JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

SUSTAINABLE ENERGY ENGINEERING STREAM

"PRE-FEASIBILITY STUDY OF WIND POWER AND SITE SUITABILITY ANALYSIS IN DIRE DAWA, ETHIOPIA"

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Sustainable Energy Engineering

By:

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December, 2021

Declaration

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been fully acknowledged.

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Dedication

This research thesis has been dedicated to:

My father, Ato Abraham Wollebo, My mother Selamnesh Jagiso,

My brothers And, Sisters

With love and respect.

Abstract

Recently, the demand for energy production has been tremendously increasing in Ethiopia due to the escalating population and industrialization. As a short-run solution to cover the increasing and suppressed demand, a fast-track execution capacity increase is compulsory. Harnessing wind energy is a promising solution for improving the lives of those who are unlikely to have access to electricity supply in the foreseeable future in Ethiopia. In the country, wind energy potential is reasonably good, but the level of investigation and exploitation is below the desired level. In this research work, a detailed pre-feasibility study has been conducted on wind farm plantations to assess wind power potential and analyze site suitability in Dire Dawa, Ethiopia. A suitable site was selected, wind power potential was assessed and financial viability was checked based on Qgis, 3D animated wind turbine and RET screen expert in a specific province, Dire Dawa. The result has been validated by comparing the national meteorological agency of Ethiopia data with NASA's MERRA reanalysis data. Based on the result, input model parameters, wind speed variability, and area wind speed were discussed. From the results, the wind energy potential of one of the sites, K'ench'era (site 1), noted at 6.4 m/sec mean wind speed with a mean wind power density of 682 w/m^2 at 100 m and 11.16 km away from the main access road, is considerably lower than the other two locations. Besides, Jelo (Site 2) distinguished a 7.0 m/sec mean wind speed with a mean wind power density of 780 w/m^2 at 100 m and 11.36 km away from the main access road, which is markedly higher than the k'ench'era (site 1). Afretu (site 3) verified a 7.4 m/sec mean wind speed, a mean wind power density of 804 w/m^2 at 100 m, and a distance of 28.83 km away from the main access road, which is noticeably higher than the two locations that could be outstanding according to the national renewable energy laboratory. The results show that Jelo (Site 2) and Afretu (Site 3) are better candidates as compared with K'ench.era (Site 1). Finally, possible direction for urban and energy planners as support in selecting the finest wind energy promises based on site characteristics and restrictions.

Key words: *Wind potential, Suitable site, Wind farm, Wind speed, wind power density.*

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Finally, I would like to extend my sincere thanks to my family and friends. Without their implausible understanding and inspiration in the past few years, it would have been unbearable for me to complete my studies.

Life is too long, so carry on!

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Acronyms

CFD	Computational Fluid Dynamics
CSA	Central Statistical Agency
DTM	Digital Terrain Model
DEM	Digital Elevation Model
EEPCO	Ethiopian Electric Power Corporation
EIA	Environmental Impact Assessment
EPC	Environmental Procedure and Construction
GIS	Geographical Information System
GoE	Government of Ethiopia
NMSA	National Meteorological Survey Agency
NASA	National Aeronautical and Satellite Agency
NREL	National Renewable Energy Laboratory
PPA	Power Purchase Agreement
QGIS	Quantum Geological Information System
WRA	Wind Resource Assessment
WT	Wind Turbine
WWEA	World Wind Energy Association
USGS	United State Geological Survey

Nomenclature

AEP	Annual Energy Production
PDF	Probability Density Function
K	Weibull Shape Factor
A	Weibull Scale Factor
R	Roughness Class
Ro	Roughness Length (m)
V_m,V_{in},$V_{out,}$$V_R$	Mean, Cutin, Cutout and Rated wind speed (m/s)

CHAPTER ONE

Introduction

1.1 Background

In developing nations, increasing the efficiency of renewable energy technologies and decreasing production costs are gaining prominence [1]. Among the familiar renewable energy sources, wind energy is the most prominent and inexhaustible, which does not cause any pollution in electricity production [2]. Wind energy shall serve as a cornerstone and driving force for the immediate application of a global energy system powered by renewable energies to completely replace fossil and nuclear sources, and has been experiencing rapid energy intensification for the last two decades.

Ethiopia is widely regarded as a bold frontrunner among developing countries in the fight against climate change and the transition to renewable energy [3]. According to Denmark's Ministry of Foreign Affairs [4], Ethiopia's wind energy potential is reasonable, but investigation and exploitation are below the desired level. Subsequently, the demand for energy production has been tremendously increasing in Ethiopia due to the escalating population and industrialization. The energy sector in Ethiopia is expanding rapidly, and even with the new hydropower plants. Thus, to guarantee the security of supply, the power generation system has to be diversified [5].

Therefore, the Government of Ethiopia (GoE) has set a goal of becoming a middle-income country by 2025, which includes aggressive power generation and connection targets. As concessional loans for government-owned/operated generation facilities have decreased significantly, the GoE has determined that private investment is critical to meeting new generation targets in the future [6].

As an organization, Ethiopian Electric Power Corporation (EEPC) administers 18 power plants there, generating a total of 4244 megawatts of electricity nationwide. Among the 18 power plants, three are wind-powered, namely Adama II (153MW), Ashegoda (120MW), and Adama I (51MW), which have generated a total of 324MW of electricity in Ethiopia [8]. The remaining 104MW of electricity is being generated by two diesel generators and the Aluto Geothermal Plant (7.3MW).

Ethiopia Electric Power Corporation (EEPCo) has appraised two alternatives: wind and diesel [7]. Because of its complementary nature with hydropower, wind energy is thought to be a good alternative source of electrical energy production. The country experiences low wind during the rainy season and high wind during the dry season. Seasonal variation creates favorable conditions for both to be used; combining wind and hydropower will increase the value of hydropower plants by extending their operational time. As a short-run solution to cover the increasing and suppressed demand, a fast-track execution capacity increase is compulsory. Harnessing wind energy is a promising solution for improving the lives of those who are unlikely to have access to electricity supply in the foreseeable future in Ethiopia [6].

However, due to the lack of reliable and accurate wind atlas resource maps, additional research on the assessment of wind energy in Ethiopia is required. One of the constraints to utilizing wind energy potential is the scarcity of organized wind data in the country that covers the entire region. Nonetheless, the potential for wind energy in various region has been identified [2].

Fortunately, the Ethiopian government (GoE) intends to build massive wind farms in collaboration with the Danish Embassy. Simultaneously, wind farm planning is required to assess the wind resource of the potential wind farm from the site [1]. Once the wind resource is known, a wind farm can be modeled and turbine can be positioned. There are several methods for simulating hypothetical wind farms and turbine placement in suitable locations.

This study concentrated on preliminary wind power assessment and site suitability analysis in Ethiopia's eastern region, known as Dire Dawa. It responds to the question, In Dire Dawa, how will the wind energy resource be evaluated? Or, how does wind energy potential assessment software provide accurate results during the Dire Dawa pre-feasibility study? It is critical in forecasting the profitability of the business for investors to decide at a regional or national level. It offers adequate data for the government or agencies to establish a specific policy and framework for utilizing and exploiting the potential on a large scale [2].

1.2 Problem Statement

The Government of Ethiopia (GoE) has set a goal of becoming a middle-income country by 2025, which includes aggressive power generation and connection targets. As concessional loans for government-owned/operated generation facilities have decreased significantly, the GoE has determined that private investment is critical to meeting new generation targets in the future [6].

According to the master plan jointly held by the Ethiopian government and the Chinese government, the Dire Dawa region is one of the best candidates for wind farm plantation with a capacity of 50 MW and 40 square kilometers [11]. However, one of the major problems is the scarcity of prefeasibility and site suitability analysis research work.

Table 2-1 Selected Wind Farm Site in Ethiopia (adopted from Dereje Derbew,[11])

No.	**Name of Site**	**Capacity (MW)**	**Area (Km^2)**	**Grading in Preliminary Selection**	**Domicile**
F1	Nazret Wind Farm	300	254	100	Oromiya
F2	Mek'ele South Wind Farm	100	77	85	Tigray
F3	Sheno Wind Farm	100	56	88	Oromiya
F4	Ch'ach'a Wind Farm	100	56	86	Amhara
F5	Phase I Wind Farm Inlteya	100	66	95	Oromiya
F6	Sulalta Wind Farm	100	60	92	Oromiya
F7	Gondar West Wind Farm	50	49	82	Amhara
F8	Imdibir Wind Farm	50	47	90	SNNP
F9	**Dire Dawa Wind Farm**	**50**	**40**	**91**	**Dire Dawa**
F10	Dilla East Wind Farm	300	268	96	SNNP
F11	Mek'ele North Wind Farm	200	185	85	Tigray
F12	Debre Markos East Wind Farm	200	143	87	Amhara
F13	Sodo Wind Farm	200	160	84	SNNP
F14	Sendafa North Wind Farm	100	70	88	Oromiya
F15	Sendafa South Wind Farm	100	70	88	Oromiya

Evidently, Dire Dawa is a region with a large number of industries, including the Eastern Industry Park. Coca-Cola soft drinks, the National Cement Factory, Aqua UNO, Aqua Dire mineral water factories, and other private businesses that require energy for their daily operations. Similarly, as the population grows, so does the demand for power. Unfortunately, there is a severe power deficit and variance in the region when it comes to supplementing. Estimation of greenhouse gas emission and mitigation methods in the electric power sector of Dire Dawa city from 2015 to 2025 [4] revealed that perhaps the industry sector consumes energy at a fast pace than the residential sector, with the industry sector's share rising from 5% to 12% and the household sector's falling slightly from 72% to 69%.

On the other hand, during 2025, greenhouse gas levels are expected to be 484,168,51 tons (co_2 equivalent) [4]. GHG emissions can be reduced by implementing the recommended options, which include both short-and long-term mitigation strategies. The research proposes a long-term mitigating strategy that involves renewable energy wind power plants and smart grid deployment, that could reduce GHG emissions by 176,720,44 tons of co_2 per year.

As a short-run solution to cover the suppressed demand and environmental impact, a fast-track execution capacity increase is compulsory in Dire Dawa. Harnessing wind energy is a promising solution for improving the lives of those who are unlikely and likely to have access to electricity supply in the foreseeable future in Dire Dawa, Ethiopia [6].

1.3 Significance of the study

Due to economic and financial constraints, Ethiopia's central government is unable to provide renewable energy to nearly half a million people in the country's eastern region, but they can attract wind energy investors from international and donor countries through a wind energy map that includes a compressive pre-feasibility study and site suitability analysis in the region. This paper could be used to accomplish various tasks, such as QGIS, virtual animated 3D wind turbines, and RET screen, among others. For this region, a wind farm with a capacity of 20 MW has been proposed. Because the region's wind energy has the ability to produce more, this will merely serve as a model.

These days, sustainability is a milestone for climate conditions as well as the growth of a country. Renewable energy, like wind energy, is one of the promising solutions for sustainability. This research paper will offer several merits for investors, agencies, and governments as well.

1.4 Research Questions

1. How will the wind energy resource be evaluated in Dire Dawa?
2. How does wind potential assessment software afford accurate results during the feasibility study in Dire Dawa?
3. How would the reported scarcity of wind energy potential support wind farm plantation?

1.5 Hypothesis

Question form hypothesis

- Is it possible that assessing wind energy potential and wind farm modeling will be critical for wind farm plantation?

Declarative statement

- A lot of research work shows that assessing wind energy potential is an obligatory step for wind farm plantations.

Directional Hypothesis

- Assessing wind energy potential will attract investors, agencies, and governing bodies.

Non- Directional Hypothesis

- Assessing wind energy potential and wind farm modeling using several simulation programs in an improper proportion will not attract inventors, agencies, and government bodies.

1.6 Objectives

1.6.1 General Objective

This research's general objective is to assess wind power potential and to model a wind farm in Dire Dawa, Ethiopia.

1.6.2 Specific Objectives

- To assess wind data, wind speed variability, and topographic conditions of Dire Dawa.
- To identify a suitable site.
- To model a hypothetical wind farm and turbine placement.
- To study financial viability and project feasibility.

1.7 Scope of the Study

This work deals with the estimation of wind energy resources in a specified area, Dire Dawa. The turbine blade's detailed performance and analysis of fatigue load impact from problematic wind conditions on some complex terrains are left for another research work. The principal purpose of this work is to study the wind resource's pre-feasibility at a given area of Dire Dawa using diverse conventional software.

1.8 Thesis Structure

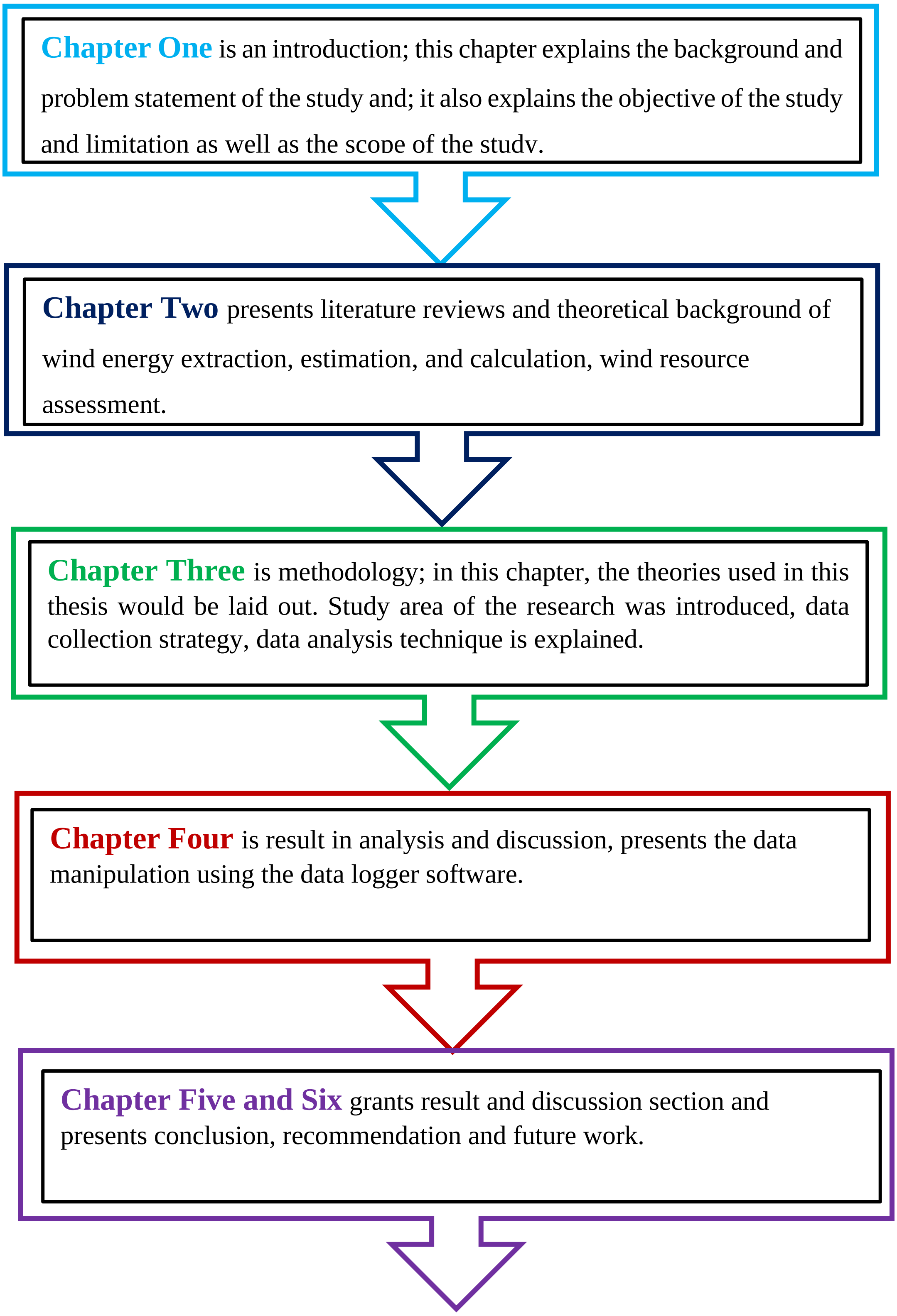


Fig 1-1 Structure of the thesis

CHAPTER TWO

Historical Background and Literature Review

2.1 Historical Background

This section attempts to provide a brief explanation of the world's wind energy potential as well as to express the available energy resources in Ethiopia.

2.1.1 History of Wind Energy

Since ancient times, people have harnessed wind energy. Over 5,000 years ago, the ancient Egyptians used the wind to sail ships on the Nile River. Later, people-built windmills to grind wheat and other grains. The earliest known windmills were in Persia (Iran). These early windmills looked like large paddle wheels. Centuries later, the people of Holland improved the basic design of the windmill. They gave it propeller-type blades, still made with sails. Windmills are famous in Holland [12].

Wind energy utilization was invented in the Orient, probably in Afghanistan, Persia, or China. There were many vertical axis machines for pumping and grinding grain, much later horizontal axis machines in Europe after 1200 AD, and few improvements over time until the end of the 18th century. The modernization of Western wind pumps is technically successful but has no commercial effect. In the "Mechanical Revolution" through wind and water mills between the 11th and 13th centuries, and in the 1800s, steam and internal combustion engines started to replace wind and watermills, but not gradually in Germany [13].

By the first decade of the 21st century, wind power had become the best hope for the future of alternative energy. It had, rather unexpectedly, become the most lauded and fastest-growing alternative energy source in the world, generating significant amounts of electricity in several countries, including the United States, Denmark, Germany, and Spain, as well as an impressive amount in many others. The new era of wind development was led by the United States during the 1980s, yet Europe has overtaken that ranking, accounting for two-thirds of total worldwide wind development by itself in 2001 [14].

2.1.2 Source of Wind Energy

The wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates. During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds [4]. At night, the winds are reversed because the air cools more rapidly over land than over water. In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles. Today, wind energy is mainly used to generate electricity. The wind is called a renewable energy source because the wind will blow as long as the sun shines [5].

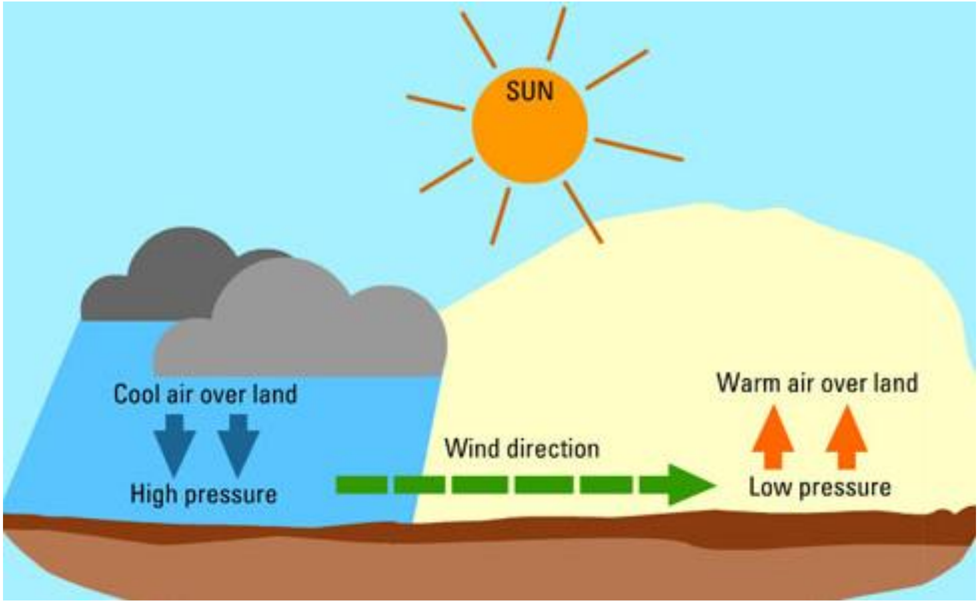


Fig 2-1 Source of wind Energy (Source: Tech-Addict)

2.1.3 Global wind Energy status quo

The global wind power market expanded 19% in 2019 to 60 GW, the second largest annual increase, for a total of 650 GW (621 GW onshore and the rest offshore). The rapid growth was due largely to surges in China and the United States in advance of policy changes and to a significant increase in Europe, despite continued market contraction in Germany.

New wind farms reached full operation in at least 55 countries, and by year's end, at least 102 countries had some level of commercial wind power capacity [6].

According to the world renewable energy report 2020, wind energy accounted for an estimated 57% of Denmark's electricity generation in 2019, with high shares also in Ireland (32%), Uruguay (29.5%), Portugal (26.4%) and several other countries. Capacity in operation worldwide at year's end was enough to provide an estimated 5.9% of global generation.

During the COVID-19 pandemic, data for countries representing more than one-third of global electricity demand showed that every month of full lockdown reduced electricity demand by 20% on average. Global electricity demand decreased by 2.5% in the first quarter of 2020, and demand for coal and oil fell by nearly 8% and 5%, respectively [6]. Renewables were the only source of electricity to record demand growth over this period, due to low operating costs and preferential access to electricity networks. The carbon intensity of electricity systems also dropped, and cities across the globe benefited from unusually high air quality.

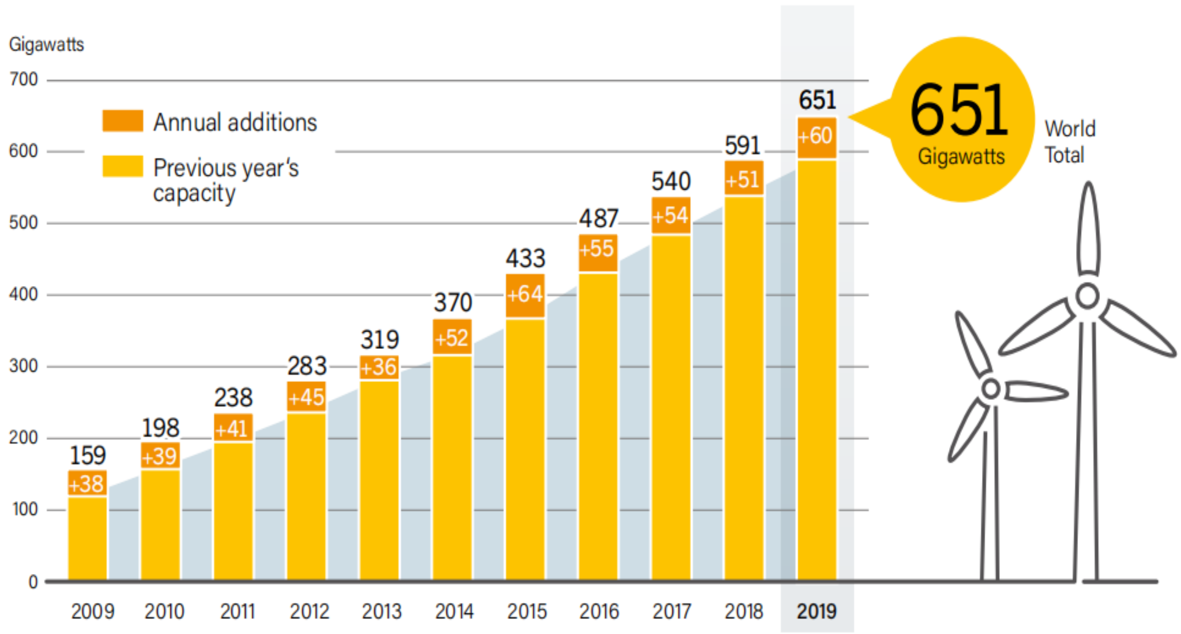


Fig 2-2 World wind energy progress (source: global renewable energy report, 2020)

Meanwhile, in the last few years, the energy sector has begun to change in promising ways, enabled by supporting policies and innovations in technologies and systems. Renewable power technologies are dominating the global market for new generation capacity.

Following increasing renewable deployments in 2019 (around 176 gigawatts [GW] added globally), indications are that 2020 will be a record year for wind and solar photovoltaic (PV) markets, with current market forecasts suggesting that about 71 GW and 115 GW are expected to be added, respectively [3].

2.1.4 Wind Energy in Ethiopia

The Government of Ethiopia (GoE) has set a goal of becoming a middle-income country by 2025, which includes aggressive power generation and connection targets. The Government of Ethiopia has determined that private investment is critical to achieve new generation targets beyond 2015 as concessional loans for government owned/operated generation facilities have decreased significantly [7]. Ethiopian Electric Power administers 18 power plants there by generating a total of 4244-megawatt electricity nationwide. Among the 18 power plants, three are wind-powered, namely Adama II (153MW), Ashegoda (120MW), and Adama I (51MW), which have generated a total of 324MW of electricity in Ethiopia [8]. The remaining 104MW of electricity is being generated by two diesel generators and the Aluto Geothermal plant (7.3MW).

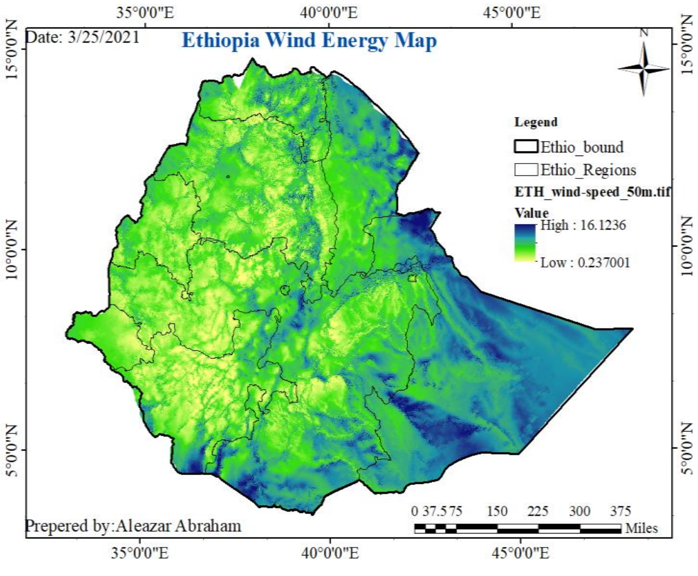


Fig 2-3 Wind Energy Map of Ethiopia (source: Arch GIS by Aleazar Abraham)

The government of Ethiopia with the collaboration of Chinese government prepared solar and wind master plan for the whole country, which can be very useful to identify the gross amount and distribution condition of wind and solar energy resources, construction conditions, cost and other limiting factors of wind and solar power generation projects. Based on the analysis of this master plan: Ethiopia has a capacity of 1,350 GW of energy from wind [9].

Ethiopia has huge renewable energy potential, which is distributed through all regions and makes the country favorable for power development and ideal for developers. More over the government of Ethiopia gives special attention and put in place a lot of favorable conditions and good working environment for developers to participate in the energy sector.

2.2 Literature Review

In 2019, wind supplied 1430 TWh of electricity, which was 5.3% of worldwide electrical generation, according to the global review of wind energy 2020 [10], with the global installed wind power capacity reaching more than 651 GW, an increase of 10% over 2018, based on the global wind report [11]. As wind energy has many advantages, academic studies are carried out using different methods and techniques to determine the regionally available wind energy potential to benefit from this energy [12].

In order to undertake the design of a wind farm, there are several issues to first consider. Most of these issues have been extensively studied in an individualized way, as a part of the complete micro-siting problem: the study of wind behavior, analysis of interactions between wind turbines, design of auxiliary facilities (access roads, electrical infrastructure, foundations), reliability, economic issues, environmental assessment, to name but a few [13].

The research studies on investigating wind energy based on simulation software utilization have come to the front with the programs' help. For example, simulation software can determine the wind energy evaluation, the preliminary-feasibility, and feasibility report for the planned investments economically and technically. Investors can contribute more safely and rationally in this direction, according to Unal Yilmaz et.al [14]. He suggested the experts work on the proper techniques to predict the results close to reality.

One of the most significant problems in designing wind farms is the high initial investment cost. With a feasibility study done wrongly, the investments in positioning these installations in problematic areas may result in severe financial losses, Semih Güzel [15].

The researcher found that [30], there are two important steps in forming suitability maps. The first step is the accurate collection of data, especially regarding the criteria for determining social and environmental effects. It is highly important to derive residential areas, buildings, and green areas. For this reason, the geographic information system (GIS) stage, which is the second step of forming suitability maps, is put into action at this point.

Cicek, a researcher, has studied the site selection of wind power plants in Turkey using a GIS/spatial statistic-based approach [17]. Similarly, Arcidiacono [18] used GIS (Geographical information system) to conduct a site potential analysis for small-scale wind power plants, and Al-Shabeeb et al. utilized GIS for a preliminary site selection and suitability map of wind turbines in Jordan's northwestern region [19].The authors, Issa and Saleous [31], outlined those analyses and evaluations that are achieved with accurate and reliable data in the GIS (geographical information system) environment are transformed into information, and successful results are ensured.

Siamak Moradi [32] designated that the multi-criteria decision making (MCDM) method and site selection criterion for wind resource assessment using ArcGIS are described and developed for the study area. The structural, topographical, and ecological criteria, along with their sub-criteria, have been directed to eliminate unsuitable locations. Pilar DazCuevas et al. [33] consistently presented a methodology capable of assessing the installation of wind farms on a regional scale. A location model using the analytical capabilities of GIS and multi-criteria decision-making MCDM has been built for this purpose. Also, Maria Margarita Bertsiou et al., [34] present a method for evaluating eligible sites for wind turbine installation for different combinations of criteria.

Evaluations of economic, social, environmental, and physical criteria with certain weights and determining suitable and unsuitable areas based on this with multiple criteria have gained importance. On the other hand, [28] proposed the analytic hierarchy process (AHP) was used in a novel approach to identify the potential sites for the wind turbine in the study area based on five physical criteria (wind speed, rainfall, slope, altitude, and land use) that affect the wind turbine sites.

Similarly, T.R. Ayodele et.al, [35] suggested the criteria weights generated, together with the preprocessed data, were inputted into the GIS-based model to generate the wind farm site criteria map (wind speed, elevation (dem), land cover, and flood areas, airports vector map, gridlines vector map, protected areas vector map, important bird areas raster map and boundaries such as roads, river lines, and urban area and exclusion map, it was implemented using the ArcGIS desktop software.

Micha Szure et.al [21], adopted sitting criteria that have been identified based on a literature review and include: technical, spatial, social, and environmental aspects of wind farm development, and also address specific geographical constraints of this part of Poland. Meng Shao et al., [22] have summarized the exclusion criteria and evaluation criteria of site selection for five energy sources. The five site selection stages, criteria selection, data normalization, criteria weighting, alternative evaluation, and result validation, are revealed by content analysis.

Kunal K. Dayal et al.,[28] evaluated the wind resource and energy potential of various locations in Fiji. This study summarizes an assessment of the wind resource at specific locations in Fiji for the potential of future utility-scale wind-power development. Furthermore, the wind quality and power availability for the two major islands in Fiji were examined using NASA’s MERRA reanalysis at a height of 50 m. On the selected sites, Rakiraki, Nabouwalu and Udu have an average wind speed of 7.6 m/s, 7.1 m/s and 7.0 m/s with an average power density of 401 W/m^2, 512 W/m^2 and 294 W/m^2, and an average annual production of 0.907 GWh, 0.804 GWh and 0.716 GWh using a 275-kW wind turbine, respectively.

Martha Bastidas-Salamanca worked on a pre-feasibility study for locating new offshore wind projects in Colombia's Caribbean. This study reviewed these factors in order to determine when they could be analyzed within three major stages (pre-feasibility, feasibility, and final decision) [29]. As a result, this study organized the main factors into three stages and conducted a pre-feasibility analysis for assessing potential offshore areas while taking technical-environmental features like spatial classification, temporal variability (magnitude and direction), and geographical constraints into account.

Moreover, suitable locations for wind power generation can be identified during onshore wind projects using professional software that models and predicts wind behavior, allowing us to estimate power production [16]. Three software packages are used during the pre-feasibility and feasibility study stages: RET Screen, HOMER, and SAM. The pre-feasibility study is conducted early in the process of analyzing a potential wind farm scenario. The level of accuracy at this stage is in the 40 [3] range. The feasibility study is an in-depth examination of the same topic as the pre-feasibility study, and it should provide sufficient information to inform the "go/no-go" decision point. The cost estimation accuracy at this stage is 25%.

In the Ethiopian context, Abdela, [23], Tadesse, [24], and Wudu, [25] conducted various types of research in determining, analyzing, and assessing the wind energy potential of Ethiopia's Adam-II windfarm, Aysha windfarm, and Mosobo-Harena windfarm using simulation programs such as WAsP, MATLAB, and M.S. Excel. Similarly, Zenebe (2019) used ANSYS simulation software to estimate turbine recital for the Debrebrehan, Enewari, and Mehalmeda wind farms in the Amhara Region [26]. On the other hand, Gaddada et al. [27], on the other hand, outlined the cost of wind energy conversion systems for electricity generation and measured wind energy potential using POLARIS P15-50, POLARIS P50-500, and VESTAS V110-2.0 M.W. wind turbines for the assessment of electric power generation in eight selected locations in Northern Ethiopia's Tigray region.

The aim of this paper would be to determine the wind energy evaluation, preliminary feasibility, and financial viability reports of a hypothetical wind farm in Dire Dawa, both economically and technically, by utilizing NASA's MERRA reanalysis data at various heights, national meteorological agency data, and vortex data. It used GIS (Geographical information system), a 3D animated wind turbine, and a RET screen expert to identify potential wind turbine sites in the study area and check wind project economic sustainability.

2.2.1 Research Gap

Recent studies have commenced to delivering preliminary wind power assessment in Ethiopia’s eastern region. Most researchers who studied wind power resource assessment used a variety of technologies, including WAsP, MatLab, ANSYS, and Microsoft Excel to address existing wind farm performance in some parts of Ethiopia.

As per the research conducted for this paper, less research has been conducted in the Dire Dawa region to assess wind power potential as well as analyze economic viability. Despite the absence of reliable wind data and resource maps, more research into the estimation of wind power in the Dire Dawa region is considered necessary. The comprehensive wind resource maps and other information in the wind atlas support the assessment of potential area for the use of wind energy technologies such as utility-scale power generation, village power, and off-grid wind energy applications.

The recent research findings show that wind energy has enormous potential in the region, providing a roadmap for firms to use small-scale wind turbine to meet their own demand as well as investors from around the world to invest in wind farm plantations. It was also discovered that the most scholars around the world conducted preliminary studies without taking wind energy potential assessment, site suitability and economic analysis into account.

Table 2-1 Strengths and weaknesses of the software used in literature. (Adopted from A.Z. Dhunny, 2019[42])

S.No	Software Tool	Application	Weakness	Developer/ Founder
1	Arch GIS	Displays high resolution and defined spatial mappings with an assorted variations of color palette.	The license fee for running the software is relatively expensive.	Esri
2	QGIS	Besides being open-source, QGIS is a cross-platform software and is adaptable on Linux, Mac and Windows	The quality of the cartographic output is weak as compared to ArcGIS	QGIS Development Team
3	RETScreen	RETScreen is an excel-based software tool that helps in decision making related to pre-feasibility, technical and financial viability of potential renewable energy, and energy efficiency.	-	Gov't of Canada
5	System Model Advisor (SAM's)	Wind Power model can model a single wind turbine or a wind farm with more than one turbine. Combine the Wind Power performance model with the Residential or Commercial financial model for a behind-the-meter project that uses wind power to reduce a building or facility's electricity bill.	Input data package is only for USA and formatting system is limited.	(NREL)

CHAPTER THREE

Methodology

3.1 Introduction

The approach followed in this study is a pre-feasibility research methodology entitled "pre-feasibility of wind power and sire suitability analysis in Dire Dawa, Ethiopia." This chapter describes the different procedures and methods used in the study. Various activities would involve answering the research questions and attaining the objectives of the study. These activities include wind energy, wind data collection, wind resource characterization, data analysis methods, and site suitability analysis. Those activities performed were determined to achieve the proposed goal of the study.

3.2 Description of Study Area

3.2.1 Site Location

Dire Dawa is a city in eastern Ethiopia near the Somali border and one of two chartered cities in Ethiopia (the other being Addis Ababa, the capital). It is divided administratively into two woredas, the city proper and the non-urban woreda of Gurgura. Dire Dawa lies in the eastern part of the nation, on the Dechatu River, at the foot of a ring of cliffs. The western outskirts of the city lie on the Gorro River, a tributary of the Dechatu River. It is situated at 9°36′ N, 41°52′ E latitude and longitude, respectively. The city is an industrial center, home to several markets and the Dire Dawa Airport. [Source: Wikipedia].

3.2.2 Climate

The mean annual temperature of Dire Dawa is about 25.9 °C or 78.6 °F. The average maximum temperature of Dire Dawa is 32.8 °C or 91.0 °F, while its average minimum temperature is about 19.0 °C or 66.2 °F. The region has two rain seasons; that is, a small rain season from March to April, and a more pronounced rain season that extends from July to August. The aggregate average annual rainfall that the region gets from these two seasons is about 670 millimeters or 26 inches. [Source: Wikipedia]

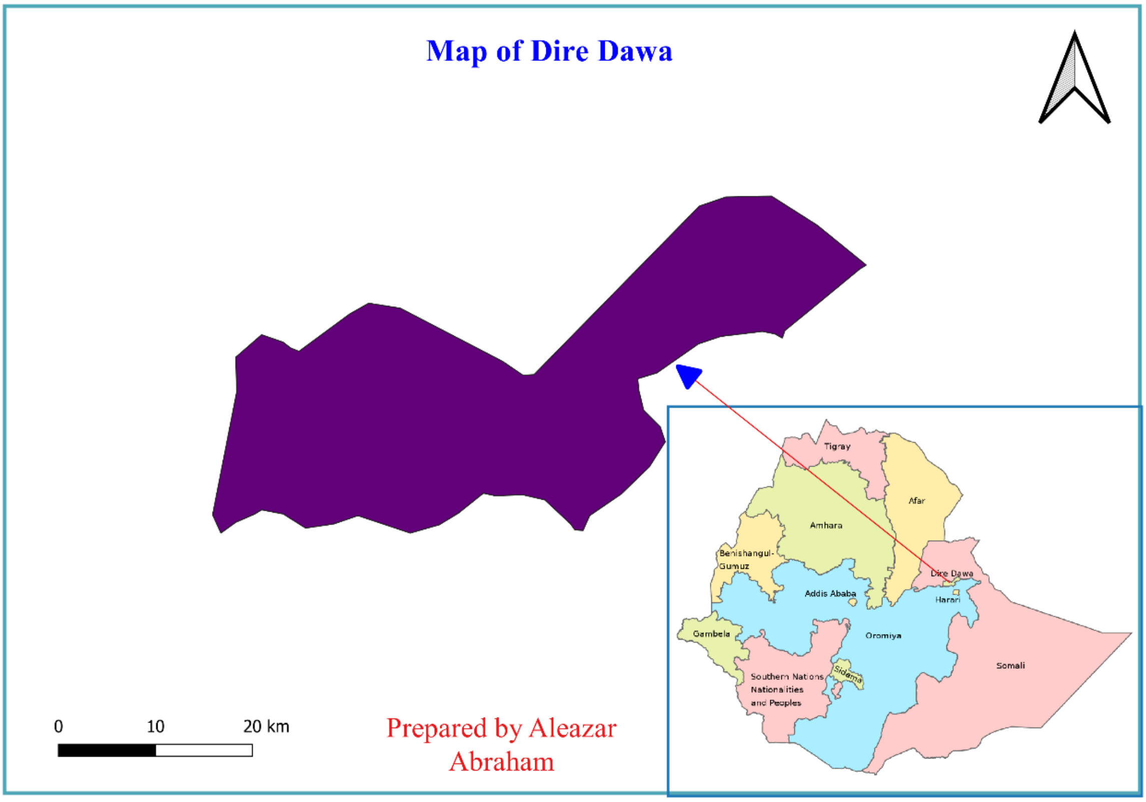


Fig 3-1 Map of Study area (source: QGIS by Aleazar Abraham)

3.3 Research Design

This research was designed in such a way that three types of data were used:

I. National Meteorological Service Agency (NMSA), and Central Statistical Agency (CSA): Wind speed and direction collected from NMSA

II. Site visiting and Interview: for modeling the community's potential electrical load demand, visiting the districts and interviewing the local people is done both in person and by phone.

III. Internet (websites): satellite-based wind speed data taken from GIS, MERRA-2 (NASA), Vortex Factoria de calculus S.L, Global Wind Atlas, Earth Data and SWERA database websites.

3.4 Wind energy project life cycle

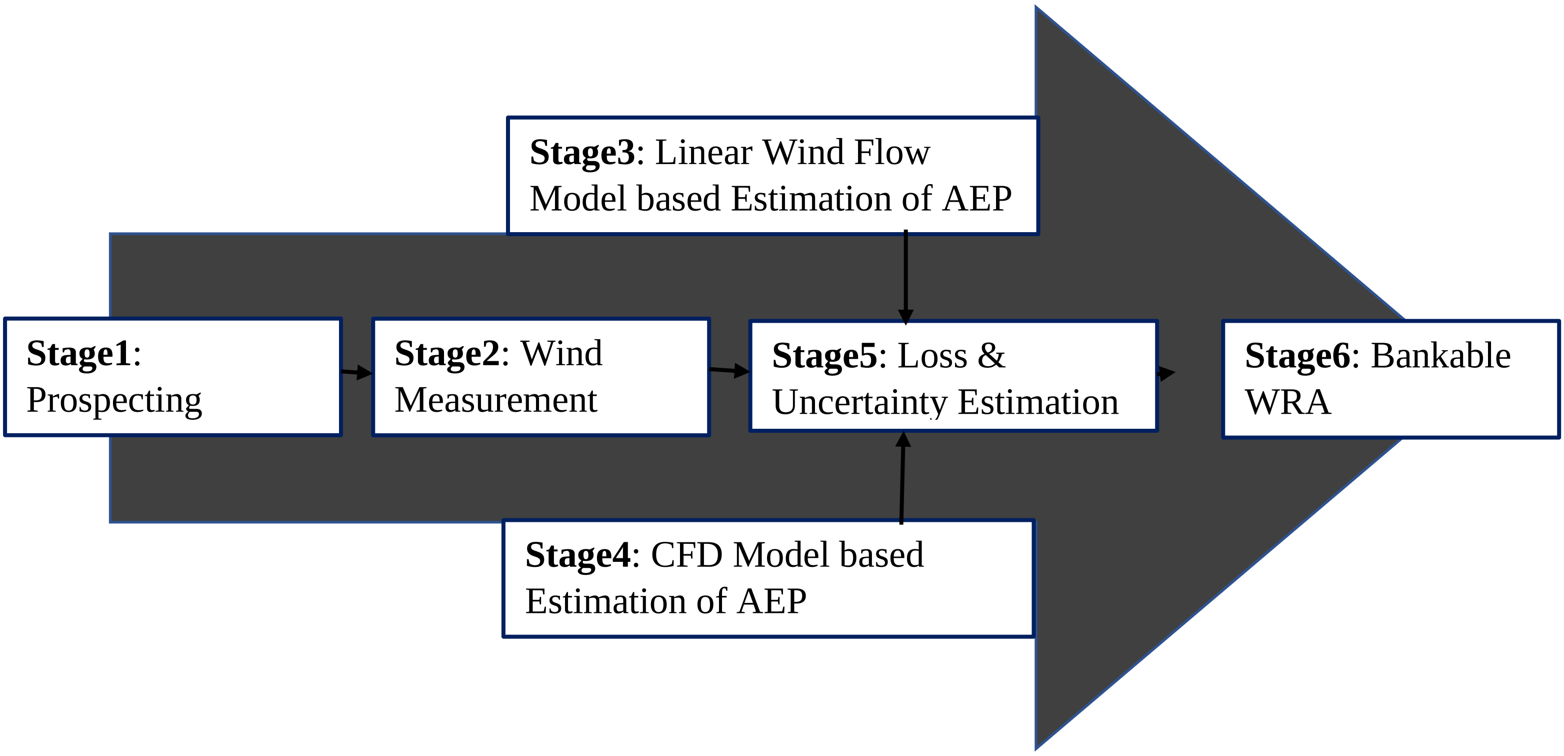


Fig 3-2 Five stages of a wind resource assessment (source: adopted from [28])

Wind energy development is fueled by the available wind resource at any given location. The initial identification of a location, coordination of participating land owners, and conceptual design for a wind farm is typically done by the wind energy company.

However, often times the prospecting activities may be conducted by smaller wind development companies or agents who are most familiar with the local conditions prior to the involvement of the wind energy company that will eventually complete the development activities.

Once the framework for a conceptual design (Conceptual design refers to the initial ideas intended for development of the wind farm prior to having enough information for more detailed design layouts. After more information is gathered from the site the concept for the wind farm is molded into an engineering design that will optimize) the performance of the operation. is put together by these entities, it is then offered to wind development companies to purchase and develop formally [3].

Table 3-1 Wind power project stages [29]

Stages of Wind Power Project	Description
Stage I: Site Identification	The process starts with regional overviews and precision GIS mapping, through which the specific opportunities are determined at a feasible site.
Stage II: Wind Resource Assessment	Accurate Wind Resource Assessment of a widely variable resource is the most critical feature for success of a wind power project. Meso-Scale and then Micro-Scale Wind Power Density/Wind Speed Map is produced for the site location through input of accurate contour/terrain data. The recorded wind data is critically analyzed and formatted to represent wind characteristics. A preliminary wind resource assessment can be carried out by using the freely available Global Wind Atlas
Stage III: Micro-Siting & Energy Estimation	This constitutes the foundation of a Wind Power Project. Wind Resource data is formatted in terms of Speed and direction.
Stage IV: Detailed Project Report	Once the site, make and rating of WEG and the selling option are finalized, detailed survey and field study is conducted.
Stage V: Project Management	Implementation and Management of Wind power project, WPP, calls for multi-disciplinary activities related to Technical, Financial and Commercial aspects.
Stage VI: Monitoring	Energy generation with respect to wind resource, frequency and type of machine and system failures needs to be critically monitored and analyzed to optimize generation.

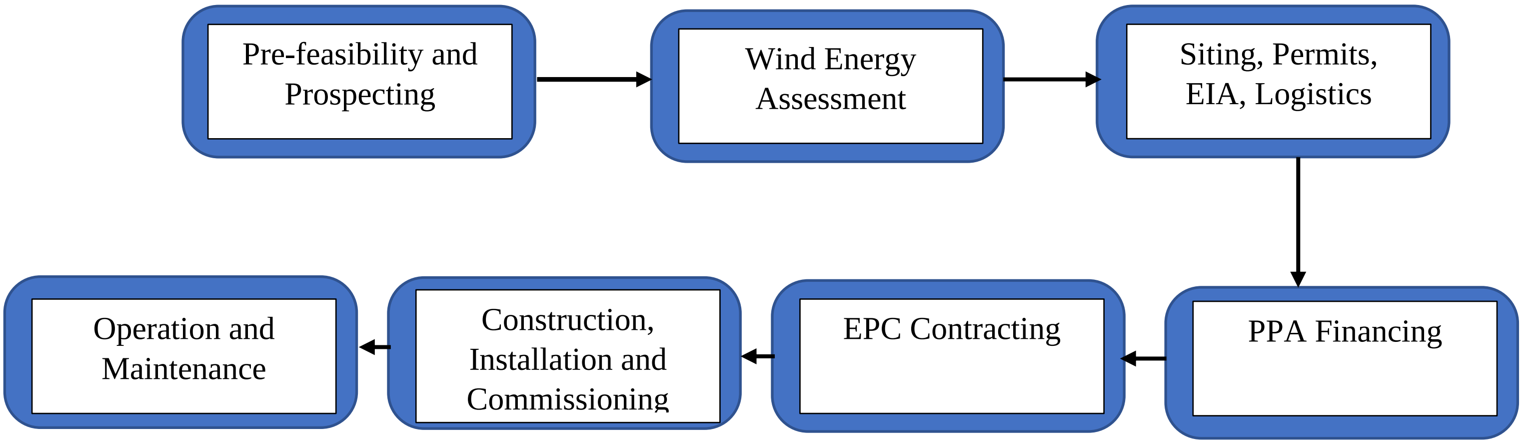


Fig 3-3 Wind energy project life cycle (EIA, PPA and EPC)

Table 3-2 Wind energy project life cycle [28]

Activity (Duration)	Description
Prefeasibility and Prospecting (3 months)	The goal of prefeasibility analysis is to determine regions that have the potential for feasible wind projects. It uses publicly available wind resource maps along with considerations such as taris, land availability, licensing process, transmission, logistics, cost of project, and others. Prospecting involves site visits to the regions that meet the prefeasibility requirement in order to collect additional data about terrain, vegetation, landownership, and other factors. The outcome of prospecting is a shortlist of regions with the highest prospects and locations for wind measurement in these regions
Wind Resource Assessment (WRA)	WRA is the quantification of wind resources to compute parameters such as average wind speed, average wind energy density, and the average annual energy production (AEP) of a proposed wind power plant. A preliminary WRA is started in the previous activity

3.5 Energy in the Wind

Wind turbines convert mechanical power from the wind into electrical power via a rotor connected to a generator. The theoretical energy which the wind transfers to the rotor of wind turbine is proportional to density of the air, the rotor area which the wind over flow and the cube of the wind speed.

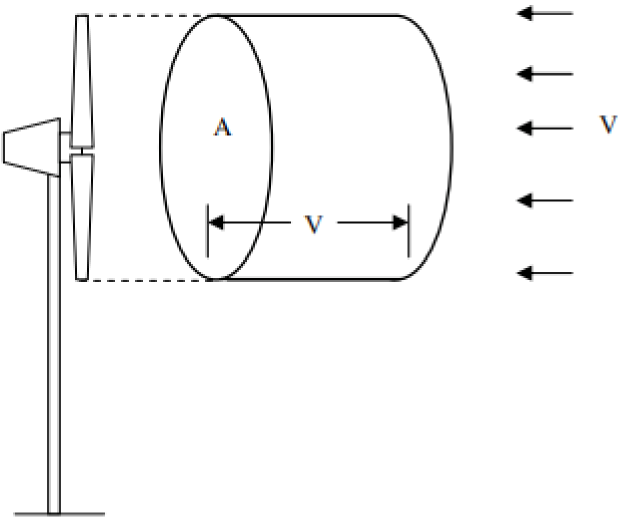


Fig 3-4 An air parcel moving towards a wind turbine [30]

The power *P* of a wind-stream, crossing an area *A* with velocity *v* is given by

$$P = \frac{1}{2}\rho A v^2 \quad (3.1)$$

It varies proportional to air density ρ, to the crossed area *A* and to the cube of wind velocity *v*.

The Power *P* is the kinetic energy

$$E = \frac{1}{2} m v^2 \quad (3.2)$$

of the air-mass *m* crossing the area *A* during a time interval

$$\dot{m} = A\rho \frac{dx}{dt} = A\rho v \quad (3.3)$$

Because power is energy per time unit, combining the two equations leads back to the primary mentioned basic relationship of wind energy utilization.

$$P = \dot{E} = \frac{1}{2}\dot{m}v^2 \times \frac{1}{2} \times \rho \times Av^3 \quad (3.4)$$

The power of a wind-stream is transformed into mechanical energy by a wind turbine through slowing down the moving air-mass which is crossing the rotor area. For a complete extraction of power, the air-mass would have to be stopped completely, leaving no space for the following air-masses [31].

3.5.1 The wind

The earth receives around $1.7\text{x}10^{14}$ kW of power from the sun in the form of solar radiation. This radiation heats up the atmospheric air [30]. The intensity of this heating will be more at the equator (0^0 latitude) as the sun is directly overhead. Air around the poles gets less warm, as the angle at which the radiation reaches the surface is more acute. The density of air decreases with increase in temperature.

Thus, lighter air from the equator rises up into the atmosphere to a certain altitude and then spreads around. This causes a pressure drop around this region, which attracts the cooler air from the poles to the equator.

This movement of air causes the wind. Thus, the wind is generated due to the pressure gradient resulting from the uneven heating of earth's surface by the sun. As the very driving force causing this movement is derived from the sun, wind energy is basically an indirect form of solar energy. One to two per cent of the total solar radiation reaching the earth's surface is converted to wind energy in this way [30].

3.5.2 Analysis of wind data

For estimating the wind energy potential of a site, the wind data collected from the location should be properly analyzed and interpreted. Long term wind data from the meteorological stations near to the candidate site can be used for making preliminary estimates.

Modern wind measurement systems give us the mean wind speed at the site, averaged over a pre-fixed time period. Ten minutes average is very common as most of the standard wind analysis software's are tuned to handle data over ten minutes.

This short-term wind data is further grouped and analyzed with the help of models and software's to make precise estimates on the energy available in the wind.

3.5.3 Power curve and air density

The Power curve of a wind turbine is an important parameter, describing the relation between the wind speed on site and the respective electrical energy output.

Power curves and ct-values (a parameter for the calculation of the wake effect) of the turbines under consideration are applied for the energy calculation.

Power curves which had been measured by independent institutions are of higher quality than calculated ones. Due to the fluctuations of both the characteristics of the wind turbine components, and the measuring conditions power curves of different measurements differing slightly between each other.

During the calculation of the energy yield, the power curves, given for the standard conditions of air density = 1.225 kg/m^3 are adapted to the air density of each individual turbine location at hub height, with the transformed power curves for the average air density [32].

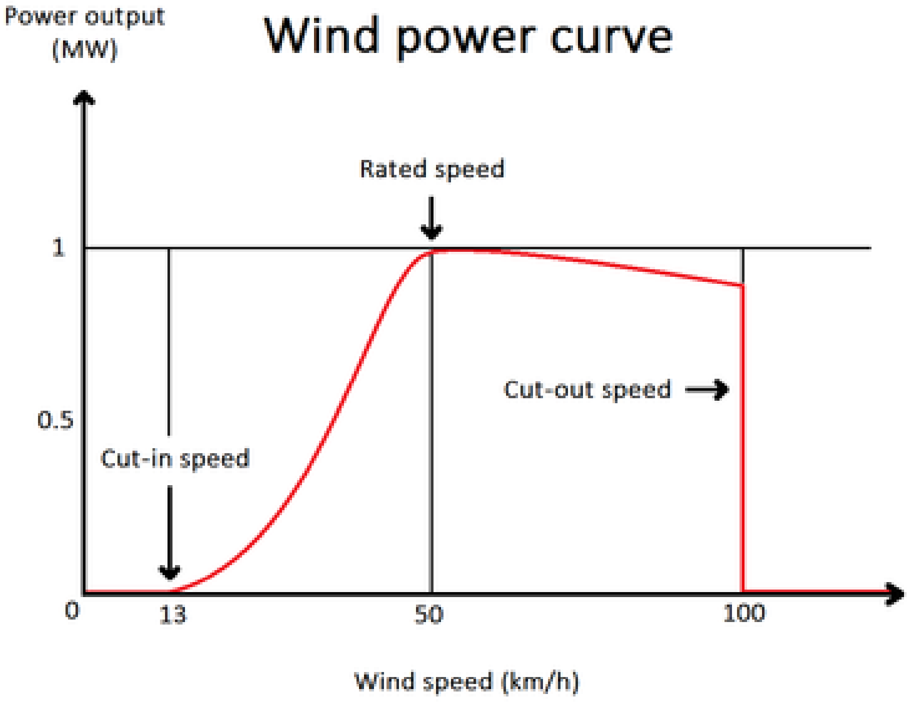


Fig 3-7 Power curve (source: Energy Education, 2020 [33])

3.6 Main areas in wind resource assessment

- Average wind speed and wind distribution
- Area data
  - Mean power density
  - Wind frequency rose, sector and degree sector
  - Mean wind speed
- Wind speed variability such as
  - Wind speed index versus (yearly, monthly and hourly data)
  - Histography of wind frequency
  - Heat map of the area (cross table and radar plot)
- Energy yield calculation
  - Determining typica Power curve
- Weibull parameters and wind frequency distribution
- Characterizing wind variation
  - Simple approach: average wind speed
  - Better approach: wind speed distribution
- Hub height
  - The best data is for the hub height of the proposed turbine.
  - Distance from the ground to the center of rotor.
  - This has been steadily growing now typically 80 meter or above.
- Input model parameters
  - Digital terrain Model (DTM) such Roughness map, Slope map and Hill shape map
  - Orography and Digital elevation model (DEM)

To simplify the wind power density, the wind resource is divided into seven wind classes. The wind class division is basically based on energy generated from a particular wind speed.

Table 3-3 Standard classes of wind power

Wind power class	Annual mean wind speed (m/s)	Annual mean wind power density (w/m^2)		Wind energy resource partition
		Method 1	Method 2	
1	0.0 – 4.4	< 100	< 50	Poor
2	4.4 – 5.1	100 – 150	50 – 150	Moderate
3	5.1 – 5.6	150 – 200	150 – 200	Good
4	5.6 – 6.0	200 – 250	200 – 250	Very Good
5	6.0 – 6.4	250 – 300	250 – 300	
6	6.4 – 7.0	300 – 400	300 – 400	
7	7.0 – 9.4	400 – 1000	400 – 1000	

3.7 Economic Analysis

Based on Great Glen Energy co-operative wind farm facts, the load factor of wind varies according to the site and the type of turbine, but it is generally around 30%. It’s higher during the winter than the summer. A typical wind farm with an installed capacity of 5 MW will produce 13,14000 kwh/year, or 30% of what it would produce if it operated continuously at maximum output. Operating lives can be up to 25, or even 30 years, depending on individual site conditions.

According to various wind turbine manufacturing companies’ market scenario on wind turbine operating cost, the typical wind turbine is 2-3 MW in power. Hence, most turbines cost in the $2-4 million dollar range. On the other hand, operational and maintenance costs run an additional $42,000-$48,000 per year, which is $1,300,000 USD per Megawatt. Meanwhile, expected one major component replacement (like rotor or gearbox) of 20% to 25% of initial cost.0

Table 3-5 RET screen Expert estimation on the economic sustainability of the hypothetical wind farm

Portion of Installed Cost	Values
Feasibility study	2%
Development	4%
Engineering	4%
Turbine cost	70%
Balance plant and Miscellaneous	20 %

Wind energy software's

QGIS functions as geographic information system (GIS) software, allowing users to analyze and edit spatial information, in addition to composing and exporting graphical maps. QGIS supports both raster and vector layers; vector data is stored as either point, line, or polygon features. Multiple formats of raster images are supported, and the software can georeferenced images [35].

ArcGIS is a geographic information system (**GIS**) for working with maps and geographic information maintained by the Environmental Systems Research Institute (Esri). It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database [36].

WRPLOT View is a fully operational wind rose program for your meteorological data. It provides visual wind rose plots, frequency analysis, and plots for several meteorological data formats. A wind rose depicts the frequency of occurrence of winds in each of the specified wind direction sectors and wind speed classes for a given location and time period [37].

SAM's Wind Power model can model a single wind turbine or a wind farm with more than one turbine. Combine the Wind Power performance model with the Residential or Commercial financial model for a behind-the-meter project that uses wind power to reduce a building or facility's electricity bill, such as a residential wind turbine, or wind turbines on a farm or ranch for self-generation [38].

Flow chart: (NMSA[1], Vortex[2] And MERRA-2[3])

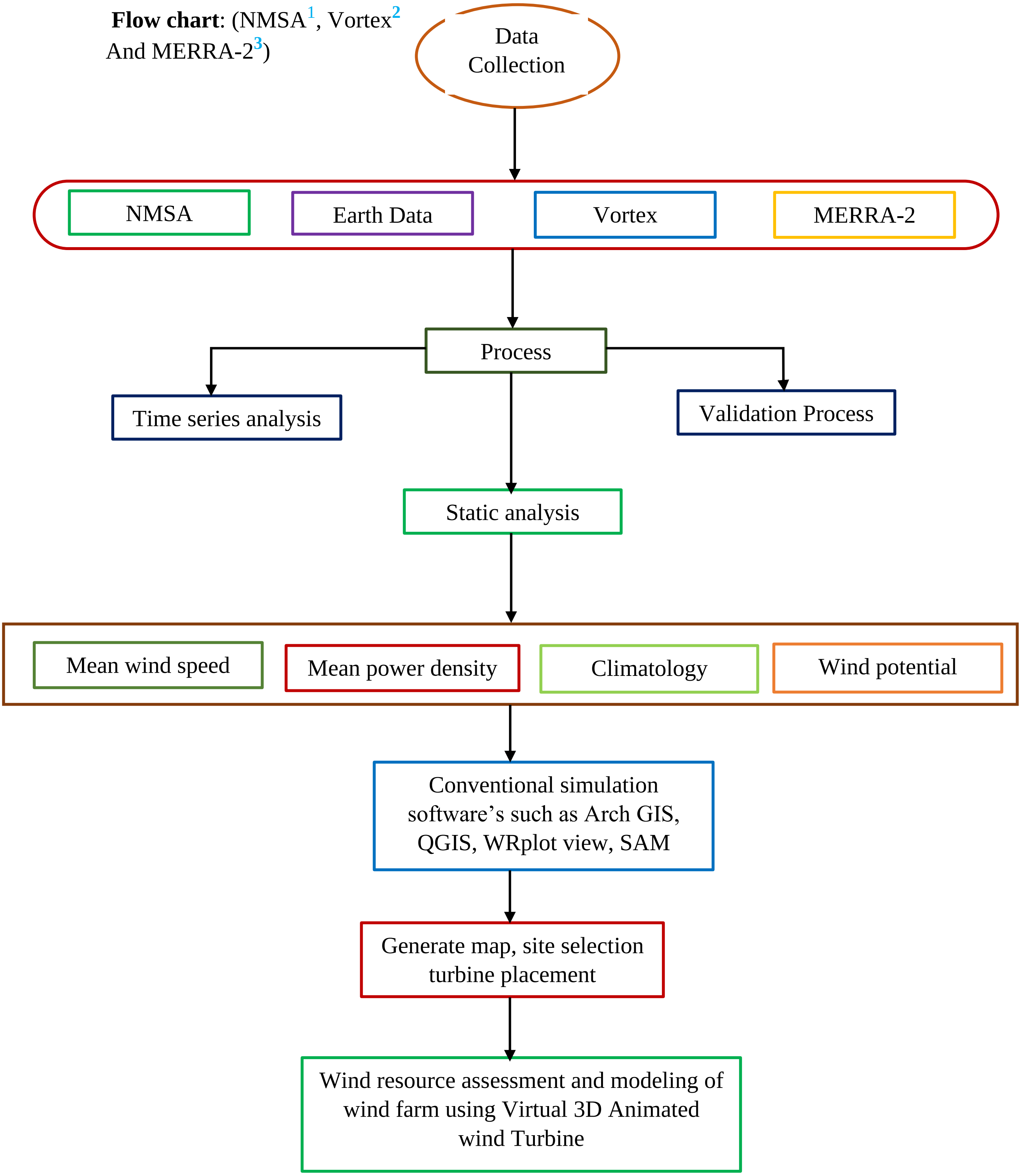


Fig 3-8 Working flow chart

CHAPTER FOUR

Wind Data Analysis

4.1 Area Wind speed data

In this section, wind frequency rose, mean wind speed, and mean wind power density were analyzed. The wind is atmospheric air in motion. It is ubiquitous and one of the basic physical elements of our environment. Depending on the speed of the moving air, the wind might feel light and ethereal, invisible to the naked eye.

Or, it can be a strong and destructive force, loud and visible as a result of the heavy debris it carries along. The velocity of the air motion defines the strength of the wind and is directly related to the amount of energy in the wind, that is, its kinetic energy **[**53**]**.

The source of this energy, however, is solar radiation. The electromagnetic radiation from the sun unevenly heats the earth's surface, with stronger in the tropics and weaker in the high latitudes. Also, as a result of the differential absorption of sunlight by soil, rock, water, and vegetation, the air in different regions warms up at different rates. This uneven heating is converted through convective processes to air movement, which is adjusted by the rotation of the earth.

The convective processes are disturbances of the hydrostatic balance whereby otherwise stagnant air masses are displaced and move in reaction to forces induced by changes in air density and buoyancy due to temperature differences. Air is pushed from high to low-pressure regions, balancing friction and inertial forces due to the rotation of the earth [56].

4.1.1 Wind frequency rose

The wind rose is the time-honored method of graphically presenting the wind conditions, direction and speed, over a period of time at a specific location. To create a wind rose, average wind direction and wind speed values are logged at a site, at short intervals, over a period of time [39]. A wind rose is a circular display of how wind speed and direction are distributed at a given location for a certain time period. The most important data is displayed by each "spoke." The length of each "spoke" tells the frequency of wind coming from a particular direction.

Table 4-1 Wind direction (Adopted from [40])

Abbreviation	Wind direction	Degrees
N	North	0°
NNE	North-Northeast	22.5°
NE	Northeast	45°
ENE	East-Northeast	67.5°
E	East	90°
ESE	East-Southeast	112.5°
SE	Southeast	135°
SSE	South-Southeast	157.5°
S	South	180°
SSW	South-Southwest	202.5°
SW	Southwest	225°
WSW	West-Southwest	247.5°
W	West	270°
WNW	West-Northwest	292.5°
NW	Northwest	315°
NNW	North-Northwest	337.5°

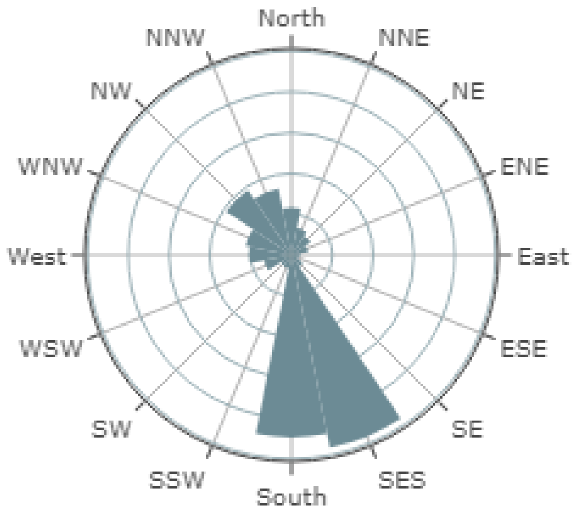


Fig 4-1 Wind Rose of Dire Dawa (Vortex)

The collected wind data is then sorted by wind direction so that the percentage of time that the wind was blowing from each direction can be determined. Typically, the wind direction data is sorted into twelve equal arc segments, 30° each segment, in preparation for plotting a circular graph in which the radius of each of the twelve segments represents the percentage of time that the wind blew from each of the twelve 30° direction segments. Wind speed data can be superimposed on each direction segment to indicate, for example, the average wind speed when the wind was blowing from that segment's direction and the maximum wind speed during the logging period [39].

Table 4-2 Wind frequency rose of Dire Dawa wind farm (Global wind Atlas, 2021)

Value	**Sector**	**Center degrees**
0.09	1	30
0.05	2	60
0.03	3	90
0.03	4	120
0.03	5	150
0.13	6	180
0.29	7	210
0.06	8	240
0.06	9	270
0.06	10	300
0.07	11	330
0.09	12	360

Table 4-3 Wind power rose of Dire Dawa wind farm (Global Wind Atlas, 2021)

Value	**Sector**	**Center degrees**
0.04	1	30
0.03	2	60
0.02	3	90
0.02	4	120
0.02	5	150
0.21	6	180
0.5	7	210
0.05	8	240
0.03	9	270
0.03	10	300
0.03	11	330
0.04	12	360

Table 4-4 Wind speed rose of Dire Dawa wind farm (Global wind Atlas)

Value	Sector	Center degrees
	1	30
	2	60
	3	90
	4	120
0.01	5	150
0.26	6	180
0.67	7	210
0.03	8	240
	9	270
	10	300
	11	330
	12	360

4.1.2 Mean wind speed

Time-averaged wind speed, averaged over a specified time interval. The mean wind speed varies with elevation above mean sea level and the averaging time interval; a standard reference elevation is 10 m and a standard time interval is 1 hour [41].

Table 4-5 Mean wind speed (Km/h) of Dire Dawa wind farm at 10 m (New_locClim)

January	February	March	April	May	June	July	August	September	October	November	December	Yearly
6.12	6.12	6.48	6.4	7.2	9.7	9	9.72	6.12	5.76	6.12	5.76	7.2
6.12	6.12	6.48	6.1	7.2	9.7	9	9.72	6.12	5.76	6.12	5.76	6.84
3.6	2.88	3.6	2.8	2.8	3.6	2.8	2.88	2.88	2.16	3.96	5.76	3.24
6.12	6.12	5.4	5.4	5.4	4.6	4.6	4.68	4.68	4.68	6.12	7.2	5.4
5.4	4.32	4.32	4.6	4.3	5.4	4.3	5.4	4.32	3.96	5.76	7.2	5.04
4.32	4.32	4.68	4.6	5.4	6.1	7.9	7.92	6.48	7.2	4.32	4.32	5.76
6.12	4.68	4.32	4.3	4.3	7.2	7.2	6.12	5.4	4.32	4.68	4.32	5.4
2.16	2.16	2.16	3.9	4.3	4.3	2.1	1.8	1.8	1.8	1.8	2.16	2.52
4.68	4.32	4.32	3.6	2.8	5.4	6.4	4.32	2.88	2.88	3.6	3.96	3.96
26.28	24.84	24.48	24.84	24.84	36.36	40.68	39.96	28.8	23.4	26.28	27	28.8
7.09	6.59	6.62	6.7	6.8	9.2	9.4	9.25	6.95	6.19	6.88	7.34	7.42

Table 4-6 Mean Wind speed of Dire Dawa wind farm from various station at 10 m (New_locClim)

Wind	[km/h]	[km/h]	[km/h]
February	6.12	3.73	8.51
March	6.12	3.8	8.44
April	6.48	4.49	8.47
May	6.48	4.4	8.56
June	7.2	4.62	9.78
July	9.72	6.14	13.3
August	9	4.84	13.16
September	9.72	5.62	13.82
October	6.12	4.03	8.21
November	5.76	3.51	8.01
December	6.12	4.34	7.9
Mean	5.76	4.58	6.94

Table 4-7 Neighbor meteorological station

Longitude [degree]	Latitude [degree]	Altitude [m]	Distance [km]	Direction	Direction	Station Name	Country Name
42.05	9.43	2125	29	131	SE	ALEMAYA	ETHIOPIA
41.83	9.13	2250	52.3	182	S	GRAWA	ETHIOPIA
42.11	9.2	1856	52.8	147	SE	HARER	ETHIOPIA
42.11	8.78	1428	95.5	163	S	MIDAGALOLOA	ETHIOPIA
42.71	9.33	1644	99	108	E	JIGGIGA	ETHIOPIA
40.63	10.08	625	143.9	292	W	GEWANI	ETHIOPIA
40.38	9.46	737	162	265	W	MELKA-WERER-AMBIBARA	ETHIOPIA
40.16	8.98	1052	197.9	250	W	AWASH	ETHIOPIA
39.9	8.86	930	229.3	249	W	METEHARA	ETHIOPIA
44.08	9.5	1326	244.8	92	E	HARGEISA	SOMALIA

Table 4-8 Mean wind speed of Dire Dawa wind farm at 10 m (RET screen Expert)

Wind speed at 10m range (m/sec)	Count
January	2.9
February	3.0
March	2.8
April	2.8
May	3.2
June	4.7
July	5.3
August	5.3
September	3.5
October	3.0
November	2.9
December	2.8
Annual	**3.5**

Table 4-9 Wind speed of Dire Dawa at 10 m (power access, NASA)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2011	4.37	4.75	4.78	4.06	4.62	6.52	6.24	7.13	5.78	5.03	4.44	4.79	5.21
2012	4.77	5.03	4.58	4.38	4.48	7	6.63	6.06	5.14	4.01	3.85	4.48	5.03
2013	4.34	4.92	4.23	3.35	4.9	7.17	6.05	6.32	4.95	3.29	3.29	3.58	4.7
2014	4.32	4.39	4	3.51	3.73	6.27	7.24	6.32	4.81	2.79	3.63	4.41	4.62
2015	4.34	4.67	4.56	4.51	4.44	5.53	7.5	7.13	5.91	4.07	4.23	4.42	5.11
2016	3.84	4.9	4	3.68	4.04	6.3	6.39	6.21	6.07	3.24	3.83	4.64	4.76
2017	4.44	4.12	4.28	3.85	3.57	6.69	7.25	6.93	5.04	3.53	4.21	4.19	4.85
2018	4.71	4.31	3.74	3.37	4.57	6.26	6.83	6.46	4.79	3.22	3.75	4.26	4.69
2019	4.66	4.65	4.03	3.67	4.25	6.14	6.86	6	5.76	3.07	3.46	3.47	4.67

Wind speed at 10 meter is not sufficiently accurate in measurement of wind farm:

- Because, output wind turbine is related to be cube of wind speed.
- There could be building and other obstacles that affects wind regimes.
- Terrain and vegetation affect wind speed.
- For large wind turbine, the tower is around 100 meter which is wind speed depends on height.

Table 4-10 Mean wind speed of Dire Dawa wind farm at 50 m (MERRA-2 Reanalyze, NASA)

Wind speed at 50m range (m/sec)	Count
5.52-5.72	9
5.72-5.92	10
5.92-6.12	11
6.12-6.32	10
6.32-6.52	6
6.52-6.72	2
6.72-6.92	1
6.92-7.12	1
Grand Total	**50**

Table 4-11 Wind speed at 50 m (power access, NASA)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2011	5.07	5.75	5.61	4.96	5.44	7.42	8.44	8.69	6.52	6.41	5.28	5.55	6.27
2012	5.55	5.86	5.53	5.52	5.89	8.01	8.46	7.76	6.2	5.07	4.84	5.13	6.15
2013	5.19	5.83	5.03	4.27	5.89	8.44	8.9	7.9	5.94	4.5	4.17	4.44	5.88
2014	5	5.07	4.77	4.66	4.75	7.69	8.87	7.8	5.77	4.03	4.66	5.12	5.69
2015	5.26	5.4	5.39	5.58	5.42	6.49	8.84	9.11	6.65	5.48	5.2	5.23	6.18
2016	4.8	5.54	5.14	4.43	4.85	7.78	8.15	8.52	7.17	4.47	4.88	5.5	5.94
2017	5.3	4.94	5.03	4.78	4.31	7.94	9.04	9.12	5.85	4.83	5.25	5.07	5.96
2018	5.45	4.99	4.92	4.23	5.57	7.49	9.11	8.48	6.34	4.51	4.52	5.03	5.9
2019	5.28	5.53	5	4.38	5.27	6.95	8.38	7.9	6.95	3.85	4.49	4.32	5.69

Table 4-12 Mean wind speed of Dire Dawa wind farm above 100 m (NASA, Vortex and Global wind Atlas)

Wind speed (m/s)	Count
6.82-7.02	8
7.02-7.22	10
7.22-7.42	12
7.42-7.62	10
7.62-7.82	6
7.82-8.02	2
8.02-8.24	2
Grand Total	**50**

4.1.3 Mean wind power density

Wind power density is a useful way to evaluate the wind resource available at a potential site (**wind resource evaluation**). The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a **wind turbine**.

Table 4-13 Mean wind speed above 100 m (Vortex, NASA and Global wind Atlas)

Mean power density (w/m²)	**Percentage of windiest area (%)**
472.6	96
505.665	86
541.02	76
575.9344444	66
610.7157143	56
645.956	46
683.0933333	36
716.84	26
746.1	16
804.66	10

4.2 Wind speed variability

In this sub topic inter annual data, annual data and diurnal data will be analyzed.

4.2.1 Inter annual data

Interannual variability (IAV) is used to describe the year-to-year variability in a given property [42].

Table 4-14 Inter annual data of Dire Dawa at 50 m, maximum (power access, NASA)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2011	7.11	7.48	7.57	6.65	7.21	9.26	10.49	10.81	8.38	7.84	6.78	7.2	8.07
2012	7.25	7.72	7.29	7.34	7.53	10.02	10.43	9.8	8.34	7.46	7.15	7.11	8.12
2013	7.06	7.56	6.84	5.97	7.82	10.33	10.97	9.88	7.97	6.66	6.32	6.77	7.85
2014	7.18	6.94	6.44	6.1	6.31	9.45	10.8	9.76	8.02	6.09	6.86	7.11	7.59
2015	7	7.3	7.12	7.22	7.2	8.4	10.71	11.11	8.37	7.13	6.87	7.06	7.96
2016	6.55	7.51	6.98	6.19	7.07	9.95	10	10.63	9.19	7.03	7.14	7.42	7.97
2017	7.25	6.7	6.78	6.57	6.08	10	10.87	11.01	7.66	6.9	7.39	7.26	7.88
2018	7.07	6.65	6.82	5.99	7.48	9.4	11.03	10.55	8.15	6.55	6.54	6.99	7.78
2019	7.22	7.16	6.67	5.5	6.92	8.77	10.19	9.7	8.96	5.18	6.28	6.4	7.42

Table 4-15 Interannual data versus wind speed index

Year	Wind speed index
2008	1.02
2009	1.01
2010	0.97
2011	1
2012	1.01
2013	0.98
2014	0.95
2015	1.02
2016	1.02
2017	1.02

4.2.2 Annual data

Significant variations in seasonal/ monthly averaged wind speeds are common over most of the world.

Table 4-16 Annual data vs wind speed index

Month	Wind speed index
1	0.44
2	0.48
3	0.76
4	0.98
5	0.97
6	1.67
7	1.98
8	1.84
9	1.25
10	0.68
11	0.52
12	0.4

4.2.3 Diurnal data

Diurnal (time of day) in both tropical and temperature, latitude, large wind variations also can occur on a diurnal or daily time scale.

Table 4-17 Hourly data vs wind speed index

Wind speed index	Time (hourly)
0.64 - 0.84	
	8.5 – 11
	11 - 13.5
	13.5 – 16
	16 - 18.5
0.84 - 1.04	
	6 - 8.5
	16 - 18.5
	18.5 – 21
1.04 - 1.24	
	6 - 8.5
	18.5 – 21
	21 - 23.5
1.24 - 1.44	
	1 - 3.5
	3.5 – 6

Table 4-18 Wind speed climatology of Dire Dawa at 50 m (power access, NASA)

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
WS50M_MAX	7.05	7.13	6.71	6.47	7.1	9.62	10.39	10.38	8.26	6.76	7.02	6.95
WS50M_RANGE	6.05	6.06	5.6	5.24	5.83	8.24	7.91	7.94	7	5.3	5.86	5.95
WS50M	3.83	3.97	3.93	4.04	4.56	5.88	6.68	6.63	4.98	4.37	4.04	3.79

Table 4-19 Wind speed climatology of Dire Dawa at 10 m (power access, NASA)

MONTHS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
WS10M_MAX	5.15	5.27	4.92	4.73	5.23	7.69	8.41	8.31	6.26	4.7	4.89	4.95
WS10M_RANGE	4.39	4.41	4.02	3.74	4.18	6.53	6.61	6.6	5.26	3.57	4	4.2
WS10M	2.91	2.98	2.83	2.83	3.24	4.65	5.25	5.01	3.49	2.96	2.86	2.8

4.3 Energy yield calculation

- Turbine type = Generic 3.45MW IEC class 2
- Power control system = Pitch
- Rated power (kw) = 3450kw
- Rotor diameter = 126m
- Hub height (meter) = 100m
- Design annual average wind speed (m/s) = 8.5 m/sec
- Power curve valid for air density (kg/m^3) = 1.225 kg/m^3

Table 4-20 Wind speed vs power

Wind Speed (m/s)	Power (kilowatt)
3	35
3.5	101
4	184
4.5	283
5	404
5.5	550
6	725
6.5	932

4.4 Elevation of Dire Dawa wind farm

Elevation is distance above sea level. Elevations are usually measured in meters or feet. They can be shown on maps by contour lines, which connect points with the same elevation; by bands of color; or by numbers giving the exact elevations of particular points on the Earth’s surface [43].

The elevation of a geographic location is its height above or below a fixed reference point. The term elevation is mainly used when referring to points on the Earth's surface.

Table 4-21 Elevation of Dire Dawa wind farm

Field	**ID**	**Elevation**
1	0	1140
2	1	1160
3	2	1170
4	3	1200
5	4	1200
6	5	1220
7	6	1220
8	7	1230
9	8	1230
10	9	1260
11	10	1270
12	11	1150
13	12	1160
14	13	1220
15	14	1170
16	15	1200

4.5 Site suitability analysis

GIS is a spatial decision support tool for wind farm location analy sis. This is done based on various site-screening criteria. Various factors are the determinants for selecting sites that may be suitable for a new wind farm development. The criteria include exclusion factors are human settlement, commercial places, water bodies, major roads, railways, forest and reserved areas. Elevation, slope, and wind power density are such important parameters to taken into account for wind resource assessment.

The GIS system performs geographic filtering in order to exclude unsuitable places for wind farm sitting. The result is a number of good sites that satisfy the requirements of a proposed wind farm [44].

Criteria for site suitability analysis:

- Wind energy potential such as wind speed, wind power density, wind rose...etc.
- Distance from access road for maintenance.
- Digital elevation model such as Slope, Contour line
- Digital terrain model such as topography, roughness, orograph...etc.
- Population density.
- Distance to transmission line.

Table 4-22 Selection criteria justification (adopted from Al-shabeeb [19])

Criteria	Justifications
Wind speed (W)	Wind turbines depend on having enough wind speed to rotate the wind turbine blades to generate electricity
Rainfall (R)	Areas with more rainfall will generate more runoff which will have an effect on the wind turbines sites
Altitude (A)	Areas with higher altitude have the potential of getting more winds than their surrounding
Slope (S)	Areas with high slope will generate more runoff. Also, high slopes cause technical difficulties when installing wind turbines
Land use (L)	Land uses are important for environmental and socio-economic reasons. It is imperative not to degrade the economic value of the land that has a fundamental use. Also, it is significant not to damage the environment; mainly the wild life (Flora and Fauna)

Table 4-23 Details of sites in Dire Dawa region

Sites	Location	Latitude	Longitude	Elevation (ft)
K’ench’era (Site1)	Dire dawa	$9^0$53’08.06’’N	$41^0$83’3.15’’N	4549
Jelo (Site2)	Dire dawa	$9^0$49’08.71’’N	$41^0$08’0.43’’N	5100
Afretu (Site3)	Dire dawa	$9^0$54’03.79’’N	$41^0$99’0.82’’N	5511

Table 4-24 Details of Ke'nche'ra (site 1) in Dire Dawa

Criteria	Justifications
Site Name	Ke'che'ra (Site 1)
Rotor diameter (m)	126
Hub height (m)	100
Air density (kg/m^3)	1.225
Mean wind speed (m/s)	6.4
Mean wind power density (w/m^2)	650
Population density	Less populated
Distance to Dire dawa km (ft)	11.16 km (6.93 miles)
Total area km (ft)	694,966.84 m^2 (7,480,560.80 ft^2)

Table 4-25 Details of Jelo (site2) in Dire Dawa

Criteria	Justifications
Site Name	Jelo (Site 2)
Rotor diameter (m)	126
Hub height (m)	100
Air density (kg/m^3)	1.225
Mean wind speed (m/s)	7.0
Mean wind power density (w/m^2)	740
Population density	moderate
Distance to Dire dawa km (ft)	11.36 km (7.06 miles)
Total area km (ft)	754,239.52 m^2 (8,118,567.03 ft^2)

Table 4-26 Details of Afretu (Site 3) in Dire Dawa

Criteria	Justifications
Site Name	Afretu (Site 2)
Rotor diameter (m)	126
Hub height (m)	100
Air density (kg/m^3)	1.225
Mean wind speed (m/s)	7.5
Mean wind power density (w/m^2)	780
Population density	Less populated
Distance to Dire Dawa km (ft)	28.83 km (17.91 miles)
Total area km (ft)	448,658.30 m^2 (4,829,317.75 ft^2)

Table 4-27 Turbine location in three sites

Sites	Site 1 (K'ench'era)		Site 2 (Jelo)		Site 3 (Afretu)	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
Turbine 1	41.533	9.26	41.89	9.501	41.80	9.478
Turbine 1	41.534	9.26	41.89	9.512	41.80	9.477
Turbine 1	41.535	9.26	41.89	9.523	41.80	9.476
Turbine 1	41.546	9.26	41.89	9.534	41.80	9.475

CHAPTER FIVE

Result and Discussion

5.1 Wind speed and wind power potential map

It is believed that this study provides a comprehensive understanding of the wind energy situation for the majority, if not the entire, of the country's rather specific area, the so-called Dire Dawa wind farm. In this research work, a detailed pre-feasibility study on wind farm plantations was conducted to assess wind power potential and analyze site suitability in Dire Dawa, Ethiopia. Based on QGIS, 3D animated wind turbine, and RET screen experts in a specific province, Dire Dawa, a suitable site was chosen, wind power potential was assessed, and financial viability was checked. The result was validated by comparing Ethiopia national meteorological agency data with MERRA 2 reanalyzed data. The results were used to discuss input model parameters, wind speed variability, and area wind speed. However, it is also worthwhile to discuss the country's potential. Wind has an estimated exploitable potential of 10 GW [45].

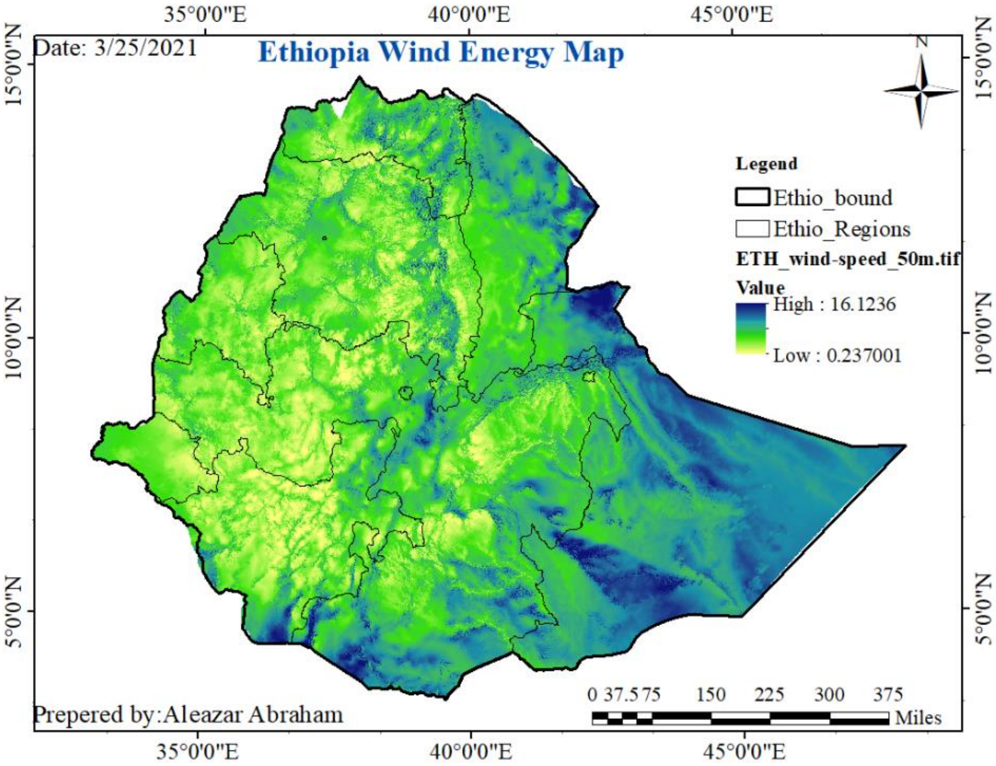
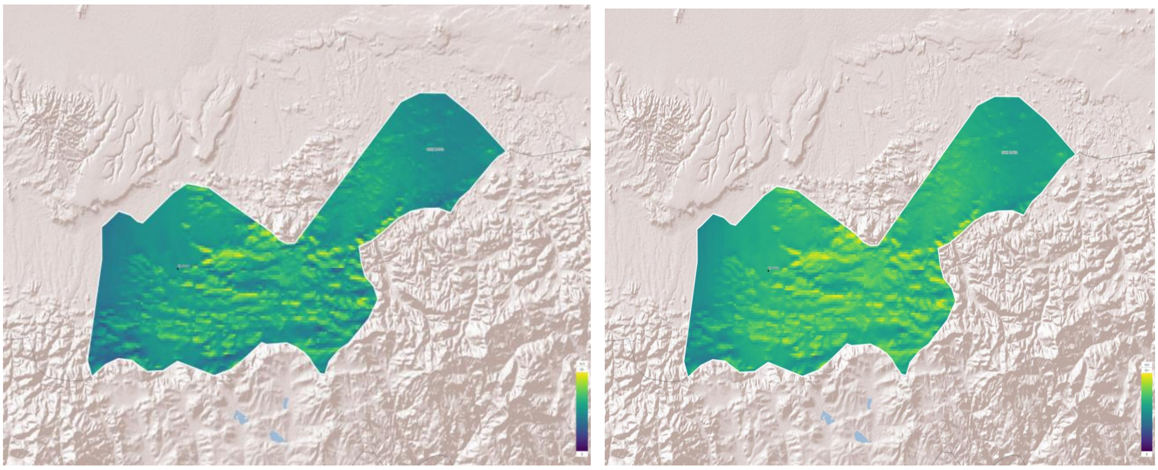


Fig 5-1 Ethiopia wind power potential map (Arch GIS by Aleazar Abraham)



(a) *(b)*

Fig 5-2 Wind speed potential in Dire Dawa region at (a) 50 m and (b) 100 meters (Global wind Atlas)

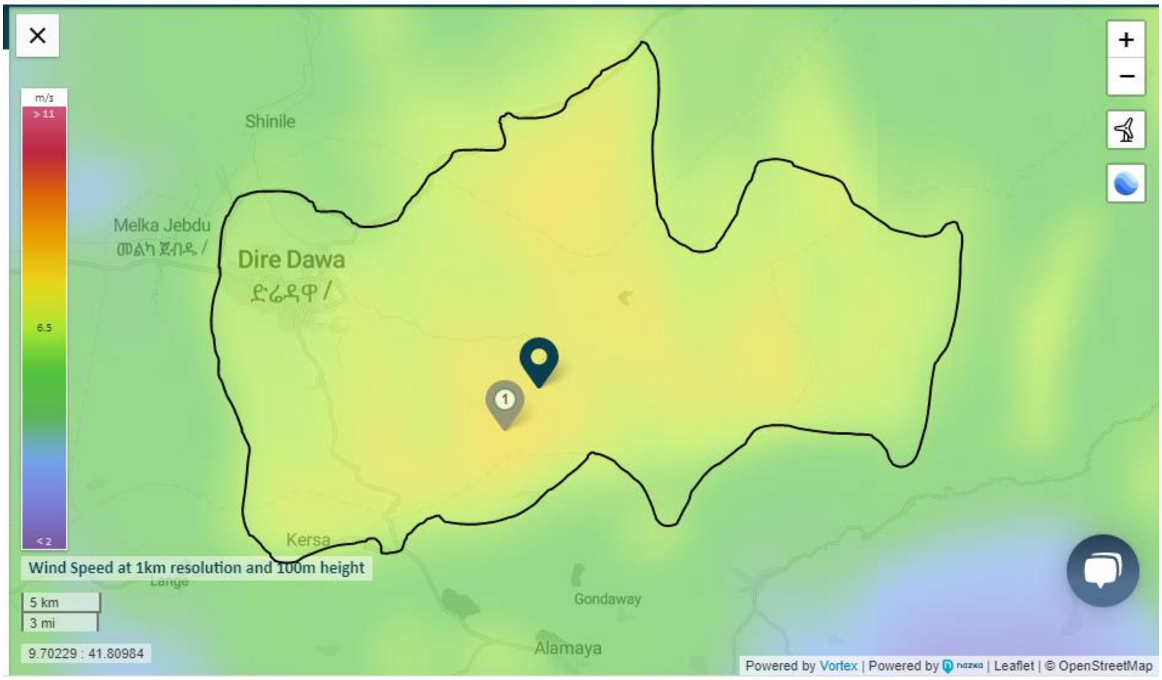


Fig 5-3 Wind speed potential in selected Dire Dawa region at 100 meters (Vortex Factoria de calculus, S.L)

According to the findings acquired in Dire Dawa from diverse wind speed prediction and estimation databases such as Vortex, MERRA-2 reanalyzed, and global wind atlas. The average wind speed at 50 m reaches up to 6.97 m/sec and at 100 reaches 8.24 m/sec, which is suitable for farm plantation, as shown in *figure 5-2 and 5-3*

As can be seen below in *Figure 5-4*, the first stage or scale of wind resource assessment approaches the so-called preliminary area identification, which is selected as a sampling site from the Dire Dawa region to raster wind speed data at 100 m via the global wind atlas.

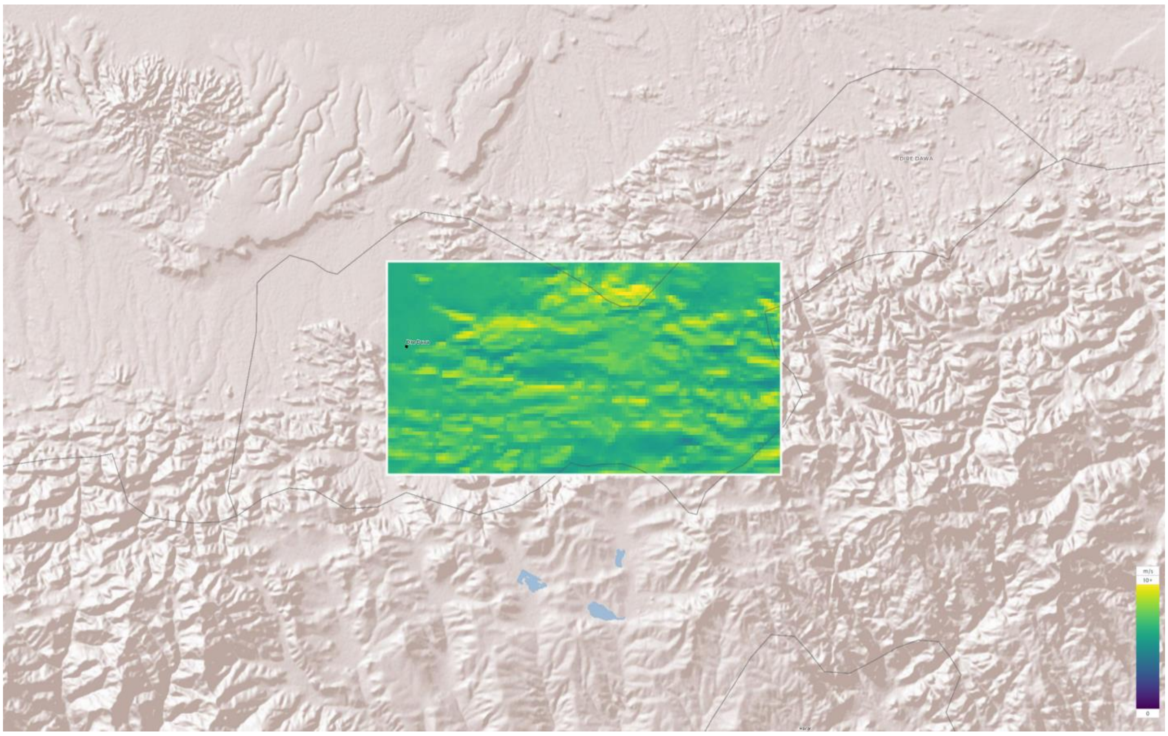


Fig 5-4 Selected Dire Dawa wind farm site at 100 m (Global wind Atlas)

5.2 Digital terrain map

Once a site is carefully chosen, some data want to be found before introducing them into any software. Essential inputs for the software have to be previously obtained and handled in a certain format.

Some of them include:

- Topographic maps,
- Height contours,
- Orography
- Roughness, and
- Slope

Topographic map

The distinctive characteristic of a topographic map is the use of elevation contour lines to show the shape of the Earth's surface. Elevation contours are imaginary lines connecting points having the same elevation on the surface of the land above or below a reference surface, which is usually mean sea level. Contours make it possible to show the height and shape of mountains, the depths of the ocean bottom, and the steepness of slopes [46].

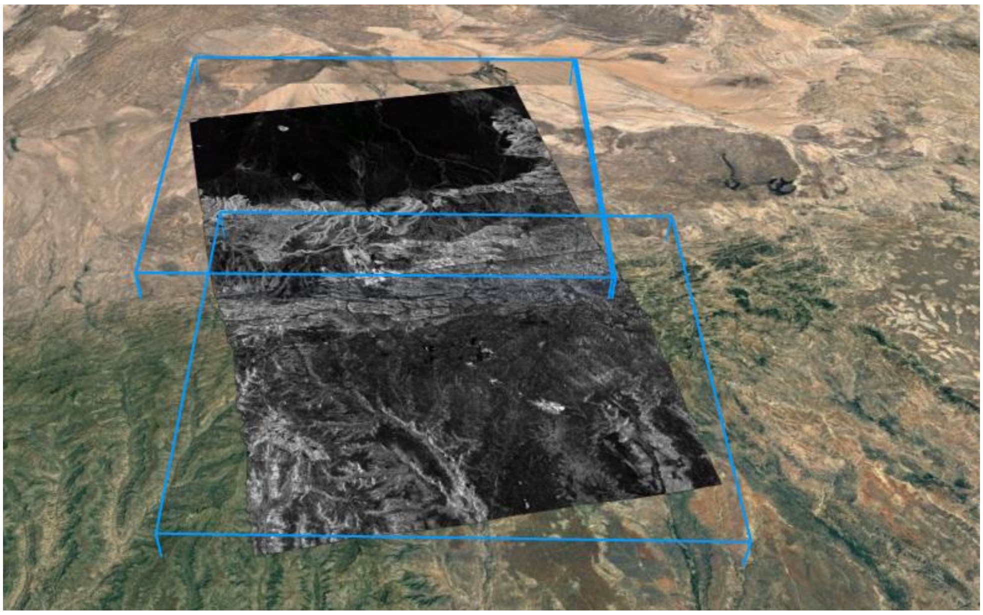


Fig 5-5 Topography map Dire dawa (QIGS via Google Earth by Aleazar Abraham)

❖ **Roughness**

Surface roughness is a component of surface texture, quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough, but when they are small, the surface is smooth.

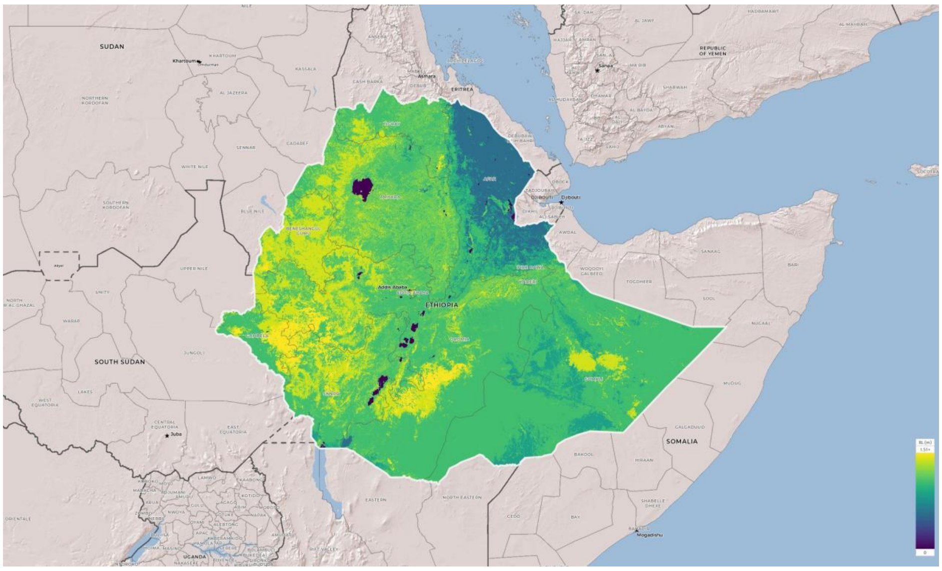


Fig 5-6 Roughness map of Ethiopia (Global wind Atlas)

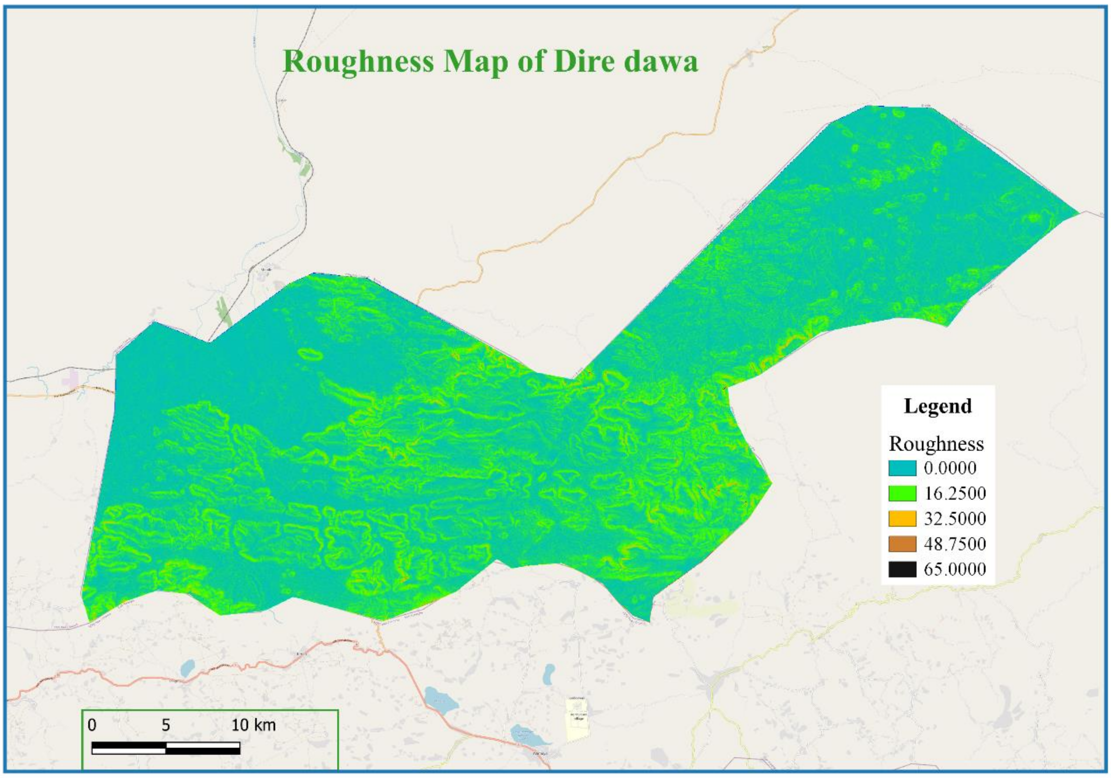


Fig 5-7 Roughness map of Dire Dawa (QGIS by Aleazar Abraham)

❖ **Orography**

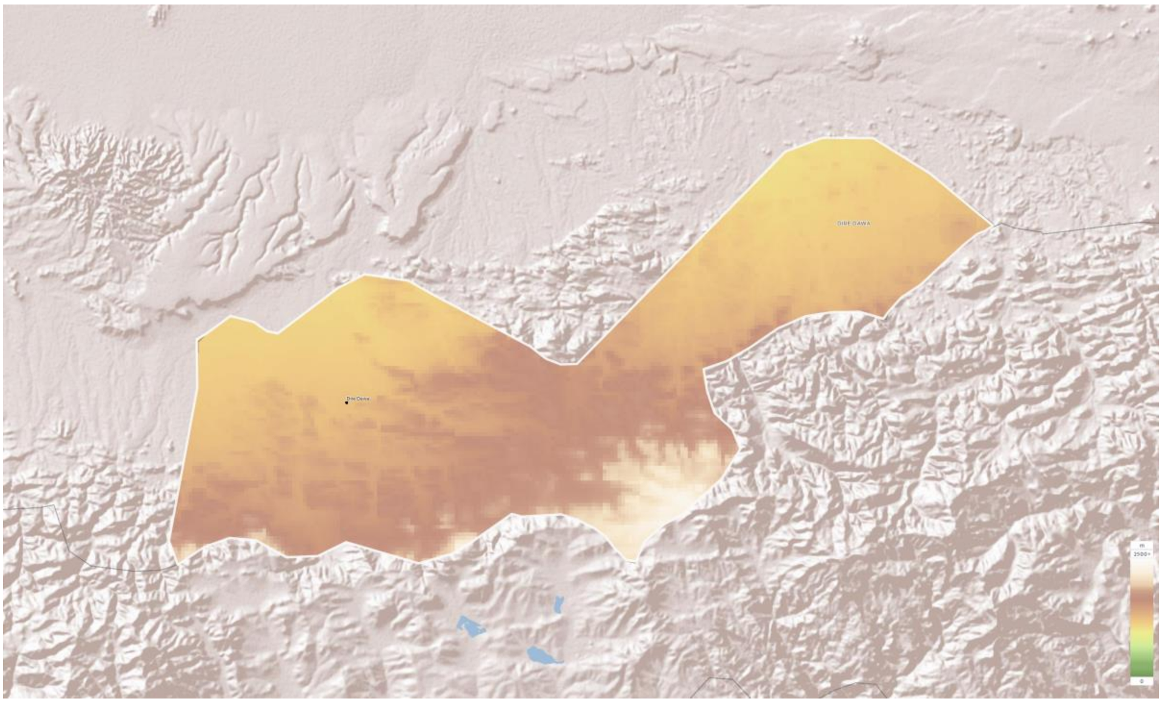


Fig 5-8 Orograph map of Dire Dawa (Global wind Atlas)

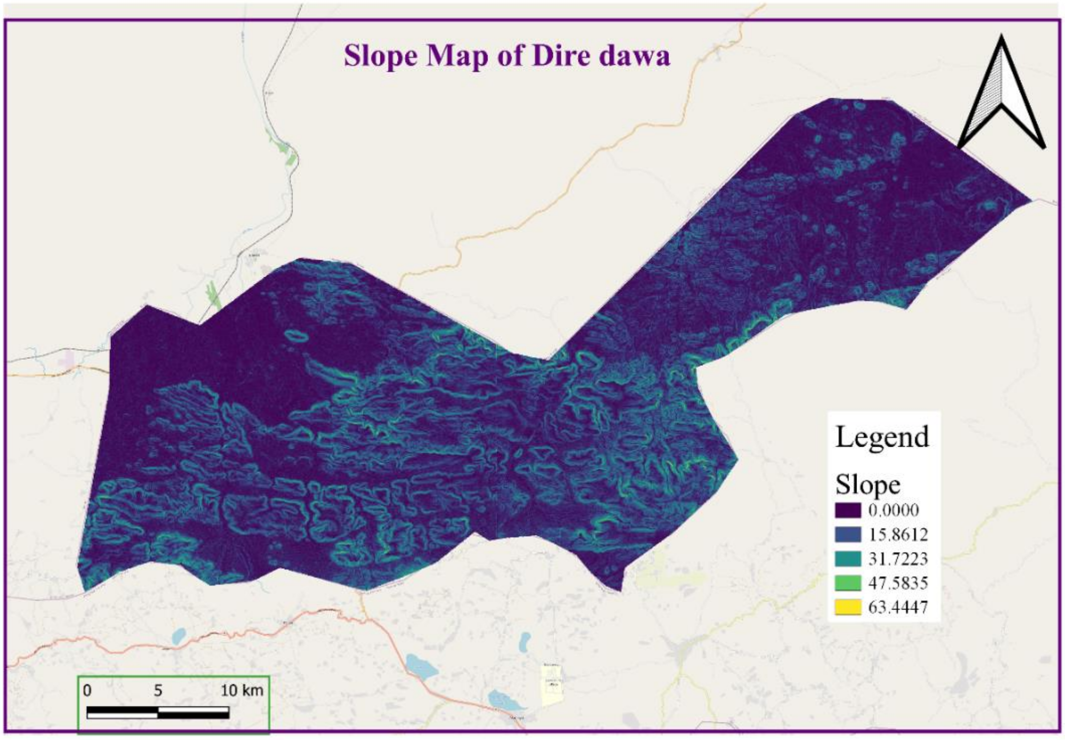


Fig 5-9 Slope map of Dire Dawa (QGIS by Aleazar Abraham)

The majority of the Dire Dawa region has minimal roughness, as shown in *figure 5-7*. Low turbulence intensity is, indeed a consequence of the low surface roughness. As a result, Mechanical loads are reduced. When compared to an identical wind turbine at an onshore position with a same mean wind speed, it may also improve the amount of energy captured [62]. As expected, surface wind speed decreases when surface roughness increases.

The topography of the region is fair, as seen in *figure 5-8.* The favorable pressure gradient enhances the wake velocity near the wall and facilities entrainment into the turbine wake when positioned at the trough of the of the wavy terrain [63]. According to *figure 5-9*, the terrain has a low slope, which is suitable for wind farming.

5.3 Digital elevation model (DEM)

DEM is *a* 3D computer graphics representation of elevation data to represent terrain, commonly of *a* planet, moon, *or* asteroid. A "global DEM" refers to a discrete global grid. DEMs are used often in geographic information systems, and are the most common basis for digitally produced relief maps (Wikipedia).

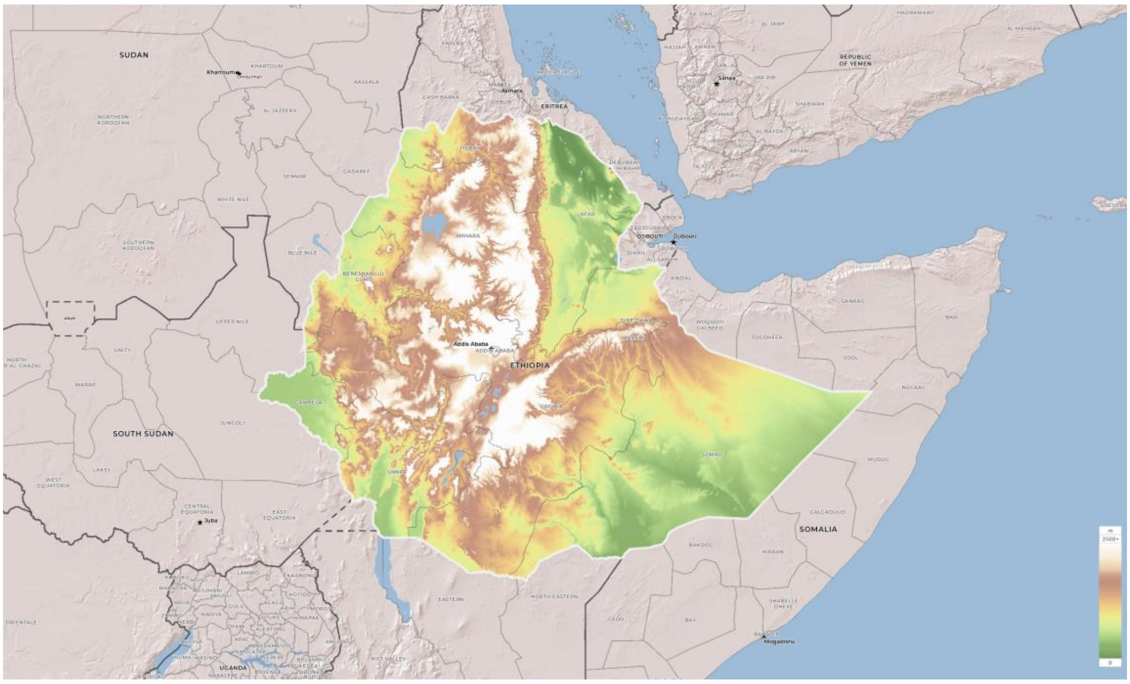
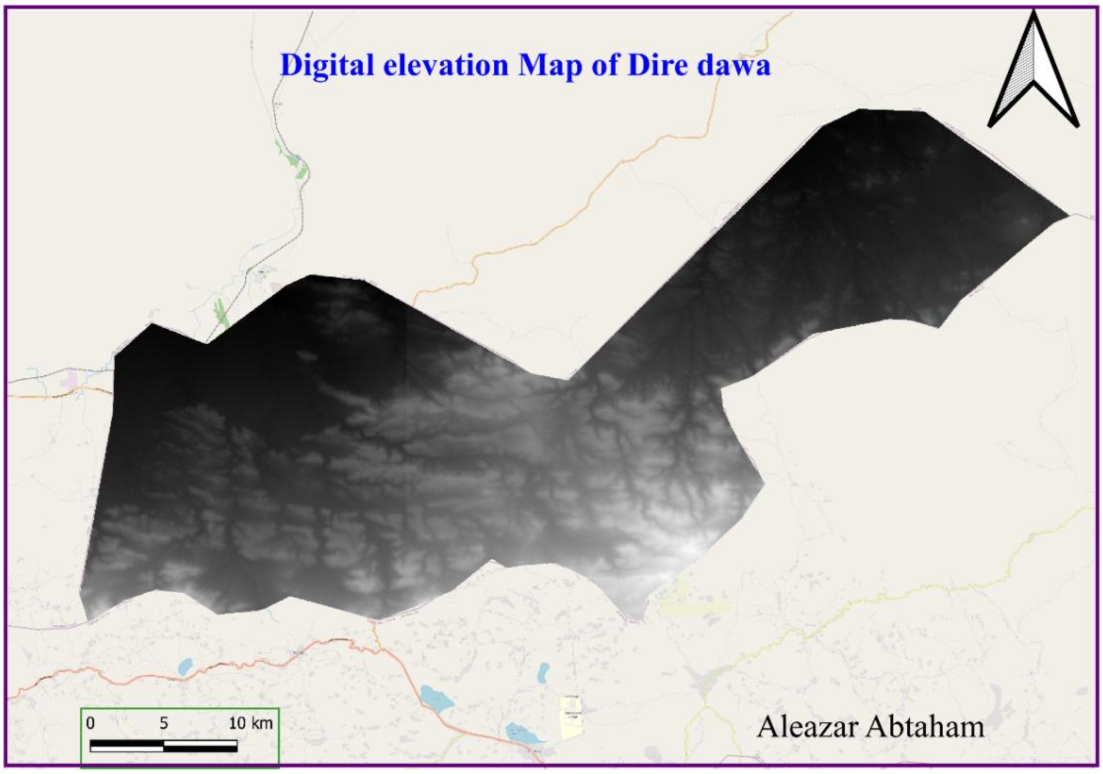
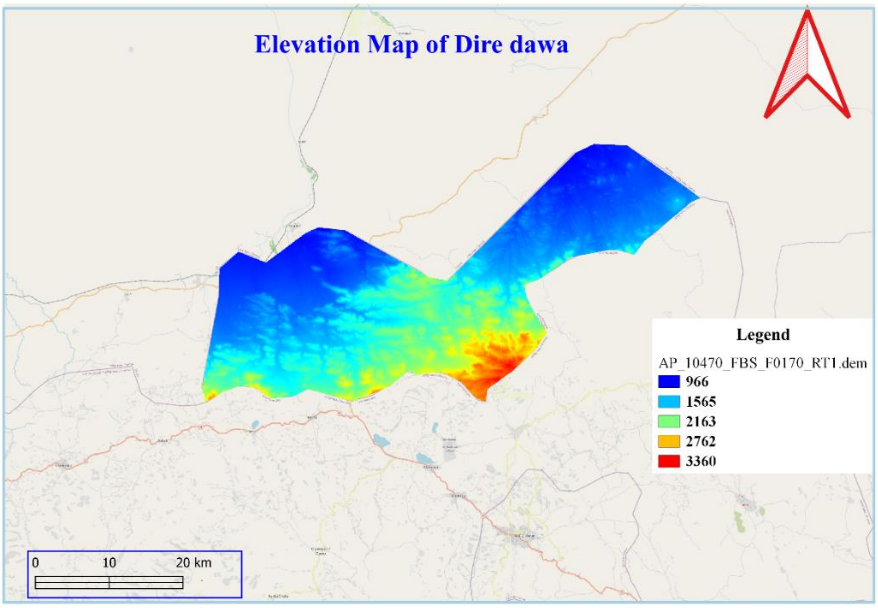


Fig 5-10 Elevation map of Ethiopia (Global wind Atlas)



(a)



(b)

Fig 5-11 (a) and (b) Elevation map of Dire Dawa (QGIS by Aleazar Abraham)

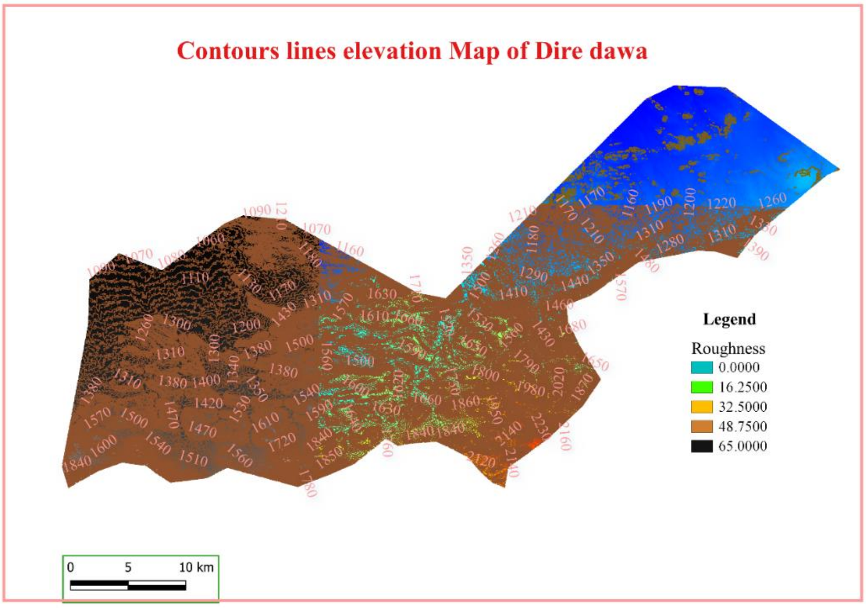


Fig 5 -12 Contours line elevation map of Dire Dawa (QGIS by Aleazar Abraham)

Going up in altitude, the pressure gradient between the warm air and the cold air increases with height. A higher slant causes a greater pressure gradient between warm and cold air, resulting in stronger wind [64]. The elevation of Dire Dawa ranges from 996m to 3360m above sea level, expressing the region's high altitude (*figure 5-12 & 5-13*).

5.4 Wind speed variability

Wind speed variability consists:

- ✓ Inter annual data
- ✓ Annual data
- ✓ Diurnal data
- ✓ Heat map

5.4.1 Inter annual data

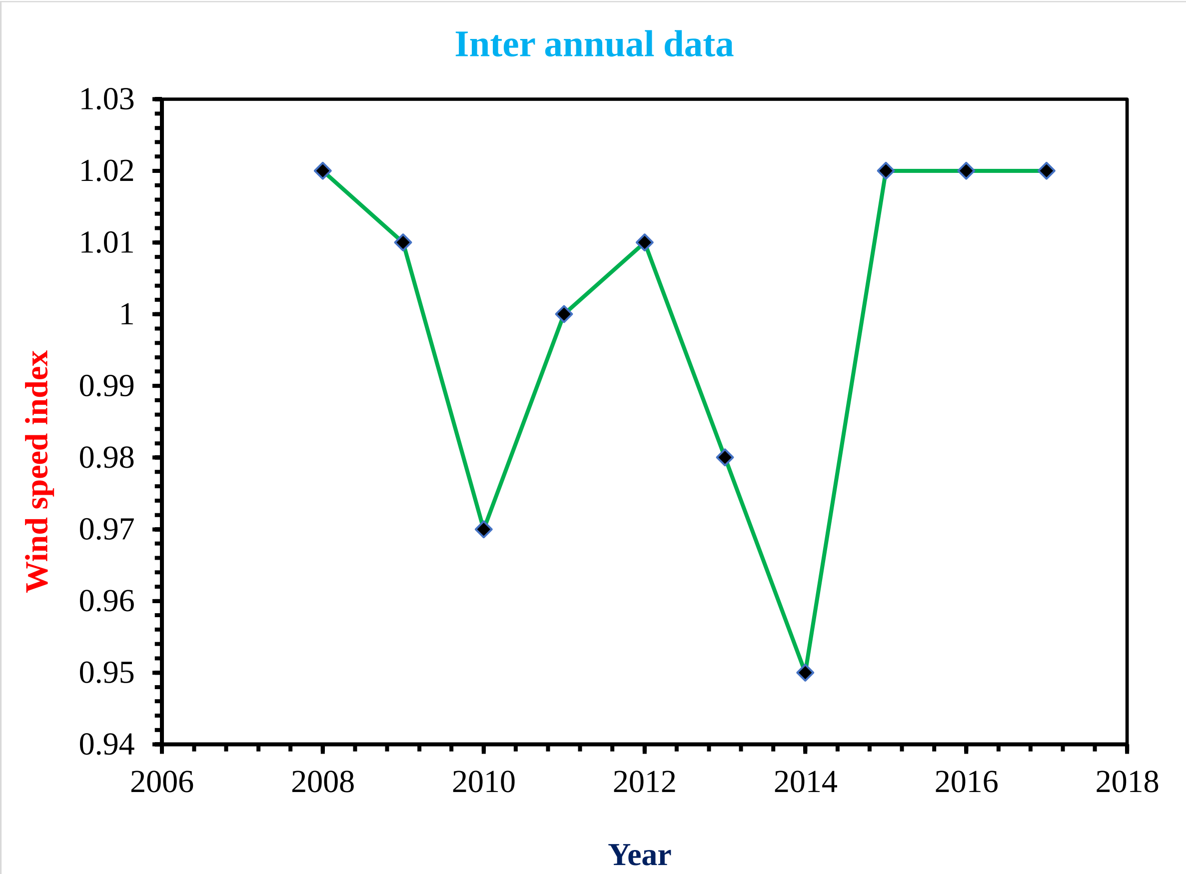
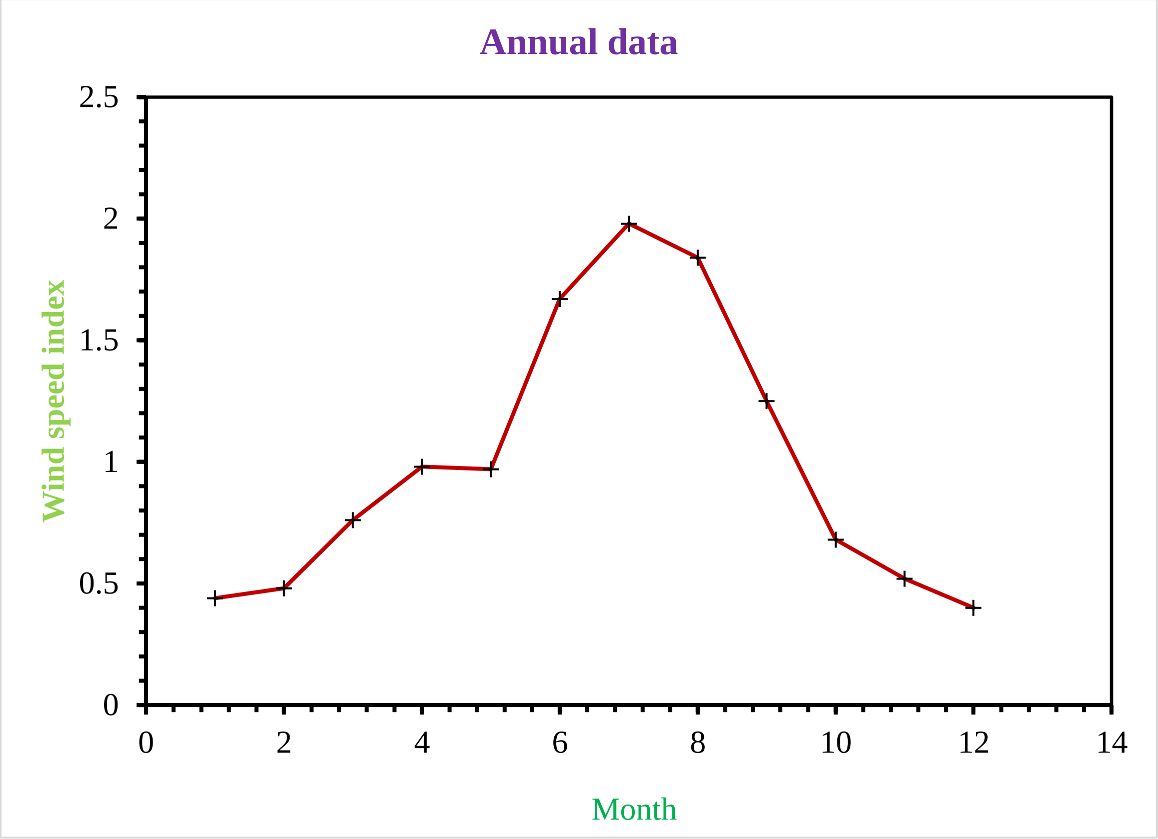


Fig 5-13 Inter annual data

The most frequent source of data for determining the long-term energy yield of wind turbines is a wind index. In Dire Dawa, the wind speed index approaches greater and more constant levels throughout the years 2015-2018, as seen in *figure 5-13*. The verified data shows a lower wind speed index in 2010 and 2014, with the remaining years being classified as moderate.

The indices enable wind turbine owners to establish whether variations in energy productivity are due to deficiencies in wind turbine performance or due to wind below expected levels. The monthly energy yields are given as relative values compared to the long-term reference [65].

5.4.2 Annual wind data



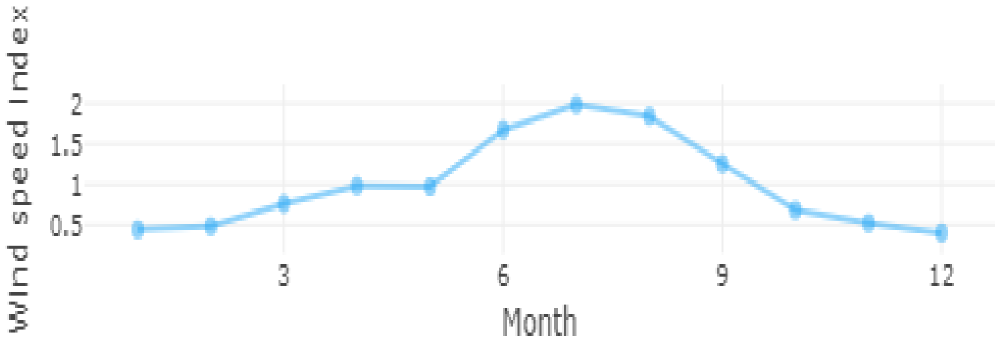
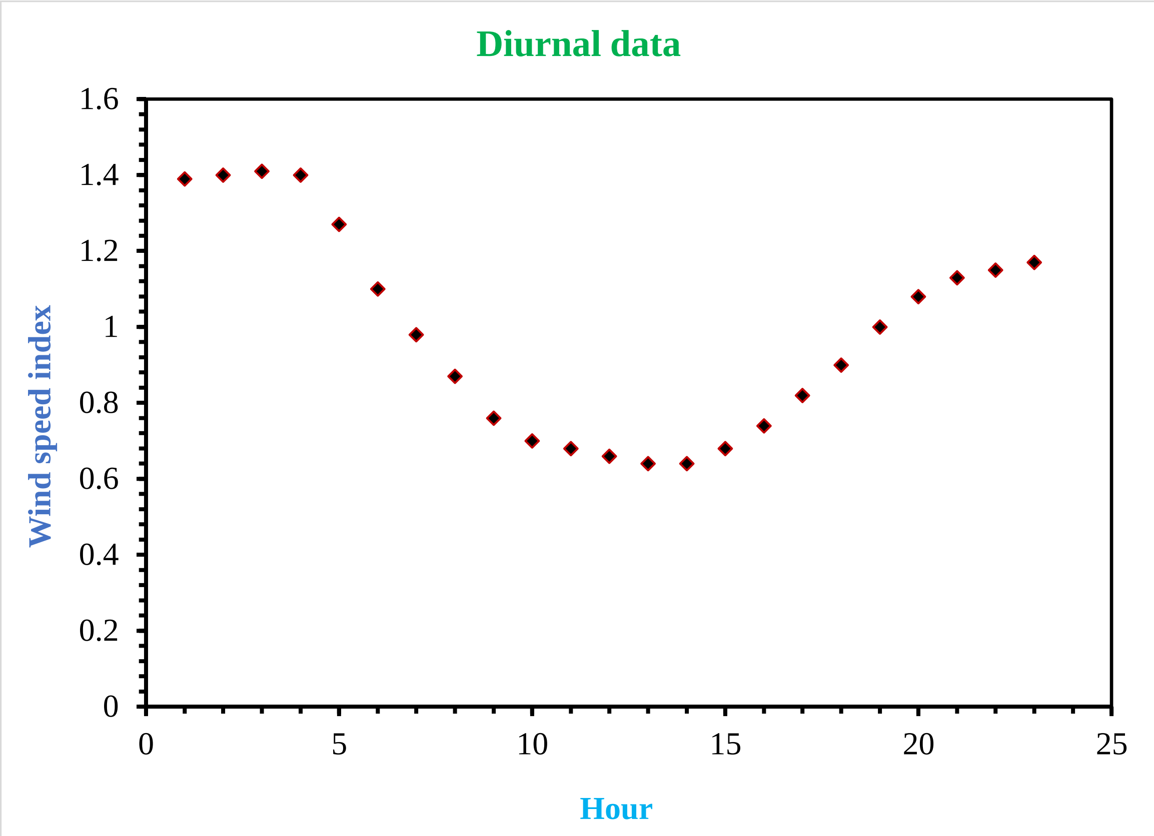


Fig 5-14 Annual wind data

5.4.3 Diurnal wind data



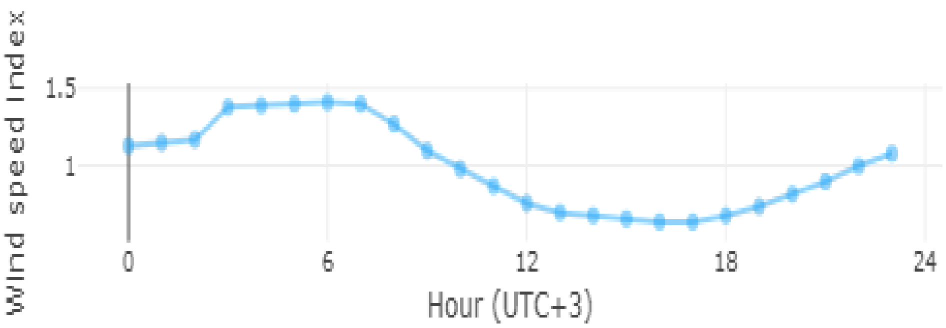


Fig 5-15 Hourly wind data

The monthly wind data collected in relation to a single reference height is also used to determine wind index areas. Based on various data inputs, monthly wind data index from May to August and the hourly wind speed index from 6 to 18 hours logged at Dire Dawa got lower, as labeled in *figure 5-14 and 5-15*. The remaining monthly and hourly wind speed in indexes, on the other contrary, keep constantly changing.

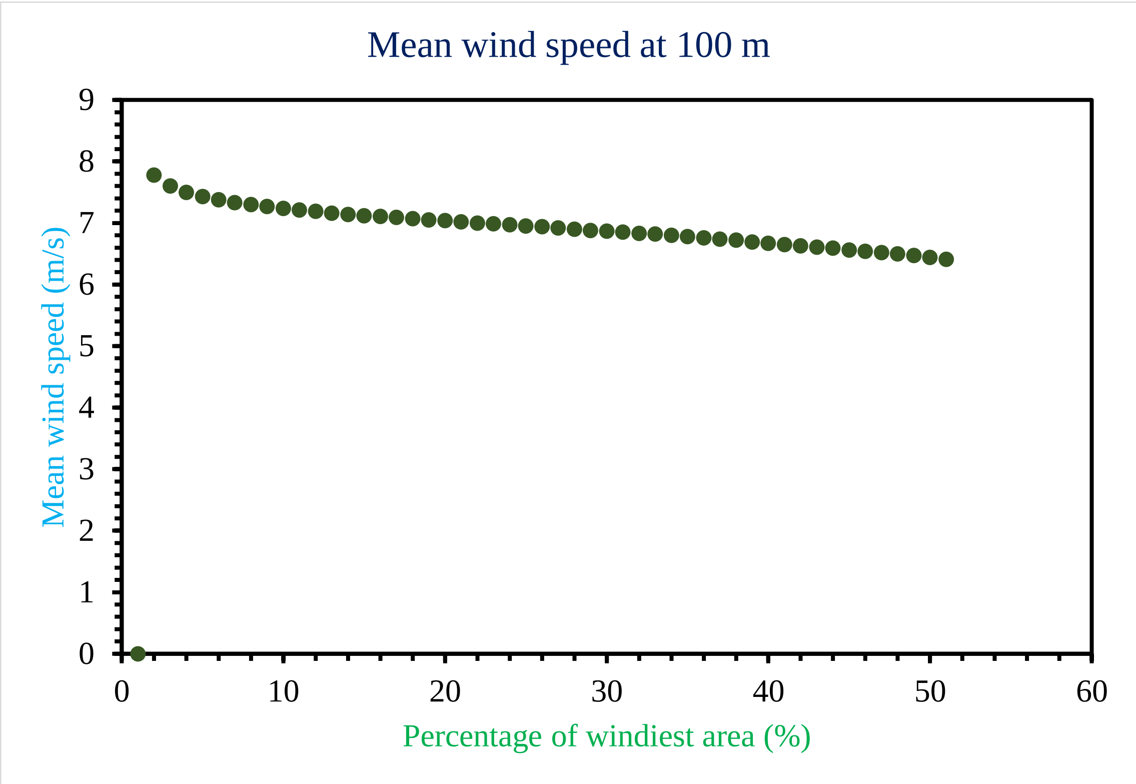
5.5 Area wind speed data

Both the speed and force of the wind can be determining factors. The more wind speed and force you have got, the greater is the amount of power your wind turbine generates. Different regions have different wind speeds [33].

Area wind speed data:

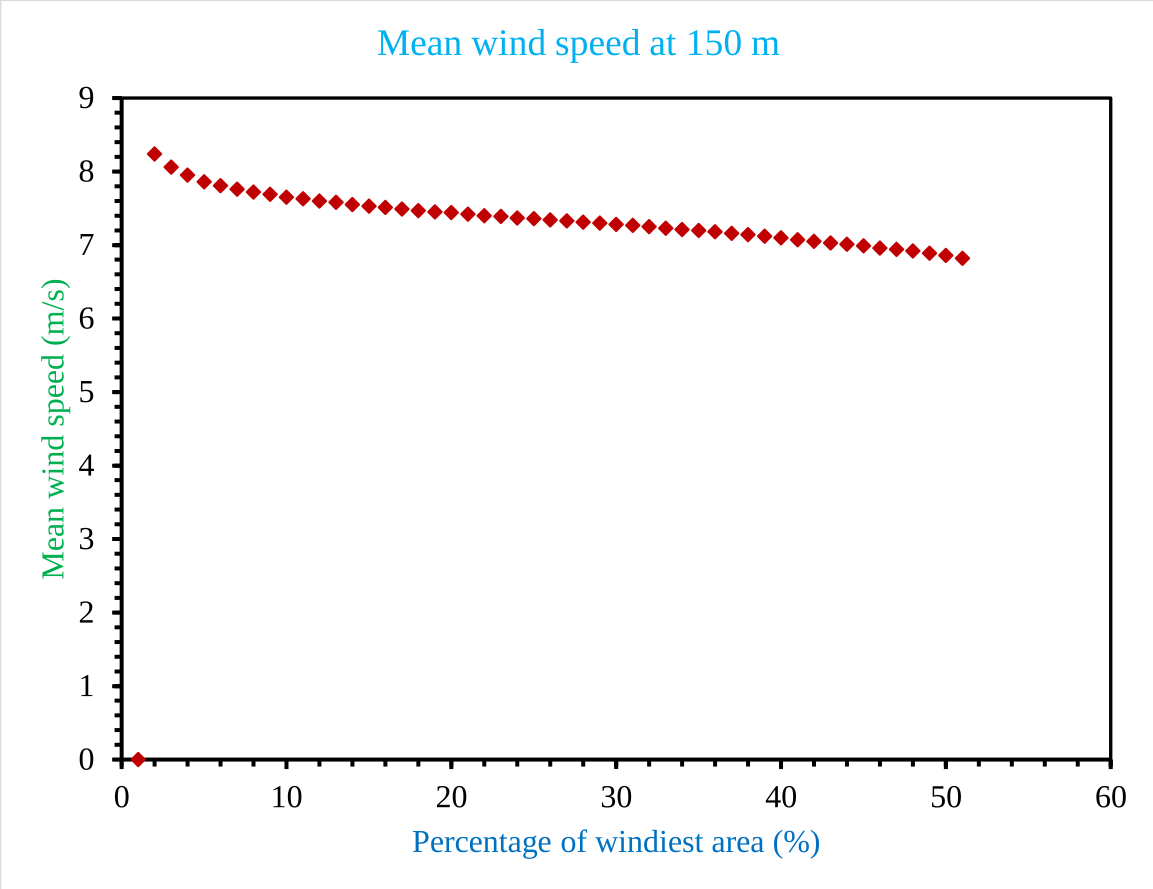
- ✓ Mean wind speed
- ✓ Mean wind power density
- ✓ Wind frequency rose
- ✓ Climatology and Wind speed distribution

5.5.1 Mean wind speed



(a)

Fig 5-16 (a) shows mean wind speed with percentage of windiest area, the mean wind speed for the10% windiest area in the selected region (dire dawa wind farm) is 7.78 m/sec at 100 m.



(b)

Fig 5-16 Mean wind speed of Dire Dawa at (a) 100 m and (b) 150 m

The amount of electricity generated by a turbine has been mostly affected by the wind speed. Since higher winds allow the blades to rotate faster, higher wind speeds offer greater power. Most mechanical power and electrical power from the generator result from faster rotation [63]. The blade commences moving and generating power at the cut-in speed. As the wind speed increases, more electricity is produced until the rated speed is reached. The turbine produces its maximum, or rated, power at this point.

As shown in *figure 5-16 (b)* with the percentage of the windiest area, the average wind speed for the 10% windiest area in the selected region (Dire Dawa region) is 8.24 m/sec.

Those measurements were taken at a height of 150 meters and came from a variety of trustworthy sources, including the global wind atlas, vortex and NASA's MERRA-2 data, which is useful for predicting wind speed in a specific area.

5.5.2 Mean wind power density

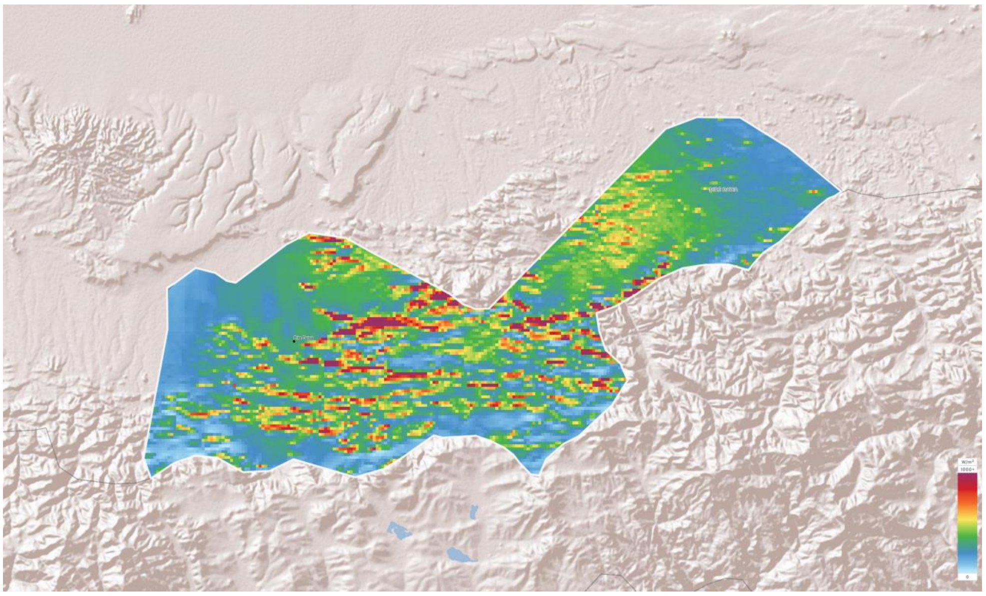
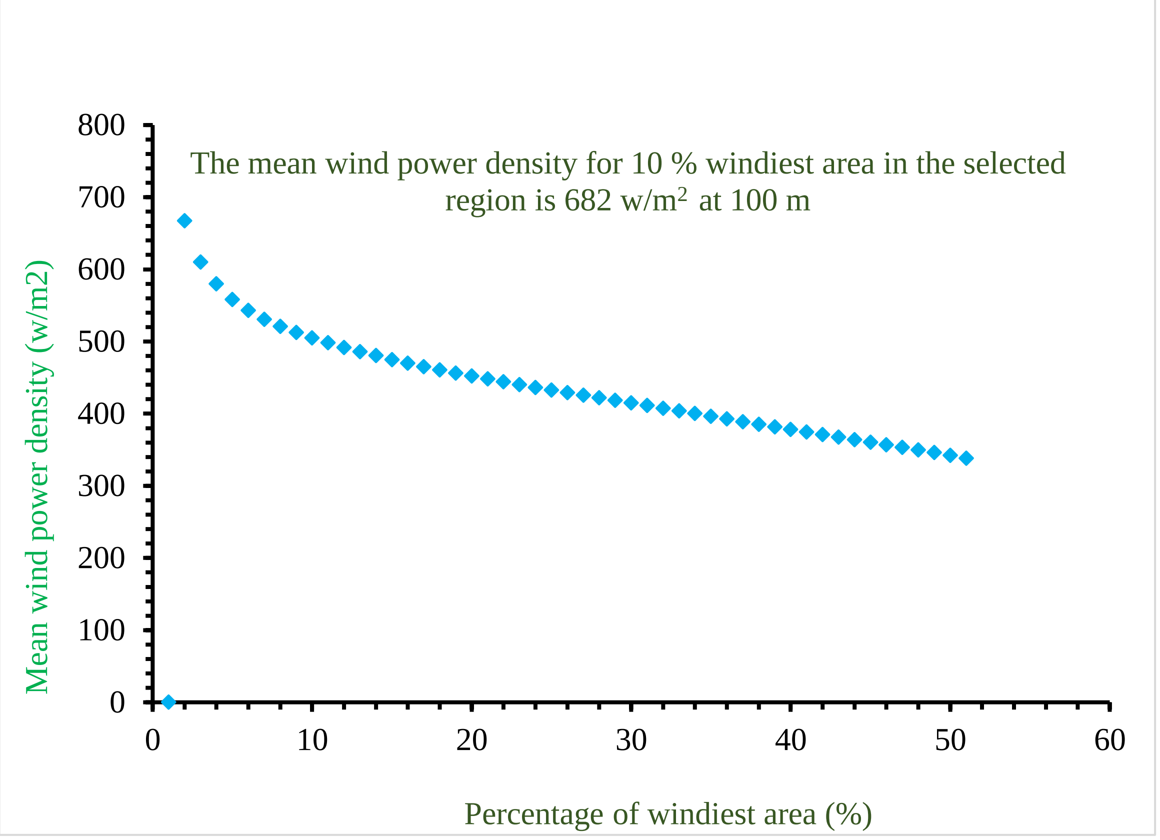
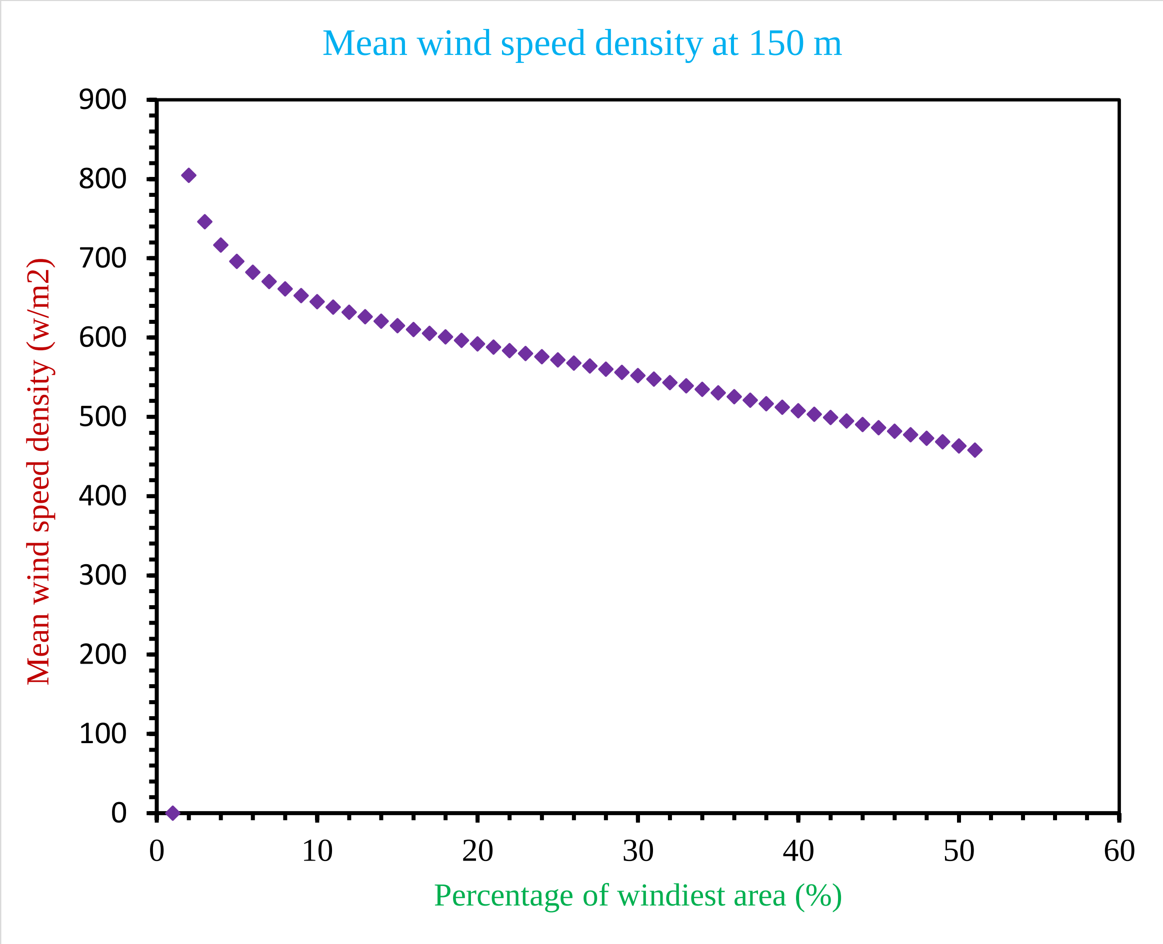


Fig 5-17 Mean Wind speed density of Dire Dawa



(a)



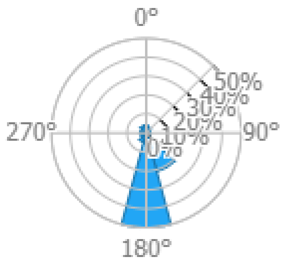
(b)

Fig 5-18 Mean wind power density of Dire Dawa at (a) 100 m and (b) 150 m

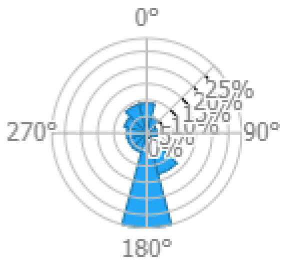
The mean wind speed power density reveals how much energy is available for conversion by a wind turbine at a certain location. The wind power density, expressed in watts per square meter. Wind speed tend to increase as height (elevation) rises, corresponding to a higher power density [66].

The mean wind speed for the 10% windiest area in the selected region (Dire Dawa wind farm) reaches 682 w/m^2 and 804 w/m^2 at 100 m and 150 m, respectively, as illustrated in *figure 5-18 (a) and (b)*.

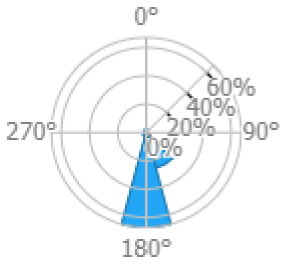
5.5.3 Wind rose of Dire Dawa



(a)



(b)



(c)

Fig 5-19 (a) Wind speed rose (b) Wind frequency rose and (c) Wind power rose

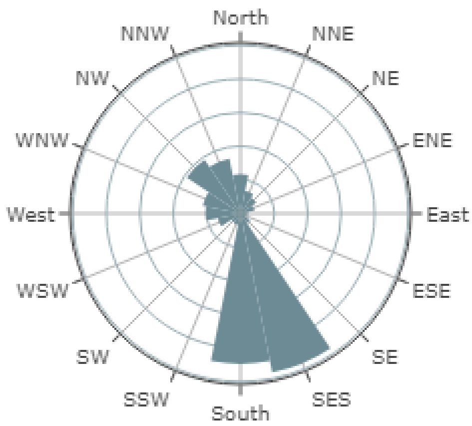
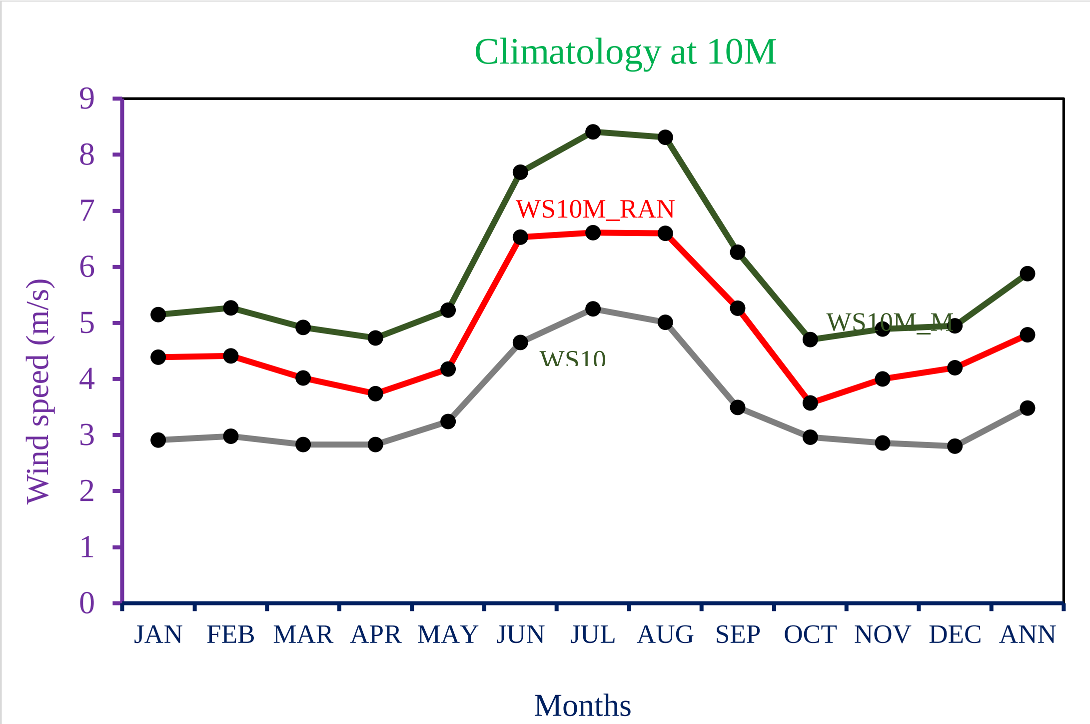
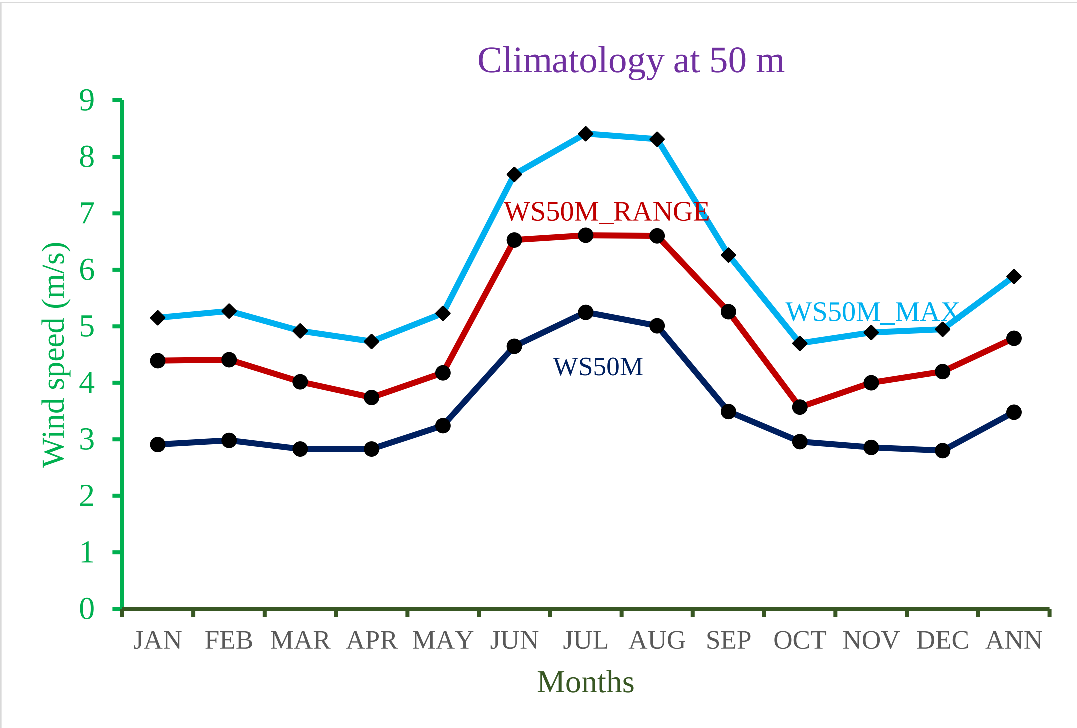


Fig 5-20 Wind rose of Dire Dawa (Vortex)

5.5.4 Climatology of Dire Dawa



(a)



(b)

Fig 5-21 (a)10 m & (b)50m Wind speed climatology of Dire Dawa (Power Access, NASA)

5.5.5 Wind Frequency Distribution

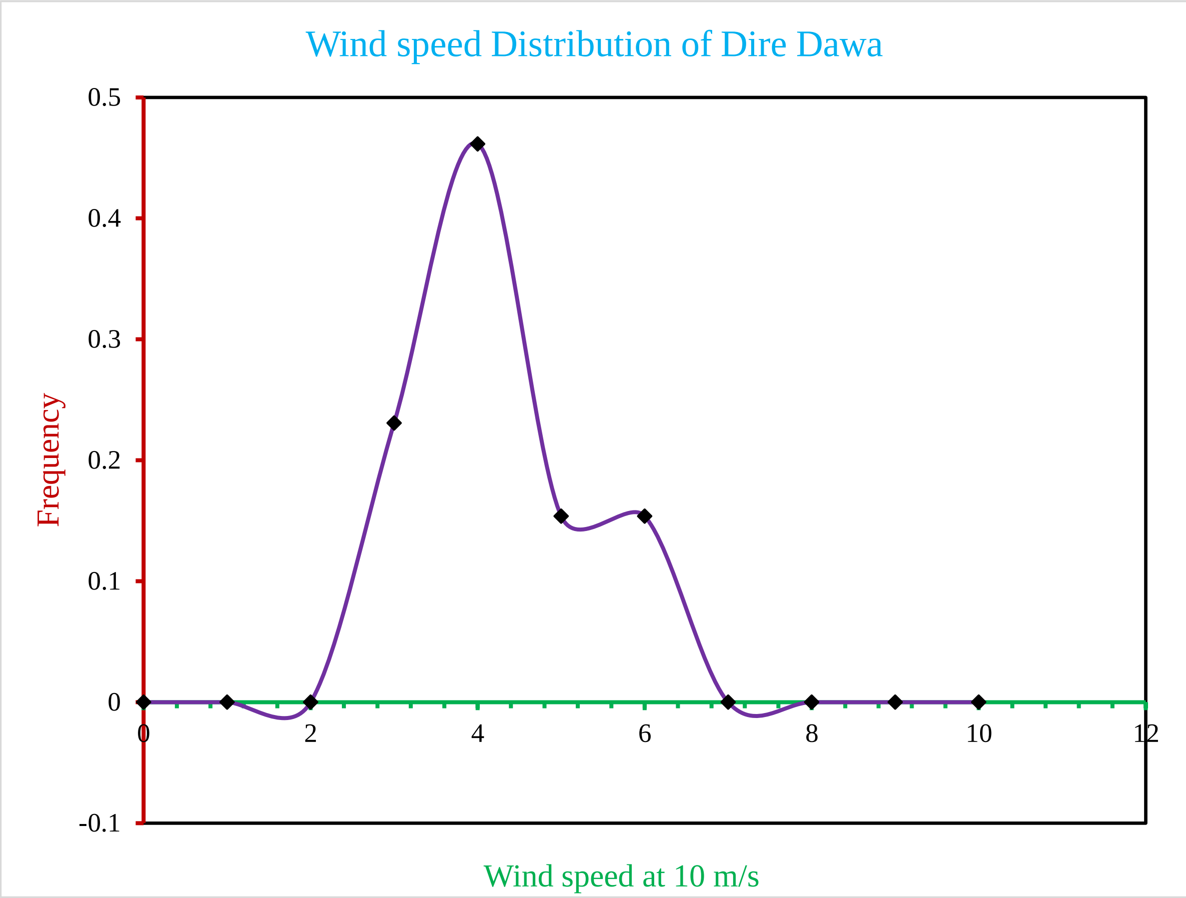


Fig 5-22 Wind speed distribution of Dire Dawa

Wind power, frequency, and rose are diagrams with radiating lines that show the frequency and strength of winds affecting a specific location from each direction. The wind power, wind frequency, and wind rose of the Dire Dawa region shown above within *figures 5-19 and 5-20* appear to suggest that the hardest-hitting wind frequency comes from the south (S) and southeast south (SES), as determined by the global wind atlas and vortex. Similarly, the wind climatology of a dire Dawa wind region specifies wind speed from early June to late August, with maximums of 10 m and 50 m, respectively, as shown in *figures 5-21(a) and (b).*

The wind speed distribution of the Dire Dawa region is seen in *figure5-22*, which would be frequent at 4 m/s and reasonable at 5 & 6 m/s. The wind speed distribution accurately predicts the performance of wind energy systems for a given location and time.

Wind Frequency Distribution

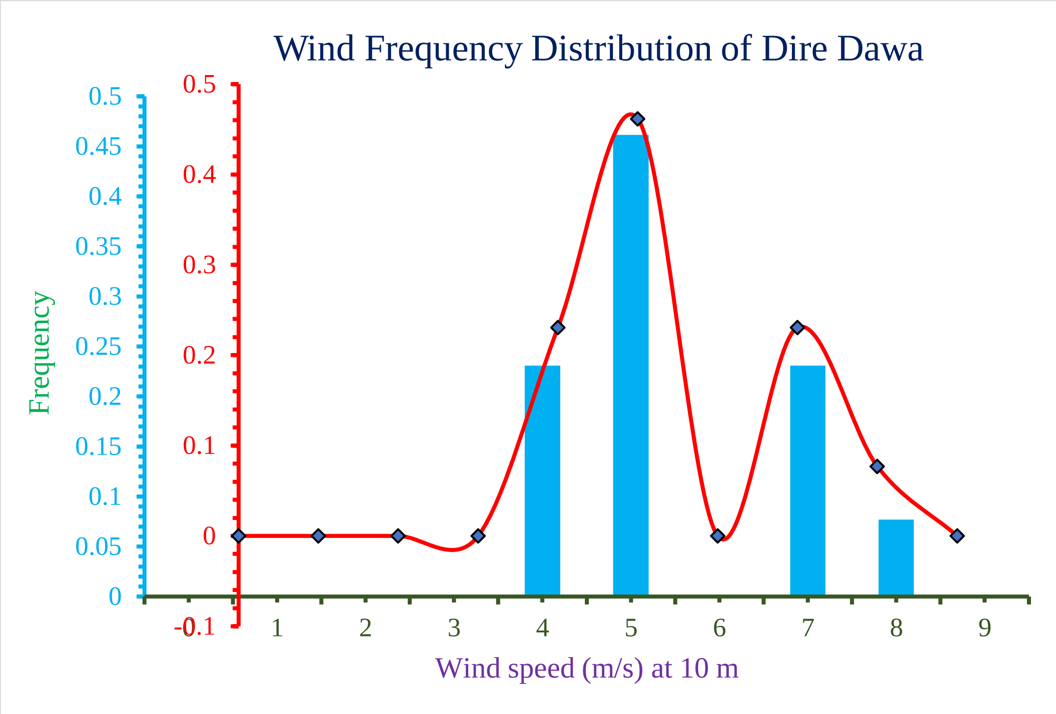


Fig 5-23 Wind frequency distribution of Dire Dawa

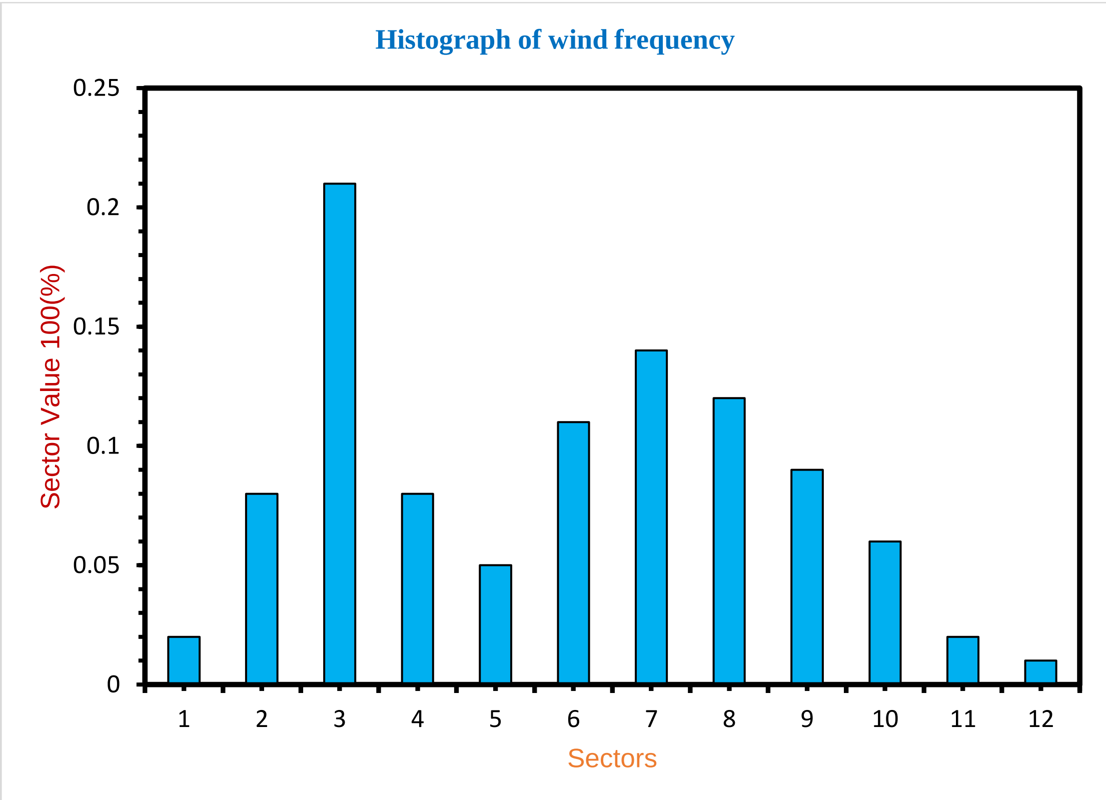


Fig 5-24 Histography Wind frequency of Dire Dawa

5.6 Power Curve and site suitability

5.6.1 Power curve of Dire Dawa

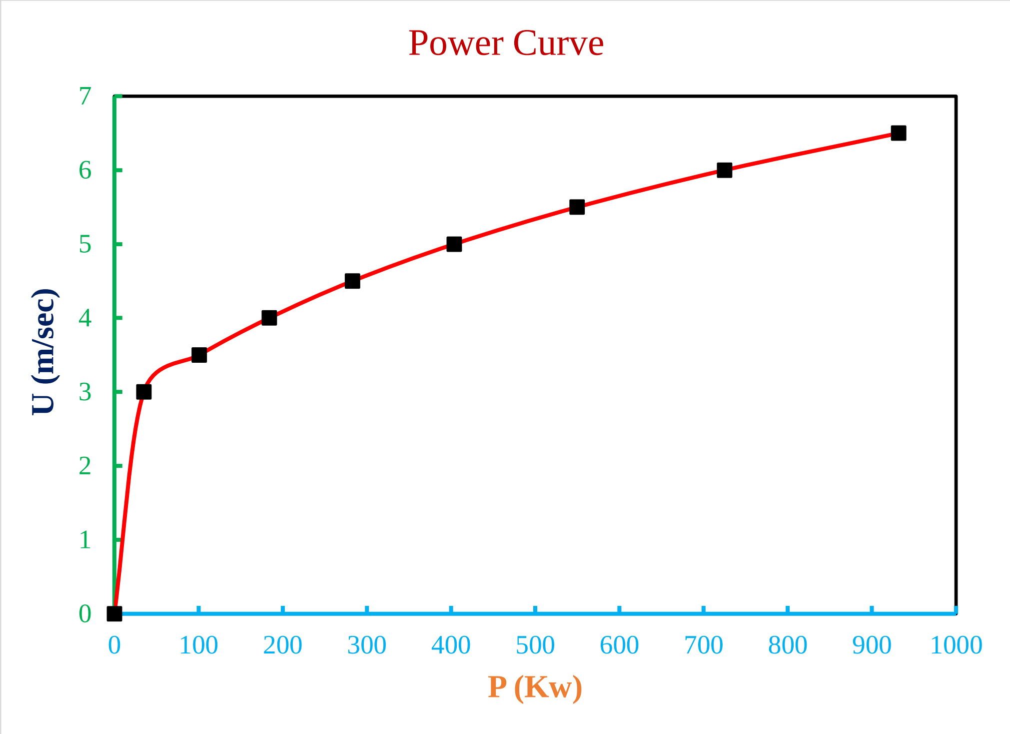


Fig 5-25 Power curve

To assess how much wind energy will be generated by a specific turbine at a specific site location, the turbine's wind speed wind power curve must be coupled with the site's wind speed frequency distribution. The wind speed frequency distribution is a histogram that represents wind speed classes and the expected number of hours per year for each wind speed class. Wind speed measurements collected at the site are typically used to calculate the number of hours observed for each wind speed class in those histograms [67].

figure 5-23 shows the wind frequency distribution of Dire Dawa wind region, which is frequent at 4m/s and moderate at 5 & 6 m/s. Likewise, *figure 5-23* displays that most months have wind speeds of 2.91 – 5.25 m/s with a higher frequency. The higher value of wind speed, 5.24 to 8.41 m/s, with some noticeable frequencies, is found in May and September. And also, *figure 5-25* points toward the power curve that associates wind speed with rated power for a selected wind farm and the data obtained from the global wind atlas.

5.6.3 Site suitability

Based on different standards three sites has been selected in Dire Dawa (*Table 4-23 to 4-26*) for this thesis:

- **<u>Site 1 (k'ench'era):</u>**

Fig 5-26 K'ench'era site map (Virtual 3D animated Turbine via google earth)

Fig 5-27 K'ench'era site turbine placement map (Virtual 3D animated Turbine via google earth)

Fig 5-28 Distance k'ench'era to Dire Dawa (Virtual 3D animated Turbine via google earth)

The turbines on hilly terrain experience higher wind loads than those on flat ground. As a result, wind moving over hilly terrain recovers its power potential faster as it moves from turbine to turbine. Hence, turbine rows on hillsides can be more closely spaced.

The K'ench'era (Site 1) is 11.16 kilometers from the center of Dire Dawa town as shown in *figure 5-28*, making it more convineint in terms of distance. Despite this, the area is more remote from access roads. On the other hand, the mean wind speed at K'ench'era (Site 1) raaches 6.4 m/s, which is lower that at Jelo (Site 2) and Afretu (Site 3). Besides, the proposed area has a lower population, which is more preferable in terms of less payment for land usage as well as lower environmental effects.

➢ **Site 2 (Jelo)**

Fig 5-29 Jelo site map (Virtual 3D animated Turbine via google earth)

Fig 5-30 Jelo site turbine placement map (Virtual 3D animated Turbine via google earth)

Fig 5-31 Distance Jelo Dire Dawa (Virtual 3D animated Turbine via google earth)

The turbines on hilly terrain experience higher wind loads than those on flat ground. As a result, wind moving over hilly terrain recovers its power potential faster as it moves from turbine to turbine. Hence, turbine rows on hillsides can be more closely spaced.

The Jelo (site 2) is 11.36 km away from the center of Dire Dawa town can be seen in *figure 5-31.* That makes it more preferable regarding distance nearer to Dire Dawa. Fortunately, the region is more distant from the access road. On the other hand, mean wind speed on site 2 (Jelo) reaches up to 7.0 m/s based on global wind atlas, vortex, and merra-2, relatively higher than K'ench'era (Site 2) and closer to Afretu (Site 3), but the proposed wind farm has low population, and the turbines are placed in an appropriate location based on their latitude and longitude.

- **Site 3 (Afretu)**

Fig 5-32 Afretu site map (Virtual 3D animated Turbine via google earth)

Fig 5-33 Afretu site turbine placement map (Virtual 3D animated Turbine via google earth)

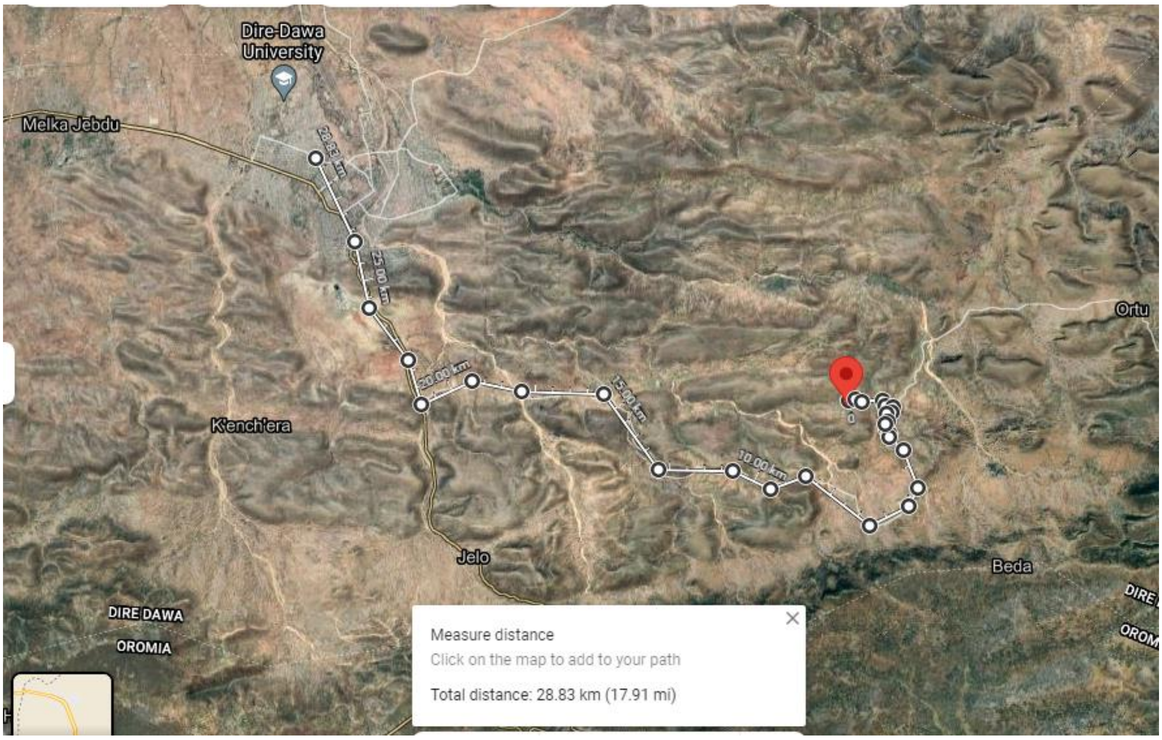


Fig 5-34 Distance Afretu to Dire Dawa (Virtual 3D animated Turbine via google earth)

The turbines on hilly terrain experience higher wind loads than those on flat ground. As a result, wind moving over hilly terrain recovers its power potential faster as it moves from turbine to turbine. Hence, turbine rows on hillsides can be more closely spaced.

The Afretu (site 1) is 28.83 km away from the center of Dire Dawa town *figure 5-34*, making it farther from the other two sites in Dire Dawa. Similarly, the region is more detached from access roads. On the other hand, the mean wind speed on site 3 (Afretu) reaches up to 7.4 m/s based on global wind atlas, vortex and merra-2 data reanalyser, relatively higher than that of sites 1 (K'ench'era) and 2 (Jelo). But the proposed wind farm has a low population and is placed in an appropriate location based on its latitude and longitude.

Based on site suitability criteria, Afretu (site 3) is more suitable for wind farm plantation in the Dire Dawa region than Jelo (site 2) and K'ench'era (site 3).

5.6 Economic Sustainability

Economics plays a central role in developing a wind energy project. The economic analysis is a very significant analysis that is completed to identify if a project will be economically feasible and sustainable. The customer, or a corporation, is unlikely to invest in a wind energy system if they know that its only benefits are to the environment. Obviously, any company considering wind power generation is going to look very carefully at economics to ensure that such a project will be profitable to them.

The initial cost and the operational and maintenance cost were put in manually into the RET screen software, while some other financial variables, including inflation rate, discount rate, reinvestment rate, debt ratio, and debt interest rate, are standards obtained directly from the financial analysis worksheet of the software as shown below in *Table 5-1*. The RET screen expert software calculates Net Present Value (NPV), Internal Rate of Return (IRR), and other financial parameters that hinge on the entered variables in *Table 5-2*: NPV, IRR, and payback period are considered as measures of a project's viability.

Table 5-1 Financial input variables from RET screen Expert

Parameters	Values
Inflation Rate	2%
Discount Rate	9%
Escalation Rate Fuel	2%
Reinvestment Rate	9%
Debt Payment	$2,118,350/yr.
Debt Ratio	70%
Debt Interest Rate	7%
Project Life Cycle	20 yrs.

Debt Term	15 yrs.
Total Initial Cost	$27,562,500
Operation and Maintenance Cost	$787,500
Rate of Energy Escalation	15%
Electricity Export Cost	$0.05/kwh
Total Annual Cost	$2,905,850

For this project shown in *figure 5-35*, the NPV, which is the variance between the present value of cash inflows and the present value of cash outflows over a period of time, was positive, and this made the project financially and economically feasible.

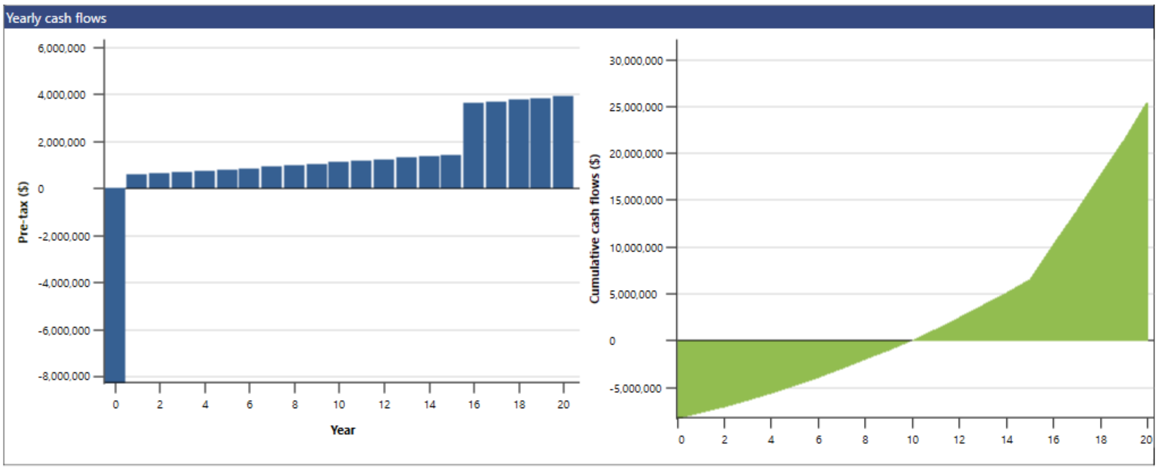


Fig 5-35 Annual cost flow of the project (RET screen Expert)

Table 5- 2 Financial output variables from the RET screen Expert

Financial Viability	**Values**
Interest Rate of Return (IRR) (%)	12.1
Net Present Value (NPV) ($)	2,953,661
Annual Life Cycle Saving ($)	323,563

Simple Payback Period (yrs.)	10.4
Benefit-cost (B-C)	1.4
Debt Service Charge	1.3

Financial viability		
Pre-tax IRR - equity	%	12.1%
Pre-tax MIRR - equity	%	10.7%
Pre-tax IRR - assets	%	1.5%
Pre-tax MIRR - assets	%	4.2%
Simple payback	yr	10.4
Equity payback	yr	9.9
Net Present Value (NPV)	$	2,953,661
Annual life cycle savings	$/yr	323,563
Benefit-Cost (B-C) ratio		1.4
Debt service coverage		1.3
GHG reduction cost	$/tCO₂	No reduction

Fig 5-36 (a) financial viability (RET screen Expert)

RETScreen - Financial Analysis — **Subscriber: Viewer**

Financial parameters		
General		
Fuel cost escalation rate		2%
Inflation rate	%	2%
Discount rate	%	9%
Reinvestment rate	%	9%
Project life	yr	20
Finance		
Incentives and grants	$	
Debt ratio	%	70%
Debt	$	19,293,750
Equity	$	8,268,750
Debt interest rate	%	7%
Debt term	yr	15
Debt payments	$/yr	2,118,350
Income tax analysis		☐

Costs | Savings | Revenue			
Initial costs			
Power system	90.7%	$	25,000,000
Balance of system & miscellaneous	9.3%	$	2,562,500
Total initial costs	**100%**	$	**27,562,500**
Yearly cash flows - Year 1			
Annual costs and debt payments			
O&M		$	787,500
Debt payments - 15 yrs		$	2,118,350
Total annual costs		**$**	**2,905,850**
Annual savings and revenue			
User-defined		$	3,430,350
GHG reduction revenue		$	0
Other revenue (cost)		$	0
Total annual savings and revenue		**$**	**3,430,350**
Net yearly cash flow - Year 1		**$**	**524,500**
Periodic costs (credits)			
Major Component replacement - 12 yrs		$	400,000

Year	Pre-tax	Cumulative
#	$	$
0	-8,268,750	-8,268,750
1	577,357	-7,691,393
2	631,271	-7,060,122
3	686,264	-6,373,858
4	742,356	-5,631,503
5	799,570	-4,831,933
6	857,928	-3,974,004
7	917,454	-3,056,551
8	978,170	-2,078,381
9	1,040,100	-1,038,280
10	1,103,269	64,989
11	1,167,702	1,232,691
12	726,126	1,958,817
13	1,300,458	3,259,275
14	1,368,834	4,628,110
15	1,438,578	6,066,688
16	3,628,067	9,694,754
17	3,700,628	13,395,382
18	3,774,641	17,170,023
19	3,850,133	21,020,156
20	3,927,136	24,947,293

Fig 5-36 (b) financial analysis (RET screen Expert)

Also *figure 5-36 (a) and (b)* shows, the value of the IRR, which is the amount of a project's cost-effectiveness that is found, is higher than the required rate of return. This makes the project economically adequate when considering the required rate of return, which is the discount rate. The simple payback period is the length of time that it will take to recover the project's initial investment. The proposed wind power project has a payback period of 10.4 years from *figure 5-36 (b)*. This simply means that the project will yield an interest in Dire Dawa for 9.9 years and 10.4 years out of the 25 years considered for the project to work.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Wind power is the fastest growing sustainable energy source, as well as the least expensive. The environmental benefits, combined with the critical economic benefit, have resulted in a favorable scenario for rapidly increasing wind power. The potential assessment of a region in terms of wind continuity with accurate parameters is extremely important for the pre-feasibility of the planned wind farm.

This study is critical for wind farm design firms because it serves as a reference in pre-feasibility and allows for the comparison of results obtained through simulation and various methods. Furthermore, it is intended to raise awareness that the region can subsidize the economy by utilizing the wind-related types of renewable energy available in the region, as the region is confident in its wind energy potential.

According to the findings, the wind energy potential of one of the sites, K'ench'era (Site 1), with a mean wind speed of 6.4 m/sec, a mean wind power density of 682 w/m^2, and a distance of 11.16 Km from the main access road, is significantly lower than the other two sites. However, it can be concluded that, in general, while the potential exists for a large, independent wind farm,

Furthermore, Jelo (Site 2) had a mean wind speed of 7.0 m/sec, a mean wind power density of 780 w/m^2, and was 11.36 Km away from the main access road, which is significantly higher than K'ench'era (Site 1), could be outstanding according to the national renewable energy laboratory (NREL).

Above and beyond, Afretu (site 3) verified a 7.4 m/sec mean wind speed, a mean wind power density of 804 w/m2, which is noticeably higher than the two locations that could be outstanding according to the national renewable energy laboratory, and a distance of 28.83 km away from the main access road, which is far more too Dire Dawa than the other two sites. The results conclude that Jelo (Site 2) and Afretu (site 3) are better candidates as compared with K'ench'era (site 1).

According to this study, it would be used as a tool by urban and energy planner to support them choose the finest alternative energy based on site characteristics and constraints. As a results, decision-makers are armed with a versatile framework for gathering information.

Future studies could fruitfully explore this issue further by employing various computational fluid dynamic (CFD) simulation software for modeling the wind farm as well as the feasibility of the Dire Dawa wind farm.

As also recommended above, future research should consider the turbine blade's detailed performance and analysis of fatigue load impacts from problematic wind conditions on some complex terrains, by employing advanced simulation for feasibility studies like Qblade, FAST, and TurbSim.

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Appendix

I. Nominal Definitions

Assessment: is the ongoing process of gathering, analysis and reflecting on evidence.

Atmospheric Stability: refers to air's tendency to either rise and create storms.

Clean Energy: is energy from source that are constantly being formed.

Pre-feasibility: an evaluation or analysis of the potential impact of a proposed project.

Simulation: a computer-based model used to run experiment on a real system.

Sustainability: meets the needs of the present without compromising the future needs.

Terrain: an area of land, when considering its natural features.

Wind Farm: an area of land with a group of energy producing wind turbines.

Wind Potential: is counting on to provide a source of sustainable non-polluting energy.

II. Area wind speed data

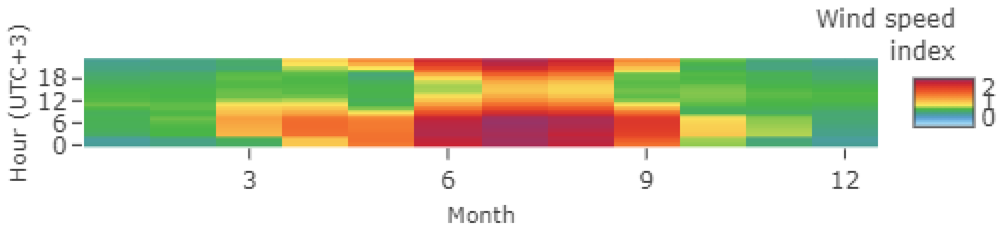

Fig2-1 Heat map of Dire dawa (Global wind atlas)

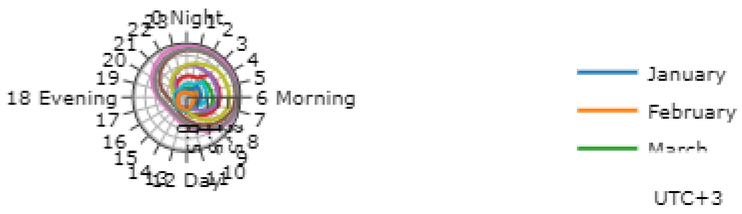

Fig2-2 Wind rose hourly Dire dawa (Global wind atlas)

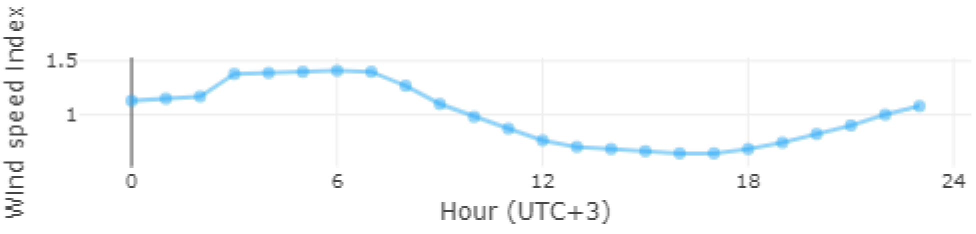

Fig 2-3 Hourly Bar chart (Global wind atlas)

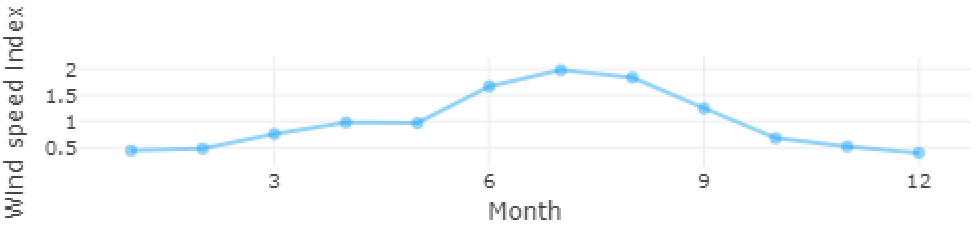

Fig 2-4 Monthly Bar chart (Global wind atlas)

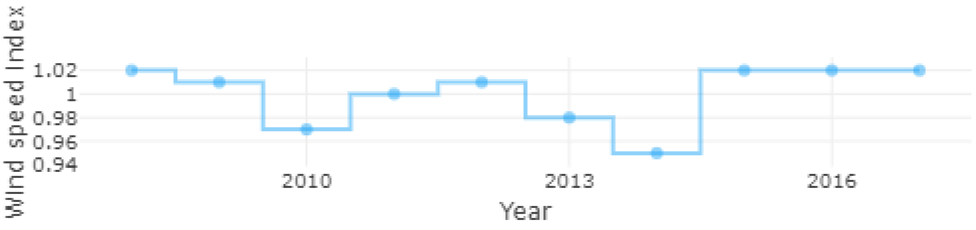

Fig 2-5 Yearly Bar chart (Global wind atlas)

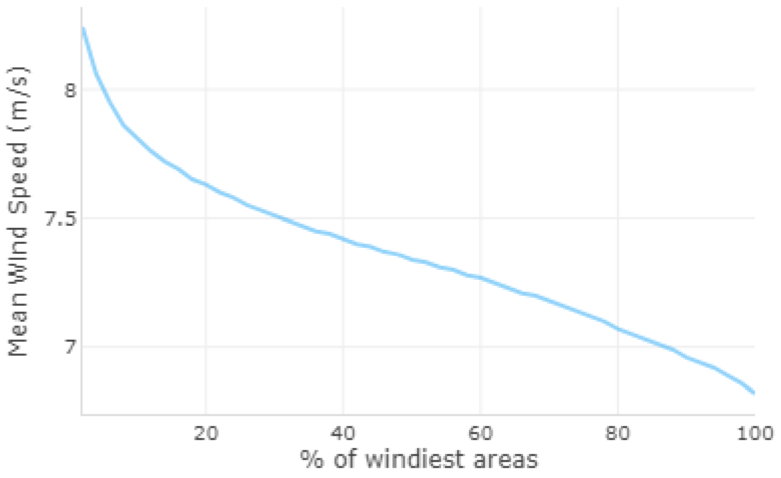

Fig 2-6 Mean wind speed vs % of windiest areas (Global wind atlas)

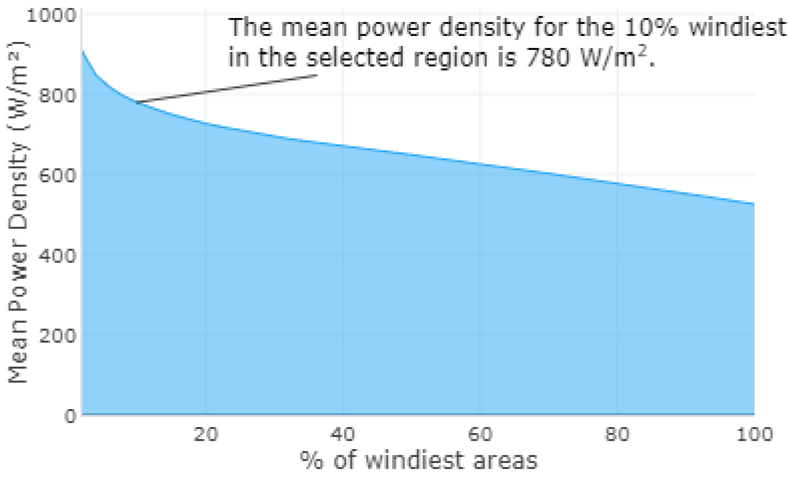

Fig 2-7 Mean power density % of windiest areas (Global wind atlas)

III. Wind map of Dire dawa

GLOBAL WIND ATLAS

MEAN WIND POWER DENSITY AT 50m

MEAN POWER DENSIT OF DIRE DAWA

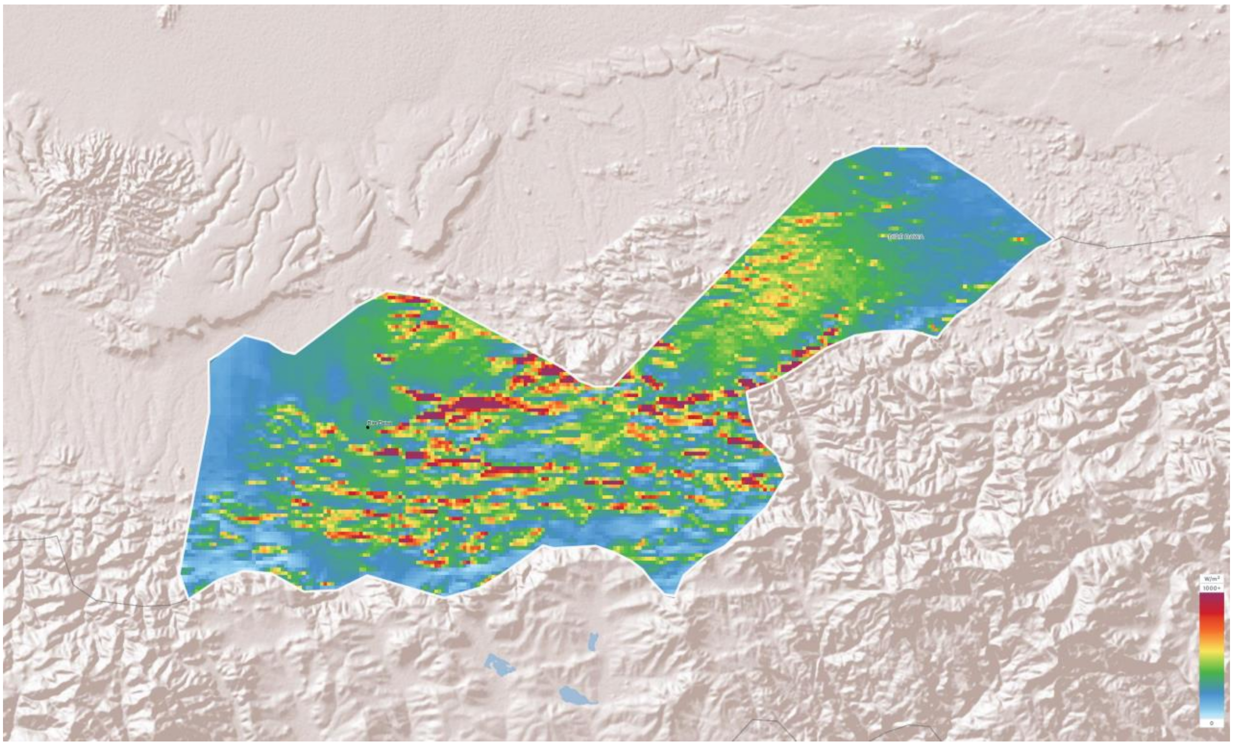

Fig 3-1 mean wind Power density at 50 m

GLOBAL WIND ATLAS
MEAN WIND SPEED AT 100 m
MEAN WIND SPEED OF DIRE DAWA

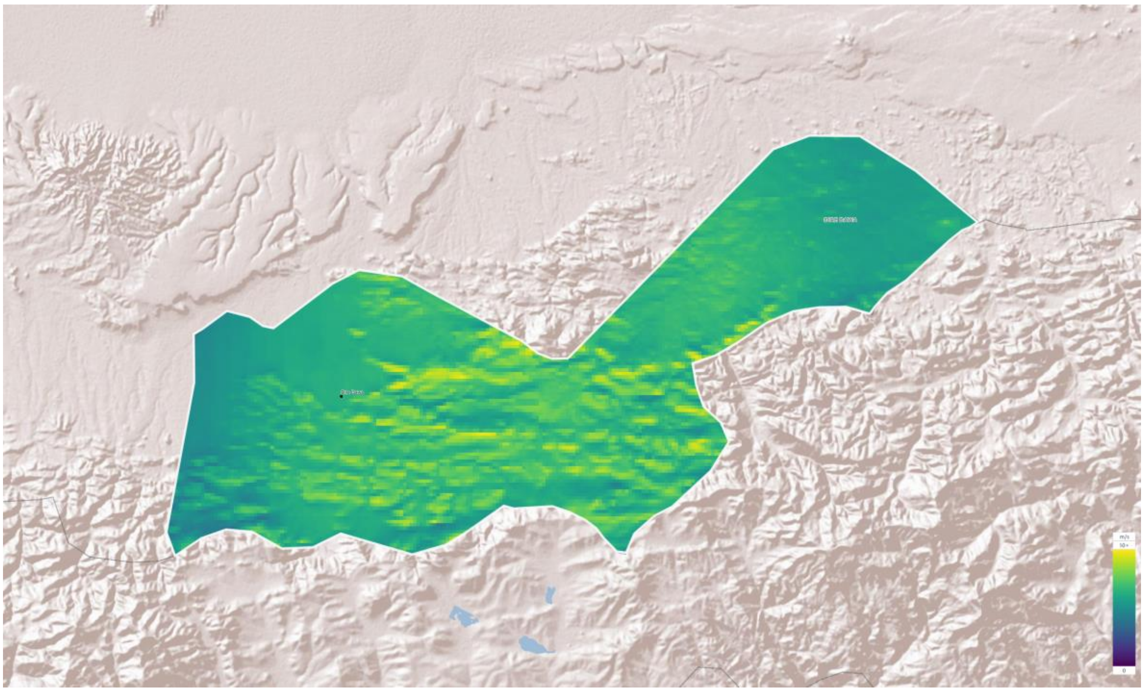

Fig 3-2 mean wind speed at 100 m

GLOBAL WIND ATLAS
Roughness
Roughness OF DIRE DAWA

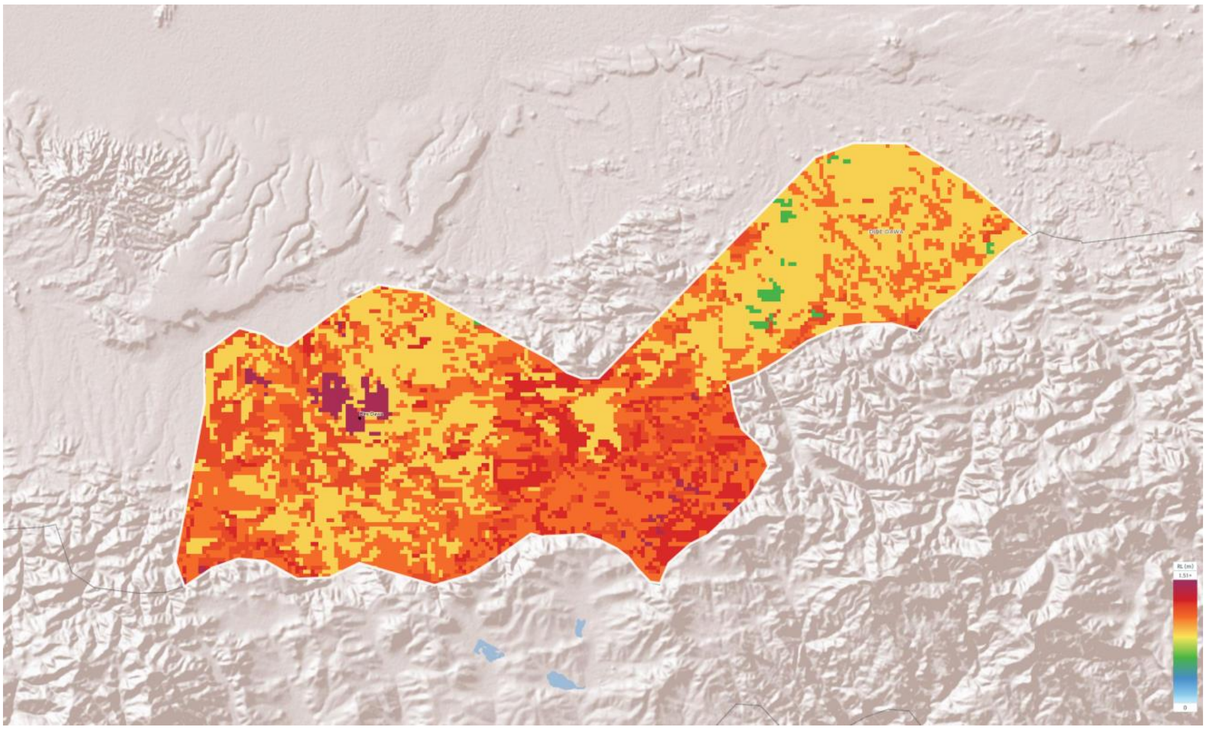

Fig 3-2 Roughness length of Dire dawa at 100 m

GLOBAL WIND ATLAS

Elevation

Elevation MAP OF DIRE DAWA

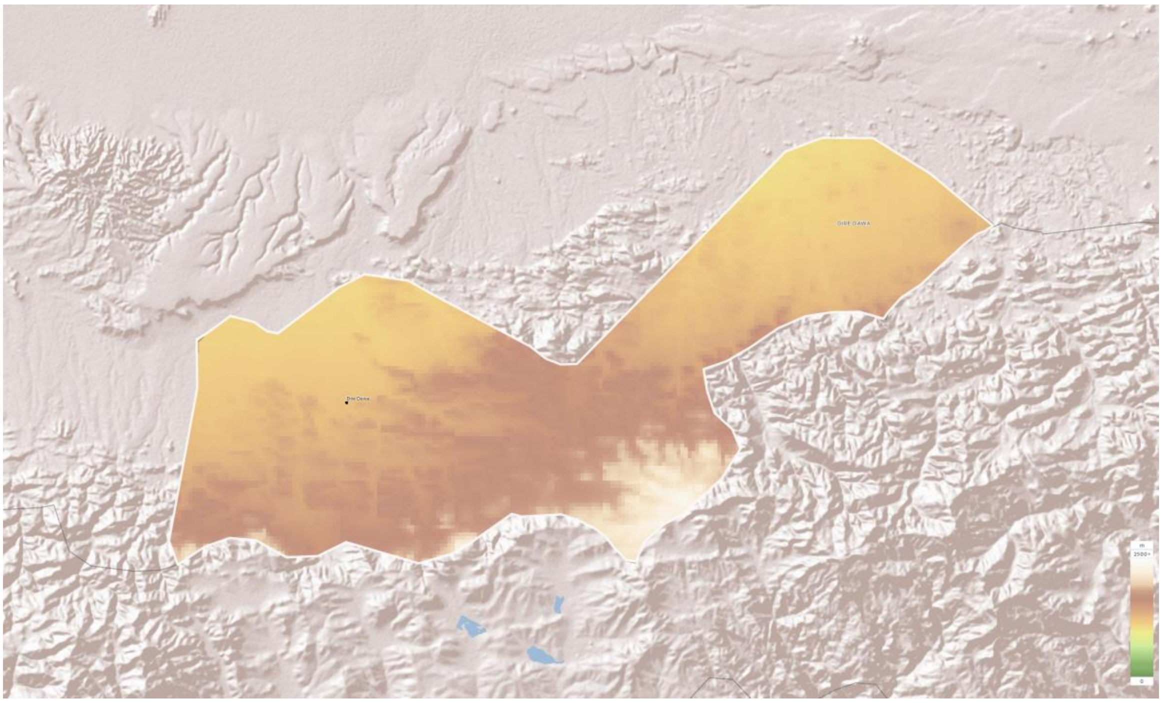

Fig 3-2 Elevation map of Dire dawa at 100 m

IV. Wind speed variability

NASA/POWER SRB/FLASHFlux/MERRA2/GEOS 5.12.4 (FP-IT) 0.5 x 0.5 Degree Interannual Averages/Sums
Dates (month/day/year): 01/01/2011 through 12/31/2019
Location: Latitude 9.608 Longitude 41.941
Elevation from MERRA-2: Average for 1/2x1/2-degree lat/lon region = 1220.08 meters
Site = na
Climate zone: na (reference Briggs et al: http://www.energycodes.gov)
Value for missing model data cannot be computed or out of model availability range: 999
Parameter(s):
WS50M_RANGE MERRA2 1/2x1/2 Wind Speed Range at 50 Meters (m/s)
WS50M_MIN MERRA2 1/2x1/2 Minimum Wind Speed at 50 Meters (m/s)
WS10M MERRA2 1/2x1/2 Wind Speed at 10 Meters (m/s)
WS50M_MAX MERRA2 1/2x1/2 Maximum Wind Speed at 50 Meters (m/s)
WS10M_MAX MERRA2 1/2x1/2 Maximum Wind Speed at 10 Meters (m/s)
WS10M_RANGE MERRA2 1/2x1/2 Wind Speed Range at 10 Meters (m/s)
WS50M MERRA2 1/2x1/2 Wind Speed at 50 Meters (m/s)
WS10M_MIN MERRA2 1/2x1/2 Minimum Wind Speed at 10 Meters (m/s)

Table 1 Inter annual data (Power access, NASA)

PARAMETER	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
WS50M_MIN	2011	0.77	1.16	1	1.14	1.04	1.05	3.17	2.23	0.91	1.9	1.12	1.05
WS50M_MIN	2012	1.14	0.95	1.28	1.27	1.82	1.29	2.6	2.47	1.27	1.29	1.07	0.81
WS50M_MIN	2013	1.19	1.14	0.9	1.07	1.15	1.41	3.89	2.31	1.33	1.6	1.09	1.16
WS50M_MIN	2014	0.94	0.85	0.96	1.46	1.21	1.7	1.98	1.98	1.24	1.67	1.28	1.01
WS50M_MIN	2015	1.32	0.89	1.02	1.21	1.22	1.17	1.54	2.46	0.91	1.94	1.36	1.22
WS50M_MIN	2016	1.35	0.94	1.3	1	1.18	1.69	2.46	3.24	1.43	1.52	1.39	1.35
WS50M_MIN	2017	1.2	1.1	0.97	1.17	0.96	1.4	2.13	2.75	0.99	1.76	1.37	1.25
WS50M_MIN	2018	1.1	0.85	1.47	1.08	1.34	1.36	2.5	2.75	1.93	1.69	0.92	1.06
WS50M_MIN	2019	0.71	1.06	1.14	0.97	1.29	1.04	1.84	2.65	1.54	1.07	1.55	1.27
WS10M_MIN	2011	0.7	1	0.83	0.91	0.82	0.9	2.2	1.57	0.75	1.38	0.84	0.76
WS10M_MIN	2012	0.78	0.83	0.95	1.14	1.4	1.01	1.84	1.7	1.06	1.05	0.99	0.66
WS10M_MIN	2013	0.86	0.92	0.8	0.92	0.99	1.26	2.85	1.58	0.99	1.2	0.88	0.86
WS10M_MIN	2014	0.68	0.69	0.77	1.15	1.02	1.42	1.63	1.48	0.96	1.24	1.02	0.71
WS10M_MIN	2015	0.91	0.72	0.83	1.07	0.98	0.96	1.34	1.98	0.74	1.41	0.97	0.81
WS10M_MIN	2016	0.96	0.64	1.14	0.75	0.81	1.48	1.75	2.31	1.1	1.23	1.06	0.86
WS10M_MIN	2017	0.86	0.82	0.75	0.93	0.74	1.25	1.79	2.19	0.81	1.3	1.04	0.88
WS10M_MIN	2018	0.74	0.68	1.17	0.85	1	1.23	2.28	2.02	1.55	1.29	0.77	0.78
WS10M_MIN	2019	0.61	0.88	0.97	0.71	1.02	0.81	1.53	1.9	1.19	0.78	1.04	0.85
WS50M_MAX	2011	7.11	7.48	7.57	6.65	7.21	9.26	10.49	10.81	8.38	7.84	6.78	7.2
WS50M_MAX	2012	7.25	7.72	7.29	7.34	7.53	10.02	10.43	9.8	8.34	7.46	7.15	7.11
WS50M_MAX	2013	7.06	7.56	6.84	5.97	7.82	10.33	10.97	9.88	7.97	6.66	6.32	6.77
WS50M_MAX	2014	7.18	6.94	6.44	6.1	6.31	9.45	10.8	9.76	8.02	6.09	6.86	7.11
WS50M_MAX	2015	7	7.3	7.12	7.22	7.2	8.4	10.71	11.11	8.37	7.13	6.87	7.06
WS50M_MAX	2016	6.55	7.51	6.98	6.19	7.07	9.95	10	10.63	9.19	7.03	7.14	7.42
WS50M_MAX	2017	7.25	6.7	6.78	6.57	6.08	10	10.87	11.01	7.66	6.9	7.39	7.26
WS50M_MAX	2018	7.07	6.65	6.82	5.99	7.48	9.4	11.03	10.55	8.15	6.55	6.54	6.99
WS50M_MAX	2019	7.22	7.16	6.67	5.5	6.92	8.77	10.19	9.7	8.96	5.18	6.28	6.4
WS10M_MAX	2011	5.07	5.75	5.61	4.96	5.44	7.42	8.44	8.69	6.52	6.41	5.28	5.55
WS10M_MAX	2012	5.55	5.86	5.53	5.52	5.89	8.01	8.46	7.76	6.2	5.07	4.84	5.13
WS10M_MAX	2013	5.19	5.83	5.03	4.27	5.89	8.44	8.9	7.9	5.94	4.5	4.17	4.44
WS10M_MAX	2014	5	5.07	4.77	4.66	4.75	7.69	8.87	7.8	5.77	4.03	4.66	5.12
WS10M_MAX	2015	5.26	5.4	5.39	5.58	5.42	6.49	8.84	9.11	6.65	5.48	5.2	5.23
WS10M_MAX	2016	4.8	5.54	5.14	4.43	4.85	7.78	8.15	8.52	7.17	4.47	4.88	5.5
WS10M_MAX	2017	5.3	4.94	5.03	4.78	4.31	7.94	9.04	9.12	5.85	4.83	5.25	5.07
WS10M_MAX	2018	5.45	4.99	4.92	4.23	5.57	7.49	9.11	8.48	6.34	4.51	4.52	5.03
WS10M_MAX	2019	5.28	5.53	5	4.38	5.27	6.95	8.38	7.9	6.95	3.85	4.49	4.32
WS50M_RANGE	2011	6.34	6.31	6.57	5.51	6.17	8.21	7.32	8.58	7.47	5.94	5.66	6.15
WS50M_RANGE	2012	6.12	6.76	6.01	6.07	5.71	8.73	7.82	7.33	7.07	6.17	6.08	6.3
WS50M_RANGE	2013	5.88	6.42	5.94	4.9	6.67	8.92	7.08	7.57	6.64	5.07	5.23	5.61
WS50M_RANGE	2014	6.24	6.09	5.49	4.64	5.09	7.76	8.82	7.77	6.77	4.42	5.58	6.1
WS50M_RANGE	2015	5.67	6.4	6.09	6.01	5.98	7.23	9.17	8.65	7.45	5.2	5.51	5.84
WS50M_RANGE	2016	5.21	6.58	5.68	5.19	5.89	8.26	7.54	7.39	7.77	5.51	5.75	6.07

WS50M_RANGE	2017	6.05	5.61	5.81	5.39	5.12	8.6	8.74	8.26	6.66	5.14	6.02	6
WS50M_RANGE	2018	5.97	5.8	5.35	4.92	6.14	8.04	8.53	7.8	6.22	4.86	5.63	5.93
WS50M_RANGE	2019	6.52	6.11	5.52	4.53	5.63	7.73	8.34	7.05	7.42	4.11	4.73	5.13
WS10M_RANGE	2011	4.37	4.75	4.78	4.06	4.62	6.52	6.24	7.13	5.78	5.03	4.44	4.79
WS10M_RANGE	2012	4.77	5.03	4.58	4.38	4.48	7	6.63	6.06	5.14	4.01	3.85	4.48
WS10M_RANGE	2013	4.34	4.92	4.23	3.35	4.9	7.17	6.05	6.32	4.95	3.29	3.29	3.58
WS10M_RANGE	2014	4.32	4.39	4	3.51	3.73	6.27	7.24	6.32	4.81	2.79	3.63	4.41
WS10M_RANGE	2015	4.34	4.67	4.56	4.51	4.44	5.53	7.5	7.13	5.91	4.07	4.23	4.42
WS10M_RANGE	2016	3.84	4.9	4	3.68	4.04	6.3	6.39	6.21	6.07	3.24	3.83	4.64
WS10M_RANGE	2017	4.44	4.12	4.28	3.85	3.57	6.69	7.25	6.93	5.04	3.53	4.21	4.19
WS10M_RANGE	2018	4.71	4.31	3.74	3.37	4.57	6.26	6.83	6.46	4.79	3.22	3.75	4.26
WS10M_RANGE	2019	4.66	4.65	4.03	3.67	4.25	6.14	6.86	6	5.76	3.07	3.46	3.47
WS50M	2011	3.7	4.31	4.19	4.13	4.56	5.64	7	6.69	5.05	5.18	4.18	4.15
WS50M	2012	4.21	4.31	4.28	4.68	5.1	5.96	6.71	6.29	5.46	4.61	4.17	3.9
WS50M	2013	3.99	4.15	4.1	3.65	5.04	6.4	7.84	6.4	4.75	4.37	3.69	3.76
WS50M	2014	3.83	3.61	3.66	3.9	4.16	6.01	6.81	6.04	4.77	4.12	4.19	4.02
WS50M	2015	4.16	4.1	4.31	4.6	4.61	5.02	6.55	7.14	4.61	4.73	4.34	4.04
WS50M	2016	3.71	4.02	4.16	3.71	4.22	6.3	6.54	7.19	5.58	4.7	4.19	4.27
WS50M	2017	4.13	3.78	3.89	4.11	3.53	6.24	6.9	7.06	4.56	4.62	4.44	4.18
WS50M	2018	4.18	3.86	4.16	3.42	4.7	6	7.32	6.82	5.24	4.45	3.74	3.95
WS50M	2019	3.85	3.91	3.89	3.28	4.44	5.23	6.29	6.33	5.39	3.35	3.98	3.79
WS10M	2011	2.77	3.24	3.1	2.95	3.3	4.46	5.48	5.27	3.75	3.69	3.08	3.11
WS10M	2012	3.17	3.27	3.17	3.4	3.71	4.8	5.33	4.67	3.9	3.14	2.93	2.88
WS10M	2013	3.03	3.19	2.96	2.59	3.8	5.3	6.16	4.72	3.25	2.9	2.56	2.72
WS10M	2014	2.87	2.83	2.65	2.8	3	4.66	5.45	4.54	3.23	2.76	2.93	2.94
WS10M	2015	3.15	3.1	3.12	3.35	3.28	3.8	5.3	5.59	3.35	3.36	3.15	3.06
WS10M	2016	2.87	3.1	3.06	2.56	2.84	4.86	5.16	5.34	4.02	3.1	2.95	3.11
WS10M	2017	3.02	2.89	2.81	2.86	2.47	4.88	5.61	5.52	3.24	3.13	3.18	3.06
WS10M	2018	3.19	2.86	3.01	2.39	3.37	4.82	6.02	5.21	3.7	3.01	2.61	2.91
WS10M	2019	2.89	3.02	2.89	2.32	3.18	4.04	5.04	4.78	3.78	2.26	2.79	2.73

Table 2 Daily Average data (power access, NASA)

YEAR	MO	DY	WS50M_RAN	WS10M_RAN	WS50M_MIN	WS10M_MIN	WS50M_MAX	WS10M_MAX
2018	7	5	8.91	6.81	5.61	5.27	14.52	12.07
2018	7	6	9.53	7.54	3.88	3.54	13.41	11.08
2018	7	7	9.74	7.91	1.71	1.8	11.45	9.71
2018	7	8	9.3	7.31	2.49	2.55	11.79	9.86
2018	7	9	9.21	7.83	1.01	1.01	10.21	8.84
2018	7	10	8.51	6.52	2.91	2.83	11.42	9.35
2018	7	11	6.5	5.53	4.29	3.72	10.79	9.26
2018	7	12	7.56	6.14	3.13	2.99	10.7	9.13
2018	7	13	8.2	6.91	2.54	2.07	10.74	8.98
2018	7	14	8.51	6.98	1.96	1.92	10.47	8.91
2018	7	15	7.67	6.22	3.24	3.1	10.91	9.32

2018	7	16	9.83	7.55	1.93	1.97	11.76	9.52
2018	7	17	8.45	7.47	1.74	1.41	10.19	8.87
2018	7	18	9.02	7.49	1.37	1.44	10.4	8.92
2018	7	19	10.13	8.07	0.44	0.53	10.58	8.6
2018	7	20	9.45	7.33	2.51	2.36	11.97	9.68
2018	7	21	7.86	6.09	3.17	3.06	11.03	9.14
2018	7	22	6.73	4.78	5.7	5.3	12.43	10.08
2018	7	23	7.8	6.14	6.02	5.63	13.83	11.78
2018	7	24	9.8	7.44	2.91	2.85	12.71	10.29
2018	7	25	8.71	6.7	0.43	0.46	9.13	7.17
2018	7	26	9.45	7.59	0.39	0.41	9.84	8
2018	7	27	8.69	6.89	0.88	0.91	9.57	7.8
2018	7	28	7.22	5.99	3.45	2.59	10.67	8.58
2018	7	29	7.68	6.71	2.98	1.57	10.66	8.28
2018	7	30	6.54	5.52	1	0.56	7.53	6.07
2018	7	31	5.26	4.88	1.6	0.96	6.86	5.84
2018	8	1	3.39	3.33	2.8	1.92	6.19	5.26
2018	8	2	5.66	4.76	2.21	1.65	7.87	6.4
2018	8	3	9.9	8.17	1.6	1.5	11.5	9.67
2018	8	4	8.58	5.97	3.91	3.44	12.5	9.41
2018	8	5	9.74	7.84	2.82	2.68	12.56	10.52
2018	8	6	11.55	8.88	1.08	1.02	12.63	9.9
2018	8	7	7.3	7.12	4.28	2.35	11.58	9.48
2018	8	8	9.85	7.56	2.52	1.58	12.36	9.13
2018	8	9	4.87	4.2	2.53	1.59	7.4	5.79
2018	8	10	7.03	4.98	3.01	2.72	10.04	7.71
2018	8	11	5.61	4.16	5.7	5.27	11.31	9.43
2018	8	12	8.5	7.22	4.55	3.33	13.05	10.54
2018	8	13	11.56	9.61	2.78	1.49	14.34	11.11
2018	8	14	7.95	7.27	2.39	1.38	10.34	8.65
2018	8	15	6.44	6.54	4.34	2.43	10.78	8.97
2018	8	16	9.23	7.33	1.69	1.54	10.91	8.87
2018	8	17	8.12	6.93	1.15	0.93	9.27	7.85
2018	8	18	7.81	6.51	2.91	1.64	10.72	8.15
2018	8	19	8.76	7.37	2.07	1.74	10.83	9.11
2018	8	20	8.82	7.34	1.44	1.14	10.26	8.48
2018	8	21	7.68	6.49	1.94	1.36	9.62	7.85
2018	8	22	6.93	5.77	2.2	1.4	9.12	7.17
2018	8	23	7.49	5.81	1.77	1.76	9.25	7.57
2018	8	24	7.12	5.62	2.38	2.2	9.49	7.82
2018	8	25	6.59	6.1	2.93	1.95	9.52	8.04
2018	8	26	7.65	6.57	3.35	1.98	11.01	8.56
2018	8	27	7.27	6.08	2.48	1.93	9.75	8.01
2018	8	28	8.33	6.68	1.74	1.72	10.07	8.4
2018	8	29	6.43	6.25	5.26	2.57	11.68	8.82

2018	8	30	7.73	5.42	2.54	2.31	10.28	7.73
2018	8	31	7.96	6.39	2.87	2.07	10.83	8.46
2018	9	1	7.83	5.91	2.08	1.98	9.91	7.89
2018	9	2	8.53	6.91	2.74	2.62	11.27	9.53
2018	9	3	7.53	6.79	4.36	3.35	11.89	10.14
2018	9	4	6.9	6.05	4.21	3.32	11.12	9.38
2018	9	5	8.3	6.6	1.13	0.85	9.43	7.45
2018	9	6	7.84	5.03	0.94	0.75	8.78	5.78
2018	9	7	6.79	5.54	2.93	2.66	9.72	8.2
2018	9	8	6.43	5.76	3.57	2.47	10	8.23
2018	9	9	6.58	4.94	0.89	0.8	7.47	5.74
2018	9	10	7.92	5.87	0.07	0.05	7.99	5.92
2018	9	11	6.47	5.26	2.28	1.99	8.74	7.25
2018	9	12	7.23	5.89	2.16	1.91	9.39	7.79
2018	9	13	7.65	5.27	0.63	0.74	8.28	6.01
2018	9	14	5.12	4.69	2.14	1.24	7.26	5.93
2018	9	15	6.65	5.68	1.35	1.13	8	6.81
2018	9	16	6.91	5.65	0.59	0.36	7.5	6.01
2018	9	17	6.31	4.51	0.01	0.03	6.33	4.54
2018	9	18	6.96	5.85	1.19	0.84	8.15	6.69
2018	9	19	6.7	4.84	0.97	0.71	7.67	5.56
2018	9	20	4.91	3.61	0.59	0.29	5.5	3.9
2018	9	21	7.23	6.1	0.74	0.63	7.96	6.73
2018	9	22	3.48	2.19	1.65	1.3	5.13	3.49
2018	9	23	3.67	3.58	4.58	2.7	8.25	6.28
2018	9	24	3.87	3.04	3.9	3.18	7.78	6.23
2018	9	25	4.52	2.51	2.26	1.84	6.78	4.35
2018	9	26	4.49	2.92	1.91	1.52	6.4	4.44
2018	9	27	6.18	3.39	0.89	1.1	7.06	4.49
2018	9	28	5.36	4.69	2.9	2.42	8.26	7.11
2018	9	29	4.53	3.19	2.41	1.96	6.94	5.15
2018	9	30	3.71	1.57	1.87	1.67	5.58	3.25
2018	10	1	5.45	3.83	1.94	1.59	7.39	5.42
2018	10	2	5.11	3.91	2.75	2.31	7.86	6.22
2018	10	3	3.69	1.8	2.33	2.32	6.02	4.11
2018	10	4	7.42	5.61	0.67	0.51	8.09	6.12
2018	10	5	4.78	3.24	3.08	2.17	7.86	5.41
2018	10	6	6.32	3.78	1.23	0.92	7.56	4.7
2018	10	7	6.89	3.67	0.34	0.47	7.24	4.13
2018	10	8	5.37	3.63	1.79	1.55	7.16	5.18
2018	10	9	7.1	4.71	0.52	0.34	7.62	5.04
2018	10	10	5.17	2.57	2.42	2	7.58	4.57
2018	10	11	5.31	2.93	2.47	1.99	7.78	4.92
2018	10	12	6.5	4.47	0.95	0.62	7.45	5.09
2018	10	13	5.73	3.8	1.69	1.43	7.43	5.23

2018	10	14	5.34	3.17	0.54	0.36	5.88	3.54
2018	10	15	4.44	1.55	1.76	1.68	6.2	3.24
2018	10	16	4	1.59	2.49	2.47	6.49	4.06
2018	10	17	3.8	1.67	1.31	1.4	5.12	3.07
2018	10	18	4.72	2.79	0.51	0.41	5.24	3.2
2018	10	19	2.98	1.35	2.24	1.78	5.22	3.12
2018	10	20	3.39	2.26	1.85	1.36	5.24	3.62
2018	10	21	3.46	2.83	1.13	0.8	4.58	3.64
2018	10	22	2.55	2.49	2.46	1.74	5.01	4.23
2018	10	23	3.72	2.07	1.22	0.91	4.94	2.98
2018	10	24	3.59	2.28	1.35	1.03	4.94	3.3
2018	10	25	3.7	3.89	2.17	1.01	5.87	4.9
2018	10	26	2.83	2.95	3.08	1.78	5.91	4.73
2018	10	27	3.08	3.32	3.26	1.91	6.34	5.22
2018	10	28	5.85	4.18	1.51	0.73	7.36	4.91
2018	10	29	5.7	3.19	0.73	0.82	6.43	4.01
2018	10	30	5.52	4.45	2.06	1.39	7.58	5.84
2018	10	31	7.25	5.79	0.45	0.3	7.69	6.09
2018	11	1	6.44	3.61	0.45	0.61	6.88	4.22
2018	11	2	6.71	3.52	0.67	0.94	7.38	4.46
2018	11	3	6.92	4.28	0.41	0.28	7.33	4.57
2018	11	4	6.09	3.55	0.78	0.96	6.87	4.52
2018	11	5	4.81	2.7	0.83	0.92	5.64	3.62
2018	11	6	5.6	3.8	1.11	0.78	6.72	4.58
2018	11	7	4.76	2.95	1.02	0.64	5.78	3.59
2018	11	8	4.41	2.28	0.54	0.79	4.94	3.07
2018	11	9	4.6	3.46	0.77	0.43	5.37	3.9
2018	11	10	5.39	3.66	0.26	0.58	5.66	4.24
2018	11	11	2.87	2.74	2.94	1.76	5.81	4.5
2018	11	12	5.95	4.45	1.25	1	7.2	5.45
2018	11	13	5.03	2.91	0.64	0.72	5.66	3.63
2018	11	14	4.15	2.04	0.58	0.82	4.73	2.86
2018	11	15	5.74	4.15	0.2	0.32	5.94	4.47
2018	11	16	4.47	1.82	0.84	0.99	5.31	2.8
2018	11	17	4.02	3.52	1.2	0.86	5.21	4.38
2018	11	18	6.24	4.1	0.69	0.63	6.94	4.73
2018	11	19	5.77	4.17	1.13	0.67	6.9	4.84
2018	11	20	5.88	4.44	0.92	0.6	6.79	5.04
2018	11	21	8.21	5.42	0.34	0.28	8.54	5.7
2018	11	22	6.51	4.26	0.99	0.72	7.5	4.98
2018	11	23	5.05	2.58	1.56	1.33	6.61	3.91
2018	11	24	5.63	3.04	0.62	0.83	6.25	3.87
2018	11	25	6.32	4.05	0.52	0.27	6.84	4.32
2018	11	26	5.2	3.44	1.78	1.55	6.98	5
2018	11	27	6.36	5.96	2.3	1.44	8.66	7.39

2018	11	28	6.64	5.68	0.15	0.06	6.79	5.74
2018	11	29	6.32	5.34	1.6	0.95	7.92	6.29
2018	11	30	6.69	4.69	0.39	0.27	7.08	4.96
2018	12	1	4.38	2.92	1.35	1	5.72	3.92
2018	12	2	6.05	4.13	1.41	0.94	7.46	5.07
2018	12	3	6.03	3.35	1.59	1.35	7.62	4.7
2018	12	4	6.27	4.39	0.99	0.8	7.26	5.2
2018	12	5	5.87	3.4	0.83	0.82	6.7	4.23
2018	12	6	5.3	3.19	0.88	0.94	6.18	4.13
2018	12	7	5	2.82	0.94	0.82	5.94	3.64
2018	12	8	6.4	4.53	0.9	0.7	7.3	5.23
2018	12	9	6.97	5.62	0.41	0.3	7.38	5.93
2018	12	10	5.1	3.34	1.33	0.97	6.43	4.31
2018	12	11	6.12	4.41	1.03	0.74	7.15	5.15
2018	12	12	6.85	5.06	0.7	0.47	7.55	5.53
2018	12	13	7.79	5.65	0.13	0.14	7.93	5.79
2018	12	14	7.17	4.82	0.33	0.32	7.5	5.14
2018	12	15	7.06	4.14	0.43	0.4	7.49	4.54
2018	12	16	7.09	5.14	0.63	0.7	7.72	5.84
2018	12	17	5.69	4.7	1.37	0.73	7.06	5.43
2018	12	18	5.2	4.34	2.08	1.27	7.27	5.61
2018	12	19	4.29	4.12	2.72	1.71	7.01	5.83
2018	12	20	6.24	5.15	0.7	0.57	6.95	5.72
2018	12	21	4.89	4.57	1.43	0.87	6.32	5.45
2018	12	22	4.83	3.9	2.27	1.4	7.1	5.3
2018	12	23	4.85	3.68	2.5	1.53	7.35	5.2
2018	12	24	6.37	5.06	0.67	0.23	7.04	5.29
2018	12	25	5.49	3.91	0.86	0.47	6.35	4.38
2018	12	26	7.09	4.71	0.28	0.14	7.37	4.86
2018	12	27	6.65	3.9	0.29	0.65	6.94	4.55
2018	12	28	4.53	3.29	1.55	1.37	6.09	4.66
2018	12	29	5.88	4.32	0.73	0.45	6.61	4.77
2018	12	30	6.57	4.54	0.6	0.77	7.17	5.31
2018	12	31	5.75	4.87	0.87	0.53	6.62	5.4
2019	1	1	6.29	4.2	0.53	0.33	6.82	4.54
2019	1	2	6.43	3.71	0.44	0.63	6.87	4.34
2019	1	3	7.41	5.95	0.86	0.89	8.27	6.84
2019	1	4	7.18	6.04	0.27	0.07	7.46	6.11
2019	1	5	6.87	5.5	0.7	0.43	7.56	5.93
2019	1	6	6.25	4.81	0.57	0.31	6.82	5.12
2019	1	7	5.89	4.47	0.64	0.39	6.53	4.87
2019	1	8	6.4	4.34	0.56	0.36	6.96	4.69
2019	1	9	6.73	4.94	0.49	0.37	7.21	5.31
2019	1	10	6.07	4.65	0.18	0.13	6.25	4.77
2019	1	11	7.84	6.75	0.13	0.05	7.97	6.8

2019	1	12	6.89	4.7	0.5	0.67	7.39	5.37
2019	1	13	5.7	3.26	0.52	0.81	6.22	4.08
2019	1	14	7.55	4.77	0.21	0.55	7.77	5.32
2019	1	15	5.96	4.06	1.5	1.39	7.45	5.45
2019	1	16	4.86	3.8	1.24	0.85	6.1	4.65
2019	1	17	7.36	5.52	0.29	0.21	7.65	5.73
2019	1	18	5.34	4.05	0.27	0.14	5.61	4.19
2019	1	19	5.71	3.88	1.21	0.82	6.92	4.7
2019	1	20	7.22	5.23	0.08	0.11	7.3	5.34
2019	1	21	5.6	4.31	1.47	1.06	7.07	5.36
2019	1	22	6.04	4.15	1.17	0.91	7.21	5.07
2019	1	23	5.45	3.01	1.87	1.66	7.32	4.68
2019	1	24	6.11	3.07	0.97	1.22	7.08	4.29
2019	1	25	7.4	5.3	0.76	0.64	8.17	5.93
2019	1	26	7.22	5.44	0.16	0.09	7.38	5.53
2019	1	27	7.68	5.43	0.44	0.52	8.12	5.95
2019	1	28	6.88	5.11	0.98	0.39	7.85	5.51
2019	1	29	5.88	4.06	0.87	1.07	6.75	5.13
2019	1	30	6.87	4.73	1.05	1.24	7.92	5.97
2019	1	31	6.93	5.35	0.96	0.74	7.89	6.09
2019	2	1	7.83	6.29	0.47	0.19	8.3	6.48
2019	2	2	6.7	5.04	1.53	1.03	8.23	6.08
2019	2	3	7.1	4.84	0.54	0.63	7.63	5.46
2019	2	4	6.86	4.73	1.78	1.19	8.63	5.91
2019	2	5	7.56	6.08	0.61	0.28	8.18	6.36
2019	2	6	6.39	4.74	0.81	0.57	7.21	5.32
2019	2	7	7.19	5.9	0.7	0.44	7.89	6.33
2019	2	8	8.08	6.14	0.09	0.34	8.17	6.49
2019	2	9	6.51	5.74	1.55	0.72	8.07	6.45
2019	2	10	4.9	3.32	1.26	0.98	6.16	4.3
2019	2	11	5.41	3.3	1.82	1.9	7.23	5.2
2019	2	12	4.91	3.23	0.74	0.38	5.65	3.61
2019	2	13	5.09	4	1.53	1.14	6.61	5.14
2019	2	14	6.57	4.93	0.27	0.41	6.84	5.34
2019	2	15	6.87	4.6	0.21	0.66	7.08	5.26
2019	2	16	7.51	5.88	0.76	0.67	8.27	6.55
2019	2	17	5.4	4.46	1.17	0.71	6.57	5.17
2019	2	18	5.33	4.23	1.49	1.03	6.82	5.25
2019	2	19	5.8	4.39	1.53	1.27	7.33	5.66
2019	2	20	5.33	3.2	0.93	1.48	6.26	4.68
2019	2	21	2.56	2	1.9	1.56	4.46	3.56
2019	2	22	4.53	4.32	1.15	0.87	5.68	5.19
2019	2	23	5.92	4.64	0.74	0.89	6.66	5.53
2019	2	24	5.89	5.32	1.43	1.19	7.32	6.51
2019	2	25	6.52	5.87	0.86	0.62	7.37	6.5

2019	2	26	7.94	6.22	0.43	0.81	8.37	7.03
2019	2	27	4.26	2.75	1.81	1.37	6.06	4.12
2019	2	28	6.03	3.94	1.47	1.43	7.5	5.37
2019	3	1	2.97	3.96	2.45	1.4	5.43	5.36
2019	3	2	3.67	3.45	2.36	1.5	6.03	4.95
2019	3	3	4.32	2.78	2.33	1.89	6.65	4.67
2019	3	4	2.98	1.26	1.71	1.75	4.69	3.01
2019	3	5	4.27	2.1	0.48	0.69	4.75	2.79
2019	3	6	2.53	1.92	2.83	2.07	5.36	3.99
2019	3	7	3.5	3.05	1.74	1.48	5.24	4.53
2019	3	8	5.55	2.84	0.74	0.72	6.29	3.56
2019	3	9	6.6	5.13	0.55	0.15	7.16	5.28
2019	3	10	6.86	5.25	0.55	0.29	7.41	5.54
2019	3	11	6.04	5.16	0.53	0.19	6.57	5.35
2019	3	12	6.84	3.95	0.33	0.32	7.17	4.26
2019	3	13	5.73	4.78	0.39	0.29	6.12	5.07
2019	3	14	5.65	4.79	1.41	1.16	7.06	5.96
2019	3	15	6.85	4.44	0.4	0.63	7.24	5.07
2019	3	16	6.58	4.49	1.1	1.11	7.68	5.59
2019	3	17	7.16	5.22	0.54	0.35	7.7	5.57
2019	3	18	6.33	3.62	0.58	0.84	6.91	4.46
2019	3	19	7.47	6	0.78	0.56	8.25	6.56
2019	3	20	6.8	4.6	0.43	0.37	7.22	4.97
2019	3	21	5.37	3.5	1.14	1.28	6.52	4.78
2019	3	22	4.64	2.51	1.05	1.34	5.69	3.85
2019	3	23	5.8	3.73	0.73	1.12	6.52	4.85
2019	3	24	6.6	4.48	1.67	1.28	8.27	5.76
2019	3	25	7.24	5.69	1.92	1.56	9.16	7.24
2019	3	26	5.79	4.17	0.69	1.04	6.48	5.22
2019	3	27	2.84	3.08	2.38	1.56	5.23	4.64
2019	3	28	5.94	4.59	0.35	0.29	6.29	4.88
2019	3	29	4.74	3.68	1.23	1.08	5.97	4.76
2019	3	30	6.6	4.54	0.6	0.7	7.2	5.24
2019	3	31	7	6.06	1.47	1.18	8.47	7.24
2019	4	1	6.08	5.17	0.29	0.2	6.37	5.38
2019	4	2	3.46	2.94	0.32	0.07	3.78	3
2019	4	3	4.11	3.32	1.56	1.14	5.68	4.46
2019	4	4	4.8	2.87	0.7	0.33	5.5	3.2
2019	4	5	4.97	4.3	0.45	0.39	5.43	4.69
2019	4	6	4.69	4.04	1.53	1.13	6.21	5.17
2019	4	7	6.13	3.97	0.29	0.48	6.42	4.45
2019	4	8	3.88	2.89	1.67	1.76	5.55	4.66
2019	4	9	4.63	4.18	2.29	1.35	6.92	5.53
2019	4	10	5.77	4.89	0.61	0.42	6.38	5.32
2019	4	11	6.68	6.1	2.21	1.54	8.89	7.64

2019	4	12	6.01	4.69	0.31	0.52	6.33	5.2
2019	4	13	5.35	4.17	0.31	0.56	5.66	4.73
2019	4	14	2.71	2.19	0.45	0.19	3.16	2.38
2019	4	15	2.59	2.22	0.85	0.63	3.44	2.85
2019	4	16	4.13	3.15	0.18	0.07	4.32	3.21
2019	4	17	3.81	2.7	0.91	0.64	4.72	3.34
2019	4	18	4.66	3.41	0.72	0.39	5.38	3.8
2019	4	19	4.52	3.42	0.62	0.39	5.13	3.81
2019	4	20	3.6	3.42	1.27	0.84	4.88	4.26
2019	4	21	2.72	2.42	1.83	1	4.55	3.42
2019	4	22	4.35	4.19	0.94	0.52	5.29	4.71
2019	4	23	2.58	2.68	1	0.59	3.57	3.27
2019	4	24	7.39	6.53	0.37	0.2	7.75	6.73
2019	4	25	4.74	4.64	2.78	1.76	7.52	6.39
2019	4	26	2.96	2.34	0.4	0.3	3.36	2.64
2019	4	27	4.27	2.89	0.51	0.8	4.78	3.69
2019	4	28	3.11	2.2	0.79	0.93	3.9	3.13
2019	4	29	4.99	3.93	1.2	0.9	6.19	4.84
2019	4	30	6.18	4.26	1.62	1.24	7.8	5.5
2019	5	1	4.87	3.53	1.8	1.4	6.67	4.93
2019	5	2	6.34	4.33	0.92	0.73	7.26	5.06
2019	5	3	6.08	4.48	0.53	0.28	6.61	4.76
2019	5	4	5.73	4.44	1.9	1.53	7.63	5.97
2019	5	5	4.49	3.36	2.78	1.99	7.27	5.34
2019	5	6	4.89	4.17	1.59	1.21	6.48	5.39
2019	5	7	5.14	4.39	2.93	2.42	8.07	6.8
2019	5	8	4.43	3.48	3.15	2.53	7.59	6.02
2019	5	9	7.79	5.44	0.42	0.34	8.21	5.77
2019	5	10	5.36	3.62	1.37	1	6.73	4.63
2019	5	11	7.43	6.15	1.53	1.14	8.96	7.29
2019	5	12	4.58	3.26	1.24	1.34	5.82	4.6
2019	5	13	6.67	5.84	0.94	0.62	7.61	6.46
2019	5	14	5.12	3.26	1.21	1.25	6.34	4.51
2019	5	15	6.89	4.91	0.21	0.25	7.1	5.17
2019	5	16	8.26	6.26	0.18	0.18	8.45	6.44
2019	5	17	8.97	6.73	0.23	0.31	9.21	7.04
2019	5	18	9.46	7.04	0.9	0.62	10.35	7.66
2019	5	19	7.61	5.26	0.32	0.39	7.92	5.64
2019	5	20	5.05	2.87	0.69	0.65	5.74	3.52
2019	5	21	4.78	4.11	1.3	1.04	6.08	5.15
2019	5	22	3.68	3.05	0.2	0.19	3.88	3.24
2019	5	23	3.88	3.53	0.23	0.18	4.11	3.71
2019	5	24	3.1	2.58	0.4	0.22	3.5	2.8
2019	5	25	3.03	2.71	2.15	1.29	5.18	4
2019	5	26	5.44	3.53	0.47	0.62	5.91	4.15

2019	5	27	4.82	3.78	1.18	0.81	6.01	4.6
2019	5	28	2.58	2.47	3.78	2.56	6.36	5.03
2019	5	29	5.61	3.95	2.4	1.91	8.01	5.86
2019	5	30	6.74	5.05	1.36	0.99	8.1	6.05
2019	5	31	5.7	4.18	1.8	1.55	7.49	5.73
2019	6	1	7.4	5.68	0.89	0.61	8.28	6.29
2019	6	2	4.94	4.89	1.69	0.79	6.63	5.69
2019	6	3	4.07	3.9	2	1.65	6.07	5.55
2019	6	4	5.91	4.62	1.4	1.02	7.31	5.64
2019	6	5	7.92	5.95	0.41	0.25	8.33	6.19
2019	6	6	6.69	5.42	1.09	0.62	7.78	6.04
2019	6	7	7.53	6.78	1.5	0.95	9.03	7.73
2019	6	8	8.83	6.59	0.33	0.21	9.16	6.8
2019	6	9	8.28	6.4	0.38	0.24	8.66	6.64
2019	6	10	7.21	5.34	0.42	0.37	7.63	5.71
2019	6	11	7.9	5.89	1.22	1.15	9.12	7.04
2019	6	12	8.64	6.89	0.26	0.11	8.9	7
2019	6	13	7.04	5.42	1.34	0.79	8.38	6.21
2019	6	14	8.64	6.63	0.06	0.06	8.7	6.69
2019	6	15	7.48	5.96	1.37	0.89	8.85	6.85
2019	6	16	7.17	5.7	0.67	0.37	7.84	6.07
2019	6	17	9.69	7.68	0.66	0.74	10.35	8.42
2019	6	18	8	6.23	1.11	0.82	9.11	7.05
2019	6	19	5.48	4.56	0.7	0.44	6.18	5
2019	6	20	5.77	4.46	0.09	0.02	5.86	4.49
2019	6	21	8.01	6.11	0.83	0.54	8.84	6.65
2019	6	22	8.01	6.3	0.98	1	9	7.3
2019	6	23	9.58	8.16	0.85	0.58	10.43	8.74
2019	6	24	9.4	7.72	0.39	0.25	9.8	7.97
2019	6	25	7.07	4.96	0.9	0.76	7.97	5.72
2019	6	26	7.27	5.85	1.26	1.1	8.54	6.95
2019	6	27	9.05	7.01	1.15	1.22	10.21	8.24
2019	6	28	8.29	6.24	3.98	3.79	12.26	10.03
2019	6	29	11.63	9.21	1.53	1.47	13.17	10.68
2019	6	30	8.85	7.52	1.77	1.59	10.62	9.11
2019	7	1	9.22	7.82	0.14	0.14	9.37	7.96
2019	7	2	7.92	6.57	1.32	0.8	9.25	7.37
2019	7	3	7.97	6.15	0.99	0.94	8.97	7.09
2019	7	4	8.78	7.58	0.36	0.25	9.14	7.83
2019	7	5	8.81	7.37	1.9	1.52	10.71	8.89
2019	7	6	10.8	8.15	2.05	2.02	12.86	10.17
2019	7	7	9.69	7.82	2.72	2.64	12.41	10.46
2019	7	8	11.41	9.07	1.53	1.52	12.94	10.59
2019	7	9	8.26	7.21	0.31	0.2	8.57	7.41
2019	7	10	5.97	4.96	1.56	1.5	7.53	6.46

2019	7	11	7.01	6.11	4.5	3.49	11.5	9.6
2019	7	12	9.55	7.35	1.86	1.75	11.41	9.1
2019	7	13	6.96	5.23	0.47	0.51	7.43	5.74
2019	7	14	6.06	4.83	4.19	3.44	10.25	8.27
2019	7	15	9.31	7.28	1.88	2.03	11.19	9.31
2019	7	16	8.35	6.7	2.13	2.09	10.48	8.78
2019	7	17	7.45	5.78	4.91	4.53	12.36	10.31
2019	7	18	7.87	6.4	3.45	2.74	11.32	9.14
2019	7	19	10.71	8.15	0.42	0.33	11.13	8.49
2019	7	20	7.71	7.06	1.81	1.1	9.52	8.16
2019	7	21	10.05	8.32	0.65	0.6	10.7	8.92
2019	7	22	8.29	7.17	2.59	1.57	10.88	8.74
2019	7	23	6.97	5.52	1.02	0.57	7.99	6.09
2019	7	24	9.32	7.11	0.85	1.21	10.17	8.32
2019	7	25	7.46	7	1.17	0.69	8.63	7.69
2019	7	26	4.51	4.96	3.88	2.43	8.39	7.39
2019	7	27	8.32	6.7	1.62	1.4	9.94	8.09
2019	7	28	8.27	7.43	1.83	1.04	10.1	8.46
2019	7	29	8.78	7.3	0.59	0.52	9.37	7.82
2019	7	30	8.33	6.72	1.59	1.23	9.92	7.95
2019	7	31	8.56	6.72	2.86	2.54	11.42	9.27
2019	8	1	7.34	6.04	4.36	3.85	11.69	9.9
2019	8	2	8.19	7.17	1.18	0.65	9.37	7.82
2019	8	3	4.99	4.46	3.27	2.3	8.26	6.76
2019	8	4	8.4	7.28	4.48	3.4	12.88	10.67
2019	8	5	10.16	7.8	3.69	3.36	13.85	11.16
2019	8	6	5.65	5.49	3.13	1.58	8.78	7.07
2019	8	7	6.14	5.65	1.8	0.91	7.94	6.57
2019	8	8	7.03	6.41	2.62	1.72	9.65	8.13
2019	8	9	5.44	5.46	4.52	2.66	9.96	8.11
2019	8	10	4.78	5.68	5.8	3.31	10.58	9
2019	8	11	4.11	4.77	3.91	1.92	8.02	6.69
2019	8	12	4.81	5.29	3.36	1.72	8.17	7.01
2019	8	13	7.46	6.42	1.19	0.7	8.65	7.11
2019	8	14	5.09	5.04	3.29	1.98	8.38	7.02
2019	8	15	8.11	5.73	1.34	1.32	9.46	7.05
2019	8	16	8.59	7.18	1.79	1.57	10.38	8.75
2019	8	17	7.77	5.92	1.46	1.04	9.23	6.96
2019	8	18	8.06	6.43	2.33	1.9	10.39	8.34
2019	8	19	8.6	6.65	1.44	1.16	10.04	7.81
2019	8	20	6.42	5.01	1.99	1.36	8.4	6.38
2019	8	21	7.07	5.85	1.98	1.93	9.05	7.78
2019	8	22	6.37	5.13	3.12	2.92	9.49	8.05
2019	8	23	8.05	6.57	2.5	2.1	10.54	8.67
2019	8	24	7.06	5.55	2.07	1.69	9.13	7.24

2019	8	25	9.14	6.92	0.86	0.87	10	7.79
2019	8	26	6.48	5.29	4.04	3.31	10.52	8.6
2019	8	27	6.64	6.7	4.62	2.37	11.26	9.06
2019	8	28	7.9	5.93	1.62	1.27	9.52	7.2
2019	8	29	7.07	4.97	1.13	1.15	8.2	6.12
2019	8	30	7.45	6.32	2.35	2.04	9.8	8.36
2019	8	31	8.26	6.81	0.77	0.77	9.03	7.58
2019	9	1	8.14	6.24	0.86	0.92	9	7.15
2019	9	2	6.68	4.25	2.09	1.63	8.77	5.88
2019	9	3	8.39	6.27	1.02	1.03	9.41	7.3
2019	9	4	7.6	5.89	2.78	2.64	10.38	8.53
2019	9	5	8.27	6.13	1.96	1.92	10.24	8.06
2019	9	6	7.64	6.51	2.03	1.68	9.67	8.19
2019	9	7	8.66	6.79	2.04	2	10.69	8.79
2019	9	8	6.97	6.91	4.76	2.99	11.73	9.89
2019	9	9	6.96	7.12	5.15	2.71	12.11	9.84
2019	9	10	9.16	6.94	2	1.44	11.17	8.38
2019	9	11	4.1	4.56	2.48	1.29	6.58	5.85
2019	9	12	5.17	3.3	1.28	1.24	6.44	4.54
2019	9	13	7.98	6.39	1.67	1.55	9.65	7.94
2019	9	14	10.48	8.44	0.13	0.19	10.61	8.63
2019	9	15	7.28	5.98	0.47	0.32	7.75	6.31
2019	9	16	7.52	4.88	0.53	0.46	8.05	5.33
2019	9	17	6.9	5.36	2.27	1.81	9.17	7.16
2019	9	18	7.42	5.54	1.98	1.84	9.4	7.38
2019	9	19	8.58	6.27	0.75	0.7	9.33	6.97
2019	9	20	6.96	5.87	2.52	1.88	9.48	7.75
2019	9	21	6.75	4.74	2.09	1.43	8.84	6.17
2019	9	22	9.32	6.79	0.19	0.12	9.5	6.92
2019	9	23	9.22	6.66	0.52	0.51	9.75	7.17
2019	9	24	8.41	6.4	0.38	0.34	8.79	6.74
2019	9	25	7.68	5.55	0.18	0.18	7.86	5.73
2019	9	26	7.56	5.62	0.77	0.65	8.34	6.27
2019	9	27	7.33	5.31	1.16	1	8.49	6.31
2019	9	28	5.77	4.08	1.71	1.12	7.48	5.2
2019	9	29	5.37	4.27	0.19	0.13	5.56	4.4
2019	9	30	4.47	3.69	0.23	0.11	4.7	3.8
2019	10	1	3.81	2.82	1	0.55	4.81	3.37
2019	10	2	3.42	1.73	0.33	0.4	3.75	2.12
2019	10	3	2.41	1.53	0.57	0.39	2.98	1.92
2019	10	4	3.47	2.71	0.6	0.41	4.07	3.12
2019	10	5	3.93	3.28	0.35	0.27	4.28	3.55
2019	10	6	3.53	2.55	0.45	0.24	3.98	2.79
2019	10	7	4.51	3.75	1.57	1.04	6.07	4.79
2019	10	8	5.87	4.73	1.83	1.54	7.71	6.27

2019	10	9	5.56	4.84	0.35	0.22	5.91	5.06
2019	10	10	3.06	2.7	1.06	0.67	4.12	3.37
2019	10	11	3.36	1.94	0.32	0.24	3.68	2.19
2019	10	12	4.63	3.77	0.82	0.6	5.46	4.37
2019	10	13	3.29	2.94	2.16	1.14	5.44	4.09
2019	10	14	2.71	2.64	0.8	0.55	3.51	3.19
2019	10	15	4.63	4.13	0.86	0.64	5.49	4.77
2019	10	16	4.57	3.63	1.59	1.01	6.16	4.63
2019	10	17	3.95	2.41	1.26	1.23	5.21	3.64
2019	10	18	6.98	5.69	0.5	0.54	7.47	6.23
2019	10	19	5.75	4.96	0.43	0.27	6.18	5.23
2019	10	20	4.83	4.11	0.79	0.47	5.62	4.58
2019	10	21	5.12	4.02	0.93	0.61	6.05	4.63
2019	10	22	2.79	3.21	3.39	2.01	6.18	5.22
2019	10	23	4.92	2.44	0.59	0.8	5.51	3.24
2019	10	24	4.36	1.78	0.91	1.01	5.27	2.79
2019	10	25	2.52	1.51	1.26	1.26	3.78	2.77
2019	10	26	1.93	1.59	1.65	1.21	3.58	2.79
2019	10	27	4.22	2.26	0.58	0.61	4.79	2.88
2019	10	28	5.01	3.14	0.98	0.78	5.99	3.93
2019	10	29	5.34	3.71	1.11	0.58	6.45	4.29
2019	10	30	3.71	3.04	2.6	1.56	6.31	4.6
2019	10	31	3.31	1.56	1.56	1.34	4.87	2.9
2019	11	1	4.54	2.79	1.46	1.03	6	3.82
2019	11	2	4.16	3.74	2.72	1.93	6.88	5.67
2019	11	3	3.5	4.39	3.77	1.77	7.27	6.16
2019	11	4	4.32	4.74	2.93	1.64	7.25	6.38
2019	11	5	5.59	4.74	0.86	0.48	6.45	5.22
2019	11	6	4.21	2.83	0.93	0.51	5.15	3.34
2019	11	7	4.11	3.02	0.32	0.17	4.42	3.18
2019	11	8	4	2.32	1.56	1.31	5.56	3.63
2019	11	9	4.1	2.06	1.66	1.41	5.76	3.47
2019	11	10	5.96	3.17	0.81	0.83	6.77	4
2019	11	11	5.6	3.18	1.05	1.03	6.65	4.22
2019	11	12	6.12	3.75	0.46	0.57	6.57	4.32
2019	11	13	5.88	3.59	0.74	0.6	6.62	4.2
2019	11	14	5.15	3.19	1.1	0.74	6.25	3.94
2019	11	15	6.6	3.88	0.24	0.19	6.84	4.07
2019	11	16	5.91	3.59	0.84	0.58	6.75	4.16
2019	11	17	6.41	3.99	0.16	0.41	6.57	4.4
2019	11	18	5.25	2.65	1.21	1.3	6.45	3.94
2019	11	19	5.72	3.57	0.57	0.46	6.29	4.03
2019	11	20	4.18	2.57	1.1	0.88	5.28	3.45
2019	11	21	4.9	3.22	1.35	1.23	6.25	4.45
2019	11	22	2.11	2.69	3.38	1.91	5.49	4.6

2019	11	23	2.3	2.93	3.24	1.73	5.54	4.66
2019	11	24	3.15	3.31	3.29	1.85	6.45	5.16
2019	11	25	2.61	2.7	3.22	2.01	5.82	4.71
2019	11	26	3.78	3.77	2.66	1.5	6.43	5.27
2019	11	27	6.08	5.05	0.21	0.17	6.29	5.22
2019	11	28	5.46	4.57	1.41	0.81	6.87	5.38
2019	11	29	5.08	4.11	1.89	1.12	6.96	5.23
2019	11	30	5.12	3.63	1.31	0.89	6.43	4.52
2019	12	1	4.94	2.79	1.79	1.3	6.73	4.08
2019	12	2	5.41	3.35	0.54	0.38	5.95	3.72
2019	12	3	6.3	4.51	0.31	0.24	6.61	4.75
2019	12	4	5.22	3.07	1.37	0.92	6.59	3.99
2019	12	5	5.76	3.59	1.81	1.17	7.56	4.76
2019	12	6	4.59	4.15	2.73	1.89	7.32	6.05
2019	12	7	5.62	3.3	1.02	0.82	6.64	4.11
2019	12	8	3.68	3.95	3.27	2.13	6.96	6.08
2019	12	9	2.78	1.98	2.85	1.61	5.63	3.6
2019	12	10	3.76	3.13	2.7	1.56	6.45	4.7
2019	12	11	2.72	2.95	2	1.26	4.71	4.21
2019	12	12	6.63	4.74	0.34	0.33	6.96	5.07
2019	12	13	4.6	1.93	1.48	1.54	6.07	3.47
2019	12	14	5.93	4.08	0.5	0.31	6.43	4.39
2019	12	15	3.95	2.49	0.56	0.36	4.51	2.86
2019	12	16	5.67	3.04	0.55	0.67	6.22	3.72
2019	12	17	6.02	3.75	0.42	0.33	6.44	4.08
2019	12	18	6.7	4.04	0.28	0.2	6.98	4.24
2019	12	19	6.05	4.28	0.84	0.52	6.9	4.8
2019	12	20	6.03	4.22	0.42	0.31	6.46	4.53
2019	12	21	5.47	3.97	1.17	0.65	6.65	4.62
2019	12	22	5.69	3.8	0.58	0.38	6.26	4.18
2019	12	23	3.49	2.4	2.19	1.44	5.68	3.84
2019	12	24	6.47	3.9	0.7	0.51	7.17	4.41
2019	12	25	3.99	3.07	2.73	1.43	6.72	4.49
2019	12	26	5.91	4.39	0.55	0.34	6.46	4.73
2019	12	27	5.81	4.04	0.17	0.11	5.97	4.15
2019	12	28	4.53	3.25	1.54	0.91	6.07	4.16
2019	12	29	3.53	2.58	2.32	1.48	5.86	4.05
2019	12	30	5.76	3.18	1.12	0.85	6.88	4.02
2019	12	31	6.05	3.69	0.58	0.38	6.62	4.07
2020	1	1	5.47	3.79	0.06	0.06	5.53	3.85
2020	1	2	6.44	3.96	0.42	0.52	6.86	4.48
2020	1	3	6.48	4.72	0.16	0.14	6.64	4.86
2020	1	4	4.83	3.61	1.48	0.86	6.31	4.47
2020	1	5	3.3	1.84	2.4	1.41	5.7	3.25
2020	1	6	5.5	3.74	0.37	0.25	5.87	3.99

2020	1	7	4.26	3.59	2.06	1.16	6.32	4.75
2020	1	8	5.46	3.87	0.77	0.61	6.23	4.48
2020	1	9	5.72	3.32	0.88	0.65	6.6	3.97
2020	1	10	3.14	2.14	2.06	1.35	5.2	3.49
2020	1	11	4.97	2.81	1.8	1.17	6.77	3.98
2020	1	12	3.83	2.13	2.97	3.05	6.79	5.19
2020	1	13	4.6	3.5	2.55	1.53	7.15	5.03
2020	1	14	3.98	3.88	2.26	1.28	6.24	5.17
2020	1	15	5.87	4.49	0.87	0.46	6.73	4.95
2020	1	16	5.3	3.43	1.56	1.21	6.85	4.64
2020	1	17	5.2	3.73	0.79	0.51	6	4.25
2020	1	18	5.74	4.34	0.31	0.17	6.05	4.51
2020	1	19	4.3	4.27	0.68	0.4	4.98	4.66
2020	1	20	5.47	4.8	0.3	0.18	5.76	4.98
2020	1	21	5.67	3.61	0.99	0.66	6.66	4.28
2020	1	22	5.89	3.48	0.75	0.48	6.64	3.96
2020	1	23	5.33	2.83	0.96	0.78	6.29	3.61
2020	1	24	6.09	4.05	0.93	0.69	7.02	4.74
2020	1	25	3.36	3.11	2.53	1.79	5.88	4.9
2020	1	26	2.57	3.04	3.66	2.49	6.23	5.54
2020	1	27	4.44	4.15	2.91	1.68	7.35	5.83
2020	1	28	4.28	2.69	2.58	2.32	6.87	5
2020	1	29	5.49	3.86	1.4	0.65	6.89	4.51
2020	1	30	6.84	4.48	0.46	0.32	7.3	4.81
2020	1	31	5.42	3.8	1.67	0.89	7.09	4.68
2020	2	1	4.02	3.31	0.18	0.29	4.2	3.6
2020	2	2	5.66	3.65	1.16	0.75	6.82	4.4
2020	2	3	5	3.79	1.48	0.7	6.48	4.48
2020	2	4	6.11	4.1	1.09	0.86	7.2	4.96
2020	2	5	6.45	4.45	1.17	0.63	7.62	5.08
2020	2	6	6.06	4.17	0.83	0.38	6.89	4.55
2020	2	7	6.56	4.76	0.35	0.22	6.91	4.98
2020	2	8	6.97	6.44	1.08	0.79	8.05	7.24
2020	2	9	6.37	4.58	0.76	0.61	7.14	5.19
2020	2	10	5.18	3.7	0.96	0.57	6.14	4.27
2020	2	11	6.82	4.12	0.84	0.8	7.66	4.92
2020	2	12	2.6	2.41	3.91	3.71	6.52	6.12
2020	2	13	3.64	3.47	4.26	3.05	7.91	6.53
2020	2	14	5.47	4.41	1.74	1.13	7.21	5.54
2020	2	15	6.59	4.57	0.35	0.22	6.94	4.8
2020	2	16	7.17	4.66	0.43	0.71	7.6	5.37
2020	2	17	7.08	4.84	0.66	0.89	7.74	5.73
2020	2	18	5.57	3.41	1.19	0.63	6.76	4.04
2020	2	19	5.06	3.35	1.41	1.32	6.47	4.66
2020	2	20	3.7	3.31	2.26	1.58	5.96	4.88

2020	2	21	5.94	4.22	1.26	0.67	7.2	4.89
2020	2	22	6.09	4.69	1.1	0.64	7.19	5.33
2020	2	23	7.07	5.51	0.44	0.33	7.51	5.84
2020	2	24	7.24	4.71	0.53	0.42	7.77	5.13
2020	2	25	6.44	3.5	1.39	1.44	7.82	4.95
2020	2	26	4.14	4.22	2.04	1.22	6.19	5.44
2020	2	27	4.41	4.06	2.53	1.74	6.94	5.8
2020	2	28	5.65	4.15	1.51	1.06	7.16	5.21
2020	2	29	4.62	2.58	2.62	1.91	7.24	4.49
2020	3	1	5.51	3.88	2.51	2.3	8.01	6.17
2020	3	2	5.69	4.18	1.13	0.73	6.82	4.91
2020	3	3	6.86	4.87	0.33	0.2	7.19	5.07
2020	3	4	7.61	5.38	0.66	0.6	8.27	5.97
2020	3	5	6.27	3.49	0.84	1.14	7.11	4.62

Table 3 Climatology (power access, NASA)

PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
WS50M_MIN	1	1.07	1.11	1.23	1.27	1.38	2.48	2.45	1.26	1.46	1.16	1	1.41
WS10M_MIN	0.76	0.85	0.9	0.99	1.05	1.16	1.81	1.72	1	1.13	0.89	0.75	1.08
WS50M_MAX	7.05	7.13	6.71	6.47	7.1	9.62	10.39	10.38	8.26	6.76	7.02	6.95	7.82
WS10M_MAX	5.15	5.27	4.92	4.73	5.23	7.69	8.41	8.31	6.26	4.7	4.89	4.95	5.88
WS50M_RANGE	6.05	6.06	5.6	5.24	5.83	8.24	7.91	7.94	7	5.3	5.86	5.95	6.41
WS10M_RANGE	4.39	4.41	4.02	3.74	4.18	6.53	6.61	6.6	5.26	3.57	4	4.2	4.79
WS50M	3.83	3.97	3.93	4.04	4.56	5.88	6.68	6.63	4.98	4.37	4.04	3.79	4.73
WS10M	2.91	2.98	2.83	2.83	3.24	4.65	5.25	5.01	3.49	2.96	2.86	2.8	3.48