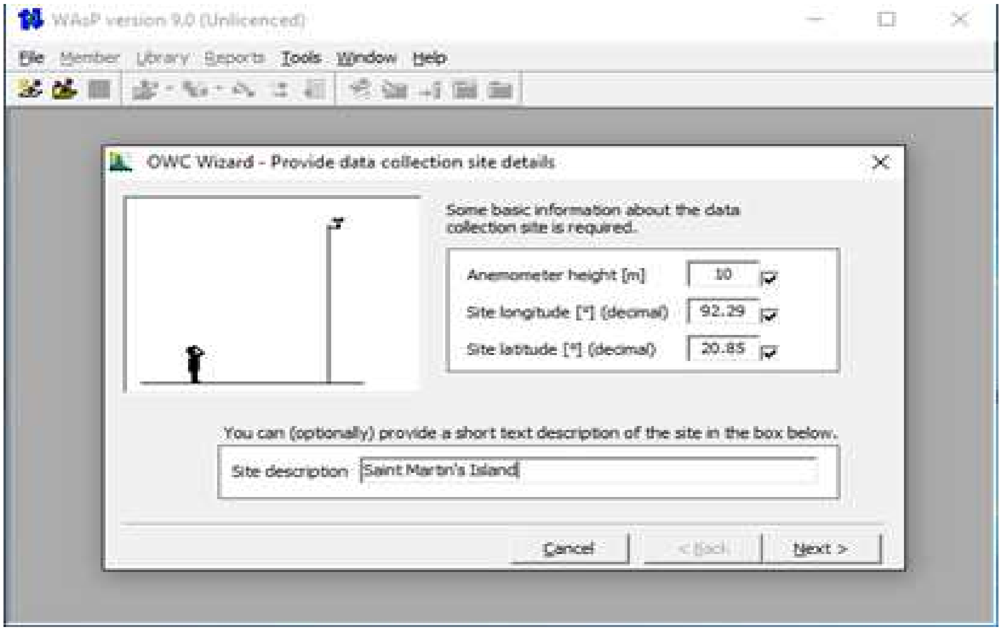


Figure 3.29. WAsP Tool Editor [216].

The WAsP product bundle further contains a Climate Analyst for making the wind climatological inputs, a Map Editor for making and altering the land inputs, and a Turbine Editor for making the wind turbine contributions to WAsP.

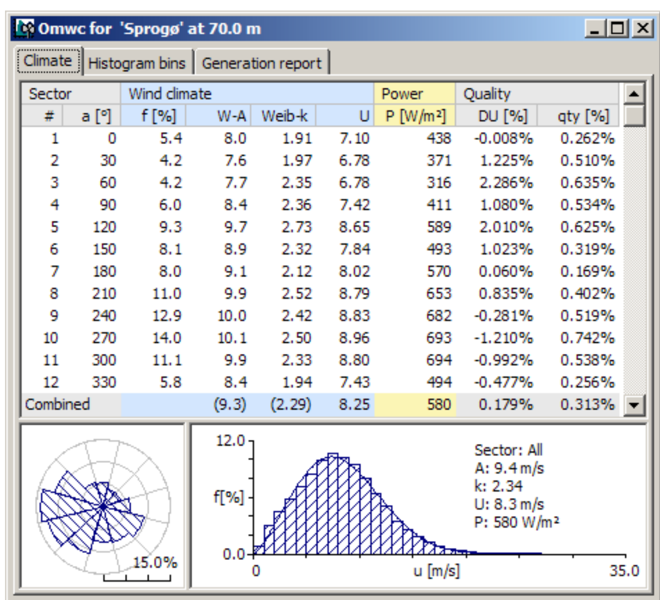


Figure 3.30. Wind Direction Data in WAsP [216]

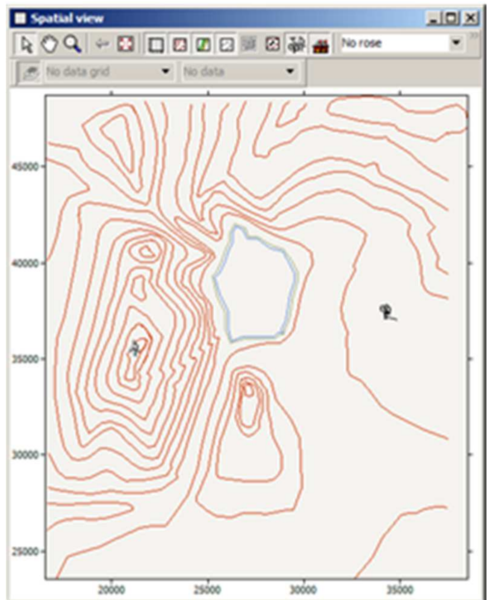


Figure 3.31. Wind Atlas in WAsP [216].

Figure 3.32 demonstrating the WAsP editorial manager filling in as an atmosphere investigator. It delineates functionally actualized tools, the WAsP Climate Analyst. In this, the wind data can likewise be appeared in a few diagrams: the time directions of wind direction and wind speed, and as a polar scatter plot of the observations.

Figure 3.15 shows a statistical substances comprises of the distribution of wind direction (wind rose) and the sector-wise wind speed distribution. These distribution establish the meteorological input to WAsP.

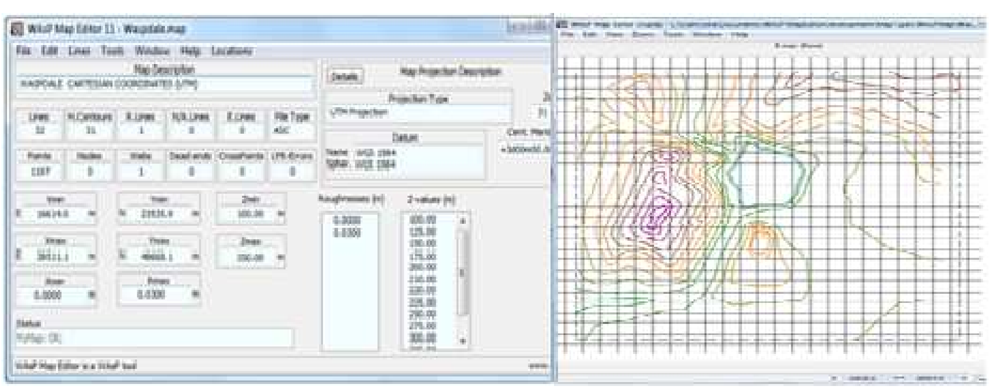


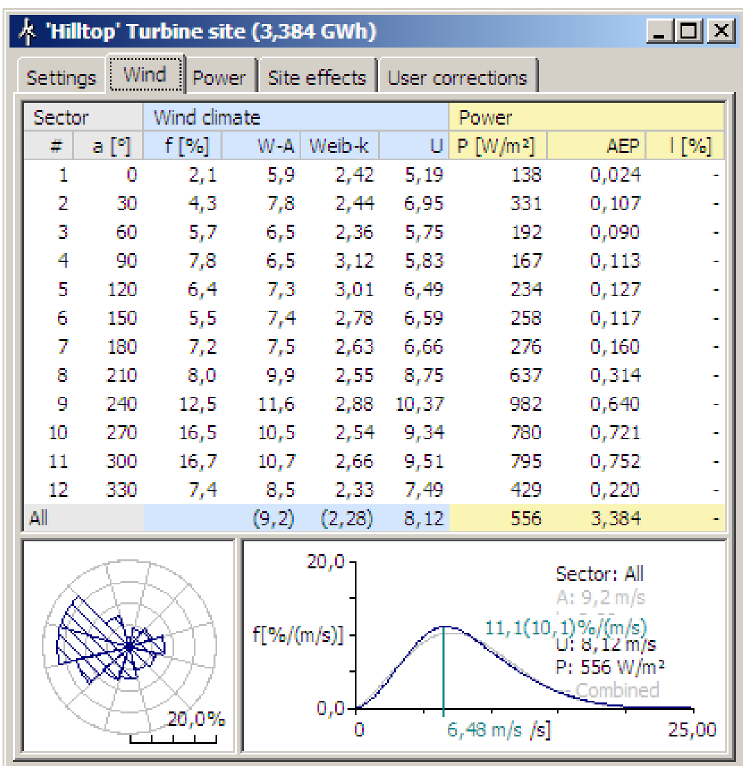
Figure 3.32. WAsP Map Editor [216].

The basics of WAsP and the wind map methodologies are portrayed in the European Wind Atlas (http://www.WAsP.dk/). WAsP is created and circulated by the

Department of Wind Energy at the Technical University of Denmark, Denmark. WAsP is utilized for:

1) Measuring efficiency of wind farms.
2) Calculating the production of wind farms.
3) Micro-siting analysis of WTG.
4) Power analysis.
5) Analysis on wind resource atlas.
6) Estimation of wind climate.
7) Genration of wind resource maps.
8) Real and simulated wind data analysis.

WAsP uses digital terrain maps for flow modeling. The figure 3.31 illustrates how WAsP makes wind atlas. The Map Editor shown in figure 3.32 is a separate utility program, included in the WAsP package, which is used to provide topographical inputs to WAsP.



Sector		Wind climate				Power		
#	a [°]	f [%]	W-A	Weib-k	U	P [W/m²]	AEP	I [%]
1	0	2,1	5,9	2,42	5,19	138	0,024	-
2	30	4,3	7,8	2,44	6,95	331	0,107	-
3	60	5,7	6,5	2,36	5,75	192	0,090	-
4	90	7,8	6,5	3,12	5,83	167	0,113	-
5	120	6,4	7,3	3,01	6,49	234	0,127	-
6	150	5,5	7,4	2,78	6,59	258	0,117	-
7	180	7,2	7,5	2,63	6,66	276	0,160	-
8	210	8,0	9,9	2,55	8,75	637	0,314	-
9	240	12,5	11,6	2,88	10,37	982	0,640	-
10	270	16,5	10,5	2,54	9,34	780	0,721	-
11	300	16,7	10,7	2,66	9,51	795	0,752	-
12	330	7,4	8,5	2,33	7,49	429	0,220	-
All			(9,2)	(2,28)	8,12	556	3,384	-

Figure 3.33. Wind climate estimation using WAsP [216].

With the map editor it may obtain digital topographical maps from web-databases or external suppliers - or can be created digital maps yourself by digitizing height and land-cover information from map images, e.g. scanned images of standard (paper) topographical maps.

A number of map-formats may be used in connection with WAsP and the WAsP Map Editor - many of them formats of maps available from external suppliers. Using the Map Editor, digital maps from external sources may be analyzed and checked, e.g. against a map image – and supplemented and edited, should changes be needed. Such changes include addition of land cover information, conversion to standard WAsP map format and change of coordinate system.

3.9.3. Estimation of Wind Climate

Using a regional wind climate calculated by WAsP or one obtained from another source, e.g. the European Wind Atlas or one of the many wind atlases now available - WAsP can predict the wind climate at any specific site and height by performing the inverse calculation as is used to generate the regional wind climate. By introducing descriptions of the terrain around the predicted site, the WAsP models can predict the actual, expected wind climate at this site.

Regional wind climate - site description - predicted wind climate (PWC)

The predicted wind climate is given in terms of the wind rose and the wind speed distributions for each sector and in total. The WAsP window corresponding to the predicted wind climate looks like figure 3.33. WAsP calculates the following data (for each sector and in total) for the site:

1) Frequency of occurrence
2) Weibull *A*-parameter
3) Weibull *k*-parameter
4) Mean wind speed
5) Mean power density
6) Annual energy production (if a wind turbine generator is associated)
7) Wake loss (if the turbine site is member of a wind farm.

3.10. WIND ENERGY ECONOMICS

It has been known that AEP varies in great amount depending on the wind of a particular site. As a result, wind speeds plays the most important role in terms of the price variation for wind energy. There is no fixed rate in wind energy price rather a range of prices is the fact when the energy economics is considered. There is an inverse relationship between AEP and prices electricity when demand is unchanged.

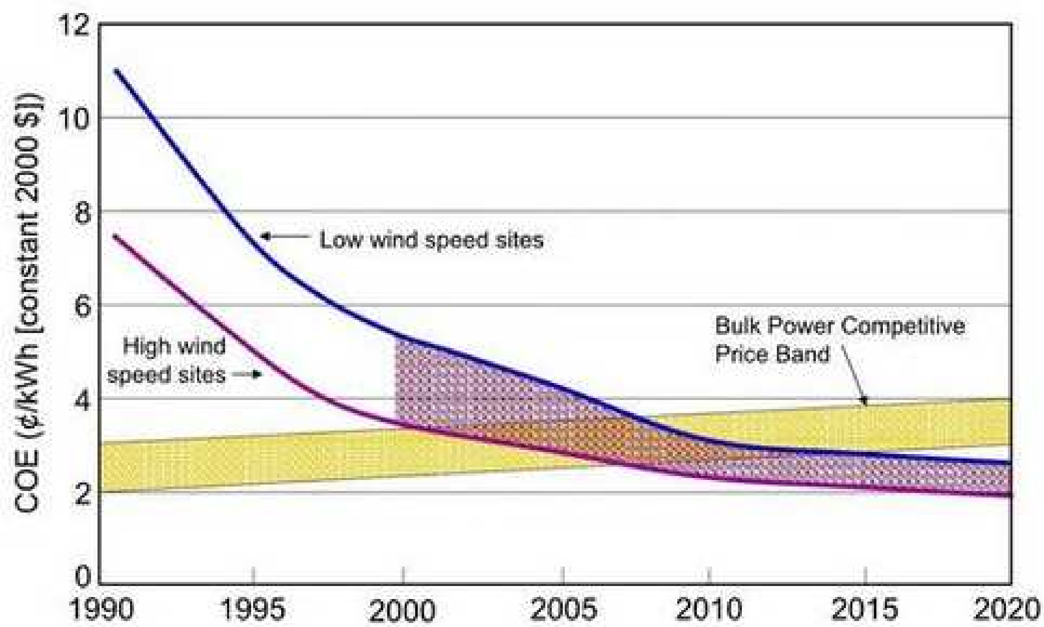


Figure 3.34. Cost of wind energy by year with a prediction for 2020 [217].

It means if AEP increases, the price of the electricity produces from WTG or wind farm will decrease. The relationship is really very easy to understand. For example, if a WTG produces twice as much energy per year, the cost of electricity will be half for every kWh/year provided that the other cost like operations, management and maintenance costs remain almost same.

3.10.1. Cost of wind energy

This section of the research will examine the cost of wind energy by finding the related factors that influence the cost. Figure 4.8 discloses the cost of electricity generated from wind turbine over the years from 1980 to 2020. It reveals the fact that, from 1980 to 1985, the cost of the energy has fallen drastically. This decline was due to the turbine size to be increased with the development of technology. Technological improvements [218] are expected to significantly lower the life cycle cost of wind energy. There is also an inverse relationship with the cost of wind energy with wind speed.

There are a number of factors that affect the economics of wind energy such as, site related factor, WTG related factor, policy related factor etc. As a result, economic feasibility study [219] will be one of the most important subject to work with. Cost of wind energy can be estimated using a number of ways: 1) cost/WTG rated power (2) cost/rotor size and (3) cost/ generated electricity (kWh). If the rated power of the WTG is P_R, and the total cost of the WTG is C_{WTG}, then the cost of one kWh of energy C_e can be estimated by equation 36.

$$C_e = \frac{C_{WTG}}{P_R} \tag{36}$$

When the rotor swept area of WTG is A_{WTG}, the cost of energy can be measured using equation 37.

$$C_e = \frac{C_{WTG}}{A_{WTG}} \tag{37}$$

If C_O is the annual operation cost which sums up the annual fixed cost and annual variable cost, and AEP is the total annual production, then the cost of wind energy can be measured using equation 38.

$$C_e = \frac{C_O}{AEP} \tag{38}$$

As $AEP = 8760 \times CF \times P_R$, the equation like equation 39.

$$C_e = \frac{C_O}{8760 \times CF \times P_R} \tag{39}$$

As far as cost of energy is concerned, the capacity factor of WTG or wind farm should be increased. Research reveals that CF can be even increased nearer to Betz limit that amounted to 41% [220]. Cost can be of various types including installed capital cost, land cost, operations and maintenance cost, grid integration cost, insurance, inflation etc.

As the cost of energy increases if the energy generated by WTG becomes less, normalized power curves and capacity factors can be initiated for a site specific matching of the turbine in order that the power output can be increased. It needs to optimize the WTG speed for the matching of the site. As there is an inverse relationship between wind energy and wind speed, this kind of optimization is very important for the turbine performance index that are obtained from normalized curves. This technique makes the WTG to have more capacity factor which indicated that the energy production will be higher. Normalization of wind data are explained in section 3.3.6.

But prior to talk about the cost of energy, it needs to know about LCOE (levelized cost of energy) for wind as described by the International Renewable Energy Association (IRENA). Levelized cost of energy can be characterized by the present estimation of all costs divided by the present estimation of all power generated over the lifetime of the project. As far as wind energy is concerned, it is an economic assessment of the average total cost to create and to operate a wind energy generation system over its lifetime divided by the total electrical energy generated by the system over that lifetime. Mathematically, LCOE can be expressed as in equation 40.

$$LCOE = \frac{\sum_{i=0}^{n} \frac{CPE_i}{(1+r)^i}}{\sum_{i=0}^{n} \frac{E_i}{(1+r)^i}} \tag{40}$$

Where CPE is denoted as the cost of produced energy in year of number i. E can be understood in year i as the product of the rated power and the average capacity factor (CF) in year i. When the total life cycle cost is considered, the mathematical expression of LCOE becomes equation 41.

$$LCOE = \sum_{i=0}^{n} \frac{TotalLifeCycleCost(TLCC)}{\frac{E_i}{(1+r)^i}} \tag{41}$$

Upon derived the value of LCOE, the model must be well adopted with the parameters given for the contribution of the Total Life-Cycle Cost. LCOE is associated to the every single unit of energy produced by the generation system over one year.

3.10.2 GHG emission reduction

Today's world, the emission of green-house gas is a challenge. WTG produces green energy and the reduction of emission of GHG can be correlated with it. In order to calculate the emission reduction from AEP of WTG, it is needed to know the value of emission factor. As an example, if the emission reduction of CO_2 is to be calculated from the AEP of a particular turbine, the emission factor of CO_2 will be needed. The equation for GHG emission reduction is shown in equation 42.

$$G = \frac{f_e \times E}{1{,}000{,}000} \tag{42}$$

Where G is the GHG emission reduction in Ton GHG/Year, f_e is the emission factor of a particular gas and E is the annual energy production (AEP) in kWh/Year.

3.11. VALIDATION ANALYSIS

It should be incumbent upon the researchers of wind energy to provide not only what has been estimated from the analysis itself, but also to present the accuracy level of the research. This simply means that, what has been found from the analysis and what was expected? This research will conduct validation study (predominantly the estimation of errors) of its diligence wind energy analysis in different perspectives namely statistical tests for goodness of fit with South Korean and Bangladeshi wind data, whereas machine learning for the validation analysis with Thailand wind data.

3.11.1. Statistical Test Models

Error in wind energy analysis expressed in percentage value is defined by the subtracted value of assumed and pre-construction long-term data (e.g. simulated retrospective data) from actual estimated energy produced from the real data. The expected data can also be estimated from the slope of the best-fit line in a scatter diagram. This research has to follow the investigations written below in consideration of the validation analysis:

1) What are the wind energy assessment methods that have been used in the research?
2) What are the criteria of the dataset?

3) What procedures are being followed in analysis?
4) How the results of validation analysis will be produced and presented?
5) Is there any measure to adjust the uncertainty of the outcomes?

The research outcome in this work has been laid down through some test for the checking of the consistency of the data. They are

1) Percentage mean relative error (PMRE),
2) Root mean square error (RMSE),
3) Mean bias error (MBE),
4) Mean absolute error (MAE)
5) Measured vs. predicted outcome (M/P).

Root mean square error (RMSE) defines the deviation between the statistically presumed values and the experimental values. The lower the values of RMSE, the more well performance a particular distribution method shows, and vice versa. RMSE should be as close to zero as possible, and it is expressed as [221] [222] in equation 43.

$$RMSE = \left[\frac{1}{N}.\sum_{i=1}^{N}(y_i - x_i)^2\right]^{\frac{1}{2}} \tag{43}$$

Mean Bias Error can be estimated by equation 44.

$$MBE = \frac{1}{N}.\sum_{i=1}^{N}(y_i - x_i) \tag{44}$$

MBE might disclose the positive or negative bias [223]. In order to understand only the value, MBE can be thought of as defining Mean Absolute Error (MAE) which can be written as in equation 45.

$$MAE = \frac{1}{N}.\sum_{i=1}^{N}\left|y_i - x_i\right| \tag{45}$$

RMSE value can be of zero to infinity. Low values of RMSE are desirable. Few errors in the sum can produce a significant increase in the indicator. Low values of MBE are also desirable, but overestimation of an individual data element will cancel underestimation in a separate observation. It is also possible to have large RMSE values at the same time a small MBE or vice versa [224]. M/P method discloses the ratio between the observed and predicted value. The ratio equals to one is the best coincidence of the result. PMRE can be thought of as the ratio like equation 46.

$$PMRE = \frac{e_m}{v_m} x100\% \quad (46)$$

Where, e_m is the mean error from n number of occurrence (e_1, e_2, e_3 ...... e_n). If v_1, v_2, v_3..... v_n are the data, of which v_m is the mean, the errors can be calculated as, $e_1 = v_1 - v_m$; $e_2 = v_2 - v_m$, *etc., and* $e_m = (e_1 + e_2 + e_3 + \ldots\ldots + e_n) / n$.

3.11.2. Machine Learning

Data and information are the feeding that keeps machine learning capable of working. Regardless of how amazing machine learning or potentially profound learning model is, it can never do how we need it to manage bad data. Arbitrary noise (for example information focuses that make it hard to see an example), low recurrence of a specific absolute variable, low recurrence of the objective classification (if target variable is downright) and wrong numeric qualities and so forth are only a portion of the manners in which information can wreck a model. While the validation process cycle can't straightforwardly discover what's going on, the process can show us at times that there is an issue with the steadiness of the model.

Total number of data	
Training Dataset	Test Dataset

Figure 3.35. Training and test data set explained for machine learning.

This is the term machine learning can be useful for data validation. This process will be applied for Thailand wind data.

3.11.2.1. Train/Validation/Test Split

The most fundamental strategy for approving the data is the point at which somebody will play out a train or test split on the data. An average proportion for this purpose may be 80/10/10 to ensure that the dataset actually holds sufficient training data. Subsequent to training the model with the training set, the user will move onto approving the outcomes and tuning the hyper-parameters with the validation set till the client arrives at a palatable performance measurement. When this stage is finished, the client would proceed onward to testing the model with the test dataset to foresee and assess the performance of the model.

3.11.2.2. Cross Validation

Cross Validation is a procedure to survey the exhibition of a measurable forecast model on an autonomous data index.

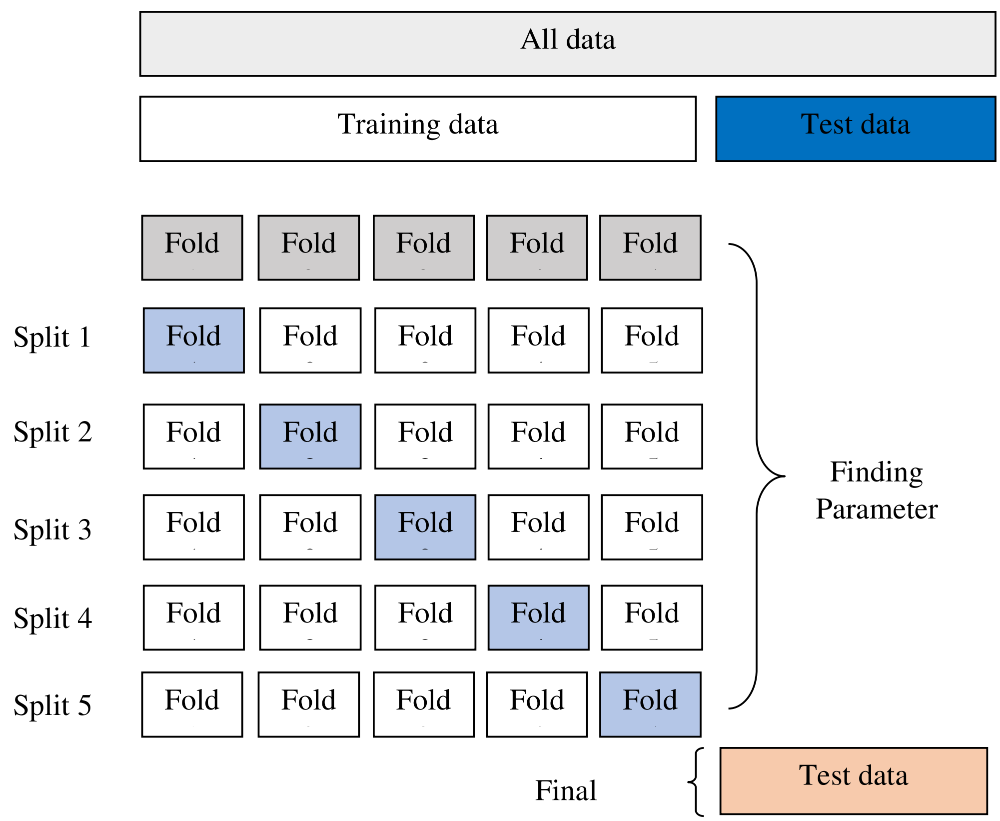


Figure 3.36. Cross validation explained for machine learning [225].

The objective is to ensure the model and the data function well all together. This process is applied during the training stage of the validation analysis where the user/client will evaluate whether the model is inclined to underfitting or overfitting to the data. The data to be utilized for cross validation must be from a similar dispersion for the objective variable or probably it can delude the observer with respect to how the model will act when all things considered.

In the condition that someone might want to safeguard however much information as could be expected for the training stage and not risk to lose important data to the validation dataset, k-fold cross validation can help. This strategy won't need the training data to give up s portion for the validation dataset. In this occasion, the dataset is broken into k number of folds wherein one fold will be utilized as the test set and the rest will be utilized as the training dataset and this will be repeated n number of times as determined by the user.

In a regression the normal of the outcomes (for example RMSE, R-Squared, and so forth) are usually utilized as the end-product. In a characterization setting, the normal of the outcomes (for example Precision, True Positive Rate, F1, and so forth) will be taken as the eventual outcome.

Validating a dataset offers reassurance to the client about the steadiness as well as reliability of the model. With machine learning entering aspects of society and being utilized in our everyday lives, it turns out to be more basic that the models are illustrative of the society. Overfitting and underfitting are the two most basic flaws that a Data Scientist can look during a model building measure. But still, validation is the doorway to the specified model used for Thailand wind data in this research being streamlined for execution and being steady for a while prior to waiting be retrained.

Chapter 4

Challenges and Gaps of Wind Energy Research

4.1. INTRODUCTION

There have been plenty of renewable energy resources especially wind energy which is found suitable for energy production only if there is a proper and systematic approach for research. Since wind energy has not been sufficiently exploited, and the energy demand is not satisfied from the existing power supply system, there are lots of work can be done in this sector such as, to work more to identify the potential areas as well as to work with energy policy to build a sustainable energy production culture. The gap among wind site exploration, funding, culture, environment and policy implementation etc. has instigated the researchers throughout the world from different aspects to work more on this sector which yielded the door of great prospect for both the community and the researchers. The deployment of wind energy extraction systems requires reliable data collected for the farms to be built-up for a particular area, and for policy makers and thinkers a great way to find suitable opportunity to match the wind technologies with those policies.

4.2. CHALLENGES IN WIND ENERGY RESEARCH

Wind power projects subsidies are not available in many countries. Investment itself is one of the greatest problems for wind farm establishment. Proper financing authorities, delegates, and investors for wind energy for both in small and medium size farms are hard to integrate. Consequently, the potential research problem of wind energy can be written down like the following:

1) The research in wind energy concerns about how local and global economy has an impact on wind energy share.
2) As policies are specific regarding local and regional aspects, it needs to find ways for integrating the policies in a global aspect.
3) The subsidies and support in wind energy application should be applied for all local enterprises and the capacity builders which needs to be associated with those local and global policies.

4) It needs to justify of what the impact is on the local, regional and global policies wind energy market along with in the business environment.
5) The researcher needs to understand the value of change in terms of renewable energy over time.
6) All positive and negative impacts of wind energy are needed to be considered carefully from socio-economic aspects.

Moreover there are a lot of imperfect and anomalous government policies throughout the globe. In addition to it, there are many regions for which no authentic literature discussing about the right wind energy policies can be achieved.

4.2.1. Economic challenges of wind energy

The wind industry has already been able to prove to be one of the best efficient competitor in energy sector in terms of cost competitiveness and efficiency by relying on one of the most important measures in the economics of energy industry - Levelised Cost of Electricity (LCOE) which is defined by the common measure of cost of energy (i.e. wind energy) and other energy sources for a number of years. LCOE of wind energy is higher with a downward trend compared to other conventional energy sources in order for electricity generation. The mitigation of monopoly in wind energy market along with the promotion of the increasing of the independence of manufacturers can reduce the wind energy costs. But reliance on local wind turbine manufacturers needs to concentrate on quality control which is one of the pre-requisite for buying turbine from them. On the bargain of quality control, the local turbine manufacturers should work on multiples of the turbine size, life cycle, reliability, cost and efficiency of turbines.

LCOE is a process to assess targets and support levels which has been practiced by the industry owners and other stakeholders along regional and global politicians related to it. LCOE is helpful in

1) Showing the trend of how wind energy is progressing
2) Identifying how wind energy became one of the cheapest energy sources.

It can be assumed that, global economy of energy systems in the near future will predominantly depend on sustainable i.e. renewable energy sources such as wind energy. Being a very much sophisticated system, wind energy supply is not all about a technical system, it has to consider all possible societal and economic challenges relating to it. The relationship between economic growth and the protection of environment, which is one of the major obstacles for ensuring sustainable development, is a big challenge and this challenge has been welcome by the globe through addressing the opportunities and challenges wind energy sector has yielded.

A great concern that all the related mechanisms in wind energy must be designed in a cost-efficient way which can be able to strengthen trust of the commoners. Only in that situation, wind energy can emerge out to be a competitive mean of energy source. There is no doubt that cost of wind energy is not the same between two countries or regions. Initial investment on the wind energy projects is quite high and a risk factor is always involved questioning the confirmed profitability of the project [226]. As a result, detail economic analysis are to be conducted in individual manner. However this is very complicated as there is no generic theories to apply to all countries or regions. In addition to this, it needs to assess the environment impact of wind energy along with economic analysis which cannot also be identified as a generic one rather diverse for the change of regions and countries. So, in terms of economic and environmental aspects, the following items should be kept in mind.

1) To understand comparative analysis of wind energy to other energy sources with respect to cost, efficiency and profit.
2) To understand the potential impacts on socio-economic and environmental effects of wind energy generation.
3) To understand wind energy value chain which consists of a number of specific steps from the supply of raw materials to the transmission of electricity.
4) To understand the opportunities of the value chain in wind energy that starts with raw materials and ends in wind farm developers.
5) To identify and understand the direct and indirect actors in wind energy sector who both play vital role from production of wind turbine to electricity generation.

6) To understand the relationship between top players with small and medium players in wind energy sector.

As design plays the most important role in the development of wind energy, a proper and dynamic cost model is needed to be formulated for understanding the effects of all possible technologies employed in wind energy application. So, design dependent technological assessment is what needs to estimate the pros and cons of the cost effect that may impact on it.

4.2.2. Environmental Challenges

When environment pollution issue is at present a burden to everywhere on earth, a very bargaining question needs to be places: How can wind farms be designed so that the environmental impacts can be minimized? Following are the considerations regarding environmental challenges:

1) Identifying of the most optimal ecological and most suited economical sites for both onshore and offshore wind at present and in the future which can be able to avoid environmental conflicts.
2) There are many countries that conduct research in showing short-term environmental effect, but a very consistent, integral and strong international approach is needed in order for the estimation of long-term and cumulative environmental effects.
3) A combined international platform is necessary for exchanging, compiling, checking, arranging and analyzing the results in an integrated approach which may initiate additional and supplementary research if needed.
4) Environmental impacts of an increasing amount of wind farms on specific animal groups should have to be estimated in local, regional and global manner.
5) It needs to find ways for harvesting the available natural resources in a sustainable manner (sustainable harvest) which could be a new idea for offshore wind energy implementation.
6) Preservation of local, regional and global flora and fauna will have to be ensured at the time of wind energy implementation.

In a nutshell, the environment barriers are connected to the following factors:

1) Visual problems like shadow flicker
2) Noise emission from turbine
3) Endangering wildlife
4) Climatic changes like hot air production
5) Harmful wastes during wind turbine generation.

The cumulative environmental impacts of increasing numbers of wind farms can be identified by analyzing and quantifying the impact of multiple wind farms on habitats, large and small quantities of animal groups, ecosystems and livelihood of human being.

4.2.3. Big data challenge

A great many amount of information is available now to support research in wind energy analysis, wind farm designs and wind energy environmental issues. Here lies the problem. Selection of correct data among those hundreds of data sources become a big challenge for a proper pathways for research. Data selected, collected and analyzed, and how can they be used for improved performance will need a proper data sourcing and validation. Some very sophisticated modern technologies are being used for recording wind data. For example, remote sensing and GIS technologies are very acceptable these days. Even, every sensitive parts of wind turbine produces data which can be recorded through sensors. But still, in the stage of recording data which are usually long - term, there are significant problems to be faced when the data are retrieved. Missing data and inconsistent data are some of them. The challenges when the data related to wind energy are considered are:

1) Quality control of the data
2) Proper filtration
3) Proper message generation of turbine system and the whole power system.
4) Decreasing the uncertainty in analysis, designing, operation and control.
5) Data integrity
6) A validated computer program

7) Validation of underlying knowledge and theories by proper scientific computations and experiments.

Though wind energy has attained a lot of maturity in the field of energy and environment technology, a proper, guided and dedicated knowledge of basic science, especially physics, mathematics and geography is required, spanning from basic fundamental science to pioneering technologies, across multiple disciplines.

4.3. KNOWLEDGE GAPS IN WE RESEARCH

There are huge potential and uncountable benefits wind energy can generate. But still there are many challenges which can take place in the future for the proper application of wind energy. Implementation of wind energy resource in commercially profitable manner should be considered in a way that barriers and challenges which are summarized below can be faced successfully.

1) The unpredictability of wind is the most common thing to face.
2) Cost of wind turbine and overall infrastructures is a very big deal in wind energy application and implementation.
3) Environmental factors are an all-time concern. It needs in the research that how the livelihood of the local people near the wind energy establishments can be affected. Relationship between wind energy generation and people's way of lives should be importantly estimated.
4) Social and cultural factors are sensitive issue. There is no formal predictions of how the opinion of local people can go for implementing wind energy farms.
5) Energy source identification is a possibility. Short - term and long-term time-series data analysis for forecasting wind power, and careful planning should help reaching a potential site to identify it to be a future wind farm. As wind is fickle in nature and the energy from it is unpredictable, an uninterrupted wind power supply demands wind energy systems to be coupled with other energy sources, for example, a national or regional electrical grid.

6) Technical hindrances are also a big challenge such as, wind turbines might cause noise due to turbine blades, distance between offshore wind farms and destinations.

4.3.1. Needs of Feasibility Studies

Feasibility studies of wind energy as well as the development of a wind energy project in a commercial level is a complex function but is important in assessing the suitability of the site as well as measuring the potentiality of sufficient wind energy. There are huge scopes for the researchers and engineers to work on feasibility studies the lack of which thrashes a wind farm to be commercially unprofitable. As the project is multifaceted, so is the process is lengthy. There is no way by wind farm building needs collaborative efforts among a number of parties and companies. Project developers perform the following:

1) Wind energy feasibility analysis,
2) Selection of suitable sites (micro-siting),
3) Wind farm design and optimization (WFDO),
4) Estimation of energy output,
5) Government permission,
6) Selection of wind turbine,
7) Leasing,
8) Contracting,
9) Construction,
10) Project financing.

In order to perform those activities, as seen, opportunities are available for many other businesses groups to be working in collaboration, or to be in sub-contracting of companies for the successful implementation of wind farms.

4.3.2. Wind as a problem by itself

This is very much essential to understand wind models. The unpredictability of the characteristics of wind can only be mitigated through the proper understanding of it. There is no way but to incorporate and getting well into the latest research and findings in wind energy along with other meteorological data. In addition, development trends of wind turbine technology updates are important in gathering knowledge. Developing methodologies for quantifying and modelling the correlation between expected and observed outcomes are a big challenge to understand wind of a particular area.

1) Wind resource and its random character
2) Pattern of wind
3) Turbulence
4) Parameters for wind turbulence
5) Structures within a turbulence situation
6) Validation of turbulence
7) Limits of predictability

Another challenge can be identified as, it needs a deep understanding of the 'whats' and 'hows' of the statistical functions employed for wind energy analysis, like why they do occur, how they do occur, how often they occur, what the reasons are of its changed behavior, and which of the magnitudes of the wind should be expected etc.

4.3.3. Policy gaps

Economic stability of any nation fully depends on its successful planning and optimizing its energy resources. Energy policy along with other policy issues related to it is thus should be very much consistence in building sustainable energy development, though there are huge gaps in applied research in energy sector especially in wind energy as far as energy policy is concerned. Moreover, policy uncertainty or change in policies have adverse effects on wind energy development programs [227]. In addition, there are very big knowledge gaps with the policy makers as well as with the stakeholders in terms of the roles, responsibilities, and the mutual opinions that are most often un-organized and un-reported. In terms of government role in various countries and regions, it needs to justify the impacts of policies on wind energy.

Climate change and Greenhouse Gas (GHG) emission is directly related and the global policy experiences a great anomaly in terms of implementing the acts created in an integrated way. Global awareness about the climate change is in fact very low among the common people regardless of the regions or countries. The globe is concerned about energy scarcity throughout the world and is well aware about the necessity of energy security, the implementation of which in fact will make it possible to develop wind energy policies (broadly renewable energy policy) in local, regional and global manner.

In order to promote wind energy in a consistent way, and to spread awareness and consciousness about the numeral benefits of the proper use of energy (solely electrical energy) generated from wind, the related body regarding renewable energy issues will not only plan and build policies, but also need to concentrate on the successful application it.

Though it is not that easy to build awareness on considerably new technology to the society, because conventional energy resources proved highly reliable to the people. Once the following incentives can be set, wind energy will have a huge possibility to be ahead of energy sector.

1) An effective policy implementations,
2) A strong and smart electrical network,
3) Private and public incentives,
4) Participation and investment in wind energy projects,
5) More research on energy prices etc.

Though it is well-known that policies are made with an aim to progress and to make proper control in wind energy development, the growth trend in the implementation of policies are not that much of worth noting.

4.3.4. Technical Gaps

In general, technological barriers take place in developing countries. The reason is the lack of infrastructures and institutions to hold and to carry out research and development. The wind turbine technology is mostly monopolized by the turbine companies in Europe. The under-developed and developing countries are to depend on their standard. Local standards in wind turbine design and manufacturing usually have mismatch with the imported components. In spite of being the modern wind turbines to be quite efficient in terms of performance and durability, but when a site-specific wind farm is concerned, the capacity and performance of individual turbine is negatively impacted by the turbines of other standards. This is because, overall wind harnessing efficiency of a wind farm is less than what could have been achieved if all the turbines were individually and independently functioning [228].

4.3.5. Social gaps

Most of the common people of society are not aware of the utility of wind energy generation systems. Comparatively being a newer technology in terms of electricity generation, sometimes, wind project faces opposition from the common people. And this generally occurs when the area selected for wind farm is culturally or historically sensitive and important as well. So, the wind site where the common people have access may produce some issues regarding their habits, attitudes, health, culture, transport etc.

4.4. ENERGY TRANSITION POLICY

Sustainable development in wind energy could only be possible once having a proper controlling in policy building, integrating and implementing within renewable energy sector. In order for getting a sustainable society, it needs to focus on energy transition policy. The following sections will discuss this issue as a comparative study for Bangladesh and Thailand. It is noted that the entire study conducted for energy transition policy of Thailand is made upon the research of Friedrich-Ebert-Stiftung (FES) [229] (through the opinions applied in the work are not necessarily from this organization, rather as a part of independent research) which reflects the ease of working for Bangladesh.

Objectives of the study of energy transition of Bangladesh includes

- To study and understand power and energy (P&E) sector as a part of level playing field for perfect competition.
- To provide recommendations for creating way in order to work more progressively for the sake of pursuing energy transition path.
- To encourage private investment for the beneficial growth of energy for the consumers in sustainable manner.
- To ensure that the general citizens/consumers can participate energy issues through building empowerment.
- To work for ensuring least cost energy and electricity supply.

Thailand energy transition study of FES was conducted with a view to concentrate on how an energy transition can be carried out in a socially just and equitable way and to concentrate on how an energy transition can be politically acknowledged and carried out, and how efficient power energy strategies' are executed.

4.4.1. Energy and Climate Change Issues

4.4.1.1. Energy Related Characteristics

Prior to deal with energy policy transition issues, it needs to understand the country-wise characteristics features that relate energy transition. If a proper investigation can be carried out, it can be seen tat, Bangladesh has numerous problems in dealing with energy transition issues (such as, readiness) with an incomplete and ambiguous political practices where dominance of corruption in the present tariff rate policy structure of energy is prevalent. It will be seen that the consumers' awareness regarding energy issues is not up to the mark, and sometimes absent, and energy sector functioning not dedicated to maintaining transparency and sustainability. These are accompanied by unplanned and disastrous development in energy sector where human resource development greatly needs for a successful public private partnership programs which are very important in going towards energy transition policy building.

Perception of the commoners on energy and its policy in Bangladesh is that the price should stay at a low level and its access should have an equal manner. The small businessman also tell the same. In general, people of Bangladesh harbor misconceptions about the energy effectiveness and their proper use consumers in Bangladesh are not much aware of efficient technologies that may help advantage getting from the understanding that how much people think about energy utilization in circumstances in which they have some immediate control. According to the evaluations of energy use and reserve funds, it tends to be expected that the connection between purchasers' appraisals and the genuine upsides of energy would be moderately level. For the energy consumers in common, perhaps it does not cause much daily trouble or thought, and energy security may not be a primary source of concern in most consumers' lives. General consumers don't bother about the link between energy consumption and environmental problems such as global climate change.

In contrast to it, Thailand is a country in needing to deal with number of deterrents and boundaries in regards to the energy progress, taking a nationwide challenge to diminish GHG outflows. The country has high venture and working expenses, and limit imperatives in the energy area with a parallel cooperation among public and private sectors. It has been observed that, Thailand has system dependability by lessening reliance on natural gas, increment the utilization of coal by means of 'clean coal technology'. Having the military government, the country wants to build better public understanding of what future fuel sources, both petroleum products and environmentally friendly power.

Petroleum products such as natural gas has arisen as the fundamental fuel for power generation in Thailand for quite a long time as a result of its natural allure, low capital escalation, more limited incubation period, and the higher effectiveness of gas-based power plant technology. But unfortunately, petroleum gas supply has been exhausted in Thailand, and the nation presently needs to import LNG for power generation. The significant impediments of building limited scope sustainable power plants looks for a solution through conceding the development initiatives of the respective authorities such as licensing measures, construction initiatives and financing, and a transparent third party access rules for power grid. Apart from natural gas, it should also be noted that, without significant coal-based energy supply in the national power generation mix, , it will be enthusiastically harder for Thailand to keep power rates low. The Thai individuals' discernment on energy costs and uses is that they ought to be steady and stay at a low level. The way of life of individuals who think of personal and combined solace over over the period has been severely dependent on the energy supply and its price. Other than these, the climate change issues with energy, energy conservation etc. are some of other issues that Thai people are more or less thinking of.

4.1.1.2. Climate change issues

Bangladesh is under extreme a worldwide temperature related danger. It encounters environment consequences, though produces insignificant measures of CO_2 emanations. Bangladesh energy policies didn't pay regard to managing tackling global warming. Still the current energy approaches are not in active functional. The lack of concern in working with environmental change issues in the existing policies in Bangladesh recognized that expanding ozone depleting substance (e.g. greenhouse gases GHGs) outflows in Bangladesh has arisen as a major issue. Following points will be worth noting for climate change issues in Bangladesh.

- Bangladesh is especially helpless against the impacts of climate change.
- Bangladesh has as of late fostered an exhaustive arrangement of strategies to response to climate change.
- Bangladesh is remaining underneath the edge to further develop its energy efficiency considerably, and it has a moderate potential for some types of sustainable energy sources.
- Increasing the application of solar power and wind energy, both right now basically at almost zero levels, should be at the center of a progress towards a low carbon economy.
- Bangladesh has taken the measures on power access for the greater part of families with the maximum capacity which might be vulnerable to the climate change unless there is a big plan for a nationwide defense mechanism.
- A considerable number of recurrence of poor village people are inadequate with regards to energy sources and cook with conventional biomass, subsequently confronting high indoor contamination levels causing air pollution alongside extreme health hazard.

Thailand has a major risk in terms of atmospheric change accounted by global carbon emission. The Twelfth plan of the country sets the principal which measures objective to decrease GHG emanations in the energy and transport sectors. The country plans to diminish the emission of ozone depleting substance (GHGs) by 20% from the projected business-as-usual (BAU) level by 2030. Under the lead of the Thai Military Government, the Prime Minister has moved forward the level of Thailand's obligation to handling environmental changes. Thailand's National Board of Climate Change Policy (NCCC) is answerable for the environmental change issues. The energy sector of the country has made a huge commitment to Thailand's reduction of the global GHG emission.

4.4.2. Proponents of Energy Transition

4.4.2.1. Champions of Bangladesh Energy Sector

Bangladesh regulatory process controls and influences which stakeholder participation are and should be allowed. Participatory freedoms in the execution of policy for partners i.e. the consumers who ought to be engaged with energy pricing and rate changes are disregarded. Plan of sustainable power and energy productivity programs for consumers will be the concentration. The Ministry of Power, Energy and Mineral Resources (MPEMR) mainly responsible for all policies and matters relating to electricity generation, transmission, and distribution from conventional and non-conventional energy sources.

- Power Division
- Energy and Mineral Resources Division

The ministerial team of the Ministry of Power, Energy and Mineral Resources is ruled and presided by the Prime Minister of Bangladesh, who is responsible to manage the office of the respective ministers and ministry as a whole. In addition to it, civil society organizations in Bangladesh has concerns for energy issues in great ways.

- Civil society organizations (CSOs) has a certain level of capabilities in protecting consumer energy rights.
- CSOs try to encourage and promote public, public-private and civil society partnerships in energy sector by building resourcing strategies of partnerships and stakeholders.
- CSOs in Bangladesh have involvement in SDG implementation.
- Working on equal rights to economic resources, and resilience building of the poor to climate and other shocks.
- Concerns for renewable energy and sustainable economic growth so that access to energy services improvement in energy efficiency can be assured.

Partners like energy clients, purchaser, promotion groups, sustainable organizations, power generators, private residents, environmentally friendly power innovation industry and so on have their separate situations to reaction to energy transition issues. Moreover, public-private partnership (PPP) have the regulatory challenges like

- PPP plays a key role in the energy sector today, and is slated for a greater role over the next few years.
- Bangladesh has looked for private area support for influence to get better incentive for cash, on time conveyance, execution affirmation, and admittance to financing.

Administrative enhancements decreased the weight of endowments on the national expenditure plan, and the danger of monetary indebtedness of entities, for example, the Bangladesh Power Development Board.

4.4.2.2. Advocating Agencies of Thailand Energy

Government organizations like NEPC, MOE and ERC are the key government organizations straightforwardly supporting environmentally friendly power and energy effectiveness in Thailand. The staple form of the public authority's monetary support for environmentally friendly power improvement in Thailand were feed-in tariffs (FiTs). Renewable energy produces get a value premium over the buy pace of SOEs and MOE gives monetary motivating forces as awards and low-interest credits. Civil Society plays an important role in taking part of the energy transition issues.

- CSOs worked with strategy research establishments furthermore, scholastic to draw in with government organizations when they created environmentally friendly power approaches.
- Thai CSOs affected the 'Public Solar Policy Initiative.
- CSOs give Thai government proposals on the most proficient method to adequately and comprehensively seek after more prominent sunlight based force improvement and execute sun oriented arrangements in the country.

A very much organized cooperation and coordination between focal specialists and the nearby local area, and gives a genuine illustration of public and private joint effort to advance energy protection by working on monetary approach and technique to lessen GHG outflows plays a significant part for the advancement of a low-carbon society. Some organizations, specifically those inside the travel industry area, have grown low-carbon structures that fuse inactive plan procedures and energy productive arrangements. Cooperation of private areas, neighborhood networks and nearby governments, upheld by focal government subsidizing, for an energy change towards a low-carbon society. Besides these, global organizations UNDP in Thailand with the Mae Hong Son Governor's Office, the DEDE, and the MOE has executed a task of promoting renewable energy in Mae Hong Son Province, which is the poorest region in the country. With the cooperation of global associations and Thailand's administration offices, the ICSs are generally sold and utilized in the North of Thailand. Project being started by a global association as a team with different focal government offices.

4.4.3. Barriers to Energy Transition

4.4.3.1. Bangladesh Hurdles

As per the investigation directed by customers association of Bangladesh (CAB), it tends to be seen that, the energy sector in Bangladesh is profoundly subject to petroleum products, as gas and coal are the overwhelming hotspots for power generation in the country. Around 62.9% of Bangladeshi created power comes from gaseous petrol, while 10% is from diesel, 5% comes from coal, 3% of heavy oil, and 3.3% is of renewable sources. In spite of the way that the Bangladesh energy sector uses and covers differed items; power, oil based commodities, petroleum gas, coal, biomass and sunlight based, yet the approach and leaders are for the most part interested with electric power, as it is the most normal utilized type of energy in the country. In 2016, the all-out number of consumers associated with the network is 21.8 million. Out of the 21.8 million, 16 million are family connection, which would address generally half of every single Bangladeshi family (30-40 million). After Bangladesh's freedom in 1971, just 3% of the absolute population got energy. Its proportion has increase to 59.6% in 2012, and practically 76% by 2016. 79% of the framework associated population endure load-shedding, and 60% experience low-voltage supply. The Bangladeshi government has set a big dream of accomplishing 100% power access by 2021, consequently by coordinating more solar PV and biomass sources, as the nation is rich with these two specific ones just around 52% of Bangladesh's complete population are associated with the national grid, while practically 75% of village people are not associated with it. Around 40% of Bangladeshi created power was produced by private sector in April, 2010, and the rates came to around 44% by April, 2011.

Despite these facts, Bangladesh got a number of potential barriers for energy transition from fossil-based fuel to diminishing carbon technology in the energy sector. Barriers for energy transition in Bangladesh incorporate the following realities: high rated initial capital, absence of monetary organizations, absence of suitable investors, contest from non-renewable energy sources, and less subsidies contrasted with customary fuel. With this, lack of adequately trained manpower with right skill also create great barrier. In addition to it, institutional barrier like the following are also prevalent in Bangladesh.

- Uncoordinated function and procedure
- Lack of inclusiveness.

Low relative priority to renewable gives Bangladesh a relative potential barrier in terms of Policy and governance. Some of the hurdles cited below are also observed when energy transition issues come forth.

- Technical barrier
- Barriers of Infrastructure and innovation
- Absence of business model
- Inappropriate subsidy allocation
- Resource and environmental barriers
- Supply-side information
- Demand-side information
- Lack of Awareness

Bangladesh has an extremely limited in the total reserve of energy with limited quantities of oil, coal and petroleum gas. The nation experiences an interior energy battle, as around 93% of the nation's energy creating thermal plants are gas-based, however the gas is additionally required for building industrial Bangladesh that needs to consistently make a few tradeoffs between power generation.

Bangladesh wants to follow how the emissions of carbon may be down through the use of renewable energy. Solar and wind energy potential estimated in different site with the moderate potential. In Bangladesh, most sustainable energy sources are limited scale and dispersed. Renewable energy is as yet treated as a specialty innovation instead of as a significant commitment to energy security and energy access. Environmentally friendly energy technologies are for the most part imported.

Too little has been done to cultivate a homegrown industry. The public authority and industry have put little into innovative work of sustainable power developments, which contrarily impacts the opportunities for upstream and downstream opportunities.

Unbalances and unfair subsidies are another big problem for fixing the energy price at low rate. Renewable energy is subsidization is not clear in the policy and still not implemented in commercial manner. Fossil-based energy sources have huge subsidies which has been made for billions of dollars of profit for a particular group of businessmen and the politicians. Because of this unjustifiable estimating, renewable energy is still at its birth-stage, and incurring higher price rate for a great many energy-stricken people and industry. The advantages of expanding clean energy in Bangladesh's energy generation mix can create the combined outcomes as set a target for 2030. Reaching potential to produce additional electricity of 30 GW from the utilization of solar PV and 53 gigawatt (GW) of electricity potential from all solar sources.

4.4.3.2. Thai Obstructions

Since 1990, the rate of electrification in the metropolitan regions in Thailand has been 100%. Thailand has arrived at 100% zap since 2008 through the transmission and distribution organization. The pace of admittance to power in country regions developed from 20% in 1975 to 98 percent in 1994. Somewhere in the range of 1995 and 2006, the 'Rural Household Electrification Project' was carried out and expanded the pace of admittance to power for provincial towns to 99.98 percent in 2006. 'New Rural Household Electrification Project' to guarantee that all towns and families in rural regions can get to power. PEA can give power to no less than close to 100% of towns and families in its space. The townspeople had the option to produce power and keep up with their frameworks for their own utilization without a grid connection. Power supply to rural regions has been vigorously financed through a uniform tax strategy.

This scenario expresses on thing that the government of Thailand is quite cordial in electrifying the nation. In this respect a question may arise that if the country is ready for energy transition from fossil-based to zero-carbon energy generation. It can be said that, there are a number of barriers in this terms which demand a point to point discussion. A number of potential barriers for implementing energy transition policy have been observed for Thailand, such as government agencies like NEPC and MOE along with the EPPO are policymakers, attracting the TIEP 2015, while the ERC is a controller, and three state owned enterprises (SOEs) are administrators in the power supply industry.

- SOEs in the energy area are predominant players in the ESI
- ERC issues licenses to the administrators

Besides these, some other barriers are noted down for the better understanding of how the country will hold the barriers and to tackle it.

- Strategy vulnerability and brokenness
  - Strategy vulnerabilities and discontinuities have been a significant hindrance with respect to a smooth energy change
  - No motivators to grow their capital-concentrated interest in the transmission and appropriation organization to serve an unexpected interest.
- Absence of coordination between public and private sector
  - The public authority alone can't offer unending monetary help, especially in energy efficiency projects
  - Coherence and coordination among public and private areas to foster tasks in both specialized and monetary angles is required
- Mutilated financial and administrative arrangement
  - Absence of control and authorization by the public authority and the hierarchy of leadership,
  - There is a trouble between government offices
- Powerless administration
  - Administration in the energy area is powerless, especially concerning autonomy, straightforwardness, public support and responsibility
  - Lack of straightforwardness and responsibility in the force arranging and improvement measure makes question among people in general.

- Ineffective energy reforms
    - SOEs are in a monopolistic way.
    - Many endeavors to seek after primary changes in the power area have fizzled
    - Regulation by the ERC on sustainable power permitting and exchanging instrument is excessively regulatory and makes managerial obstacles.

4.4.4. Energy Transition Policy Recommendation

4.4.4.1. Recommendations for Bangladesh

Energy transition of Bangladesh will lead be a mix of fossil fuel based energy and renewable energy rather than complete transformation towards renewables. The vision for energy transition will be made up for securing energy access for all and maintaining energy efficiency. A proper way of energy utilization, climate change dealing and environmental conservation along with their promotion should be increased through encouraging public–private partnerships in the energy sector. Investment through private organization in renewable energy and energy efficiency projects needs proper financial mechanisms that will be well accordance with the government of Bangladesh. It needs to ensure the environment and the climate incur minimum damage while implementing energy sector transition. Fundamental right of saving life will be preserved while working for energy transition. Integrated national energy transition plan on creation of green jobs and green skills in energy sector is needed. Renewable energy wings of the government will have total freedom to work for being self-reliant and self-sufficient. Energy phase of energy related issues will have to be dealt with transparency so that the consumers can get standard energy service at minimal cost. Usage of fossil-based fuel will have to be minimal.

- It needs to improve the level of understanding of the consumers of energy issues
- It needs take the institutional and regulatory challenges and opportunities for the use of energy in different levels of communities.
- Public and private sector participation in energy transition issues needs to be transparent and statutory.

- Correlated energy and environmental issues are to be dealt with sustainable mechanism for the sake of fighting against climatic problems.
- It needs to fix the tariff anomalies in energy sector
- Specialized as well as truly independent energy research institutions are to be built for technology transfer, training, partnership building etc.
- Energy pricing or tariffs will be based on the dynamic capacities of the consumers by economy, residential, commercial, and industrial connections.
- Energy prices should reflect the true cost of energy to give end-users.
- Poor coordination between ministries of Bangladesh and other agencies needs to be improved towards a combined development plans which so far have been sought to be inconsistent and unclear.
- Bangladesh should work in a true sense sufficiently for energy and renewable energy training programs can adequately meet workforce needs.
- Civil society and local community should work as a partnership party in terms of information exchange, miscellaneous training programs for knowledge and expertise build-up etc.
- Bangladesh should provide a space for dialogue at local as well as national level to encourage a renewable energy transition at a certain level based on the capacity and readiness. Also, Bangladesh ought to give a space to discourse among the financial bodies, investors and other government offices, and civil society associations to examine the proper subsidizing model for environmentally friendly power improvement endeavors.
- Energy transition in Bangladesh should be well accord with 2015 Paris Agreement targeted to protecting the environment.

Bangladesh needs to overhaul its government enterprises which are both significantly inefficient and vulnerable to political interventions. Public-private partnership program in energy sector should be strengthened. Energy sector reformation is needed, specially un-ruled and uncontrolled subsidization. Bangladesh energy transition policy should be drafted and enacted through the collaboration among the Public-Private parties, Government itself as well as local and regional authorities. Framework for energy transition will give priorities for policy advocacy for rural people and the deprived consumers in a form of practical actions.

4.4.4.2. Energy Transition Proposals for Thailand

As FES longsighted in Thailand, a basic changes in energy policies ought to be carried out in arrange to reduce market control and dominance with a venture of the decentralized renewable energy. Electricity tax with cross-subsidization which makes market distortions should be dealt with good-governance and smart administration in terms of energy policy planning, its proper direction, regulation and operation. Governments ought to build up and fortify associations for distinctive stakeholders in this regard. Infrastructure and grid-related issues and administrative and regulatory hurdles should cut the boundaries to progress in energy efficiency.

Government organizations should launch interview program which will be the best to be practiced for the assessment and appraisal of approaches, plans and regulations. Academic and research institutes will need to work on innovation and information exchange through maintaining joint research work, and will work for preparing organizations for partnership building within the locale and over regions among scholarly institutes. They also can trade programs for understudies, addresses and researchers. Private segment: They will prepare for instructive programs for promoting innovation and technology transfer collaboratively done with research institutes. Civil society organizations will take ventures with related organization (e.g. other CSOs) in terms of information exchange regarding energy policy transition and its prospects. Local community will be working within the field for preparing training and other instructive programs.

4.5. CONCLUSION

Wind energy innovation is as of now demonstrated and making progress throughout the world with a big pace though there are a number of hurdles residing in the renewable policy frameworks locally and globally. Bridging those gaps to take the challenges and opportunities for the expansion of renewables will yield the full-fledged streaming of sustainable energy for carbon mitigation movement throughout the earth. Based on the comparison with subjective and quantitative information of the policy related issues and other aspects, there will be scopes to extend the opportunities for working with green energy through distinguishing the crevices and opportunities at a local and territorial level.

Chapter 5

Result and Discussion

5.1. INTRODUCTION

This research will focus on the following area to work which figure 5.1 accumulates all together.

1) Wind energy potential analysis with the data recorded at meteorological stations (real data)

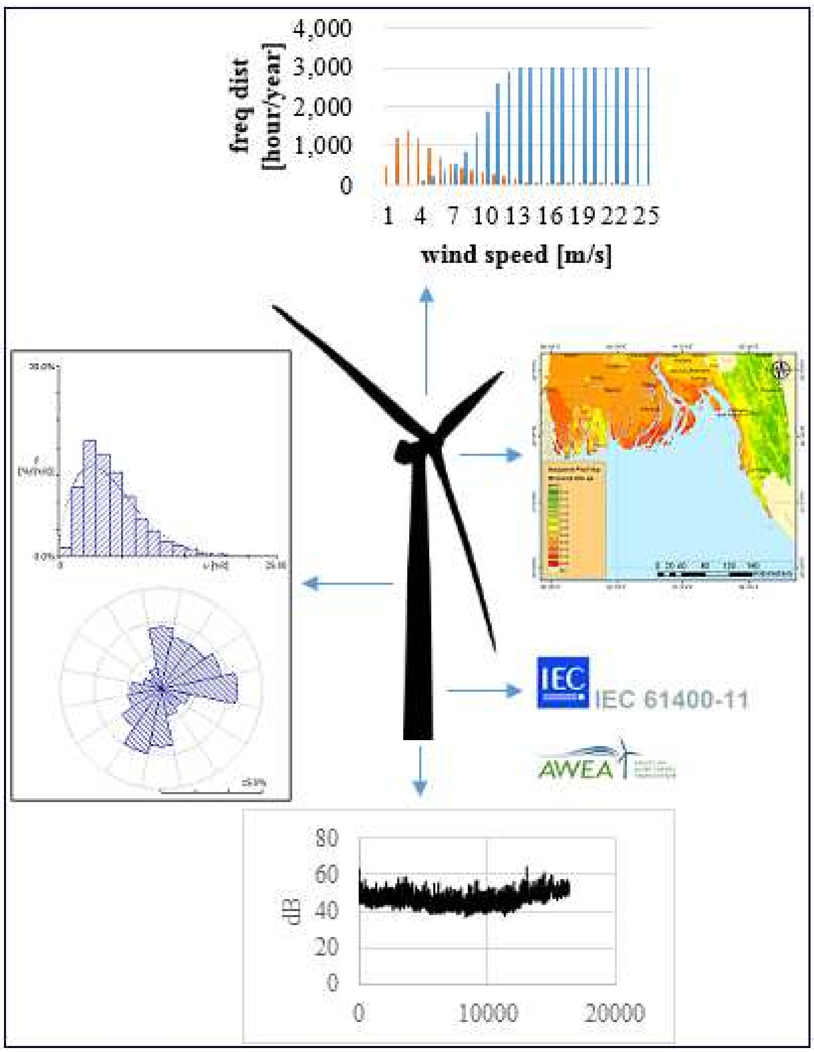


Figure 5.1 The accumulated expected results of the research [230].

2) On the availability of simulated data from some well-known online databases e.g. MERRA 2 database, the research will also focus on validating the data.
3) Wind resource mapping (both mesoscale and microscale).
4) Wind turbine generator (WTG) noise analysis.
5) Working on AEP with site suitable WTG.
6) Environmental and economic analysis of projected wind energy sites.
7) The research in addition will focus on maintaining recognized international standard upon the operations like IEC and AWEA.

This research will further tend to implement some possible innovations and solutions into the demonstrated sites as stated in chapter 3, in order to create more opportunity to test, verify and validate the data and the results under real-time operating conditions. The actionable plans related to the outcome of the research can be stated as follows:

1) To undertake projects relating the statistical wind analysis.
2) To further comparative analysis of various engineering and statistical tools used for assessing the prospects of wind.
3) To gain experience in critical, scientific based work with energy problems.
4) To prepare for continuous activity both within and outside of academia
5) To suffice opportunity for the young researchers of doing advanced study on wind energy and to yield way for the researchers to think more about wind prospect that will include
    - ✓ Wind energy production, storage, transportation, distribution and its rational usage.
    - ✓ Design wind energy production process in a way to increase energy efficiency
    - ✓ Energy mapping
    - ✓ Study of wind energy conservation system (WECS)
    - ✓ CO_2 capture and storage
6) To help realizing the fact of wind power in favor of the government and other non-government organizations (NGOs) to setup wind farms once wind atlas can be built.

This plans will help the researcher to attain knowledge and wisdom in a continuous manner that motivated him to work for the society as a whole in both local and global perspectives.

5.2. WIND DATA STATISTICAL ANALYSIS

The research has considered all the possible methodologies for wind resource assessment using most fruitful mathematical models the result of which is able to predict wind speed with a minimal standard RMS error using some suitable computer software. The following sections will analyze wind data for Thailand and South Korea.

5.2.1. Thailand Wind Data Analysis

This section presents the analysis of the real wind data recorded from the respective meteorological stations of the Western and North-East Thailand. Table 5.2 shows the facts of the data and the analysis. Notable that, the analysis depends in the availability of the data which have been shown in table 5.1, table 5.2 and figure 5.2.

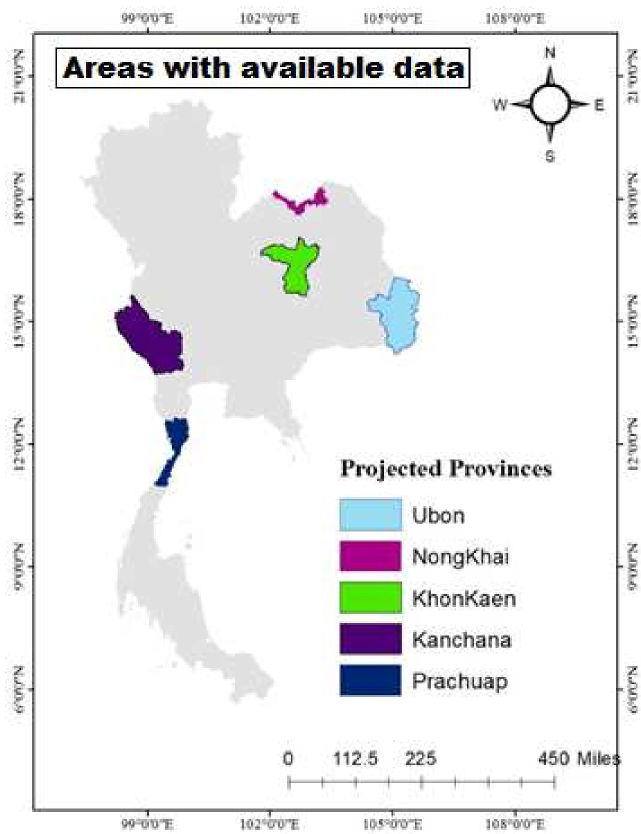


Figure 5.2. Real met data availability.

Table 5.1. Fact sheet of the real met wind data and analysis.

Stations Name	*Analysis Name*	*Remarks*
Kanchanaburi, KhonKaen, Nongkhai, Prachuap Khiri Khan, Ubon Ratchathani	Sector-wise data interpretation	Number of available data in each wind direction sector
	Mean wind speed and power density estimation	Statistical inferences through mathematical modeling
	Estimation of Weibull shape and scale parameter	Mathematical modeling
	Interpretations of Weibull probability distribution functions (PDF)	WAsP analysis
	Wind rose analysis	16 sectors by WAsP

Table 5.2. Real wind data availability.

Province	Kanchanburi	Prachuap Khiri Khan	NongKhai	KhonKaen	Ubon Ratchathani
Region	Western Thailand		North-East Thailand		

Table 5.4 displays the mean wind speed of the five provinces of the projected area at different height.

Table 5.3. Mean wind speed (m/s)

Height AGL (m)	*Mean wind speed (m/s)*				
	Kanchanburi	*KhonKaen*	*NongKhai*	*Prachuap Khiri Khan*	*Ubon Ratchathani*
10 m	1.25	1.12	1.37	1.86	1.68
15 m	1.49	2.18	1.04	1.95	1.44
20 m	3.11	2.49	0.96	3.77	3.09
25 m	2.56	0.83	0.93	4.40	3.60
30 m	4.35	1.44	1.03	5.62	5.47

Table 5.4. Wind power density.

Height AGL (m)	*Wind Power Density (W/m²)*				
	Kanchanburi	*KhonKaen*	*NongKhai*	*Prachuap Khiri Khan*	*Ubon Ratchathani*
10 m	4	2	4	12	7
15 m	5	9	2	13	3
20 m	43	10	2	112	21
25 m	17	3	1	182	35
30 m	84	4	1	381	116

Table 5.5. Weibull shape and scale parameters.

Height AGL (m)	*Kanchanburi*		*KhonKaen*		*NongKhai*		*Prachuap Khiri Khan*		*Ubon Ratchathani*	
	k	*C*	*k*	*C*	*k*	*C*	*k*	*C*	*k*	*C*
10 m	1.32	1.30	1.48	1.20	1.51	1.50	1.38	2.00	1.64	1.90
15 m	1.50	1.70	3.11	2.40	1.32	1.10	1.51	2.20	3.02	1.60
20 m	1.46	3.20			1.31	1.00	1.45	4.40	5.04	3.40
25 m	2.23	2.80	0.81	0.60	1.42	1.00	1.46	5.20	3.67	3.90
30 m	2.03	4.70	1.97	1.60	1.77	1.10	1.46	6.70	4.85	6.00

Following figures are the interpretations of the wind speed and wind power from the real met station data of the available stations.

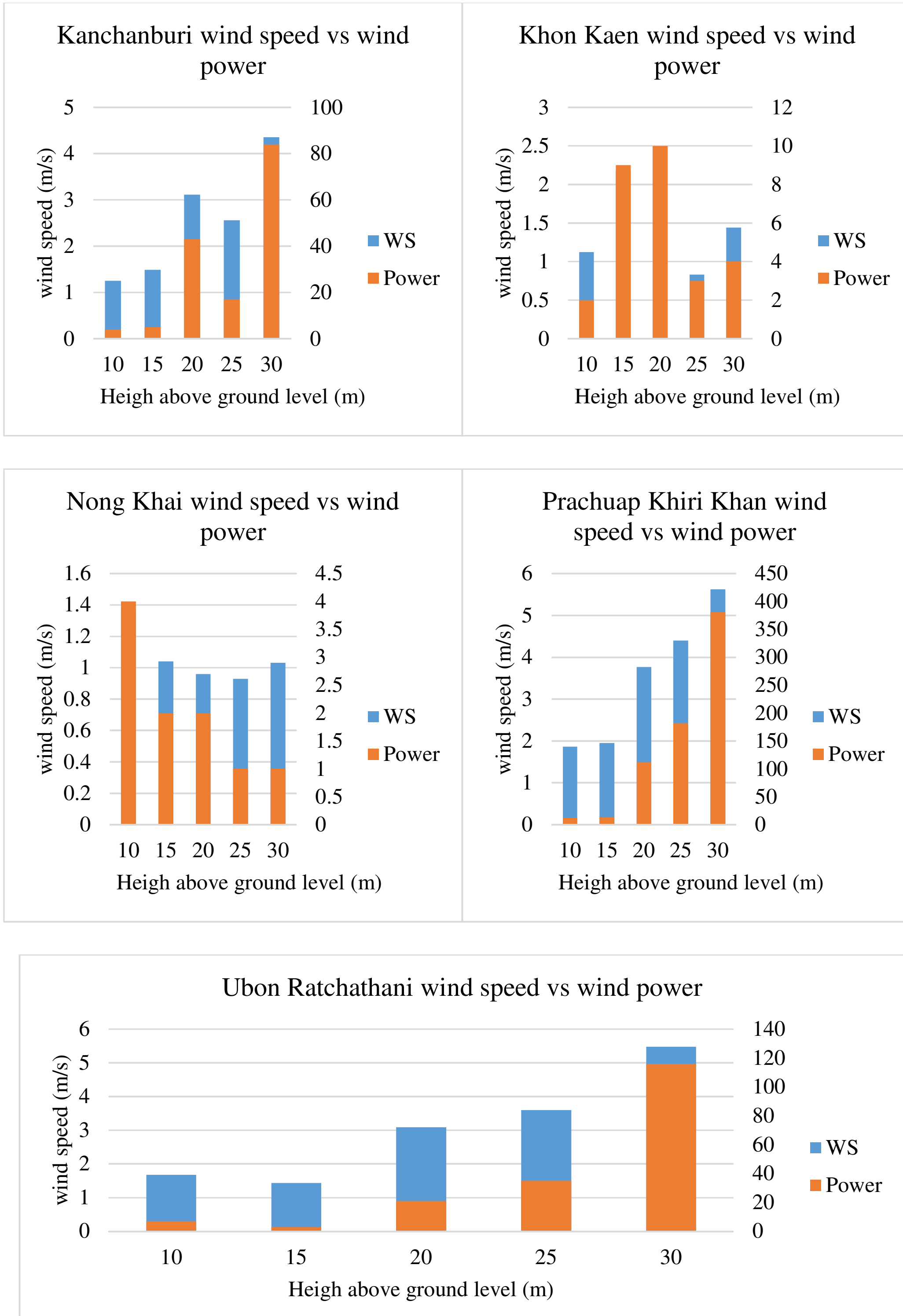


Figure 5.3. Wind speed and wind power from the real met station data for five met stations.

Following figures are the interpretations of the Weibull Probability Distribution, and frequency distribution, wind direction analysis of the wind data from the Kanchanaburi met station.

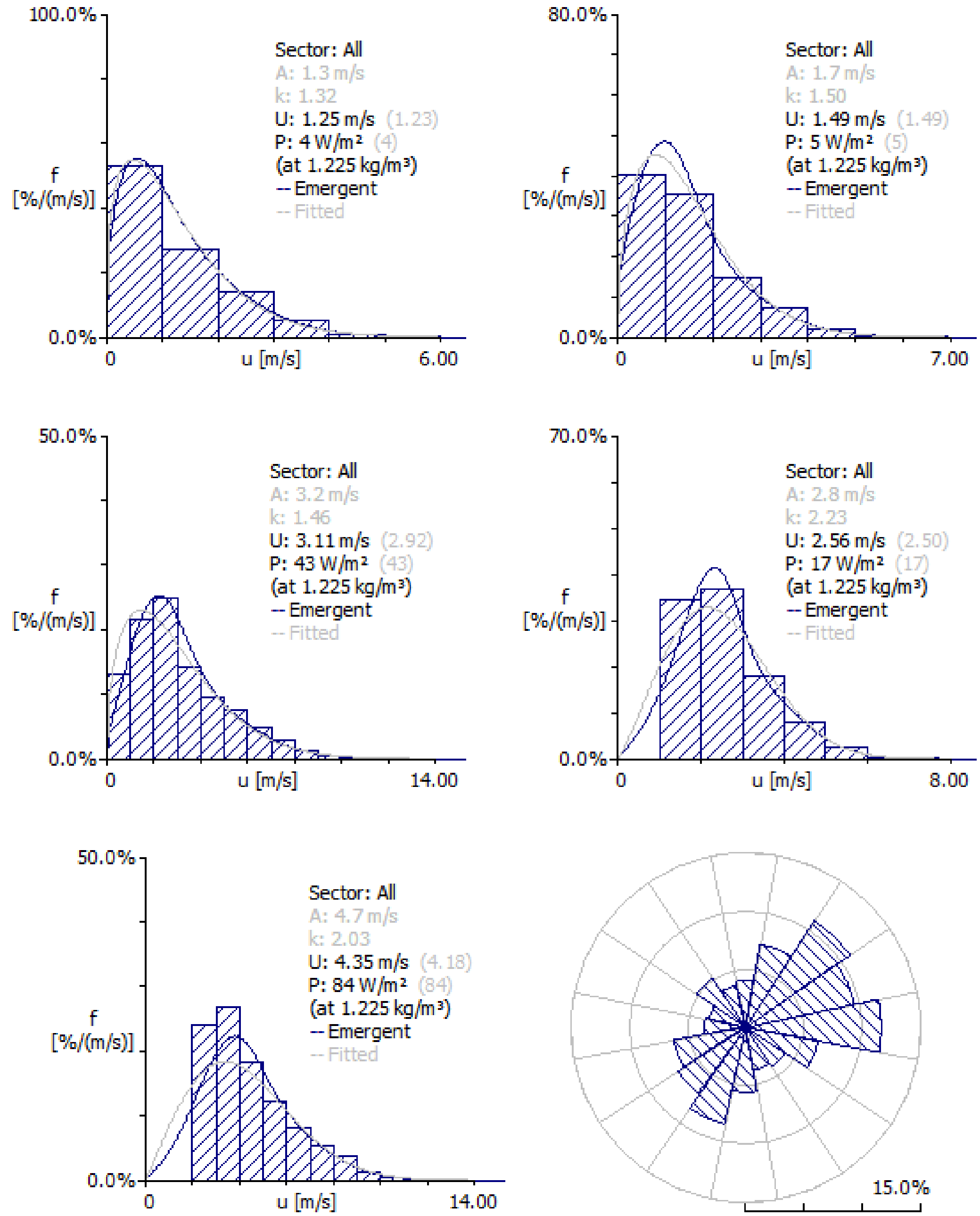


Figure 5.4. Weibull PDF for different height of the real wind data for Kanchanaburi province.

Figure 5.5. Kanchanaburi wind data interpretations for 10 m and 15 m AGL.

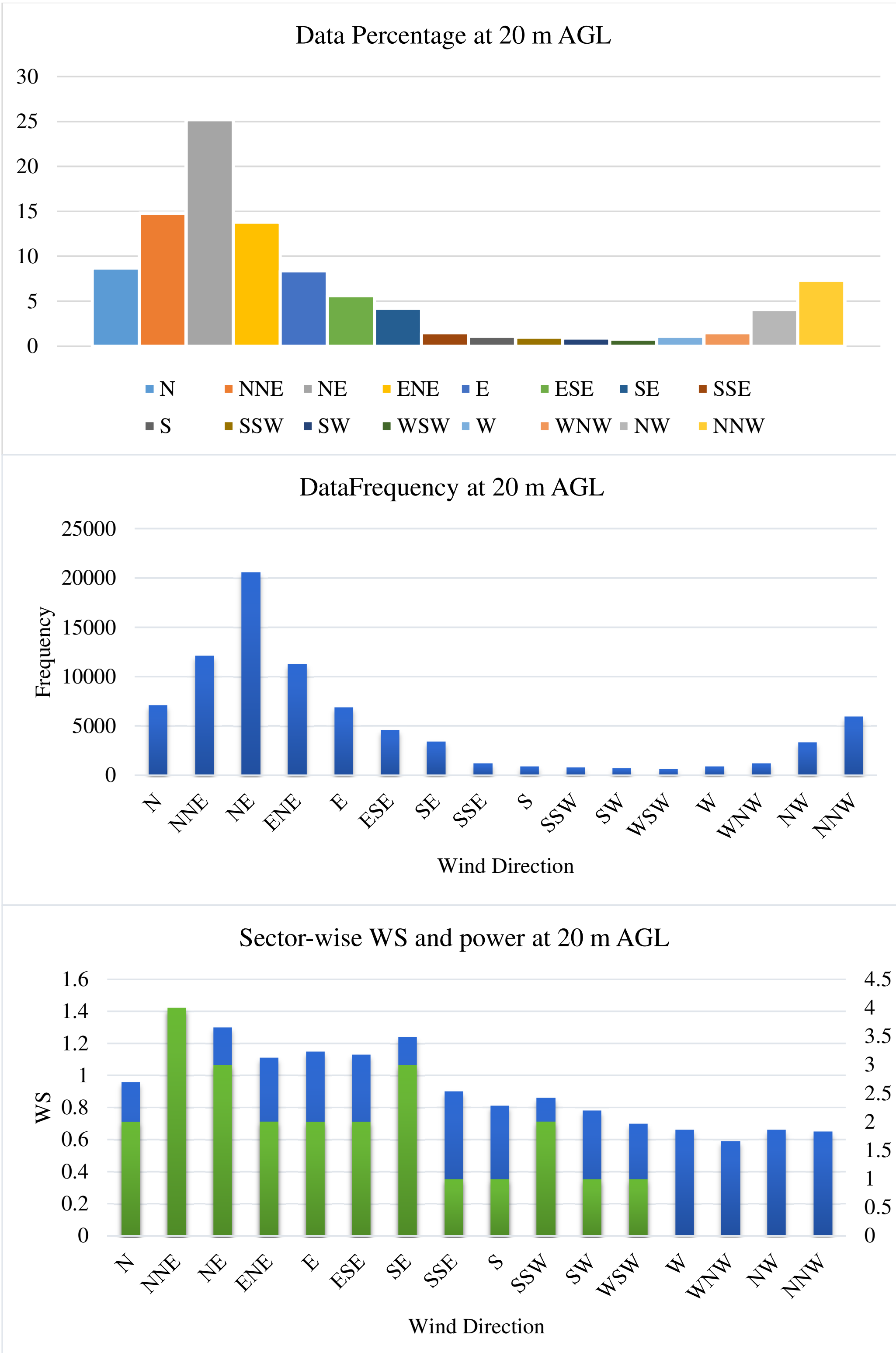


Figure 5.6. Kanchanaburi wind data interpretations for 20 m AGL.

Figure 5.7. Kanchanaburi wind data interpretations for 25 m and 30 m AGL.

Following figures are the interpretations of the Weibull Probability Distribution, and frequency distribution, wind direction analysis of the wind data from the Khon Kaen met station.

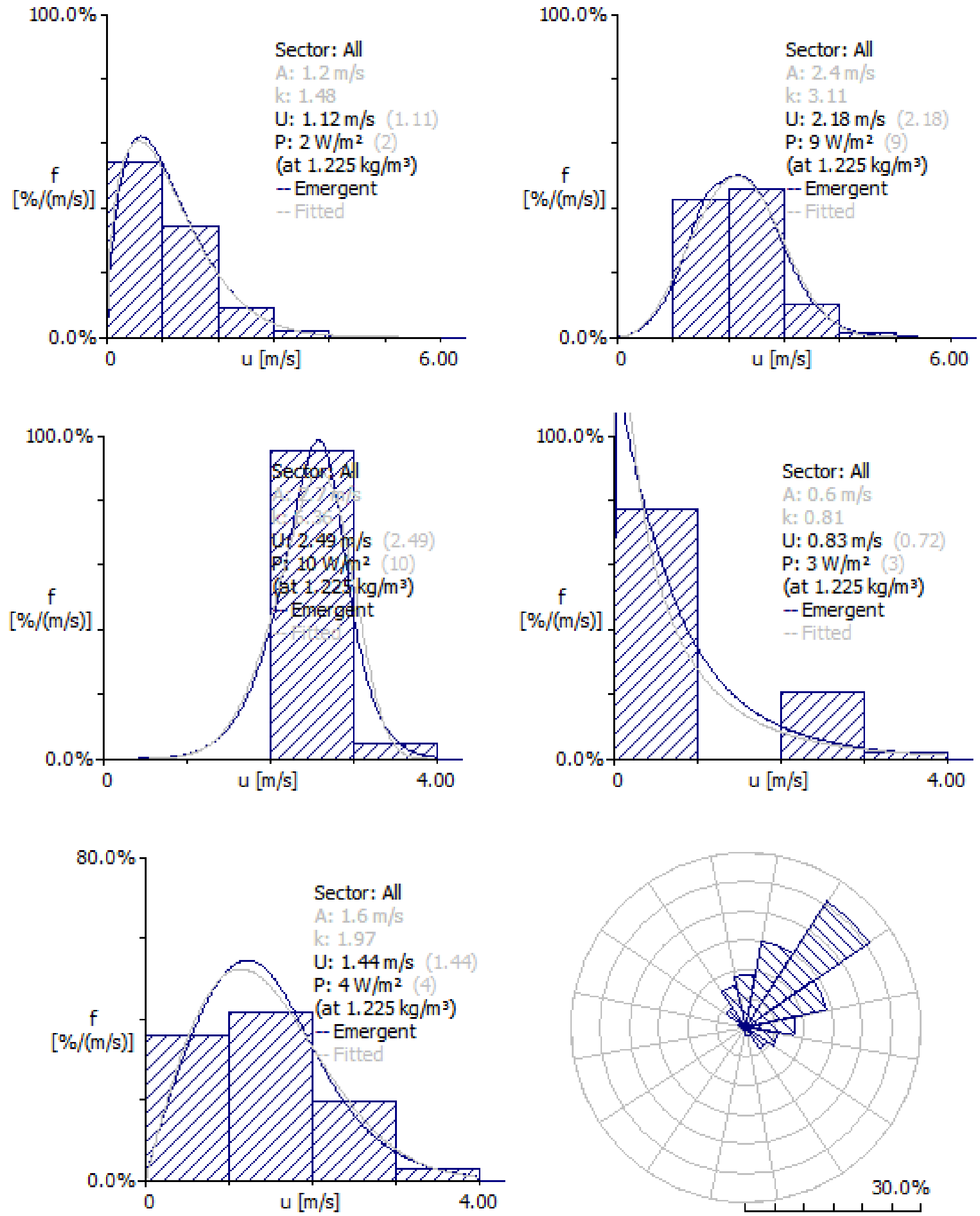


Figure 5.8. Weibull PDF for different height of the real wind data for Khon Kaen province.

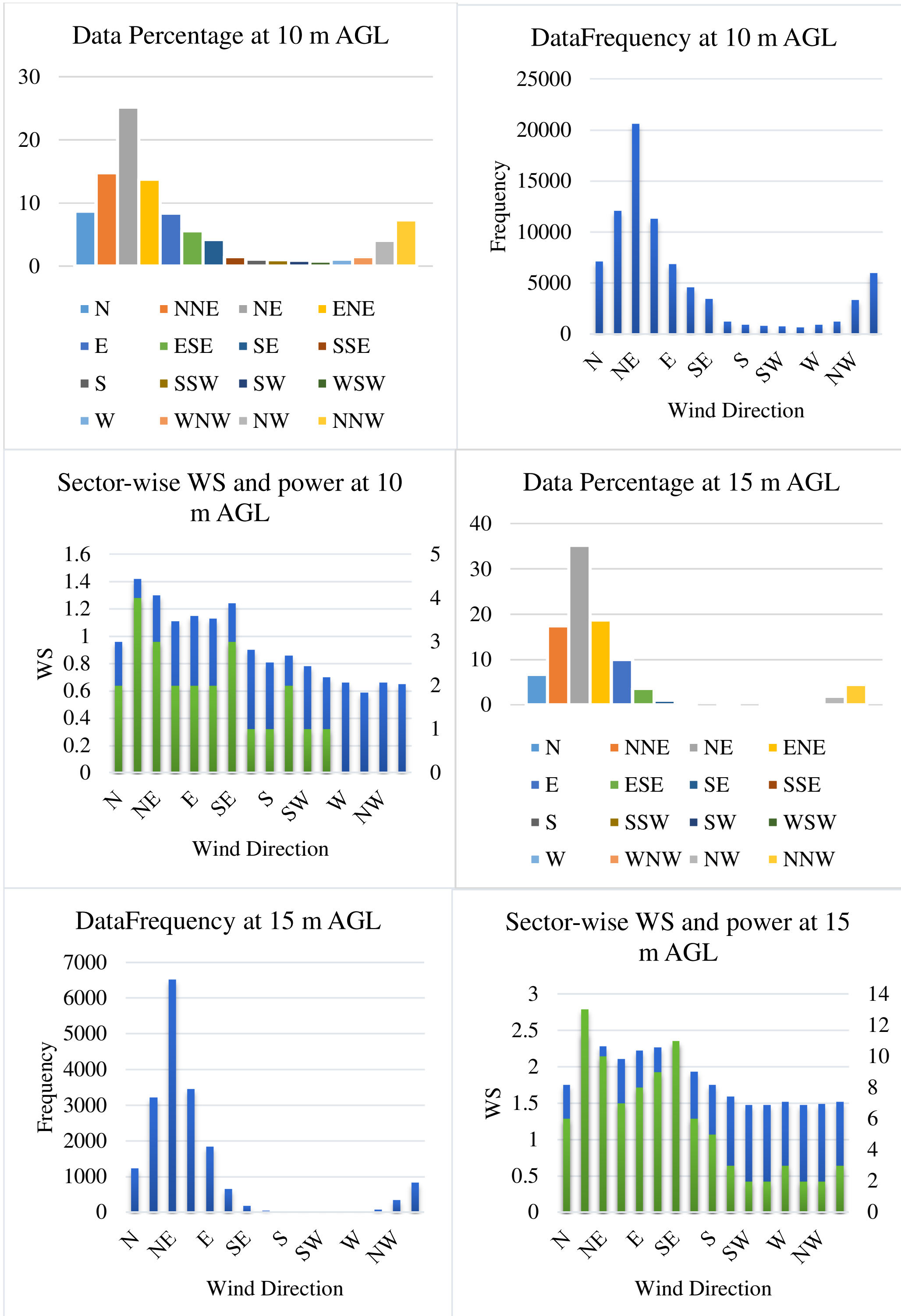


Figure 5.9. Khon Kaen wind data interpretations for 10 m and 15 m AGL.

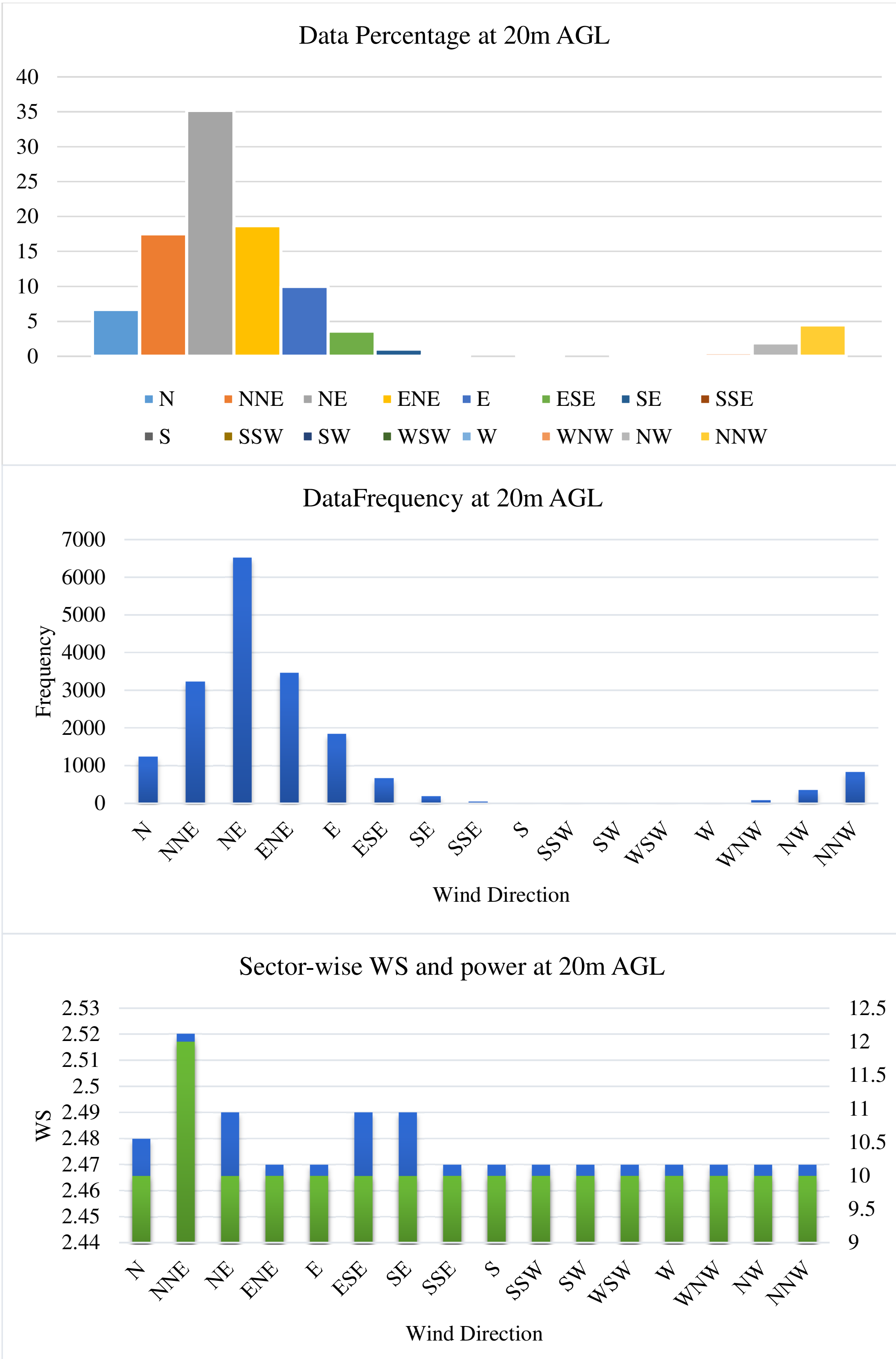


Figure 5.10. Khon Kaen wind data interpretations for 20 m AGL.

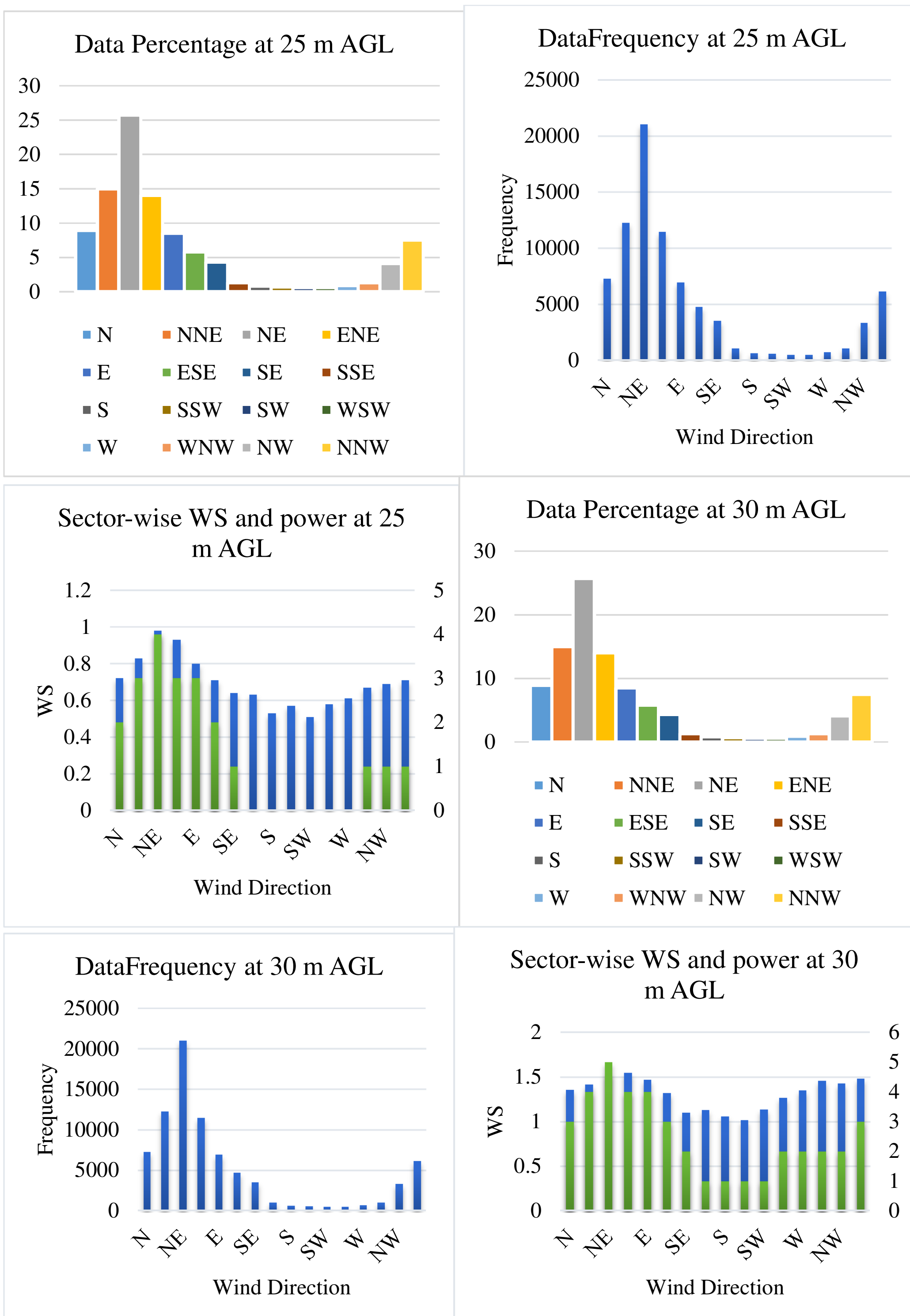


Figure 5.11. Khon Kaen wind data interpretations for 25 m and 30 m AGL.

In the same manner, the data outcomes are shown for other stations as well in table 5.4 - table 5.6.

5.2.2. South Korea Wind Data Analysis

This section will analyze in detail of the time-series measured wind data from 1 January 2017 to 31 December 2017 for two offshore area of South Korea as per IEC 61400-12-1.

5.2.2.1. Time-Series Data Analysis of Mal Do

This section analyzes the prospects of wind, from the engineering point of view, in Maldo, an Island of Republic of Korea as per IEC 61400-12-1. 0.5 m/s and 1 m/s bin have been considered for analysis. Data pre-processing as per IEC 61400-12-1 is launched in this research with considering the air density range defined by the cited standard. For standard analysis, the data have been laid down to check as per the conditions made by the above standard. Wind resource is a prominent sector of renewable energy, and being situated in a tropical region, Republic of Korea gets lots of wind flow in a varying speed all around the year. In this section, one year wind speed data of the island taken has been analyzed for the research. Wind speeds at ten meters height were used to measure at fifty meters using power law.

Table 5.6. IEC 61400-12-1 requirement check-up.

Requirements	*MAL DO data*	*Status*
Selected data sets based on 10 minute periods?	YES	PASS
Wind speed data normalized?	Normalization **NOT** needed	PASS
The database includes a minimum of 180 hours of sampled data?	YES (dBase includes 8430 hours of sample data)	PASS
Each bin consists of minimum 30 minutes data?	Several bin have data under 30 minutes.	-

Shape and scale parameter of Weibull probability distribution have been estimated using graphical method for the current research. Seasonal and yearly average wind speed of the island was found to have fair in terms of wind energy potential, though research regarding wind energy is still in the crawling level in the country. According to the data and statistical analysis, the wind in Mal Do has been proved to have class one wind category. Technologically uplifted altitude of wind turbines to be set up on the Island might resolve the problem of this category.

5.2.2.1.1. Data Pre-processing

Prior to professor the data, database is made to be fit as per the requirement set by IEC 61400-12-1 standard.

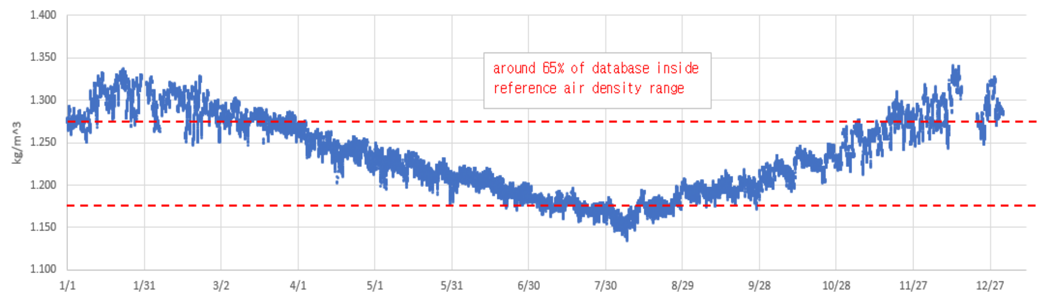


Figure 5.12. Data integrity test as per IEC 61400-12-1.

Before analysis, it should be checked whether the wind database that is collected meet the rule and regulations of IEC 61400-12-1 standards.

5.2.2.1.2. Database Rejection and Normalization

Refer to IEC 61400-12-1 standard about "data rejection", the analyst should be ensure the database used for analysis are not corrupted under several conditions. In Mal Do database, some data are corrupted (e.g. un-recorded data) and need to be excluded. After the data filtered, refer to IEC 61400-12-1 standard about "data normalization", the analyst should be ensure the database are under the same assumption of air density with International Standard 1.225±0.05 kg/m^3. After the data processing, it was found that 65% of database's air density is inside the range of reference air density while 35% outside the range. In respect to that, it assumed that all data is in match with reference air density and no need for database normalization.

5.2.2.1.3. Frequency Distribution

For estimating the wind energy potential of a site, the wind database should be properly analyzed and interpreted. In this section, one year (2017) wind speed data at 10 m AGL has been statistically analyzed using Weibull Probability Density Function (PDF). 4 different methods to calculate the shape parameter k and scale parameter C are utilized in this analysis namely

- Graphical Method (GM)
- Standard Deviation Method (std_dev)

- Energy Pattern Factor Method (EPF)
- Maximum-Likelihood Method (MLM)

Refer to IEC 61400-12-1 standard, the selected data sets have been sorted using the "method of bins" procedure. 0.5 m/s and 1 m/s bin methods are used and compared each other which one give the best fit for wind speed characteristics. Table 5.7 shows a frequency of the wind in details at 10 m AGL using 1 m/s bin.

Table 5.7. Frequency Distribution 1 m/s bin method.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
N	211	115	365	772	863	700	476	510	508	562	435	253	152	54	33	15	3	0	0	0	0	0	0		6027
NNE	4	115	253	549	687	553	372	387	296	267	271	183	101	37	12	3	0	0	0	0	0	0	0		4090
NE	2	157	280	519	641	450	311	204	155	149	128	87	29	3	0	0	0	0	0	0	0	0	0		3115
ENE	2	156	418	408	218	76	26	14	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0		1322
E	3	195	461	243	56	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		973
ESE	1	268	938	883	464	213	63	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		2832
SE	5	285	697	509	262	132	77	19	18	4	0	0	0	0	0	0	0	0	0	0	0	0	0		2008
SSE	7	327	1139	1673	1576	1352	992	710	546	393	292	174	104	68	7	8	0	0	0	0	0	0	0		9368
S	4	159	517	590	504	373	223	188	176	98	49	11	8	5	0	0	0	0	0	0	0	0	0		2905
SSW	6	202	437	296	240	106	60	25	23	1	0	0	0	0	0	0	0	0	0	0	0	0	0		1396
SW	6	295	340	123	89	30	3	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0		888
WSW	0	218	393	298	120	86	37	22	8	1	5	1	6	2	1	0	0	0	0	0	0	0	0		1198
W	1	69	233	359	258	192	144	92	54	29	11	5	8	7	14	8	6	0	0	0	0	0	0		1490
WNW	2	72	190	295	260	227	220	129	79	64	49	51	64	26	22	15	10	0	0	1	0	0	0		1776
NW	1	81	274	400	377	421	335	311	212	157	138	136	124	134	112	98	80	31	25	13	18	4	4		3486
NNW	3	94	259	455	582	676	697	624	634	667	644	651	665	568	345	223	106	36	19	9	4	0	0		7961
	258	2808	7194	8372	7197	5602	4036	3237	2710	2394	2025	1552	1261	904	546	370	205	67	44	23	22	4	4		TOTAL

Notable that, from the table, 0 m/s wind speed is described as "calm wind". Bin 23 (10 minutes) in the table is neglected as it do not meet the requirement of IEC-61400-12-1 about 30 minutes data. Table 5.8 shows the frequency of the wind in details at 10 m AGL using 0.5 m/s bin.

Table 5.8. Frequency Distribution 0.5 m/s bin method.

	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	20.5	21	21.5	22	22.5	
N	211	30	85	127	238	326	446	438	425	375	325	234	242	250	260	283	225	295	267	232	203	157	96	91	61	29	25	21	12	11	4	2	1	0	0	0	0	0	0	0	0	0					6027
NNE	4	36	79	107	146	230	319	347	340	308	245	193	179	197	190	142	154	128	139	141	130	107	76	64	37	23	14	9	3	3	0	0	0	0	0	0	0	0	0	0	0	0					4090
NE	2	41	116	115	165	223	296	324	317	255	195	189	122	117	87	82	73	73	76	64	64	54	33	21	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					3115
ENE	2	63	93	158	260	226	182	129	89	55	21	17	9	9	5	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					1322
E	3	46	149	230	231	168	75	38	18	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					973
ESE	1	65	203	437	501	479	404	285	179	120	93	45	18	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					2832
SE	5	79	206	335	362	280	229	145	117	65	67	50	27	15	4	7	11	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					2008
SSE	7	97	230	430	709	841	832	869	707	698	654	515	477	370	340	296	250	222	171	155	137	104	70	60	44	43	25	5	2	7	1	0	0	0	0	0	0	0	0	0	0	0					9368
S	4	54	105	231	286	321	269	246	258	236	137	109	114	100	88	93	83	64	34	25	24	6	5	8	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					2905
SSW	6	68	134	255	182	160	136	136	104	63	43	22	38	16	9	9	14	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					1396
SW	6	67	228	219	121	88	35	38	51	19	11	2	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					888
WSW	0	55	163	199	194	184	114	60	60	61	25	15	22	14	8	5	3	1	0	1	4	0	1	4	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0					1198
W	1	32	37	91	142	181	178	142	116	95	97	86	58	49	43	32	22	14	15	3	8	3	2	4	4	5	2	9	5	5	3	3	3	0	0	0	0	0	0	0	0	0					1490
WNW	2	27	45	79	111	133	162	150	110	104	123	121	99	82	47	40	39	29	35	26	23	23	28	38	26	18	8	12	10	11	4	5	5	0	0	0	0	1	0	0	0	0					1776
NW	1	26	55	102	172	203	197	189	188	223	198	192	143	180	131	118	94	75	82	67	71	72	64	64	60	67	67	66	46	39	59	60	20	15	16	13	12	9	4	13	5	3					3481
NNW	3	39	55	102	157	230	225	274	308	351	325	353	344	298	326	324	310	297	370	324	320	344	307	326	339	294	274	186	159	124	99	71	35	24	12	8	11	7	2	1	3	0					7961
	258	825	1983	3217	3977	4273	4099	3810	3387	3039	2563	2143	1893	1699	1538	1431	1279	1205	1189	1041	984	870	682	680	581	487	417	309	237	200	170	141	64	39	28	21	23	17	6	14	8	3					TOTAL

Bin 21, 21.5, 22, 22.5 is neglected as it do not meet the requirement of IEC-61400-12-1 about 30-minute data.

5.2.2.1.4. Wind Rose Graph

Wind rose is used to get a complete view of how wind speed and direction are typically distributed at a particular location. The yearly wind rose in figure 5.13 shows that the wind at Mal Do during 2017 blows from the SSE much of the time. However, if seen in the bigger picture, it can be found that most of the wind come from Northern part of Mal Do site (NNW, N, NNE) which is of 33.86%. Wind directions priority in each month is shown in table 5.9.

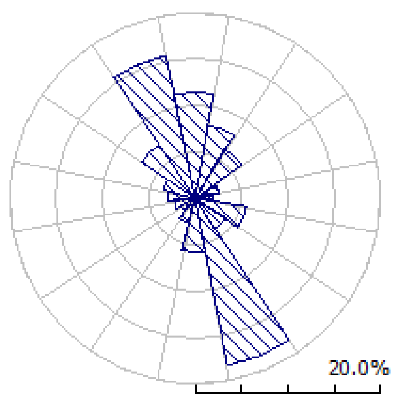


Figure 5.13. Wind rose of Mal Do in 2017.

Table 5.9. Monthly Mal Do wind direction priority in 2017.

Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
NNW	NNW	NNW	SSE	SSE	SSE	SSE	SSE	NNW	N/NNE	NNW	NNW/SSE

The wind speed at 10 m from the ground was converted to the speed at 50 m up from the ground using power law. After calculating the wind speed at 50 m from the above equation, monthly mean wind speed of the table 5.5 can be identified. The same formula can be applied to measure the mean wind speed for minutes, hours and days. Table 5.10 reveals the fact that, as those months are in the Monsoon season, the season tops in wind speed as shown in the table.

Table 5.10. Mean Seasonal and Yearly Wind Speed for Mal Do.

Location	Month	Season	Mean Wind Speed (10 m)	Mean Wind Speed (50 m)
Mal Do	February March April May	Summer	2.74	4.23
	June July August September	Monsoon	2.91	4.45
	October November December January	Winter	2.39	3.76
	Whole Year		2.67	4.23

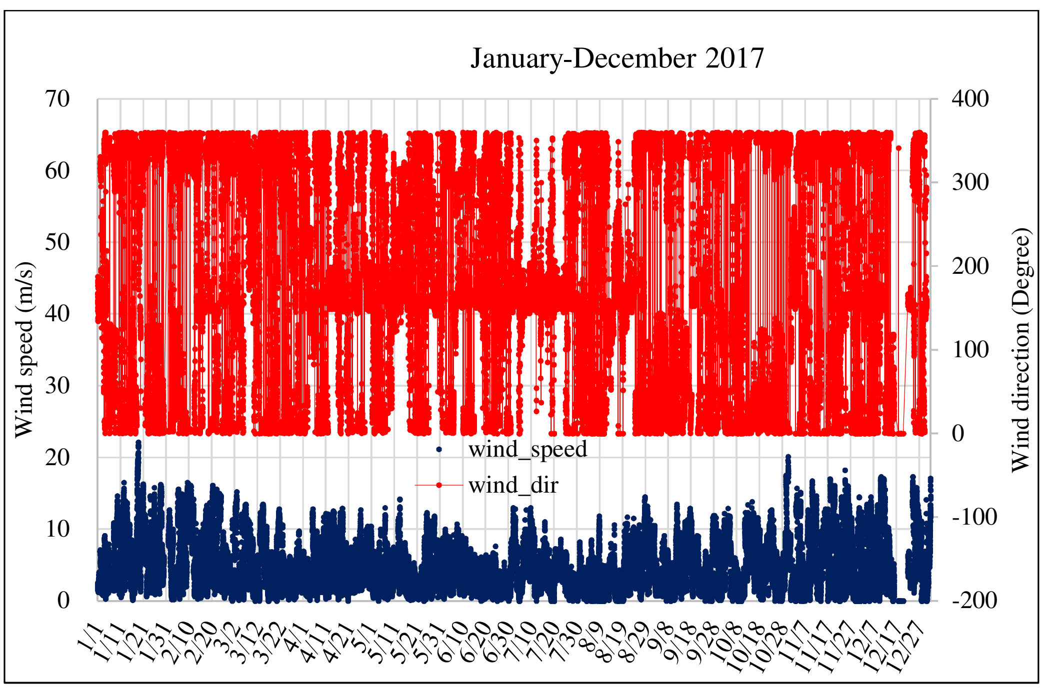


Figure 5.14. Variation of MALDO's Wind speed and Directions.

Wind energy is only sometimes steady and mostly fluctuate with respect to time, season of the year, height over the ground, type of landscape, and from year to year, consequently ought to be examined cautiously and completely [15]. So it needs more to explore how wind acts in various occasions in a year. That is the reason, subsequent to finding the mean speeds of various time range (day by day, hourly, month to month and so forth), some of following figures can be appeared to comprehend the wind qualities. Investigation of wind speed system throughout some undefined time frame in a territory can truly assist with improving the plan of the wind energy transformation framework by guaranteeing less energy producing costs [16]. As in Figure 5.14, it has been shown that how wind cooperate in ordinarily of a year. For 365 days of a year to show in a figure is hard to comprehend, that is the reason hourly and month to month figure ought to likewise be broke down regarding three prominent seasons in Republic of Korea for better understanding. Wind speed recorded over minutely or hourly basis over 24 hours in a day, and accordingly is kept on chronicle the information a few months, or even a number of years.

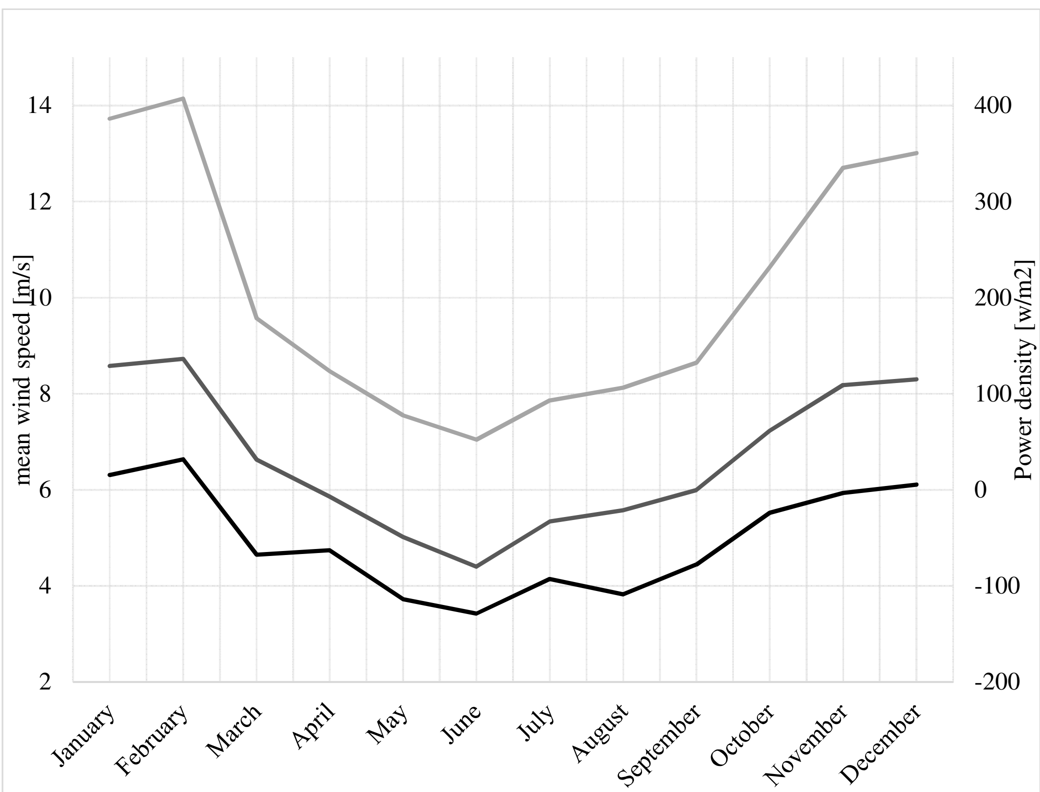


Figure 5.15. Average Wind Speed and Power at 10 m AGL.

Table 5.11. Wind Power Class of NREL

	10 m (33 feet)		*50 m (164 feet)*	
Class	*P (W/m²)*	*Wind Speed (m/s)*	*P (W/m²)*	*Wind Speed (m/s)*
1	0-100	0.00-4.40	0-200	0.00-5.50
2	100-150	4.40-5.10	200-300	5.60-6.40
3	150-200	5.10-5.60	300-400	6.40-7.00
4	200-250	5.50-6.00	400-500	7.00-7.50
5	250-300	6.00-6.40	500-600	7.50-8.00
6	300-400	6.40-7.00	600-800	8.00-8.80
7	400-1000	7.00-9.40	800-2000	8.80-11.90
8	>1000	>9.40	>2000	>11.90

Figure 5.12 and figure 5.13 help to give a big picture of a period where the wind energy potential high or low. Moreover, the graph also give a big picture of the major changing of wind directions. By just looking at this graph, we can know that from April-August 2017, most of wind at Mal Do site coming from southern part. We can know that Jan, Feb, Nov, and Dec 2017 are a months that have high wind energy among the others. The wind distribution series for monthly data can be seen in the next for details analysis. Figure 5.4 shows the average wind speed for a complete year with respect to 24 hours.

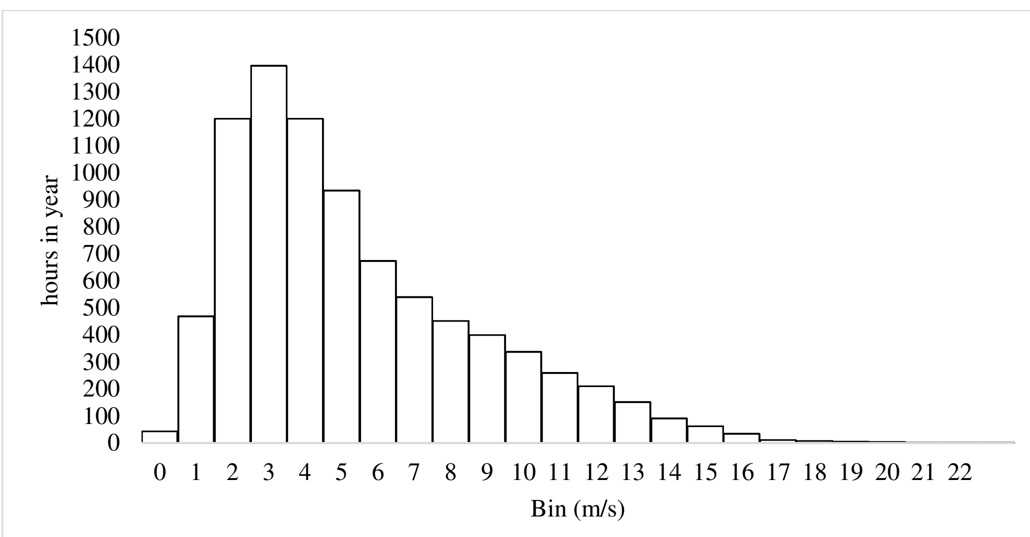


Figure 5.16. Wind Distribution at 10 m AGL for 1 m/s bin method.

It means that, the first hour of every day of the year is recorded and averaged. In this way, the other hours average wind speed is calculated. Figure 5.11 shows that, for the whole year, the island gets much wind speed after the midday. The graph above help to give a big picture on average wind speed and average power density of Mal Do site at monthly basis. As we predict from wind variations graph, now we can see clearly that high wind power density is occur at Jan, Feb, Nov and Dec 2017. It is also found that from calculation an average wind speed and power density at yearly basis in Mal Do at 10 m AGL is 4.92 m/s and is 207.70 Watt/m^2, respectively.

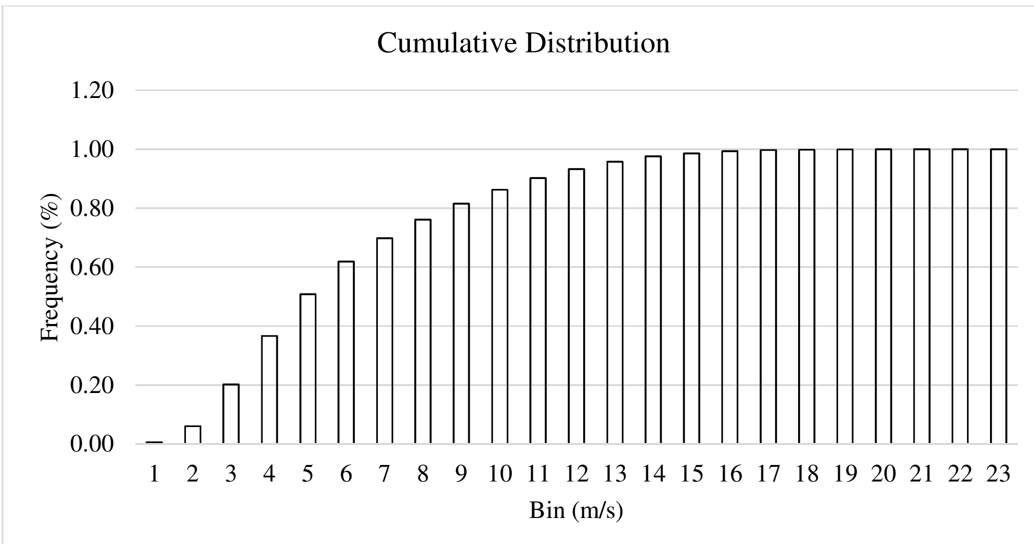


Figure 5.17. Cumulative Frequency Distribution at 10 m AGL for 1 m/s bin method.

In this analysis, it is found that wind class at MALDO site fall under 'Class 4' of NREL wind classification and are deemed suitable to outstanding for wind turbine applications. Wind speed of the whole year has been analyzed using frequency distribution for, it can condense large amount of data into a very tiny set, and gives more opportunity to identify the characteristics of the data. Figure 5.4 shows that, in the months of March and June 2015, the mean wind speed was higher, and more than 5 m/s. From figure 5.18 it can be interpreted that 3 m/s (i.e. 5 m/s at 100 AGL) wind speed have the highest share among the others while calm wind (0 m/s at 10 AGL) only share 0.5% of the total. It can also interpreted that unproductive wind speed which below 4 m/s at 100 AGL (i.e. 3 m/s at 10 AGL) and higher than 25 m/s (i.e. 16 m/s at 10 AGL) is accounted for 1,737 hours per year (i.e. 20.51% of total hours).

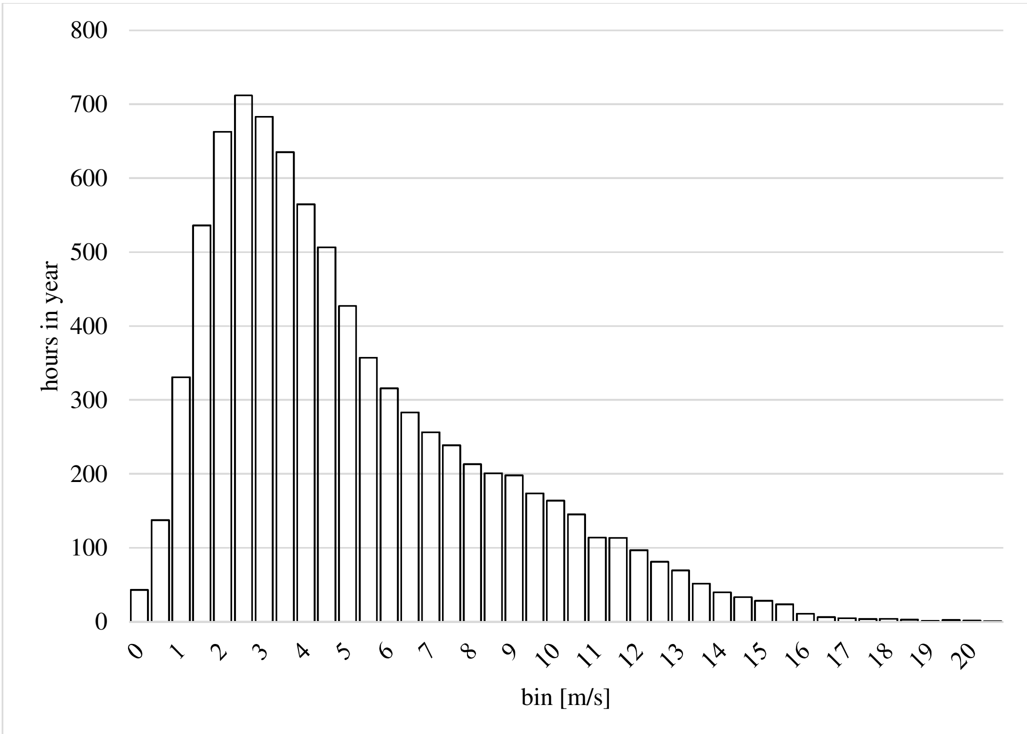


Figure 5.18. Wind Distribution at 10 m AGL for 0.5 m/s bin method.

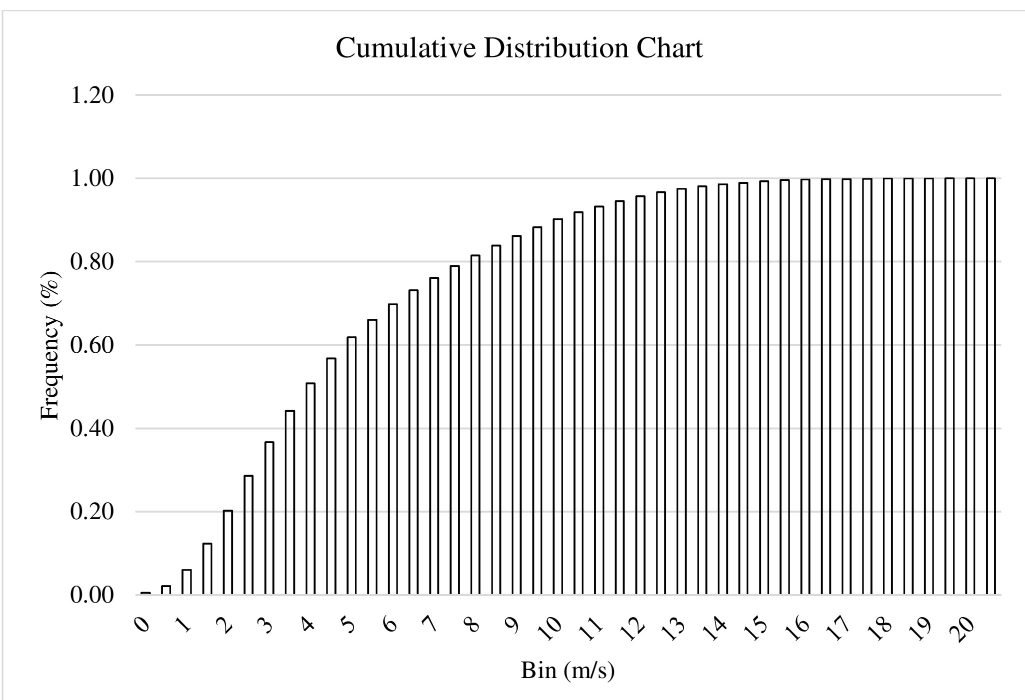


Figure 5.19. Cumulative Frequency Distribution at 10 m AGL for 0.5 m/s bin method.

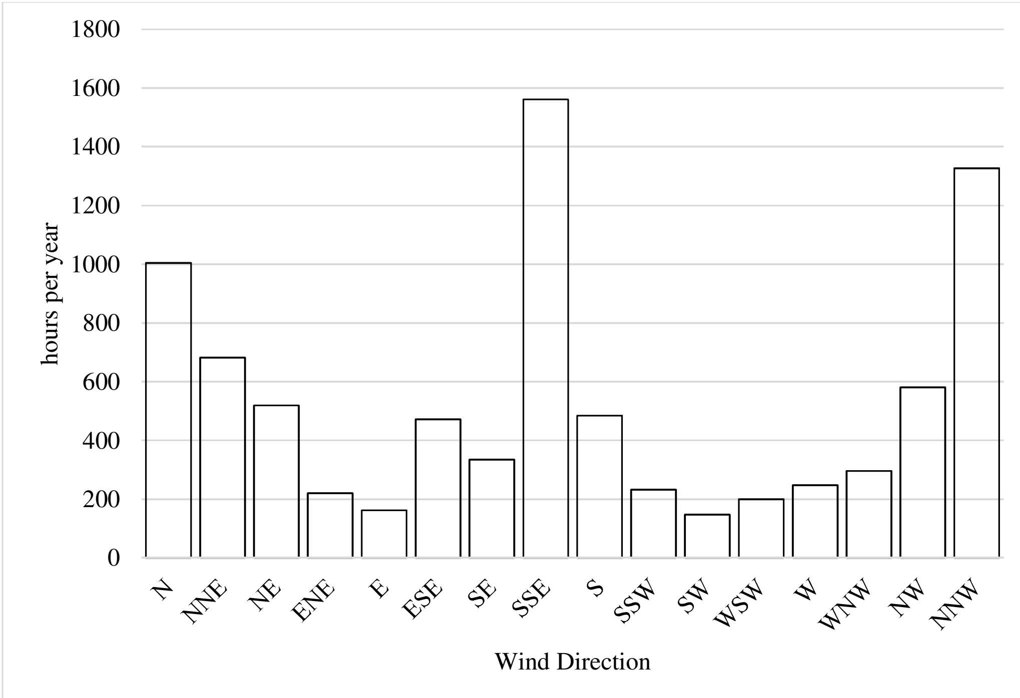


Figure 5.20. Yearly wind direction distribution by hours at 10 m AGL.

Again, wind distribution at 10 AGL 0.50 m/s for one year has been interpreted in figure 5.17 and 5.18. From those graphs, it can be interpreted that 2.50 m/s (4.00 m/s at 100.00 AGL) wind speed have the highest share among the others while calms wind (0 m/s at 10 AGL) only share 0.5% of the total. It can also interpreted that unproductive wind speed which below 4 m/s at 100 AGL (2.50 m/s at 10.00 AGL) and higher than 25.00 m/s at 100 m AGL (16.00 m/s at 10.00 AGL) is accounted for 1,737 hours per year (20.51% of total hours) which is no difference with calculation in bin 1 m/s. Wind speed is recorded in a time-series format giving it a large amount of data for analysis. The complete frequency distribution of the year or the month is expected only by annual or monthly average wind [17]. In order to determine frequency distribution of the wind speed, it is a must first to divide the wind speed domain into a number of intervals, mostly of equal width of 1.00 m/s [18].

5.2.2.1.5. Determination of Probability Distribution

It involves normal perception that the wind isn't consistent and to compute the mean power conveyed by a wind turbine from its power curve, it is important to know the probability density distribution of the wind speed. From the above rules applied to the data, shape and scale parameter could be derived as well as the power in the wind for every season and the whole year. These are shown in table 5.12.

Table 5.12. Value of Power Law Exponent and Weibull Parameters.

Location	*Season*	*α*	*k*	*C*	*Power (W/m^2)*
Maldo Island	Summer	0.28	1.46	4.19	189.00
	Monsoon	0.28	1.43	4.53	249.50
	Winter	0.29	1.53	3.95	145.15
	Whole Year	0.30	1.45	4.31	209.94

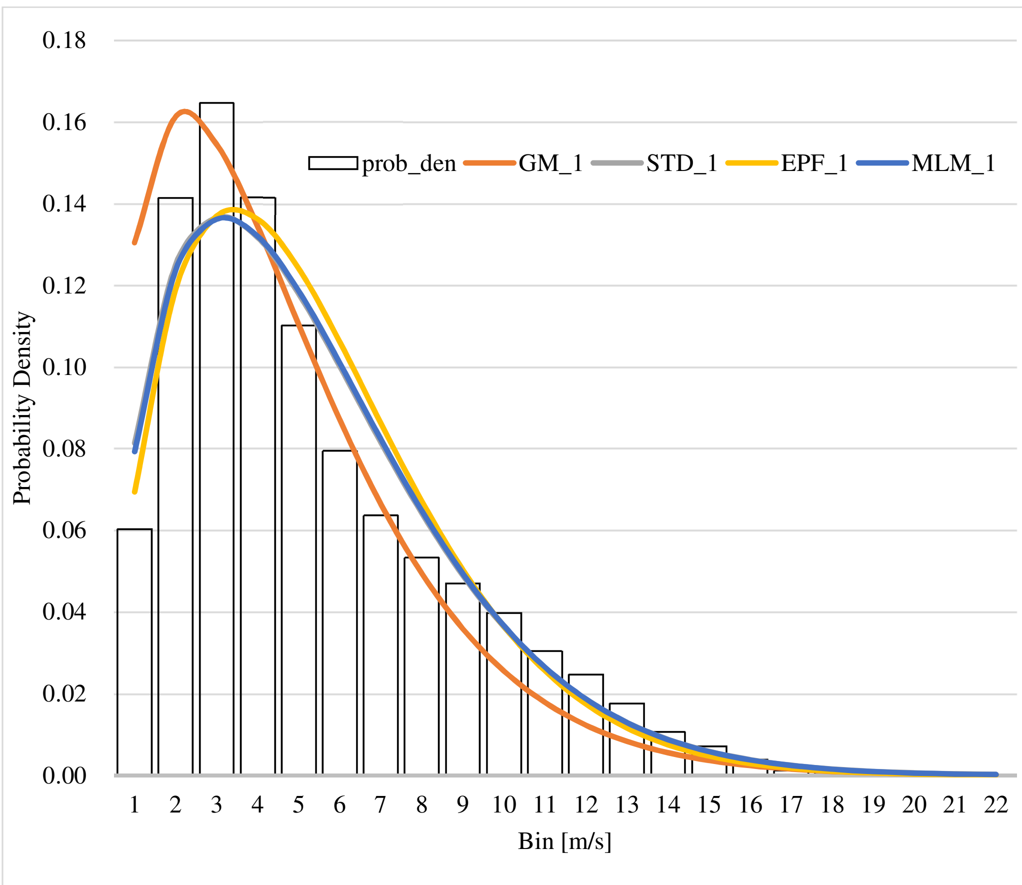


Figure 5.21. Weibull Probability Distribution at 10 m AGL for 1.00 m/s bin method.

Figure 5.19 is presented for the three prominent seasons, which has been drawn for Weibull probability distribution. It also gives the yearly Weibull distribution. From the error analysis, it can be seen that STD and MLM fit the cumulative frequency very well while EPF give the largest error value. From figure 5.19 and figure 5.20, it is clear that, in monsoon, f(v) is much comparison to the other two. This clearly reflects that the wind turbines would produce appreciably more energy during monsoon.

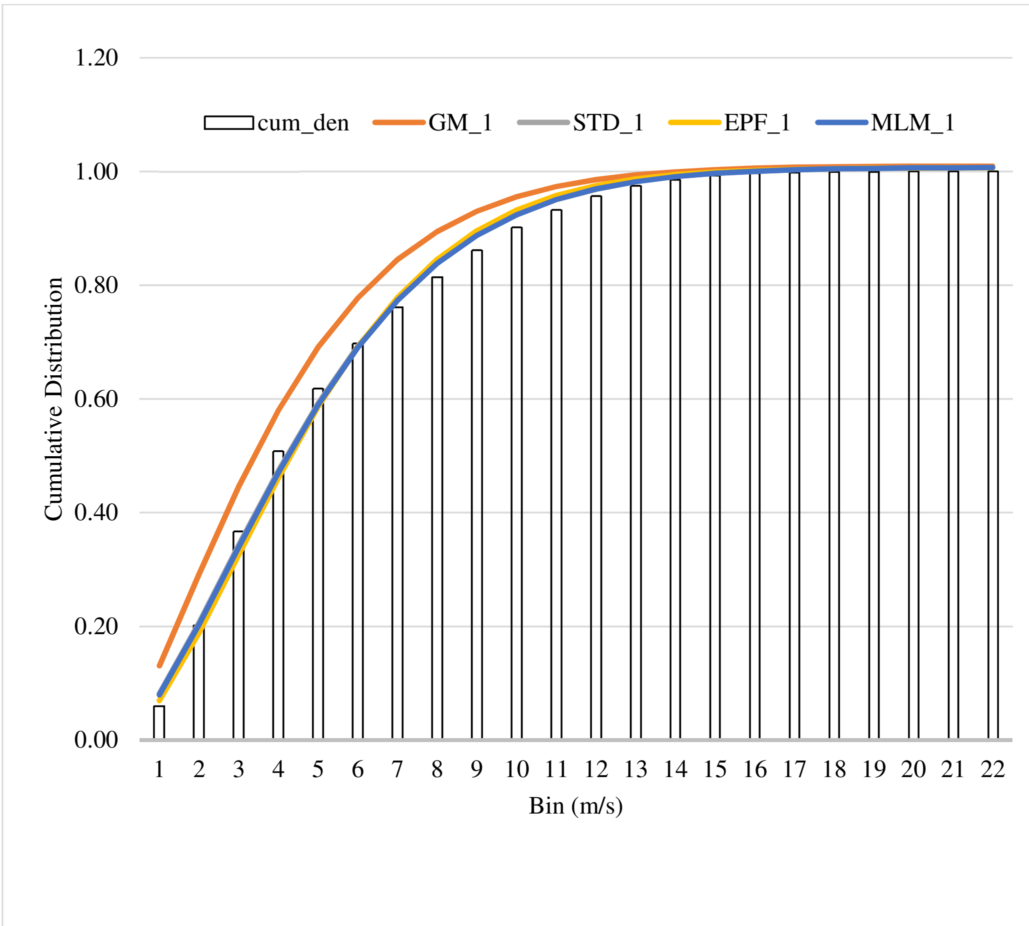


Figure 5.22. Cumulative Distribution at 10 m AGL for 1.00 m/s bin method.

Table 5.13. Parametric Values of Weibull probability Distribution for 1 m/s bin method.

Weibull Parameters	GM	STD	EPF	MLM
k	1.37	1.50	1.59	1.51
C	4.59	5.45	5.48	5.47

Table 5.14. Error estimated for different methods for 1 m/s bin method.

Bin (m/s)	Error (%)			
	GM	STD	EPF	MLM
0.50	126%	47%	-58%	43%
1.50	44%	4%	-66%	3%
2.50	21%	-6%	-66%	-7%
3.50	13%	-6%	-63%	-7%
4.50	11%	-4%	-59%	-4%
5.50	11%	0%	-54%	-1%
6.50	11%	2%	-49%	2%
7.50	10%	3%	-44%	3%
8.50	8%	3%	-40%	3%
9.50	6%	3%	-36%	3%
10.50	4%	2%	-32%	2%
11.50	3%	1%	-28%	1%
12.50	2%	1%	-25%	1%
13.50	1%	1%	-22%	1%
14.50	1%	0%	-18%	0%
15.50	1%	0%	-16%	0%
16.50	1%	1%	-13%	1%
17.50	1%	1%	-11%	1%
18.50	1%	1%	-9%	1%
19.50	1%	1%	-7%	1%
20.50	1%	1%	-6%	1%
21.50	1%	1%	-5%	1%

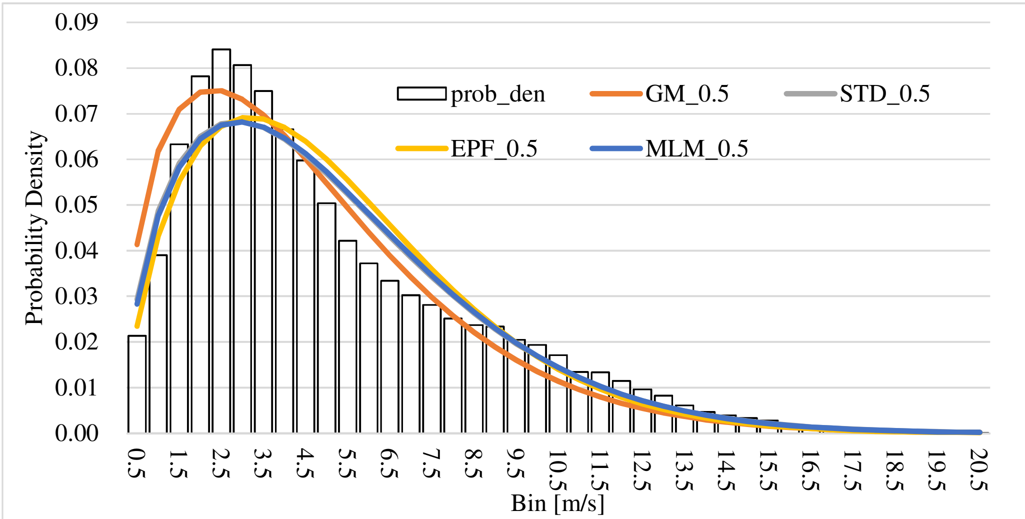


Figure 5.23. Weibull Probability Distribution at 10 m AGL for 0.50 m/s bin method.

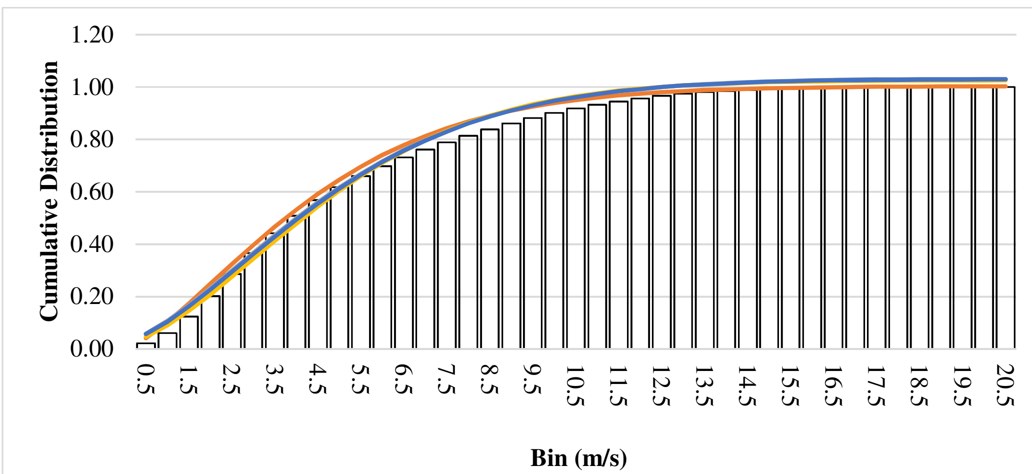


Figure 5.24. Cumulative Distribution at 10 m AGL for 0.50 m/s bin method.

STD line is difficult to be seen as it almost same with MLM line. STD, EPF and MLM method will be give same k and C value both for Bin 1.00 m/s and 0.50 m/s as it calculated with data time-series not bin method.

Table 5.15. Parametric Values of Weibull Probability Distribution for 0.5 m/s bin method.

Weibull Parameters	GM	STD	EPF	MLM
k	1.45	1.49	1.59	1.51
C	4.99	5.45	5.48	5.47

Table 5.16. Error estimated for different methods for 0.5 m/s bin method.

Bin (0.5 m/s method)	*Error (%)*			
	GM	*STD*	*EPF*	*MLM*
0.25	129%	80%	44%	74%
0.75	72%	41%	20%	37%
1.25	37%	15%	2%	13%
1.75	20%	2%	-7%	1%
2.25	10%	-4%	-11%	-6%
2.75	6%	-7%	-12%	-8%
3.25	3%	-8%	-11%	-8%
3.75	3%	-7%	-10%	-8%
4.25	3%	-6%	-8%	-7%
4.75	3%	-5%	-6%	-5%
5.25	4%	-3%	-3%	-3%
5.75	5%	-1%	-1%	-2%
6.25	6%	0%	0%	0%
6.75	6%	1%	2%	1%
7.25	6%	2%	3%	2%
7.75	6%	2%	3%	2%
8.25	6%	3%	4%	3%
8.75	5%	3%	3%	2%
9.25	5%	2%	3%	2%
9.75	4%	2%	3%	2%
10.25	3%	2%	3%	2%
10.75	3%	1%	2%	1%
11.25	2%	1%	2%	1%
11.75	2%	1%	1%	1%
12.25	1%	1%	1%	1%
12.75	1%	0%	1%	0%
13.25	1%	0%	1%	0%
13.75	1%	0%	0%	0%
14.25	0%	0%	0%	0%
14.75	0%	0%	0%	0%
15.25	0%	0%	0%	0%
15.75	0%	0%	0%	0%
16.25	0%	0%	0%	0%
16.75	0%	0%	0%	0%
17.25	0%	0%	0%	0%
17.75	0%	0%	0%	0%
18.25	0%	0%	0%	0%
18.75	0%	0%	0%	0%
19.25	0%	0%	0%	0%
19.75	0%	0%	0%	0%
20.25	0%	0%	0%	0%

From the error analysis, it can be seen that 0.50 m/s bin give less error value for all method compared to 1.0 m/s bin.

5.2.2.1.6. Power Density Calculation at 100 m AGL

To calculate power density of air at 100m AGL, some parameter need to be modified for a desired altitude based on the calculation, it is found that the air density at 100 m AGL is 1.217 kg/m^3 as for wind speed will be adjusted based on Hellman Extrapolation. In order to validate the procedure of this analysis, power density for 100 m AGL will be calculated by converting the average wind speed (cubic wind speed) at 10 m AGL into 100 m AGL in order to calculate power density.

Table 5.17. Power density calculations.

Measured Parameters	*Values*
v (10 m AGL, cubic average)	6.90 m/s
alpha	0.20
v (100 m AGL, cubic average)	10.94 m/s
P (10 m AGL, cubic average)	201.53 W/m^2
P (100 m AGL, cubic average)	795.80 W/m^2

Table 5.18. Power density at 100m AGL using Weibull PDF.

Measured Parameters	*GM (1 m/s)*	*GM (0.5 m/s)*	*STD (1 m/s)*	*STD (0.5 m/s)*	*EPF (1 m/s)*	*EPF (0.5 m/s)*	*MLM (1 m/s)*	*MLM (0.5 m/s)*
k	1.37	1.457	1.50	1.50	1.59	1.59	1.51	1.51
C	4.59	4.99	5.45	5.45	5.48	5.48	5.47	5.47
N value	0.24	0.23	0.22	0.22	0.22	0.22	0.22	0.22
k (100 m AGL)	1.40	1.48	1.53	1.53	1.62	1.62	1.54	1.54
C (100 m AGL)	7.91	8.44	9.06	9.06	9.10	9.10	9.09	9.09
P (100 m AGL)	693.42	750.75	873.27	874.27	804.03	804.03	870.78	870.78
P_e (100 m AGL)	-12.86%	-5.66%	9.73%	9.73%	1.03%	1.03%	9.42%	9.42%

5.2.2.1.7. AEP calculation

In order for calculating Annual Energy Production (AEP) form the real wind data, table 5.19 turbine specification has been used. Figure 5.23 shows the power curve for the selected Doosan WinDS3000/134 - 3 MW WTG.

Table 5.19. A 3.0 MW wind turbine power curve specification.

Wind speed (m/s)	1	2	3	4	5	6	7	8	9
Power (kW)	0	0	0	108	210	351	529	820	1288
Wind speed (m/s)	10	11	12	13	14	15	16	17	18
Power (kW)	1887	2576	2900	3000	3000	3000	3000	3000	3000
Wind speed (m/s)	19	20	21	22	23	24	25		
Power (kW)	3000	3000	3000	3000	3000	3000	3000		

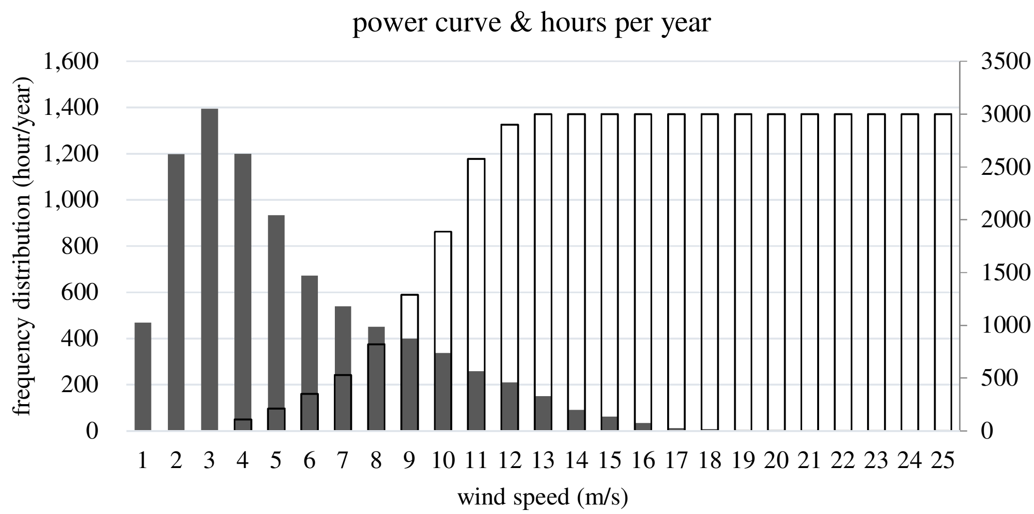


Figure 5.25. Power curve for Doosan WinDS3000/134 - 3 MW WTG.

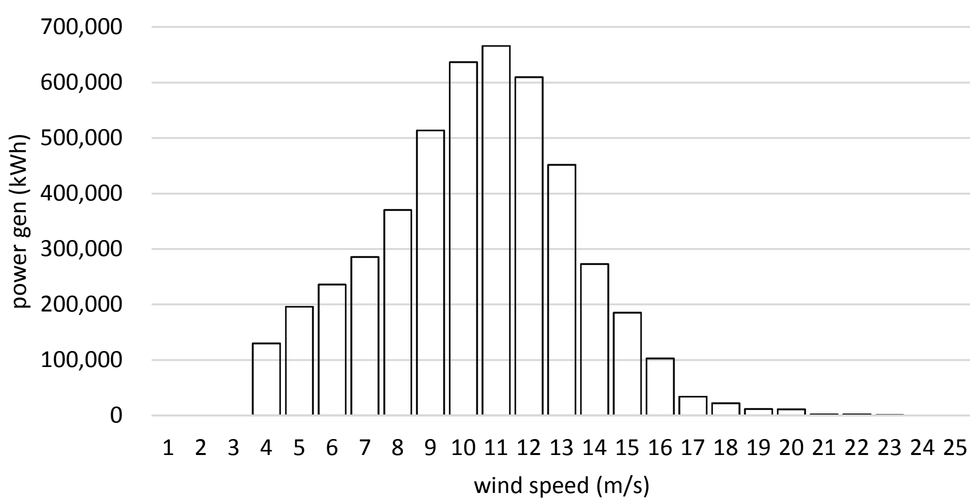


Figure 5.26. Available Energy in Mal Do in 2017.

In order to calculate power produce by wind turbine at 100 m AGL, it needs to convert the bin from 10 m AGL using Hellman Extrapolation and to find the capacity factor of wind turbine at MALDO site, it needs to find the value of maximum power produced by assuming wind turbine running at its maximum power over a year.

Table 5.20. AEP findings for 3 MW WTG.

Measured Items	*Values*
Energy produced (kWh/year)	25290000
Maximum energy produced (kWh/year)	4739067
Capacity Factor (CF)	18.74%

Power Availability and specifications of 5.5 MW Wind Turbine used in this test is presented below:

General data: Manufacturer: Hyundai, Model: HQ5500/140, Rated power: 5,500 kW, Rotor diameter: 140 m, Available model, Wind class: IEC IIIs, Offshore model: yes, Swept area: 15,394 m², Power density: 2.80 m²/kW, Number of blades: 3.

Rotor: Cut-in wind speed: 3.50 m/s, Rated wind speed: 12.00 m/s, Cut-off wind speed: 25.00 m/s

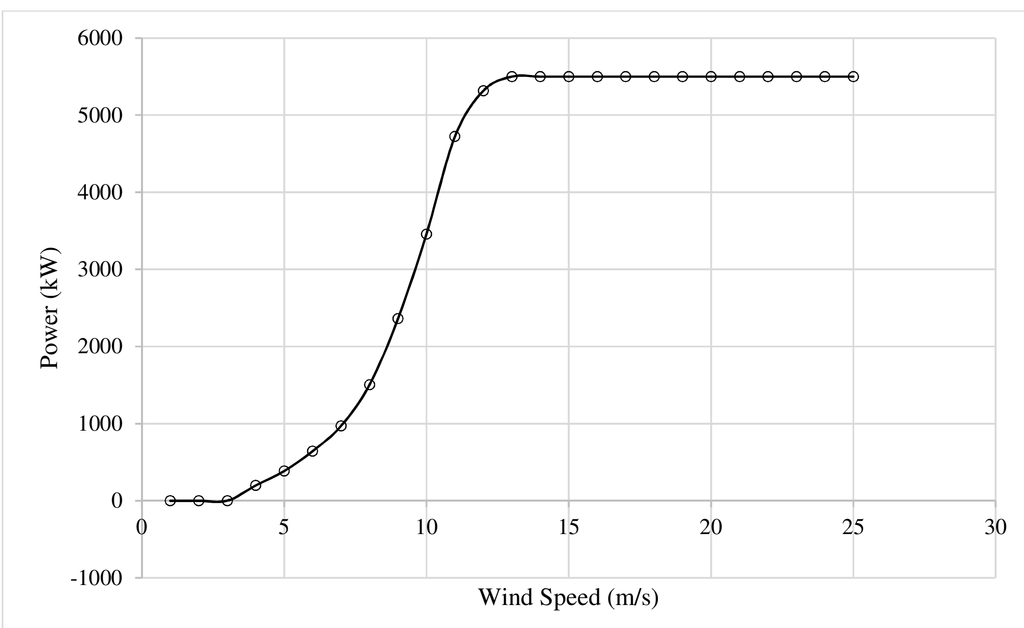


Figure 5.27. Power Curve for a 5.50 MW WTG.

Table 5.21. Power Curve for 5.50 MW WTG.

Bin	Wind Speed at 100 m AGL	Power Curve	Hours (one year)	Power from WTG
0.25-2.25	0.40-3.50	No power	No power	No power
2.25	3.57	172	712	122447
2.75	4.36	314	683	214844
3.25	5.15	592	635	375649
3.75	5.94	889	565	501888
4.25	6.74	1215	507	615167
4.75	7.53	1623	427	693301
5.25	8.32	2163	357	772509
5.75	9.11	2841	316	896460
6.25	9.91	3610	283	1022312
6.75	10.70	4371	256	1120465
7.25	11.49	5001	239	1192653
7.75	12.28	5396	213	1150225
8.25	13.08	5500	201	1104583
8.75	13.87	5500	198	1089917
9.25	14.66	5500	174	954250
9.75	15.45	5500	164	902000
10.25	16.25	5500	145	797500
10.75	17.04	5500	114	625167
11.25	17.83	5500	113	623333
11.75	18.62	5500	97	532583
12.25	19.42	5500	81	446417
12.75	20.21	5500	70	382250
13.25	21.00	5500	52	283250
13.75	21.79	5500	40	217250
14.25	22.59	5500	33	183333
14.75	23.38	5500	28	155833
15.25	24.17	5500	24	129250
15.75	24.96	5500	11	58667
16.25-22.75	27-36	cut-out	cut-out	cut-out

In order to calculate power produce by wind turbine at 100 m AGL, it needs to convert the bin from 10 m AGL to a specified height (here 100 m AGL) using Hellman Extrapolation (power law profile) and to find the capacity factor of wind turbine at MALDO site, we need to find the value of max.

Power produced from the wind data is assumed with the test wind turbine running at its maximum specified power over a year. From this notion, table 5.22 data have been calculated for AEP and capacity factor.

Table 5.22. AEP calculated for a 5.50 MW WTG.

Items	*Values*
Energy produced (kWh/year)	17,163,504
Maximum energy produced (kWh/year)	46,599,667
Capacity Factor (CF)	36.83%

From the result, it can be seen a sign that, MALDO site is suitable for wind energy generation, where a 5.50 MW wind turbine predicted can produce 17 GWh of electricity for a year.

5.2.2.2. Time-Series Data Analysis of Hoenggyeong Island

This section analyzes the prospects and possibilities of wind energy from the engineering point of view in Hoenggyeong do, a small island of the Jeollabuk province of the Republic of Korea. As wind resource is a prominent sector of renewable energy of Korea in the recent era having lots of wind flow in a varying speed all around the year, this research attempts to analyze the 10-minutes averaged wind speed and direction data for the year of 2017 of the proposed island with a view to identify the possibilities of building-up off-shore wind farm in the near future.. Wind speed and direction at 30 meters height were used to extrapolate the wind speed and direction at 80 m above the ground level (AGL) using power law.

5.2.2.2.1. Geographic statistics

Table 5.23 shows the geographical detail of a proposed Island in South Korea named Hoenggyeong Do.

Table 5.23. Geographical Coordinates of Hoenggyeong Island, Republic of Korea.

Name of the site	*Variables*	*Value*
Hoenggyeong Island, Jeollabuk province, Republic of Korea	Latitude	35° 52' N - 35°51 N
	Longitude	126°23'31" E - 126°26'00" E
	Anemometer height	30.00 m
	Maximum elevation from sea level	3.00 m

In order to get the primary idea of the wind energy status of the Island, table 5.24 presents the offshore wind energy potential in the Jeollabuk province where Hoenggyeong Do is situated.

Table 5.24. Sea potential of wind energy of Jeollabuk-do [13].

Site name	Sea potential (MW)			
	Potential (GWh)	*Develop (GWh)*	*Facilities capacity (GW)*	*Area (km^2)*
Jeollabuk-do	80.75 (equivalent to 6943 Ton oil (TOE))	27,771	10.73	3,575

The next section will discuss about data analysis of South Korea as per IEC 61400-12-1 standard.

5.2.2.2.2. Data analysis

Table 5.19 is the monthly presentations of the statistical inferences of the wind data for the year 2017. Weibull parameters, mean wind speed and power density are calculated. 10-minute averaged wind speed data of the Hoenggyeong Island have been statistically analyzed. The monthly mean wind speed values calculated for year 2009 shown in figure 5.17 identifies that, wind characteristics of the island id irregular and Months of March and December have more wind speed with 8.18 m/s and 8.01 m/s respectively comparing to other months.

Table 5.25. Monthly Rayleigh and Weibull distribution analysis result for Hoenggyeong Island at 80 m AGL.

Month	*Rayleigh*			*Weibull*		
	V_{mean} (m/s)	*C*	*Power Density (W/m^2)*	*k*	*C*	*Power Density (W/m^2)*
January	7.21	8.14	433.77	1.58	8.03	416.43
February	6.76	7.63	357.24	1.48	7.47	335.24
March	9.03	10.19	850.97	1.97	10.19	850.97
April	5.32	6.01	174.59	1.65	5.95	169.41
May	6.10	6.88	261.91	1.87	6.87	260.77
June	5.50	6.21	192.60	1.38	6.02	175.46
July	6.43	7.26	307.75	1.18	6.81	253.99
August	5.38	6.07	179.87	1.76	6.04	177.21
September	5.14	5.79	156.11	2.11	5.80	156.92
October	6.65	7.51	340.65	1.78	7.47	335.24
November	8.13	9.17	620.15	1.74	9.13	612.07
December	9.22	10.40	904.67	1.68	10.32	883.95
Whole Year	6.90	7.78	379.77	1.47	7.63	557.23

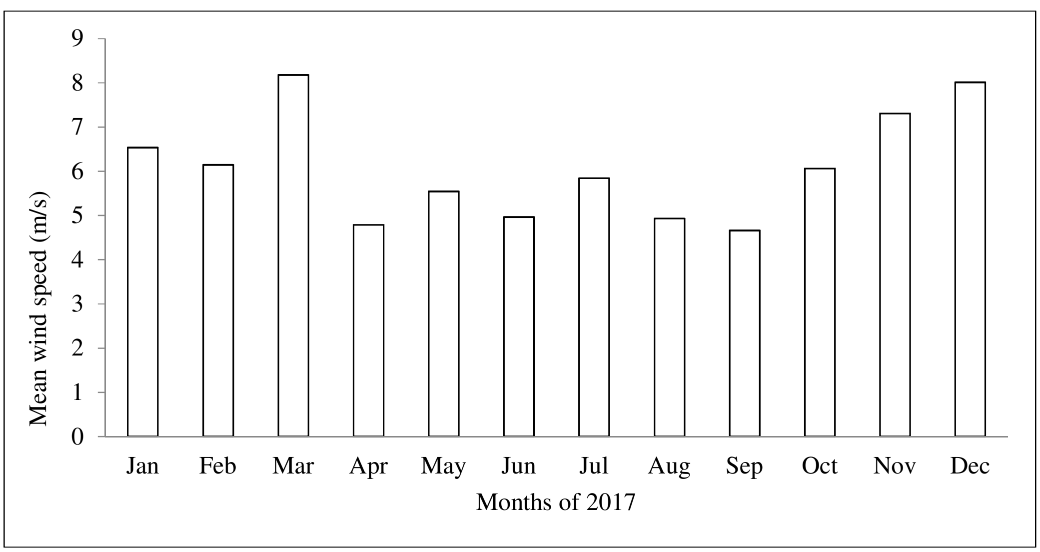


Figure 5.28. Monthly variation of mean wind speed for the year 2017.

Table 5.26 is the presentations of the statistical inferences of the wind data for the year 2017 as per Weibull and Rayleigh PDF. Wind speed is calculated for both of the PDF. The table contains the power density of the wind from the mean wind speed of the observed data.

Table 5.26. Rayleigh and Weibull distribution analysis result for Hoenggyeong Island at different mast height.

			Rayleigh			*Weibull*			
Mast height (m)	V_{mean} *(m/s)*	*Observed power density (W/m²)*	*C*	*Power density (W/m²)*	*Assumed mean wind speed (m/s)*	*k*	*C*	*Power density (W/m²)*	*Assumed mean wind speed (m/s)*
30	6.04	363	6.77	249	5.99	1.38	6.2	348	5.83
50	6.45	455	7.28	310	6.45	1.39	7.2	529	6.71
80	6.90	554	7.78	380	6.89	1.65	7.68	545	7.21
100	8.19	752	8.65	521	7.66	1.39	8.52	724	7.44

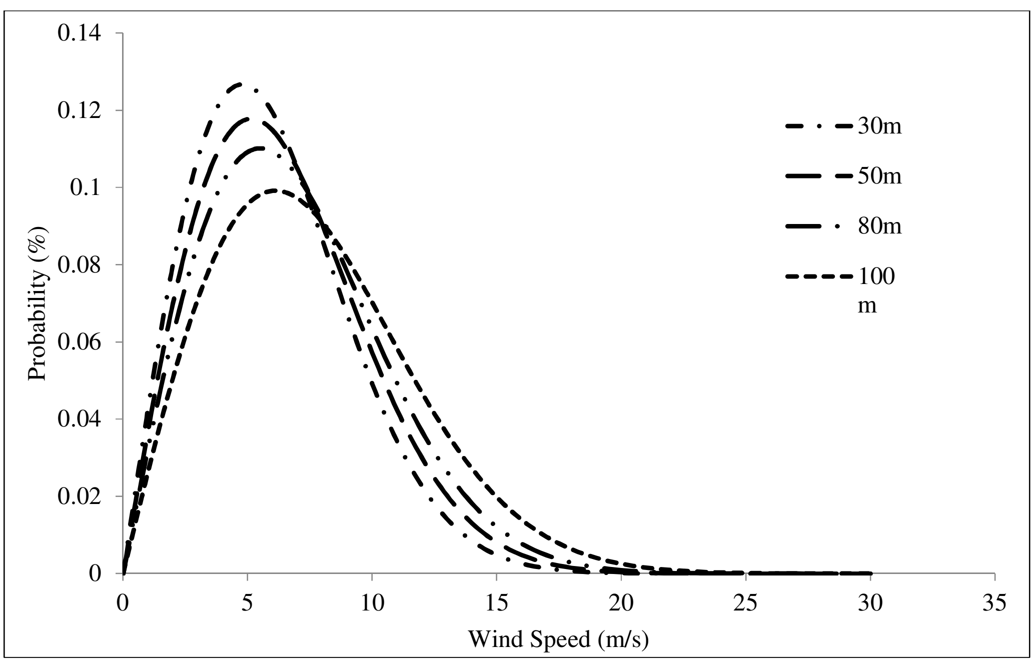


Figure 5.29. Rayleigh distribution of wind speed of year 2017 at 30 m, 50 m, 80 m and 100 m AGL.

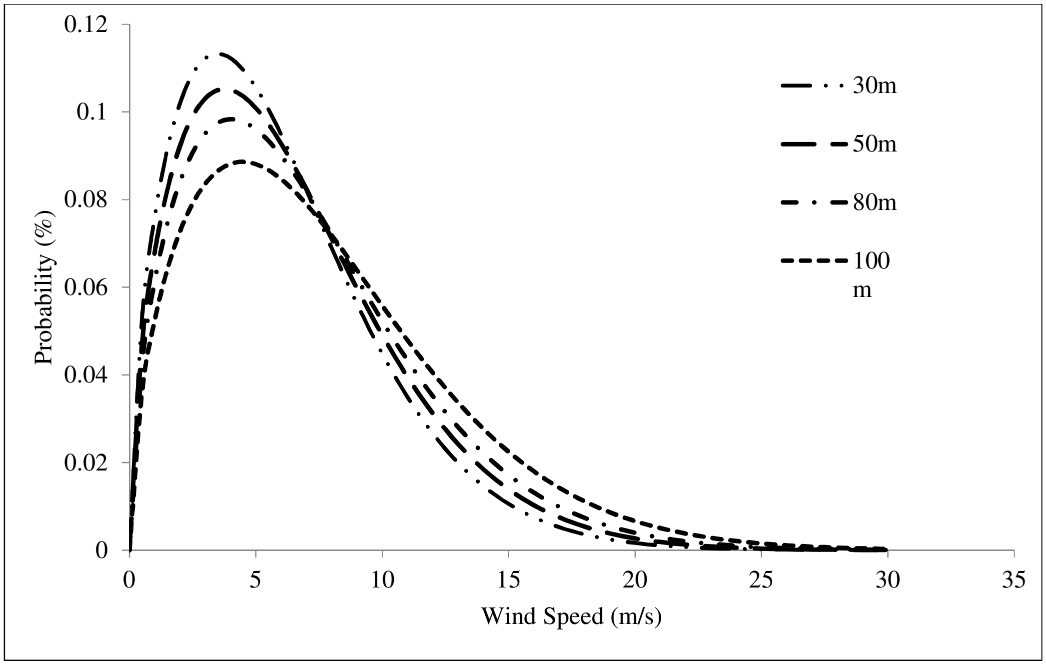


Figure 5.30. Weibull distribution of wind speed of year 2009 at 30 m, 50 m, 80 m and 100 m AGL.

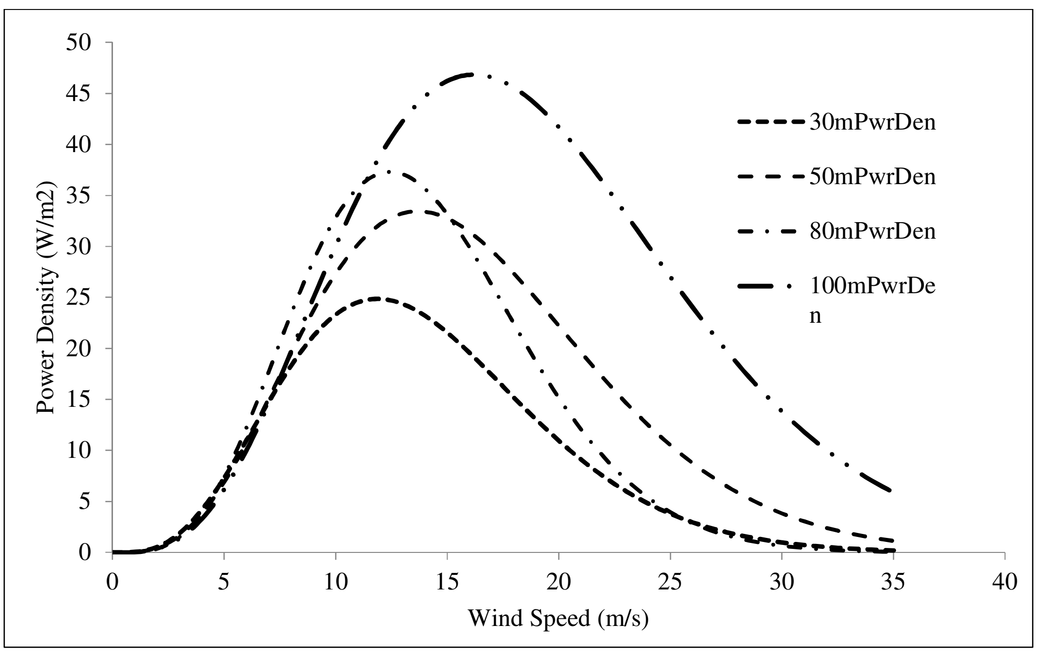


Figure 5.31. Weibull wind power density distribution.

This is very much practical to consider the distribution of the wind speed data in order to identify the power density which actually is responsible for the exact estimation whether it is from direct data by frequency distribution or by the assumption based on probability distribution functions. In order to identify the two parameters along with power density and mean wind speed from Weibull PDF, WAsP tool has been employed. The method used in WAsP [37] using the third moment and the probability of winds above the empirical mean wind speed [38]. In WAsP, the data are divided into several direction sectors and one distribution is fit for each sector. This is not the case here; there is no division according to the wind direction.

Figure 5.27, figure 5.28 and figure 5.29 show for yearly Weibull and Rayleigh distribution findings at Hoenggyeong Island for the year 2009 by month plotted with the measured wind speed. These curves illustrate the Weibull methods that fit best to the measured wind speed data.

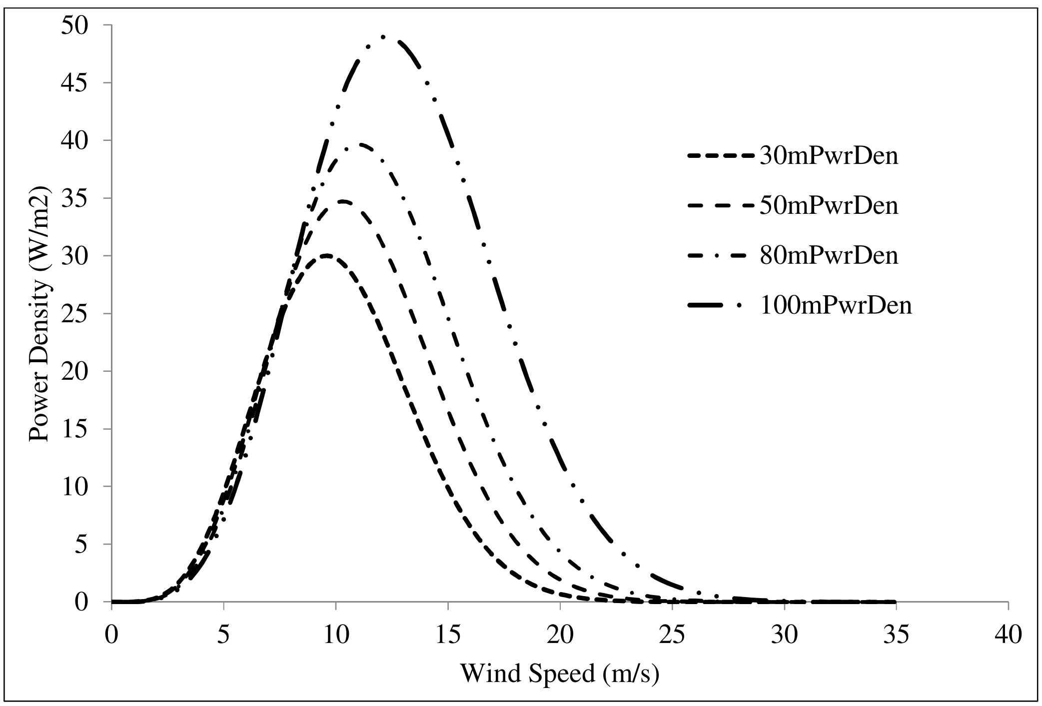


Figure 5.32. Rayleigh wind power density distribution.

Wind power density is required for the estimation of power potential from wind turbines within a wind farm or even a standalone turbine. It is a nonlinear function of the wind speed probability density function (PDF) specially derived from Weibull PDF. Wind speed PDF is usually estimated from data and then used as a functional in the power distribution function, which can be integrated to obtain the power density [21]. The wind speed PDF has traditionally been estimated using a parametric model applied to wind speed data at turbine height. These models generally include the Weibull [22], Rayleigh [23], and lognormal functions [24].

The Weibull function is so far the best for the representation of the wind speed frequency distribution. Two Weibull parameters (scale factor C and shape factor k) from simple wind statistics are used for frequency distribution from where power distribution can be made. Figure 6 show the fitted curve for Weibull PDF with a view to understanding of the distribution with the wind speed for the year 2017 of Hoenggyeong Island for different height.

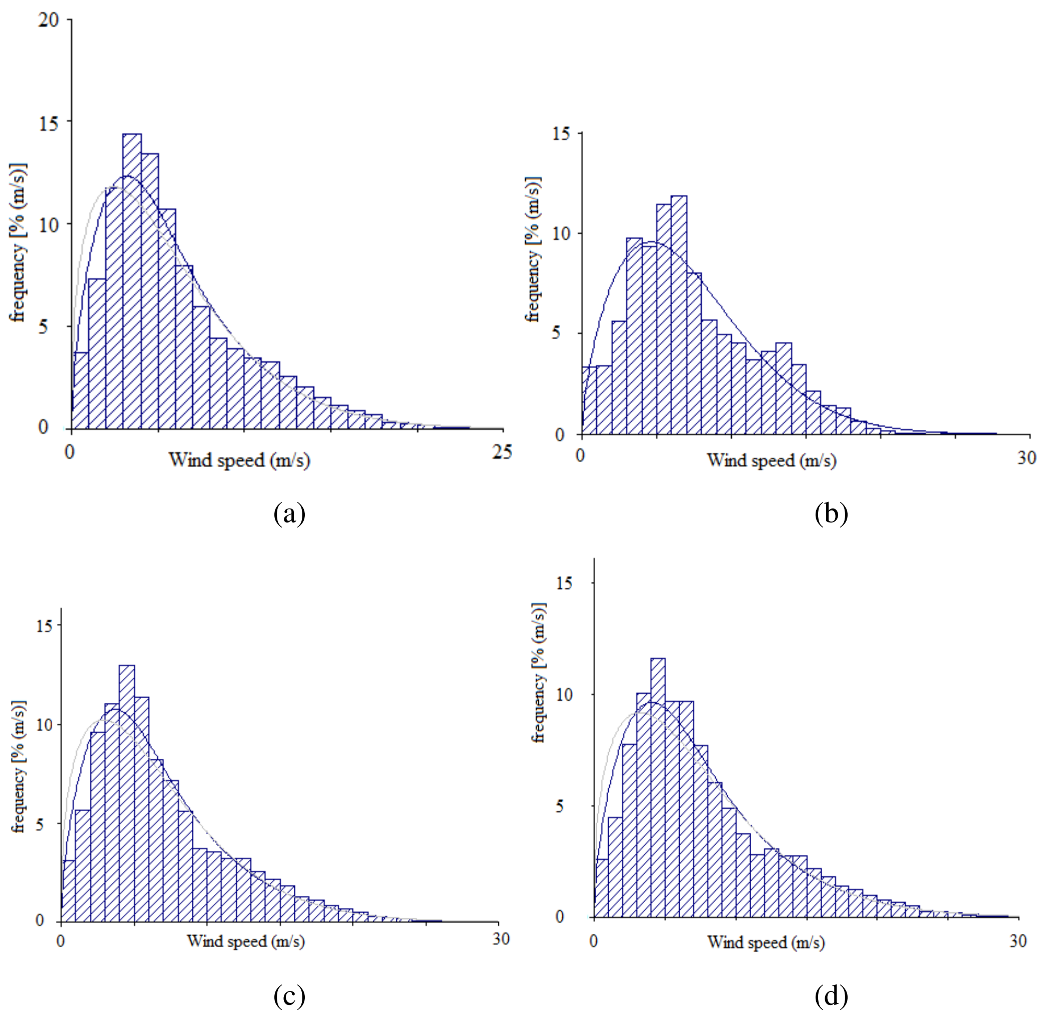


Figure 5.33. Weibull PDF with fitted histogram at (a) 30 m AGL, (b) 50 m AGL, (c) 80 m AGL and (d) 100 m AGL.

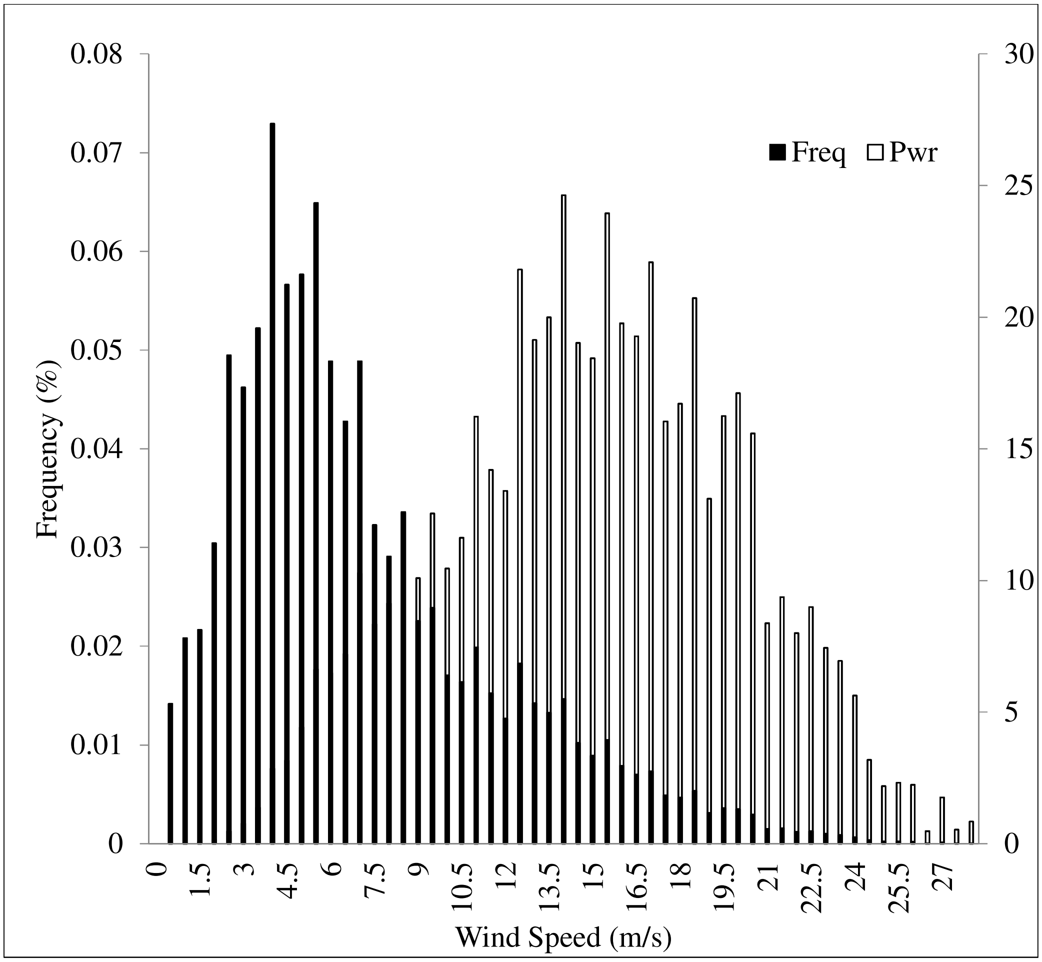


Figure 5.34. Frequency and power distribution for 2009.

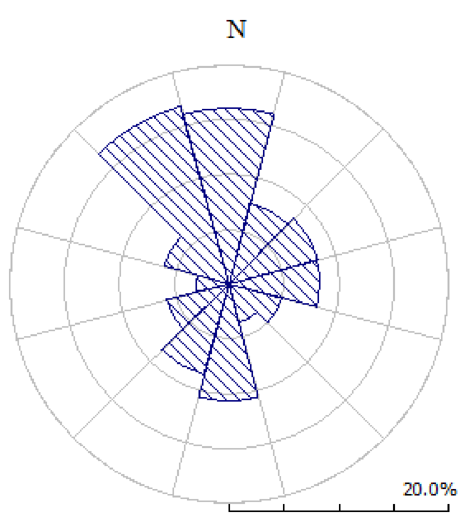


Figure 5.35. Wind rose of Hoenggyeong Island for 2017.

Table 5.27. Dimensions explained for analytical hierarchy process.

SN	*Features*	*Importance*	*Resulting Priorities (%)*
1.	High wind speed	Identification of what feature is more important than other (paired comparison) which is scaled from 1 to 9.	61.10
2.	Low population		5.80
3.	Good site access		9.60
4.	No special environmental sensitivity		11.10
5.	Heritage		12.40

The directions from which the wind is originated for the year 2009 as the measuring instrument identified, a sample of which are presented in figure 5.33. The figure shows that, wind rose is dominated by the northern as well as south-west sector of the compass. Monthly wind rose are shown in the appendix.

5.2.3. Bangladesh wind data analysis

5.2.3.1. Coastal area

The resulting priorities of the features that have been considered for analytical hierarchical process in order to select the site suitable criteria has been presented in table 4. It shows that wind speed possesses the first priority which indicates that the top most windy area should be selected for further analysis. 10-min averaged wind data in this research has been estimated from 1-minute averaged met data recorded at 10 m AGL for the selected sites as per the rule set by IEC 61400-12-1, the statistical findings of which are presented in table 5.28 and table 5.29. The wind power density distribution has been computed using the measured wind data or directly from Weibull distribution which has been presented for all sites in figure 5.34. The sites demonstrated here in the research shows that not all the areas are suitable for power generation. Wind speeds with sufficient power generation quality in this area mostly fall into IEC-61400-1 wind class IV/S.

Table 5.28. WAsP estimated parametric values of Weibull probability distribution function.

SN	Station Name	C (m/s)					k				
		10	*40*	*60*	*80*	*100*	*10*	*40*	*60*	*80*	*100*
1.	Charfashion	4.0	5.9	6.8	7.5	8.2	1.9	2.2	2.3	2.4	2.5
2.	Monpura	3.8	5.7	6.5	7.2	7.9	1.9	2.2	2.3	2.5	2.6
3.	Hatia	2.7	4.1	4.8	5.4	6.0	1.6	1.9	1.9	2.0	2.1
4.	Noakhali Sadar	1.7	2.8	3.3	3.7	4.2	1.4	1.7	1.7	1.9	1.9
5.	Companigonj	2.5	3.9	4.5	5.1	5.6	1.5	1.8	1.8	1.9	2.0
6.	Sonagazi	1.9	3.0	3.6	4.1	4.6	1.7	1.9	2.1	2.1	2.2
7.	Sandweep	2.7	4.2	4.9	5.4	6.0	1.5	1.8	1.9	2.0	2.1

Table 5.29. Mean wind speed estimation for coastal area of Bangladesh.

SN	Station Name	Mean Wind Speed (m/s)				
		10 m	*40 m*	*60 m*	*80 m*	*100 m*
1.	Charfashion	3.6	5.3	6.1	6.8	7.3
2.	Monpura	3.4	5.1	5.8	6.5	7.1
3.	Hatia	2.4	3.7	4.3	4.8	5.3
4.	Noakhali Sadar	1.5	2.4	2.9	3.3	3.7
5.	Companigonj	2.2	3.4	4.0	4.5	5.0
6.	Sonagazi	1.7	2.7	3.2	3.6	4.1
7.	Sandweep	2.4	3.7	4.4	4.9	5.4

Table 5.30. Power density estimation by WAsP for coastal area of Bangladesh.

SN	Station Name	Power Density (W/m^2)				
		10 m	*40 m*	*60 m*	*80 m*	*100 m*
1.	Charfashion	58	158	225	296	372
2.	Monpura	47	134	194	258	326
3.	Hatia	21	63	94	127	164
4.	Noakhali Sadar	6	21	33	46	62
5.	Companigonj	19	56	83	113	146
6.	Sonagazi	7	24	37	53	71
7.	Sandweep	23	67	99	134	171

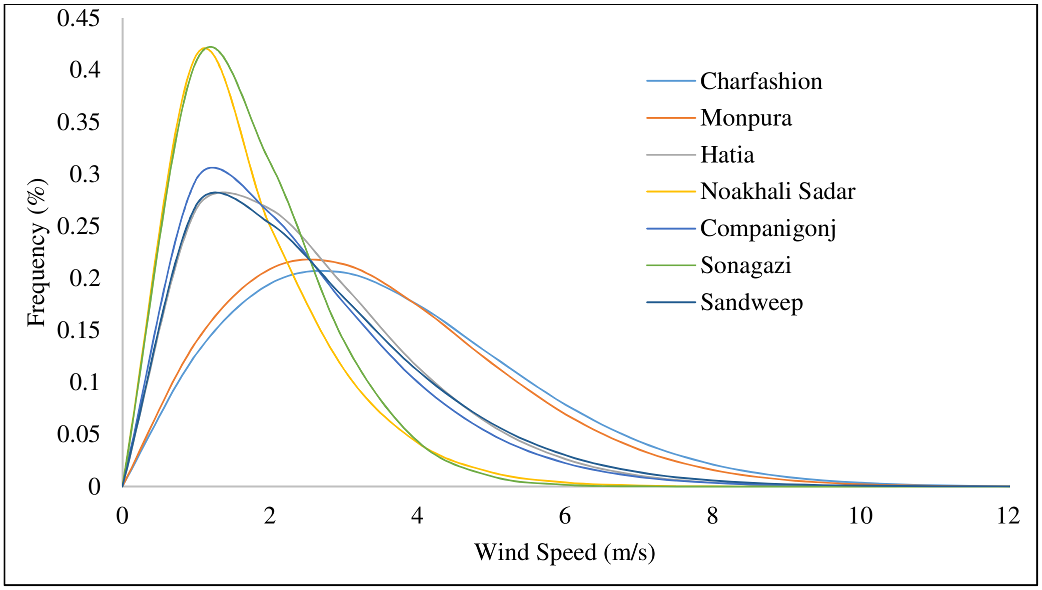


Figure 5.36. The Weibull probability distribution for the selected coastal sites at 10 m AGL.

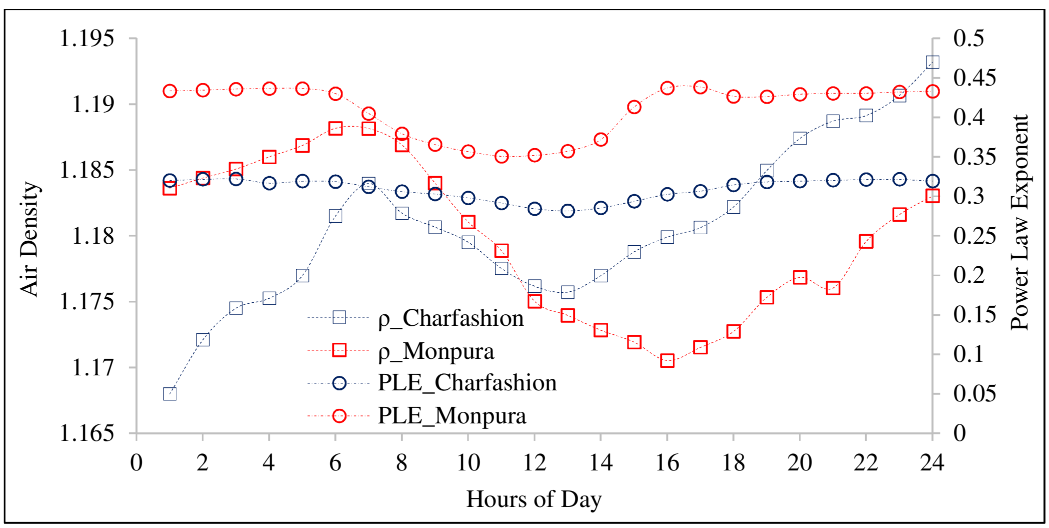


Figure 5.37. The diurnal variation of power law exponent (PLE) and air density for Charfashion and Monpura micro-site.

The value of the wind speed with this class 1 is below 4.40 m/s [44]. Suitable average wind speed for a profitable wind project should be more than 5.00 m/s. For this research, this value has been achieved by two sites named Charfashion (5.30 m/s) and Monpura (5.10 m/s) at 40 m, 60 m and 80 m AGL. If the height of the wind turbine is set to 100 m AGL, all the sites except for Noakhali Sadar (3.70 m/s) and Sonagazi (4.10 m/s) show average wind speed that exceed 5.00 m/s at that height.

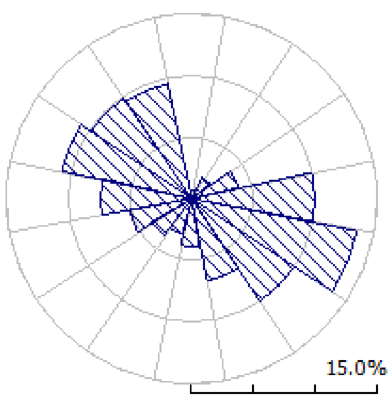
As the air density plays important role for wind speed, it estimated from met station through measured air pressure and temperature is shown in table 5.31. As the standard value of air density is considered by ignoring the values of temperature and pressure in a particular site, it is important to include recorded or mathematically calculated air density values from the recorded temperature and pressure for the estimation of true wind speed of the selected sites.

Table 5.31. Average air density for the selected coastal sites.

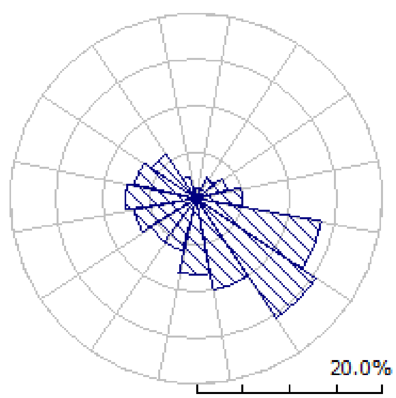
Site	*Charfashion*	*Monpura*	*Hatia*	*Noakhali Sadar*	*Companigonj*	*Sonagazi*	*Sandweep*
ρ	1.179	1.177	1.175	1.176	1.178	1.174	1.173

The derived value of PLE has relation with the varying temperature, because the ambient heat influences the atmospheric boundary layer movement significantly and thus the value of PLE too [51] [52] [53].

Wind characteristics are not only determined by the vertical thermal convection but also by the horizontal movement. The movement of predominant wind speed can be visualized through wind rose for the year 2017 for different micro-site is presented in figure 5.36.



(a)



(b)

Figure 5.38. The wind rose for two prominent coastal sites (a. Charfashion, b. Monpura) at 10 m AGL.

The knowledge of the direction of the wind speed is important for commercial power production. For the selected sites, southeast direction is the determinant at 10 m AGL, though a significant amount of wind blows from northwest and northeast direction.

5.2.3.2. Airports wind data analysis

Measuring weather situation esp. wind is a must in airports for better airplane performances and airports management. As depicted by the US Federal Aviation Administration (FAA), wind examination is of basic significance for deciding runway direction. In a perfect notion, a runway ought to be lined up with the overarching wind to limit the crosswind segments. Weather stations in airports are usually equipped with automated sensor packages which are intended to serve flight operations, meteorological functions as well as forecasting of daily weather. The purpose of setting up weather analysis facility in airports are to

1) Increase Safety at Airports

   Observation, perception and estimation of surface wind at airport terminals is fundamental to guarantee the protected take-off and landing of airplanes. The wind speed and direction data shape the Automatic Weather Observing System (AWOS) of the airports.

2) Maximize Airport Efficiency

   In outrageous weather conditions and without exact weather information, airport terminals are compelled to close runways, thus lessening its effectiveness. By utilizing appropriate estimating frameworks, air terminals can stay open until ideal operational security limits are reached.

Safety is the situation with regards to flying, explicitly airplane departures and arrivals. Because of this exclusive requirement the Federal Aviation Administration orders that weather analysis should be taken everywhere in the airport terminals, and it utilizes government dollars to complete this. This section interprets the one year wind speed and wind direction data analysis of a number of airports in Bangladesh. The particulars of the airports are given in table 5.32. The data are recorded from the met stations setup in the respective airports.

Table 5.32. Wind data specification at four airports in Bangladesh.

SN	Airport Name	Location	Data Types	Year
1.	Cox's Bazar Airport	Cox's Bazar, Bangladesh	Wind speed and wind direction	2017
2.	Jessore Airport	Jessore, Bangladesh		2015
3.	Shah Makhdum Airport	Rajshahi, Bangladesh		2016
4.	Osmani International Airport	Sylhet, Bangladesh		2016

The statistics of the wind speed data are placed in table 5.33.

Table 5.33. Outcome of wind data analysis of the airports at 10 m AGL.

SN	Airport Name	V_m (m/s, 10 m AGL)	P (w/m^2)	Weibull parameters	
				k	C (m/s)
1.	Cox's Bazar Airport	2.82	13.74	0.97	3.10
2.	Jessore Airport	2.32	7.65	1.52	2.60
3.	Shah Makhdum Airport	2.63	11.14	1.42	2.90
4.	Osmani International Airport	4.83	69.02	1.17	4.70

As per the analysis outcome, it has been noticed that Osmani airport has got much wind in the year 2016. Strong surface winds at 5.50 m/s may cause jerk at the time of takeoff. Horizontal winds also termed as crosswinds in excess about 50 kilometer/hour are generally exorbitant of takeoff and landing. But the actual phenomenon depends on the particular aircraft design and specification as every single aircraft or a particular design has its own crosswind limitation. The wind data analysis for 20 m AGL and 30 m AGL is presented in table 5.34.

Table 5.34. Wind speed and power density at 20 m AGL and 30 m AGL.

SN	Airport Name	20 m AGL		30 m AGL	
		WS, m/s	*WP, w/m^2*	*WS, m/s*	*WP, w/m^2*
1.	Cox's Bazar Airport	3.11	18.49	3.30	22.01
2.	Jessore Airport	2.56	10.30	2.71	12.25
3.	Shah Makhdum Airport	2.90	15.00	3.08	17.85
4.	Osmani International Airport	5.33	92.92	5.65	110.57

The prominence of the wind direction at 10 m AGL is shown in table 5.35.

Table 5.35. Prominence of wind direction at the airports.

SN	Airport Name	Wind direction priority	Year
1.	Cox's Bazar Airport	North	2017
2.	Jessore Airport	North, North-West	2015
3.	Shah Makhdum Airport	South, North	2016
4.	Osmani International Airport	North	2016

Wind direction pointers give pilots the data they need to evaluate the wind direction and wind speed. Wind direction measurement is important as it is described by high permeability and openings for illumination during activity in darkness. In addition to it, accuracy of surface wind speed measurement is necessary for pilots as well as for the ground staffs at the time of take-off or landing.

5.3. WIND MAPS

The research has dealt with building wind energy maps from NOAA online database for some coastal area of Bangladesh along with western and north-eastern region of Thailand. For Bangladesh, firstly mesoscale maps have been built for a better understanding of the characteristics of wind in a vast area (a big domain of a grid in a map). Mesoscale and microscale modeling can be explained from the map as shown in table 5.36 by the identification of their distinction.

Table 5.36. Mesoscale and microscale map explained.

Mesoscale map	Microscale map
• Solve velocity, temperature and many factors. • Usually weak mass conservation. • Coarse grid resolution (a few kilometers to 500 m). • Ignore local effects (hill).	• Solve velocity and pressure, sometimes temperature. • Have a high grid resolution (a few meters) • Detailed ground roughness models and forest. • Computationally expensive. • Ignore a lot of atmospheric phenomena • Usually use idealized wind profile.

After getting the results of mesoscale map, suitable sites might be selected from the map in order to build microscale maps. If the research can be able to build maps in a suitable way, this will act as a huge source of future energy solution.

5.3.1. Thailand Wind Map

This section will present wind resource maps for Thailand as the project demands in terms of wind speed and wind power density. In order to build wind map, wind speed data from NOAA satellite was retrieved as a daily basis for one year (March 2019 - March 2020). The simulated data holds most of the south-east Asian countries. Parts of Malaysia, Vietnam and Laos are also excluded from the raster (a rectangular pattern of points shown in figure 4.7 hold wind speed data which are arranged parallel) data, the specification of which is shown in table 5.37. The raster can be viewed in figure 5.37.

Table 5.37. Simulated NOAA wind speed data specifications.

Raster data type	Wind speed
Data record criteria	Daily average
Coverage area	South-east Asia (except Indonesia, Timor-Leste and Philippines)
Resolution	5000 m
Wind power data	No (it has been generated with power model built in ArcMap 10.3)

The motivation behind this mapping endeavors is to encourage the advancement of wind energy throughout the projected area along with the other region. Both the utility-scale generation of energy for off and on-grid applications may be included in this regards. Potential stakeholders of this map have big opportunity to incorporate with government authorities, global organizations for the advancement in thinking for energy issues by dint of the mapping endeavors of this kind in order for building sustainable development. Some criteria related to this wind mapping approach is pointed out:

1) The map was made conceivable by the advancement of a complex wind planning framework called MesoMap.
2) Validation of this mapping approach done in different provinces (as per the availability of the data and promising potential of wind energy) show that the technique is exact to 1% of the genuine mean wind speed.
3) The wind map can be utilized for distinguishing potential wind advancement zones.
4) Conceivable potential provinces or areas can be easy for thinking up in order for future wind project.
5) Making of explicit objectives or focuses for wind asset improvement at a territorial, public, or common interest.
6) Wind energy assessment or study projects in this research led through on location estimations to affirm the wind resource map.
7) The hot and tropical environment of Thailand as a part of Southeast Asia can be delegated to this kind of sustainable energy development activities which will help to step forward for carbon mitigation.

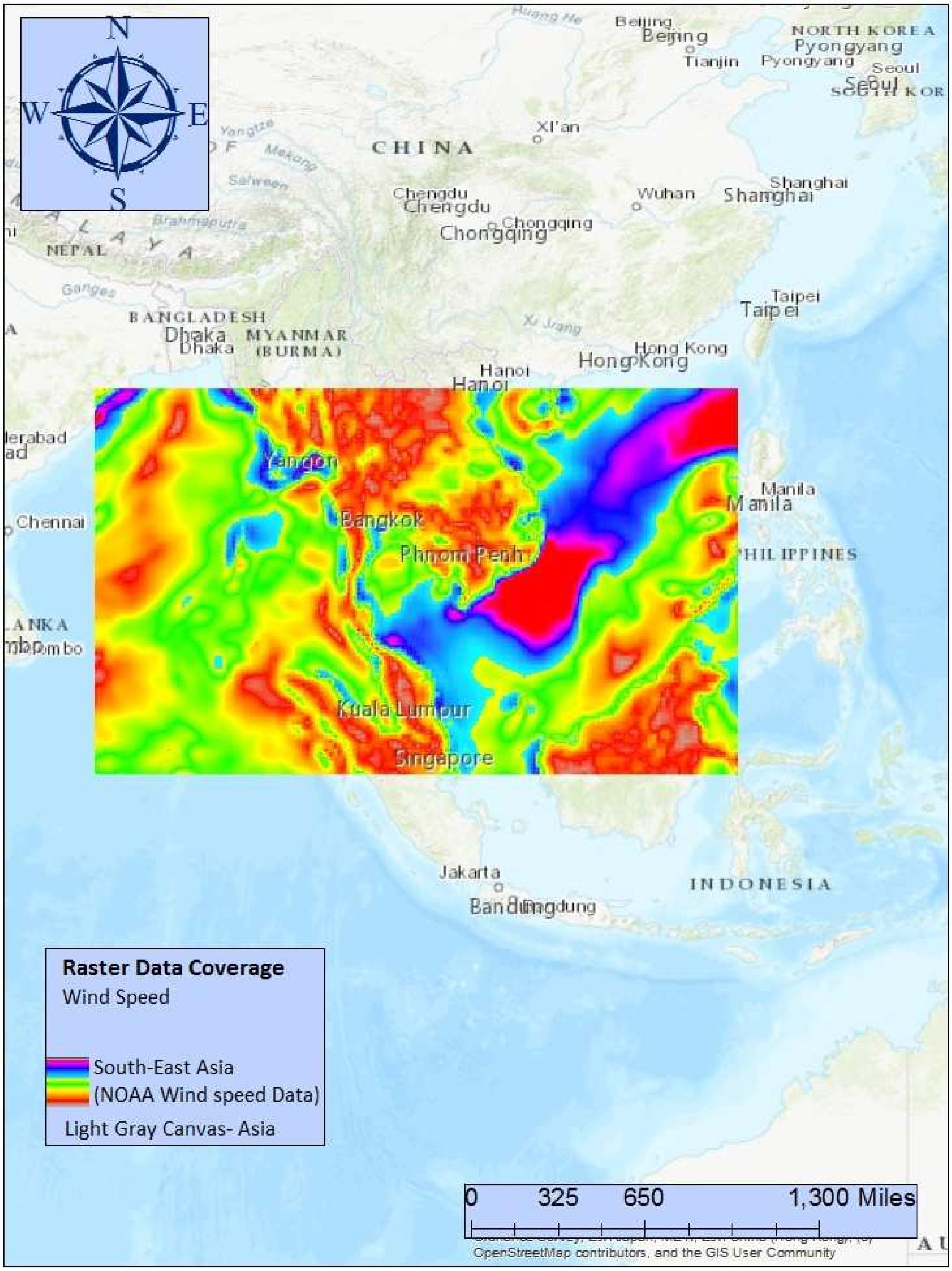


Figure 5.39. Raster data coverage area.

The project was to identify the wind speed for western Thailand and north-east Thailand. From the wind speed map of Thailand shown in figure 5.38, masking was done in ArcMap 10.3 for the identification of the wind map area for the northeast and western region.

The final map for these two regions are shown in figure 5.39.

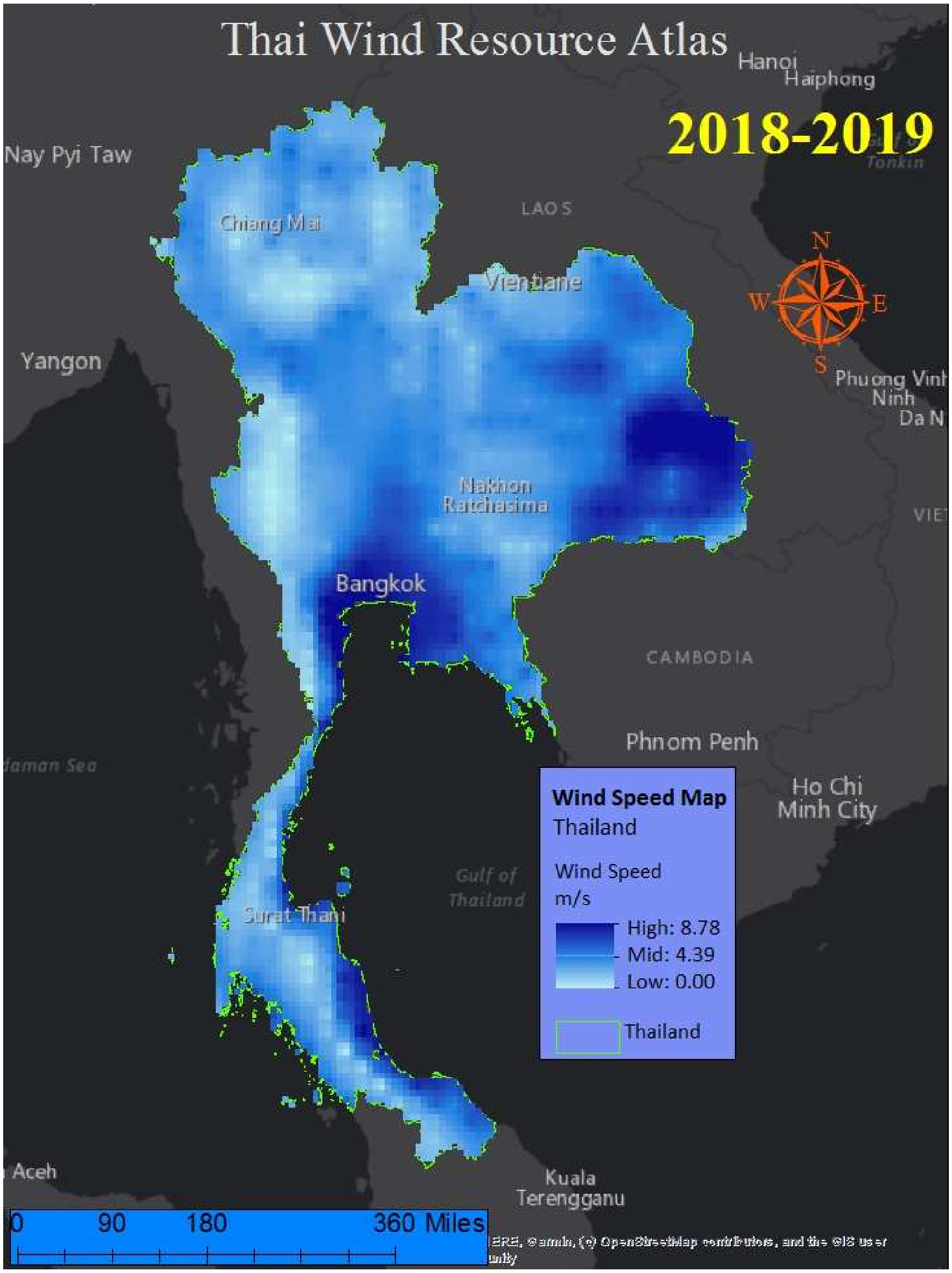


Figure 5.40. Wind speed map for Thailand from NOAA satellite data during 2018 2019.

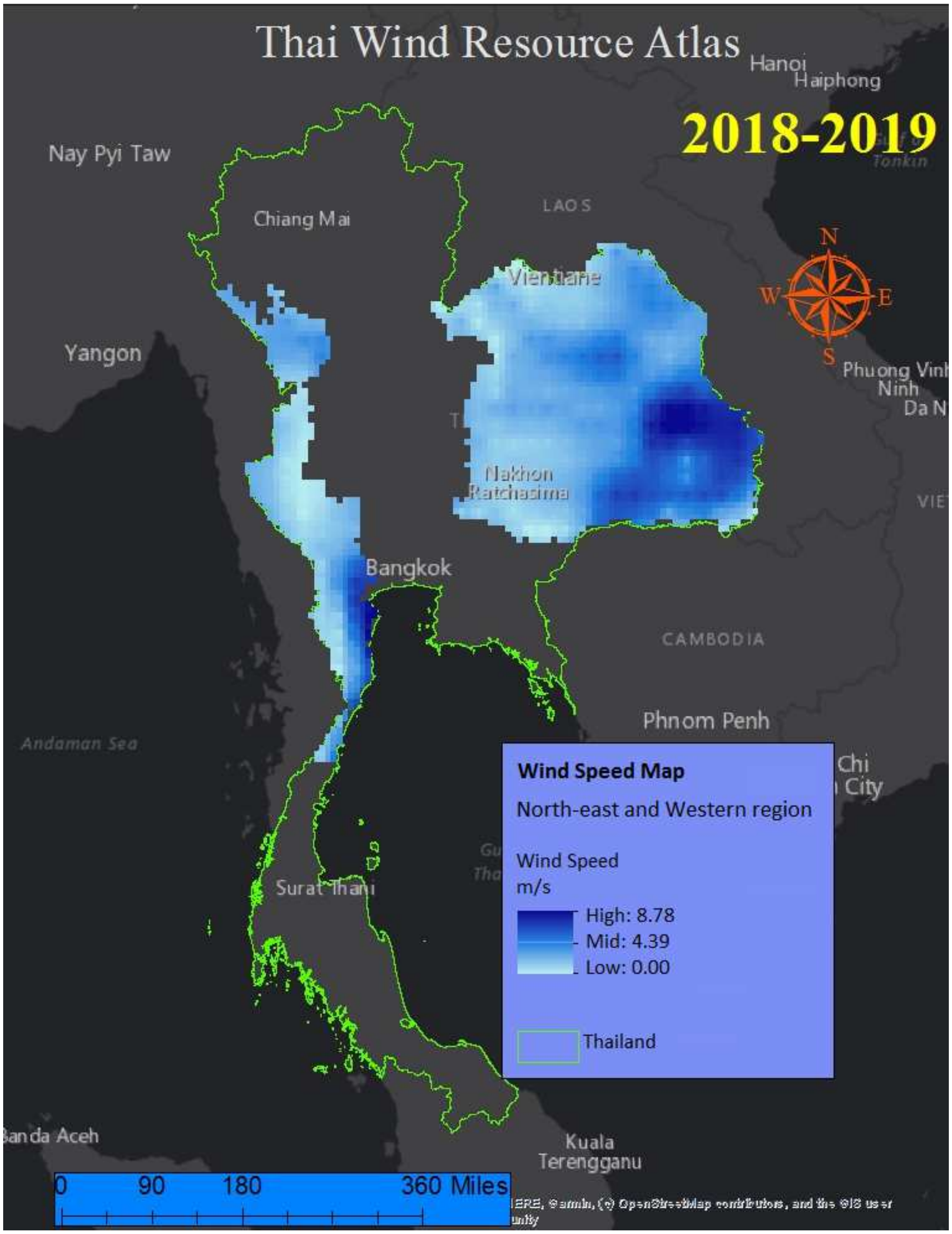


Figure 5.41. Wind Speed map for North-East and Western Thailand during 2018-2019.

After the wind speed map is built, it is possible to model wind power density map in ArcMap 10.3. Figure 5.40 and figure 5.41 is meant for unmasked (the whole raster) and masked (for Thailand) wind power density map.

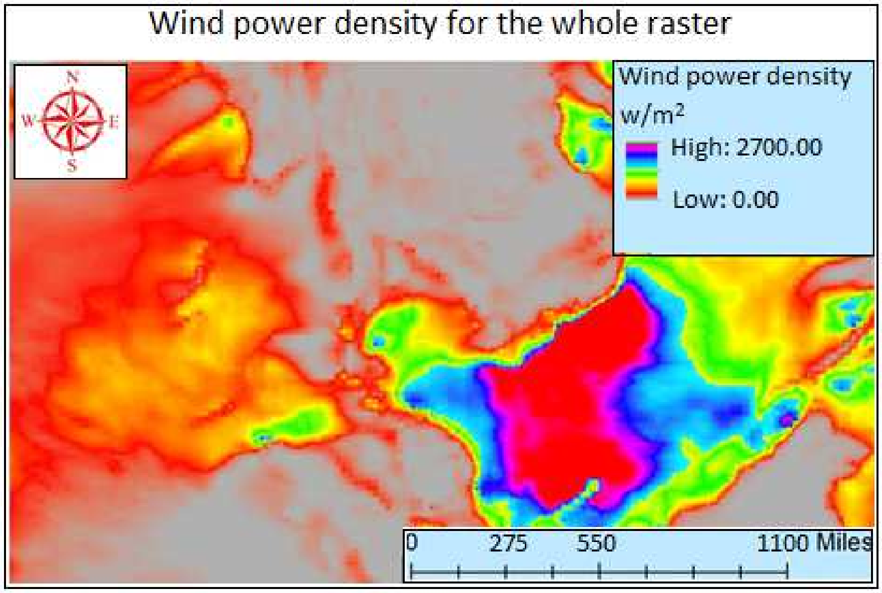


Figure 5.42. Wind power map showing wind power density variation for the whole raster as defined by NOAA satellite (unmasked for Thailand).

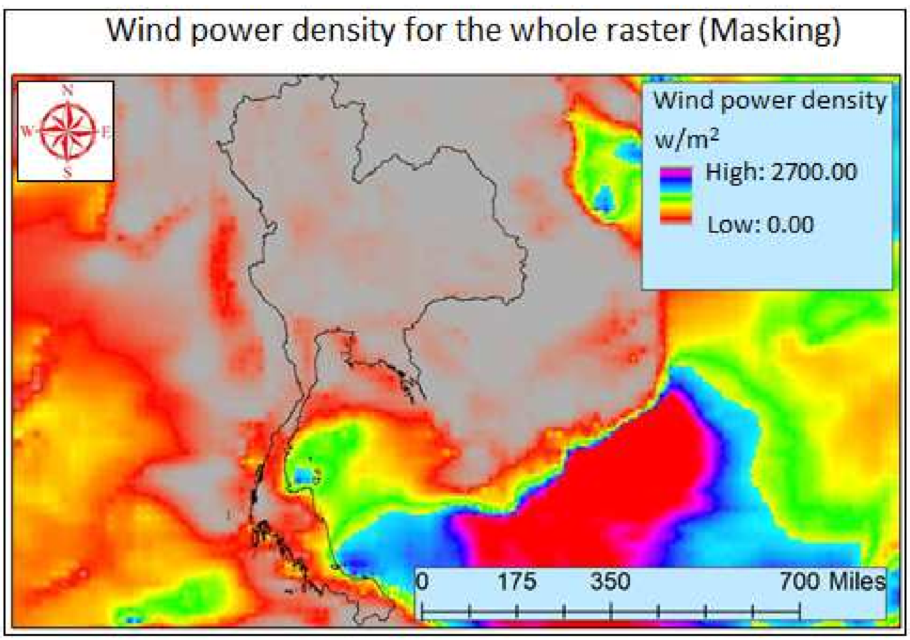


Figure 5.43. Wind power map showing Thai wind power density after masking in ArcMap 10.3 with showing the whole raster as defined by NOAA satellite.

In order for the comparison of wind power density of Thailand with the rest of the region in raster shown in figure 5.41 can be understood once the value of the power density ranges is shown in figure 5.42.

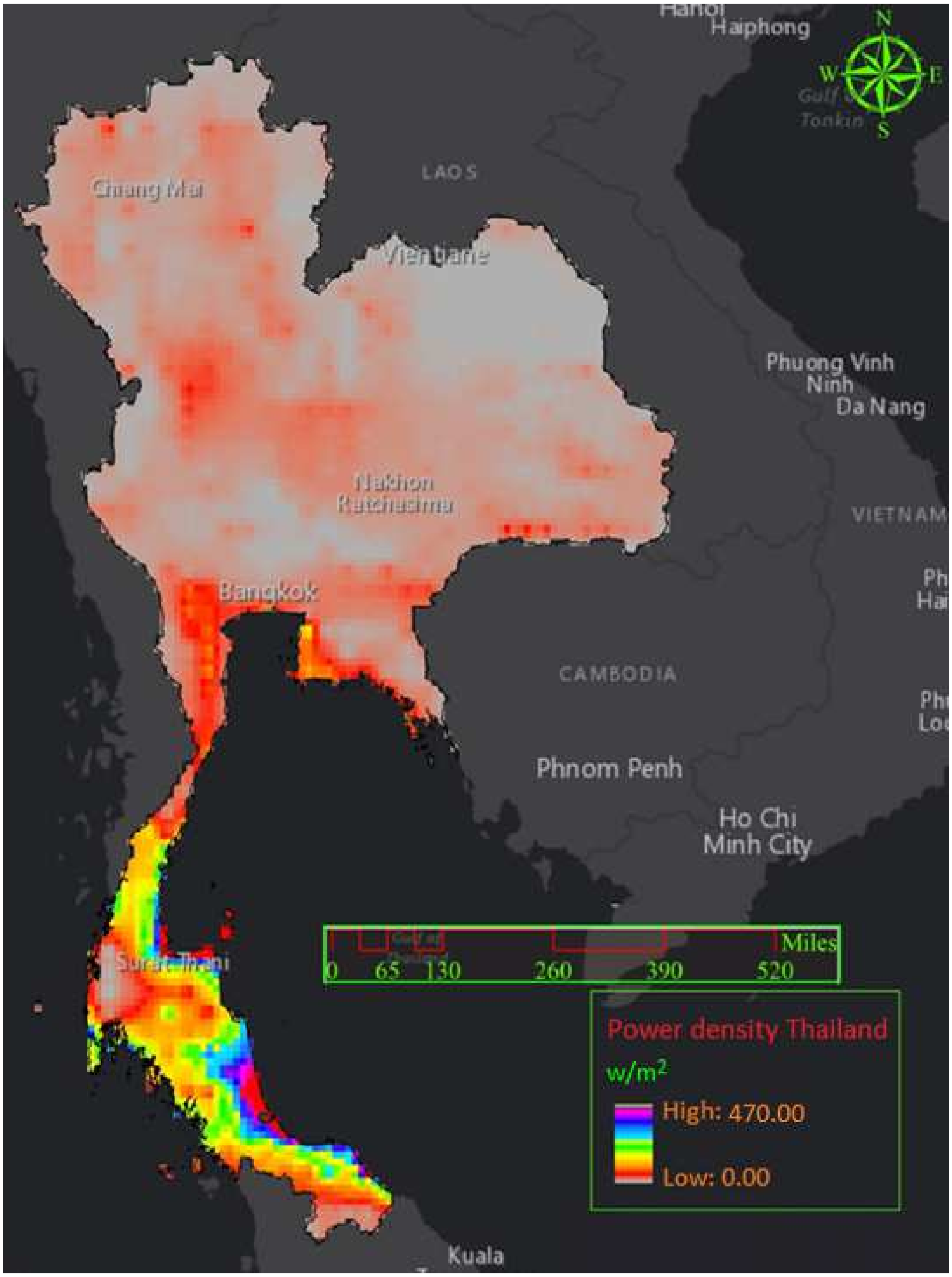


Figure 5.44. Wind power density separated by masking in ArcMap 10.3 from the NASA/NOAA defined raster for Thailand**.**

From the result of the map, it has been found that the wind speed and power density if Thailand is not that much higher in comparison to many of other areas in the raster. But this wind can generate electricity if proper wind energy modeling is done through the selection of suitable wind turbine, since the lack of proper selection of wind turbine may incur an unsuccessful project.

Table 5.38. Findings from Thailand wind resource map.

Area/Region	*Wind Speed Range (m/s)*	*Power Density Range (W/m^2)*	*Remarks*
Whole Raster		0.00 – 2700.00	There are more windy area other than Thailand in this raster.
Thailand	0.48 - 8.78	0.00 – 470.00	
Western Region	1.07 - 7.64		
North-East Region	0.55 - 8.78		

The table 5.38 shows the wind speed and wind power density findings from the map for the raster as well as whole of Thailand area and the selected north-east and western region of the country.

5.3.2. Bangladesh Wind Resource Maps

This section will consider modern wind mapping methodologies for wind resource assessment of the coastal area of Bangladesh which will be able to predict wind speed using some suitable computer software. The research will be divided into a several parts:

1. Statistical analysis of measured one year (2017) wind data.
2. Wind resource mapping using long-term simulated wind data (MERRA2/NASA)
3. Validation analysis.

5.3.2.1. Selected Area

It has been found from the primary investigation based on the mean wind speed as the foremost priority followed by heritage and environmental sensitivity, the coastal region of the country fall into the area of interest.

Figure 5.45. Southern area of Bangladesh for mesoscale modeling analysis.

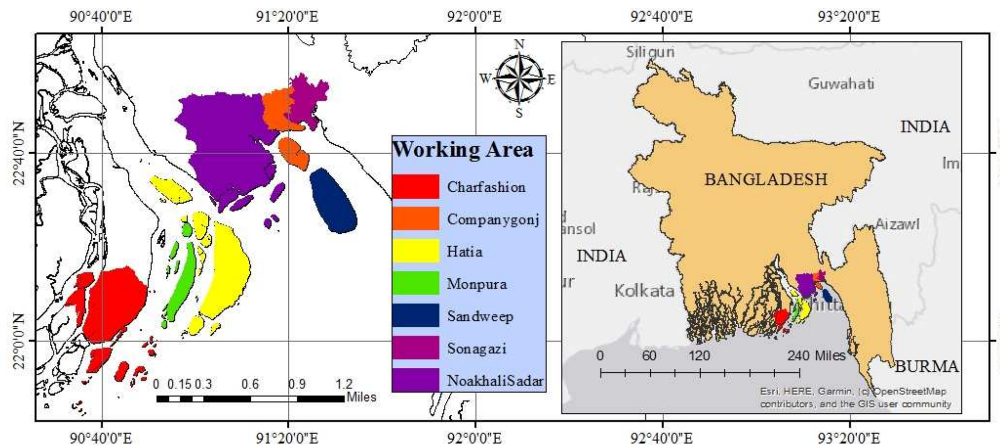


Figure 5.46. Coastal area of Bangladesh for microscale analysis.

Wind resource assessment studies can be placed into three basic categories - preliminary area identification, area wind resource evaluation and micro-siting [42]. For this work, southern part of Bangladesh has been taken as overall investigation whereas seven selected sites in the coastal area of the country have been considered for in-depth analysis.

5.3.2.2. Mapping Technique

This work has manipulated computerized wind resource mapping system that replaces the manual analysis.

5.3.2.2.1. Mesoscale and Microscale Modeling

Mesoscale modeling with significant simplifications is able to provide real value for studies at the sites selected for wind atlas analysis. It resolves meteorological conditions within its modeling domain through solving a set of equations describing the atmosphere. As understood, the development of wind energy requires a thorough analysis of the wind resource, and a wind map helps understanding the insides of wind characteristics.

Table 5.39. Wind resource mapping criteria.

SN	*Mapping criteria*	*Resolution (m)*	*AGL (m)*	*Remarks*
1.	Mesoscale mapping	3000	10 m, 40 m, 60 m, 80 m, 100 m.	For a rough idea of the wind of a bigger geographical area.
2.	Microscale mapping	200		For better understanding of wind of a particular place (e.g. a couple of sqkm).

Table 5.40. Site descriptions for the coastal area of Bangladesh.

SN	*Site Name*	*Coordinates*	*Measurement Period*	*Type of Terrain*
1.	Charfashion	22.18° N, 90.75° E	01 JAN17 - 31DEC17	Near Island, flat
2.	Monpura	22.19° N, 90.95° E		Near Island, flat
3.	Hatia	23.28° N, 85.30° E		Near Island, flat
4.	Noakhali Sadar	22.82° N, 91.10° E		Building, populous
5.	Companigonj	22.82° N, 91.26° E		Coastal and flat
6.	Sonagazi	22.84° N, 91.39° E		Coastal and flat
7.	Sandweep	22.49° N, 91.42° E		Near Island, populous

For a particular area to be taken as a future energy generating site, it needs to understand the nature of wind that flows over there for a long-time basis. Computer generated maps built today is generally a simulated map which goes through a comprehensive validation test using the real wind data from that site the map was built. Mesoscale modeling (MC2) provides important values for studies at the sites selected for wind atlas analysis resolves meteorological conditions within its modeling domain through solving a set of equations describing the atmosphere.

But any kind of scientific analysis demands real and simulated data. In this work, a globally recognized reanalysis database named MERRA2 (Modern Era Retrospective and Reanalysis 2) operated and controlled by NASA (National Aeronautic and Space Administration, USA) estimated on the grid resolution of 1-degree in every 6 hour as climatic input parameters for wind resource assessment has been used to obtain the simulated wind data.

The output from the mesoscale modeling (i.e. WRF), wind speed at 10 m to 100 m at different elevation has been used as virtual meteorological mast at the most promising coastal area for wind energy assessment. The wind characteristics found out from the analysis of mesoscale modeling will be fed into the real data from meteorological tower in order for the consideration of the wind resource analysis in more acute observation.

Table 5.41. Wind speed and power density range for mesoscale map in coastal and near-coastal area of Bangladesh.

Mapping elevation (m)	10	40	60
Wind speed range (m/s)	0.83 - 3.83	2.04 - 4.71	2.32 - 4.89
Mapping elevation (m)	80	100	
Wind speed range (m/s)	2.52 - 5.02	2.45 - 5.31	

The output of MC2 analysis is used to create microscale (MS-Micro) modeling for in-depth analysis of the wind speed of some selected sites which are accompanied by the Weibull probability distribution function (PDF) and wind rose for a full reference year of 2017 calculated form the wind dataset (measured met station data for 2017).

Microscale model output that estimates wind power plants productivity can be used as a reliable source of wind resource in the in the coastal area of Bangladesh.

5.3.2.3. Mesoscale Wind Map

The spatial distribution of the wind resource obtained with the MC2 from mesoscale wind resource maps of 3000 m resolution is presented in this section. The average wind speed for mesoscale modeling at different elevation for coastal and near-coastal area of Bangladesh are produced and is illustrated in figure 5.45. The accumulated wind speed ranges for the maps of different heights are presented in table 5.37.

The results obtained from the mesoscale maps (MC2 modeling) discovers how potential the selected areas are in terms of wind speeds which shows the range of around 1.00-6.00 m/s in varying elevation. At higher altitude, it shows better wind resource in the assessments which demands more in-depth investigation for micro-siting which is usually considered as the process of technical feasibility assessment for wind power development.

5.3.2.4. Microscale Wind Map

MS-micro atmospheric modeling (microscale wind maps) of 200 m resolution is presented in this section. The average wind speed maps for microscale modeling at 10 m, 40 m, 60 m, 80 m and 100 m AGL coastal area of Bangladesh are shown in figure 5.46. The accumulated wind speed ranges for the maps of different heights are presented in table 5.42.

Table 5.42. Wind speed and power density range for microscale map in coastal area of Bangladesh.

SN	Area	Mapping elevation (m)	Wind speed range (m/s)
1.	Near-coastal and coastal region of Bangladesh	10	2.73 - 3.89
2.		40	3.53 - 4.89
3.		60	3.56 - 4.97
4.		80	3.69 - 5.37
5		100	3.83 - 6.37

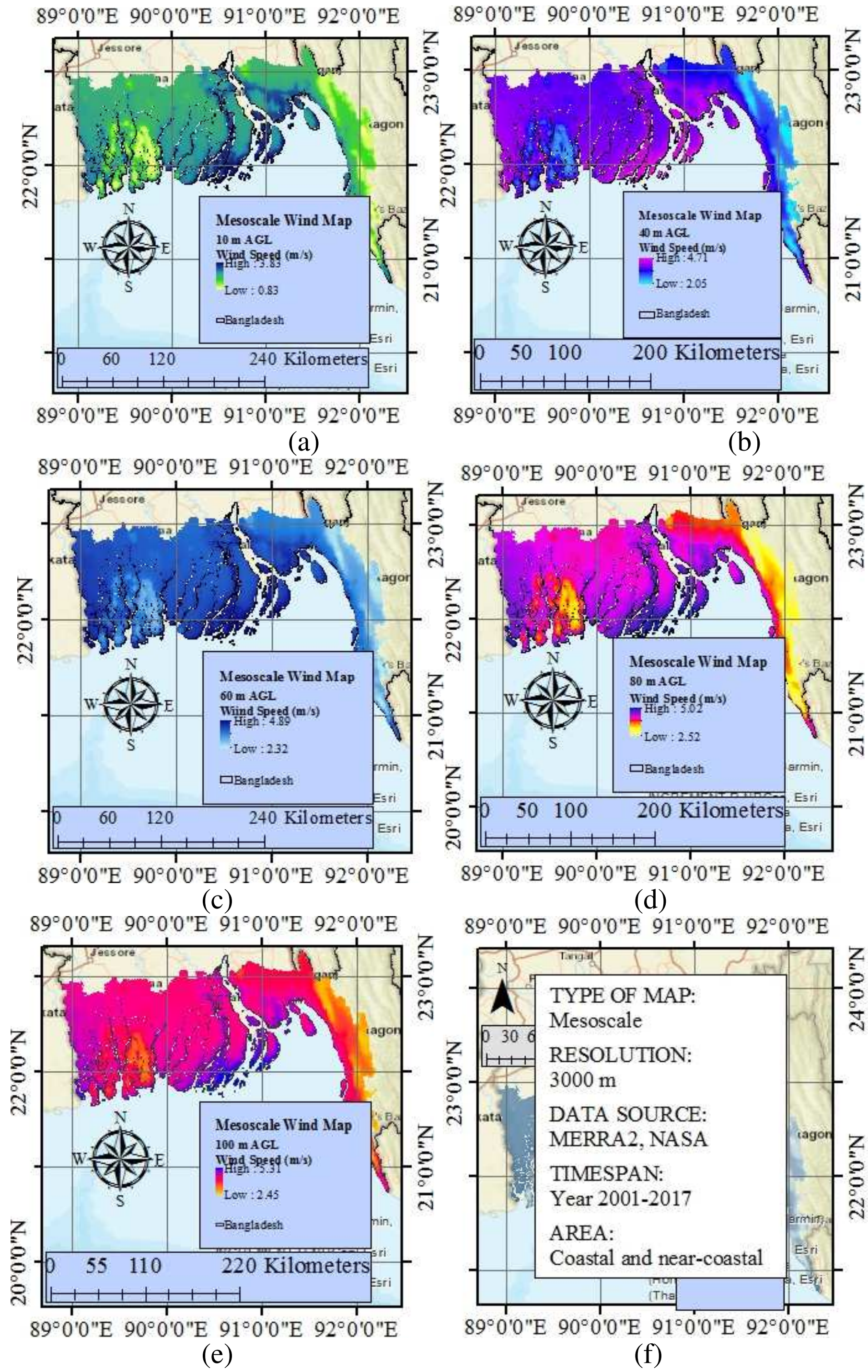


Figure 5.47. Mesoscale wind speed map of coastal and near-coastal area of Bangladesh at (a) 10 m AGL, (b) 40 m AGL, (c) 60 m AGL, (d) 80 m AGL, (e) 100 m AGL and (f) Map details.

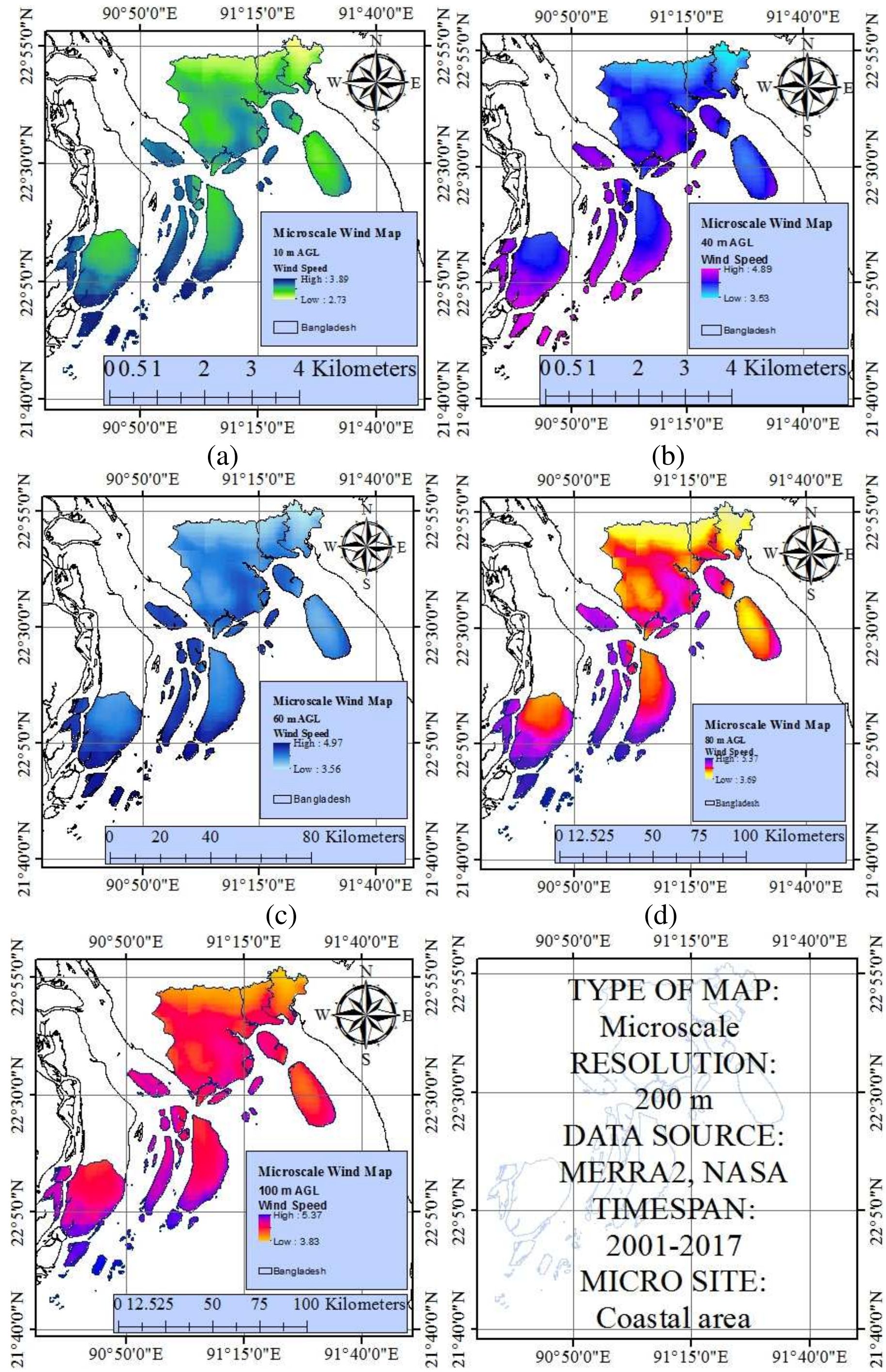


Figure 5.48. Microscale wind speed map of coastal area in Bangladesh at (a) 10 m AGL, (b) 40 m AGL, (c) 60 m AGL, (d) 80 m AGL, (e) 100 m AGL and (f) Map specifications.

The result shown in figure 5.46 and table 5.36 for MS-micro reveals the fact that the wind speeds available in some of the selected area is not viable for power generation. However, the highest wind speed area are to be located for future wind farm development. Table 5.43 shows the wind speed ranges for better potential sites in the coastal area with mean wind speeds in the range of up to around 5.0-6.5 m/s at higher elevation.

Table 5.43. Wind speed range from microscale map for Charfashion and Monpura micro-site.

		Mapping elevation (m)				
SN	*Site Name*	*10*	*40*	*60*	*80*	*100*
		Wind speed range (m/s)				
1.	Charfashion	3.19-3.80	3.89-4.83	4.52-4.93	4.89-5.37	5.43-6.37
2.	Monpura	3.48-3.72	4.24-4.89	4.49-4.97	4.68-5.31	5.17-6.19

Nowadays, commercial wind turbines are available in the market which can operate at low wind regime. As a result, wind speed shown in the selected sites in the microscale maps should eventually be able to get sufficient benefit from wind energy farms. Wind maps produced by this method must need to be fed through independent validation (i.e. mathematical comparison between observed and predicted model) before this is accepted and accessed by the related wind energy society as well as the developers [54].

5.4. WIND TURBINE NOISE ANALYSIS

As stated earlier in this chapter, the research will also analyze the noise emitted from wind turbine. Measuring noise from the turbine at different distances can be shown like the figure 5.37. Noise analysis is necessary for understanding the environment effect that might be caused by wind turbine. Noise from different distance will be measured as per international standard like AWEA 9.1-2009 as well as IEC 61400-11.

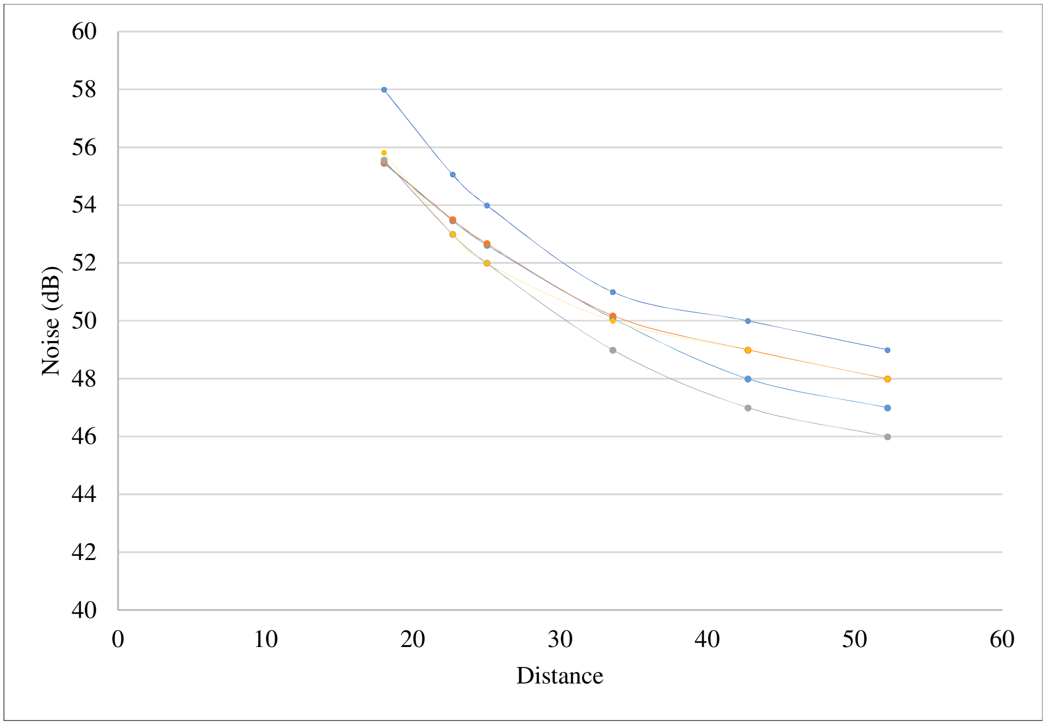


Figure 5.49. Overall noise level as per the standard of AWEA 9.1-2009 at different distances (m) from the rotor center of WTG.

Table 5.44 shows the sample WTG noise levels for different distances between WTG rotor hub to the noise measurement sensor as per the standard.

Table 5.44. Overall noise level at different distances from WT.

Hub Height (m)	WT-Sensor Distance	Distance from Rotor center (R)	Overall noise level at AWEA rated sound level (L_{AWEA}) of 40 dB				
15	10	18	50.48	50.57	50.82	51.5	53.24
	17	23	48.51	48.65	49.03	50.1	52.31
	20	25	47.68	47.84	48.3	49.5	51.98
	30	34	45.19	45.46	46.23	48	51.21
	Background noise level (dB)		30	35	40	45	50
	AWEA rated noise level (dB)		40	45	50	55	

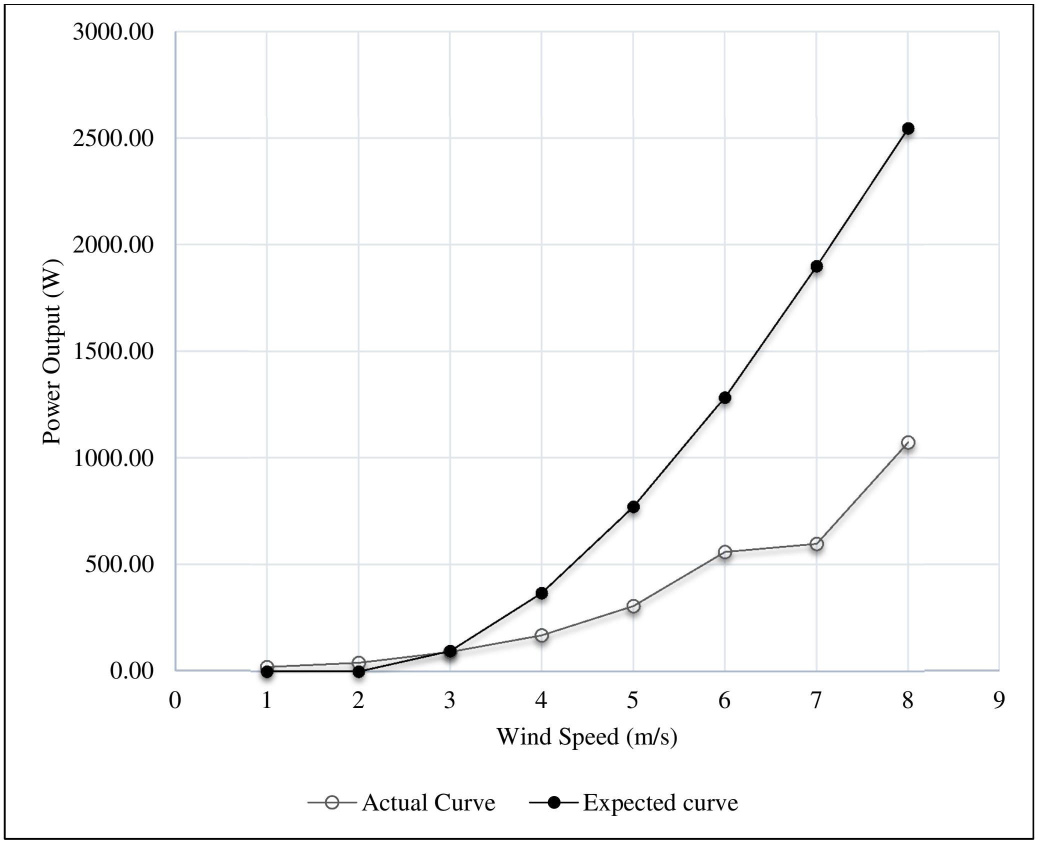


Figure 5.50. Actual (experimental) and expected (WTG specification) power curves.

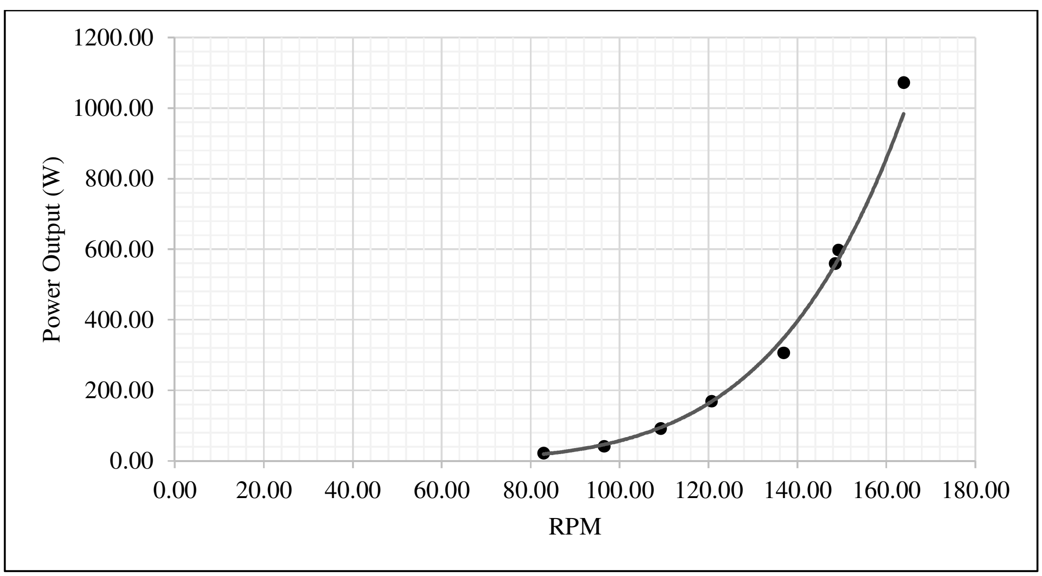


Figure 5.51. Power output according to RPM.

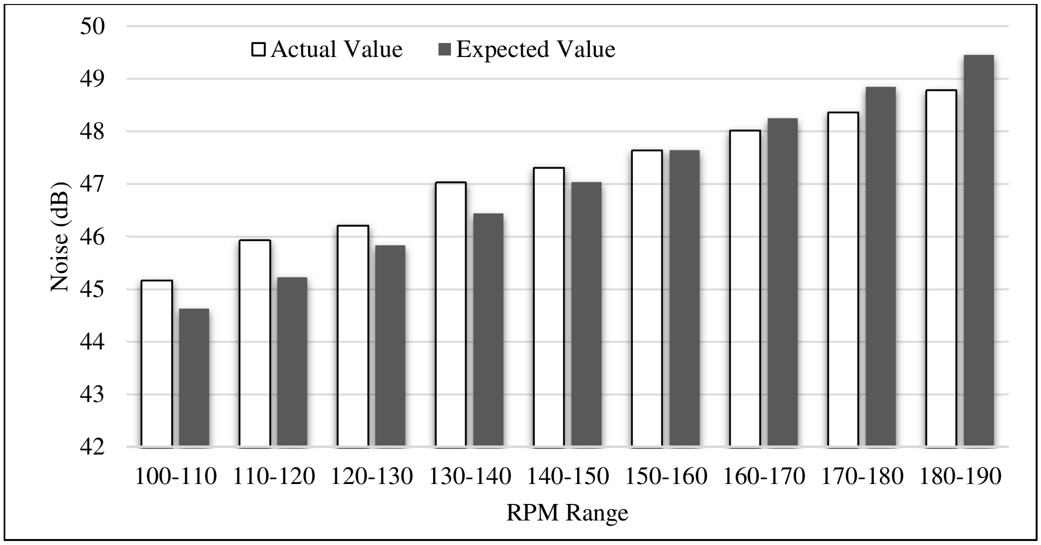


Figure 5.52. RPM-Noise relationship.

Ambient sound can be responsible to mask the sound from WTG. As a result, background noise levels are to be considered. Figure 5.49 shows the actual power produced at various wind speeds by the WTG with also showing the theoretical power in the wind as specified by the WTG manufacturer at these wind speeds. As a part of noise analysis, the power output of the WTG can be correlated with RPM like a sample shown in some figures like figure 5.48, 5.49 and 5.50.

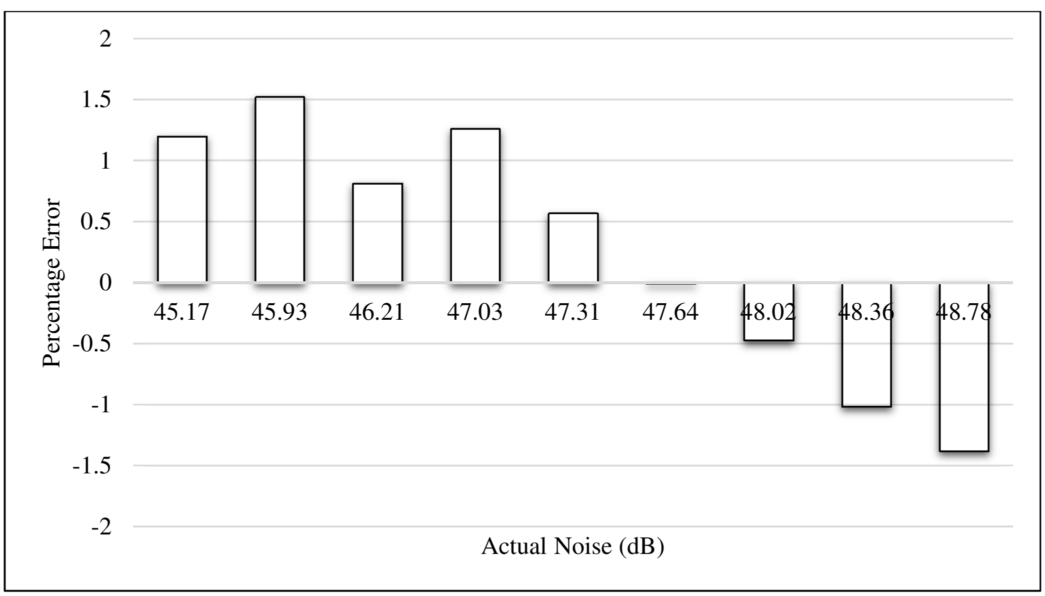


Figure 5.53. Estimation of noise error.

Once this research is done successfully, the outcome of gathered knowledge of wind energy will be able to emancipate itself in the form of sharing, promoting, conferring, and consulting to the respective parties in a form of knowledge transfer for the cumulative betterment of the society. Now the possibility of health hazards that may incur from the noise emitted from the turbine will be discussed as a form of expected output in future. Various research indicates that, exposure to extremely high noise levels can also cause headaches, irritability, fatigue, constricted arteries, and a weakened immune system [231]. A study conducted in Europe, incorporating sixteen sites from Denmark, Germany and Netherlands showed that only 5.40 per cent of the residents felt that the noise from wind turbines as annoying [232].

Table 5.45. Perception of noise due to its rate of increase.

Increase of noise (dB)	1	3	6	10
Level of perception	Insignificant	Just perceptible	Clearly perceptible	Drastically perceptible

Table 5.46. Tolerable limits of wind turbine noise by countries.

Countries	Maximum tolerable noise (dB)			Remarks
	Day-time	*Night-time*	*Sensitive area*	
Sweden	40			
USA		50		Oregon Department of Energy
Denmark	45		40	Special government legislation for wind turbine in residential area.
Germany	50	40		Residential area
Netherlands	50	40		Permitted noise vary with wind speed

This research will indicate that, due to the increase in distance between the WTG tower and the sensor, the noise intensity reduces significantly which is beyond the harmful level of human ear and other sensitive units of human body. Although the limit varies from country to country, most of the countries have strict regulations on the levels of noise emissions permissible in residential localities [233]. For example, the highest permissible noise level from wind turbines in some countries can be shown in table 5.46 which are proved to be safe for human health. It is to be noted that this increment is not all about the health hazard caused by noise emitted from WTG.

Sounds lower than 16 Hz are infrasound whereas higher than 20 kHz is known as ultrasound [234][234] which human hearing does not perceive, and which are not a subject matter of this research. Higher levels of infrasound and ultrasound evoke a feeling of discomfort, and cause harm to human health [236][237]. However, this experiment reveals that, as the distance between the WTG rotor and the noise sensor increases, the captured noise become more close to the background noise as shown in table 5.46 [238]. This means, with the increment of the distance, WTG emitted noise insignificantly influence the total noise level. The inverse linear relationship between the noise intensity and distance with rather invoke more background noise that helps initiating the masking of the WTG noise.

Research indicates that the sound levels of noise, which are higher than 140 dB, evoke pain and may injure hearing organs [239][240]. In the current research on small WTG, the measured noise ranges between 45.17 dB to 48.78 dB which is not responsible for any kind of health issue like this. Health impact due to acoustic pollution form the emitted noise of small WTG which usually is used for standalone power source application in residential places or other selected areas can thus be easily formulated.

5.5. VALIDATION ANALYSIS

The possible validation analysis will check how fine the experimented results match with the expected result. The following two things are points to be noted:

1) Simulated wind speed and power result should reflect the real met data.
2) It needs to check how simulated and real data correlate**.**

The facts of validation analysis are:

1) All simulated and real data meet point should lie on x = y line.
2) Data will be reliable upon how much deviated they are from that line.
3) There is no ideal case.

5.5.1. Machine Learning

A perfectly recorded wind data especially wind speed is important for planning a wind farm for power generation. Wind is an unreliable as well as unpredictable energy source which can greatly affect stability of the energy system and the quality of electrical energy. An error-free or at least more accurate prediction for wind speed is necessary in order to properly integrate and feed the power from a wind farm into the grid power system. As mostly the wind data are recorded from 10 m AGL (considered as international standard), the commercial wind speed at different heights is necessary to know. In this regards, many mathematical models are employed. However, not all the models may be suitable for predicting the wind speed or direction at a particular height. It needs to identify the more accurate method.

Machine learning can serve this case. As *machine learning* emphasizes on the *prediction* based on known properties learned from the training data, it is possible to test the mathematical model that is used for predicting the wind speed at different height.

5.5.1.1. Thailand Wind Speed Time-Series Data Test

Wind data are recorded normally at 10 m AGL by an anemometer of meteorological stations. The WTG installed in a particular site has a defined hub height, typically from 30 m to 100 m. At this height, all the anemometers in the meteorological stations to be setup will be a very expensive task. Consequently, as the wind speed varies in variation of the height, some mathematical functions are used to calculate wind speed at different height from the standard wind speed data (recorded 10 m AGL generally) like power law and logarithm law. Besides this, regression analysis is suitable for the estimation of the wind speed at different heights above ground.

This experiment will see how the mathematical models used for estimating wind speed at different height are suitable.

5.5.1.2. Statistical Analysis

Wind speed data at 10 m AGL has been converted to the wind speed at different height namely, 20m, 25m and 30m AGL using regression analysis. The wind speed is separated into three classes as per the wind speed range- 0-3m/s as low wind, 3-6m/s as medium wind and more than 6 m/s has been considered as high wind speed.

Let us actually eyeball the time-series wind data. A sample of 10 out of nearly 45000 data has been presented here in table 5.47.

Table 5.47. Class-wise data presentation.

No. of Data	*10 m*	*20 m*	*25 m*	*30 m*	*class*
0	1.20	1.40	1.56	1.97	L
1	3.50	3.60	4.13	4.50	M
2	2.30	2.81	3.19	3.70	M
3	2.60	2.80	2.90	3.23	M
4	1.90	2.00	2.00	2.12	L
5	1.40	1.90	2.00	2.10	L
6	4.50	4.90	5.10	5.30	M
7	3.30	3.70	4.00	4.60	M
8	6.10	6.80	7.00	7.10	H
9	3.90	4.20	4.50	4.67	M

Now take a look at a summary of each attribute. This includes the count, mean, the min and max values as well as some percentiles.

Table 5.48. Statistical inferences of the data.

Items	*10 m*	*20 m*	*25 m*	*30 m*
count	44640	44640	44640	44640
mean	1.59	3.76	4.38	5.65
std	1.59	3.19	3.69	4.73
min	0.00	0.56	0.69	0.92
25%	0.00	0.56	0.69	0.92
50%	1.39	3.35	3.91	5.05
75%	2.81	6.19	7.19	9.25
max	7.81	16.22	18.77	24.10

It can be seen that all of the numerical values have the same scale (wind speed in m/s unit). Now take a look at the number of instances (rows) that belong to each class.

Table 5.49. Number of data in each class for 10 m AGL.

class	*No. of Data*
H	213
L	34824
M	9603

It can be viewed this as an absolute count and can be seen that each class has the different number of instances.

5.5.1.3. Data Visualization: Univariate Plots

Let us start with some univariate plots, that is, plots of each individual variable. Given that the input variables are numeric, it can be created box and whisker plots of each.

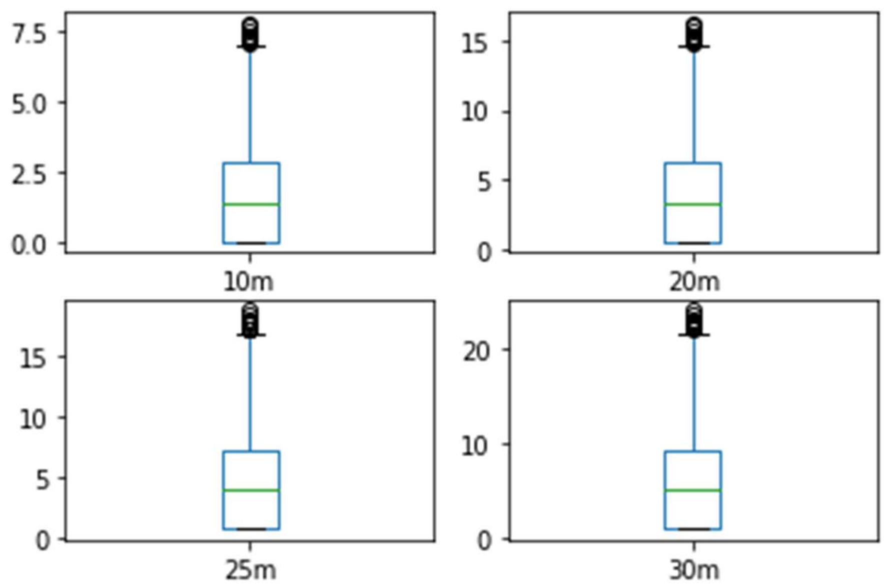


Figure 5.54. Univariate plots for wind speed at different height.

Histogram of each input variable can also be shown to get an idea of the distribution.

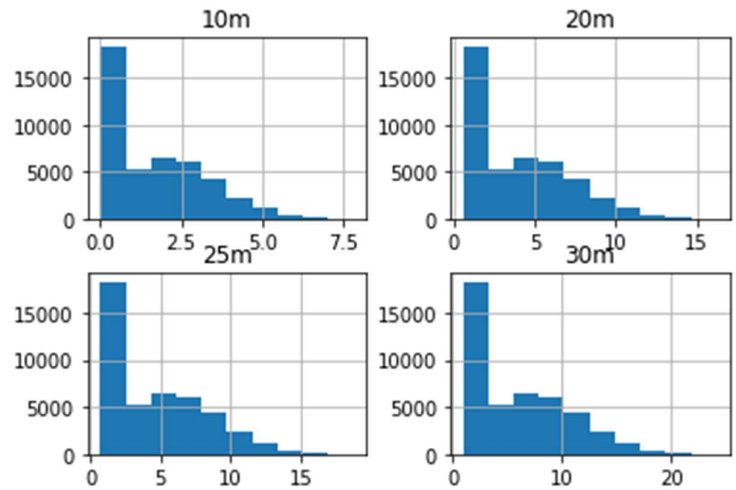


Figure 5.55. Histogram for wind speed data frequency at different height.

5.5.1.4. Evaluation of Some Algorithms

This section will describe how a model is selected from a few models. The steps of the selection procedure which works on data and measure their exactness or accuracy over that unseen data are shown here that needs to cover in this progression:

- Separate out an approval dataset.
- Set-up the test outfit to utilize 10-fold cross approval.
- Build various models to anticipate species from wind estimations
- Select the best model.

5.5.1.5. Create a Validation Dataset

It has to realize that the model that has been made work well and its outcome is acceptable. Afterward, factual techniques will be utilized to assess the exactness of the models that has been made on unseen data. A more substantial gauge of the exactness of the best model on unseen data will likewise be required by assessing it on real data. That is, it will keep down certain information that the algorithms will not see what inside the data are and this data will be utilized to find out about how precise the best model may really be. The stacked dataset will be parted into two, 80% of which will be utilized to prepare, assess and select among our models, and 20% that will be keep down as a validation dataset.

5.5.1.6. Build Models

It is preposterous to expect to know which algorithm would be acceptable for the current problem for begin sure about the designs that is to utilize. Yet, it is to get a thought from the pictures that a portion of the classes are somewhat straightly detachable in certain measurements, so we are expecting commonly acceptable outcomes.

Let us test the following different algorithms:

- Logistic Regression (LR)
- Linear Discriminant Analysis (LDA)
- Gaussian Naive Bayes (NB).

This is a good mixture of simple linear (LR and LDA), nonlinear NB algorithms.

The models and accuracy estimations for each can be presented as follows. It needs to compare the models to each other and select the most accurate.

Running the example above, the following raw results are generated:

Table 5.50. Accuracy rate for the algorithms

LR	0.99	-1E-04
LDA	0.97	-0.002
NB	0.94	-0.004

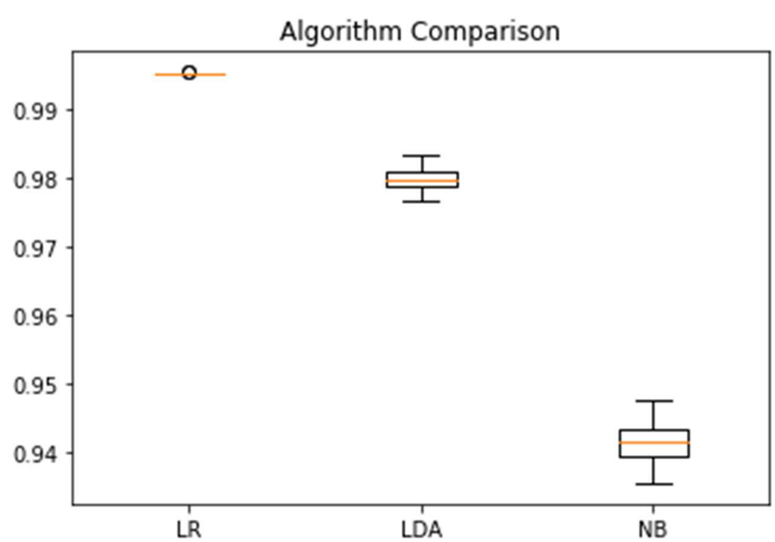


Figure 5.56. Comparison of Algorithm.

```
0.9949
[[   0    0   45]
 [   0 6941    0]
 [   0    0 1942]]
precision    recall  f1-score   support
         H       0.00      0.00      0.00        45
         L       1.00      1.00      1.00      6941
         M       0.98      1.00      0.99      1942
   accuracy                          0.99      8928
  macro avg       0.66      0.67      0.66      8928
weighted avg       0.99      0.99      0.99      8928
```

5.5.1.7. Scores of the algorithms

For this situation, it very well may be seen that it appears as though LR has the largest assessed precision score at around 0.99 or almost 100%. It can likewise be made a plot of the model assessment results and look at the spread and the mean exactness of each model. There is a population of precision measurement for every algorithms in light of the fact that every algorithm was assessed multiple times (through 10 fold cross validation). A valuable way of contrasting the examples of results for every algorithm is to make a box and whisker plot for every distribution and then to compare those.

5.5.2. South Korea Data Test

5.5.2.1. Goodness of Fit with Wind Speed of South Korea

To decide whether a hypothetical PDF is reasonable to portray the wind speed data, a few markers can be utilized.

Table 5.51. Test result for the wind speed for Weibull distribution

Test Method	*30 m AGL*	*50 m AGL*	*80 m AGL*	*100 m AGL*
PMRE	3.47	4.03	4.49	9.15
M/P	1.03	0.96	0.96	1.10
RMSE	0.67	0.71	0.74	0.93
Chi-square	0.007	0.010	0.013	0.075

Table 5.52. Test result for the wind speed for Rayleigh distribution

Test Method	*30 m AGL*	*50 m AGL*	*80 m AGL*	*100 m AGL*
PMRE	0.66	0.03	0.07	6.39
M/P	1.01	0.99	1.00	1.07
RMSE	0.44	0.20	0.26	0.85
Chi-square	0.00	0.00	0.00	0.035

For each wind site and fitting technique, the accompanying pointers were thought of: (1) percentage mean relative error (PMRE), (2) root mean square error (RMSE) and (3) measured versus predicted (M/P). RMSE defines the deviation between the statistically presumed values and the experimental values. The test result can be shown I table 5.51 and table 5.52 for both of the distribution methods.

5.5.2.2. Goodness of Fit with Power Density

To decide whether a specific Probability Distribution Function is appropriate to portray the wind speed data, indicators can be utilized. For each wind site and fitting technique, this work considers power density errors to comprehend the wind power for various seasons for different distribution strategies. The test result for power density error analysis can be shown in table 5.53 and table 5.54 for both of the distribution methods.

Table 5.53. Test result for the power density for Weibull Distribution

Test Method	*30 m AGL*	*50 m AGL*	*80 m AGL*	*100 m AGL*
PMRE	4.13	16.26	1.62	3.72
M/P	1.04	0.86	1.01	1.04
RMSE	1.96	2.93	1.73	2.30
Chi-square	51.67	67.23	79.93	102.91

Table 5.54. Test result for the power density for Rayleigh Distribution

Test Method	*30 m AGL*	*50 m AGL*	*80 m AGL*	*100 m AGL*
PMRE	31.27	31.75	31.44	30.77
M/P	1.45	1.46	1.46	1.44
RMSE	3.26	3.46	3.63	3.90
Chi-square	0.64	10.35	0.14	1.08

The errors are presented as a pictorial view in figure 12 and figure 13.

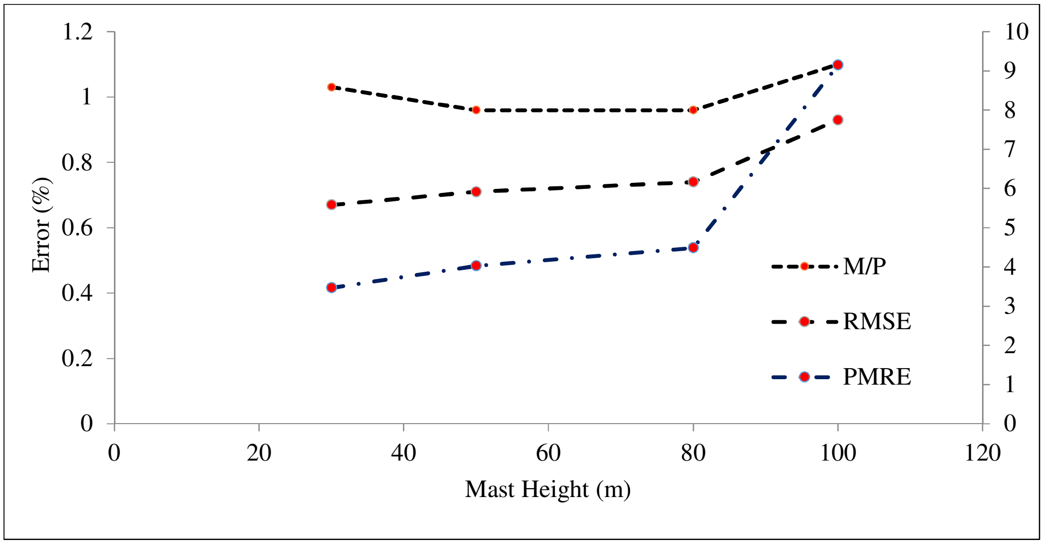


Figure 5.57. Representation of error for wind speed at different height for Weibull distribution.

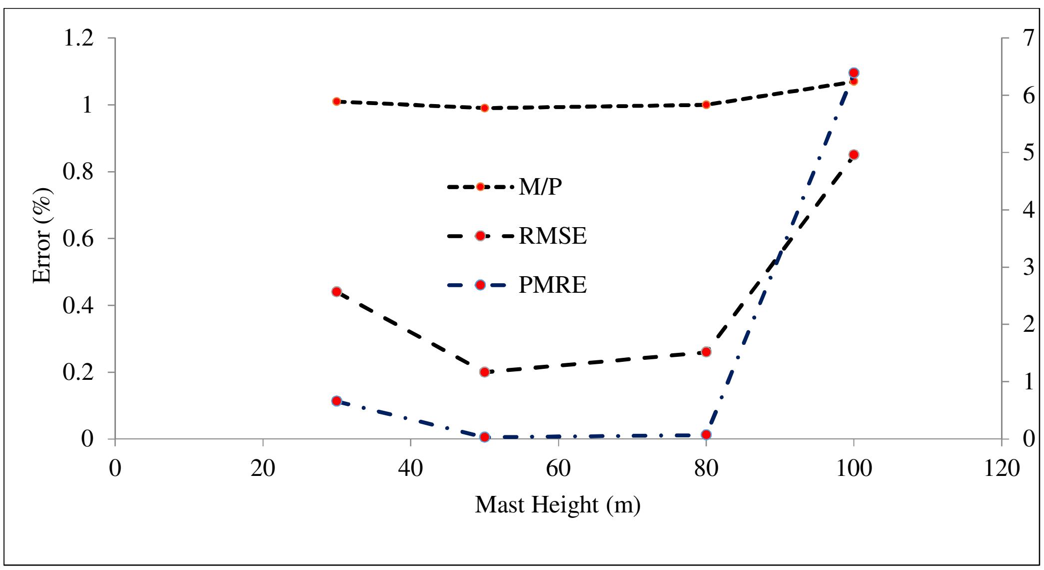


Figure 5.58. Representation of error for wind speed at different height for Rayleigh distribution.

5.5.3. Bangladesh Map Accuracy Calculation

The accuracy of the numerical wind data of wind resource maps were computed by comparing measured wind data. Building a high resolution and accurate wind atlas mostly depend on the quality as well as quantity of both predicted and measured wind data. Each data set used in this research will play an integral role for overall assessment.

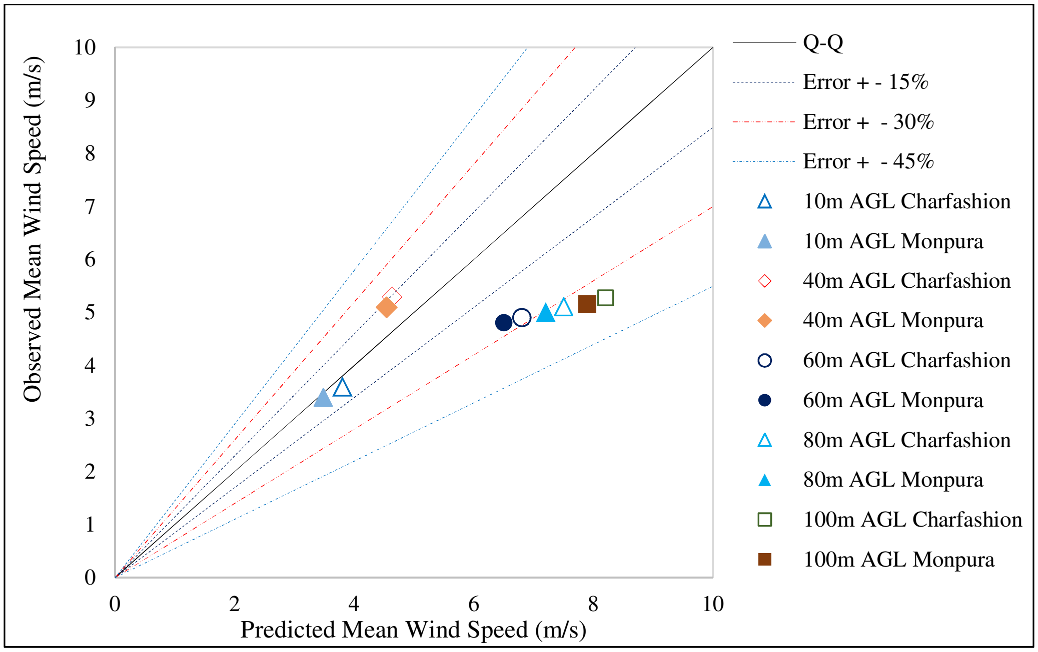


Figure 5.59. Quantile-quantile plot for long-term measured and simulated mean wind speed for two prospective coastal sites named Charfashion and Monpura.

Table 5.55. Validation of the wind resource maps of two prospective coastal area of Bangladesh.

Test Method		*PMRE*	*M/P*	*RMSE*
Area	Charfashion	5.55%	0.95	0.20
	Monpura	2.35%	0.98	0.08

In order to recognize the critical importance of verifying the accuracy of the maps has greatly bolstered the map validation efforts. Wind speed and wind power output from the simulated result should reflect the same weather conditions for when a particular wind site is considered for building power plant. Table 5.55 shows the Measured/Predicted ratio (M/P), Percent Mean Relative Error (PMRE) and Root Mean Square Error (RMSE) obtained for the case of validating the microscale wind resource maps of the coastal area (two promising micro-sites) of Bangladesh. It can be noticed from the values derived for M/P ratio that the real met station data and the simulated data coincide very well as the best case for M/P ratio is 1. PMRE and RMSE both have very small findings which indicates the integrity of the data.

Assessing the accuracy of the wind resource map is important. In this view, observed mean wind speeds and predicted mean wind speeds are presented as a correlation in a quantile-quantile (Q-Q) plot. The Observed-Predicted wind speed data plot line in should be expected to follow the solid line of Q-Q slope which will indicate that the predicted wind speeds are equal to the observed wind speeds. But in practical this does not happen. As a result, error range between 15 and 45% are to be added to understand how much deflected the data are. From figure 5.57, it can be noticed that the predicted and measured wind speed coincide well at 10 m AGL. But as the measured wind speeds are computed for different heights using power law profile, it gives overestimated wind resource data. It has been observes that the errors tend to increase while the heights increase from 40 m AGL to 100 m AGL.

Table 5.56. Q-Q plot statistics for two selected micro-sites (Charfashion and Monpura).

Error Range	Error ±(0-15)%	Error ±(15-30)%	Error ±(30-45)%	Error ±(45-100)%
Percentage	40%	30%	30%	0%

It is very important to determine and to mitigate any kind of test errors, for which a variety of factors may be at work, among which three factors have often been significant: the parameterization of surface roughness, the simulation of the stable boundary layer, and the mesoscale model grid scale [55]. Even if the accuracy is improved, it is unlikely that wind resource maps, whether public or commercial, will eliminate the need for on-site measurements for utility-scale wind generation projects [56].

Presenting wind speed data in $x = y$ line i.e. a Quantile-Quantile plot (Q-Q plot) can be thought of as a good way to understand the reliability of the data, because spatial and temporal correlation is essential for integration studies [57] for wind data analysis. Reanalysis data sets like data from NOAA satellite etc. have many of the same flaws concerning the discrepancy of conditions at geographically proximate locations. In addition, reanalysis data sets often contain substantial biases [58] and have a resolution that is too coarse for integration studies.

5.5.3.1. AEP and Carbon Mitigation

Table 5.51 shows the wind class as per IEC 61400-1:2019 (edition 4). It also gives the rate of measured data recovery for one complete year in 2017. Table 5.53 summarizes the amount of annual energy production for different models of wind turbines as well as the computed capacity factors of each turbine. It is not profitable to produce power at 60 m AGL with low wind speed though there are WTGs found that work on low wind speed. As it has been seen from table 5.58 that, a hypothetical WTG model WinWinD-1/60 gives annual energy amounted to be around 1.70 GWh and 1.07 GWh with a capacity factor of 19.22% and 12.78% in Charfashion and Monpura respectively.

Table 5.57. Wind class as per IEC 61400-1-2 of the selected micro-sites.

Site Name	IEC61400-1 wind class and data recovery rate (%)		
	60 m AGL	*80 m AGL*	*100 m AGL*
Charfashion	Class S (designer sp.) (96.27%)	Class S (designer sp.) (94.56%)	Class IIIB (93.58%)
Monpura	Class S (designer sp.) (77.56%)	Class S (designer sp.) (77.34%)	Class IIIB (77.92%)

For 80 m AGL, this paper chose Goldwind GW155-3.3 MW WTG as a good option for lower wind speed producing more than 10.00 GWh and 8.00 GWh of electricity with a capacity factor of 37.38% and 28.32% respectively.

Table 5.58 AEP for the selected micro-sites.

Site Name	Annual Energy Production (AEP)		
	60 m AGL (WinWinD-1/60)	*80 m AGL (GW155-3.3)*	*100 m AGL (GE 1.6-100)*
Charfashion	1.72 GWh	10.81 GWh	6.22 GWh
Monpura	1.08 GWh	8.19 GWh	4.83 GWh

Table 5.59. IEA composite electricity/heat factors of Bangladesh.

Electricity specific factors (kgCO_2/kWh)	IEA composite electricity/heat factors (kgCO_2/kWh)	Difference (gCO_2/kWh)	Difference (%)
0.63714323	0.5737064	0.06344	11.10%

For the same area, measuring AEP at 100 m AGL with IEC class IIIB wind turbine tested with the WTG model GE1.6-100 has a capacity factor of 43.79% and 34.03% respectively. Energy produced in one year is helpful for the amount of reduction of CO_2 for a single turbine at different height which is shown in table 5.60. According to the estimation of International Energy Agency (IEA) estimating CO_2 emission factors of Bangladesh is given in table 5.59.

Table 5.60. CO_2 emissions reduction for different types of WTG at different heights.

Working Area	Total energy produced (GWh/year) and CO_2 reduction		
	60 m AGL	*80 m AGL*	*100 m AGL*
Coastal (two micro-sites)	2.79 GWh, 1781.69 Ton CO_2/year	18.99 GWh, 12098.54 Ton CO_2/year	11.044 GWh, 7035.03 Ton CO_2/year

The wind power generated can significantly reduce theoretical CO_2 emissions that helps mitigating global climate change which promotes sustainable development throughout the nation and the globe as a whole.

Chapter 6

Conclusions & Recommendations

6.1. CONCLUSIONS

The summary of the proposal can be accompanied by finding answers of the following three questions:

1) What will be the research?
2) Why is this topic?
3) How will this research will be performed?

The easiest answer for the first question is wind energy. In conquest of reducing the level of fossil fuel, this proposal will pay complete attention to work deep on wind energy, which has been a proven field of one of the most prominent fields of sustainable energy sources. The current proposal has thus described all the possibilities and scopes of doing research in wind energy as per the capability and opportunity of the researcher.

1) Global wind energy study
2) Regional wind energy study
3) Research gap study
4) Wind energy policy study
5) Wind Energy potential study
6) Wind Map
7) Wind Turbine Noise

In order for the second question - why is this topic, the answer can be arranged like the following:

1) Sustainability
2) Participation in global carbon reduction movement
3) Scopes for correlation and comparison
4) Proposed wind research might be a good referential resource for furthering the research of this very promising field all over the world.

This research will undergo with measuring the wind potential along with building wind map and WTG noise measurements of a number of countries in Asia-Pacific region, namely Thailand, South Korea and Bangladesh. Finally the answer of the third question can be summed up the following:

1) Statistical analysis of wind
2) Weibull probability distribution function will be used to understand the wind characteristics.
3) A number of statistical methods will have been explained to understand the Weibull parameters. This digs out the idea of which method suits better for the site-specific wind.
4) Time-series data will be analyzed through detailed statistical inference.
5) Wind map of some selected sites incorporating mesoscale modeling with some levels will have been identified with the help of simulated wind data from some prominent online database like MERRA 2.
6) Microscale modeling will be done for some prominent sites after learning from mesoscale if possible.
7) Global climatological database will have been ensured the data for the assistance to build the maps.
8) Mesoscale modeling may be done for a number of heights like 10 m, 40 m, 60 m and 80 m above ground level (AGL).
9) The data from the global database (MERRA online database) can be validated using the real data.
10) Correlation and comparison can be satisfactorily ensured for this research.
11) Proposed wind research might be a good referential resource for furthering the research of this very promising field all over the world.

In conquest of reducing the level of fossil fuel, this research has paid complete attention to work deep on wind energy data analysis, wind mapping technique and machine learning all of which have been a proven field of working with one of the most prominent sector of sustainable energy sources i.e. wind energy. This research has undergone with pursuing some recent techniques of data analysis and wind mapping. In order to understand wind characteristics, the research adopted using WAsP, the most recognized software package for wind energy analysis, along with using ArcGIS having the most prominent environment in working with map. More academic and professional research along the government and NGOs patronization can help creating wind farm in the country where energy issues the most core concern from household necessities to industrial level. This research will help to understand in detail about data and imagery handling from satellite along with maintaining the statistical approach from the met station big data. In addition to it, remote sensing (RS) and GIS application will help to finalize the report through building wind map from data, compilation of geographic data, analyzing and discovering mapping information etc.

In this test of machine learning upon time-series wind data, there gets an opportunity to be discovered step-by-step how to complete this project in Python. It can also be discovered that completing a small end-to-end project from loading the data to making predictions is the best way to get familiar with a new platform. A number of algorithms can be fed into in the data so as to test their accuracy in this environment.

South Korean wind was south to be much better in this regard. The potential of wind in Maldo Island has been estimated as per IEC 61400-12 standard. Minutely wind speed data in time-series format of Maldo Island of Republic of Korea have been explained here. The data were taken for one year from November 2014 to November 2015 recorded in every minute. Statistically analyzed data helped identifying the prospect of wind power of the island. However, the following conclusion might be pointed out:

1) Shape (k) and scale parameter (c) have been determined using graphical method for whole year and three seasons.
2) k and c remain between 1.43 – 1.53 and 3.95 – 4.53 respectively.
3) Mean wind speed of the island remains in the range of 3.76 – 4.45 m/s.
4) Maximum wind power has been obtained in the season of monsoon, which is 249.5 W/m^2.

The aim of the study was to analyze the potential of wind after the data to be found. For the foundation of wind turbines for meeting the daily power needs of the inhabitants of the island may be difficult for mass level electricity production. More research with a couple of year's data might be analyzed for further decision.

In addition to it, 10-minute averages wind speed data in time-series format from January 2017 to December 2017 for Hoenggyeong Island, South Korea have been statistically analyzed based on Weibull probability distribution function. The point of the examination of the part of this work was to research the wind energy of some Island in South Korea with respect to shape and scale parameters of Weibull PDF. The exploration as the outcome has been delivered, proposes that reasonableness of the techniques utilized here may change with the example data size, test data distribution, test data design and so on is a proficient strategy for deciding the k and c parameters to fit Weibull distribution for the wind speed data at Hoenggyeong Island.

Bangladesh wind energy analysis was accompanied with this research. The investigation of the coastal and near coastal wind power potential of Bangladesh through mesoscale and microscale modeling discloses the fact that there are a number of promising locations for wind power development in Bangladesh. The meteorological wind resource data of Bangladesh used for detailed statistical analysis as per the regulations of IEC-61400-12-1 incorporated with mapping technique helped identifying a number of promising sources of wind energy in order for achieving the energy target of the country. Results presented in this work for the investigation of the effectiveness of the MC2 model united with MS-Micro modeling through building wind resource atlas of Bangladesh for both the model specified with the help of simulated seventeen-year (2001-2017) MERRA2/NASA data validates the overall wind resource in the projected region. The distribution function of microscale modeling was done for the coastal part of the country as it was found from the mesoscale modeling that wind speed is this part of the country is higher compared to other part. As a result, coastal wind energy of Bangladesh has been highlighted which is able to add more economic co-benefits through the reduction of the emission of GHGs, especially CO_2 (carbon calculus). A number of virtually tested WTGs with different models and capacity installed for the selected coastal area shows that there are some good micro-sites for commercial power production. The wind resource map in the coastal area of Bangladesh predicted in this work have been validated with apparently located wind mast in the area of the most available and promising wind resource. Correlation and comparison analyses were performed for the checking of accuracy of the data. Proposed wind map can be a good referential resource for furthering the research of the wind profile of Bangladesh. In addition, this research didn't consider the factors other than wind speed as the AHP outcome gave wind speed to be the most important factors for wind farm build-up. But there are lots of opportunities to work with other factors. The final outcome of this work is based on the application of scientific and engineering tools as it approaches and is likely to be able to deal with the wind energy issues in renewable energy and sustainable development sector.

Finally, it can be said that Thailand, South Korea and Bangladesh wind profile is not that much compared to that of countries like Germany, China, and Denmark etc., where wind energy has become a very prominent sector in providing power solution. Though, if compared, South Korea wind is very far better than Bangladesh, and for Thailand, the wind speed is still promising. In Bangladesh, some coastal region might be suitable for wind energy generation as far as the energy potential is concerned. More academic and professional research along the government and NGOs patronization can help creating wind farm in these countries specially in Bangladesh where energy crises is yet to solve even for household and industrial level.

6.2. RECOMMENDATIONS

Because of the wind energy sector being not a homogeneous area but rather is exceptionally assorted, policy measures will be following various procedures and will address various perspectives and partners. The strategy for wind energy ought to reach out from the definition of the final stage of the wind energy frameworks in the drawn out future to the critical drivers of the energy interest and the wind energy proficiency and potentials, a technological analysis of market interest and the market potential, and the particular policy estimates needed to carry out a hypothetical idea in the genuine market place.

The following steps for wind energy policy can be summed up [241]:

- Define the greatest share of carbon financial plan and different targets, achievements, and limitations to accomplish the environmental goal.
- Define wind energy potentials and cutoff points inside a space-constrained environment.
- Identify the monetary and cultural drivers of interest of wind energy and energy as a whole.
- Define wind energy potentials and wind energy prospects by renewable energy administration and service providers.
- Establish timetables and accounts for the innovation execution on the end-user and supply sides.
- Estimate the foundation needs, energy generation costs, and other related impacts.
- Identify the necessary wind energy policies and examine the policy options.

Renewable energy targets are essential to speed up the arrangement of environmentally friendly power sector. Experiences of the previous twenty years obviously show the adequacy of wind energy strategy advancement. The Renewable Policy Network for the 21st Century (REN21) states in their yearly market investigation [242]. The main mediation to speed up wind energy progress can be suggested like the accompanying points:

- Wind energy targets and motivating forces ought to be taken into sharp considerations for their deployment and development.
- Internalization of external expenses by carbon assessment or overcharge ought to be dispatched.
- Phase-out of non-renewable energy source endowments ought to be done.
- Accelerated substitution of petroleum fuel and wasteful innovations ought to be affirmed.

Environmental change prompts various sorts of ecological harm. Fossil fuel byproducts lead to environmental change. Along these lines, it is imperative to put a cost on carbon to disguise the external costs. Carbon-estimating plans can be set up as cap-and-trade schemes or taxes. To make carbon estimating a proficient measure, the cost of carbon should be adequate to reflect the ecological harm it causes and it should be reliable. Therefore, a base cost ought to be executed to give arranging security [243]. Endowments of petroleum fuels check any endeavors to make energy effectiveness and environmentally friendly power competitive. Economic policy measures and the more clear definitions and stringent authorization of global norms will speed up the execution of the best accessible advances in the industry. Both a base cost on carbon and the quick eliminate of petroleum product appropriations should be carried out to help the worldwide energy progress. Strategy support for technology innovation is another significant measure to make the reason for the energy progress measures. Besides working with policy, the following items should be taken into considerations:

- The evaluation of wind energy potential ought to incorporate both the adequacy and effectiveness of alternatives. It is critical to check whether the investigation is capable to getting desired results as a partner with fulfilling the energy needs.
- It is to be checked if the disadvantaged communities are confirmed with low cost of power.
- Wind energy investigation and potential estimations should be considered extensively. For instance, coordinating carbon evaluating and asset estimating inside the general setting is required in accomplishing wind energy outcomes.
- As the cost measures of wind energy are significant, the expansion of the utilization of wind energy whose expenses are presently generally high, it is fundamental for get and keep up the strength of the wind energy facilities to diminish investment risks.
- A legitimate data network among the nations in regional and worldwide way ought to be set up and kept up to empower the sharing of information and discoveries on wind energy and the advancement of best practices [244].

Not far, wind energy will be one of the primary contributor of the execution of environmentally friendly power production all through the globe. In spite of the fact that the current innovative work facilities are still at its rudimentary stages regarding the worldwide production of energy, the response to the worldwide energy challenges will discover viable approaches to examine wind energy in appropriate way just as to carry out it for the mitigation of worldwide carbon to ensure sustainable development.

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APPENDIX

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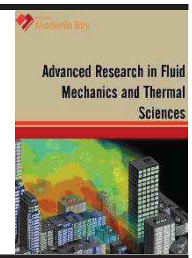
Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Investigation of Small Wind Turbine Noise as per IEC 61400-11 and AWEA 9.1 Standard

Open Access

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ARTICLE INFO

Article history:
Received 22 April 2020
Received in revised form 4 June 2020
Accepted 10 June 2020
Available online 15 August 2020

Keywords:
Small wind turbine; noise analysis; IEC 61400-11; AWEA 9.1; health impact

ABSTRACT

This paper analyzes the noise generated from a 5 kW test wind turbine generator (WTG), having hub height, rotor diameter, cut-in and rated speed of 15m, 4m, 3 m/s and 12 m/s respectively, according to IEC 61400-11 (acoustic noise) standard. It discusses the realistic and comparable performances of small WTG that sets its own characteristics in terms of power and acoustic performances. Standard set by American Wind Energy Association (AWEA 2009) has also been incorporated in this research together with IEC 61400-11. For measuring noise level, the averaging period has been considered to be 10-second as per AWEA 2009. The study attempts to analyze time-series noise data recorded at different distance from the WTG for finding Noise (dB)-Frequency (Hz), RPM-Volt and Noise-RPM relationship. The current analysis done with the help of wind speed histogram bin each of size 1 m/s estimates that, the ranges of RPM, overall noise and background noise lie between 0 - 170, 45.17 (dB) - 48.78 (dB) and 33.2 (dB) - 65.6 (dB) respectively. The correlation between the WTG noise and background noise indicates for the research that the environmental impact due to noise for the WTG is subject to analyze and may not be underrated.

1. Introduction

Concentration of greenhouse gas is increasing due to increase in use of fossil fuels [1-3] causing the whole world to find alternative solution of energy sources. Wind energy being not a new idea or concept is such a kind of source which helps to build a sustainable energy solution by dint of the proper and systematics use of wind energy. For multifaceted energy application, wind has been used from the remote past of human civilization. Recent era has witnessed that, wind has become one of the core concerns of research in energy sector. Concerning about global climate change due to the emission of CO_2 from over-industrialization has been increased after the decisions taken from many of the global summits and conventions like Kyoto Protocol 1997, Paris Climate Convention in 2015

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https://doi.org/10.37934/arfmts.74.2.183195

etc. Generation of wind energy is thereby considered to have greener solution to mitigate the climate problem throughout the globe. Wind as proven to be one of the sources of an optimal power generation system can control CO_2 emissions by 828 g/kWh compared to coal power generation. As far as the wind energy is considered, the emission of pollutants such as CO_2 and CH_4 is 1/50 to 1/100 that of other energy sources, assuming that the wind speed is more than 8 m/s [4].

But the environmental and social issues caused by wind turbine generator (WTG) have also become prominent to work with. Noise defined as any "unwanted sound" [5] emitted from WTG is one of such issues regarding the sentiments of the general public. In the 1980s the first articles regarding noise annoyance from large wind turbines were published by Manning [6] and Hubbard *et al.,* [7]. A close vicinity of WTG in operation produces noise which may be a good reason of public annoyance [8]. Noise gives very indefinable impression to people in variable manners. Noise that may be soothing to one person may make another person crazy [9]. For WTG, noise may come from a number of sources like WTG aerodynamics and its mechanical equipment, though mechanical noise is not considered to be the dominant source of noise from wind turbines [10,11] at its first phase of life-cycle. The rotation of the rotor along with other parts are responsible of emitting mechanical noise, though this kind of noise impact significantly less when environment is concerned. Notable that the rotor of a WTG is connected to a generator that converts mechanical energy into electrical energy [12]. Noise generated for WTG aerodynamics is louder enough to be perceivable by the human ear within a certain decibel level, and the pressure range of noise at which it is heard is a dependent factor. Each wind turbine produces noise from its own character and level depends on many variables taken into account [13].

There is a dependent relationship wind speed and noise emitted by WTG - more the wind blows, more the WTG rotor rotates and more the energy is produced. And one thing is left - more the noise is emitted from WTG. The noise output of a wind turbine generator is universally determined from controlled site tests in accordance with international standard IEC 61400-11 "Wind turbine generator systems - Part 11: Acoustic noise measurement techniques" [14] though different noise emission regulations and standard for wind turbines exist on earth. For example, the German noise standard [15] allows for a sound level of 45 dB, whereas the Dutch noise regulation [16] adjust the allowed turbine limits depending on the wind speed. Again, the British assessment method [17] allows for 5 dB higher turbine sound level L_{Aeq} than the measured background sound levels $L_{A,90}$ at different wind speeds. There are four types of noise generated from a wind turbine in operation: (1) tonal noise which has a discrete frequency, (2) broadband noise which has a continuous frequency, (3) low frequency/infrasound noise e.g. noise below 200 Hz as Lowson [18] and Jhu et.al [19] describe are in fact predominant in the case of emitting noise from WTG generated from the interaction between environment and the turbine blades, and (4) impulsive noise. Notable that, broadband noise is caused by the interaction of boundary layer turbulence with the trailing edge of the turbine blades and is also described as a characteristic "swishing" or "whooshing" sound [20]. Aerodynamic noise is in fact a broadband type noise with having some low-frequency and tonal characteristics. A typical aerodynamic noise from a 2 MW turbine can reach up to the level of 99.2 dBA [21]. But for small WTG, which is the concern of this paper, will also be important to assess the noise frequency and magnitude level for the vicinity of habitats. WTG noise contains less low frequency compared to road traffic noise levels which are considered normal and acceptable [22], yet there are effects to be noted for the emitted noise.

Frequency as well as magnitude are the two major factors that help defining the characteristics of noise. The magnitude of noise can be well explained either in terms of noise power level indicating the acoustic power with which the noise is emitted from the source, and/or noise pressure level indicating the intensity of noise propagated experienced by the listener located at a given point [23].

Though to some extent, the noise propagated from the WTG is masked by the background noise created from trees, forests, buildings etc., the propagated WTG noise needs to be estimated. Masking wind turbine noise has been studied with natural ambient noise and noise from road traffic [24]. Ambient noise level usually increases faster than the WTG noise, thereby increasing the masking probability [25].

Focusing on small scale wind turbine with the capacity of 5 kW is only in the sense that, small wind turbines in generally are meant to be installed near residential areas adjacent to power loads, and much of relevant researches in this respect have been conducted [26,27], this research will investigate the noise generated from WTG through showing the correlation of some related variables like Wind speed, RPM, Volts etc. It will also investigate if the noise emitted from the experimented WTG is a kind of annoyance to the people according to the standard. The research is novel in the sense that it combines time-series noise measurement as per both of IEC 61400-11 standard and AWEA 2009 standard analysis that also tends to deal with environmental issues.

2. Theoretical Analysis of WTG Noise

Wind energy as it is known from the name itself is such a renewable energy source that does not cause environmental pollution, and its use is growing very fast around the world [28] with having been reported that the noise emitted from WTG may cause environmental pollution. The identification and perception of noise varies for different people. But it is well known that, the easiest way to identify the noise from WTG is to let to feel oneself 'how annoying' the noise exactly is, and there are a number of mathematical equations available for modeling the noise emission and propagation from wind turbines [29]. Sound intensity in physics is estimated in decibels and is calculated using the following formula

$$L_I = 10\, log(\frac{I}{I_0}) \quad (1)$$

where I is the measured sound intensity in W/m^2, I_0 is the limitary intensity of sound hearing. It can be expressed as in [30]

$$I = \frac{Power}{Area} = \frac{Energy}{Time*Area} \quad (2)$$

WTG noise data should be declared in accordance with IEC TS 61400-14 and will be defined as

$$L_{WD} = L_W + 1.645 \times \sigma \quad (3)$$

where L_{WD} and L_W are declared noise level and measured noise level respectively according to IEC 61400-11. σ is the standard deviation while measurement uncertainty are taken into account. The other computational method used for noise propagation over land when the noise pressure level L_P at a distance R from a wind turbine, radiating noise at an intensity of L_W is given by [31,32]

$$L_P = L_W - 10\, log_{10}(2\pi R^2) - \alpha R \quad (4)$$

where α is the sound absorption coefficient. For a given noise level of L_P, the sound power P_N expressed in W/m^2 can be approximated as

$$P_N = 10^{\left(\frac{Lp-90}{10}\right)} \tag{5}$$

The research considers the background noise level caused by wind while estimating noise level of small WTG. When the background noise and wind turbine noise are at the same magnitude, the wind turbine noise gets lost in the background [33]. Typical background sound levels range from 35 dBA (quiet) to 50 dBA for urban setting [34]. AWEA attempts to measure the turbine noise level from Eq. (6).

$$WTGNoiseLevel \quad = L_{AWEA} + 10\,log(\,4\pi 60^2) - 10\,log(\,4\pi R^2) \tag{6}$$

After that, once the background noise has been acquired, the overall noise level is measured from Eq. (7) [35,36].

$$OverallNoiseLevel \quad = 10\,log(\,10^{\frac{WTGNoiseLevel}{10}} + 10^{\frac{BackgroundNoiseLevel}{10}}) \tag{7}$$

Theoretically estimated noise level depends on the distance between WTG rotor hub to the noise sensor. There are different absorption coefficient values which are also important to consider to indicate that the impact of atmospheric absorption coefficient cannot be negligible to estimate noise level. In addition to it, it is also necessary to evaluate the fact that in any experimental environment, other noise sources are also available which too are needed to be estimated.

3. Experimental Study

In order to assess the noise from a WTG and to get detailed result, it requires time-series data for a number of operations in terms of maintaining different distances between the rotor hub and the noise sensor. The distance can be measured in a number of ways as suggested by IEC 61400-11. As shown in Figure 1, if hub height is *H*, and the rotor diameter is *D*, then the distance *X* of the position of sensor from the centre of the turbine base mathematically, according to the rule setup by IEC 61400-11, should be *X = H + r*, where r is the radius of the swept are, i.e. *D/2*.

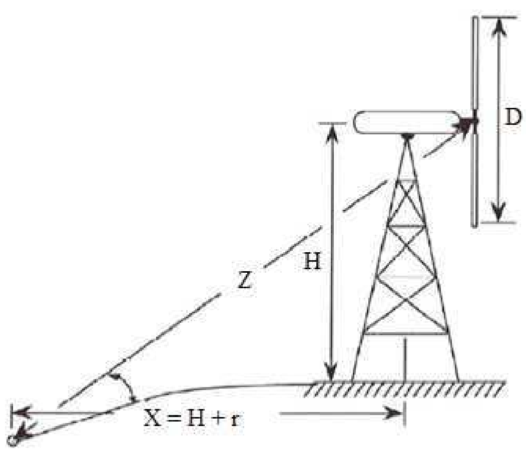

Fig. 1. Measurement scheme of noise through determining the distance between the sensor and the WT [37] (upwind direction)

Correct noise power level can be obtained through the estimation of the noise power from each sensor using the exact distances between the centre of the rotor and the sensor. Another approach is, to consider the distance to be measured from the centre of the rotor to the sensor, *Z*. It should be noted that, the noise of WTG needs to correlate with the wind speed measured at a specified or required height with the help of wind profile power lay shown in Eq. (8) where the reference height *z* must be utilized.

$$U_z = U_r \left(\frac{z}{z_r}\right)^{\varepsilon} \tag{8}$$

$$\varepsilon = \frac{ln(U_z)-ln(U_r)}{ln(Z)-ln(z_r)} \tag{9}$$

The standard measurement height of *z* is in generally accepted to be of 10 m. Practically WTG works in much higher altitude than standard measurement as wind speed increases with the increase in the height. Wind speed near the ground becomes lower and more turbulent due to many obstacles like forest, building, hills, vegetation etc. So it is impractical to commercialize WTG at lower level. That's why it needs to interpolate the wind speed at the reference height *z* to a specific height as per some international standards with the help of mathematical equations like power law profile given in Eq. (8) and (9). More the wind speed is, more is the RPM, and thereby more power is generated from the wind. Eq. (10) represents the power of the wind flowing into the wind turbine rotor [38].

$$P = \frac{1}{2}\rho A V^3 \tag{10}$$

Eq. (11) is the mechanical power output generated by the rotation of the wind turbine rotor.

$$P = T\omega \tag{11}$$

In order to understand the efficiency of the turbine it needs to calculate the coefficient of power, C_p, which is actually the ratio of the power generated by the WTG to the wind power specified by the manufacturer of the WTG. C_p can be conceived as a concept of aerodynamic energy conversion efficiency index. A WTG can never produce the power as specified by the manufacturer. Theoretically, the maximum value of the power coefficient is 0.593 for a horizontal axis wind turbine. This maximum value is known as Betz limit. The Betz limit is derived from actuator disk momentum theory and is the theoretical maximum assuming that the flow is steady-state, in viscid, and irrotational [39]. Normally noise propagation methods use general simplified meteorological assumptions, e.g. constant downwind measures, temperature inversion etc. This research has been conducted on the experiment for the analysis of WT generated noise and influence of background noise with a turbine capacity of 5 kW. The current wind turbine profile used for the research indicates the frequency and volt relationship as 1 Hz equals to 6.2 volt the WT generates. The calculated Hz then will be used to find RPM of the turbine as 1 Hz equals to 4 RPM. Different wind speed was considered to measure the noise with TES 53H noise sensor which is tested and validated for wind turbine noise calculations. For the ease of analysis and to estimate the noise level, two procedures in the research are possible - measurements and predictions, though in terms of noise analysis, predictions are considered acceptable it gives a reasonable accuracy. AWEA defines a number of rated noise level like 40 dBA, 45 dBA, 50 dBA, 55 dBA, all those can sum up from the derivations of the values of WTG Noise Level and Overall Noise Level from Eq. (6) and (7) in order to derive graphs shown in Figure 2 and Figure 3 respectively.

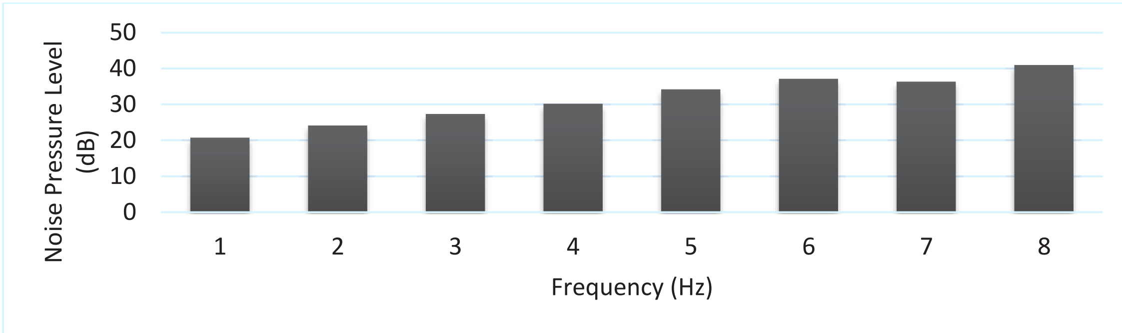

Fig. 2. WT generated acoustic noise spectrum variation different frequency

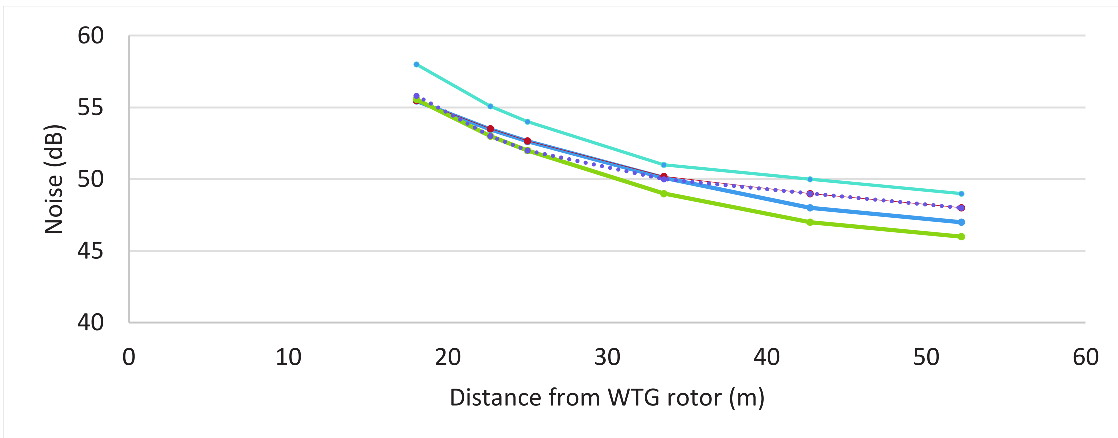

Fig. 3. Overall noise level for AWEA rated noise level of 45 dB at different distances (m) from the rotor centre of WTG

From the obtained experimental research, it may be observed that the noise level of WTG significantly depends on the background noise level. Table 1 presents wind speed at WTG height at reference conditions.

Table 1
Reference conditions

Hub height (m)	15						
Wind speed (m/s)	3	4	5	6	7	8	9

According to AWEA 9.1-2009 section 3.1 (more specifically sub-section 3.1.1 to 3.1.4), WTG noise levels must be measured in accordance with IEC 61400-11 ed.2. But it gives some additional guidance after which Table 2 is presented that displays the WTG noise level at different specified AWEA rated noise levels. AWEA 9.1-2009 specifies that the time-series noise data will be of 10-second averaged instead of 1-minute [34].

4. Results

4.1. Noise Distribution

Wind speed and direction have also been measured directly from the turbine height rather than to use power profile law, and method of bin has been employed to analyse the data as specified by AWEA 9.1-2009. Noise from different distance has been measured as per IEC 61400-11 as shown in Figure 1. Table 2 shows the WTG noise levels for different distances between WTG rotor hub and the noise measurement sensor. Ambient sound can be responsible to mask the sound from WTG. As a result, background noise levels are also to be considered as stated.

Table 2
WTG noise level at AWEA rated noise level of 40dB, 45dB, 50dB and 55dB

Distance, m (WTG Rotor Hub-Sensor)	40dB	45dB	50dB	55dB
18	50.44	55.44	60.44	65.44
23	48.45	53.45	58.45	63.45
25	47.60	52.60	57.60	62.60
34	45.05	50.05	55.05	60.05
43	42.95	47.95	52.95	57.95
52	41.21	46.21	51.21	56.21

It was determined that WTG generated noise level at different wind speed that, when the distance of the sensor from the WTG hub increases, the noise recorded from it becomes more close to the background noise level. The power curve shown in Figure 4 is a 5 kW wind turbine with maximum RPM of 200, cut-in speed of 3 m/s, rated wind speed 12 m/s, which can withstand the wind speed with the maximum value of 60 m/s. Figure 4 shows actual power produced at various wind speeds by the WTG with also showing the theoretical power in the wind as specified by the WTG manufacturer at these wind speeds.

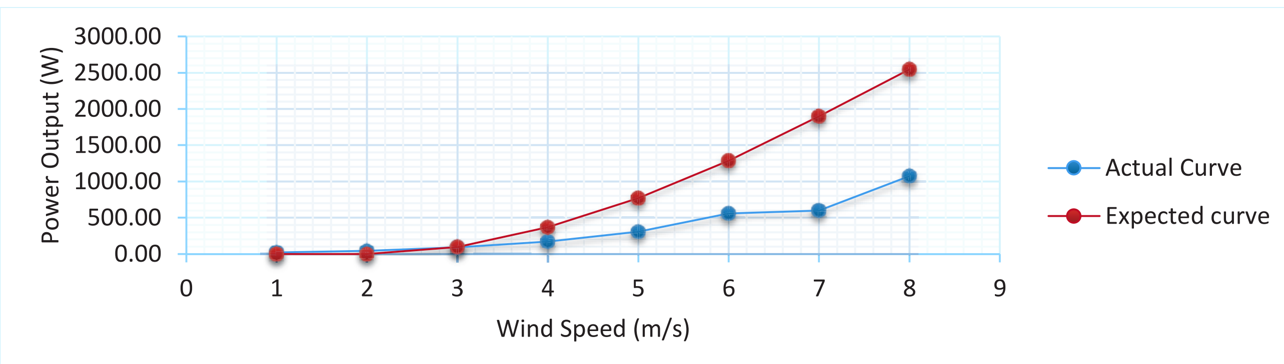

Fig. 4. Actual (experimental) and expected (WTG specification) power curves

4.2. Estimated Error

Table 3 and Figure 5 interpret the values of noise error. The estimated power error can be calculated from experimental findings and the manufacturer specification as identified in Figure 2.

Table 3
Error analysis for bin averaged experimental data

SN	RPM Range	Average RPM	Noise (dB)	Error (%)
1.	100-110	105	45.17	1.19
2.	110-120	115	45.93	1.51
3.	120-130	125	46.21	0.81
4.	130-140	135	47.03	1.26
5.	140-150	145	47.31	0.57
6.	150-160	156	47.64	-0.01
7.	160-170	165	48.02	-0.47
8.	170-180	174	48.36	-1.01
9.	180-190	182	48.78	-1.38

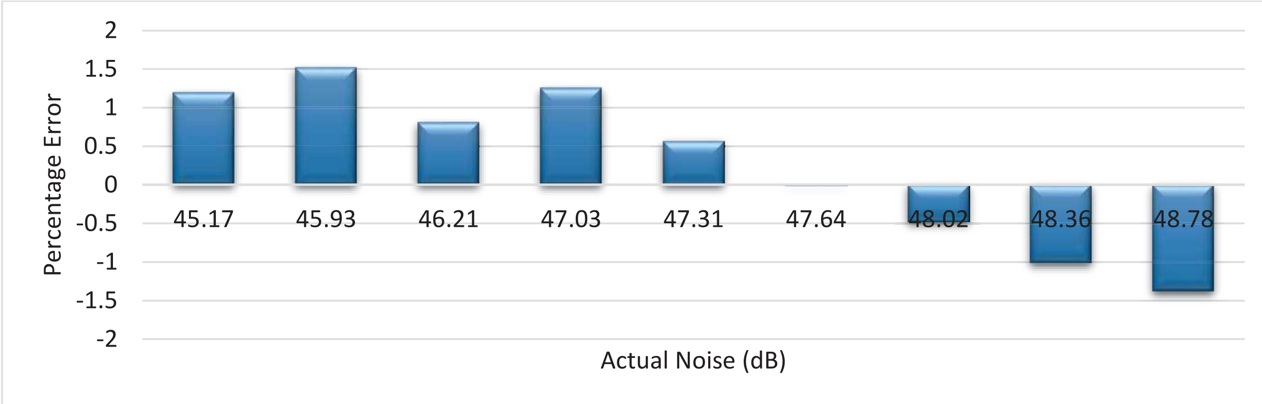

Fig. 5. Noise error from experimental data

The percentage power measurement error is of the wind turbine as specified by the manufacturer shown in Figure 6.

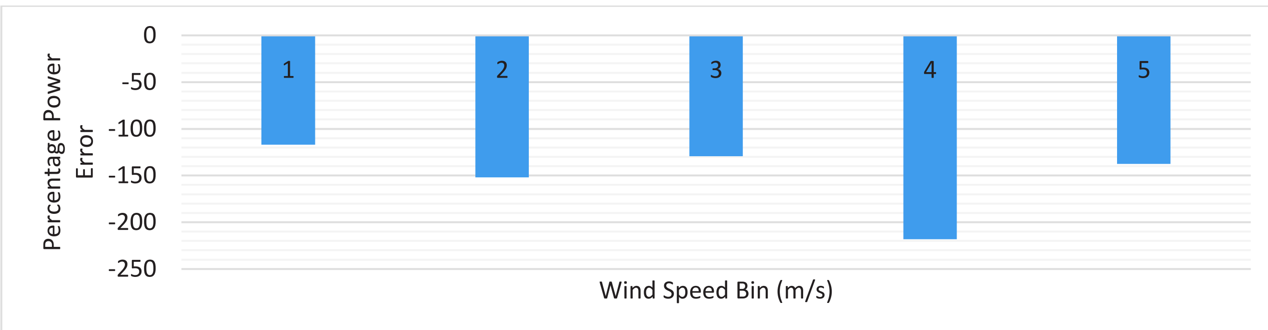

Fig. 6. Percentage error of power measurement according to WTG specification

The cut-in speed of the tested WTG is 3 m/s, and as it is being seen from the Table 3 above that, the power increases as the wind speed increases. The linear relationship of wind speed with RPM is also clear from the table. From 3 m/s as the rated speed, the power output starts generating electrical energy at a rotation speed of 91 RPM. In general, if higher wind speeds are available, the noise generated from the WTG is masked by the background noise. In order to test the performance of the WTG, a number distance was observed. The noise from each distance has been estimated as shown in Table 4.

Table 4
Overall noise level at different distances from WT

Hub Height (m)	WT base-Sensor Distance	Distance from Rotor centre (R)	Overall noise level at AWEA rated sound level (L_{AWEA}) of 40 dB				
15	10	18	50.48	50.57	50.82	51.5	53.24
	17	23	48.51	48.65	49.03	50.1	52.31
	20	25	47.68	47.84	48.3	49.5	51.98
	30	34	45.19	45.46	46.23	48	51.21
Background noise level (dB)			30	35	40	45	50
AWEA rated noise level (dB)			40	45	50	55	

Though, this is a fact that WTG noise may not be heard on the condition that the WTG is emitting a noise at 10 dB lower than the background noise. Coefficient of power declines significantly as the wind speed increases and so does RPM both of which are shown in Table 5.

Table 5
Power output and power coefficient according to wind speed

Wind Speed (m/s)	RPM	Power Output (W)	C_p	Comments
1	82.93	21.71		Before reaching to cut-in speed (3 m/s), WTG produces zero power output.
2	96.50	41.78		
3	109.21	91.38		
4	120.67	169.02	0.46	
5	136.94	306.00	0.40	
6	148.50	559.72	0.44	
7	149.22	597.74	0.31	
8	163.89	1072.25	0.42	

It can be understood from Figure 2 that, the coefficient of power minimizes to 31% during the production of power of the WTG at the wind speed of 7 m/s. In that context, the tested WTG gives a satisfactory output. From the analysis, the power estimation has been done as shown in Figure 7 and RMP-Noise relationship from the actual experimental values as shown in Figure 8.

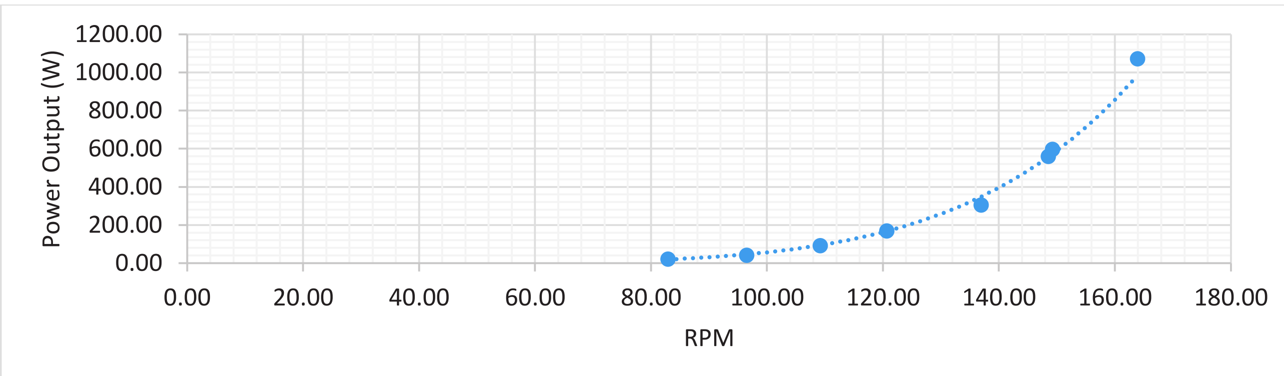

Fig. 7. Power output according to RPM

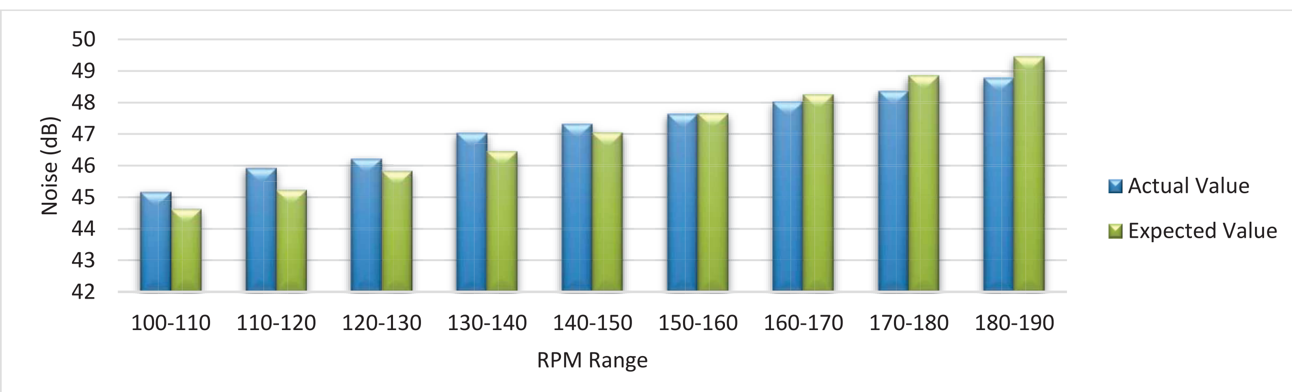

Fig. 8. Noise-RPM relationship for expected value and actual experimental data (bin averaged)

It will be worth to note here that, the most important property of a wind turbine is its power coefficient (Cp) that measures the actual power output generated by the turbine [40]. In general point of view, good quality wind turbines fall in the 35-45% range of the power coefficient level.

4.3 Health Impacts of Noise Exposure

This section will analyse the possibility of health hazards that may incur from the noise emitted from the turbine. Various research indicates that, exposure to extremely high noise levels can also cause headaches, irritability, fatigue, constricted arteries, and a weakened immune system [41]. A study conducted in Europe, incorporating sixteen sites from Denmark, Germany and Netherlands showed that only 6.4 per cent of the residents felt that the noise from wind turbines as annoying [42]. Perceptivity of the noise as per the rate of its increase is shown in Table 6.

Table 6
Perception of noise due to its rate of increase

Increase of noise (dB)	1	3	6	10
Level of perception	Insignificant	Just perceptible	Clearly perceptible	Drastically perceptible

This research indicates that, due to the increase in distance between the WTG tower and the sensor, the noise intensity reduces significantly which is beyond the harmful level of human ear and other sensitive units of human body. Although the limit varies from country to country, most of the countries have strict regulations on the levels of noise emissions permissible in residential localities [43]. For example, the highest permissible noise level from wind turbines in some countries can be shown in Table 7 which are thought of as proven to be safe for human health. It is to be noted that this increment is not all about the health hazard caused by noise emitted from WTG.

Table 7
Tolerable limits of wind turbine noise by countries

Countries	Maximum tolerable noise (dB)			Remarks
	Day-time	Night-time	Sensitive area	
Sweden	40		Not Specified	
USA	Not Specified	50		Oregon Department of Energy
Denmark	45		40	Special government legislation for wind turbine in residential area.
Germany	50	40	Not Specified	Residential area
Netherlands	50	40	Not Specified	Permitted noise vary with wind speed

Sounds lower than 16 Hz are infrasound whereas higher than 20 kHz is known as ultrasound [44,45] which human hearing does not perceive, and which are not a subject matter of this research. Higher levels of infrasound and ultrasound evoke a feeling of discomfort, and cause harm to human health [46,47]. However, this experiment reveals that, as the distance between the WTG rotor and the noise sensor increases, the captured noise become more close to the background noise as shown in Table 6 [48]. This means, with the increment of the distance, WTG emitted noise insignificantly influence the total noise level. The inverse linear relationship between the noise intensity and distance with rather invoke more background noise that helps initiating the masking of the WTG noise.

Research indicates that the sound levels of noise, which are higher than 140 dB, evoke pain and may injure hearing organs [49,50]. In the current research on small WTG, the measured noise ranges between 45.17 dB to 48.78 dB which is not responsible for any kind of health issue like this. Health impact due to acoustic pollution form the emitted noise of small WTG which usually is used for standalone power source application in residential places or other selected areas can thus be easily formulated.

5. Conclusions

This research was conducted with a test WTG having a hub height of 15 m along with a 4 m of rotor diameter, a total distance of 17 m between the sensor and the centre of the base of WT has been ensured as per both IEC 61400-11 and AWEA 9.1- 2009 standard. The following are the summation of the current research

i. International recognized standards ensued in this research suggest to collect data with varying distances for the understanding of the noise.
ii. A total of four different distances between rotor hub and the sensor have been ensured to measure noise data.
iii. Noise data have been analysed as per AWEA rated noise level defined as 40 dBA, 45 dBA, 50 dBA, 55 dBA. WTG noise level for all the defined rated levels has been measured in this research.
iv. Overall noise level has been measured with the aid of AWEA rated background noise.
v. Noise intensity which is a function of wind speed in terms of when WTG noise is analyzed has been experimented in this research with the aid of AWEA rated background noise level.
vi. It was determined that WTG generated noise level at different wind speed that, when the distance of the noise sensor from the center of WTG hub increases, the noise recorded from it becomes more close to the background noise level.

The points outlined above identify that the influence of WT noise on the environment could not be underrated for WTG generated noise level calculation as in this research is corresponding to experimental measurements under natural conditions. The experimental study was accomplished at different distances from the wind turbine hence it may have a very good scope which might be applied for the understanding of noise pollution when wind turbine will be set up for power generation.

Acknowledgement

This work was supported by the Graduate School (research grant of Interdisciplinary Graduate School (IGS)), Prince of Songkla University, Hat Yai-90112, Songkhla, Thailand.

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https://doi.org/10.1121/1.1815091

energies

Article

Wind Energy Analysis in the Coastal Region of Bangladesh

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Abstract: Diversifying the energy mix of Bangladesh is becoming indispensable not only to improve its energy security, but also for a more sustainable economic development. This study focused on mapping the wind potential of southern coastal areas of Bangladesh to estimate the wind energy potential, along with the reduction in carbon emissions due to wind energy. Analysis of the carbon footprint was based on the annual energy production (*AEP*) from the selected low-wind turbine generators (WTGs). The time series-measured and -predicted wind data were incorporated with the high-resolution mesoscale and microscale wind re-source mapping technique at 60, 80, and 100 m above ground level (AGL). Coupling mesoscale and microscale modeling provided reliable mapping results for the commercially exploitable wind resource and was verified by ground-based wind measurement. The results revealed that, among the selected areas, two sites named Charfashion and Monpura have a promising annual mean wind speed of 7.3 m/s at 100 m AGL for energy generation. Different WTGs with ranges of 1–3.3 MW were used to estimate the wind energy generation capacity at different sites in the study area. A WTG with a 1 MW wind energy generation capacity installed at 60 m AGL in the selected site has the potential to produce 2.79 GWh/year of clean energy, reducing 1781.689 tons of CO_2 per year, whereas a 3.3 MW WTG at 80 m AGL can produce 18.99 GWh/year of energy, reducing 12,098.54 tons of CO_2 per year, and a 1.6 MW WTG at 100 m AGL produces 11.04 GWh/year of energy, cutting 7035.028 tons of CO_2 per year. With its reliable scientific and time-tested wind energy estimation method, this research is very important for the development of wind energy in the southern coastal areas of Bangladesh to meet the increasing energy demands through initiating the development of renewable energy to improve the energy security and reduce the carbon emissions of the country.

Keywords: wind energy; wind resource atlas; statistical analysis; carbon footprint

Citation: Islam, K.D.; Theppaya, T.; Ali, F.; Waewsak, J.; Suepa, T.; Taweekun, J.; Titseesang, T.; Techato, K. Wind Energy Analysis in the Coastal Region of Bangladesh. *Energies* **2021**, *14*, 5628. https://doi.org/10.3390/en14185628

Academic Editor: Fausto Pedro García Márquez

Received: 17 July 2021
Accepted: 31 August 2021
Published: 7 September 2021

1. Introduction

Wind energy, along with solar energy, is among the fastest-growing renewable energy sources and destined to become the backbone of the future zero-carbon energy system. Due to fossil-based fuels being a global threat to the existence of humankind, a durable and sustainable energy transition mechanism for energy generation is needed. Wind resources are one of these sustainable energy sources, and estimates can be developed in several ways [1]. To test the potential of a particular area or site, high-resolution wind speed maps have to be developed. Wind resource maps are a tool that hold simulated wind speed data for a given area, which are usually correlated with the real wind speed data recorded from local meteorological stations. Wind maps can help identify potentially promising locations, aid utilities with long-range planning, and assist governments in formulating sustainable energy policy [2].

With increasing installations and technological innovations, wind energy has already become a cheaper alternative to coal and oil as an energy source [3] and is being increasingly considered as a preferred choice for energy production due to its wide accessibility, low investment cost, and so forth [4]. Wind energy, as one of the most productive renewable energy sources, is thus considered for energy generation in both developed and developing countries in order to tackle the growing environmental challenges, such as atmospheric pollution and global warming, while ensuring energy security and justice.

Bangladesh, as a developing economy, fulfills most of its energy requirements from fossil fuels, which are not only responsible for greenhouse gas (GHG) emissions, but also undermine the energy security of the country due to supply shortages, as the fossil fuels are imported from other countries. To meet the growing demand, Bangladesh's government has to import electricity from neighboring countries such as India and Nepal [5]. In addition, natural gas accounts for 75% of the country's electricity generation, followed by coal, which is both expensive and polluting. Bangladesh should opt for diversifying its energy through the induction of local renewable energy sources not only to improve its energy security, but also to decrease its carbon footprint, thereby fulfilling the Sustainable Development Goals (SDGs) proposed by the United Nations at the Paris Agreement (CoP21) in 2015.

The development of wind energy, along with other alternative energy sources such as solar energy, needs to be accelerated in Bangladesh to diversify its energy mix and to relieve the reliance on imported fossil fuels, thereby establishing a pathway toward energy transition. Long-time wind speed data are essential for the development of wind energy projects, but it has been found that the wind speed data recorded by the Bangladesh Meteorological Department (BMD) are not consistent and are high in terms of data analysis for theoretical power generation. Yet, some coastal studies have shown that the mean annual wind speeds are as high as 6.5 m/s recorded at 50 m above ground level (AGL) [6]. Several potential sites with higher wind speeds remain undiscovered due to a lack of sufficient wind speed data. All of the necessary mechanisms are to be employed in these areas so that the potential can be assessed. Bangladesh lacks a comprehensive high-resolution wind resource map, particularly of its coastal and offshore areas, which offer greater wind speeds, which is severely hindering the country's prospects of wind development. A detailed assessment of the wind speeds of Bangladesh's coastal areas through wind mapping and data analysis using different scientific models is thus very important for both de-carbonizing the environment and meeting the country's growing energy demands. As the wind speeds in coastal areas are much higher than across the mainland [7], attention should be given to investigating the coastal areas of the country.

This research is focused on mapping the wind energy potential of the coastal areas of Bangladesh, employing time series wind speed data via reliable scientific techniques to utilize the data for estimating the annual energy production (*AEP*) from different types of low-wind speed wind turbines at different altitudes. The estimation of *AEP* using low-wind speed wind turbines at different altitudes is a novel idea, as it has not been carried out before in Bangladesh. This work also includes a calculation of the carbon footprint, which will play an important role in the global CO_2 mitigation movement. This research is of paramount importance for Bangladesh in terms of energy transition, as it will help the country develop its wind energy resources to expand its energy mix, improve its energy security, and reduce its carbon footprint.

2. Methodology

This study incorporated the most well-recognized and suitable tools and methods. The related mathematical models, along with mapping techniques, are presented in this section.

2.1. Data Sources and Input Data

Wind data from both meteorological stations (where data are usually measured in time series of 1 min averaged data) and satellite (15 years (2001–2015) of predicted data) for the coastal areas of Bangladesh were used in this research. For the measured wind data, there are many instruments in meteorological stations that adopt the process of measuring. Traditionally, a cup anemometer (anemometer is the common name of the instrument used for measuring wind speed) is used for this purpose, comprised of three or four cups usually of conical shape placed on their sides at equal angles, which are then attached to a central mast that allows the cups to spin freely. The cups rotate when the wind blows, and the number of rotations for a specified time is recorded manually or by a computer system, which can then be converted to wind speed data. A sonic anemometer is another option for measuring wind speed, especially in a rough environment. An anemometer is often accompanied by a wind vane, which is used for finding the direction of the wind. The accuracy of the measured wind speed greatly depends on the precision of the anemometer used. However, for this analysis, 1 min averaged wind speed data recorded by BMD using a cup anemometer were used. To accord the analysis with the standard guidelines of the International Electrotechnical Commission (IEC; one of the international standards and conformity assessment bodies for all fields of electrotechnology), named IEC 61400-12-1, the 1 min wind speed data were transferred to 10 min averaged wind speed data using the weighted average method [8], which were then processed and analyzed with suitable computer tools.

2.2. Vertical Extrapolation

A suitable mathematical model was used to calculate the wind speeds at different altitudes above ground. For this purpose, the power law profile, along with regression analysis, were used to compute the wind speeds. This section describes the Hellman's power law profile, which is the most well-recognized and commonly used mathematical formulae to determine the value of the power law exponent α that correlates wind speed at two different levels of altitude. Wind speed data are usually measured from the meteorological stations at a specified height, although other wind speed data are recorded at an unknown height, which is needed to estimate a required height. The exponent of Hellmann's power law α is shown in Equation (1) [9,10].

$$\alpha = \frac{\ln\left(\frac{v_2}{v_1}\right)}{\ln\left(\frac{z_1}{z_2}\right)} \tag{1}$$

From Equation (1), the required wind speed v_2 at a specified height z_2 can be calculated, and the new equation looks like Equation (2).

$$v_2 = v_1\left(\frac{z_2}{z_1}\right)^{\alpha} \tag{2}$$

Wind speed v_2 at any specified and desired height can be predicted using Equation (2), where v_1 is the reference wind speed (m/s), z_1 is the reference height (m), and z_2 is the height where v_2 is calculated. The value of the power law exponent can again be computed using Equation (3) [11].

$$\alpha = \frac{0.37 - 0.088\ln\left(v_{ref}\right)}{1 - 0.088\ln\left(\frac{z_{ref}}{10}\right)} \tag{3}$$

In addition, α also can be estimated using Equation (4).

$$\alpha = 0.37 - 0.088\ln\left(v_{ref}\right). \tag{4}$$

where v_{ref} is the reference wind speed (v_1 in Equation (1)) and z_{ref} is the reference height (z_1 in Equation (2)). The 1/7 power law explicitly uses 0.143 as the value of α, which is sometimes used even though it is not practical for offshore wind. The 1/7 power law usually yields conservative yet reasonable wind power estimates in situations where the roughness length for the projected sites is at least an order of magnitude smaller than the height of the reference level [12]. For offshore wind energy potential analysis, 1/9 is usually recommended for the power exponent value, as it has been found that under neutral stability conditions, the power law exponent value of 0.11 (1/9) provides a good approximation [13]. However, wind speed over different types of roughness of land cannot be estimated accurately using this method. As a result, the power law exponent needs to be estimated from the real wind speed data and other related information if available. However, for the current analysis, α was estimated using Equation (3), as both the reference wind speed v_{ref} and the reference height z_{ref} are known because the reference wind speed is the measured wind speed at a specified height.

2.3. Distribution Function

Wind data collected from meteorological stations usually recorded at 10 m AGL are illustrated by the most well-recognized distribution function of wind speed v, called the Weibull model, which is characterized by two parameters—the Weibull shape parameter k and the scale parameter C [14,15]. Wind speed data distributed as a function of the Weibull probability distribution function (PDF) use Equation (5) [16].

$$f(v) = \frac{k}{C}\left(\frac{v}{C}\right)^{k-1} exp\left(-\left(\frac{v}{C}\right)^{k}\right) \tag{5}$$

The shape and scale parameters of the Weibull PDF are measured using Equations (6) and (7) [17].

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \tag{6}$$

$$C = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \tag{7}$$

where k is the Weibull shape parameter, v_m is the mean wind speed shown in simple terms in Equation (8), and σ is the standard deviation of the wind data, which can be calculated using Equation (9) [17].

$$v_m = \frac{1}{N}\left(\sum_{i=1}^{N} v_i\right) \tag{8}$$

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(v_i - v_m)^2} \tag{9}$$

where v_m is the mean wind speed, v_i is the mean hourly wind speed, and N is the number of measured hourly wind speed data. However, for wind energy calculation, the wind speed is weighted for its power content and is calculated using Equation (10) [17].

$$v_m = \sqrt[3]{\left(\frac{1}{N}\sum_{i=1}^{N} {v_i}^3\right)} \tag{10}$$

The average wind speed from Equation (10) at 10 m AGL needs to be converted to the wind speed at a desired height above ground level using the power exponent law. The wind power density is calculated by considering the calculated air density value in kg/m^3 from Equation (11) [18].

$$P = \frac{1}{2}\rho A v^3 \tag{11}$$

where P is the wind power, ρ is the air density measured in kg/m^3, A is the wind turbine rotor swept area, and v is the mean wind speed. Consequently, power density estimation is carried out using Equation (12).

$$\frac{P}{A} = \frac{1}{2}\rho v^3 \quad (12)$$

The air density is calculated as shown in Equation (13) that uses the ideal gas law equation from the combinatorial relationship of Boyle's Law, Charle's Law, and Gay-Lussac's Law, similarly to Equation (12) [19].

$$B = \rho R_d T \quad (13)$$

where B is the measured 10 min averaged air pressure, ρ is the derived 10 min averaged air density, and T is the measured 10 min averaged absolute air temperature, all of which were measured in S.I. units for this equation to work, using the value of 287.05 J/(kg^{-1}K) as a gas constant of dry air R_d.

These data need to meet the requirements prescribed by IEC 61400-12-1 standard shown in Table 1. In fact, the wind data in the current research were analyzed based on IEC 61400-12-1, because it gives an international standard of the investigation of wind energy in order to promote international cooperation that is concerned about the standardization of the energy fields. If sensors for air temperature and humidity are used, those shall be installed within 10 m of hub height, as prescribed by IEC 61400-12-1 (2017) [20]. The mean wind speed and power density should be measured in terms of both the rule of weighted average and cubic average as per international standards.

Table 1. IEC 61400-12-1 standard requirements for wind data analysis [8].

Requirements	Database Criteria	Status	Remarks
10 min averaged data	10 min averaged data	Pass	
Normalized wind speed data with two reference air density measurements if the site's air density is out of the range of 1.225 ± 0.05	Most of the air density inside the range required by IEC	Pass	Minimum of 65% of air density data are inside the range set by IEC 61400-12-1
Database includes a minimum of 180 h of sample data	Includes more than 8000 h of sample data	Pass	
Each bin shall consist of a minimum of 30 min of data	At least 3 single 10 min averaged data	Pass	

Assessing the economic feasibility for the installation of a WTG for the generation of power, AEP is determined as shown in Equation (14) [21].

$$AEP = 8760 \int_{v_{ci}}^{v_{co}} P_t(v)\, f(v) dv \quad (14)$$

The AEP produced from a WTG is estimated using the power curve of the respective WTG with the help of the frequency of hour of the measured data using the method of bin, the most prominent method for interpreting frequency distribution where the wind data are sorted by the discrete group into some wind speed intervals (usually intervals of 0.5 or 1 m/s). For each bin of the interval, the frequency of the wind speed is counted and then calculated to find the average wind speed. Once the annual energy of one year from the frequency distribution is estimated, the capacity factor (CF) can be calculated using Equation (15) [22].

$$\text{CF} = \frac{AEP}{8760 \times N \times C_R} \times 100\% \quad (15)$$

where AEP is the annual energy production in kWh/year, 8760 is the number of hours in a year, v_{ci} is the cut-in wind speed of the wind turbine, v_{co} is the cut-off wind speed of the wind turbine, P_t is the power output curve of the wind turbine, N is the number of wind turbines, and CR is rated capacity. The CO_2 emissions can be estimated from

AEP using the country-wise carbon emission factor from the simple and straightforward Equation (16) [23].

$$GHG_e = \frac{EF \times AEP}{1000000} \quad (16)$$

where *GHGe* is the estimated reduction in greenhouse gas emissions in tons of CO_2 per year, *EF* is the country-wise emission factor in g/kWh, and *AEP* is the annual energy production in kWh/year.

2.4. Wind Resource Mapping

This section discusses the overall mapping criteria for the study sites detailed herein.

2.4.1. Selected Area

It was found from a primary investigation that, based on the mean wind speed as the foremost priority, followed by heritage and environmental sensitivity, the coastal region of the country falls into the area of interest. Wind resource assessment studies can be placed into three basic categories—preliminary area identification, wind resource evaluation of that area, and micrositing [24].

For this work, the southern part of Bangladesh was taken as the overall region of preliminary investigation, whereas seven selected sites in the coastal area of the country were considered for in-depth analysis. The site-specific information is presented in Table 2. Figures 1 and 2 show the selected working area.

Table 2. Site descriptions.

Area	Coordinates	Measurement Period	Topography
Charfashion	22.18° N, 90.75° E	1 January 2017 –31 December 2017	Near island, flat
Monpura	22.19° N, 90.95° E		Near island, flat
Hatia	23.28° N, 85.30° E		Near island, flat
Noakhali Sadar	22.82° N, 91.10° E		Building, populous
Companigonj	22.82° N, 91.26° E		Coastal and flat
Sonagazi	22.84° N, 91.39° E		Coastal and flat
Sandweep	22.49° N, 91.42° E		Near island, populous

2.4.2. Mapping Technique

This work manipulated a computerized wind resource mapping system, replacing the manual analysis that was conducted before suitable software was developed (previous-era mapping endeavors). Developing final wind resource maps has three steps: (1) preliminary map building, (2) validating the preliminary maps, and (3) revisions of the final maps [25]. Meanwhile, the modeling of the mapping system consists of three components, namely, models, databases, and computer and storage systems [26].

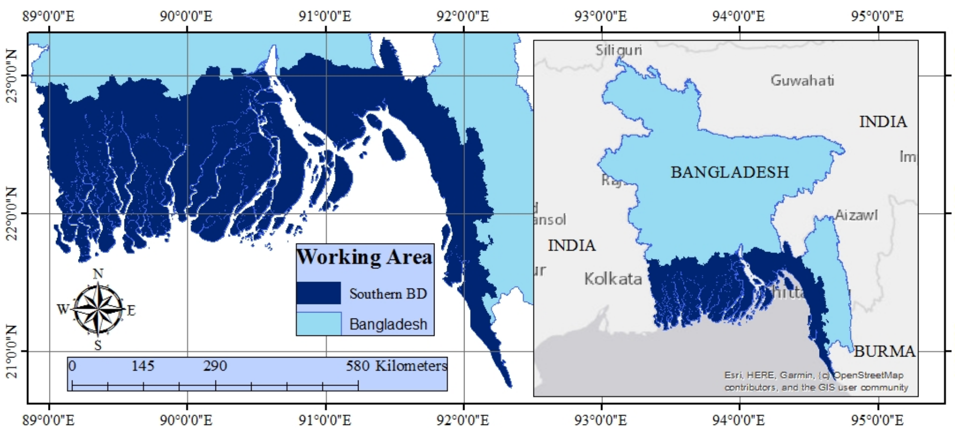

Figure 1. The southern area of Bangladesh for mesoscale modeling analysis.

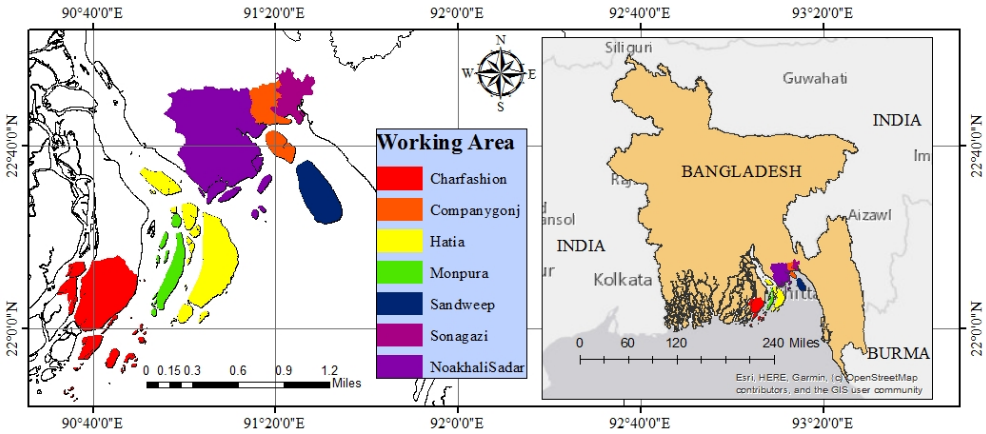

Figure 2. The coastal area of Bangladesh for microscale analysis.

2.4.3. Coupling of Meso- and Microscale Modeling

Though the results are subject to significant uncertainties and thus measurements requiring confirmation of the modeling results [27], mesoscale modeling provides important values for reading the wind speed across a vast area. The meso-field resolves the meteorological conditions within its modeling domain through solving a set of equations that describe the atmosphere, which are the input into what is called microscale modeling. The average meso-field value is transferred and modeled through the microscale, and is thus coupled for finding the wind characteristics. Exploration of the wind resources within this atmosphere, both on a utility-scale and for small-scale applications, increasingly relies on advanced modeling tools and measurement techniques [28]. The output from the mesoscale wind pattern at 10–100 m AGL at different elevations has been used as a virtual meteorological mast in the most promising coastal areas of Bangladesh. The specifications of the meso- and microscale modeling used in this research are presented in Table 3.

Table 3. Wind resource mapping criteria.

Mapping Criteria	Resolution (m)	AGL (m)	Remarks
Mesoscale mapping	3000	10, 60, 80, and 100 m	For a rough idea of the wind of a bigger geographical area
Microscale mapping	200		For a better understanding of the wind of a particular place (e.g., a couple of sqkm)

A horizontal resolution of 3 km was chosen for the mesoscale analysis, because less than this is computationally too expensive and does not necessarily produce a more accurate result. Research suggests that using a grid spacing of 1.1 km for wind mapping does not improve a wind resource compared to a 3.3 km grid [29]. Consequently, a 3 km resolution was considered for the current mesoscale modeling, which is regarded as the most standard resolution value. The output of the mesoscale analysis was transferred to create coupled meso- and microscale modeling for in-depth analysis of wind speed. The Weibull probability distribution function (PDF) and a wind rose graph for a full reference year (i.e., 2017) were calculated from the real one-year (2017) wind dataset. The microscale modeling output that estimates wind power plants' productivity was used as a source for identifying wind resource potential microsites in the coastal area of Bangladesh.

2.5. Validation of the Wind Resource Atlas

To validate the predicted map results, the simulated wind speed data of the map were compared to the measured wind speed. As part of the validation process, several statistical tests were performed. The measured vs. predicted ratio (*M/P*) is the simplest test, which is shown in Equation (17). Derivation of the percent mean relative error (*PMRE*) for the simulated wind speed is shown in Equation (18).

$$\frac{M}{P} = \frac{O_i}{P_i} \tag{17}$$

$$PMRE = \frac{1}{n}\sum_{i=1}^{n}\frac{(O_i - P_i)}{O_i} \times 100\% \tag{18}$$

where O_i and P_i denote the observed data and predicted data, respectively. In addition to the measurement of the performance, the root mean square error (RMSE) was also used, the expected value of which should be close to zero, and is expressed [25,26] in Equation (19).

$$RMSE = \left(\frac{1}{n} \times \sum_{i=1}^{n}(O_i - P_i)^2\right)^{\frac{1}{2}} \tag{19}$$

where O_i and P_i are the observed and predicted wind speed respectively, both measured in m/s, and n is the number of wind data. In addition to the statistical tests, the measure–correlate–predict (MCP) method, a very useful tool by which the predicted wind speeds are correlated with the measured wind speeds, was utilized.

3. Results and Discussion

The results from both the statistical and the mapping analyses are presented in the following sections.

3.1. Data Analysis Outcome

The 10 min averaged wind data in this research were estimated from 1 min averaged met data recorded at 10 m AGL for the selected sites, as per the rule set by IEC 61400-12-1 [8], the statistical findings of which are presented in Tables 4 and 5.

Table 4. Weibull probability distribution function.

Station Name	C(m/s), AGL (m)				k, AGL (m)			
	10	60	80	100	10	60	80	100
Charfashion	4.0	6.8	7.5	8.2	1.9	2.3	2.4	2.5
Monpura	3.8	6.5	7.2	7.9	1.9	2.3	2.5	2.6
Hatia	2.7	4.8	5.4	6.0	1.6	1.9	2.0	2.1
Noakhali Sadar	1.7	3.3	3.7	4.2	1.4	1.7	1.9	1.9
Companigonj	2.5	4.5	5.1	5.6	1.5	1.8	1.9	2.0
Sonagazi	1.9	3.6	4.1	4.6	1.7	2.1	2.1	2.2
Sandweep	4.0	6.8	7.5	8.2	1.9	2.3	2.4	2.5

Table 5. Mean wind speed and power density estimation by WASP.

Station Name	Mean Wind Speed (m/s)				Power Density (W/m^2)			
	10	60	80	100	10	60	80	100
Charfashion	3.6	6.1	6.8	7.3	58	225	296	372
Monpura	3.4	5.8	6.5	7.1	47	194	258	326
Hatia	2.4	4.3	4.8	5.3	21	94	127	164
Noakhali Sadar	1.5	2.9	3.3	3.7	6	33	46	62
Companigonj	2.2	4.0	4.5	5.0	19	83	113	146
Sonagazi	1.7	3.2	3.6	4.1	7	37	53	71
Sandweep	2.4	4.4	4.9	5.4	23	99	134	171

The wind power density distribution was computed using the measured mean wind data. The Weibull distribution is presented for all sites in Figure 3. The sites demonstrated in Tables 4 and 5 and Figure 3 show that all of the areas, except two (i.e., Charfashion and Monpura), are not suitable for power generation.

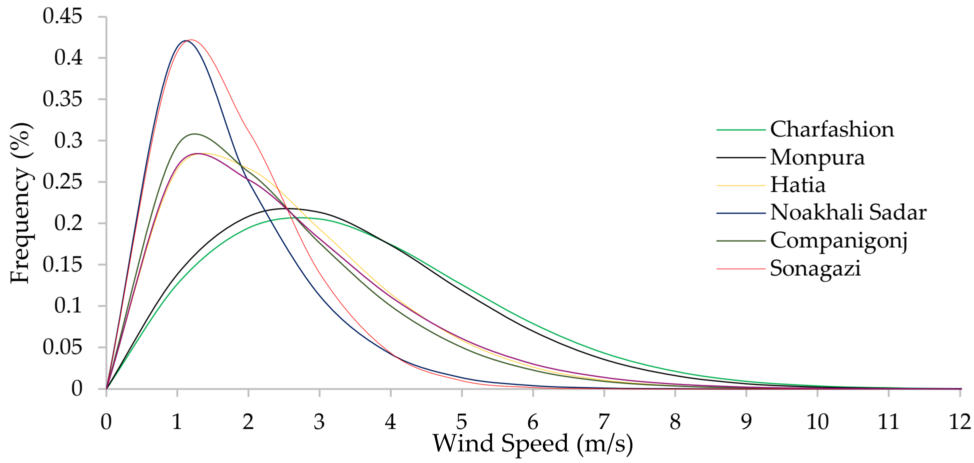

Figure 3. The Weibull probability distribution for the selected coastal sites at 10 m AGL.

The wind speeds of these two sites able to generate power commercially fall into IEC-61400-1 wind class IV/S. The suitable average wind speed for a profitable wind project should be more than 5.00 m/s. For this research, these two sites—Charfashion (5.3 m/s) and Monpura (5.1 m/s)—achieved this value. Several altitudes, such as 80 and 100 m AGL, were tried for estimating the energy from wind. If the height of the wind turbine was set to 100 m AGL, all the sites except for Noakhali Sadar (3.7 m/s) and Sonagazi (4.1 m/s) showed an average wind speed that exceeded 5.00 m/s at this height. As a result, for more details on the probability of wind speed at different wind shear values of the two prominent areas (Charfashion and Monpura), their Weibull PDFs are shown in Figures 4 and 5.

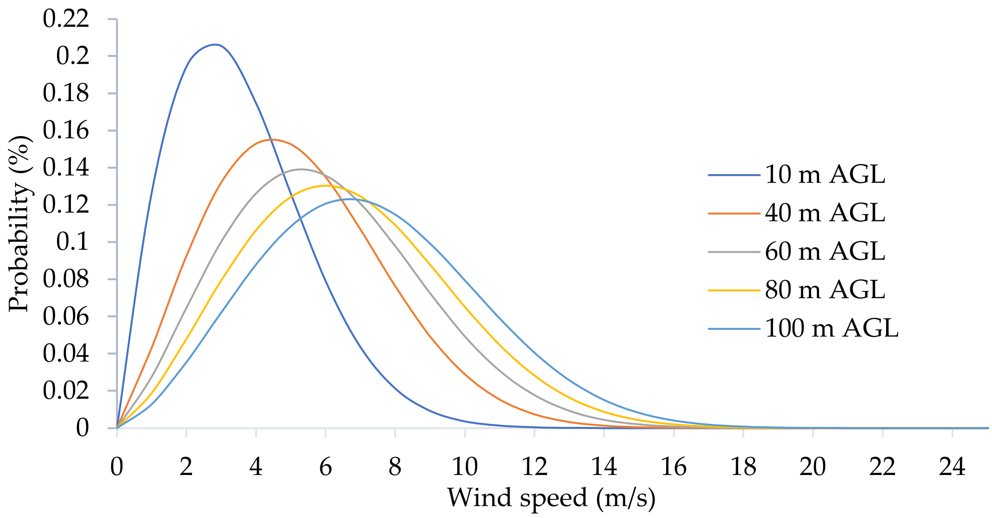

Figure 4. The Weibull probability distribution for the Charfashion site at different wind shear values.

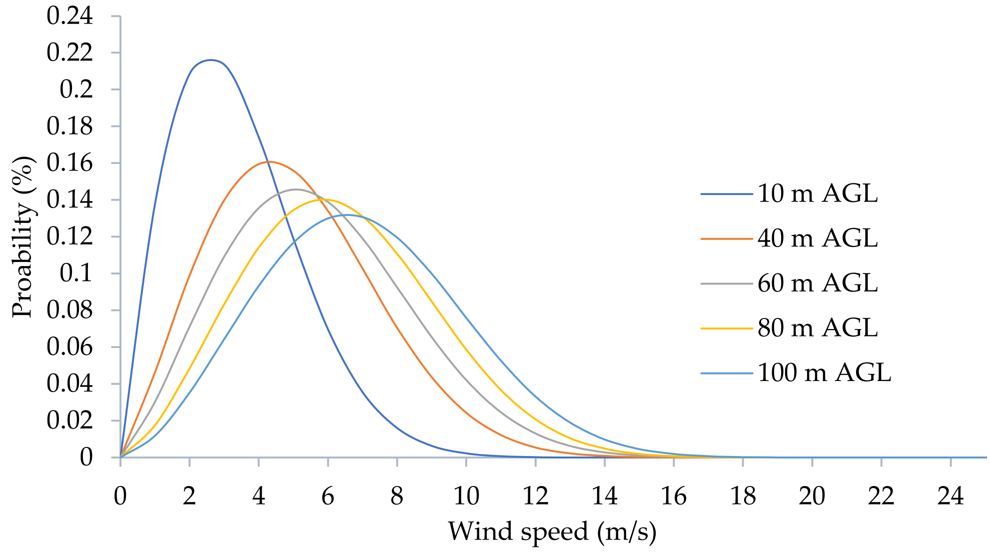

Figure 5. The Weibull probability distribution for the Monpura site at different wind shear values.

From Figures 4 and 5, it can be understood that there is a clear difference between the probabilities of wind speed when its value increases significantly at different wind shear values, which tends to be capable of producing commercial-level power. For a better understanding of the wind characteristics of these two sites, the movement of predominant wind speed must also be visualized through wind rose graphs, which are presented in Figure 6.

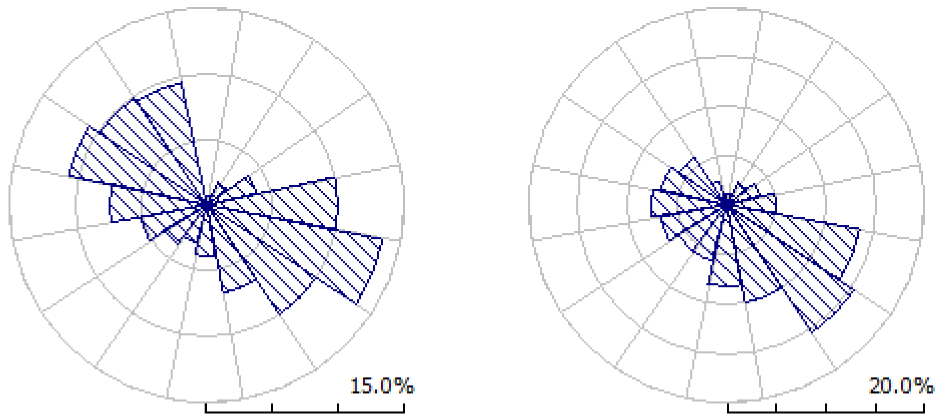

Figure 6. The wind rose for the (**a**) Charfashion and (**b**) Monpura microsites at 10 m AGL.

The power law exponent (PLE) value α, as derived from Equation (3), varies with the varying temperature. The ambient heat influences the atmospheric boundary layer movement and it significantly affects the PLE value. The PLE value is usually higher during the night, as the temperature decreases at night time, causing the wind above the ground to become cooler, thus providing denser air [27]. The diurnal variations for the power law exponent and air density for the two selected sites are shown in Figure 6. Additionally, the yearly average air density of the sites is presented in Table 6, as its calculation is important for the understanding of the varying nature of wind speed at different heights.

Table 6. Average air density for the selected coastal sites.

Area	Charfashion	Monpura	Hatia	Noakhali Sadar	Companigonj	Sonagazi	Sandweep
Air density (ρ, kg/m^3)	1.179	1.177	1.175	1.176	1.178	1.174	1.173

It is important to consider the recorded or mathematically calculated air density and thus the PLE values from the real temperature, as well as the pressure, for the estimation of the true wind speed of the selected sites, which was performed in the current analysis, as shown in Table 6 and Figure 7.

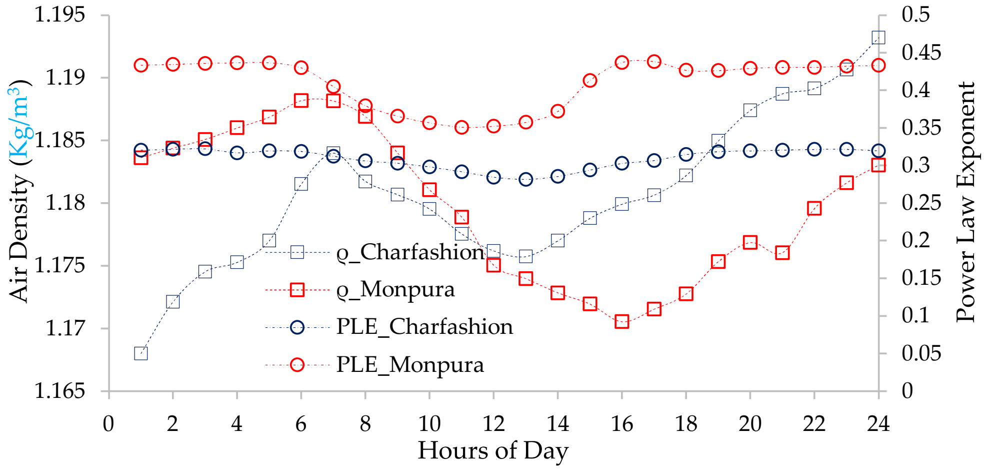

Figure 7. The diurnal variation of the power law exponent (PLE) and the air density of the Charfashion and Monpura microsites.

The standard value of air density considered for dry air, which is 1.225 kg/m^3, should be ignored, as the values of temperature and pressure vary at different heights in a particular site, which importantly affects the wind speed.

3.2. *Wind Resource Maps*

This section presents the mesoscale and microscale maps of the southern and coastal regions of Bangladesh.

3.2.1. Mesoscale Wind Map

The spatial distribution of the wind resources obtained from the mesoscale wind resource maps of a 3000 m resolution are presented in this section. The average wind speed for the mesoscale modeling at different elevations for the coastal and near-coastal areas of Bangladesh is shown in Figure 8. The accumulated wind speed ranges for the maps of different heights are presented in Table 7.

Table 7. The wind speed ranges of the mesoscale maps of the coastal and near-coastal areas of Bangladesh.

Mapping Elevation (m)	10	60	80	100
Wind speed range (m/s)	0.83–3.83	2.32–4.89	2.52–5.02	2.45–5.31

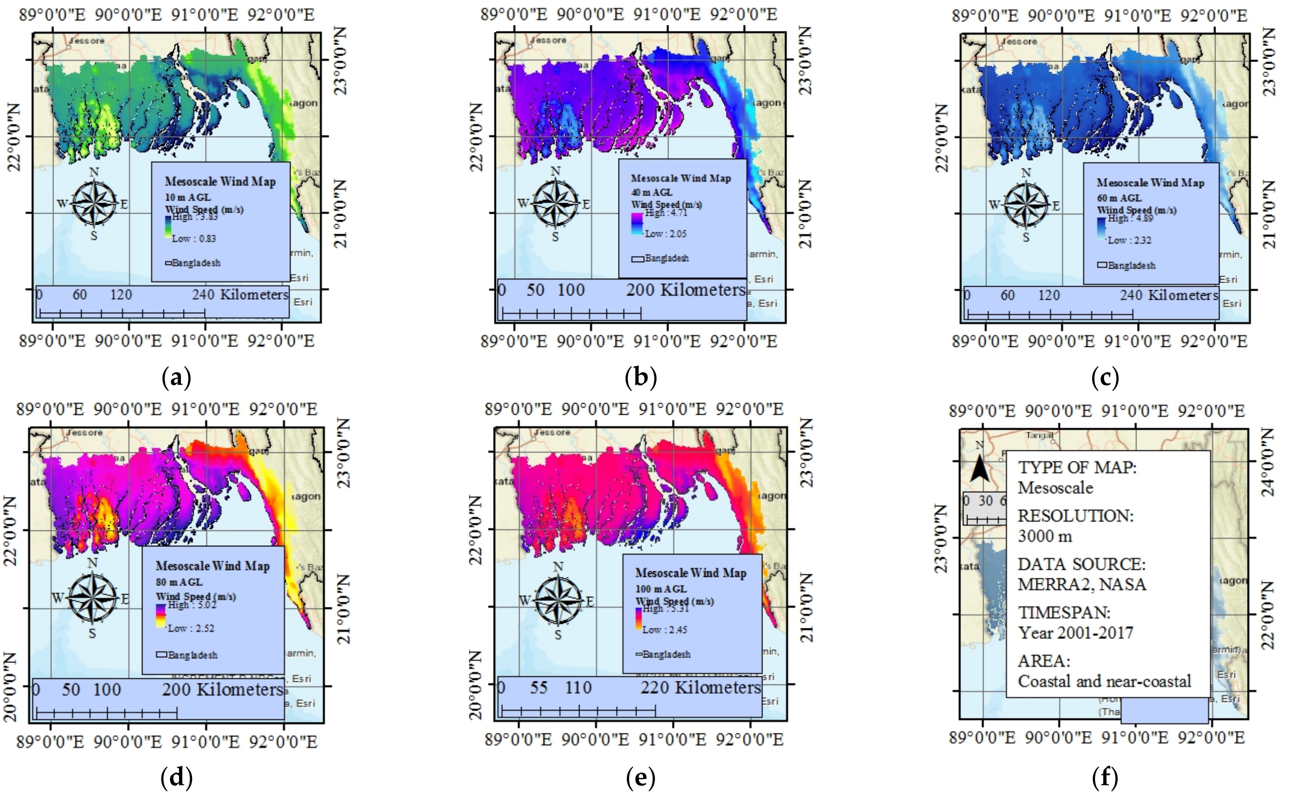

Figure 8. Mesoscale wind resource maps of the coastal and near-coastal areas of Bangladesh at (**a**) 10 m AGL, (**b**) 40 m AGL, (**c**) 60 m AGL, (**d**) 80 m AGL, and (**e**) 100 m AGL and the (**f**) map specifications.

The results obtained from the mesoscale map indicate the potential of the selected areas in terms of wind speed, showing a range of around 1.0–6.0 m/s at varying elevations. At a higher altitude, better wind resources were observed in the assessments, thus demanding a more in-depth investigation for micrositing, which is usually considered as the process of a technical feasibility assessment for wind power development.

3.2.2. Microscale Wind Map

The microscale wind maps of a 200 m resolution are presented in this section. The maps for the coastal area of Bangladesh are shown in Figure 6. The accumulated wind speed ranges for the maps of different heights are presented in Table 8. The results shown in Table 8 and Figure 9 for the microscale analysis reveal the fact that the wind speeds available in some of the selected areas are not viable for power generation.

Table 8. The wind speed range for the microscale maps in the coastal area of Bangladesh.

Area	Mapping Elevation (m)	Wind Speed Range (m/s)
Coastal area	10	2.73–3.89
	60	3.56–4.97
	80	3.69–5.37
	100	3.83–6.37

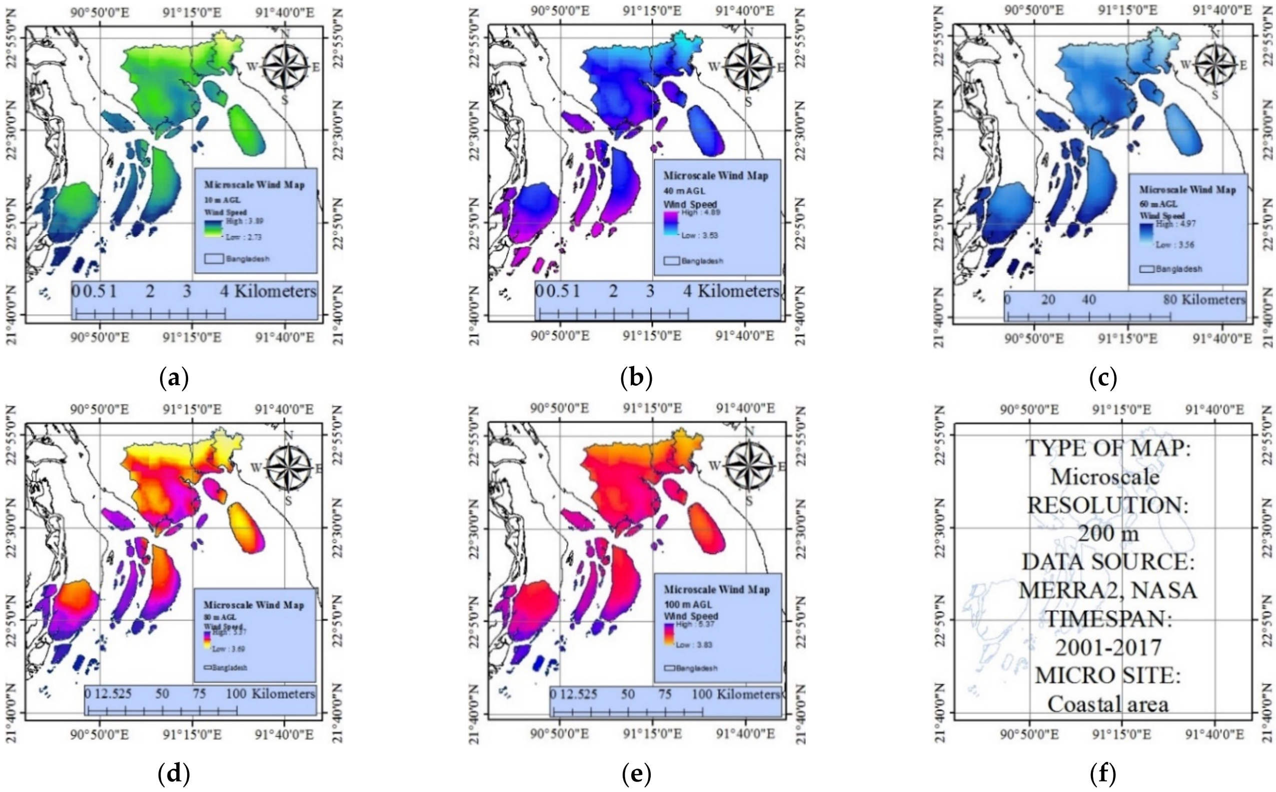

Figure 9. Microscale wind resource maps of the coastal area in Bangladesh at (**a**) 10 m AGL, (**b**) 40 m AGL, (**c**) 60 m AGL, (**d**) 80 m AGL, and (**e**) 100 m AGL and the (**f**) map specifications.

However, the highest wind speed area is to become the location for future wind farm development. Table 9 shows the wind speed ranges for better potential sites in the coastal area, with mean wind speeds in the range of up to 5.0–6.5 m/s at a higher elevation. Nowadays, commercial wind turbines are available on the market, which can operate at low wind regimes. As a result, based on the wind speeds shown in the selected sites in the microscale maps, sufficient benefit from wind energy farms should eventually be obtained.

Table 9. Wind speed ranges from the microscale maps of the Charfashion and Monpura microsites.

Site Name	Mapping Elevation (m)			
	10	60	80	100
	Wind Speed Range (m/s)			
Charfashion	3.19–3.80	4.52–4.93	4.89–5.37	5.43–6.37
Monpura	3.48–3.72	4.49–4.97	4.68–5.31	5.17–6.19

The two selected prominent wind energy sites identified from the microscale wind modeling are capable of producing sufficient wind energy.

3.2.3. Map Accuracy Calculation

The accuracy of the numerical wind data of the wind resource maps was computed by comparing the measured wind data.

Building a high-resolution and accurate wind map relies upon the quality of both the anticipated and estimated wind data. To confirm the precision of a map and whether the map validation process is supported, the same weather conditions should be mirrored when a specific wind site is considered. The validated results are shown in Table 10.

Table 10. Statistical tests for the two prospective coastal areas of Bangladesh.

Test Method		PMRE	M/P	RMSE
Microsites	Charfashion	5.55%	0.95	0.20
	Monpura	2.35%	0.98	0.08

It can be noticed from the values derived for the M/P ratio that the real met station data and the simulated data coincide very well, as the best case M/P ratio is 1. The PMRE and RMSE both have very small values, which indicates the integrity of the data. Assessing the accuracy of a wind resource map is important; in light of this, the observed and predicted mean wind speeds are presented as a correlation in the quantile–quantile (Q–Q) plot. The observed–predicted wind speed data plotline should be expected to follow the solid line of the Q–Q slope, indicating that the predicted wind speeds are equal to the observed wind speeds. However, in practice, this does not happen.

As a result, the error range of the occurrences of points indicating the observed-predicted scenario between 0 and 15%, 15 and 30%, and 30 and 45% were added, as shown in Table 11 for understanding how deflected the data are from the ideal line (Q–Q line). The findings shown in Table 11 are well explained in Figure 10, where it can be noticed that the predicted and measured wind speeds coincide well at 10 m AGL. However, as the measured wind speeds were computed for different heights using the power law profile, overestimated wind resource data were provided, which tend to fall far from the Q–Q line. It was observed that the errors tended to increase when the heights increased from 40 to 100 m AGL, and thus determining and mitigating these kinds of test errors are very important. Regardless of whether the precision is improved in wind maps, the requirement for site-specific precision for utility-scale wind energy estimation is undeniable.

Table 11. Q–Q plot statistics for the two selected microsites (Charfashion and Monpura).

Error Range	Error ± (0–15)%	Error ± (15–30)%	Error ± (30–45)%	Error ± (45–100)%
Percentage	40%	30%	30%	0%

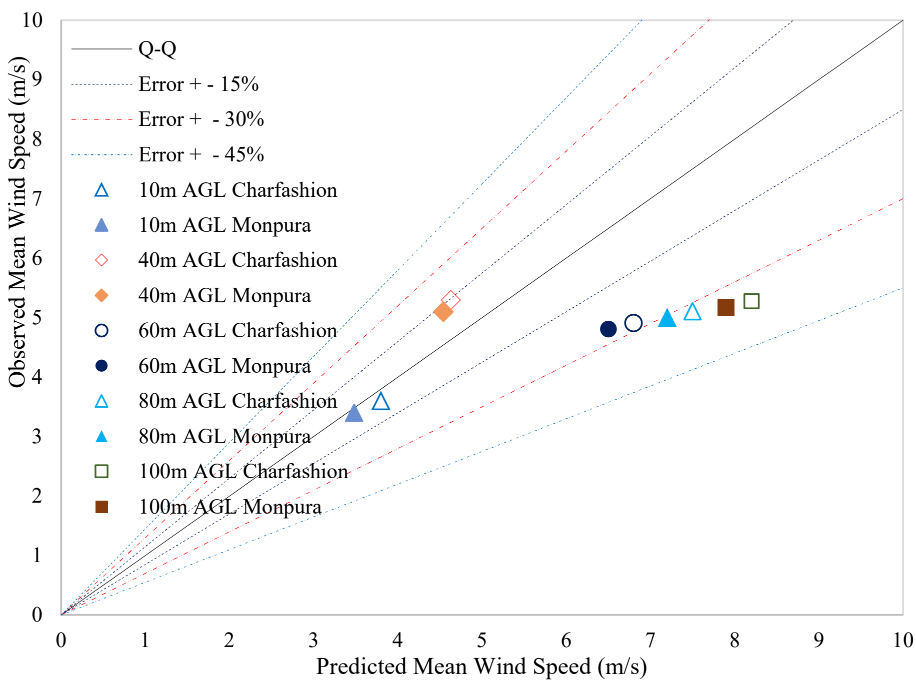

Figure 10. Quantile–quantile plot for the long-term measured and simulated mean wind speeds of the two prospective coastal sites (Charfashion and Monpura).

Presenting the wind speed data in $x = y$ line, i.e., a Q–Q plot, can be thought of as a good way to understand the reliability of the data. It should be noted also that although spatial and temporal correlation analyses are essential for overall wind data analysis, the simulated reanalysis datasets from satellites, etc., also have many shortcomings and flaws concerning the discrepancy of the conditions at geographically proximate locations.

3.2.4. Annual Energy Production (*AEP*) and Carbon Mitigation

Table 12 shows the wind class as per IEC 61400-1:2019 [30]. It also provides the rate of measured data recovery for one complete year (i.e., 2017). Table 13 summarizes the amount of annual energy production for different wind turbine models, as well as the computed capacity factors of each turbine. It is not profitable to produce power at 60 m AGL with low wind speed, though there are WTGs that work on low wind speed. As can be seen from Table 13, a hypothetical WTG model (WinWinD-1/60) provides an annual energy amount of around 1.7 and 1.07 GWh with a capacity factor of 19.22 and 12.78% in Charfashion and Monpura, respectively.

Table 12. Wind class of the selected microsites as per IEC 61400-1-2.

Site Name	**IEC61400-1 Wind Class and Data Recovery Rate (%)**		
	60 m AGL	**80 m AGL**	**100 m AGL**
Charfashion	Class S (designer sp.) (96.27%)	Class S (designer sp.) (94.56%)	Class IIIB (93.58%)
Monpura	Class S (designer sp.) (77.56%)	Class S (designer sp.) (77.34%)	Class IIIB (77.92%)

Table 13. *AEP* for the selected microsites.

Site Name	**Annual Energy Production (*AEP*)**		
	60 m AGL (WinWinD-1/60)	**80 m AGL (GW155-3.3)**	**100 m AGL (GE 1.6-100)**
Charfashion	1.718 GWh	10.806 GWh	6.215 GWh
Monpura	1.079 GWh	8.187 GWh	4.829 GWh

For 80 m AGL, this paper chose Goldwind GW155-3.3MW WTG as a good option for lower wind speed, producing more than 10.0 and 8.0 GWh of electricity with a capacity factor of 37.38% and 28.32%, respectively.

For the same area, measuring the *AEP* at 100 m AGL with IEC class IIIB, the wind turbine tested with the WTG model GE1.6-100 demonstrated a capacity factor of 43.79% and 34.03%, respectively. The energy produced in one year is helpful for determining the reduction in CO_2 for a single turbine at different heights, which is shown in Table 14. According to the estimation of the International Energy Agency (IEA), the estimated CO_2 emission factors of Bangladesh are given in Table 15.

Table 14. IEA composite electricity/heat factors of Bangladesh.

Electricity-Specific Factors (kgCO_2/kWh)	**IEA Composite Electricity/Heat Factors (kgCO_2/kWh)**	**Difference (gCO_2/kWh)**	**Difference (%)**
0.63714323	0.5737064	0.06344	11.10%

Table 15. CO_2 emission reductions for different types of WTGs at different heights.

Working Area	Total Energy Produced (GWh/year) and CO_2 Reduction		
	60 m AGL	80 m AGL	100 m AGL
Coastal (two microsites)	2.79 GWh, 1781.689 tons of CO_2 per year	18.993 GWh, 12,098.54 tons of CO_2 per year	11.044 GWh, 7035.028 tons of CO_2 per year

It can be well understood from the Table 15 that the generated wind power can significantly reduce CO_2 emissions passively through a carbon emission avoidance mechanism, which is the most effective carbon management technique.

4. Conclusions

An investigation of the coastal and near-coastal wind power potentials of Bangladesh was carried out through real wind data statistical analysis as per the regulations of IEC-61400-12-1 standard, and via simulated wind energy mapping for mesoscale and microscale modeling. The analyses at 60, 80, and 100 m AGL all demonstrated the fact that there are several promising locations for wind power development in Bangladesh. Several WTGs with different models designed for low wind, such as WinWinD-1/60 for 60 m AGL, GW155-3.3 for 80 m AGL, and GE 1.6-100 for 100 m AGL, were applied to the selected coastal area, and it was identified that two microsites (i.e., Charfashion and Monpura) have promising wind speeds, reaching 7.3 m/s at 100 m AGL, meaning their south-east wind flow can produce significant energy. WTGs with a capacity factor of 19.22 and 12.78% for the two sites, respectively, installed at 60 m AGL have the potential to produce 2.79 GWh of wind power, thus reducing 1781.689 tons of CO_2 per year, whereas a wind turbine installed at 80 or 100 m can produce 18.933 or 11.044 GWh power, reducing 12,098.54 or 7035.028 tons of CO_2 per year, respectively. The capacity factor significantly increases as the height of a WTG increases (ranges between 28 and 43%). This reduction in carbon could play an important role for carbon trading if a wind power plant is registered as providing certified emission reductions (CERs). Unlike the carbon sequester method that captures carbon directly from the source of emission before its release into the atmosphere, this passive way of mitigating carbon through the generation of wind energy, along with other renewable energy, is safe for replacing the carbon-emitting source of energy. This can help to deal with the global challenges of climate change, thereby promoting sustainable development.

Meso and microscale modeling for wind mapping were validated with real wind resource data in the projected region and showed that, with a 15% error margin, wind speed tends towards a smooth over-estimation than with a 30 or 45% error margin (this is due to the variable roughness of the topography). Correlation and comparison analyses were performed to check the accuracy of the data. The coastal wind energy of Bangladesh can add more economic benefits through the reduction of GHG emissions, especially carbon dioxide.

This research estimated the wind power potential of coastal areas of Bangladesh using the most effective statistical tools, which helped the validation analysis of the meso- and microscale wind resource maps of the same region. The findings of this research can be used effectively to sustainably develop the wind power of Bangladesh's coastal areas to meet the energy demands of the country and to help reduce its carbon footprint.

Author Contributions: Conceptualization, K.D.I.; Methodology, K.D.I.; Software, T.T. (Thanansak Theppaya) and T.T. (Tanita Suepa); Validation, T.T. (Teerawet Titseesang) and T.T. (Thanansak Theppaya); Formal analysis, J.T.; Investigation, J.T.; Resources, F.A.; Data curation, J.W.; Writing—original draft preparation, K.D.I.; Writing—review and editing, T.T. (Teerawet Titseesang), F.A., and K.D.I.; Visualization, T.S.; Supervision, K.T. and J.T.; Project administration, J.T.; Funding acquisition, J.T. and K.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This work was supported by the Interdisciplinary Graduate School of Energy System (IGS-ENERGY), Prince of Songkla University, Hat Yai-90112, Songkhla, Thailand.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

AEP	Annual energy production
AGL	Above ground level
BMD	Bangladesh Meteorological Department
CO_2	Carbon dioxide
CoP21	Conference of parties
CR	Rated capacity
GHG	Greenhouse gas
GWEC	Global Wind Energy Council
GWh	Gigawatt hour
IEC	International Electrotechnical Commission
kg	Kilogram
km	Kilometer
kWh	Kilowatt hour
MCP	Measure–correlate–predict
M/P	Measured/predicted
MW	Megawatt
PDF	Probability distribution function
PLE	Power law exponent
PMRE	Percentage mean relative error
RMSE	Root mean square error
SDG	Sustainable Development Goal
WAsP	Wind Atlas Analysis and Application Program
WTG	Wind turbine generator

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Islam, K.D.; Theppaya, T.; Ali, F.; Waewsak, J.; Suepa, T.; Taweekun, J.; Titseesang, T.; Techato, K. Wind Energy Analysis in the Coastal Region of Bangladesh. *Energies* 2021, *14*, 5628. https://doi.org/10.3390/en14185628.

Khandaker Dahirul Islam, Juntakan Taweekun, Thanansak Theppaya, Investigation of Small Wind Turbine Noise as per IEC 61400-11 and AWEA 9.1 Standard, International Conference on Recent Advances in Sustainable Energy Research 2019 (RAISER 2019), December 16, 2019, Penang, Malaysia (Best paper award).