Ethiopian Institute of Architecture, Building Construction and City Development

Identification of Potential Sites for Harvesting Wind Energy in the Town of Dessie, Ethiopia

by

Mulugeta Yenenew Mekonen

A Thesis Submitted to graduate studies of Addis Ababa University

Presented in Partial Fulfillment of the Requirement for Degree of Masters of Science in Urban Design and Development

Addis Ababa University

Addis Ababa, Ethiopia

October 2020

Ethiopian Institute of Architecture, Building Construction, and City Development

Identification of Potential Sites for Harvesting Wind Energy in the Town of Dessie, Ethiopia

by

Mulugeta Yenenew Mekonen

A thesis submitted for the Partial Fulfillment of the Requirement of Masters of Science in Urban Design and Development

October 2020

Addis Ababa

Addis Ababa University

School of Graduate Studies

This Thesis is submitted to the School of Graduate Studies of Addis Ababa University in the Partial Fulfillment of the Requirements for the Degree of Master of Science in Urban design and Development.

Title of Thesis: **Identification of Potential Sites for Harvesting Wind Energy in the town of Dessie, Ethiopia**

By: Mulugeta Yenenew Mekonen

October, 2020

Approved by Board of Examiners:

	---------------------------	--------------------------
Advisor	Signature	Date
	---------------------------	----------------------------
External Examiner	Signature	Date
	---------------------------	----------------------------
Internal Examiner	Signature	Date
	----------------------------	-----------------------------
Chairman	Signature	Date
	------------------------------	-----------------------------
Graduate Program Director	Signature	Date

Declaration

I, the undersigned, declare that this thesis prepared for the partial fulfillment of the requirements for the degree of Master of Science in Urban Design and Development entitled "**Identification of Potential sites for Harvesting Wind Energy in the town of Dessie, Ethiopia"** is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

Mulugeta Yenenew Mekonen

Signature: ______________________

October 2020

Confirmation

This thesis can be submitted for examination with my approval as a university advisor.

____

Tibebu Assefa (assistant professor)

October 2020

ACKNOWLEDGMENT

Above all, I would like to thank my almighty God and St. Merry for helping me in all of my life and achievement. Next, my sincere gratitude goes to my advisor, Dr. Tibebu Assefa, for his continuous support and valuable advice. Despite, his tight schedule, in addition to giving his very valuable comments, corrections, and suggestions. He was devoting his time to helping me with the implementation of the research outcome.

I would like to thank Dr. Hayal Desta for providing me his valuable comments, corrections, and suggestions. Also, I would like to seek to be a salute to all of my classmates. I also need be praise to my friends, Ato Ayelegn Tebeje and Aboma Workneh, my son Ermiyas Mulugeta and my daughters Mahder and Lidet Mulugeta for their continues support in a different aspect. Moreover, I would also thank the Dessie City administration municipality staff, associations that are organized with the cooperative.

Finally, my thanks go to my wife Birtukan Misganaw, who shoulder all family responsibility and encourage me in all aspects of the completion of this program.

Abstract

To find solutions for the global energy crisis, an analysis of a helical vertical axis wind turbine was conducted with the consideration of renewables and energy efficiency. Dessie town, one of the towns in the Amhara region, which uses different energy resources such as wood, charcoal, kerosene, animal dung, and hydroelectric power for heating, lighting, and transport. As the need for energy is increasing, the scratch for harvesting more energy sources is inevitable for cities and towns to be sustainable. This study was carried out in three steps: to map windy area in the town, the realization of the analytical calculation of a helical wind speed turbine power output which then informed the most wind harvesting potential sites. So, this study particularly aimed to address its use as the electricity supply for residential buildings or any other places with less ideal economic conditions. The easy and highly available mechanism using basic materials is to give individuals to have a viable option on their electricity production. Finally, based on findings, the study recommends wind energy could be a convenient planning strategy to inhabit and to supply affordable energy options for the growing urban population. The study also recommends proper energy regulations concerning alternative wind energy to improve, to achieve sustainability, and for the efficient utilization of wind energy.

Keywords: wind energy, wind speed, wind direction, and potential sites, Dessie town.

Contents

	page
Content	v
List of figures	viii
List of table	x
Acronyms and Abbreviations	xi
Chapter One: Introduction	1
1.2.Problem Statement	4
1.3 Objective	5
1. 4. Research Questions	5
1.5 Scope	6
1.5 Significance	6
1.7. Structure of the document	6
1.8. Description of the study area	7
Chapter Two: Literature Review	9
2.1. Theoretical review	10
2.2. Concept and definition of energy	13
2.3. Measure Wind Speed and Direction	18
2.4. Screen out the Most Wind Harvesting Potential Sites	23
2.5. Mapping Windy Area	25
2.6. Criteria for Wind Potential Site identification	26
2.7. Contextual review	27
Chapter Three: Material and Method	39
3.1. Description of the study area	39
3.2 Research Approach	41

3.3 Types of data 41

3.3.1 Data collection 42

3.3.2 Digitization 44

3.3.3 Dessie town wind speed and direction recorded data 44

3.3.4 Wind speed and direction 45

3.4 Wind power density 48

3.5 method 50

3.6 GIS Analysis 54

3.7 Exclusion of sites using buffer area 53

3.7.1 Settlements 54

3.8 Overly Analysis 54

3.9 site selection in the town 55

3.10 Slope 57

3.11 GIS integration 57

3.12 Research Design 58

3.13 Physical Observation 60

3.14 Data presentation 61

Chapter Four: Result 61

4.1 map windy area in the town of Dessie 61

4.2 Sort wind speed and direction measurement in the town 65

4.2.1Dessie town wind speed and direction recorded data 65

4.3 Shade out the most potential sites screening in the town 67

Chapter Five: Discussion 70

5.1 Map of windy area in the town 70

5.2 Sort wind speed and direction in the town 71

5.3 Shade out the most potential sites screening in the town 71

Chapter six: Findings, Conclusions and Recommendations 76

6.1 Findings 76

6.2 Conclusions 76

6.3Recommendations 77

References 79

Appendixes 81

List of figures

page

Figure 1: Location map of study area 8

Figure 2: Variations of wind speeds with heights and times of a day 13

Figure 3: Annual mean wind in Ethiopia 22

Figure 4: Wood collection for cooking 27

Figure 5: wind production complementary to hydro power Ethiopia (EEPCo) 36

Figure 6: Site location for simulation 40

Figure 7: Digital elevation model of Dessie town 43

Figure 8: Wind site suitability area map 45

Figure 9: Existing housing 46

Figure 10: Anemometer 47

Figure 11: Wind speed and direction simulation at 3:00pm and 6:00am respectively (Ayeteyef site) 51

Figure 12: Wind speed and direction simulation at 3:00pm and 6:00am respectively (Bus station site) 51

Figure 13: Wind speed and direction simulation at 10:00pm and 16:00am respectively (St.Merry site) 51

Figure 14: Wind speed and direction simulation at 3:00pm and 6:00am respectively (Tossa site) 52

Figure 15: Wind speed and direction simulation at 3:00pm and 2:00am respectively (Ber/Kella site) 52

Figure 16: Wind speed and direction simulation at 3:00pm and 6:00am respectively (Azewagedel site) 52

Figure 17: Total available area map and wind site suitability area map 54

Figure 18: Wind site suitability area map 56

Figure 19: Slope area map of Dessie town 57

Figure 20: Research design flow chart 59

Figure 21: Dessie town windy map 61

Figure 22: Dessie town rose diagram 62

Figure 23: Average wind speed at 10m height (NASA91989-2018) 63

Figure 24: Average wind speed at 10m height (NASA91989-2018) 63

Figure 25: Average wind direction at 10m height (NASA91989-2018) 64

Figure 26: Average wind direction at 10m height (NASA91989-2018) 66

Figure 27: the cumulative distribution of wind speed (NASA 1989-2018) 67

Figure 28: wind power density map of Dessie town 68

Figure 29: turbine needed in the building 74

List of the table

page

Table 1: Wind power density classification 11

Table 2: Wind speed equivalents 19

Table 3: Example of recent studies for actual site locations 23

Table 4: Energy in Ethiopia 32

Table 5: Climate data for Dessie 37

Table 6: Data types, source, collecting, analysis, method, for specific objectives 41

Table 7: spatial data collected 42

Table 8: Dessie town wind speed and direction recorded data at 10m and 50 height(2019) 44

Table 9 : Wind speed in (KmPH) 48

Table 10: Wind power density classification 49

Table 11: Analysis of wind power density classes 50

Table 12: Details of layer name distance from the buffer 53

Table 13:Wind turbine power output 73

Acronyms and Abbreviations

CFD	Computational Fluid Dynamic
CSA	Central Statistical Agency
CWET	Centre for Wind Energy Technology
DSS	Decision Support System
EEPCo	Ethiopia Electric Power Corporation
EG	Electricity Generation
EIABC	Ethiopian Institute of Architecture Building Construction And City Development
EMD	Ethiopian Meteorological Department
ETB	Ethiopian Birr
EU	Energy Utility
GERD	Grand Ethiopian Renaissance Dam
GIS	Geographic Information System
GoE	Government of Ethiopia
GTP	Growth and Transformation Plan

GWh	Gega Watt Per Hour
GW	Gega Watt
ICS	International Climate Service
IEA	International Energy Authority
KMh	Kilometer per hour
KW	Kilowatt per hour
m/s	Meter per second
NASA	National Aeronautics and Space Administration
NDC	National Determined Contribution
NMSA	National Metrological Service Agency
PE	Primary Energy
SCS	Self-Contained System
UEAP	Universal Electrification Access Program
UNDP	United Nation Development Plan

CHAPTER ONE

INTRODUCTION

Energy is the prime driving force for any economic development and industrialization around the world. The increasing concerns of rising energy prices, the security of energy supply, environmental sustainability, and global climate change have emphasized to consider renewable energy technologies are the viable option (Lee AHI, et al, 2012).

Today wind energy is a fast-growing, mature, cost-effective technology with a commercially attractive source to generate electricity (Uselli D, et al., 2013). The generation of electricity from wind power has become competitive with power from fossil fuel plants (Hulle and Fichaux, 2010). The total installed renewable power capacity across the globe, by 2010, is 305 GW (Saidur R, et al., 2010).which is expected to grow 1120 GW by the year 2030. In the last decade the utilization of renewable energy as sunlight, wind, rain, and geothermal heat which are replenished naturally has been increased extensively. In 2008, 19% of energy consumption comes from 13% traditional biomass used for heating, 3.2% from hydroelectricity (Mostafaei pour, 2010). Among above mentioned renewable energy sources Wind power is growing at the rate of 30% annually, with a worldwide installed capacity of 158 GW in 2009, (Ucar A, 2010) and is widely used in Europe, Asia, and the United States.

This is due to the advancement of technology in extracting power from wind turbines. Currently, it is possible to generate up to 5MW (Lee AHI, et al. 2012), of power from a single wind turbine. This leads to an increase in the number of manufactures and designers in the area of wind energy, and most countries today use the merit of wind energy as an alternative form of energy sources. This wind energy can be either a large wind farm or small scale wind power. The selection of potential sites is the main technical challenges in the twin of a wind site (Ucar A, 2010). The power enterprises face difficulties in identifying potential locations of wind power system because the decision of power plant sites has a strong relationship with the future demand, environmental impacts at the local level, supply and prices, and regulatory risks when making the investment decisions (Islam MR, et al., 2010).

In recent years, Geographic Information Systems (GIS) have emerged as a decision support system (DSS) to assist in spatial planning and management (Malczewski J, 2006). GIS-based multi-criteria decision analysis process changes and wed geographical data and value clamping (decision-makers' preferences) to achieve relevant information in spatial decision making (Ignacio J, et al.2008). Several studies have been to make to assess land convenient for wind expedient site development, by aggregation GIS with multi-criteria analysis (Van R, et al, 2011).

Ethiopia being a developing country has witnessed the growing concern of energy demands. The primary energy demands are met largely from fossil fuels which have contributed to conservatory gas releases and other atmospheric pollution (Mostafaei pour, 2010). And also, the current Ethiopian electrical energy supply is mainly from hydropower. Wind energy is an alternative energy that can complement hydropower, especially during the dry season. Due to the fast economic twit in recent years, the country is looking for more power plants to satisfy the high demand for electricity (Kim, 2006).

In Ethiopia, various studies showed that there are potential areas of generating power from wind. It is estimated that from the wind more than 10,000 MW electricity power can be generated (Pantaleo A, 2009) especially for small-scale wind turbines (turbine rated under 100kW). This is because they have been used to power home, small business, and to meet the energy requirement of the village, cottage facilities in remote areas which don’t have available to the main grid (Pantaleo A, 2009).

The work in this paper was extended the town-wide to six sites based on the wind speed and wind direction the wind speed and direction map were mapped concerning different building orientation and site elevation.

To perform the described work, data from Global Weather Data for NASA for analyzing and understanding the main climatic variables temperature, humidity, heating, wind speed, and wind direction of the town concerning the climate were studied.

This study attempts to identify potential sites for harvesting wind energy through multi-criteria analysis in Arc GIS for Dessie town. Wind energy scenario in Dessie town faces two unique challenges in terms of the failure of power provision and blackout (on-off) from the conventional sources strong power evacuation system.

As a result, town windy map of site elevation based classification for Dessie was prepared with Arc GIS tools followed by analysis and calculation of wind speed and wind direction including wind potential sites were used to map windy map, and screen out the most potential sites, which assure wind speed and wind direction access for buildings with Arc GIS and ENVI-met analysis software as a tool. Finally, user-friendly parametric wind turbines were installed for the referenced sites in the town.

1.2. Problem Statement

One of the main problems of electricity is a power outage (on-off or system) loss. The electricity supply in most sub-Saharan African countries is characterized by high system losses when compared to the international target of 10-12%. Some of the African countries record losses as high as 30%.

Ethiopia, one of the developing countries characterized by its low urbanization and rapid rate of growth as compared to other African countries and the impact of hydropower provision and on-off (blackout) become a big challenge in many towns of the country.

The frequent power blackout occurring all over the country in Ethiopia has become a perennial issue. The routine exchange and blackout of electric power within the country is causing a lot of stuff on the residence: bound from household level to business facilities, citizens and both governmental institutions and the private sector have been constantly complaining that the frequent power outage is disrupting their day to day businesses (Eth. Herald.14 Sep. 2017), the other problem is the accessibility problem. A quaint provide of ample energy is essential for urbanization.

In other words to the minimum ample speed to electricity, another challenge in the energy terry is that Ethiopia is too rely on hydropower, which causes blackouts during the dry period (Embassy of Japan in Ethiopia, 2008).

Dessie is a town in Ethiopia, where this thesis was presented, had also an experience of greater changes concerning energy provision currently and in the previous years. Despite the rapid economic growth and urbanization, the supply from the major development challenge facing the town. It is common, as well as power on-off (blackout) due to extreme energy provision events and the (blackout) is more aggravated in the dry season. So, the patronage behind this thesis is based on the fact that during the last few three decades the growth of Dessie town has been dramatic and more concentrated and expanded in the north and west direction and it brings a challenge to supply energy sustainably and potential windy sites are on the very of highly used for settlements, to make the town self-sufficient identifying its windy sites for wind energy harvesting is important in identifying the windy sites as possible sources of alternative energy. This requires the identification of potential sites for harvesting wind energy sites in the town of Dessie, Ethiopia.

1.3 Objective

General Objective:

To identify potential sites for harvesting wind energy in the town of Dessie.

Specific objectives:

1. To map windy area in the town

2. To sort wind speed and wind direction measurement in the town

3. To shade out the most wind harvesting potential sites screening in the town

1. 4. Research Questions

1. Where are windy sites in the town of Dessie?

2. What is the wind speed and direction measurement in the town of Dessie?

3. Which sites are highly suitable for harvesting wind energy in Dessie?

1.5. Scope

The study was done for Dessie town and settlements found within the town. It only focuses to identify potential sites for harvesting wind energy in Dessie town.

1.6. Significance

This study can contribute to the improvement of wind energy potential sites area selection not only in the town but also in other towns nationally. This research helps to encourage the administration and its residences to be drawn to wind energy to widen the alternative energy supply to the town for its socio-economic development. Moreover, it can provide data to policy and decision-makers to design appropriate policies and strategies for identifying immediate resources. Besides this, other researchers, who want to make research on this field of study, can take it as references for similar work.

1.7. Structure of the document

This paper contains six chapters. It starts with the introduction part which introduces energy, problem statement, objectives, research questions, scope, significance, the structure of the document, and description of the study area. The second chapter is a literature review having, theoretical and contextual review. The third chapter describes the method and material of the research. The fourth chapter will present the result of the paper. The fifth-chapter is about Discussion and finally, Chapter six which includes the findings, conclusion, and recommendation of the study. References and appendices are also included.

1.8 Description of the stud area

Dessie is a zonal town in South Wollo district having an area of 150,000 square kilometers it is the trade and administrative hub of South Wollo. It has the co-ordinates of 11' 8°N 39'38°E. The study area of Dessie town is characterized by significant variations in topography. Its average temperature, precipitation, humidity, wind speed, pressure, and visibility are 19^0c (high 28^0c, low 11^0c), 18.7mm, 51%, 11 km/h, 1015 m ber, and 24 km respectively.

Location Map of Study Area

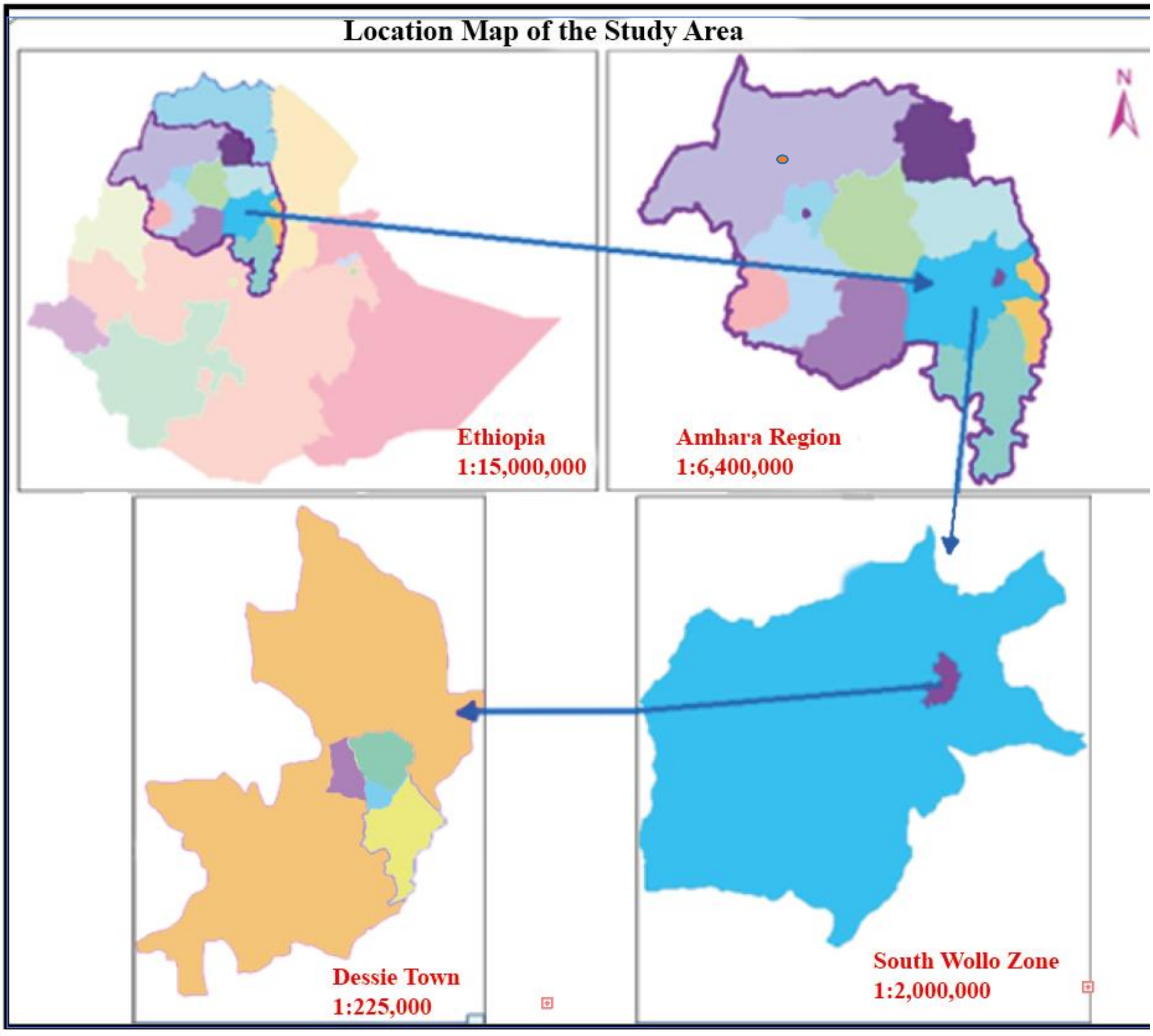


Figure 1 Location map of the study area

CHAPTER TWO

LITERATURE REVIEW

The wind is not a new terminology for humans. Mankind has been using the wind that can be traced back to 3000 years. In earlier times, humans were mostly using wind for agricultural, irrigation, and navigation purposes however, fossil fuels were the main source of power production. In the 19th century, commercial exploration shifted from coal to petroleum. Coal and natural gas are still considered the most common and cheapest form of power production (Oke, T.R, 1987).

Many scientists and researchers consider wind as a potential resource for meeting the future's electricity demands. The damaging effects caused by the burning of fossils fuels started the need for an alternative source of power generation. Social and eco-environment consciousness spread around many countries demanding a new reliable and clean source of energy. That was the beginning of research and development in the wind industry which continues to flourish till today (Oke, T.R, 1987).

Wind power is an option wealth to coal, petroleum, and nuclear energy which is more dozen, renewable, commonly distributed and has fewer extinct effects on the environment. The wind is the result of an air pressure gradient. It is generated due to the variations in the temperature of different areas. Land and sea have a different composition which gives them unique temperature characteristics (CIA, 2016).

Generally, more wind is available on the sea as related to the land. A wind turbine is a machine that utilizes wind energy and changes it into electric energy. The wind gives into the mechanically driven shaft that rotates and produces electricity. The production of electricity is contingent upon the obtainable wind speed. Wind speed varies very significantly in each hour of the day but the despicable wind speed remains consistent throughout each day. This mean wind speed is used for performance and output power calculations. Therefore wind turbines are always used in conjunction with some electric power sources to stabilize the output (Oke, T.R, 1987).

2.1 Theoretical Review

2.1.1 Wind power

A measure of available energy at any location is called the Wind Power. The power limited in the wind is "P" and power that can be extracted from the incoming power of wind "Pa" power can be calculated by the following equations (Hau.E,2006)

$$P=1/2PAv$$

$$P_a=1/2PAV^3C_P \quad \text{...........................eq.1}$$

Where,

P = Power that is contained in the wind (watts)

ρ = Air density – varies by temperature and altitude

A = Rotor swept area (m^2)

v = Wind speed (m/s)

Pa = Power that can be extracted by a wind turbine (watts)

Cp = Power Coefficient due to losses

Power Coefficient (Cp) is the measure of the efficiency of a wind turbine. The power coefficient is measured and provided by the turbine manufacturers against various wind speeds. Generally, it contains all the combined losses counting automatic pieces of machinery victims, aerodynamic, and electrical fatalities. The Germa physicist Albert Betz decided in 1919 that no wind turbine can change more than 59.3% of the kinetic energy of the wind which is called the Betz Law. It is also noted that the Betz bound is the theoretical maximum value that no practical wind turbine can operate. Practically, this value is around 35% to 40% (Oke, T.R. 1987).

2.1.2 Wind Power Density

Wind power density (WPD) of an area helps in the comparison and selection of the best suitable sites for the windy sites (Hau. E, 2006).WPD is defined as:

Where,

$$WPD = 1/2\ p\ V^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{eq .2}$$

WPD = Wind power density (watt / sq. area)

ρ = Air density

v = Wind speed

According to the American wind energy association, wind can be classified, which indicates a potential site for windy harvesting sites (Hau. E, 2006).

Table 1 Wind power density classification

Wind power class	Resource potential	WPD AT 50M w/m^2	Wind speed at 50m m/s
1	Poor	0-200	0-6
2	Marginal	200-300	6-6.8
3	Fair	300-400	6.8-7.5
4	Good	400-500	7.5-8.1
5	Excellent	500-600	8.1-8.6
6	Outstanding	600-800	8.6-9.5
7	Superb	>800	>9.5

Source: Wind speed equivalents, (Saidur R, et al.2010)

Table 1 indicates Wind power density classification, wind power, resource potential and wind speed at 50m shows its wind power density classification.

2.1.3 Wind Profile

The wind is unpredictable and wind speed has a dependency on time and location. Wind speed differs throughout the day in addition to the superficial roughness of different sites. Wind profile is an important maker in determining the ability of the wind turbines to be mounted. The terrains that don't have many hindrances like trees, houses, or buildings will have less roughness length and can have higher wind speeds, whereas, urban areas are usually the regions with low wind speeds. On seas or oceans, much higher wind speeds are faced compared to wind speeds on land (Oke, T.R, 1987). On sunny times, wind speed is more relative to the predictor cloudy days. At shows altitudes, wind speed differences are more similar to the oceans than on the land. During day time, wind speeds are commonly fewer than during the nights. At lower altitudes, wind speeds are faster in the daytime than at nights and higher altitudes (Oke, T.R, 1987). This different behavior can be counted for the more temperature change near the surface than the higher altitudes where temperature exchange between different air layers is not significant (Oke, T.R, 1987).

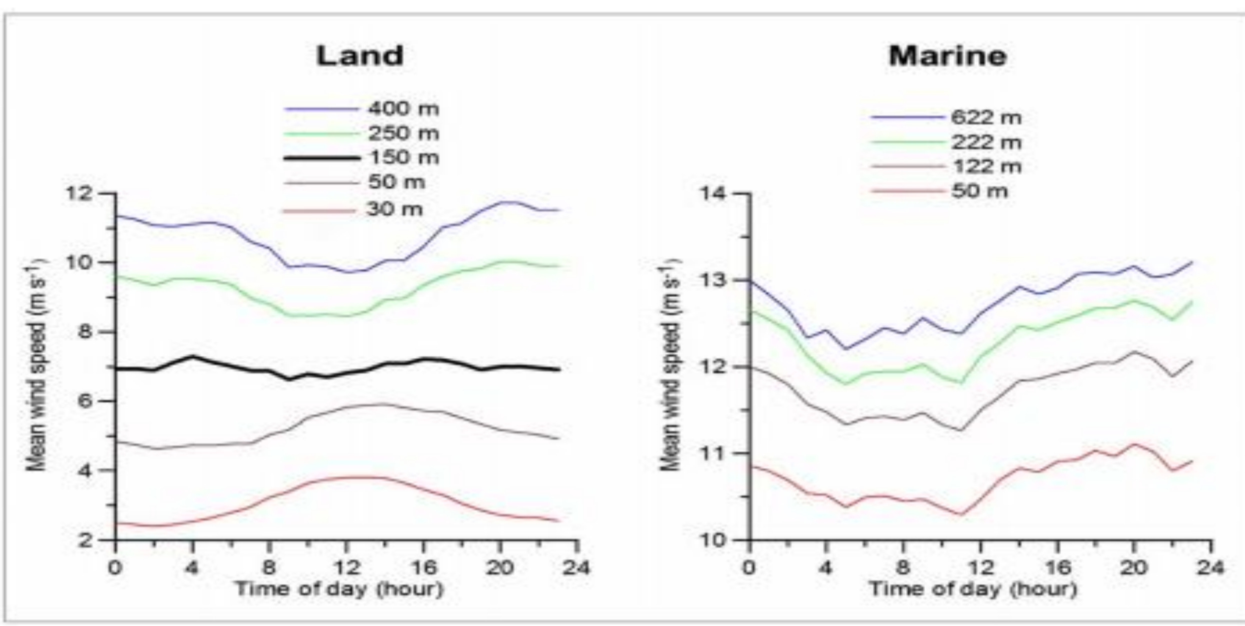


Figure 2 Variations of wind speeds with heights, surfaces, and times of a day

Figure 2 indicates, Variations of wind speeds with heights, surfaces, and times of a day inland and marine

2.2. Concept and Definition of Energy

Energy is the capacity to do work. Individual's custom energy for different purposes from walking to transfer cosmonauts into interplanetary (CIA, 2016).

Types of energy: they are:

1. Stored (potential) energy
2. Working (kinetic) energy

For example, a person who eats food encompasses chemical energy and supplies this energy until he or she usages it as kinetic energy during labor or production (CIA, 2016).

Forms of Energy:

1. Heat (thermal
2. Light (radiant)
3. Motion (kinetic)
4. Electrical
5. Chemical
6. Nuclear energy
7. Gravitational

Energy sources can be categorized as renewable or nonrenewable

When individuals usage electricity in their households, the electrical power is maybe produced by scorching coal or usual gas, by a nuclear response, or by a hydroelectric plant on a river, to name a fair insufficient basis.

(Kosterlitz, 2016). When individuals seal up a carriage's fuel ampule, the energy basis is petroleum (gasoline) advanced from crude oil and may contain fuel ethanol made by rising and dispensation Coal, natural gas, nuclear, hydropower, petroleum, and ethanol are called energy bases (CIA, 2016).

Energy sources are divided into two groups:

- Renewable
- Nonrenewable
- Renewable and nonrenewable energy bases can be used as primary energy bases to produce valuable energy such as temperature or secondhand to produce secondary energy bases such as electricity (phebe, 2016).

Renewable energy

The main five renewable energy sources:

- Solar energy from the sun
- Geothermal energy from the heat inside the earth
- Wind energy
- Biomass from plants
- Hydropower from flowing water (Fabrice,2017)

Nonrenewable energy Robert Hine

Most of the energy spent in the United States is from nonrenewable energy bases:

- ✓ Petroleum products
- ✓ Hydrocarbon gas liquids
- ✓ Natural gas
- ✓ Coal

- ✓ Nuclear energy (Robert Hine,2014)

Crude oil, natural gas, and coal are called fossil fuels because they were shaped over masses of years by the act of temperature after the earth's core and pressure from rock and soil on the remains (or remnants) of dead plants and beings such as microscopic diatoms. Most of the petroleum products spent in the United States are made from crude oil, but petroleum liquids can also be made from natural gas and coal (Harper, Douglas, 2007). Nuclear energy is produced from uranium, a nonrenewable energy source whose atoms are split (through a process called nuclear fission) to create heat and, eventually, electricity (Harper, Douglas, 2007). Wind energy is the most significant renewable energy resources. Today wind energy is a fast-growing, mature, cost-effective technology with commercially attractive sources to generate electricity (CIA, 2016).

Before the industrial revolution, energy needs were modest. For heat, trusted on the sun and scorched wood, straw, and dehydrated manure when the sun unsuccessful humanoid. For transportation, the influence of livestock and the power of the wind in navigates appropriated to every angle of the world. For work, used animals to do occupations that couldn't do with their labor. Water and wind herd the simple tackles that crushed grain and pumped water (Cornell University Press, 1988). Simple machines based on the ability to harness the power of steam have been dated by some sources as far back as ancient Alexandria. The evolution of the steam engine continued over time and significantly ramped up in the 17th and 18th centuries. But it was the useful improvement of Thomas Newcomen and James Watt in the mid-1700s that gave birth to the modern steam engine, opening up a world of possibility. A solitary vapor machine, powered by coal excavated from the pits of England and Appalachia, could do the work of quantity of livestock (Cornell University Press, 1988).

More convenient than wind and water and less expensive than a stable full of horses, vapor engines were soon generating locomotives, factories, and farm apparatuses. Coal was also used for space heating buildings and melting iron into the brace. In 1880, coal produced a steam engine connected to the world's first electric generator. Thomas Edison's produced in New York City gave the first electric light to Wall Street financiers and the New York Times (Touchstone, 1992).

Few a years later, the world's first hydroelectric plant went on-line in Appleton, Wisconsin. Fast percolate rivers that had slosh wheels to grind corn were now grinding out electricity instead. Within a few years, Henry Ford hired his friend Edison to help build small hydropower produce to power his home in Michigan.

By the late 1800s, a new form of fuel was catching on: petroleum. For years it had been irritation, polluting wells for drinking water. Primarily sold by hucksters as medicine, oil became an appreciated product for lighting as the whale oil industry waned. By the tray of the century, oil, processed into gasoline, was passion inside pedicle motor (Harper and Rowe, 1986).

The Great Energy Crash

The 1973 oil crisis forced Denmark to rethink its energy policy; in 1978 coal contributed 18%, and the Tuvin wind turbine was built, along with the creation of a wind turbine industry (David Roberts, 2016).

Wind power in Denmark

Wind provided 39% of the electricity generated in Denmark in 2014,(Danish Ministry of Climate and Energy,2011) and 42.1% of Denmark's sum of energy consumption in 2015 (Energinet.dk,2016). Denmark is a long-time leader in wind power, and as of May 2011, Denmark derives 3.1 percent of its Gross Domestic Product from renewable energy technology and energy efficiency, or around €6.5 billion ($9.4 billion) (Energy Statistics, 2008).

To improve investment in wind energy, the residence was offered a tax exemption for generating their electricity within their own or touching community. While this could include acquiring a turbine outright, more frequently families purchased stocks in wind turbine cooperatives which in turn capitalized in public wind turbines. By 2004, 150,000 Danes were either associate or links or owned turbines, and about 5,500 turbines had been coupled, although with greater private sector participation the amount kept by organizations had tumbled to 75%.

Ethiopian first wind farm in Mekelle

With almost 100 million inhabitants 85% of the population in rural areas Ethiopia is suffering from a chronic under-capacity in power generation and from frequent blackouts. In 2006, only 6% of the population had access to the power grid (Um.dk, 2016).

In the 1960s, the Ethiopian government undertook to develop the grid, mainly through the public utility EEPCo (now Ethiopian Electric Power, EEP). However, the fast-growing demand (+12% a year on average) and the needs of the neighboring countries (Djibouti, Kenya, Sudan) are compelling Ethiopia to rapidly develop its generation capacity (Um.dk, 2016).

As part of its strategy to diversify its energy mix, over 90% of which is currently based on hydropower, Ethiopia is increasingly targeting alternative renewable energy sources, including wind energy (Um.dk, 2016).

2.3. Measure Wind Speed and Direction

Wind rate is a three-dimensional trajectory quantity with small scale random variations in space and time superimposed upon a larger scale structured flow. For air protection and loading of airplane ratio, otherwise, the surface wind will be careful mainly as a two-dimensional vector quantity stated by two numbers representing direction and speed. The degree to which wind is considered fast differences is referred to as gustiness, and single differences are called squalls.

Be around numbers are quantities (for example, horizontal wind speed) that are averaged throughout 2 to 60 min as used for predicting purposes (IEA, 2014). Climatologically statistics usually require averages over each whole hour, day and night.

Peak gust is the supreme observed wind speed over a quantified time interval. With hourly weather harbors, the highest gust refers to the wind, risky in the last full hour.

duration is a measure of the duration of the observed peak gust. The duration is determined by the response of the system. Slowly responding systems smear out the extremes and measure long, smooth gusts; fast response systems may indicate sharp wavefront gusts with a short duration (IEA, 2014).

Meteorological requirement

Wind annotations or capacities are required for weather nursing and predicting, for wind load climatology, for the prospect of wind damage and assessment of wind energy, and as part of the estimation of surface instabilities, for example, evaporation for air pollution dispersion and agricultural applications. Uncertainties for a horizontal speed of 0.5 m /s below 5 m/ s and better than 10 % above 5 m /s one is usually sufficient (IEA, 2014).

Measurement of surface wind

Surface wind can be restrained by a wind slat and mug or propeller anemometer. When the instrumentation is temporarily out of operation or when it is not provided, the direction and influence of the wind may be predictable personally (IEA, 2014).

Table 3 Wind speed corresponding at an ordinary height of 10m above open flat crushed, beau fort gage number and account conditions for assessing speed over land and key findings done by different scholars worldwide

Table 2 wind speed equivalents

Beaufort scale number and description	Wind speed equivalent at a standard height of 10m above open flat ground				Specifications for estimating speed over land
	(kt)	(ms^{-1})	$(Kmh)^{-1}$	$(mih)^{-1}$	
0 Calm	< 1	0-0.2	< 1	< 1	Calm; smokes vertically
1 Light air	1-3	0.3-1.5	1-5	1-3	The direction of wind shown by smoke- drift but not by wind vanes
2 Light Breeze	4-6	1.6-3.3	6-11	4-7	The wind felt on face; leaves rustle; ordinary vanes moved by the wind
3 Gentle Breeze	7-10	3.4-5.4	12-19	8-12	Leaves and small twinges in constant motion; wind extends light flag
4Moderate Breeze	11-16	5.5-7.9	20-28	13-18	Raises dust and lose papers; small branches are moved
5 Fresh Breeze	17-21	8.0-10.7	29-39	19-24	Small trees in leaf begin to sway, crested wavelets form on land waters

6 Strong Breeze	22-27	10.8-13.8	39-49	25-31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
7 Near Gale	28-33	13.9-17.1	50-61	32-38	Whole trees in motion; inconvenience felt when walking against the wind
8 Gale	34-40	17.2-20.7	62-74	39-46	Breaks twigs off trees; generally impedes progress
9 Strong gale	41-47	20.8-2.44	75-88	47-54	Slight structural damage occurs (chimney-pots and slates removed)
10 Storm	48-55	24.5-28.4	89-102	55-63	Seldom experienced inland ;trees uprooted; considerable structural damage occurs
11 Violet storm	56-63	24.6-32.6	103-117	64-72	Very rarely experienced accompanied by widespread damage
12 Hurricane	64 and over	32.7 and over	118 and over	73 and over	

Source: Wind speed equivalents, (Saidur R, et al.2010)

Table 2 Wind speed equivalent at a normal elevation of 10m above open flat crushed, beau fort scale number and description specifications for approximating speed finished terrestrial and key findings done by different scholars worldwide.

Estimation of Wind

In the absence of equipment for measuring wind, the observations must be made by estimation. The errors in observations made in this way may be large, but, provided that the observations are used with caution, the method may be justified as providing data that would otherwise not be available in any way. If whichever provisionally or lastingly the wind data of some positions are found by assessment in its place of extent, this circumstance should be recognized in position accounts made available to data operators (IEA, 2014).

Wind speed

Assessments are based on the result of the wind on portable objects. Almost anything which is reinforced so that it is allowed to change below the impact of the wind can be used, but the expressive stipulations given in the Beaufort gage of wind vigor (IEA, 2014).

Wind direction

In the case of an absence of instruments, or when the instrumental equipment is unserviceable, the direction should be estimated by observing the drift of smoke from an elevated chimney, the movement of leaves, and so on, in an open situation, or a streamer or pennant fixed to a tall flagstaff. Also, the wind drogue at an airport may be used when the wind speed is sufficient to move such a device. From Figure 3 power density in w/m^2 in Dessie town 10-300 and velocity in m/s 1.0-6.4.

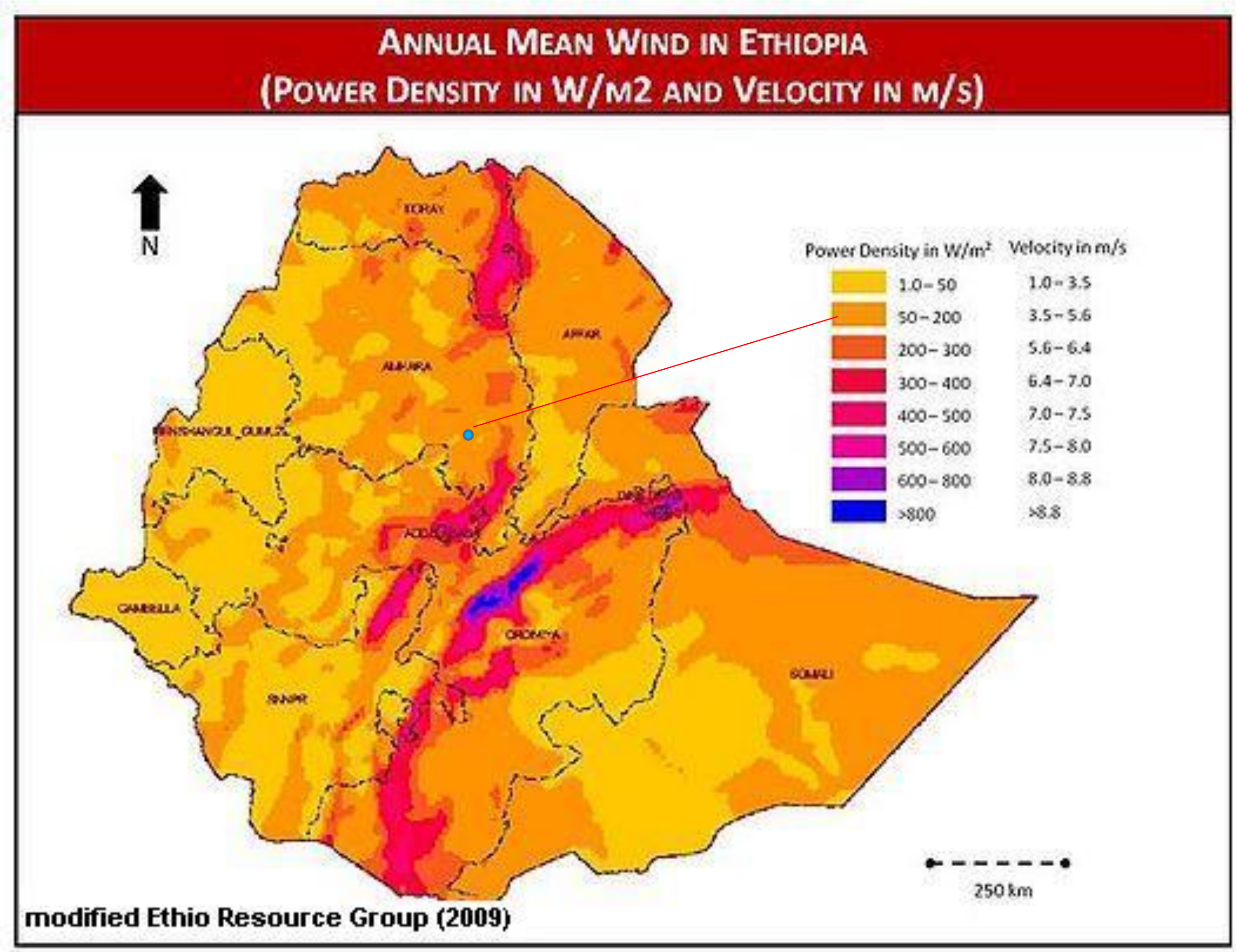


Figure 3 Annual Mean Wind in Ethiopia, Source: (Modified Ethio resource group, 2009).

2.4 Screen out the most wind harvesting potential sites

The wind has been used as an energy basis since 1998. The supremacy of wind was used to sail ships, to mill grain, and to pump water. Wind supremacy is currently considered as one of the most feasible substitutes for fossil fuels because it is renewable, widely spread, and clean with no greenhouse gas releases produced during operation. However, in urban and suburban areas, the land is limited and this is considered a major limit for the connection of large plants. A substitute choice is an alternative to structure combined wind energy organizations. Considerable a smaller amount of consideration has been given to wind energy connections close buildings, (Campbell and Stankovic, 2001; Beller, 2009; Sharpe and Proven, 2010). The thought of an on-site micro wind energy cohort is stimulating because the energy is before created close to the location where it is obligatory (Campbell and Stankovic, 2001).

So, Table 3 indicates the study, data collection approach, site model (concerned building), simulation flow, prediction/error, and key findings done by different scholars worldwide.

Table 3 Example of recent studies for actual site locations

Study	Data collection approach	Site model (concerned building)	Simulated Flow	Prediction /error	Key findings
LU and SUN 2014	ENVI-met	LeeShavkee building(97.4x38.7x69.9)(L, W, H)kowloon' Hong Kong	RNGke	No validation	Minimum height above the the roof is recommended for turbine installations building proximity effects can increase the wind power significantly (1.5-5.5) times at 4m above the building roof
Tabrizi et al. (2014)	ENVI-met field measurements from one location	Bunning's warehouse H=8.4m port Kennedy 'western Australia. The radius of the surrounding 200m	Steady RANS with k.e computational domain (H) 0.2km	Wind speed error < 20%	A small HAWT is recommender to be installed in the middle of the roof

AlQuran et al. (2016)	Wind tunnel experiments field measurements from two locations	Ev building (76m high) Equerry building (23m high) Montreal Quebec Canada.	Homogeneous terrain non homogeneous terrain	Wind error < 9%wind energy 5% <error <20%	Accuracy of wind tunnel results depends on the upstream terrain
Yang et al. (2016)	ENVI-met field measurements from 10 locations	The building has dimensions of68.9x62.5 x33.5m (L, W, H) in central metropolitan Taipei, Taiwan.	Standard keRNG Ke realizable computational domain (L,W,H) 16x8x0.3km	Turbulence intensity error<56% (ring ke model) error <20% reliable ke model wind speed error <20% (reliable ke model) wind direction prediction of reliable ke is more reliable than RNG ke and standard ke.	Recommended increasing the hub height and install microturbines on the wind wade side of the building curved roof edges increase the power density

Source: Actual site locations, (Mostafaei pour, 2010)

In recent years, ENVI-met has conventional a great deal of consideration and therefore, it has been widely modified in several requests, mainly for the resolve of mean flow conditions primarily for topics in environmental wind engineering such as pedestrian-level wind conditions, the natural airing of buildings and wind-driven rain. However, the results of ENVI-met replications should undergo detailed resolution confirmation and validation, as they are very complex to the wide range of computational parameters, (Campbell and Stankovic, 2001; Beller, 2009; Sharpe and Proven, 2010).

2.5 Mapping Windy Area

The wind resource assessment was based on surface wind data, coastal marine area data, and upper-air data, where applicable. In data-scarce areas, three qualitative pointers of wind speed or power were used when appropriate: topographic/meteorological pointers (e.g. valleys, elevation peaks, protected valleys); wind-distorted foliage; and eolian landforms (e.g. playas, sandbanks) (Campbell and Stankovic, 2001; Beller, 2009; Sharpe and Proven, 2010).

Hilltops, ridge crests, mountain summits, large clearings, and other locations free of local obstruction to the wind will be well exposed to the wind. In contrast, locations in narrow valleys and canyons, downwind of hills or obstructions, or in forested or urban areas are likely to have poor wind exposure(Campbell and Stankovic, 2001; Beller, 2009; Sharpe and Proven, 2010).

2.6 Criteria for wind potential site identification

For identifying a site for wind energy harvesting, the following are important criteria to be considered.

(a) The wind resource available

The availability of wind resources is dominant for the use of electricity cohort. A viable wind power project requires regular and sufficient wind speed at the hub height of the turbines. For commercial wind energy, class 3 or developed wind supply (i.e. wind resources greater than 300 W/m^2) are more appropriate (Anon, 2014d).

(b) Land use restrictions

The existing land use of an area with adequate wind resources also plays an important role in selecting a suitable wind energy site. For instance, there are areas where no wind energy can be built though adequate wind supply happens in those areas. Such areas include forests, wetlands, archaeological sites, aviation, and military zones (Talinli et al., 2011). These constraints are related to land use and the existing condition of the land. Grasslands and bare lands are highly preferred.

Proposed land use also affects the decision to site wind energy. Valuable land uses for the public such as agriculture, potential suburban or industrial area, and tourism cause obstructions and require a more detailed analysis of the decision (Talinli et al., 2011).

(c) Proximity to roads

The site should be accessible by roads for the transportation of the turbine components, construction materials, and other equipment. The maximum distance by which the site can be accessed must be suitable (i.e. distances not more than 2 km away from major roads). Distances bigger than 2 km are fewer appropriate and must be evaded (Talinli et al., 2011).

(d) Slope

Steady slopes cause an increase in wind speed and road convenience. Construction is also more possible on gentle slopes. Slope angles less than 30° are extremely appropriate (Chaudhry, 2008).

(e) Elevation

For efficient energy generation, wind turbines must be located in open areas and on higher elevations than the surrounding area, preferably, elevations greater than 100m (Chaudhry, 2008).

2.7 Contextual Review

2.7.1 History of Energy in Ethiopia

In figure 4 because of wood collection for cooking deforestation inland resources in Ethiopia.

Figure 4 Wood collection for cooking

Figure 4 shows, Ethiopia produces its primary energy exclusively from inland resources. These inland resources are almost entirely traditional renewable from biomass and biofuels (wood) and wastes (IEA energy statistics, 2014). A common type of renewable biofuel is wood for heating or cooking in households, a type of resource that is increasingly overused and over consumed due to the Ethiopian population growth. Current natural reproduction of wood does not cover the annual use of 37 million tons of wood, 50% of the Ethiopian wood reserves of 1,120 million tones are exploited (Ministry of water and energy, 2017). Consequently, deforestation is a common problem in Ethiopia with all of its negative implications. Due to the population growth, energy demand is increasing, which is increasingly (due to the stressed primary energy sources) covered by secondary energy imports.

Nevertheless, the use of primary energy is also increasing. In part, this is due to the further effective usage of agricultural wastes. Ethiopia has agricultural wastes "reserves" of 38 million tons per annum, but in 2011 only 6 million tons of them were used (Ministry of water and energy, 2017). Such wastes can be used in households or industrial processes, for example in thermal processing. Beyond the renewable, Ethiopia also has resources of nonrenewable primary energies (oil, natural gas, coal), but it does not exploit them. It also does not export them.

Energy reserves

Solid and liquid fuels

Ethiopia currently relies much on its reserves of wood for energy generation, Ethiopia also has liquid and solid hydrocarbon reserves fossil fuels: oil by 253 million tons of oil shale and more than 300 million tons of Coal (Ministry of water and energy, 2017). There are no plans in Ethiopia to exploit them and to use them for energy generation. The previous time there were plans, in 2006, a 100 MW coal power plant (the Yayu coal power plant) with a nearby coal mine was under consideration. Due to simple environmental anxieties, all plans were stationary and void in September 2006. The predictable environmental devastation was considered to be way too simple (Addis Fortune, 2017).

Electricity

Renewable energy in Ethiopia

Electricity production potential

The country focuses on the construction of electricity from a mix of cheap and clean renewable primary energy sources like hydropower or wind power. Ethiopia has a full identified economically viable probable of 45 GW of hydropower and 1,350 GW of wind power (International Hydropower Association, 2019). The recognized frugally viable latent from photovoltaic amounts to 5.2 GW while that from geothermal vitalities amounts to ~7 GW (Pv magazine, 2017). Ethiopia plans to exploit these properties.

For a modest normal capacity factor of 0.4, that would mean total electricity manufacture latent of around 4,900 TWh, ~9 times the total primary energy the country did devour in 2014. As is clear from such numbers, the country could substitute most of its primary energy use through the use of electricity. More than that, the country could become a major exporter of electricity. It is an expressed wish of the Ethiopian government to become a world-class exporter of large amounts of clean, cheap renewable energies in the future. However, going from 1% in 2010 to 4% in 2016 to 100% or even 900% in the (far) future is a long way to go.

In 2014, the country had an annual electricity production of 9.5 TWh. With this, Ethiopia was at situation 101 and with related electricity generation capability of 2.4 GW at the position 104 worldwide according to the CIA (CIA, 2016). In July 2017, the so-called nameplate power capacity, the overall installed power capacity, was up to 4,267.5 MW. 97.4% of that was from renewable primary energies like water and wind, with electricity from hydropower plants dominating with 89.7% and wind power with 7.6%. The completion of Gilgel Gibe III in 2015/16 added another 1870 MW capacity to the country's power production, more than doubling the country's production capacity from the year before.

In 2010, electricity creation made up only ~1 % of Ethiopia's main energy. In 2010 and 2016, the creation of electricity exited up from around ~5 TWh to around ~22 TWh (4% of the main energy value). This was due to a ruthless program to build wind farms and hydropower plants to produce electricity (GTPII, 2016). By looking at the table above, the annual production of energy carriers (electricity) within Ethiopia is growing faster than the growing need for primary energy. But the need for primary energy is still increasing in Ethiopia, even on a per person base. So, while energy carriers are increasingly produced, the general availability of them is not given to an extent that would allow the reduction of the use of primary energy. Also, imports of polished oil products are increasing, which cannot be avoided for a developing country (the transport of goods becomes much more important than for a subsistence economy).

Transport of electricity is done through electricity containers, such as power transmission lines and batteries. Especially the obtainability of a network of power transmission lines, a power grid, defines the amount of availability of electricity as the major source for secondary energy. Of course, also in the event of Ethiopia, this is given through the degree of electrification. Higher electrification means an increasing request for electricity.

In Ethiopia, the entire request for electrical power is cumulative by ~30 % annually (Capital Ethiopia, 2016). There is a race between accessible power cohort capacities and the electrification and accessibility of energy. In 2016 and 2017, while sufficiently of electricity was accessible through the totaling of the new Gilgel Gibe III power plant to the national supremacy grid, substations and power transmission lines were running out of capacity, with frequent outages and shortages which resulted in a wave of additions of substations and power spread lines (Addis Fortune,2017).

Wind power

The Ethiopian government increasingly focuses on wind power. In contrast to hydropower projects, which re-allocate water resources to some extent, only locals feel negatively impacted by wind farms to some extent. The leveled cost of electricity from wind power worldwide is falling and is now roughly that of hydropower. It is probable to drop further due to maturing technologies, increasing wind power popularity, and more suitable sites where wind power plants can be installed when compared to hydropower. By taking these developments into account, the Ethiopian Ministry of Water and Energy revised its numbers on an economically feasible wind power potential within only a few years from 10 GW to 1,350 GW (Ministry of Water and Energy,2017).

Wind power is ideally suited to complement hydropower. Oversimplified is wind power available in Ethiopia in times of water shortages, while abundant water is present when no wind is blowing. During the Ethiopian dry seasons, steady trade winds are blowing all over the country while it is dry. During the summer wet season, the wet rainy season dominates in Western Ethiopia with adequate water existing, while winds are slightly weak over most of Ethiopia.

Almost 80% of the identified favorable sites for wind power development are within the Somali Region of Ethiopia, most of it which would require long transmission lines to the Ethiopian cities. The remaining ~300 GW are more squarely distributed across Ethiopia (1,000 TWh per annum for a bulk factor of 0.4). This possible is still much better than that from hydropower.

Table 4 Energy in Ethiopia

Energy in Ethiopia		
	Primary energy	Secondary energy

	Population	TPES	Primary Energy per person	Primary Energy production	Primary Energy from imports	Secondary energy from imports	Electricity Generation	EG/TPES* 100	CO_2-emission
	Million	TWh	MWh	TWh	TWh	TWh	TWh	%	Mt
2004	74.5	418	5.6	400	0	16.4	2.54	0.61	4.8
2007	80.9	456	5.6	435	0	23.3	3.55	0.78	5.39
2010	87.6	496	5.7	473	0.2	26.0	4.98	1.00	5.96
2013	94.6	546	5.8	515	2.1	34.0	8.72	1.60	8.50
2014/	97.0	563	5.8	529	2.3	37.3	9.62	1.71	9.13

Table 4 Energy in Ethiopia, TPES, and Primary Energy per person, primary energy from imports, secondary energy from imports electricity generation.

Mtoe (as provided by the IEA) = 11.63 TWh TPES (Total Primary Energy Supply) includes energy fatalities PE production is the produced PE without fatalities PE imports does not unavoidably nasty that their vigor is free (introductions can also be rehabilitated into manufacturing resources or energy transporters), PE: Ethiopia did not export PE in the year PE: all PE ingresses were bituminous resources (natural asphalt used as an engineering material for the construction of roads),

SE: Ethiopia did export electricity; a single-digit percentage of the produced electricity, the annual quantity is not revealed in the table, SE: SE imports are sophisticated oil products only, SE: In 2014, SE importations were mostly gasoline (2.7 TWh), kerosene (8,7TWh) and diesel (20.1 TWh).Source: (Ministry of Water and Energy, 2017).

2.7.2 Energy production in Ethiopia

Introducing new technology

Menelik II introduced electricity to Addis Ababa, like the telephone, telegraph, the motor car, and modern plumbing. In 1894.

According to one tenacious story, Menelik heard about the modern method of performing offenders using electric chairs during the 1890s and ordered 3 for his Empire. When the seats inwards, Menelik learned they would not work, as Ethiopia did not up till now have an electric supremacy industry. Slightly than unused his speculation, Menelik used one of the chairs as his sovereignty, sending another to his second (Lique Mekwas) or Abate Ba-Yalew.

Ethiopia is the least developed country in the world. Approximately 34 % of its over 100 million inhabitants live below the poverty line (IEA, 2016). It has the lowest rates of access to modern energy services, whereby the energy supply is primarily based on biomass. With a share of 92.4% of Ethiopia’s energy supply, waste and biomass are the country’s primary energy sources, followed by oil (5.7%) and hydropower (1.6%) (IEA, 2016).

Energy situation

Ethiopia is energy consumption is estimated at around 40,000 GWh, whereof 92 % are consumed by domestic appliances, 4 % by the transport sector, and 3 % by industry. Most of the energy supply thereby is covered by bioenergy, which in the case of domestic use is usually stemming from unsustainable sources. The produced electricity of ~ 9000 GWh/ is primarily produced by hydro energy (96 %) shadowed by wind energy (4 %), whereof in total 11 % become spread. In distinction, the main part of the energy source for transport is introduced in forms of petroleum (IEA, 2013).

Ethiopia is gifted with renewable energy bases. These contain first of all hydro, but also wind, geothermal, solar in addition to biomass. Only a small portion of the potential is harnessed today.

Due to its fast economic growth, the energy demand is increasing enormously. Therefore it is predictable to rise by a rate of 10 -14 % per year until 2037(EEPCo, 2016).

Today only 27 % of the populations have contact with the electricity grid. This part is increasing due to a delay in the national grid on the one hand and an increasing number of Separate-organizations and Mini-grids alternatively.

Wind Energy

Ethiopia has good wind resources with velocities ranging from 7 to 9 m/s (Walelu, 2006). Its wind vigor potential is projected to be 10,000 MW (GTZ, 2007). The Ethiopian National Meteorological Services Agency (NMSA) initiated work on wind data collection in 1971 using some 39 soundtrack stations located in selected locations. Ever since the formation of these stations, wind velocity is restrained and data made accessible to clients. However, the number of stations established, the quality of data (in terms of comprehensiveness), and the distribution of the stations leave much to be desired.

On the source of data found from existing wind capacity stations two important assumptions can be drawn:

- Leading and principal, Ethiopia's wind energy possible is significant.
- Next, wind energy is extremely adjustable over the environment mostly as a meaning of the structure of the country. Pockets of spaces within elevation wind hustles of up to 10 m/s are dispersed throughout the Eastern half of the country, including the western escarpment of the Split Gorge.

Seasonal and daily variation in wind velocity is also considerable; wind speed is sophisticated between daybreak and mid-day and in terms of periodic difference, in the hilltop area there are two highest periods – March to May and September to November; and in the eastern grasslands wind speed spreads its maximum between May and August. In a maximum of these places, extreme wind speeds are 3 to 4 times greater than the minimum. Medium to a high wind speed of 3.5 to 6 m/s exists in most Eastern parts and central Rift Valley areas of the country. Perhaps due to their mountainous terrain and land use/land-cover type, most western and north-western parts of the country have generally low wind velocity (GTZ, 2011).

Up till now, no commercial wind energy power plants exist, nevertheless EEPCo is planning to develop seven wind sites that are near the ICS by 2015, ranging between 50 and 300 MW. In sum, the connected wind power volume would be approximately 720 MW (Walelu, k., 2011). Wind energy is considered promising complementation to hydropower since the two resources unfold their potential anti-cyclic: in rainy seasons the hydropower potential is high whereas low winds prevail. Vice versa hydropower potential is low in the dry season whereas the wind potential is high. Unlike large hydropower plants, wind energy plants do not have any negative environmental impacts (Meder, k., 2011). Figure 5 shows Wind production complementary to hydropower in Ethiopia.

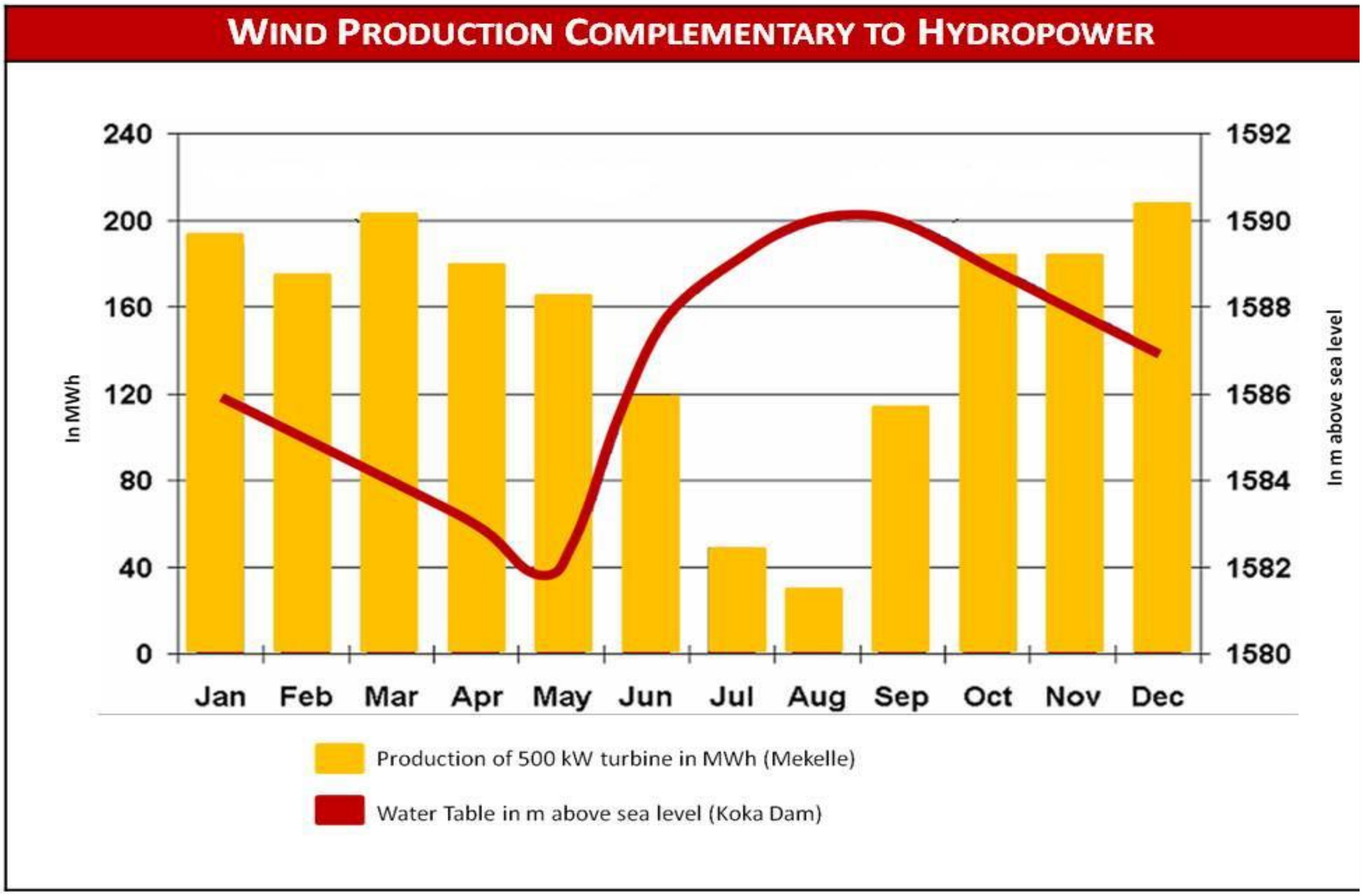


Figure 5 Wind production complementary to hydropower Ethiopia (Source: EEPCo, 2011).

2.7.3 History of Energy in Dessie

Dessie town, its climate is warm. In winter, there is much the temperature here averages 15.2 °C. The average annual rainfall is 1145 mm. Dessie is located at an altitude of 2,470 meters (8,100 ft.) above sea level in low-shrouded mountains and hills (MCWAEA, 2008). Dessie has a subtropical highland climate. More to the east, there is a hot semi-arid climate.

Table 5 Climate data for Dessie

Climate data for Dessie

Month	Jan	Feb	Mar	Apr	May	Jun
Average high °C (°F)	22.7 (72.9)	23.1 (73.6)	22.4 (72.3)	23.4 (74.1)	24.5 (76.1)	25.3 (77.5)
Average low °C (°F)	5.4 (41.7)	7.1 (44.8)	6.9 (44.4)	8.4 (47.1)	8.1 (46.6)	9 (48)
Average precipitation mm (inches)	25 (1.0)	40 (1.6)	81 (3.2)	95 (3.7)	75 (3.0)	41 (1.6)

Source: *Climate-Data.org*, altitude: 2,470m

The difference in precipitation between the driest month and the dampest month is 263 mm. During the year, the average temperatures vary by 4.3 °C.

Dessie is a town in Ethiopia, where this thesis was directed, have also an experience of greater changes concerning energy provision currently and in the previous years. The energy provision has different aspects from season to season. The motivation behind this thesis was based on the fact that during the last few three decades the growth of Dessie has been dramatic. The growth of the town is more concentrated and expanded in the north and southwest direction and it brings a challenge in the provision of energy to the urban built-up areas and the significant portion of the city. However, all at once, there is a realization that certain parts of the town especially in the northern direction have been as such new settlement development. For this settlement, energy provision and energy on-off (blackout) have many causal factors. So alternative energy resources are needed, the main alternative is wind energy because of the potential and topography of the thesis area is expected the desirable one, reported in this paper to identified potential sites for urban wind energy in the town of Dessie.

CHAPTER THREE

MATERIAL and METHOD

3.1 Description of the study area

Dessie, aged more than a hundred and ten years is located in north-central Ethiopia along the Addis Ababa Mekele road in South Wollo Administrative Zone of the Amhara Region, The town is found at latitude and longitude of 11' 8°N and 39'38°E with an elevation that ranges from 2250 and 2470 meters above sea level. According to the information from the town administration, the current population of the town is estimated to be 174,705 people.

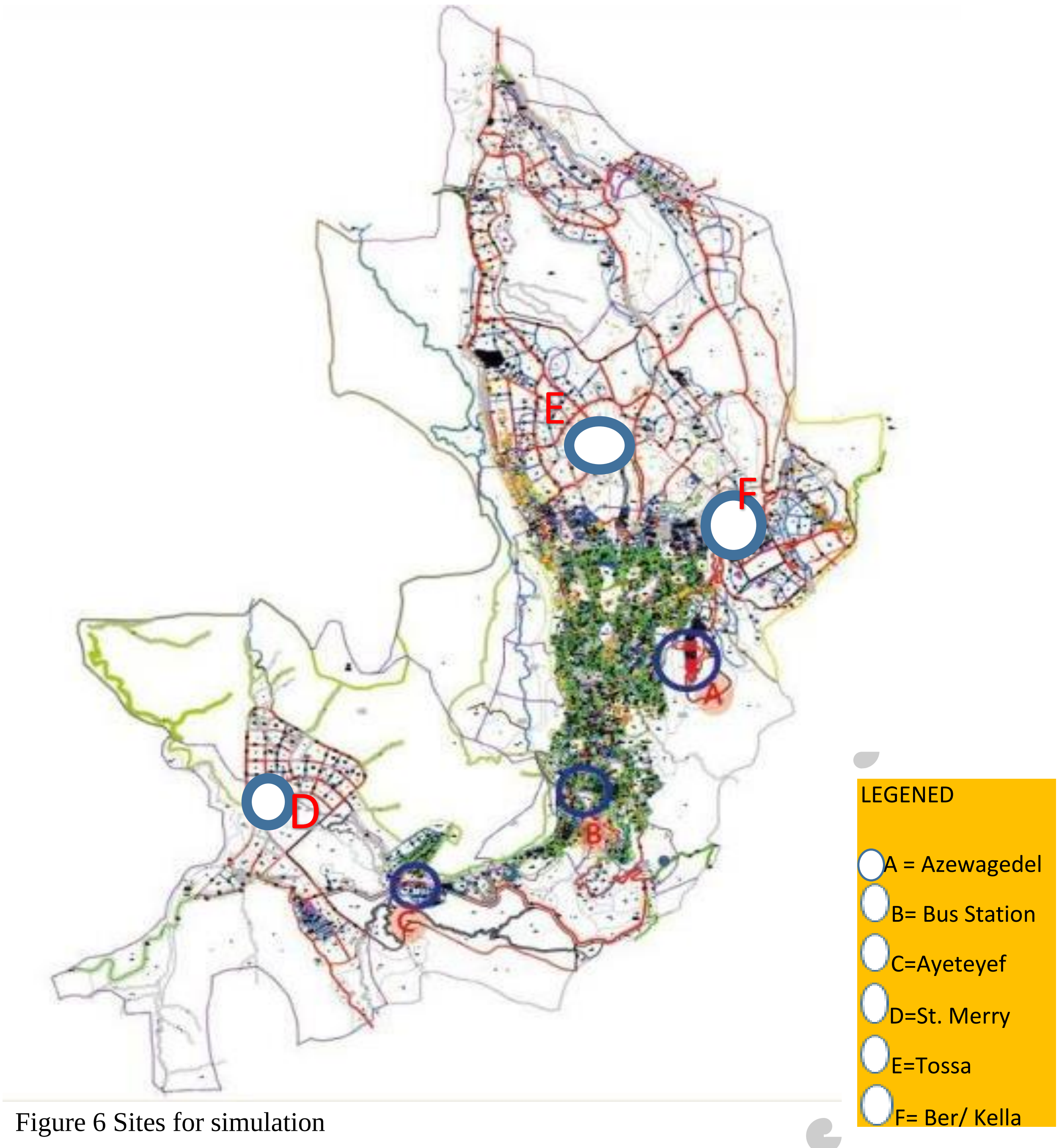


Figure 6 Sites for simulation

3.2 Research Approach

In this thesis, wind speed and wind direction data have used the precipitation of the resident toward wind speed, humidity, and wind direction were used to study wind pressure sensational of Dessie town and for identifying the windy sites.

3.3 Types of data

Table 6 summarizes the type of data, method of data collecting some of the data instruments used research analysis for each specific objective.

Table 6 Data types, source, collecting and analysis methods for specific objectives

Objectives	Type of data	Method and data collection	source	Instrument used	Analysis
1. To map windy area in the town	wind speed, and wind direction	Measure and compute wind speed and wind direction	Survey computed data, NASA recorded data	ENVI-met, GIS	Map and show the identified windy site
2. To sort wind speed and direction measurement in the town	wind speed, and wind direction Measurement	Measurement	Structure map of Dessie, Google map,	Anemometer	Measure And registered, identifying wind turbulence speed
3. To shade out the most wind harvesting potential sites screening in the tow	Windy area, land use, proximity roads, slope, elevation	Physical observation interview	Dwellers, NASA recorded data	checklist	Observing, registering, and identifying wind speed and direction

Source: (survey data,2019)

3.3.1 Data Collection

The first important stage in the GIS environment is data collection. And the second step is the identification of the objectives and the economic possibility criteria it requires different geographic data. And it also includes the collection of the data and digitization of the study area. The depicted table shows the collected spatial data.

Table 7 spatial data collected

Name of Data	Resolution /scale	Source
Topographic Map of Dessie	1:40000	Survey of Dessie
Wind Power Density Map	5km	CWET CHENNAI
Dessie boundary	1:85000	street map of Dessie
ASTER imagery	ASTER imagery resolution	USGS
Transmission network		GPS surveying

Source: (Bhavya, et al, 2009).

Geo-referenced top sheets are used to prepare a land-use pattern map of Dessie. The Satellite Imagery of Dessie is taken from the TERRA/ASTER (2009) which has great potential to track the conversation which is due to the various characteristics like spatial and spectral resolution. Dessie town covers replicated colors that are given in the image shows the difference between both the images which are geo-referenced to follow the geographical coordinate system in (WGS84), which is clipped from ESRI-Shape file using Arc GIS10.3. The software which is used for editing spatial data and the cropped image was re-projected and merged with GIS software. The spatial resolution of Dessie town ASTER image is 15m in below Figure 7 (Bhavya, et al, 2009).

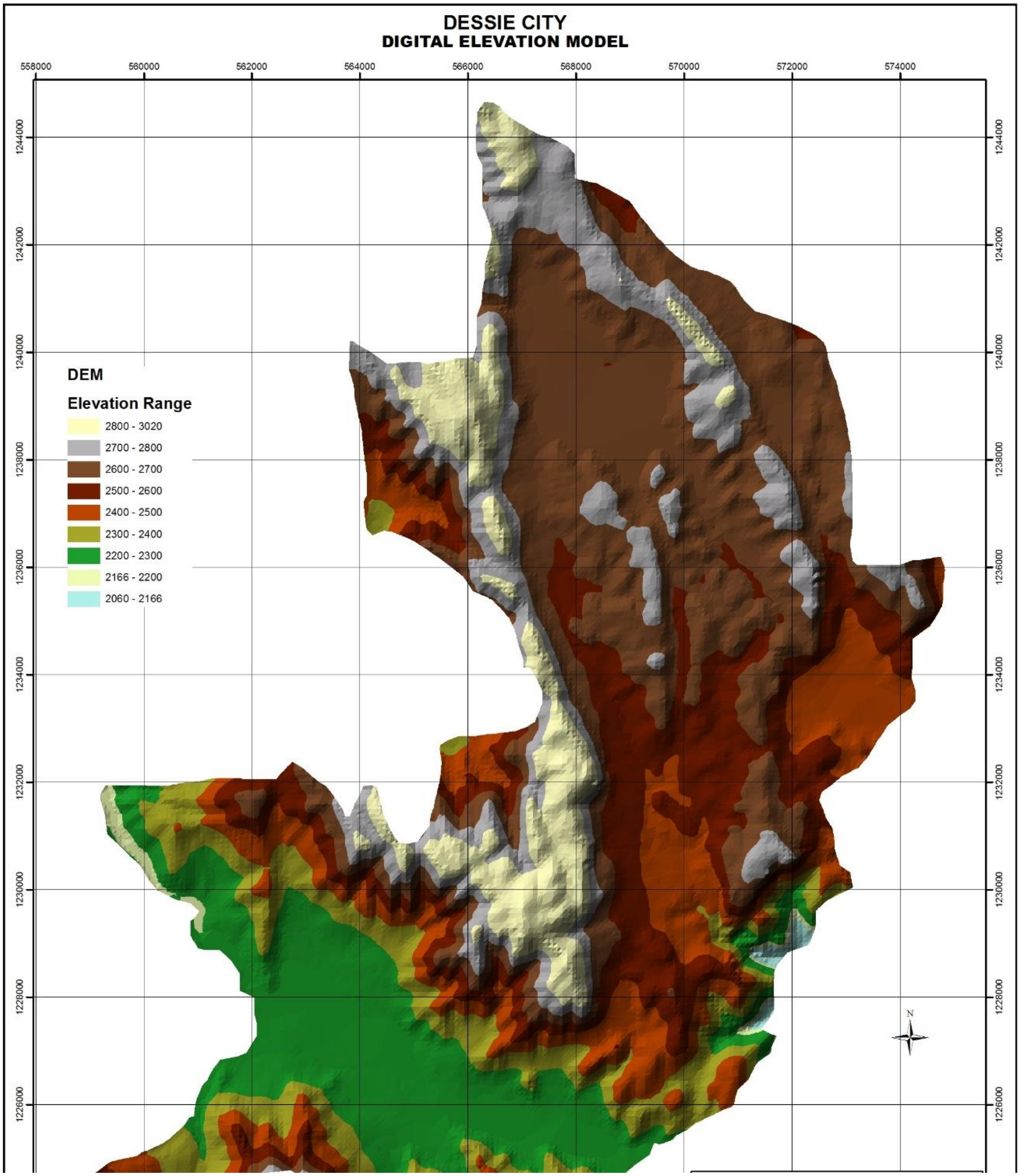


Figure 7 Digital elevation model of Dessie town

3.3.2 Digitization

By using GIS 10.3 and ENVI-met software the data is digitized with the help of ASTER imagery. Wind power density, slope, proximity to roads settlements, water bodies associated with wind turbines are identified. All these data are correlated and standardized based on the World Geodetic System.

3.3.3 Dessie town wind speed and direction Recorded data

The data set needed for this research (wind speed and direction) were found from NASA and on spot summarizing at selected (Tossaa, Azewagedel, St. Merry, bus station, Ayeteyef, and Ber/Kella). After observing wind sites in Dessie town which were identified by an anemometer was used to measure the wind speed and wind direction.

Table 8 Dessie town wind speed and direction recorded data at 10m and 50m height (2019).

Season and month	Station	The height of sites	Average Wind speed (m/s)	Wind direction (deg)
Winter/Bega/	Azewagedel	10m	2.29	87.82
February	Tossa	50m	2.49	95.16
Summer/kiremet	Bus station	10m	2.49	34.49
June	St.merry	50m	3.49	23.35
Spring/Tseday	Ber/kella	10m	2.49	60.16
May	Ayeteyef	50m	2.82	62.16

Source: (survey data,2019)

3.3.4 Wind Speed and Direction

The wind speed and wind direction are prepared in Arc GIS and ENVI-met by using the available data by selecting six sites in the town, which is shown in Figure 8.

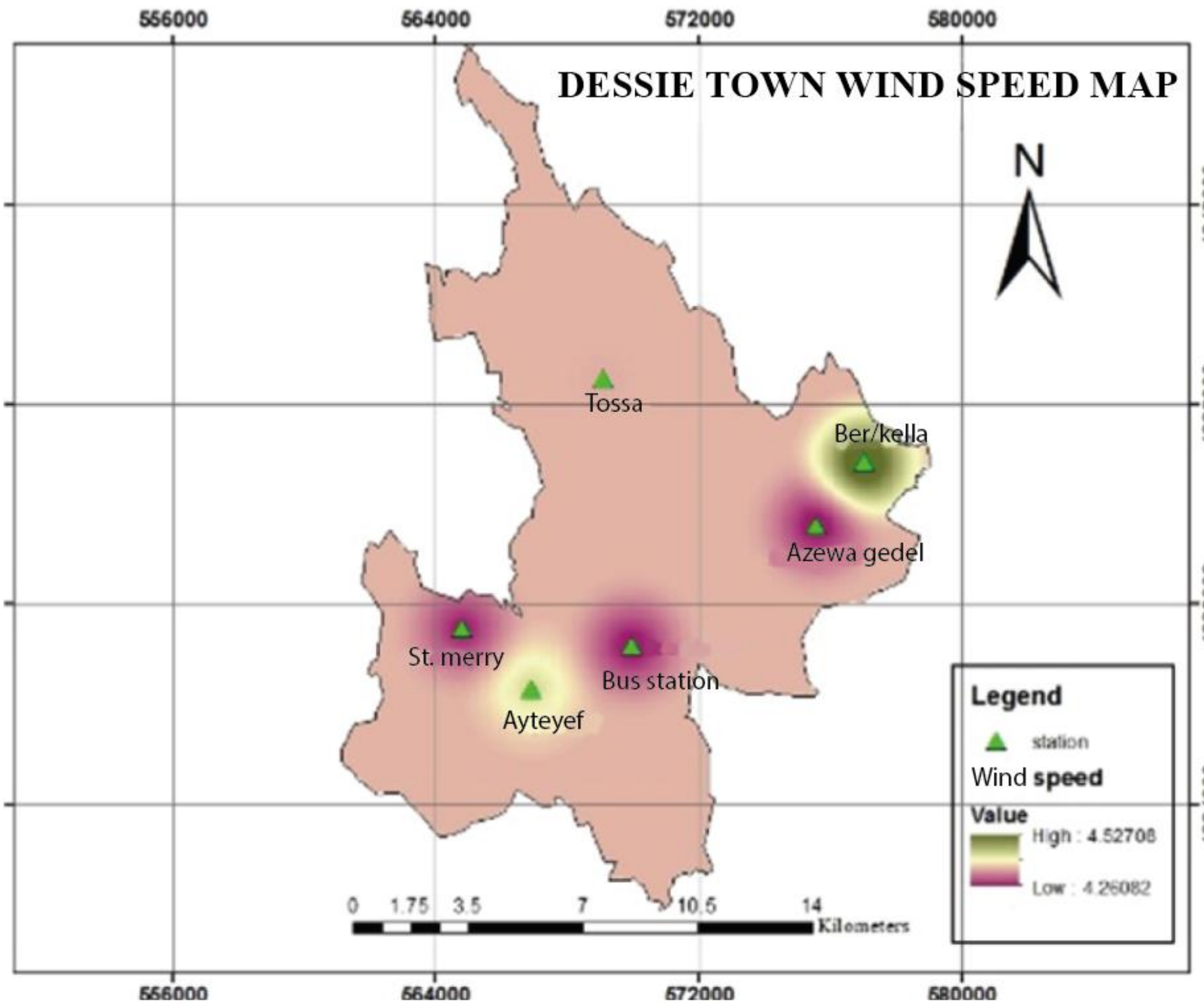


Figure 8 Wind site suitability area map

After observing wind sites in Dessie town which were identified by anemometer was used to measure the wind speed and direction. Besides data obtained from NASA was used to verify the data characterize were prepared for observing the town, these are the current status of land use of the area, classification of land use with a dominant type of land use, the topography of the area, main road outlets, the density of settlements sprawl characteristics of settlements, new and old settlements and building height and density.

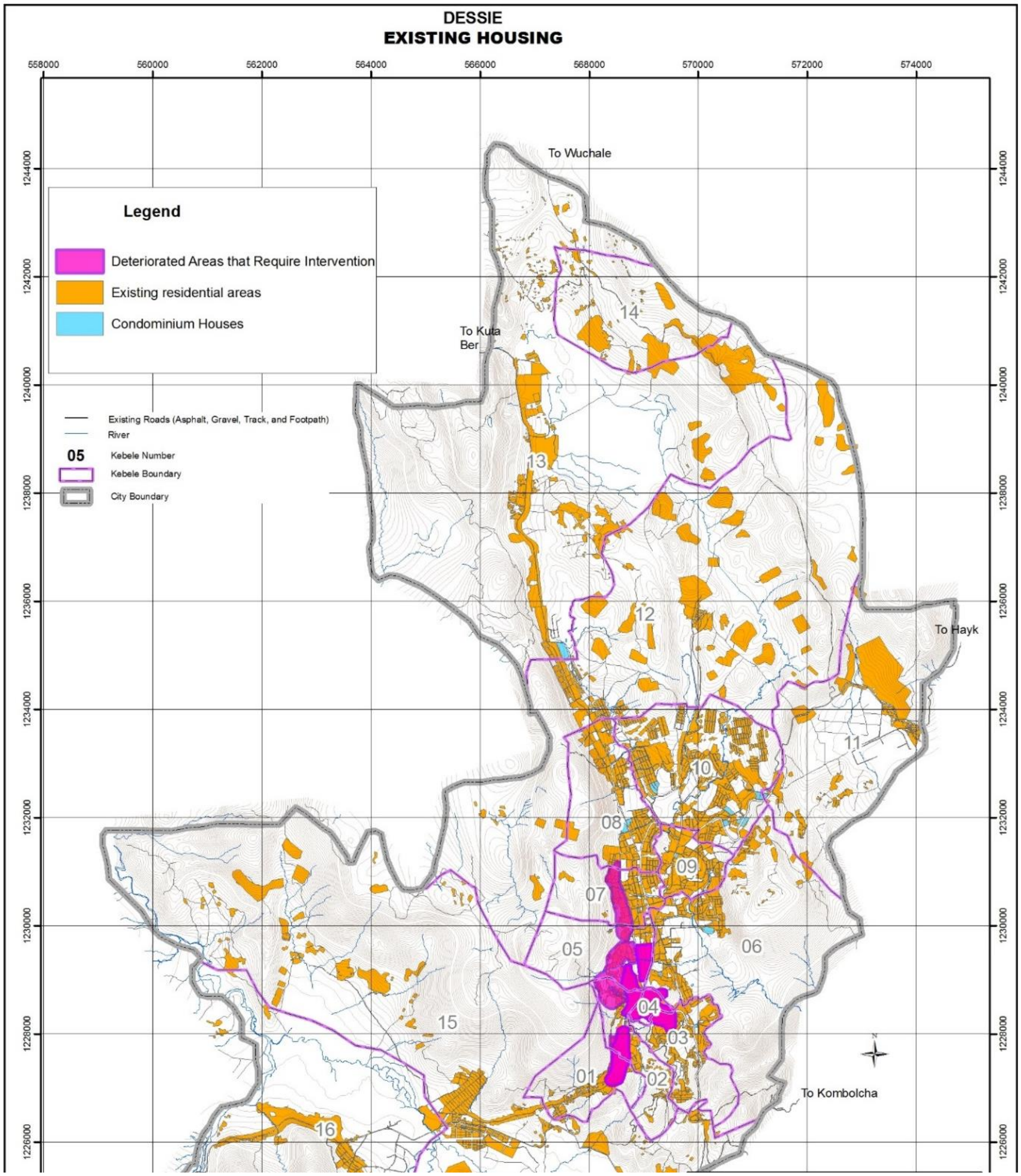


Figure 9 Existing housing

For the preparation and analysis of the thematic maps, the Arc GIS and the ENVI-met software are used for geographic and geospatial data analysis. The functions of the Arc GIS are included in the system to improve the capability and the appropriate locations for the wind site identification. The functions of the Arc GIS are depicted in Figure 9. The process is divided into three main processes. The first is the digitization and collection of data, Second is that data is incorporated as a single system. Last is the geospatial analysis. Wind Potential site identification Using Arc GIS 10.3. And in Figure 10 the research data collected by the following anemometer.

Figure 10 Anemometer

The wind is the horizontal movement of air. The instrument used to measure wind speed is called an *anemometer*, which is an indicator that will spin in the wind. An anemometer alternates at the same haste as the wind. It gives a straight measure of the wind speed. Wind speed is dignified by paying the Beaufort Wind Scale which is 0-12 grounded on pictorial signs.

The number of rotations is counted which is used to calculate the wind speed and then gets displayed on a calibrated digital wind speed meter.

For the maximum precise readings, an anemometer must be connected around 10 meters *(32.8 feet)* above the crushed in an open area. Hiring it close to huge objects that will affect airflow can clue to a false reading. Depending on the skill of the operator, it is perhaps adequate that they know tranquil air and calm, moderate, and robust winds. For example, the user can use a simplified scale in table 9.

Table 9 wind speed in (KmPH)

Wind Speed (KmPH)	Term	Description
0-5	Calm	Smoke goes straight up
6-20	Light	The wind is felt on face; weather vanes turn, leaves rustle
21-39	Moderate	Raises dust; flags flap
40-61	Strong	Large branches move; umbrellas turn inside out
62 or more	Gale / Whole Gale	

Source: (Hau.E,2006)

3.4 Wind Power Density

Wind power density (WPD) of an extent aids in the comparison and collection of the greatest suitable sites for the wind turbines. Turbines that are connected to areas having advanced WPD usually generate more electrical energy (Hau.E,2006).

. WPD is defined as:

Where,

$WPD=1/2PV^3$ q.3

WPD = Wind power density (watt / sq. area)

ρ = Air density

v = Wind speed

According to American wind vigor connotation, wind can be classified into different categories, which can be used as a suggestion for a possible site for future wind harvesting sites.

Table 10 Wind power density classification

Wind power class	Resource potential	WPD AT 50M w/m^2	Wind speed at 50m m/s
1	Poor	0-200	0-6
2	Marginal	200-300	6-6.8
3	Fair	300-400	6.8-7.5
4	Good	400-500	7.5-8.1
5	Excellent	500-600	8.1-8.6
6	Outstanding	600-800	8.6-9.5
7	Superb	>800	>9.5

Source: (Hau.E,2006)

Wind Power Density Map

The map obtained from the Center for Wind Energy Technology (50m) resolution is used during processing. And the map is geo-referenced by assigning the wind speed data, the density is divided into three layers such as the High (90 w/sq.), Moderate (60 w/sq.) and Least (30 w/sq.) as shown in table 11.

Table 11 Analysis of Windpower density classes

Classes	the power generated from Wind density (speed m/s)	The available area in sq.km
Highly potential	90	23.52 km^2
Moderate potential	60	82.31km^2
Least potential	30	44.17 km^2

Source: Windpower density classes (Hau.E,2006)

3.5 Method

i) Screen out the most wind harvesting potential sites

Dessie is found between two big mountains Tossa and Azewagedel the topography varies its slopes so, took wind speed and direction data from NASA recorded data and to triangulate it with measured wind speed and wind direction data with an anemometer.

The sites were selected by the city's topography i.e. elevation, distance from roads, slopes, building height, land use land cover, and settlement conditions. The simulation was done by using ENVI-met 4.4.4. For the simulation, the starting time date is 1989 because the microclimate data was taken since 1989. In addition to this, the wind speed measured in 10m height to evaluate its flow and also its impact on the wind speed in the selected particular sites. Based on this, the wind simulation of each site indicates the situation at 6:00 am and 3:00 pm since 1989.

In addition to wind and temperature simulation was done and the output of ENVI-met is shown in Figure 20 up to Figure 26 for temperature simulation the minimum temperature is 15^0C and its maximum temperature value is 28^0C. The output of the temperature simulation of the sites starts in 1989 and the particular time of the outputs is at 6:00 am and 3:00 pm.

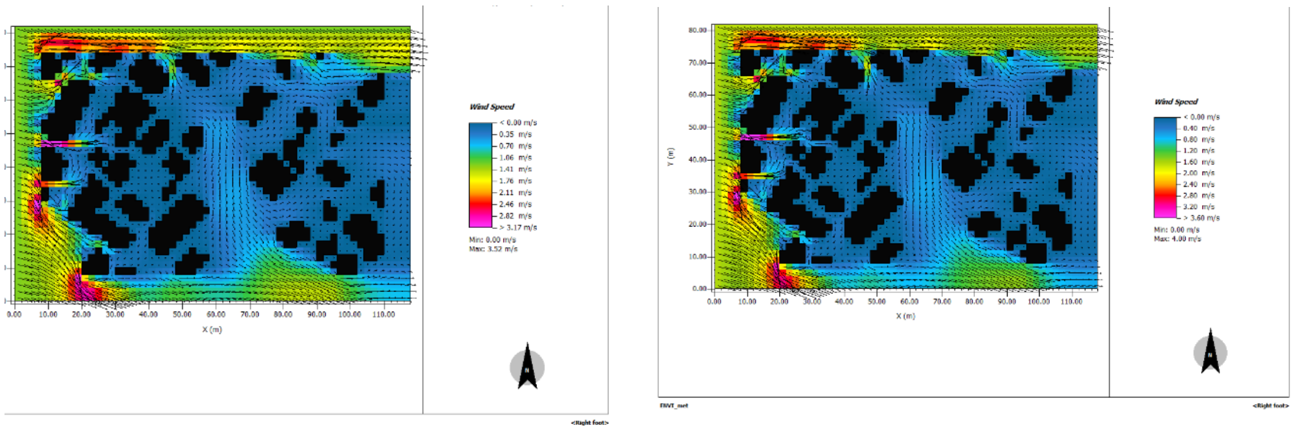


Figure 11 Wind Speed and Direction Simulation at 3:00 pm and 6:00 am respectively (Ayeteyef site)

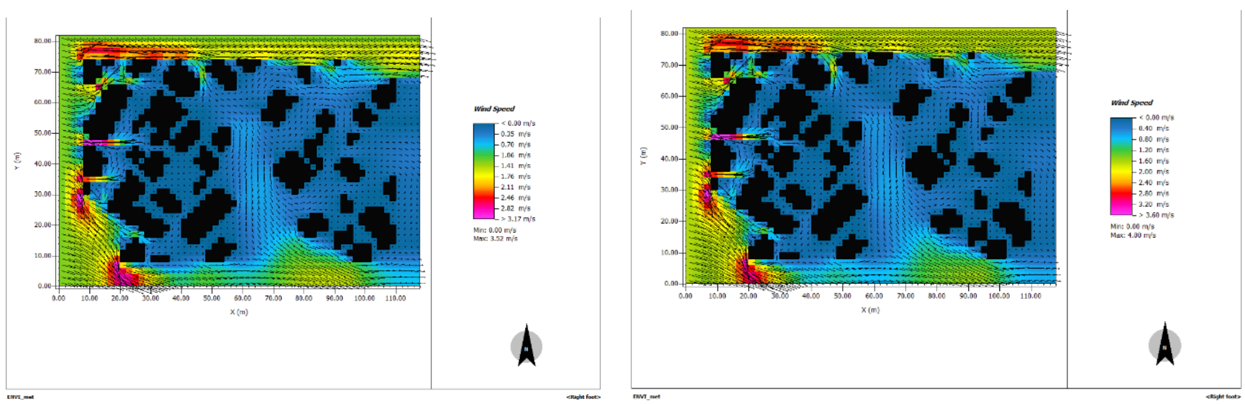


Figure 12 Wind Speed and Direction Simulation at 3:00 pm and 6:00 am respectively (bus station site)

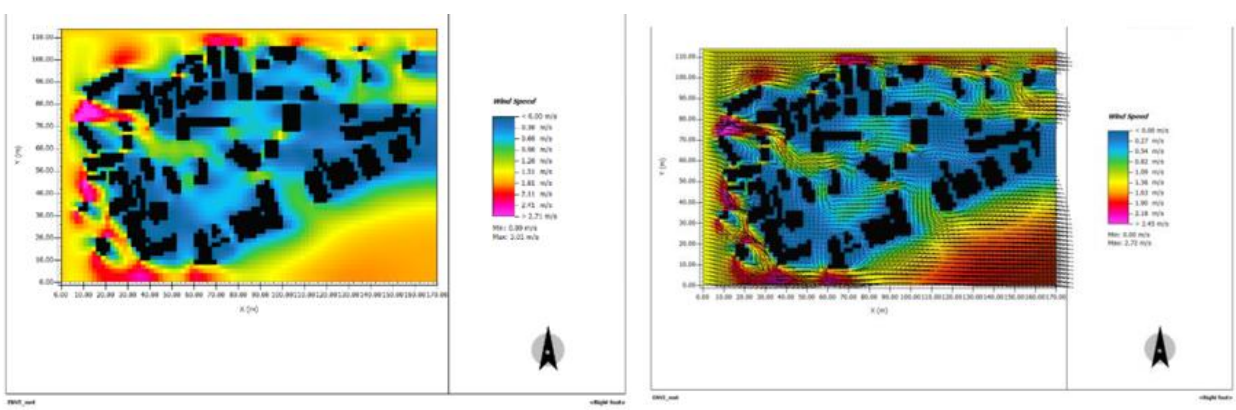


Figure 13 Wind Speed and Direction Simulation at 10:00 and 16:00 respectively (St. merry site)

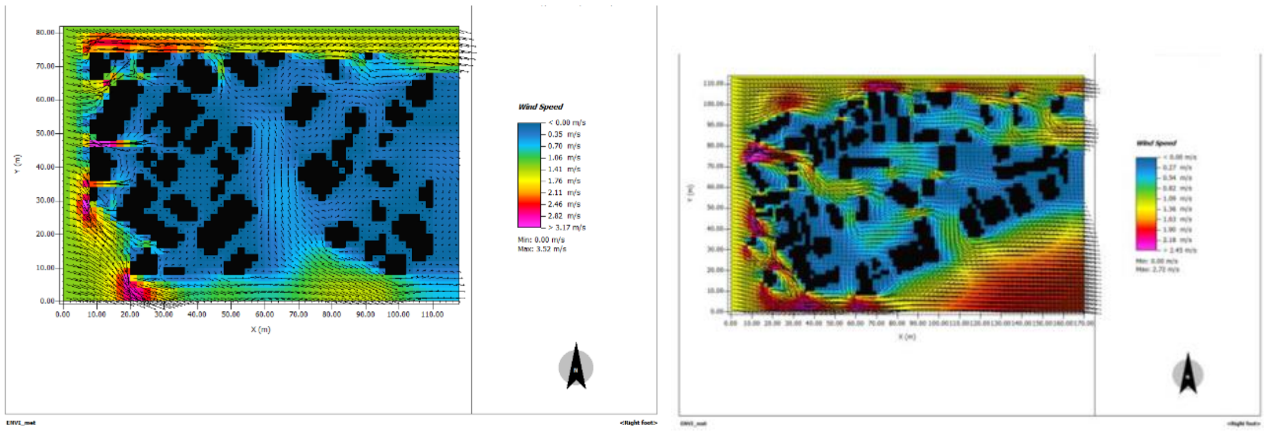


Figure 14 Wind Speed and Direction Simulation at 3:00 pm and 6:00 am respectively (Tossa site)

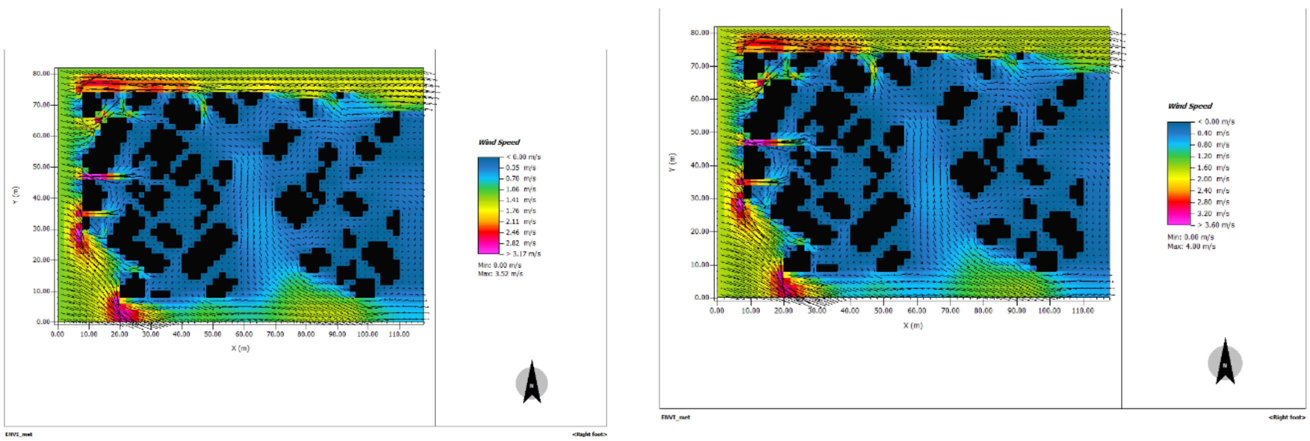


Figure 15 Wind Speed and Direction Simulation at 3:00 pm and 2:00 am respectively (Ber/Kella site)

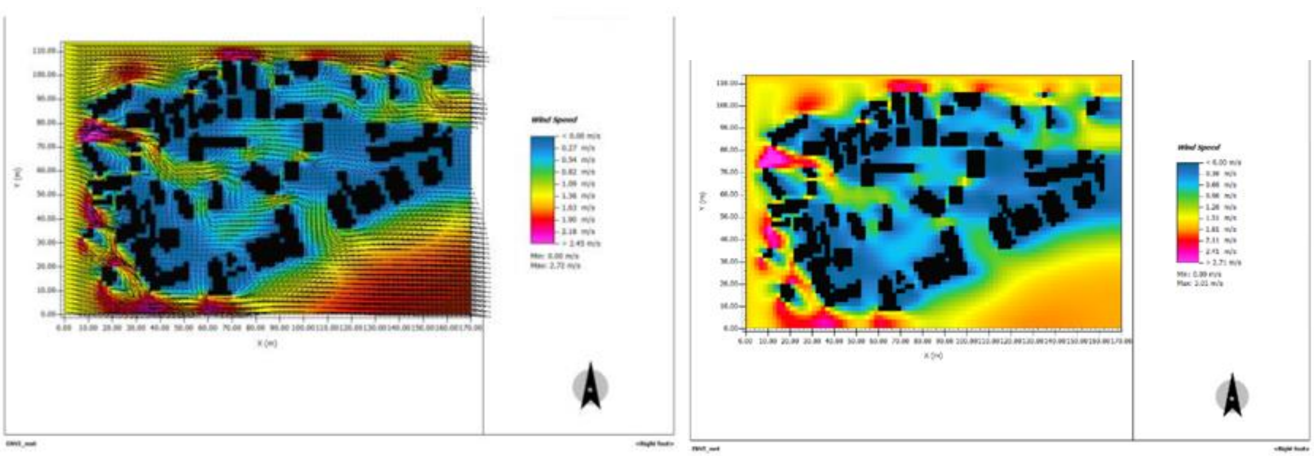


Figure 16 Wind Speed and Direction Simulation at 3:00 pm and 6:00 am respectively (Azewagedel site)

3.6 GIS Analysis

The purpose of the site selection wind speed, area, proper ground condition, and the settlement to access the electrical grid is the required important necessities. In the study area, the suitability of the wind site is found through the open-source (without obstacles) i.e. trees, buildings. The effect of wind site identification has a direct influence on the nearby area and the population. And the different effects of wind energy are also accepted. In this study, the ecological impacts like forests, cemeteries, historical buildings, underground resources linked with wind energy are studied to develop the acceptability for the other locations for the installation of the wind turbines (Gray et al. 2013).

3.7 Exclusion of Sites Using Buffer Area

The surrounding areas are identified using buffer analysis. Ole˛dzki (2004) the buffer and the buffer distance are taken from the different articles that are crawled. According to (Aydin, 2009).

Table 12 Details of the layer name, distance from the buffer.

S.NO	Layer name	Distance from the buffer
1	Stream lines	50m
2	Water bodies	30m
3	Roads	50m
4	Villages	25m

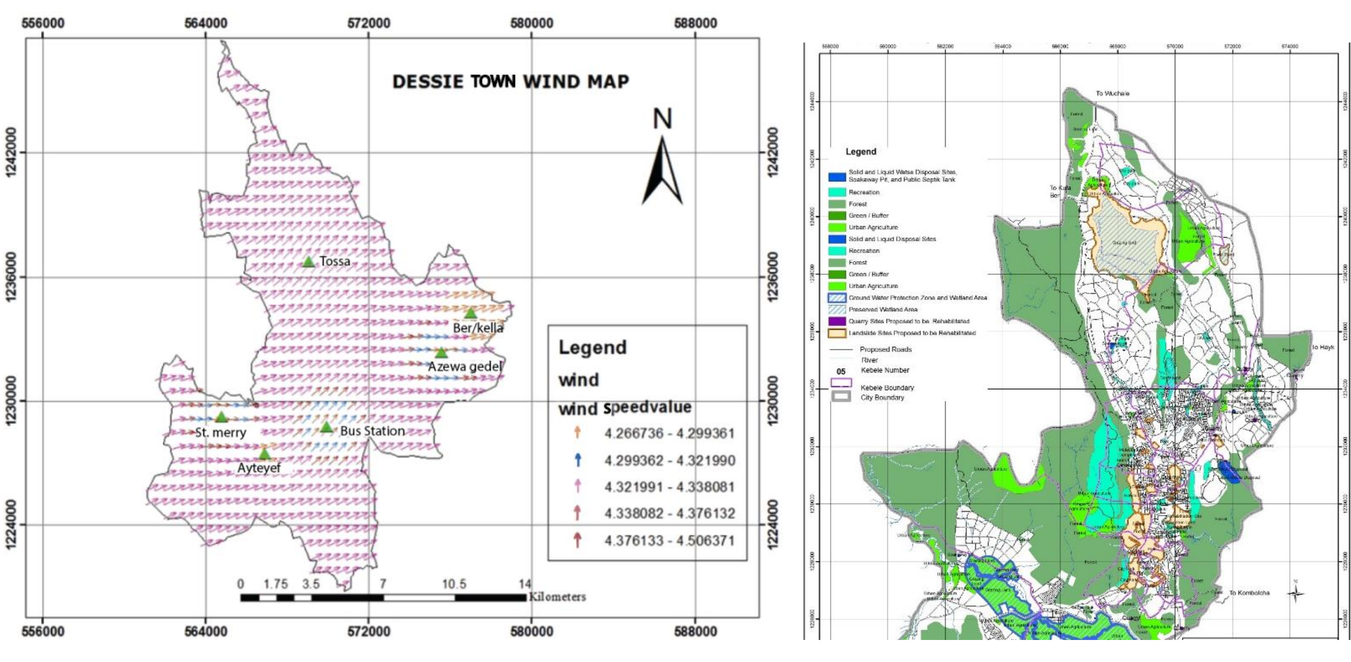
Source: (Aydin, 2009)

3.7.1 Settlements

With the help of ASTER satellite Imagery and the topographic sheet, the settlement areas have been interrupted. Village areas and city area boundaries are captured and stored as a polygon feature. The attributes of the settlement are obtained from a topographic sheet (Aydin, 2009). The clipped portion of the buffers around the features which exceed the boundary limit is clipped and sent for overlay analysis. The total area is that which is not included is taken from the clipped area.

3.8 Overlay Analysis

The spatial overlay provides the solution of spatial relationships among the attributes. And it is done by combining the various data sets that split or only the part of a similar area. The combination of the unique data set is that which identifies the spatial interaction as the result. Figure 17 (a) and (b) show the total available area of 150,000 km^2 and the suitability for the wind sites and is done by investigating the variation aimed between the boundary layer and the total area of prohibiting the Dessie town.



(a) (b)

Figure: 17 (a) Total Available area map (b) Wind site suitability area map

3.9 Site selection in the town

Dessie is found between two big mountains Tossa and Azewagedel its topography is rugged the wind speed and direction data takes of interviewing elder on spot measurement of wind speed and direction was taken and triangulated NASA data.

The sites were selected by the town's topography i.e. elevation, distance from roads, slopes, building height, land use land cover, and settlement conditions.

The simulation was done by using ENVI-met4.4.4. For the simulation, the starting date is 1989 because the microclimate data was taken since 1989. Based on this, the wind simulation of each site indicates the situation at 6:00 am and 3:00pmsince 1989. For the value of the minimum and maximum temperature is 15^0c and 28^0c, respectively the simulation was done since the year1989 from the time of 6:00 am and 3:00 pm.

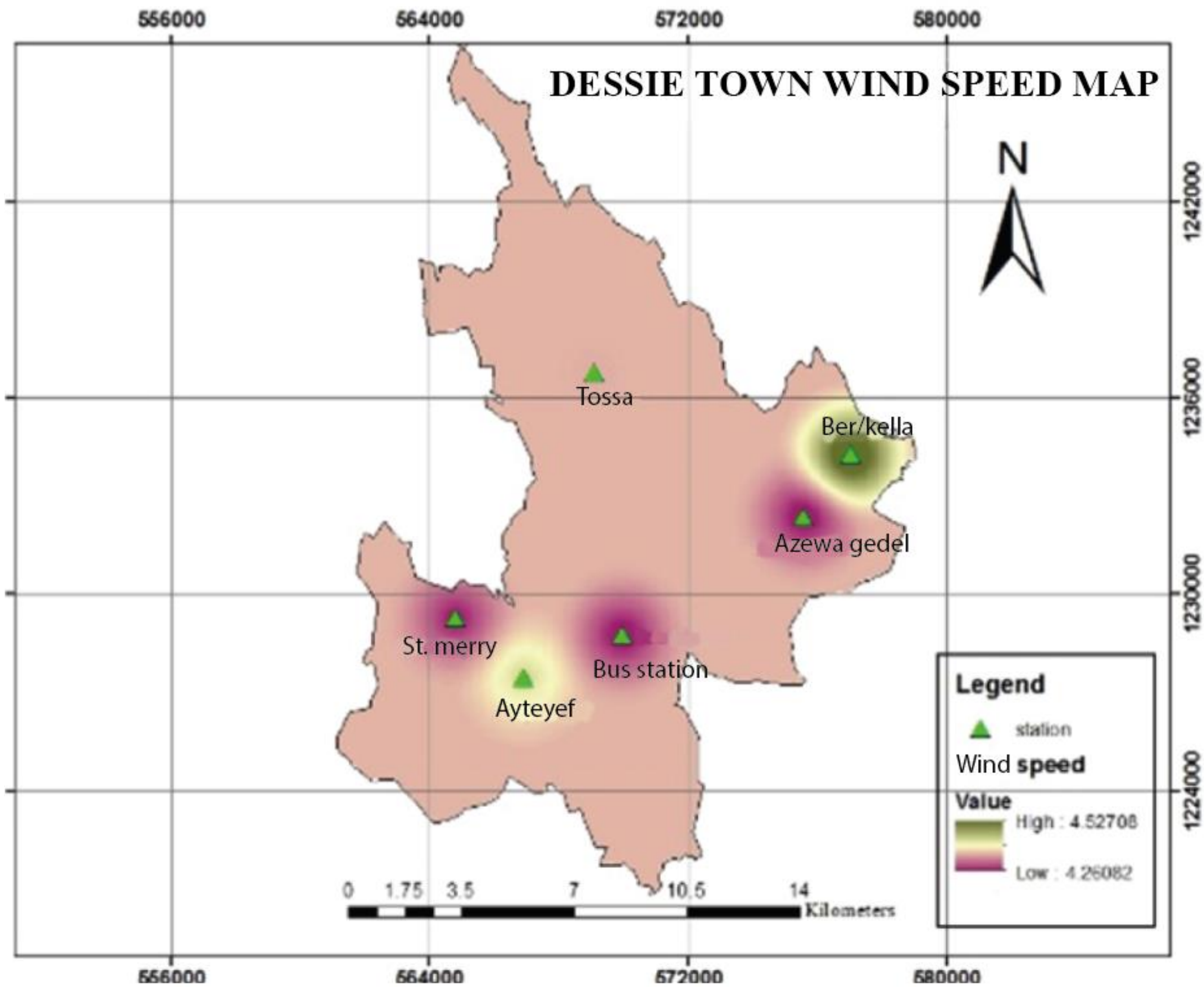


Figure 18 Wind site suitability area map

3.10 Slope

The graphical interface of the GIS software system is employed in creating a slope map of Dessie. In setting up a wind site potential slope is important. Activities in the wind site are easier when the slope is flatter. The economic variability of the wind site identification Clarke (1991) depends on the terrain chosen (the terrain also decides the variability of the energy, it generates). According to Figure 19, a suitable area that is recommended for wind site development is the flat area.

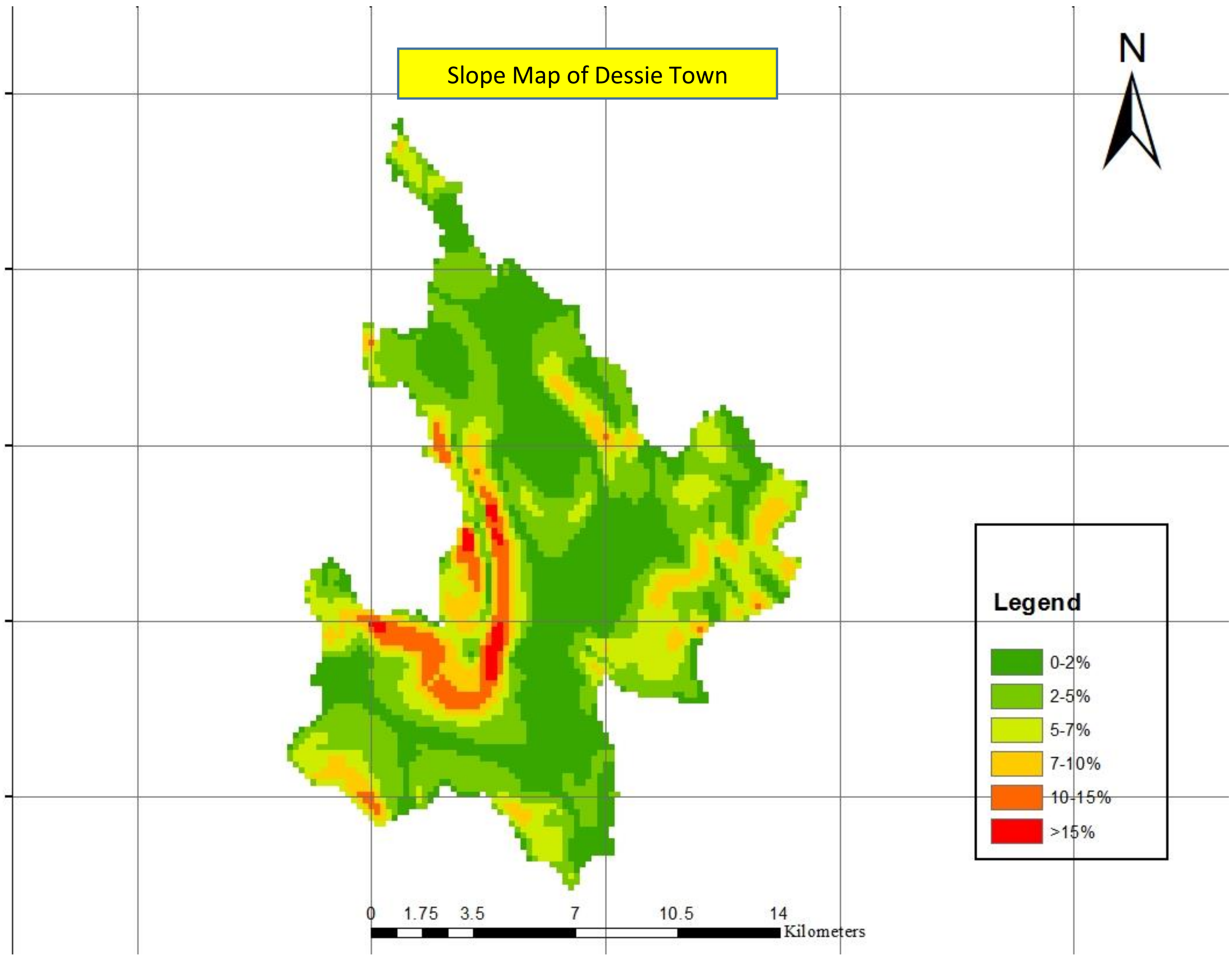


Figure 19 Slope area map of Dessie town.

3.11 GIS Integration

The statistical data obtained from different functional units of research (land use, Revenue Villages, Wind power density, Transmission network) are collected and are added into the desirable software unit. The topological representation of vector data aids to make and sustain (Gupta, 2011) vector maps, and topological errors are corrected accordingly. The corrected layers are used for analysis GIS and are used in various operations like questioning etc. By using the method of GIS software various structural attributes are buffered.

3.12 Research Design

The research is based on mixed methods that encompass both numerical and qualitative methods of research design. As pointed out in Creswell (2009), mixed-method enables one to better understand the problem more comprehensively and it is the most popular application method in conducting research. Quantitative and qualitative methods are combined and integrated to add value to the arguments from different perspectives and enable them to answer research questions more deeply. The study was employing a descriptive type of research design to make an intensive investigation of wind harvesting mechanisms. In this case, the research is more described as the existing situational analysis of the study town.

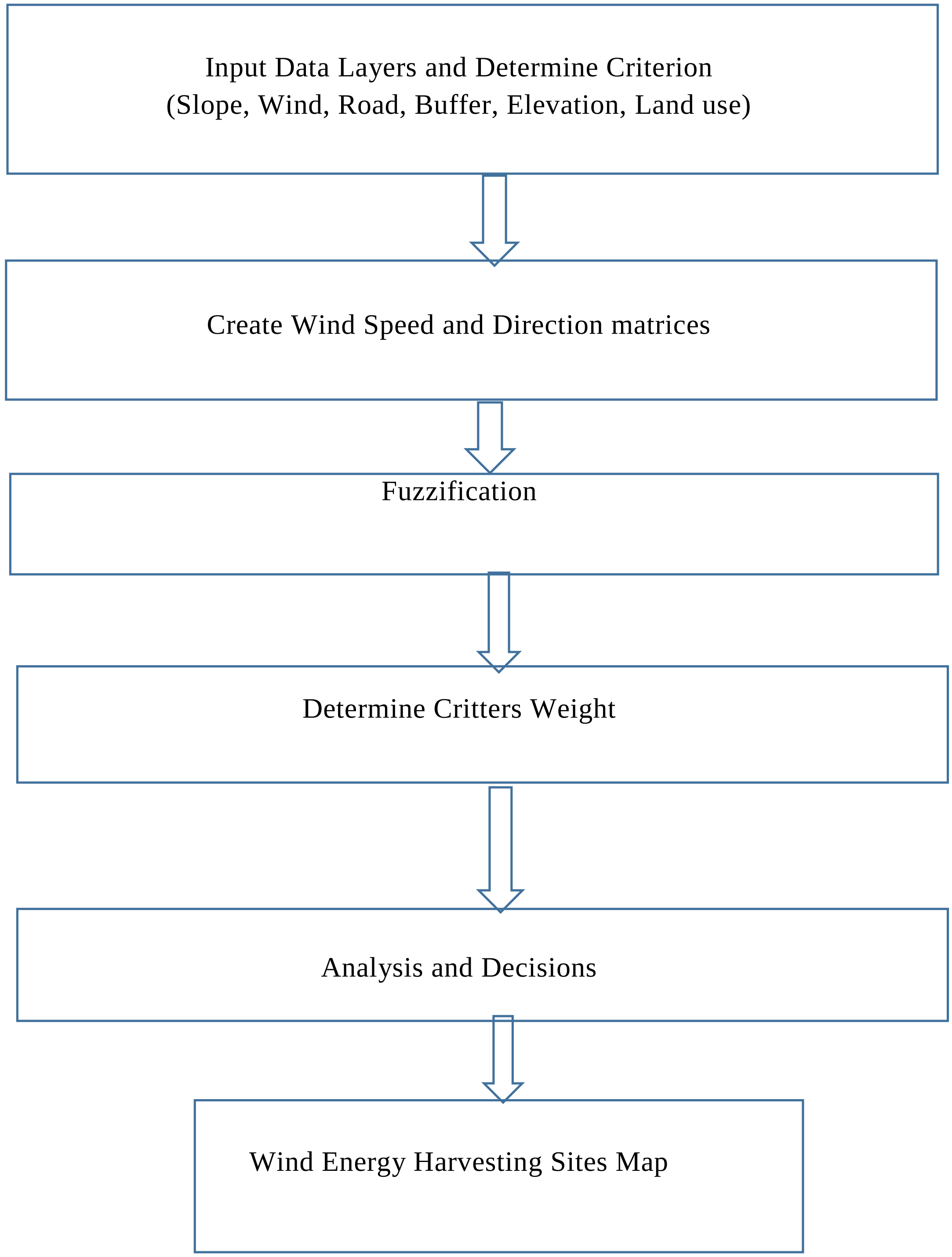


Figure 20 Research design flow chart

3.13 Physical observation

Checklists were prepared to observe the existing condition of the thesis area (refer to Annex 13). The main points which are included under the checklist are wind speed and wind direction in the city for 3 months twice per day from 1:00 to 2:00 hour i.e. (90 days x 2 or 180 daily data).

3.14 Data presentation

The analyzed data were presented using tables, graphs, charts, and maps.

CHAPTER FOUR

RESULT

Analyzing the town are identified in Figure 21the majority of wind speed value ranges from 4.26m/s to 4.52m/s. the extreme windy hot spots in Dessie town are Azewagedel, St. merry, Ayeteyef, and Ber/ Kella, and the mean wind speed is 3.5m/s.

4.1 Map windy area in the town of Dessie

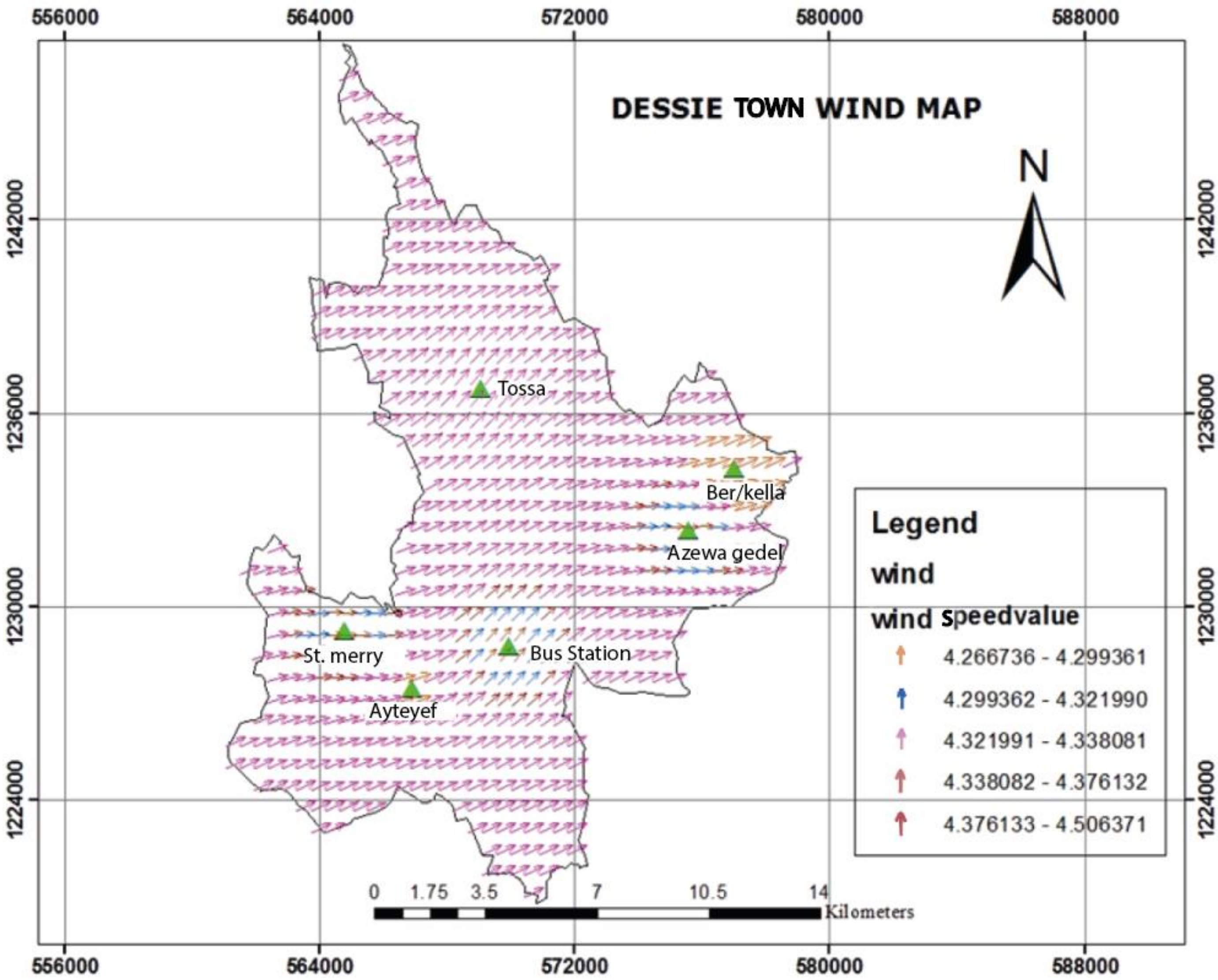


Figure 21 Dessie town windy map

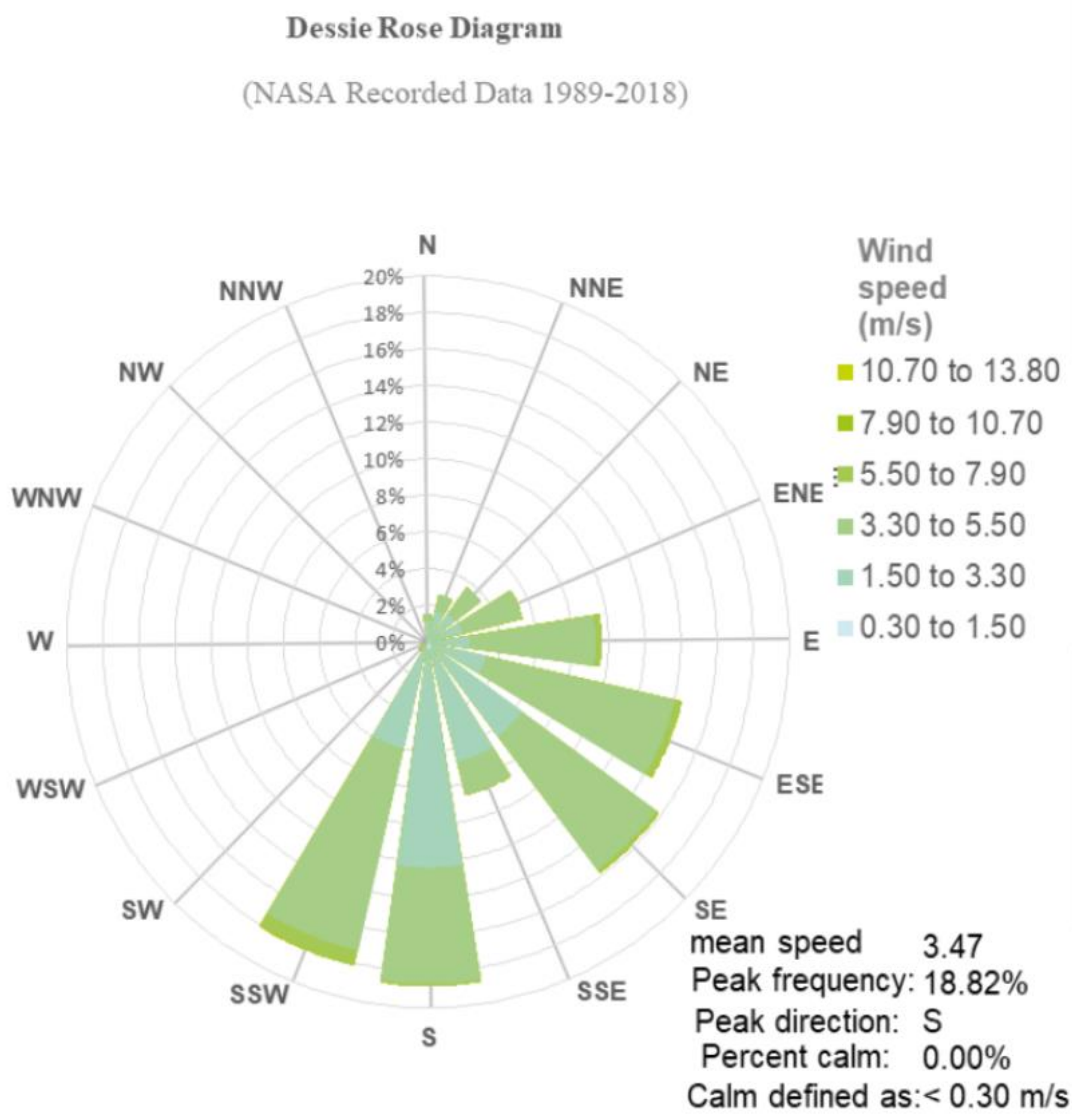


Figure 22 Dessie rose diagram

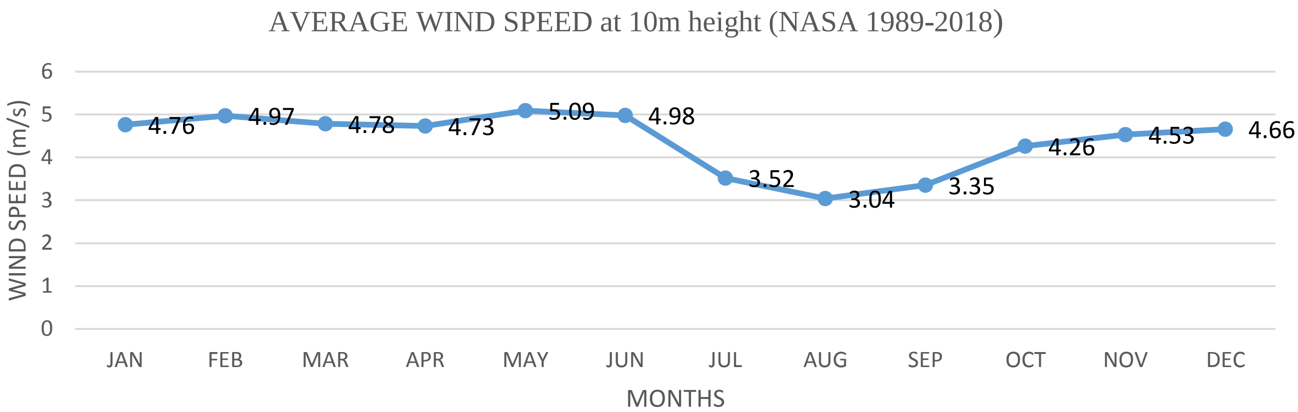


Figure 23 Average wind speed at 10m height (NASA 1989- 2018)

As shown in Figure 23 of average wind speed at 10m height the minimum and maximum wind speed at 10m above ground level are found to be 3.04m/s (Aug) and 5.09 m/s(June), respectively (Figure 23) summarizes the monthly wind speed at 10m level from the natural ground level for all sites.

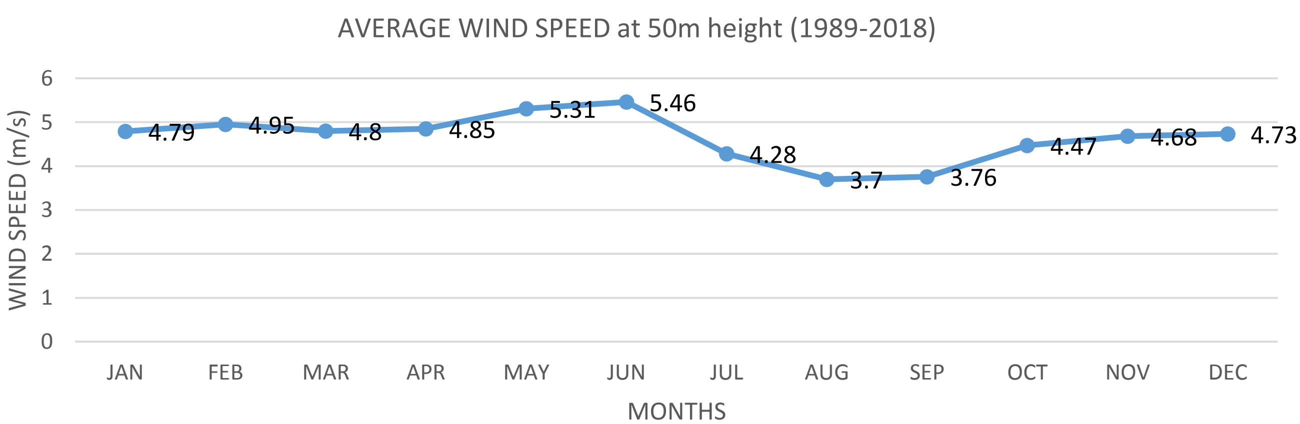


Figure 24 Average wind speed at 50m height (NASA 1989- 2018)

Windy are identified in Figure 24, Average wind speed at 50m height, the majority of wind speed value ranges from 3.70 m/s to 5.46 m/s. the extreme windy hot spots in Dessie town are Azewagedel, St. merry, Ayeteyef, and Ber/ Kella.

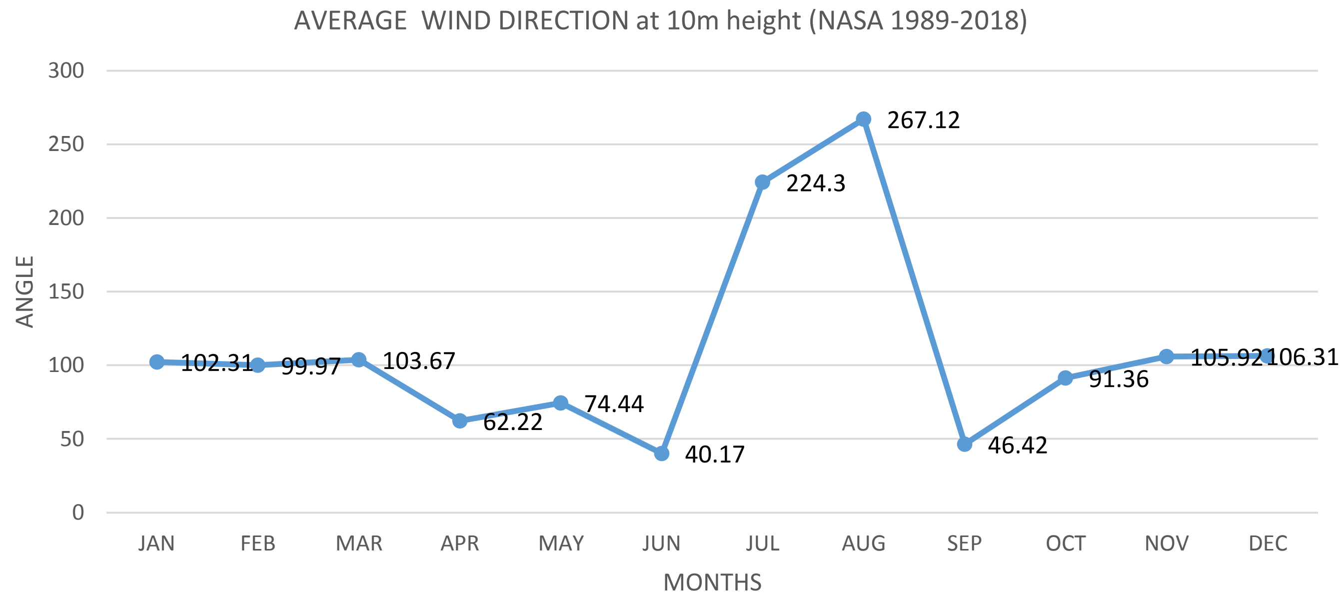


Figure 25 Average wind direction at 10m height (NASA 1989- 2018)

In Figure 25 of average wind direction at 10m height, NASA recorded data 1989-2018 shows august have 267^0 (SE) is the highest value compared that of other months.

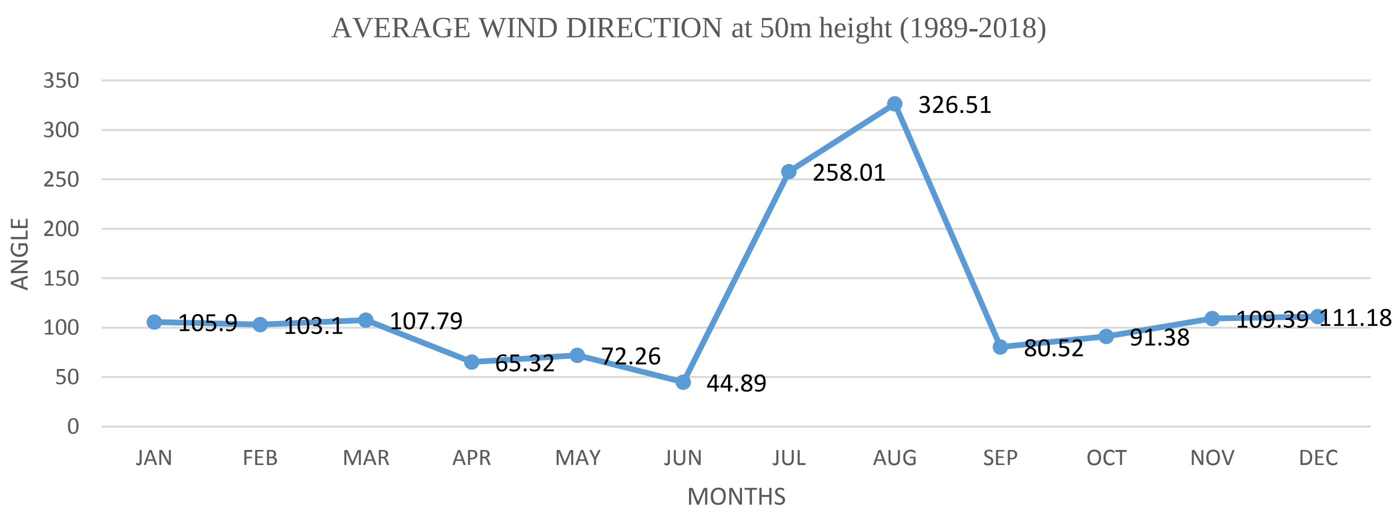


Figure 26 Average wind direction at 50m height (NASA 1989- 2018)

As shown in Figure 26 Average wind direction at 50m height of NASA recorded data 1989-2018 shows august have 327^0 (SE) is the highest value compared that of other months.

4.2 Sort wind speed and wind direction measurement in the town

Wind speed is one of the factors that affect wind energy 50% of the value of wind speed is above 2.6 m/s for the last 30 years and the wind speed range is between 2.1 m/s and 5.0 m/s with 3.55 m/s average wind speed. In February and May (5m/s) there is high wind speed which is the highest value whereas, 2.1m/s is the lowest value of wind speed that occurs in July.

Spatial analytics provides a logical solution for the setting up of windy sites. The target areas are tagged and the remaining areas which are having at least one negative facts consist of the site that is suitable for wind site identification. Wind site Potential identifying Using Arc GIS 10.3.

4.2.1 Dessie city wind speed and direction recorded data

The wind speed and wind direction are prepared in Arc GIS by using the available data by selecting six simulation sites in the town, which is shown in Figure 27.

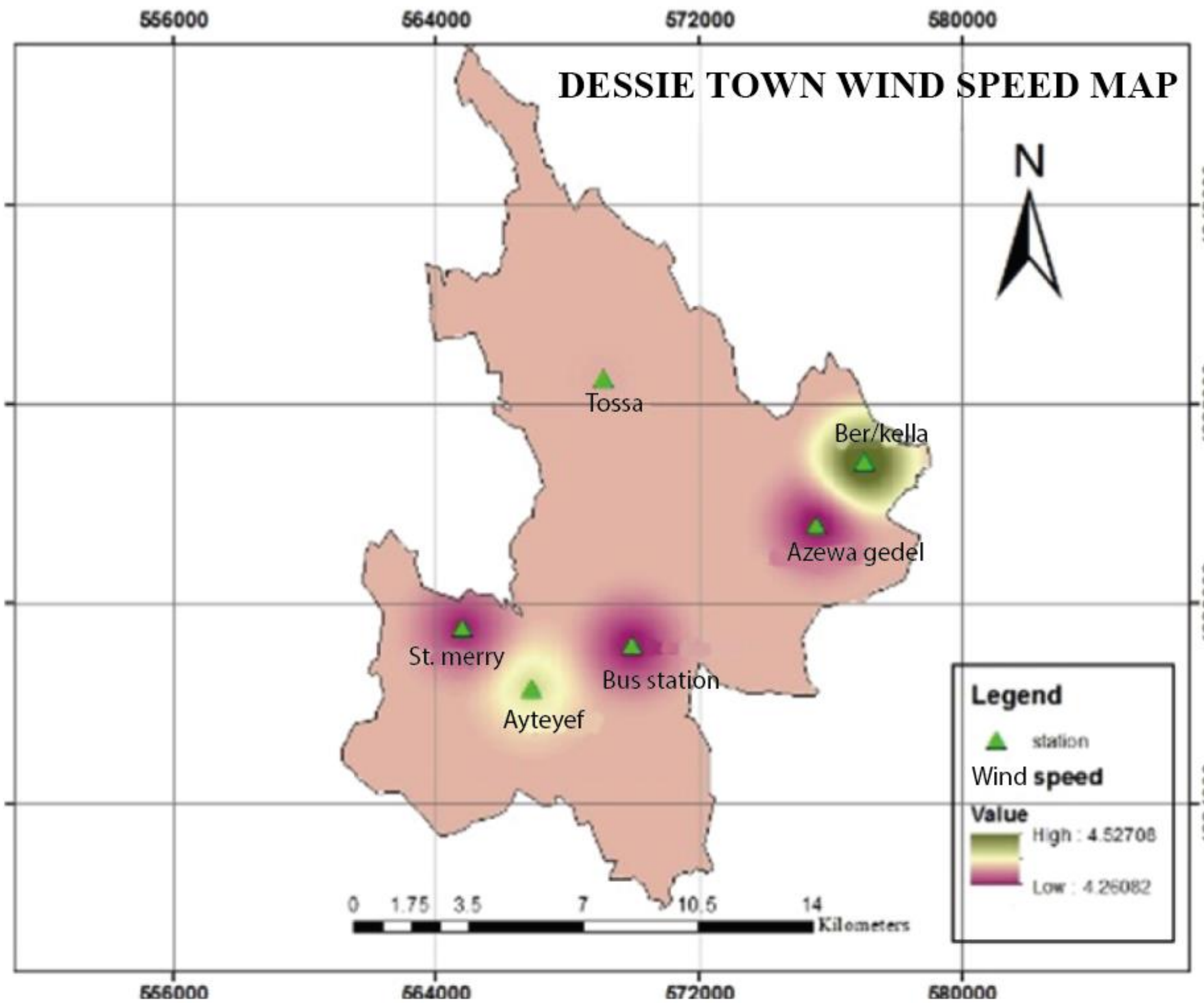


Figure 27 Dessie town wind speed map

In Figure 27 Dessie town wind speed and direction recorded data (2019) Wind speed is one of the issues that affect wind energy, the wind speed range is between 4.26 m/s up to 4.52 m/s.

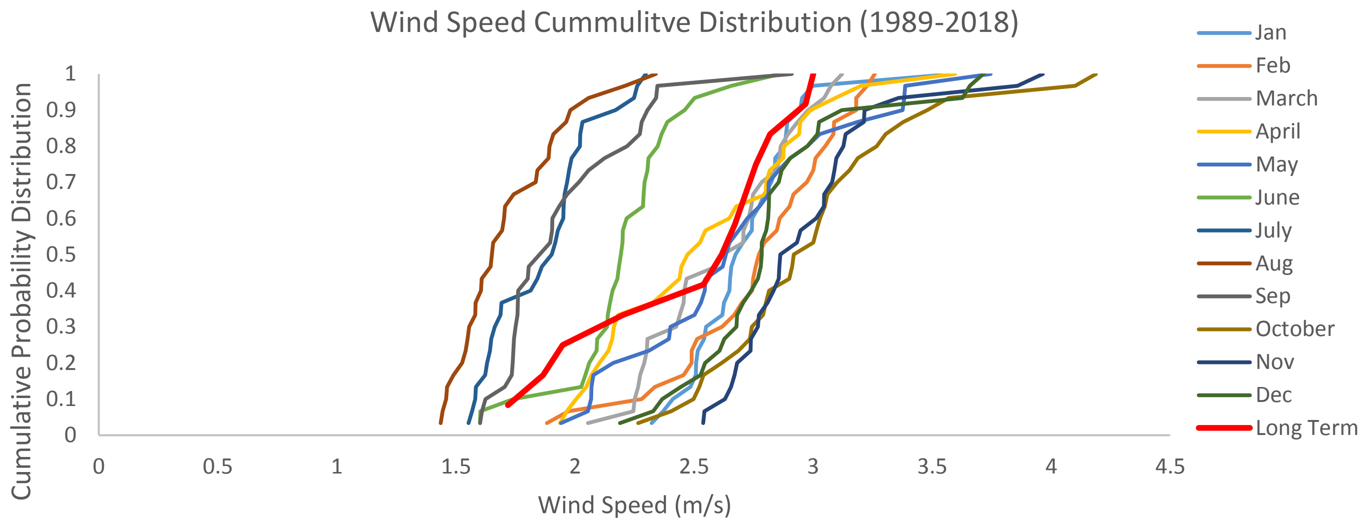


Figure 28 the cumulative distribution of Wind Speed (NASA 1989-2018)

4.3. Shade out the most wind harvesting potential sites screening in the town

In Figure 29 the magnitude of the wind direction in Dessie town for wind hot spot areas, St. Merry, Ayeteyef, Bus station, Azewagedel, Tossa, and Kella/Berr . The direction ranges from 35.55^0 to 94.55^0 (SE) southeast direction.

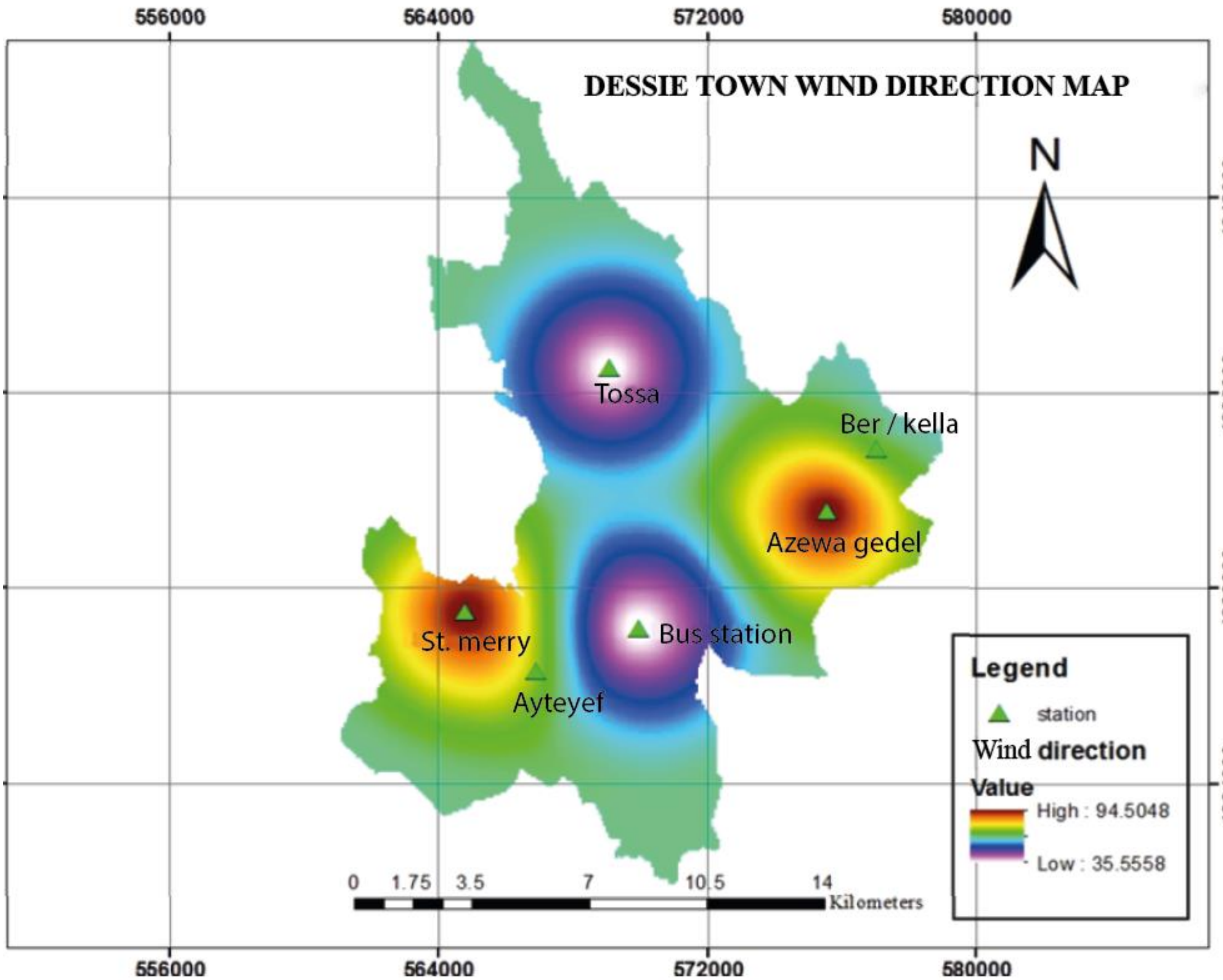


Figure 29 Wind power density map of Dessie town.

As seen in Figure 29 the study area is suitable for urban wind energy harvesting i.e. 6,000 km^2 5.7% Tossaa , 15,000 km^2 14.3% Azewagedel 22,000 km^2 20.9% St.Merry12,000 km^2 11.4% bus station,26,000 km^2 24.7% Ayeteyef 24,000 km^2 22.8% Ber/Kella. Maximum wind speed is found to be 22.8 %(Ayeteyef) and 24.7% (Ber/Kella) respectively from a total area of 150,000km square 105,000 km square (70%) is suitable for urban wind energy harvesting.

Figure 29 the wind direction at 50m SE angle accordingly the same direction as10m height is port for harvesting wind energy. SSW and S faced elevation of buildings situating turbines to harvest the wind energy of these sites as it is evident by the wind.

CHAPTER FIVE

DISCUSSION

For harvesting wind energy in the Dessie town wind area, a wind speed of >4 m/sec has been considered at Height = 20 m and also at higher altitudes. There is a possibility that may expect much for higher wind speed with the increase of height, which would result in more power generation. To meet the present energy crisis, it is very needed to go for renewable energy. The use of wind power can minimize the problem to a great extent. Wind energy is more reliable because it is free and pollution-free.

As a result, interest in wind as a source of energy is increasing day by day. Now the most frequent current use of wind energy in electricity production. Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation.

The research was designed based on three objectives. Two of them are strongly related to identifying on-site selection and wind measurement, and one is related to improving the urban energy blackout and provide energy through renewable energy resources, wind energy.

5.1. Map windy area in the town

The various degrees of suitable wind speed and direction areas the majority of wind direction value lays the range 4.26 m/s - 4.55 m/s. The highly and extremely suitable regions, therefore, desired for the determinations of this study Ayeteyef and Ber/Kella.

5.2 Sort wind speed and wind direction measurement in the town

Based on the windy site selection criteria. Their differences were created for 4 classes at equal intervals of 4.26- 4.52m/s wind speed and 35.55o- 94.50^{o} SE of wind direction, (Stations St. Merry and Azewagedel) have wind direction nearly 94.50^{0} SE direction.

5.3 Shade out the most wind harvesting potential sites screening in the town

The period starts from February, May, and June 2019 with a time step of 1 to 2 hours depending on the station. The measured and computed wind speeds and wind direction for the station's St. Merry, Ber/Kella, Ayeteyef, Bus Station, Tossa, and AzewaGedel.

The computed values underestimate the mean speed and direction recorded at the different seasons in the station that is winter, spring, and summer for 5 days and 3 times a day in SSW, S, SE, and ESE directions enormous, wind energy incorporated plan is required to create comfortable, livable, and self-sufficient alternative energy i.e. wind energy area.

The wind speed and wind direction of the urban area are the two critical factors that affect the wind speed and wind direction suitable for urban wind energy. In a given particular area, (St. Merry and Azewagedel) in Dessie town simulation result of ENVI-met indicate that the maximum wind speed at the center of the town is 4.52m/s at 6:00 pm. To achieve wind energy production, it needs urban design intervention mechanisms like neighborhood shading, building orientation according to wind speed and wind direction, and suitability of wind turbine installation. From the cumulative probability of Dessie town, the average wind speed value is 3.50m/s and wind direction is 35.55^{0} SE -94.55^{0}SE direction.

Analyzing the calculated data from sites the value of wind speed and wind directions varies from site to site. The highest value of wind speed Ayteyef and the lowest value of wind speed are found in the Tossa mountain.

This difference in wind speed values from the site to the site shows the intense contrast in the topographic characteristics between geographic points and it gives an idea about the energy demands.

As a result, wind speed is constructed for the demand for May and June. Finally, the wind speed for town responsive for high wind speed velocity in June. Comparing densities as shown in table 13 like (Hau.E, 2006), wind speed and wind direction studies in Specific sites have the least density than N - S and N- W. To test the sensitivity of the results to different wind speed and wind direction conditions, After analyzing and comparing the results with the analytical data, it was determined that the helical wind turbine could be a viable alternative option for its users to generate cost-competitive energy.

[1] From studies in India, Performance measurement of a two-bladed helical savories rotor (Chennai, 2010)

[2] Studies about Wind Energy explained, theory, design, and application (Wiley, 2002) and.: Wind Turbines, Fundamentals, Technologies, Application, (Hau, E,2006)

The studies in this paper are brought a method to secure shade out the most wind harvesting potential site screening in the town.

The study was realized as an anemometer for the velocity flow measure. The anemometer was installed one over the other in a vertical position to cover all the rotor sweep area. To calculate the velocities profile, the airflow was measured. According to (Hau.E, 2006) the power output of the wind turbine is given by the equation: $P = 1/\ 2\ \rho A v^3\ \eta T \eta G$, calculated air density of Dessie is 1.209kg/m^3 the turbine and generator efficiencies 0.35 and 0.9 respectively, the power output at 5 m/s produced by a 3.4 m^2 rotor is given by the equation:

$$P = \frac{1/2\ (1.209\ \mathrm{kg/m^3})(3.4\ \mathrm{m^2})(5\ \mathrm{m/s})^3(0.35)(0.9)}{1000}$$

$$= \mathbf{0.0809\ kW/h}$$

There are 8760 hours in the year (hence,365days x 24hours),the 0.0809 kW/h are equivalent to 708.68 kW/h per year (0.0809 x8760) .The table 13 shows 3.4 m^2 wind turbine power output (Hau.E,2006)

Velocity m/s	Power output kW/h	Power output kW/h per year
3	0.0174	152.42
5	0.0809	708.6
7	0.2220	1945.28
10	0.6474	5671.39
15	2.1850	19140.95
20	5.1793	45371.15

Source: (Hau.E,2006)

In Dessie, In 3m/s = 0.0174 kW/h and 152.42 kW/h per year, In 5m/s = 0.0809 kW/h and 708.68 kW/h per year to produce electricity. Wind speed in the building 5m/s, total energy produce 708.92 kW/h per year in one turbine Building energy consumption 1200 kW/h per year (hence 100kw/h/per month (EEA,2019). The total amount of turbine needed in the building is 2.

Figure 29 turbine needed in the building

The measurements of the velocity test range from 5 m/s to 20 m/s and the turbine power curve was determined by obtaining the torque produced by the rotor in each velocity. The results shown in the above table 13 are for the 1 m^2 turbine. The 1200 kW/h per year is reached at the velocity of 5 m/s approximately, equivalent to 708.68 KW/h/year in the 3.4 m^2 turbine. These results are similar to the analytical data shown before.

According to the selected criteria of the wind potential suitability criteria, each criterion maps monthly wind speed variation, average wind speed variation, the variability of land use and land cover classes, road network, and variability of slope classes were prepared using Arc GIS 10.3 software. In this study, these sites were grouped into three categories as “low suitable”, “moderately suitable” and “high suitable”. The monthly wind potential sites for summer and winter months. The wind direction potential sites with a satisfactory degree of suitability sites in Dessie town. As a result, high suitable areas occupy 50,000 km^2 (47.5%), moderate suitable sites cover 37,000 km^2 (35.20%), low suitable sites cover 18,000 km^2 (17.10%) and 45000 km^2 (30.0%) of the study area has not any significant suitable area. Therefore, there is a sufficient area of 105,000 km^2 (70.0%) where wind potential sites may be established in the study area. The areas of Ayeteyef and Ber/Kella are falling under high suitable potential areas. The average monthly wind speed of the study area during the year 1989–2018 at high suitable potential sites.

Based on the trend analysis it has been found that the wind speeds in April to mid-September are found maximum than the relative months. The maximum wind speed has been recorded in June. Wind flow developed due to the differential heating of earth is modified by its rotation and further influenced by local topography that causes the wind to flow at a high speed and changes in wind patterns. The increased heat energy generated due to expansion settlement and growing population in urban areas results in heat which affects the wind flow as well. So the summer season is considered the finest season for rotating the turbines through wind potentials. In the winter season wind flows relatively at a lower speed than in the summer that also causes the turbine to rotate but not at a more effective rate than the summer season.

CHAPTER SIX

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Findings

In this thesis, the wind speed and wind energy possible in selected six sites in the southeastern part of Dessie were investigated. The findings from this study can be summarized as follows:

(1) The annual mean minimum and maximum wind speeds value of Dessie, ranges from 4.26m/s to 4.52 m/s, respectively.

(2) The annual mean minimum and maximum wind direction value of Dessie, ranges from 35.5^0 - 94.5^0 southeast degree respectively.

(3) From the total area of 150,000km^{2,} 105,000km^2 or 70% area of the town is suitable for wind energy harvesting sites.

Therefore, based on the wind data used in this thesis, the wind energy resource in a south-east direction. Dessie classified into different classes, however, based on monthly mean power density, the wind resource may fall into a higher class category in some cases. It is essential to have accurate data for wind speed at higher altitudes.

6.2. Conclusions

The international policies and the global green movement have accentuated the focus on cheaper and renewable environmentally friendly sources of energy. Wind energy seems to be a rational choice of renewable and environmentally clean energy for developing countries. The potential wind resources most suitable sites are located in the southwest (along, Ayeteyef, and Ber/Kella) of Dessie town and blessed with good wind potential. Power production from wind resources would facilitate meeting the local energy demand, as an electric power supply in expansion areas is unpredictable and insufficient. It can be harnessed locally in a decentralized approach in expansion settlement localities for applications such as heating and lighting. Wind-driven electricity generation can be utilized as a standalone system and also to supplement the regional grid supply during peak hours (dry season). This study can offer a methodology and decision support to the decision-maker who has an interest in establishing wind potential sites in the study area.

The current methodology which has been adopted for the assessment of the wind energy potential sites in Dessie town provides a great scope in the development and establishment of the wind potential sites. Dessie, the dry air town, being a perfect location for harnessing the renewable forms of energy, is an asset for exploiting these renewable sources to generate power for urban and expansion settlement infrastructure. This study provides a great scope for future research and development works in the renewable energy resources sector.

6.3 Recommendations

Based on the above conclusions and findings the succeeding recommendations are forwarded:

- The town Administration should give due attention to harnessing this potential as soon as possible.
- Predominant wind direction with higher power density is in south-east direction obstacle from this direction should be avoided or taken in to account in the future.
- Wind measurement instruments should be installed close to the hub height to measure wind speed, temperature, pressure, and humidity, for many years, to calculate air density to better accuracy. This helps in reducing uncertainties related to predicting the annual energy production of the site.
- Arrangement of routine maintenance of the wind vane shall be done between July and August since the wind energy resource is at its minimum value during this year.
- Monitoring and maintenance of the mast should be given due attention not to miss long-range data due to failure of an anemometer or wind vane that arises from prevalence of high wind which is common at the site, and also recommended that:

- The existing and proposed land uses as well as land ownership of the selected sites should be investigated before establishing the building on the site.
- Wind speed calculating poles should be founded at the several sites selected to accurately ascertain the economic feasibility of developing commercial wind turbines.
- The layout design for the other selected sites should also be designed for optimum energy capture.
- The use of building-integrated wind turbines should be sought for city development.
- The energy plan, the building should be constructed on such wind size to supplement the mega hour with energy.

References

Daniel Yergin, The Prize: The Epic Quest for Oil, Money, and Power, Touchstone, 1992.

Ethiopian Electric Agency, Energy Access Project (2004): *The Ethiopian PV Commercialization Project, a Strategy for Solar Commercialization and Capacity Building*, Draft Final Report, Addis Ababa, July 2004.

The Federal Democratic Republic of Ethiopia, Ministry of Water Resources (2002): *Water Sector Development Program 2002 – 2016*, Main Report, Addis Ababa, 2002.

The Federal Democratic Republic of Ethiopia, Ministry of Water Resources (2002): *Water Sector Development Program 2002 – 2016*, *Hydro Power Development Program*, Addis Ababa, 2002.

Hulle FV, Fichaux N. Powering Europe: wind energy and electricity grid Report, European Wind Energy Association. Available From: ⟨http://www.ewea. org/ file admin/ewea_documents/documents/publications/reports/Grids_Report_2010.pdf⟩; 2010.[accessed:12.04.13].

IgnacioJ, RamírezR, EduardoGG, AlfredoL, FernándezJ, PedroJ, ZorzanoSMC, Miranda V. Promotion of new wind farms based on a decision support system. Renew Energy2008; 33:558–66

John Campbell, *Collapse of an Industry: Nuclear Power and the Contradictions of US Policy*, Cornell University Press, 1988.

LeeAHI, Chen, Kang HK. Multi-criteria decision making on strategic selection of wind farms.RenewEnergy2009; 34:120–6. LeeAHI, LinCY, KangHY, LeeWH. An integrated performance evaluation model for the photovoltaic industry. Energies 2012; 5:1271–91.

Michael Brower, *Cool Energy: Renewable Solutions to Environmental Problems*, MIT Press, 1994.

Mostafaei pours A. Feasibility study of harnessing wind energy for turbine installation in the province of Yazd in Iran. Renew Sustain Energy Rev2010; 14:93– 111.

Pantaleo. Feasibility study of offshore wind farms: an application to the Puglia region. SolEnergy2005; 79:321–31.

Saidur, Islam MR, RahimNA, SolangiKH. A Review on Global Wind Energy Policy. Renewable and Sustainable Energy Reviews2010; 14:1744–62.

UcarA, Balog. Assessment of wind power potential for turbine installation in coastal areas of Turkey. Renew Sustain Energy Rev2010; 14:1901–12.

Vaclav Smil, *Energy in World History*, West view Press, 1994

Appendixes

Appendix1 Minimum wind speed and direction recorded data at 10m and 50m height (x=11.140153, y=39.651652, x=11.115459, 39.628044)

Season and Month	date	Height	station	Time					
				6am		3pm		8pm	
				Ws (m/s)	Wd (deg)	Ws (m/s)	Wd(deg)	Ws (m/s)	Wd (deg)
Winter/ Bega/ February	01/2019	10 m	Azewagedel	2.34	89.93	2.42	86.42	2.13	87.13
			Tossa	2.14	82.14	2.12	83.12	2.44	86.44
		50 m	Azewagedel	2.93	99.93	2.42	88.42	2.13	97.13
			Tossa	2.14	92.14	3.12	93.12	2.44	96.44
	02/2019	10 m	Azewagedel	2.12	88.16	2.16	85.18	2.12	87.04
			Tossa	2.14	83.43	2.10	89.12	2.06	89.47
		50 m	Azewagedel	2.12	91.12	2.16	92.16	2.12	98.12
			Tossa	2.14	90.14	2.10	98.10	2.06	96.06
	03/2019	10 m	Azewagedel	2.16	89.93	2.18	86.42	2.16	87.13

		Tossa	2.43	82.14	2.12	83.12	2.20	86.44
	50 m	Azewagedel	2.16	98.16	2.18	95.18	2.04	97.04
		Tossa	2.43	93.43	2.12	99.12	2.47	99.47
04/2019	10 m	Azewagedel	2.86	88.16	2.17	85.18	2.04	87.04
		Tossa	2.44	83.43	2.10	89.12	2.47	89.47
	50 m	Azewagedel	2.86	90.86	2.17	92.17	2.20	94.20
		Tossa	2.44	96.44	2.10	90.10	2.12	96.12
05/2019	10 m	Azewagedel	2.13	80.13	2.20	82.16	2.20	88.20
		Tossa	2.14	88.14	2.12	81.20	2.12	80.12
	50 m	Azewagedel	2.13	90.13	2.16	92.16	2.20	98.20
		Tossa	2.14	98.14	2.20	91.20	2.12	90.12

Appendix2 Minimum wind speed and direction recorded data at 10m and 50m height (x=11.120974, y=39.634924, x=11.120974,y=39.634924)

date	Height	station	Time		
			6am	3pm	8pm

Season and Month				Ws (m/s)	Wd (deg)	Ws (m/s)	Wd(deg)	Ws (m/s)	Wd(deg)
Summer/	21/2019	10 m	Bus station	2.93	19.93	2.42	36.42	2.13	47.13
Kiremet/			St. merry	2.14	22.14	2.12	43.12	2.44	36.44
June		50 m	Bus station	3.93	20.93	3.42	37.42	3.13	49.13
			St. merry	3.14	24.14	3.12	44.12	3.44	38.44
	22/2019	10 m	Bus station	2.12	21.12	2.16	42.16	2.12	38.12
			St. merry	2.14	20.14	2.10	38.10	2.06	46.06
		50 m	Bus station	3.12	23.12	3.16	44.16	3.12	34.12
			St. merry	3.14	22.14	3.10	39.10	3.06	48.06
	23/2019	10 m	Bus station	2.16	18.16	2.18	35.18	2.04	37.04
			St. merry	2.43	23.43	2.12	39.12	2.47	39.47
		50 m	Bus station	3.16	19.16	3.18	36.18	3.04	39.04
			St. merry	3.43	25.43	3.12	38.12	3.47	41.47
	24/2019	10 m	Bus station	2.86	20.86	2.17	42.17	2.20	34.20
			St. merry	2.44	26.44	2.10	40.10	2.12	36.12

		50 m	Bus station	3.86	44.86	3.17	45.17	3.20	38.20
			St. merry	3.44	28.44	3.10	40.10	3.12	38.12
	25/2019	10 m	Bus station	2.13	20.13	2.16	42.16	2.20	38.20
			St. merry	2.14	28.14	2.20	41.20	2.12	40.12
		50 m	Bus station	3.13	22.13	3.16	42.16	3.20	40.20
			St. merry	3.14	30.14	3.20	41.20	3.12	42.12

Appendix3 Minimum wind speed and direction recorded data at 10m and 50m height (x=11.145205, y=39.644302, x=11.112241, 39.633142)

Season and Month	date	Height	station	Time					
				6am		3pm		8pm	
				Ws (m/s)	Wd (deg)	Ws (m/s)	Wd(deg)	Ws (m/s)	Wd(deg)
Spring/	15/2019	10 m	Ber/kella	2.93	56.93	2.42	66.42	2.13	57.13
Tuesday/			Ayeteyef	2.14	65.14	2.12	83.12	2.44	76.44
May		50 m	Ber/kella	2.93	58.93	2.42	68.42	3.13	59.13

		Ayeteyef	2.14	67.14	3.12	85.12	2.44	78.44
16/2019	10 m	Ber/kella	2.12	61.12	3.16	72.16	2.12	68.12
		Ayeteyef	3.14	70.14	2.10	78.10	2.06	76.06
	50 m	Ber/kella	3.12	63.12	3.16	74.16	2.12	70.12
		Ayeteyef	2.14	72.14	3.10	79.10	3.06	78.06
17/2019	10 m	Ber/kella	2.16	58.16	2.18	65.18	2.04	57.04
		Ayeteyef	2.43	73.43	2.12	69.12	2.47	69.47
	50 m	Ber/kella	3.16	60.16	2.18	82.17	2.04	59.04
		Ayeteyef	2.43	75.43	3.12	70.10	2.47	69.47
18/2019	10 m	Ber/kella	2.86	60.86	2.17	82.17	2.20	64.20
		Ayeteyef	2.44	66.44	2.10	70.10	2.12	56.12
	50 m	Ber/kella	2.86	65.86	3.17	67.18	2.20	64.20
		Ayeteyef	2.44	68.44	3.10	71.12	3.12	58.12
19/2019	10 m	Ber/kella	2.13	80.13	2.16	62.16	2.20	78.20
		Ayeteyef	2.14	68.14	2.20	71.20	2.12	70.12
	50 m	Ber/kella	3.13	80.13	2.16	68.16	3.20	78.20
		Ayeteyef	3.14	68.14	2.20	74.20	3.12	70.12

Appendix 4 Maximum wind speed and direction recorded data at 10m and 50m height (x=11.140153, y=39.651652, x=11.115459, 39.628044)

Season and Month	date	Height	station	Time 6am		3pm		8pm	
				Ws (m/s)	Wd (deg)	Ws (m/s)	Wd(deg)	Ws (m/s)	Wd(deg)
Winter/	01/2019	10 m	Azewagedel	3.93	-	3.42	-	3.13	-
Bega/			Tossa	4.14	-	5.12	-	4.44	-
Feburary		50 m	Azewagedel	4.93	-	4.42	-	4.13	-
			Tossa	5.14	-	4.12	-	4.44	-
	02/2019	10 m	Azewagedel	4.12	-	5.16	-	5.12	-
			Tossa	4.14	-	5.10	-	5.06	-
		50 m	Azewagedel	4.12	-	4.16	-	4.12	-
			Tossa	4.14	-	4.10	-	4.06	-

03/2019	10 m	Azewagedel	5.16	-	5.18	-	5.04	-
		Tossa	5.43	-	4.12	-	5.47	-
	50 m	Azewagedel	4.16	-	4.18	-	4.04	-
		Tossa	4.43	-	4.12	-	4.47	-
04/2019	10 m	Azewagedel	4.86	-	5.17	-	4.20	-
		Tossa	4.44	-	5.10	-	5.12	-
	50 m	Azewagedel	4.86	-	4.17	-	4.20	-
		Tossa	4.44	-	4.10	-	4.12	-
05/2019	10 m	Azewagedel	5.13	-	4.16		4.20	-
		Tossa	4.14	-	5.20		4.12	-
	50 m	Azewagedel	4.13	-	4.16	-	4.20	-
		Tossa	4.14	-	4.20	-	4.12	-

Appendix 5 Maximum wind speed and direction recorded data at 10m and 50m height (x=11.120974, y=39.634924, x=11.120974,y=39.634924)

date	Height	station	Time		
			6am	3pm	8pm

Season and month				Ws (m/s)	Wd (deg)	Ws (m/s)	Wd(deg)	Ws (m /s)	Wd(deg)
Summer/ Kiremet/ June	21/2019	10 m	Bus station	3.93	-	4.42	-	4.1 3	-
			St. merry	4.14	-	4.12	-	5.4 4	-
		50 m	Bus station	4.93	-	4.42	-	4.1 3	-
			St. merry	4.14	-	5.12	-	5.4 4	-
	22/2019	10 m	Bus station	5.12	-	5.16	-	5.1 2	-
			St. merry	5.14	-	4.10	-	4.0 6	-
		50 m	Bus station	4.12	-	4.16	-	4.1 2	-
			St. merry	4.14	-	4.10	-	4.0 6	-

23/2019	10 m	Bus station	5.16	-	5.18	-	5.04	-
		St. merry	5.43	-	4.12	-	5.47	-
	50 m	Bus station	4.16	-	4.18	-	4.18	-
		St. merry	4.43	-	4.12	-	4.12	-
24/2019	10 m	Bus station	4.86	-	5.17	-	4.20	-
		St. merry	4.44	-	5.10	-	5.12	-
	50 m	Bus station	4.86	-	4.17	-	4.20	-
		St. merry	4.44	-	4.10	-	4.12	-
25/2019	10 m	Bus station	5.13	-	4.16		4.20	-

			St. merry	4.14	-	5.20		4.12	-
		50 m	Bus station	4.13	-	4.16	-	4.20	-
			St. merry	4.14	-	4.20	-	4.12	-

Appendix 6 Maximum wind speed and direction recorded data at 10m and 50m height (x=11.145205, y=39.644302, x=11.112241, 39.633142)

Season and Month	date	Height	station	Time 6am		3pm		8pm	
				Ws (m/s)	Wd (deg)	Ws (m/s)	Wd(deg)	Ws (m/s)	Wd(deg)
Spring/	15/2019	10 m	Ber/kella	5.93	-	4.42	-	5.13	-
Tuesday/			Ayeteyef	5.14	-	5.12	-	5.44	-
May		50 m	Ber/kella	4.93	-	4.42	-	4.13	-
			Ayeteyef	4.14	-	4.12	-	4.44	-
	16/2019	10 m	Ber/kella	5.12	-	5.16	-	5.12	-

		Ayeteyef	5.14	-	4.10	-	4.06	-
	50 m	Ber/kella	4.12	-	4.16	-	4.12	-
		Ayeteyef	4.14	-	4.10	-	5.06	-
17/2019	10 m	Ber/kella	4.16	-	4.18	-	4.04	-
		Ayeteyef	4.43	-	4.12	-	4.47	-
	50 m	Ber/kella	5.16	-	5.18	-	5.04	-
		Ayeteyef	4.43	-	4.12	-	4.47	-
18/2019	10 m	Ber/kella	4.86	-	4.17	-	4.20	-
		Ayeteyef	5.44	-	4.10	-	5.12	-
	50 m	Ber/kella	4.86	-	4.17	-	4.20	-
		Ayeteyef	4.44	-	5.10	-	5.12	-
19/2019	10 m	Ber/kella	4.13	-	4.16		5.20	-
		Ayeteyef	4.14	-	4.20		5.12	-
	50 m	Ber/kella	5.13	-	4.16	-	4.20	-
		Ayeteyef	4.14	-	4.20	-	4.12	-

Appendix 7 Minimum average wind speed (m/s) at 10m height (NASA recorded data 1989-2018)

(x=11.15731, y=39.68161)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989	0.58	0.93	0.73	0.78	0.62	0.6	0.72	0.59	0.42	0.67	0.52	0.83	0.66
1990	0.72	0.47	0.5	0.52	0.65	0.7	0.7	0.6	0.46	0.63	0.94	0.89	0.65
1991	0.65	0.82	0.7	0.64	0.63	0.73	0.65	0.59	0.4	0.49	0.82	0.6	0.64
1992	0.8	0.62	0.68	0.58	0.57	0.75	0.56	0.61	0.41	0.54	0.69	0.9	0.64
1993	0.88	0.62	0.61	0.64	0.56	0.77	0.77	0.56	0.41	0.37	0.72	0.78	0.64
1994	0.78	0.7	0.65	0.71	0.57	0.75	0.57	0.53	0.43	0.66	0.6	0.75	0.64
1995	0.69	0.54	0.68	0.64	0.52	0.7	0.58	0.56	0.52	0.58	0.72	0.88	0.64
1996	0.91	0.62	0.62	0.61	0.51	0.8	0.68	0.69	0.46	0.53	0.73	0.76	0.66
1997	0.83	0.54	0.56	0.43	0.63	0.51	0.67	0.51	0.49	0.57	0.63	0.61	0.58
1998	0.9	0.62	0.57	0.67	0.53	0.77	0.76	0.71	0.45	0.55	0.6	0.65	0.65
1999	0.71	0.83	0.62	0.47	0.6	0.54	0.69	0.49	0.49	0.38	0.63	0.83	0.6
2000	0.6	0.54	0.68	0.49	0.5	0.66	0.69	0.77	0.58	0.63	0.67	0.79	0.64
2011	2.45	2.85	2.48	2.55	2.51	2.56	2.15	2.05	2.25	2.73	2.57	2.52	2.47

2012	2.67	2.9	2.67	2.3	2.97	2.92	2.33	1.79	1.98	2.62	2.5	2.46	2.51
2013	2.45	2.84	2.48	2.44	2.65	2.49	2.23	1.65	1.81	1.88	2.26	2.35	2.29
2014	2.43	2.45	2.57	2.74	2.67	2.63	2.03	1.75	1.77	1.98	2.4	2.34	2.31
2015	2.54	2.66	2.81	3	2.75	2.55	2.07	1.68	1.76	2.3	2.39	2.3	2.4
2016	2.26	2.67	2.46	2	2.04	2.41	1.97	1.77	1.79	1.89	2.24	2.5	2.16
2017	2.55	2.51	2.24	2.53	2.3	2.76	2.37	1.71	1.87	2	2.27	2.39	2.29
2018	2.53	2.43	2.48	2.05	2.62	2.55	1.82	1.74	1.88	2.16	2.37	2.35	2.25
2011	2.45	2.85	2.48	2.55	2.51	2.56	2.15	2.05	2.25	2.73	2.57	2.52	2.47
2012	2.67	2.9	2.67	2.3	2.97	2.92	2.33	1.79	1.98	2.62	2.5	2.46	2.51
Sum	54.22	55.56	53.87	52.23	54.23	55.9	45.62	40.14	40.41	48.17	52.69	53.03	50.48
Ave	1.80	1.85	1.79	1.74	1.80	1.86	1.52	1.33	1.34	1.60	1.75	1.76	1.68

Appendix 8 Minimum average wind speed (m/s) at 50m height (NASA recorded data 1989-2018)

(x=11.157, y=39681)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989	0.87	1.32	1.07	1.14	0.88	0.87	1.04	0.83	0.63	1.01	0.77	1.29	0.98
1990	1.02	0.72	0.7	0.73	0.84	0.93	1.05	0.92	0.67	0.96	1.43	1.31	0.94

1991	0.93	1.19	1.08	1	0.97	1.07	0.88	0.84	0.56	0.73	1.26	0.88	0.95
1992	1.17	0.97	0.99	0.84	0.82	1	0.79	0.88	0.61	0.85	1.09	1.34	0.95
1993	1.3	0.85	0.85	0.94	0.83	1.08	1.1	0.84	0.61	0.56	1.11	1.19	0.94
1994	1.16	0.97	0.94	1.05	0.79	0.99	0.77	0.77	0.61	1.03	0.93	1.13	0.93
1995	1.02	0.81	1.03	0.96	0.73	0.91	0.82	0.82	0.77	0.85	1.09	1.34	0.93
1996	1.4	0.9	0.93	0.94	0.68	1.18	0.98	0.98	0.65	0.81	1.1	1.13	0.97
1997	1.16	0.76	0.81	0.58	0.93	0.79	0.98	0.7	0.7	0.89	0.98	0.88	0.85
1998	1.27	0.89	0.84	0.96	0.73	1.03	1.04	1.05	0.65	0.86	0.92	0.97	0.93
1999	1.06	1.22	0.89	0.67	0.85	0.75	0.99	0.67	0.7	0.57	0.97	1.24	0.88
2000	0.85	0.79	0.97	0.7	0.65	0.88	1.01	1.1	0.85	0.97	0.99	1.18	0.91
2001	1.03	0.84	1	0.76	0.7	1.21	1.11	1.28	0.86	0.88	1.01	1.07	0.98
2002	0.88	1.14	1.03	0.9	0.86	1.15	1.07	1.03	0.8	1.1	1.21	1.1	1.02
2003	1.04	0.8	0.95	0.86	0.8	1.17	1.04	1.04	0.75	0.95	1.29	1.06	0.98
2004	0.99	1.27	0.93	0.79	0.86	0.93	1.23	1.03	0.97	1.13	1.28	1.18	1.05
2005	1.01	0.89	0.93	0.99	0.55	1.02	1.33	0.74	0.95	1.08	1.07	1.26	0.99
2006	1.31	1.19	0.93	0.71	0.84	1.29	1.01	1.11	0.89	0.87	0.96	1.22	1.03
2007	1.27	0.85	1.07	0.71	1.08	1.3	0.97	0.91	0.99	0.89	1.28	1.07	1.03

2008	1	1.4	1.18	0.74	0.79	0.77	1.07	0.79	0.74	0.83	1.2	0.99	0.96
2009	1.08	0.98	0.89	0.85	0.82	0.99	0.96	0.97	1.03	1.19	1.08	1.05	0.99
2010	1.23	1.1	0.97	0.79	1	1.1	1.11	1.12	0.77	1.08	1.39	1.17	1.07
2011	1	1.04	0.98	0.88	0.78	0.94	1.11	1.1	1.03	1.13	1.14	0.98	1.01
2012	1.04	1.06	0.83	0.78	0.85	1.14	1.3	0.91	0.83	0.94	1	0.84	0.96
2013	1.12	1.04	0.97	0.69	1.01	1.01	1.39	0.76	0.78	0.59	0.89	1.07	0.94
2014	1.01	1.06	0.92	0.93	0.96	0.88	0.78	0.86	0.74	0.52	1.16	0.9	0.89
2015	1.02	0.93	1.05	0.77	0.98	0.87	0.61	0.79	0.69	0.95	1.1	1.11	0.91
2016	0.84	1.09	0.89	0.87	0.75	0.97	1.12	0.77	0.75	0.66	0.97	0.73	0.87
2017	1	1.2	0.7	0.93	0.64	1.03	1.07	0.85	0.77	0.79	1.05	1.01	0.92
2018	0.91	1.15	1.12	0.61	0.88	1.06	0.85	0.87	0.78	0.65	1.05	1	0.91
Sum	31.99	30.42	28.4	25.0	24.8	30.3	30.5	27.33	23.1	26.3	32.7	32.6	28.67
Ave	1.06	1.01	0.94	0.83	0.82	1.01	1.01	0.91	0.77	0.87	1.09	1.08	0.95

Appendix 9 Minimum average wind direction (deg) at 10m height (NASA recorded data 1989-2018)

(x=11.15731, y=39.68161)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989	92.12	99.72	101.7	120.8	80.96	50.13	358.38	357.38	60.83	94.59	100.15	108.5	85.69
1990	105.01	105.63	98.46	101.8	61.16	45.02	35.83	5.73	42.99	101.2	113.95	113.5	84.94
1991	102.92	102.04	116.0	96.64	77.04	52.04	1.84	350.49	49.26	95	112.45	103.4	86.42
1992	103.1	94.54	102.9	93.43	85.46	47.79	18.85	351.11	63.85	86.32	110.51	98.58	85.65
1993	97.16	95.73	103.2	113.5	89.48	35.05	355.69	3.69	35.39	99.29	112.38	117.5	88.71
1994	107.57	97.09	104.6	98.98	89.42	31.75	340.39	355.19	71.5	104.4	97.35	106.4	89.89
1995	105.54	103.45	104.6	106.9	85.74	48.82	2.76	346.1	58.48	92.2	104.73	116.0	89.68
1996	107.94	103.35	100.0	101.7	80.83	17.44	352.4	350.34	40.42	93.09	112.47	112.7	86.79
1997	101.58	90.35	98.42	86.76	78.19	64.71	1.86	8.34	58.79	87.48	97.65	99.91	83.32
1998	99.38	97.11	104.1	105.8	76.14	38.21	319.51	325.38	19.64	87.05	114.64	112.3	85.16
1999	106.28	107.31	96.64	96.06	72.15	55.92	328.35	348.5	60.65	96.49	111.72	113.9	87.66
2000	99.16	98.26	98.39	89.59	71.44	44.98	352.28	320.22	51.68	77.16	99.66	103.9	78.49
2001	94.49	98.42	129.3	92.78	66.85	18.31	359.07	330.98	45.17	81.15	102.5	109.1	81.16
2002	98.02	106.76	110.3	92.73	62.92	30.5	13.97	6.03	61.15	95.93	110.73	98	82.07
2003	102.57	97	100.1	95.78	89.42	33.62	359.43	347.41	63.4	98.32	105.17	114.2	85.95

2004	100.64	95.3	101.0	107.8	64.25	40.4	348.76	7.1	55.22	92.22	104.65	102.7	81.99
2005	105.07	103.72	99.17	102.3	76.34	42.44	342.47	23.95	51.65	90.4	105.87	117.2	85.48
2006	107.16	104.26	105.6	98.2	71.1	24.84	336.74	318.21	13.79	91.4	105.33	96.23	83.36
2007	105.29	102.34	102.1	96.89	76.93	12.18	329.71	348.83	10.93	94.4	106.58	109.1	84.51
2008	102.78	102.03	103.1	93.8	69.97	42.1	11.26	351.66	41.65	75.58	113.7	107.1	81.25
2009	106.11	106.2	97.49	91.98	73.68	58.19	328.06	356.75	34.93	85.3	107.28	109.3	83.4
2010	106.05	111.9	103.7	104.8	53.7	28.79	332.58	315.68	38.59	84	116.5	113.6	83.3
2011	109.41	94.79	106.9	99.41	77.17	36.1	350.52	357.9	49.98	88.56	81.84	97.12	79.29
2012	98.07	102.72	99.14	97.03	72.97	38.73	354.55	357.88	48.74	96.13	102.75	100.8	80.19
2013	98.34	101	108.0	92.25	72.25	37.22	318.53	342.56	29.45	93.05	104.61	103.0	81.29
2014	106.89	95.16	102.2	93.17	80.07	52.81	24.59	355.12	46.47	89.09	97.24	101.7	83.37
2015	91.29	97.17	103.5	82.79	76.21	47.04	39.57	356.58	49.04	94.13	96.36	96.82	81.74
2016	99.2	104.37	101.1	111.3	65.94	30.03	337.48	336.95	35.58	91.67	109.7	102	85.61
2017	107.81	101.28	106.4	100.4	78.64	50.01	17.8	358.05	36.81	78.3	102.06	109.1	83.27
2018	102.61	80.39	100.9	999	56.84	50.16	55.83	19.51	66.79	106.9	117.27	94.47	139.2
Sum	3069.56	2999.3	3110.	1866.	2233.2	1205.	6729.0	8013.6	1392	2740.	3177.8	3189	2578
Ave	102.31	99.97	103.6	62.22	74.44	40.17	224.30	267.12	46.42	91.36	105.92	106.3	85.96

Appendi 10 Minimum average wind direction (deg) 50m (NASA recorded data 1989-201ε (x=11.15731,y=39.68161

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989	92.91	101.74	104.5	128.51	80.7	44.48	349.63	340.96	42.01	95.41	102.66	111.3	85.61
1990	108.6ς	107.91	100.4‹	107.71	55.73	38.66	26.86	355.2	16.61	103.2ℤ	119.07	119.21	84.28
1991	106.3ℨ	105.26	120.61	97.94	76.27	46.68	350.26	336.8	38.85	95.34	117.69	107.48	86.28
1992	106.4⁊	95.59	104.9ℨ	95.41	85.96	41.2	7.88	336.8	56.23	85.92	113.77	100.67	85.03
1993	100.11	97.62	106.1ξ	118.06	90.27	26.54	345.51	349.0	359.67	100.3ϵ	116.5	122.86	89.16
1994	113.11	99.75	107.7‹	102.27	91.03	20.42	328.03	341.4	63.68	106.2	99.7	110.25	90.73
1995	110.5ς	106.72	107.7ς	110.34	86.22	42.98	346.31	332.3	51.13	91.97	109.71	120.3	90.2
1996	110.8ℨ	107.56	102.11	104.58	79.87	7.26	341.24	337.6	23.09	93.07	116.16	118.03	86.49
1997	105.8‹	90.57	100.6ℤ	88	77.75	59	347.29	347.5	49.7	86.83	98.88	103.07	82.47
1998	101.8ξ	99.4	106.7ϵ	109.39	73.93	30.82	312.41	317.8	354.06	84.87	119.07	117.63	83.62
1999	109.8‹	112.19	99.29	97.87	69.66	51.72	319.95	333.3	38.39	96.25	115.73	118.89	87.64
2000	102.0⁊	101.03	100.0ℨ	89.16	68.74	39.27	345.29	314.1	42.07	74.43	102.46	107.89	75.86
2001	97.21	100.61	138.4	94.78	62.93	6.06	349.57	323.7	35.01	80.77	106.06	113.82	78.87

2002	100.11	111.71	115.27	94.01	58.25	19.93	7.49	357.8	55.49	97.97	115.38	100.35	80.76
2003	106.05	99.25	102.37	99.01	91.33	25.53	353.43	336.4	58.59	100.54	108.83	120.4	85.87
2004	104.27	97.81	104.53	113.72	60.31	31.64	339.69	355.8	50.21	93.5	108.59	106.27	80.98
2005	108.45	107.42	101.55	106.44	73.91	36.41	332.61	17.08	45.09	91.3	109.79	123.6	84.99
2006	110.71	108.07	109.88	101.83	68.14	15.87	321.63	308.0	352.15	91.94	108.7	98.99	82.38
2007	109.55	105.21	105.03	99.25	75.53	358.36	319.25	335.7	357.68	95.31	109.91	114.24	83.66
2008	106.04	105.78	107.77	94.51	67.12	35.2	2.36	339.4	27.01	73.28	119.48	112.73	79.79
2009	111.77	110.86	100.29	93.88	71.6	54.28	319.71	340.2	24.53	84.32	111.56	113.68	82.64
2010	110.86	118.24	107.96	109.46	46.73	22.06	321.75	309.0	22.84	82.88	121.56	119.73	82.65
2011	114	96.8	111.19	102.43	75.63	29.28	338.07	349.2	44.74	89.37	81.1	100.72	77.06
2012	100.71	106.34	102.13	103	72.71	32.74	345.8	347.8	45.01	97.87	107.02	104.64	79.18
2013	101.7	104.64	113.2	95.01	70.18	30.44	310.26	326.6	9.93	93.46	107.97	107.37	80
2014	111.94	97.84	105.52	94.23	79.5	47.15	12.44	342.5	33.02	88.36	98.46	105.46	82.67
2015	93.12	100.02	106.8	82.92	75.4	39.66	29.1	338.6	32.96	94.89	97.37	98.19	80.44
2016	102.51	108.7	102.86	121.59	55.89	20.87	323.73	321	11.46	92.47	113.97	105.03	85.67
2017	113.56	103.66	111.57	103.38	76.24	44.95	7.3	342.7	13.09	74.26	105.17	114.94	81.5
2018	105.92	84.8	126.57	-999	50.51	47.53	285.54	359.2	61.46	105.13	119.62	117.94	155.48

Sum	3177.1	3093.1	3233.8	1959.6	2168.	1346.9	7740.3	9795.	2415.7	2741.4	3281.94	3335.6	2571.9
Ave	105.90	103.10	107.79	65.32	72.26	44.89	258.01	326.5	80.52	91.38	109.39	111.18	85.73

Appendix 11 Maximum average wind speed (m/s) 10m (NASA recorded data 1989-2018) (x=11.15731, y=39.68161

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989	4.78	5.04	4.44	3.76	5.17	5.22	3.88	2.69	3.04	3.74	4.43	4.11	4.19
1990	4.74	3.73	4.5	3.95	4.87	5.38	3.75	2.87	2.89	4.18	4.24	4.86	4.17
1991	5.15	4.84	4.43	5.39	5.97	5.35	3.44	2.9	3.15	4.32	4.51	4.69	4.51
1992	4.41	4.18	4.87	4.95	5.1	4.71	3.56	2.73	3.35	4.16	4.56	4.86	4.29
1993	4.92	4.92	5.22	4.02	4.19	4.28	3.32	3.07	2.84	3.86	4.15	4.75	4.12
1994	5.07	5.3	4.66	5.35	5.49	4.41	2.97	2.7	3.28	4.65	4.52	4.96	4.44
1995	5.21	4.66	4.52	4.66	4.91	5.1	3.06	2.91	3.34	4.49	4.7	4.61	4.34
1996	4.31	5.19	4.6	4.65	4.57	4.4	3.2	3.12	3.04	4.15	4.46	4.53	4.18
1997	4.43	5.39	4.63	4.49	5.45	4.33	3.14	2.85	3.43	4.33	4.27	4.75	4.28
1998	4.8	4.36	4.69	4.74	4.97	5.06	2.84	2.84	2.81	3.6	4.18	4.62	4.12

1999	4.57	5.42	4.64	5.36	5.86	4.83	3.15	2.82	3	3.75	4.42	4.58	4.36
2000	5.13	5.42	5.47	5.34	5.59	5.57	3.47	3.27	3.26	4.38	4.88	4.86	4.72
2001	4.74	5.25	3.95	5.08	4.44	4.26	3.39	3.37	3.67	4.24	4.97	5	4.35
2002	4.64	5.2	4.46	5.04	4.97	4.87	3.78	3.37	3.87	4.86	5.01	4.54	4.54
2003	4.72	5.07	5.04	4.7	5.89	5.14	3.94	3.25	3.75	5.01	5.03	4.6	4.68
2004	4.55	5.16	5.14	4.28	5.7	4.55	3.82	3.41	4.2	5.06	5.21	4.8	4.66
2005	4.44	5.21	5.05	4.72	4.43	5.7	3.95	3.55	3.9	4.76	5.04	5.14	4.65
2006	5.29	5.1	4.51	4.21	5.08	5.02	3.15	2.87	3.01	4.1	4.42	4.86	4.3
2007	4.65	4.68	5.18	4.82	4.97	4.85	2.99	3.03	3.33	4.41	4.89	5	4.4
2008	5.06	5.48	5.57	5.91	5.48	5.31	4.07	3.17	3.22	4.23	4.25	4.57	4.69
2009	4.66	5.19	5.34	5.01	6.14	5.33	3.27	2.92	3.59	3.9	4.51	3.9	4.47
2010	4.99	3.95	4.6	4.54	4.4	5.2	3.55	3.01	3.15	4.01	4.26	4.26	4.16
2011	4.59	5.36	4.69	4.92	4.86	5.1	3.63	3.7	4.14	5.12	4.7	5.06	4.65
2012	5.14	5.69	5.19	4.15	5.75	5.51	4.08	3.1	3.73	4.91	4.82	4.78	4.73
2013	4.68	5.42	4.5	4.72	4.92	4.72	3.43	2.77	3.2	3.5	4.25	4.35	4.2
2014	4.62	4.37	4.82	5.24	5.06	5.25	3.79	3.05	3.21	3.97	4.31	4.52	4.35
2015	4.91	5.23	5.32	5.72	5.13	4.97	4.15	2.96	3.21	4.45	4.38	4.23	4.55

2016	3.98	5.07	4.66	3.7	3.81	4.56	3.31	2.9	3.17	3.61	4.19	5.06	4
2017	5.07	4.69	4.35	4.87	4.62	5.57	4.42	2.96	3.4	3.84	4.16	4.6	4.37
2018	4.84	4.53	4.45	3.9	5	5	3.33	3.14	3.53	4.35	4.45	4.58	4.26
Sum	143.	149	143	142	152	149	105	91.3	100	127	136	140	131.73
Ave	4.76	4.97	4.78	4.73	5.09	4.98	3.52	3.04	3.35	4.26	4.53	4.66	4.39

Appendix 12 Maximum average wind speed (m/s) at 50m height (NASA recorded data 1989-2018) (x=11.15731,y=39.68161)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1989	4.72	4.99	4.58	4.03	5.39	5.51	4.67	3.16	3.44	3.95	4.65	4.23	4.44
1990	4.8	3.69	4.43	4.18	5.09	5.7	4.2	3.36	3.43	4.46	4.49	4.89	4.4
1991	5.16	4.82	4.52	5.61	6.36	5.71	3.97	3.45	3.5	4.59	4.71	4.77	4.76
1992	4.44	4.12	4.79	4.98	5.24	5.01	4.2	3.29	3.62	4.3	4.72	4.91	4.47
1993	4.92	4.89	5.19	4.17	4.32	4.69	4.02	3.46	3.24	4.14	4.29	4.89	4.35
1994	5.22	5.34	4.59	5.33	5.62	5	3.76	3.12	3.57	4.87	4.68	4.97	4.67
1995	5.32	4.71	4.68	4.74	5.03	5.47	3.66	3.45	3.75	4.84	4.9	4.67	4.6
1996	4.3	5.22	4.58	4.7	4.72	4.91	4.07	3.78	3.33	4.36	4.67	4.78	4.45

1997	4.55	5.39	4.7	4.55	5.7	4.67	3.53	3.35	3.82	4.7	4.46	4.93	4.53
1998	4.89	4.42	4.69	4.76	5.2	5.68	3.92	3.62	3.29	3.88	4.26	4.62	4.44
1999	4.62	5.38	4.73	5.36	6.21	5.13	4	3.34	3.38	3.94	4.58	4.79	4.62
2000	5.06	5.34	5.4	5.6	5.89	5.98	4.13	4.16	3.65	4.64	5.06	4.83	4.98
2001	4.78	5.16	4.16	5.13	4.63	4.97	4.01	4.3	3.99	4.37	5.11	4.95	4.62
2002	4.5	5.17	4.47	5.23	5.14	5.33	4.26	3.81	4.17	5.05	5.13	4.58	4.73
2003	4.69	4.99	4.99	4.85	6.07	5.75	4.68	3.89	4.01	5.11	5.11	4.64	4.9
2004	4.59	5.09	5.09	4.36	5.97	5.06	4.62	4.17	4.54	5.29	5.31	4.92	4.92
2005	4.54	5.24	5.14	4.88	4.55	6.21	4.66	4.16	4.23	4.93	5.07	5.12	4.89
2006	5.25	5.05	4.5	4.2	5.39	5.67	3.97	3.93	3.75	4.27	4.56	4.87	4.61
2007	4.73	4.65	5.16	4.91	5.15	5.8	3.87	3.56	3.85	4.57	5.03	4.83	4.67
2008	5.07	5.4	5.52	6.09	5.74	5.71	4.72	3.94	3.71	4.48	4.34	4.66	4.95
2009	4.66	5.03	5.2	5.17	6.39	5.69	4.2	3.56	3.97	4.15	4.7	4.13	4.73
2010	5.15	4.39	4.63	4.59	4.69	5.74	4.56	4.23	3.62	4.22	4.5	4.3	4.55
2011	4.53	5.31	4.61	5.1	5	5.58	4.47	4.32	4.57	5.23	4.77	4.96	4.87
2012	5.11	5.51	5.06	4.44	6	5.97	4.9	3.77	4.19	5.12	4.82	4.76	4.97
2013	4.71	5.32	4.76	4.76	5.27	5.14	5.13	3.42	3.81	3.75	4.35	4.63	4.58

2014	4.59	4.52	4.89	5.38	5.31	5.62	4.42	3.7	3.64	4.15	4.46	4.7	4.61
2015	4.89	5.12	5.33	5.73	5.33	5.39	4.67	3.6	3.52	4.64	4.52	4.24	4.74
2016	4.37	5.08	4.67	3.87	4.1	5.15	4.33	3.63	3.7	3.71	4.42	5.13	4.34
2017	4.92	4.66	4.37	4.86	4.79	6.04	5.08	3.72	3.88	4.04	4.27	4.7	4.61
2018	4.87	4.51	4.65	3.97	5.22	5.57	3.77	3.92	3.85	4.54	4.61	4.58	4.51
Sum	143	148	144	145	159.5	163.8	128.4	111	113.0	134	140	141	139
Ave	4.79	4.95	4.80	4.85	5.31	5.46	4.28	3.70	3.76	4.47	4.68	4.73	4.65

Appendix 13 checklist for wind speed and direction information

No	Topic	Subtopic	Methodology for data collection
1	General description of the research	✓ Wind speed ✓ Wind direction ✓ Climate condition	Updating the structure map using GIS and field observation
2	Existing wind speed and direction analysis of the town	Wind speed and direction characteristics	Field inventory interviewing
3	The energy management system of the town	Application of technologies like ENVI-met, GIS in wind speed and direction change	

Annex 15

A photo showing how its topography affects the wind speed and direction change in the town