Abdalla Hamada Abdelnaby

WIND POWER GENERATION SCENARIOS IN LEBANON

MASTER THESIS

2023

NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF MECHANICAL ENGINEERING

WIND POWER GENERATION SCENARIOS IN LEBANON

M.Sc. THESIS

Abdalla Hamada Abdelnaby

Nicosia

June, 2023

NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF MECHANICAL ENGINEERING

WIND POWER GENERATION SCENARIOS IN LEBANON

M.Sc. THESIS

Abdalla Hamada Abdelnaby

Supervisor

ASSOC. PROF. DR. YOUSSEF KASSEM

Nicosia

June, 2023

Approval

We certify that we have read the thesis submitted by Abdalla Hamada Abdelnaby, titled **"(WIND POWER GENERATION SCENARIOS IN LEBANON)"** and that in our combined opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Mechanical Engineering.

Examining Committee	Name-Surname	Signature
Head of the Committee:	Prof. Dr. Hüseyin Gökçekuş	
Committee Member*:	Assoc. Prof. Dr. Hüseyin Çamur	
Supervisor:	Assoc. Prof. Dr. Youssef Kassem	

Approved by the Head of the Department

18/6/2023

Assoc. Prof. Dr. Hüseyin ÇAMUR

Head of Department

Approved by the Institute of Graduate Studies

Prof. Dr. Kemal Hüsnü Can Başer

Head of the Institute

Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Abdalla Hamada Abdelnaby

18/6/2023

Acknowledgments

First and foremost, I am deeply grateful to Professor Yousef Kassem, whose wisdom, expertise, and dedication have been a source of inspiration for me. His insightful guidance, constructive feedback, and commitment to excellence have significantly impacted my academic growth. Professor Kassem's mentorship has not only broadened my horizons but has also instilled in me a profound passion for the subject matter. I am truly privileged to have had the opportunity to learn from him and will forever cherish the lessons imparted.

I would also like to express my utmost appreciation to my family for their constant support and unwavering belief in my abilities. Their love, encouragement, and sacrifices have been the driving force behind my pursuit of knowledge. Their unending support, both emotionally and academically, has been invaluable to me. I am forever grateful for their unconditional love, understanding, and belief in my potential. Their encouragement has fueled my determination to overcome challenges and achieve my goals.

Furthermore, I would like to extend my gratitude to all my professors, whose passion for teaching and commitment to imparting knowledge have been instrumental in shaping my academic path. Their dedication, expertise, and willingness to go the extra mile to ensure our understanding have had a profound impact on my education. I am indebted to them for their guidance, encouragement, and for fostering an environment of intellectual curiosity.

Name and Surname of Student
Abdalla Hamada Abdelnaby

Abstract

Wind Power Generation Scenarios in Lebanon

Abdalla Hamada Abdelnaby

MA, Department of Mechanical Engineering

June, 2023, 65 pages

Wind energy have the potential to play a crucial role in Lebanon's efforts to increase its energy capacity, enhance energy security, mitigate environmental impacts, and resolve the persistent electricity crisis. To achieve these goals, urgent steps must be taken to reduce the country's carbon footprint and promote the development of sustainable energy technologies. A recent study has evaluated the feasibility of wind energy as a viable alternative for powering homes across Lebanon. By analysing existing data, the study identified the most suitable location for the installation of a wind farm in Ain ed Dabaa. Furthermore, the study developed a techno-economic model to evaluate the cost-effectiveness of various wind turbines. The results indicate that a Barber wind turbine is highly competitive compared to eight conventional wind turbines. Overall, the study highlights the potential for wind energy to provide a continuous, affordable, and eco-friendly source of electricity for countries grappling with electricity shortages. it is worth noting that while Lebanon has made some progress in transitioning towards renewable energy, there is still a long way to go. The country heavily relies on expensive and polluting diesel generators to meet its electricity needs, which has led to significant economic, social, and environmental costs. Embracing renewable energy technologies such as wind and solar can help Lebanon diversify its energy mix, reduce its reliance on fossil fuels, and lower its carbon footprint. However, the road to renewable energy transition in Lebanon is not without challenges. The lack of supportive policies, regulatory frameworks, and financial incentives, coupled with limited technical expertise and inadequate infrastructure, poses significant barriers to the widespread adoption of clean energy. Addressing these challenges will require strong political will, effective governance, private sector engagement, and international cooperation.

Key Words: Renewable energy; Lebanon; Wind turbine; Economic; Wind power.

Abstract

Wind Power Generation Scenarios in Lebanon

Abdalla Hamada Abdelnaby
MA, Department of Mechanical Engineering

December 2021, 86 pages

***Key Words**:* Renewable energy; Lebanon; Wind turbine; Economic; Wind power.

Table of Contents

CHAPTER IV

CHAPTER V

List of Tables

Page

List of Figures

Page

List of Abbreviations

PDF: probability density function

CDF: Cumulative Distribution Function

LCEC: Lebanese Center for Energy Conservation

CF: Capacity Factor

CC: Capital Cost

NASA: National Aeronautics and Space Administration

OMC: Operation and Maintenance Cost

CWTs: Conventional Wind Turbines

FWWT: Ferris Wheel Wind Turbine

WPD: Wind Power Density

EPC: Energy Production Cost

LCOE: Levelized Cost of the Electricity

SD: Standard Deviation

CV: Coefficient of Variation

EGC: Electricity Generated Cost

AEP: Annual Energy Produced

SPP: Simple Payback Period

CHAPTER I

Introduction

Background

Today, wind energy is one of the fastest-growing sources of electricity worldwide. According to the International Energy Agency, wind power accounted for 7% of global electricity generation in 2020, and this is expected to increase to 18% by 2025. In some countries, wind energy is already a major contributor to the electricity grid. In Denmark, for example, wind energy provided 47% of the country's electricity in 2020, while in Portugal, wind energy accounted for 27% of electricity generation in the same year according to International Energy Agency (2020).

One of the key advantages of wind energy is that it is a domestic source of energy that can reduce a country's reliance on imported fossil fuels. Additionally, wind energy has a relatively small land footprint compared to other sources of electricity generation. This means that wind turbines can be installed in rural areas without displacing significant amounts of land use. According to European Wind Energy Association (2011). wind energy is also a low-emission source of electricity, with a typical wind turbine producing 20-30 times less CO_2 per unit of electricity than a coal-fired power plant.

However, wind energy is not without its challenges. One of the main challenges are that wind is an intermittent source of energy, meaning that the amount of electricity generated by a wind turbine varies depending on the wind speed. This makes it difficult to integrate wind energy into the electricity grid, as electricity supply must match demand in real-time. Additionally, wind turbines can be noisy and may have visual impacts on the surrounding landscape.

Despite these challenges, according to U.S. Department of Energy (2021). the growth of wind energy shows no signs of slowing down. In recent years, advances in technology have made wind turbines more efficient and cost-effective. For example, the use of larger rotors and taller towers has increased the amount of energy that can be captured from the wind. Additionally, the development of offshore wind farms has allowed wind turbines to be installed in areas with higher wind speeds, which can lead to greater electricity generation.

Purpose of the Study

Wind energy and its associated technologies play a crucial role in supporting electricity consumption and addressing the electricity crisis worldwide. The recent study by the author examines the potential of wind and solar energy in various locations, with a focus on assessing wind potential in different areas of Lebanon.

The study collects data from meteorological services between 2010-2017 and utilizes the Weibull distribution function to evaluate wind speed characteristics in selected locations. Distribution parameters are estimated using the maximum likelihood method, and power density is calculated to evaluate wind energy potential.

Additionally, the study employs the Power-Law exponent method to estimate wind speed at different hub heights. Despite wind power being low and unsustainable in many regions of Lebanon, this study aims to evaluate the performance of the new Ferris wheel-based wind turbine technology called Barber Wind Turbine in low wind speed locations. The techno-economic performance of the selected wind turbine is compared with conventional wind turbines under similar economic conditions. In conclusion the study also aims to assess the performance of the Ferris wheel-based wind turbine, Barber Wind Turbine, a new wind turbine technology, at low wind speed locations in Lebanon, and compare its performance with conventional wind turbines under similar economic conditions. The existing literature suggests that wind power is not a viable option in many regions of Lebanon due to low and inconsistent wind speeds.

Limitations

One of the major limitations for wind energy farms in Lebanon is the availability of suitable wind resources. The country's topography and geographical location result in varied wind patterns, making it challenging to identify optimal sites for wind farms. Future work could focus on conducting extensive wind resource assessments using advanced modeling techniques and deploying anemometer towers at potential locations to gather accurate wind data for informed decision-making.

CHAPTER II

Energy situation in Lebanon

Research related conceptual definitions, descriptions and information related to the subject that already exists in the literature are given in this chapter.

Lebanon

Lebanon is a small country situated in the Middle East, on the eastern shore of the Mediterranean Sea. It has a strategic geographic location, bordered by Syria to the north and east, Israel to the south, and the Mediterranean Sea to the west. The country's population is estimated to be around 6.8 million, with about 1 million living in the capital city of Beirut.

Lebanon's geography is characterized by a narrow coastal strip along the Mediterranean Sea that runs north to south and is only 225 kilometers long. The country's terrain rises steeply from the coast to the Lebanon Mountains, which run parallel to the coast and reach an elevation of 3,088 meters at Qornet es-Sawda. The country's highest peak, Mount Hermon, is situated on the border with Syria and stands at 2,814 meters.

The population of Lebanon is diverse, with the majority being Arab Muslims and Arab Christians. There are also small populations of Druze and Armenians. The official language is Arabic, but French and English are widely spoken, especially in urban areas. The country has a rich cultural heritage, with a blend of Eastern and Western influences.

Lebanon's borders have been a source of conflict for many years. The country shares a long border with Syria, which has been a major factor in Lebanon's political and security situation. The border with Israel has also been a source of tension, with periodic clashes between the two countries over the years. The maritime border with Israel has also been the subject of recent disputes, with Lebanon claiming that Israel is encroaching on its exclusive economic zone.

Lebanon's strategic geographic location, diverse population, and complex borders have contributed to the country's unique character and its challenges. Despite these challenges, Lebanon remains an important center of culture, commerce, and education in the Middle East, with a vibrant and resilient society that continues to adapt and thrive.

Lebanon is a country located in the Middle East, with a long history of political instability and economic challenges. The country has faced numerous setbacks in recent years, including a devastating explosion in Beirut in August 2020, and a severe economic crisis that has caused widespread poverty and unrest. This essay will explore the economic and political situation in Lebanon and the challenges that the country faces.

The economic situation in Lebanon is dire, with the country experiencing a severe financial crisis. The Lebanese pound has lost more than 90% of its value since late 2019, causing inflation to skyrocket and prices of goods and services to increase. This has resulted in widespread poverty and food insecurity, with many families struggling to make ends meet. The country's GDP has also plummeted, and unemployment rates have increased, with many businesses closing down due to the economic crisis.

The roots of Lebanon's economic crisis can be traced back to decades of corruption, mismanagement, and political instability. The country's political leaders have failed to implement much-needed economic reforms, and the government's financial policies have been heavily criticized. The country's large public debt, estimated at around 170% of GDP, is also a major concern, with many experts calling for debt restructuring and other measures to address the crisis.

The political situation in Lebanon is also complex and volatile. The country has a sectarian political system, with power shared among different religious groups. However, this system has been plagued by corruption and political infighting, leading to a lack of progress on important issues such as economic reform, infrastructure development, and social welfare. In addition, the country has been heavily influenced by regional politics, with Iran and Saudi Arabia both vying for influence in the country.

The recent explosion in Beirut, which killed over 200 people and destroyed large parts of the city, has further exacerbated the country's problems. The blast was caused by a stockpile of ammonium nitrate that had been stored in the city's port for years, highlighting the government's negligence and lack of accountability. The explosion sparked widespread protests, with many Lebanese citizens calling for political change and reform.

In conclusion, Lebanon is facing a challenging economic and political situation, with deep-seated issues that require significant reforms and political will to address. The country's leaders must take urgent action to address the economic crisis, implement much-needed reforms, and ensure accountability for past mistakes. The international community can also play a role in supporting Lebanon through aid and assistance, while also putting pressure on the country's leaders to take decisive action to address the challenges facing the country.

Figure 2.1

Map of Lebanon.

Energy situation in Lebanon

Situated between a latitude of 33.8547° N and a longitude of 35.8623° E on the Eastern edge of the Mediterranean Sea, Lebanon currently relies on fossil fuels (97%) and hydropower (3%) as its primary sources of electrical energy. While the country's production capacity of electricity is 3600MW, the actual production capacity is currently limited to 2000MW. Lebanon's electricity is generated by seven thermal power plants, six hydroelectric plants, and two power ships. However, according to IEA Electricity Information, the demand for electricity has increased due to population growth and the use of new appliances see (Figure 2.2).

Furthermore, in 2016, the Council for Development and Reconstruction found that only 70% of the total power generated met the country's energy needs. The electricity crisis has had a significant impact on the daily lives of citizens, shop owners, and small businesses in Lebanon for years. The country has suffered from a severe shortage of energy due to decades of mismanagement, weak policies, and a lack of proper planning, resulting in power cuts lasting more than 20 hours a day. Consequently, citizens have been forced to rely on domestic or small home generators, leading to additional financial burdens According to Wehbe and Farhat et al. (2019), private generators are the third main source of electricity production in the country see (Figure 2.3).

Figure 2.2

Electrical Power Demand Distribution.

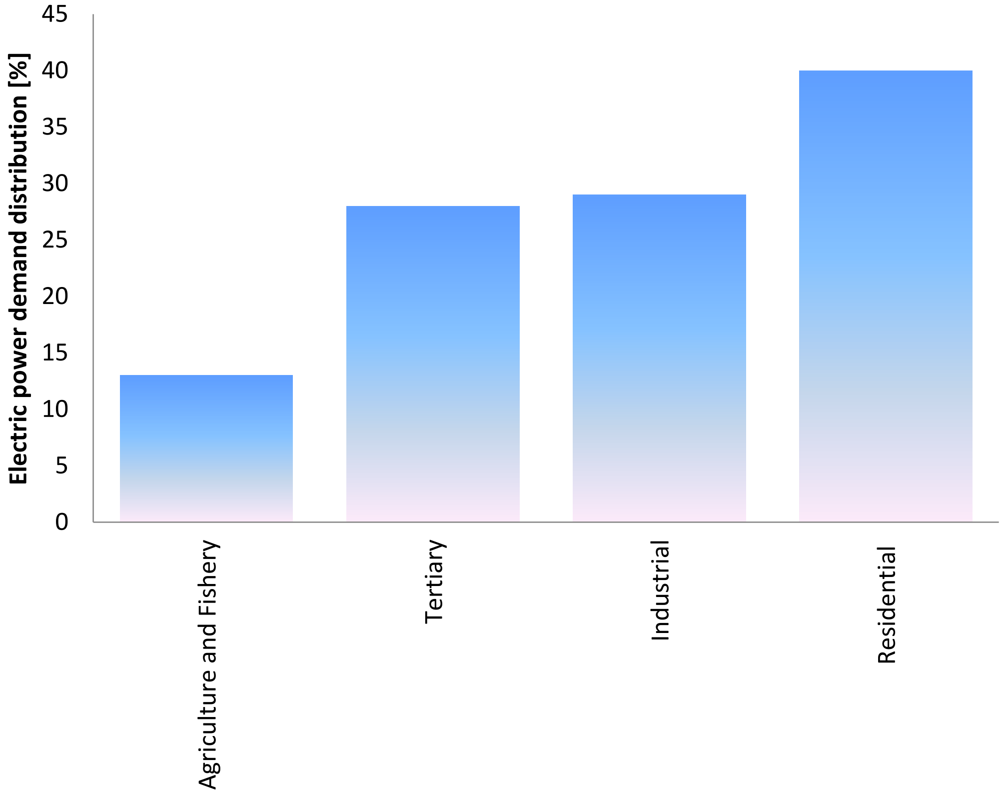
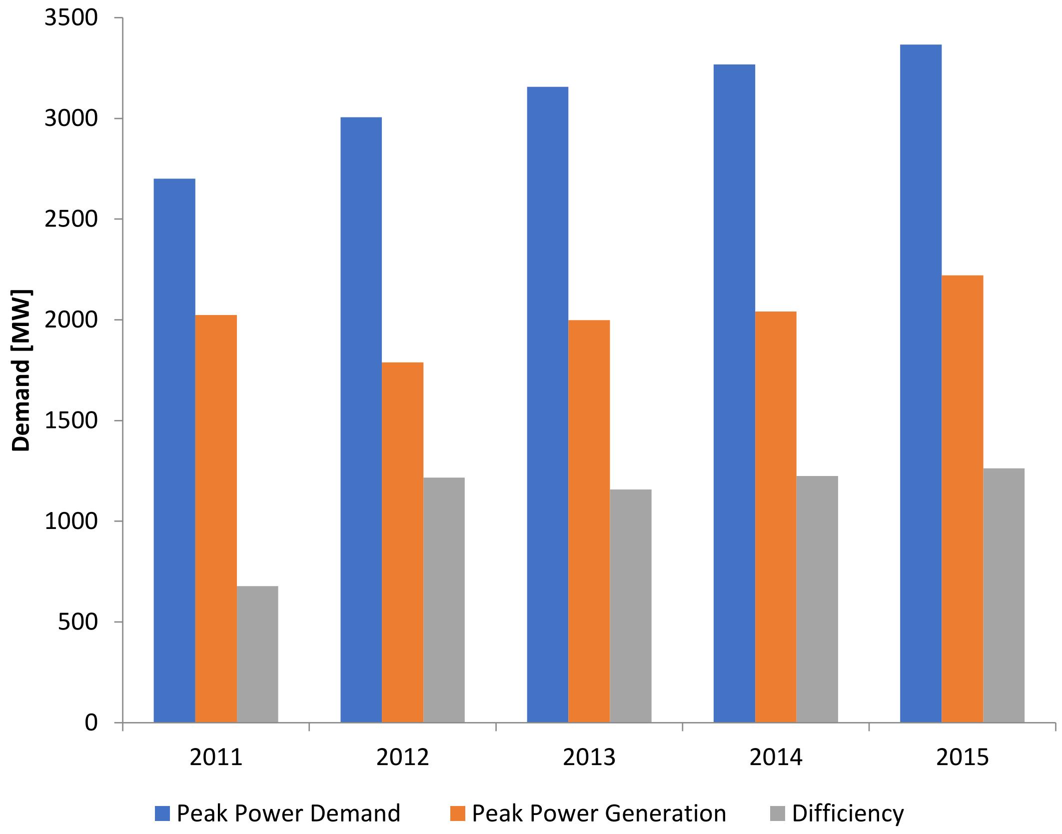


Figure 2.3

Electrical Power Demand and Generation.



One of the major issues contributing to the energy crisis in Lebanon is the lack of investment in the country's energy infrastructure. The country relies heavily on imports of oil and natural gas to meet its energy needs, which makes it vulnerable to fluctuations in global energy prices. Additionally, Lebanon's power plants are outdated and suffer from chronic maintenance issues, resulting in frequent blackouts and power cuts. The government has attempted to address the energy crisis by implementing various policies and initiatives, such as promoting the use of renewable energy sources and investing in new power plants. However, these efforts have been largely unsuccessful due to a lack of funding, political instability, and corruption.

The energy crisis has had a significant impact on the country's economy, with businesses and households struggling to afford the high cost of energy. This has led to a decline in economic growth and increased poverty levels, further exacerbating the crisis.

In conclusion, the energy situation in Lebanon is dire, and urgent action is needed to address the issue. The government must prioritize investment in the country's energy infrastructure, promote the use of renewable energy sources, and address issues related to corruption and political instability to effectively tackle the energy crisis and improve the country's economic outlook.

Renewable Energy in Lebanon

Lebanon has been facing a growing energy crisis due to its high dependency on imported fossil fuels, which accounts for over 90% of its energy consumption. To address this issue, the Lebanese government has been increasingly exploring renewable energy sources, including wind energy, to diversify its energy mix and reduce its carbon footprint.

The potential for wind energy in Lebanon is significant, particularly in coastal areas where there are favorable wind conditions. In fact, a study conducted by the Lebanese Center for Energy Conservation (LCEC) found that the country has a wind energy potential of over 2,000 megawatts (MW), which could provide around 10% of Lebanon's total electricity needs.

Despite this potential, progress in the development of wind energy in Lebanon has been slow due to several challenges. One of the main challenges is the lack of a clear regulatory framework for renewable energy projects, including wind energy. This has led to delays in project approvals and uncertainty for investors.

Another challenge is the lack of financing and incentives for wind energy projects. Private sector investments in renewable energy have been limited, and the government has not provided sufficient financial support for renewable energy initiatives. This has made it difficult for wind energy projects to compete with traditional fossil fuel-based energy sources.

In addition, the development of wind energy in Lebanon is hindered by the limited grid infrastructure and weak interconnections with neighboring countries. The national grid is outdated and poorly maintained, making it difficult to integrate wind energy into the existing system. The lack of interconnections with neighboring countries also limits the potential for energy exports and imports.

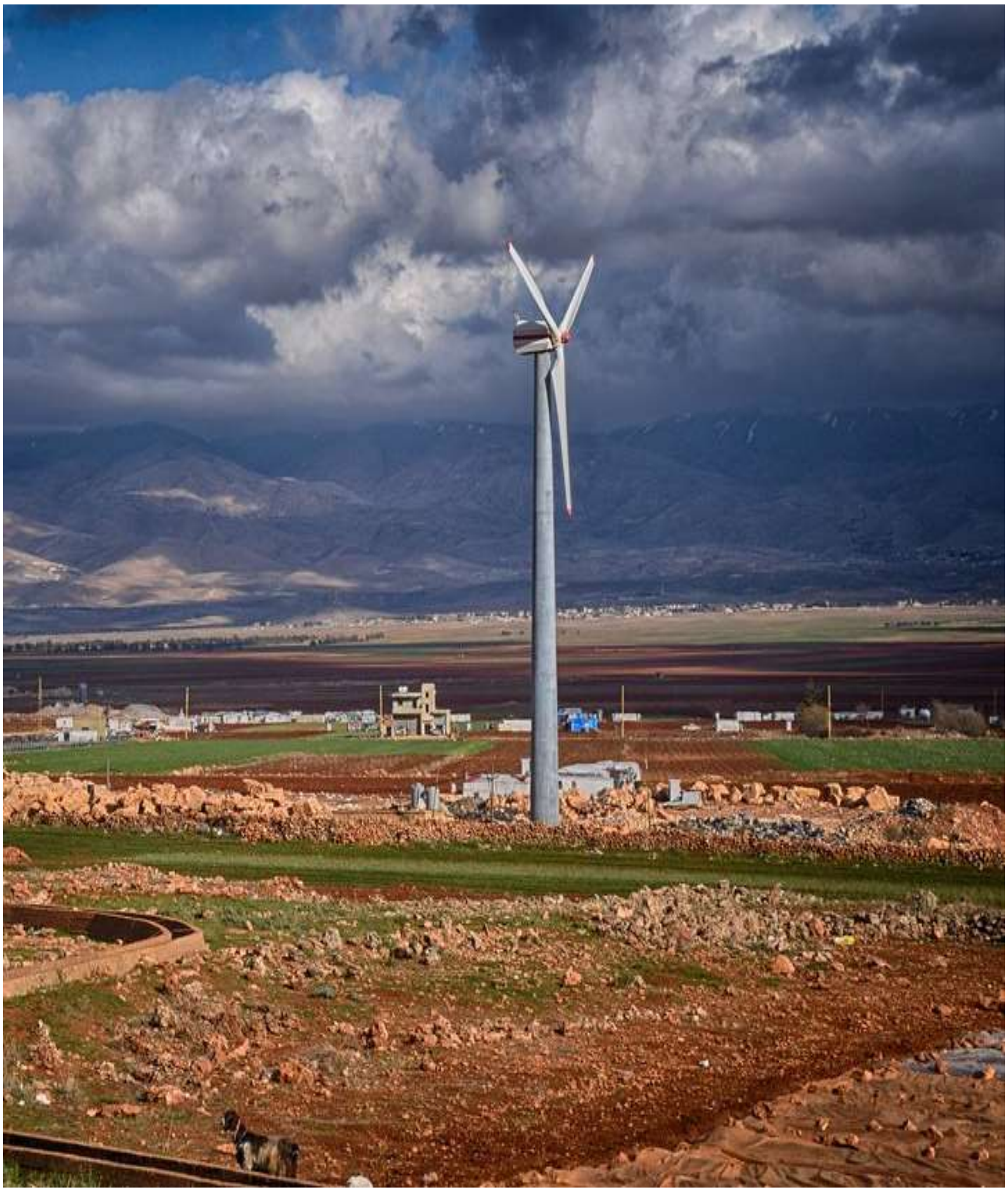
Despite these challenges, there have been some positive developments in the wind energy sector in Lebanon. The LCEC has launched a national wind energy program, which aims to develop wind energy projects across the country and increase the share of wind energy in the national energy mix. Several wind energy projects have been proposed, including a large-scale wind farm in Akkar that would have a capacity of 200 MW.

To further support the development of wind energy in Lebanon, the government is working on updating its regulatory framework to provide more incentives and support for renewable energy projects. The government has also launched a program to install wind turbines on public buildings, such as schools and hospitals.

In conclusion, wind energy has great potential in Lebanon and can play a significant role in diversifying the country's energy mix and reducing its carbon footprint. However, the development of wind energy in Lebanon faces significant challenges, including the lack of financing, regulatory framework, and grid infrastructure. To overcome these challenges, the government and private sector must work together to develop a sustainable and renewable energy sector in Lebanon.

Figure 2.4

Deir el Ahmar Wind Turbine.



Wind Turbines

Lebanon Wind turbines are machines that convert the kinetic energy of the wind into electrical power. They have become increasingly popular in recent years due to their ability to generate renewable and clean energy. Wind turbines are used in a variety of settings, from large-scale wind farms to smaller residential applications.

Wind turbines consist of several key components, including a rotor, a generator, a gearbox, and a tower. The rotor, which is typically comprised of two or three blades, rotates as wind flows over it, turning the generator and producing electricity. The gearbox is responsible for converting the low-speed rotation of the rotor into the high-speed rotation required by the generator. The tower supports the rotor and nacelle, which houses the generator and gearbox.

Wind turbines come in a variety of sizes, ranging from small turbines designed for home use to large-scale turbines used in wind farms. The size of the turbine is typically determined by the amount of power it can generate, with larger turbines capable of producing more electricity.

The use of wind turbines has several benefits, including their ability to generate renewable energy without producing greenhouse gas emissions. They also have a relatively low environmental impact compared to other forms of energy generation, such as coal-fired power plants. In addition, wind energy is becoming increasingly cost-competitive with traditional forms of energy, making it an attractive option for energy producers. However, there are also some challenges associated with the use of wind turbines. These include their intermittent nature, as wind speeds can vary significantly, and their potential impact on wildlife and habitats.

Overall, wind turbines are a promising technology for generating clean and renewable energy. With continued innovation and development, they have the potential to play a significant role in meeting our energy needs while minimizing our impact on the environment.

Conventional Wind Turbines

Wind power has been used for centuries to power various mechanical devices, such as water pumps and mills. The first wind turbine designed to generate electricity was built in 1887 by Scottish engineer James Blyth. This early turbine was small, with a rotor diameter of only 10 meters, and produced just enough electricity to power a few light bulbs.

Over the following decades, wind turbines continued to evolve, with researchers and engineers making significant advances in their design and performance. In the 1940s and 1950s, the Danish engineer Poul La Cour developed the first large-scale wind turbines, which were used to power rural electrification efforts in Denmark.

The first commercial wind turbine was built in 1981 by the US company U.S. Wind power. This turbine had a capacity of 55 kW and a rotor diameter of 15 meters. Since then, wind turbine technology has continued to improve, with larger and more efficient turbines being developed.

Conventional wind turbines consist of a rotor, a gearbox, a generator, and a tower. The rotor is typically comprised of two or three blades, which rotate as wind flows over them. The gearbox is used to convert the low-speed rotation of the rotor into the high-speed rotation required by the generator, which produces electricity. The tower supports the rotor and nacelle, which houses the generator and gearbox.

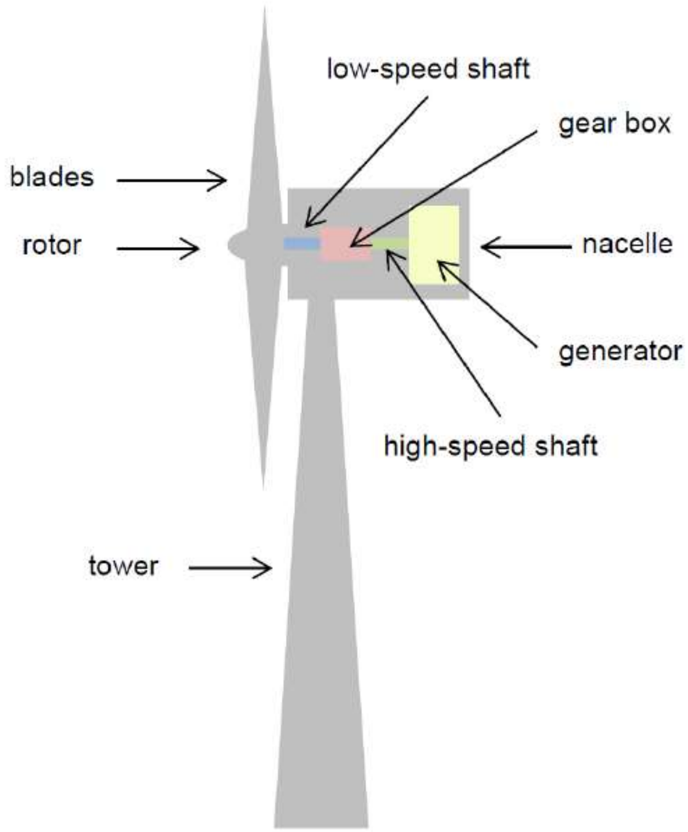
Modern wind turbines are much larger than their predecessors, with rotor diameters of up to 200 meters and power capacities of several megawatts. These large-scale turbines are typically used in wind farms, which consist of multiple turbines located in a single location. The use of wind turbines has several advantages over other forms of energy generation. Wind power is renewable and does not produce greenhouse gas emissions, making it a cleaner source of energy. It is also becoming increasingly cost-competitive with other forms of energy, such as fossil fuels.

However, wind power also has some drawbacks. Wind speeds can vary significantly, which can make wind power intermittent and difficult to predict. In addition, wind turbines can have a visual impact on landscapes and may pose a risk to wildlife, particularly birds and bats. Despite these challenges, wind power is becoming an increasingly important source of energy around the world. In 2021, wind power accounted for 7% of global electricity generation, and this is expected to increase significantly in the coming years as more wind farms are built and wind turbine technology continues to improve.

In conclusion, conventional wind turbines have a rich history that dates back to the 19th century. They have evolved significantly over the years, with modern turbines being much larger and more efficient than their predecessors. While wind power has some challenges, it is becoming an increasingly important source of clean and renewable energy around the world.

Figure 2.5

Conventional Horizontal Axis Wind Turbine



New Technology Barber Wind Turbine

The Barber Wind Turbine is a new type of wind turbine that was designed by a team of engineers led by the British inventor James Dyson. It differs from conventional wind turbines in several key ways, which makes it more efficient and potentially more cost-effective.

One of the main features of the Barber Wind Turbine is its bladeless design. Instead of using traditional blades, the turbine uses a series of curved walls to create a vortex that captures the kinetic energy of the wind. This design is more efficient than traditional wind turbines because it eliminates the need for gears and other mechanical components that can reduce efficiency and increase maintenance costs.

Another key feature of the Barber Wind Turbine is its ability to operate in low wind conditions. Conventional wind turbines require a minimum wind speed of around 3.5 meters per second to generate electricity, but the Barber Wind Turbine can operate at wind speeds as low as 1.5 meters per second. This makes it a good option for locations with lower wind speeds, such as urban environments. The Barber Wind Turbine is also designed to be quieter than traditional wind turbines. The bladeless design means there is less noise from the mechanical components, and the turbine can be positioned closer to residential areas without causing disturbance.

The turbine has been tested in several locations around the world, including the United States and the United Kingdom. In 2016, a prototype of the turbine was installed in Texas and produced electricity for the grid for the first time. The company behind the turbine, Sir James Dyson's Dyson Ltd., has plans to further develop the technology and bring it to market.

While the Barber Wind Turbine shows great promise, it is important to note that it is still in the development stage and has not yet been widely adopted. It also faces some challenges, such as the need for a high initial investment to manufacture the turbine and the potential for the vortex to become unstable in high wind conditions.

In conclusion, the Barber Wind Turbine is a promising new technology that has the potential to be more efficient, cost-effective, and quieter than traditional wind turbines. Its bladeless design and ability to operate in low wind conditions make it a good option for a variety of locations. However, more research and development are needed before the technology can be widely adopted.

Figure 2.6

Barber Wind Turbine

CHAPTER III

Methodology

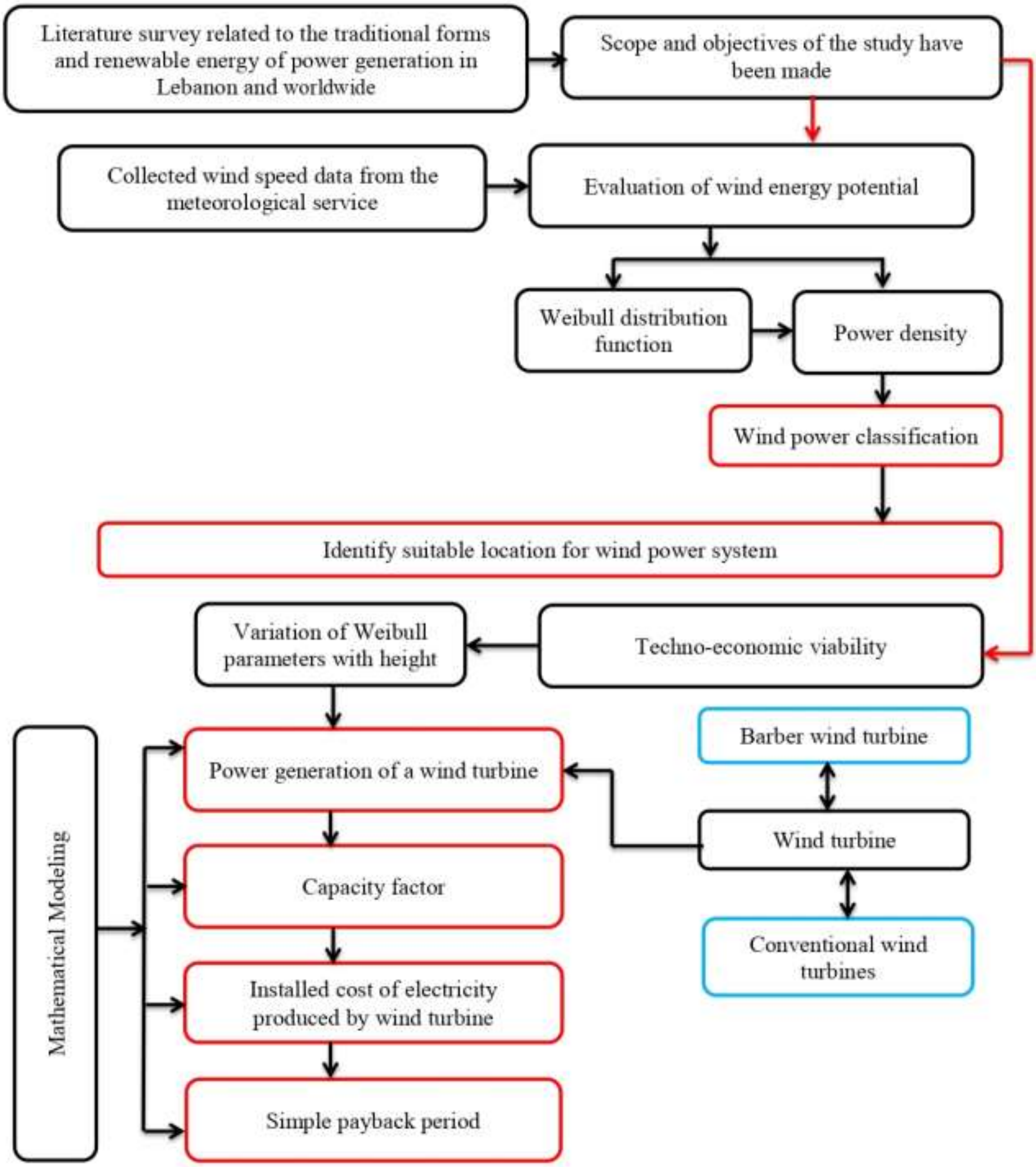
This chapter provides information about the data collection and analysis procedures as well as how the findings are analysed.

Material and Methods

In this section, the potential of wind energy is examined in 12 locations in Lebanon, with the goal of identifying suitable locations for future wind power systems. The methodology involves assessing the economic viability of these systems as well. This study's methodology is schematically shown in Figure 3.1.

Figure 3.1

Schematic Description for the Proposed Methodology.



Data and Study Area

The purpose of this study was to determine the optimal location for installing wind power systems in selected areas of Lebanon. (Table 3.1) provides an overview of the geographic details of the chosen locations. Historical data from the meteorological service was collected on a monthly basis for the period of 2010-2017.

Table 3.1

The 12 Locations' Geographical Coordinates and Altitude.

Location number	**Name of location**	**Latitude [°N]**	**Longitude [°E]**	**Elevation [m]**
Location 1	Younine	34.0776	36.2750	1198
Location 2	Birket Aarous	34.2911	36.1456	2766
Location 3	Hekr El Dahri	34.6306	36.0237	10
Location 4	Ain ed Dabaa	34.4431	35.8992	296
Location 5	Mqaybleh	34.6460	36.3577	330
Location 6	Ras Ouadi Ed Darje	34.2533	36.5775	1555
Location 7	Kfardebian	34.0017	35.8349	1670
Location 8	Qaraoun	33.5669	35.7193	913
Location 9	Khartoum	33.4079	35.3751	305
Location 10	Iskandarounah	33.1550	35.1685	53
Location 11	Beirut	33.8938	35.5018	40
Location 12	Khiam	33.3294	35.6148	697

Procedure of wind energy analysis

Accurately identifying the probability distribution of wind speed plays a crucial role in assessing the wind energy potential in a particular area. Consequently, having knowledge of the wind speed distribution at a given location is essential for determining the potential of wind speed. Researchers commonly use the two-parameter Weibull distribution to analyse the properties of wind speed. The Weibull probability density function (f(v)) and cumulative distribution function (F(v)) can be expressed as follows:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (3.1)$$

$$F(v) = 1 - exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (3.2)$$

where v is the mean wind speed in m/s, k is the shape parameter, c is the scale parameter of the Weibull distribution respectively (Sarben et al., 2020).

In order to determine the distribution parameter, maximum likelihood (ML) method is used to determine the k (Eq. (3.3)) and c (Eq. (3.4)) (Guarienti et al., 2020).

$$k = \left(\frac{\sum_{1}^{n} v_i^k ln(v_i)}{\sum_{1}^{n} v_i^k} - \frac{\sum_{1}^{n} ln(v_i)}{n}\right)^{-1} \quad (3.3)$$

$$c = \left(\frac{1}{n}\sum_{1}^{n} v_i^k\right)^{1/k} \quad (3.4)$$

In addition, to estimate the average wind speed and standard deviation of the wind speed, respectively Eqs. (3.5) and (3.6) were utilized.

$$v_m = c\Gamma\left(1 + \frac{1}{k}\right) \tag{3.5}$$

$$\sigma = \sqrt{c^2\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]} \tag{3.6}$$

Wind power density

To estimate the potential of wind energy, Eq. (3.7) is utilized to calculate the wind power density (WPD) at a certain location.

$$\left(\frac{P}{A}\right)_W = \frac{1}{2}\rho c^3\Gamma\left(1 + \frac{3}{k}\right) \tag{3.7}$$

Additionally, according to (Kassem et al., 2021) the average value of WPD can be calculated applying the following expression Eqs. (3.8-3.10).

$$\frac{P}{A} = \frac{1}{2}\rho v^3 \tag{3.8}$$

$$\frac{P}{A} = \frac{1}{2}\rho v^3 f(v) \tag{3.9}$$

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho \bar{v}^3 \tag{3.10}$$

where P is wind power density in W, $\bar{P}$ is mean wind power density in W, A is swept area in m^2, ρ is the air density in kg/m^3, $f(v)$ is the probability density function (PDF), and $\bar{v}$ is the mean wind speed in m/s.

Wind speed data extrapolation at different hub heights

Typically, wind speed is measured at a distance of 10 meters from the ground. According to (Kassem et al., 2018) In order to generate energy from wind turbines, it's crucial to calculate wind speed at different hub heights using the Equation.

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^{\frac{0.37-0.088ln(v_{10})}{1-0.088ln(z_{10}/10)}} \tag{3.11}$$

where v is the wind speed at the wind turbine hub height z, v_{10} is the wind speed at the original height z_{10}.

Energy output from wind turbine

According to (Kassem et al., 2018) the total energy output of a wind turbine (E_{out}) can be calculated using Eq. (3.12)

$$E_{out} = \sum_{i=1}^{n} \mathrm{P_{out}}\, t \tag{3.12}$$

where t is time and $\mathrm{P_{out}}$is to be estimated using Eq. (3.13)

$$P_{out} = \begin{cases} 0 & when\ v < v_{ci} \\ \dfrac{P_R v_{ci}^k}{v_{ci}^k - v_R^k} + \left(\dfrac{P_R}{v_R^k - v_{ci}^k}\right) v^k & when\ v_{ci} \le v \le v_R \\ P_R & when\ v_R \le v \le v_{co} \\ 0 & when\ v > v_{co} \end{cases} \tag{3.13}$$

where P_R is the rated power of the wind turbine and v_{ci} turbine's cut-in speed, v_{co} turbine's cut-off speed, and v_R rated wind speed of the wind turbine.

In addition, the average power generation of the turbine can be calculated using the following equation according to (Bilir et al., 2015)

$$P_{out} = P_R \left[\frac{exp\left[-\left(\frac{v_{ci}}{c}\right)^k\right] - exp\left[-\left(\frac{v_R}{c}\right)^k\right]}{\left(\frac{v_R}{c}\right)^k - \left(\frac{v_{ci}}{c}\right)^k} - exp\left[-\left(\frac{v_{co}}{c}\right)^k\right] \right] \tag{3.14}$$

Additionally, the capacity factor (CF) of a wind turbine can be determined by Eq. (3.15) as concluded by (Kassem et al., 2018).

$$CF = \frac{E_{out}}{8760 P_R} \tag{3.15}$$

In this research, different wind turbines were utilized as the load profile for every month of the year. Table 3.3 shows that nine wind turbines were selected, which have different characteristics such as the capital cost of acquisition (CC) and O&M cost (OMC) Table 3.3. Usually, conventional wind turbines (CWTs) are designed to generate electricity at high wind speeds, with their cut-in speed and rated wind speed ranging between 3-5m/s and 12-15m/s, respectively (Rehman et al.2018). Furthermore, CWTs are heavy and costly to procure, install, and maintain. As a result, the performance of Ferris wheel wind turbine (FWWT) is compared with chosen CWTs in this study because of its many advantages such as its lightweight design and ability to generate power with lower weight to power ratios, among others according to (Adeyeye et al. 2021).

Table 3.2

Selected Wind Turbines.

Model No.	**Wind turbine model**	**Manufacture**
Model#1	Enercon E5	Enercon GmbH
Model#2	Enercon E44	Enercon GmbH
Model#3	EWT DW61	Emergya Wind Technologies B.V.
Model#4	GE SLE 1.5	Winergy/Eickhoff/Bosch.
Model#5	AN Bonus 1 MW/54	Siemens Wind Power A/S
Model#6	DEWIND-62-91.5 m	DeWind
Model#7	Neg-Micon	NEG Micon A/S
Model#8	Vestas-V66	Vestas Wind Systems A/S
Model#9	Barber wind turbine	BarberWind Turbines

Table 3.3

Characteristics and Specifications of the Selected Wind Turbine.

Model No.	**HH [m]**	P_R **[kW]**	v_{ci} **[m/s]**	v_R **[m/s]**	v_{co} **[m/s]**	**CC [USD]**	**OMC [USD/y]**
Model#1	76	800	3	13	25	1750000	51250
Model#2	55	900	3	16.5	34	2337500	51250
Model#3	69	900	2.5	10	25	1918770	57158
Model#4	85	1500	3	14	25	3375000	57158
Model#5	50	1000	3	15	25	863530	25043
Model#6	91.5	1000	2.5	11.5	23	1124758	32618
Model#7	70	1000	4	14	20	1162460	33711
Model#8	67	1650	4	16	25	1768000	51272
Model#9	70	800	3	9.6	20	1400000	42000

Economic viability for wind system

The cost-effectiveness of a wind energy farm depends on its capability to produce energy at a low operating cost. This research paper utilizes the Levelized Cost of Electricity (LCOE) to compute the cost of electricity generated by the wind turbine. Eq. (3.16) is used to express the LCOE according to (Adeyeye et al. 2021).

$$LCOE = \left(\frac{\frac{i(1+i)^n}{(1+i)^n - 1}}{8760 f(v) \left[\frac{1}{2} \rho A v^3 C_p \right]} \right) \left[1 + \frac{C_{om}}{i - e} \left[1 - \left(\frac{1+e}{1+i} \right)^n \right] \right] \tag{3.16}$$

The equation consists of various parameters such as air density (ρ=1.23kg/m^3), swept area (A) in square meters, Betz limit power coefficient (C_p) which has a theoretical value of 0.59, escalation rate of operation and maintenance (e), interest rate (i), useful lifetime of the turbine in years (n), and operation and maintenance costs (C_{om}) for the first year.

Moreover Eq. (3.17) can be used to estimate the simple payback period (SPP).

$$SPP = \frac{I}{8760 f(v) \left[\frac{1}{2}\rho A v^3 C_p\right] P_e} \qquad (3.17)$$

Where I is the capital cost installed of the wind turbine in addition to the costs of civil works and P_e is the cost of electricity ($/kWh).

CHAPTER IV

Findings and Discussion

This chapter presents the findings based on the collected data.

Characteristics of wind speed

Table 4.1 summarizes the statistical description of monthly wind speed for all selected locations, which includes the mean, standard deviation (SD), coefficient of variation (CV), minimum (Min.), maximum (Max.), kurtosis (K), and Skewness (S).

The results reveal that Ain ed Dabaa has the highest mean monthly wind speed of 4.90m/s, while Khiam and Khartoum have the lowest with a value of 2.81. The monthly wind speeds of Ain ed Dabaa and Khartoum are depicted in Figure 4.1.

It can be observed that the maximum value of monthly wind speed is recorded in January with a value of 5.82m/s. For Khartoum, the highest value of 3.03m/s is recorded in June as shown in Figure 4.1. Additionally, the CV values are moderately low, ranging from 6.52% to 17.25%. Furthermore, all Skewness values for the selected locations are negative, indicating that the distributions are left skewed.

Table 4.1

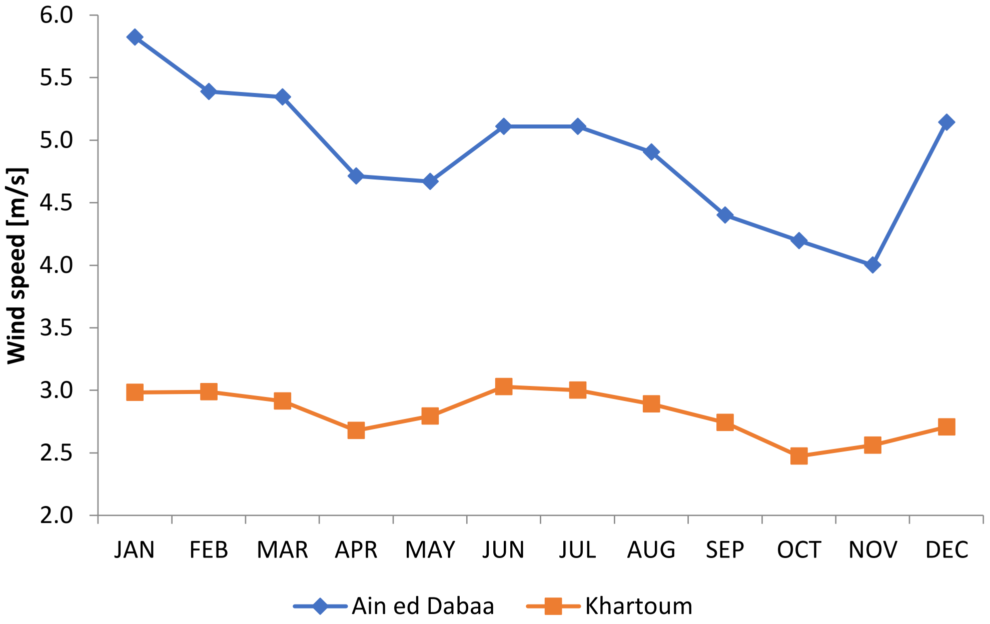
Descriptive Statistics of Wind Speed Data for All Selected Locations

Variable	**Younine**	**Birket Aarous**	**Ras Ouadi Ed Darje**
Mean	2.90	3.01	3.19
SD	0.45	0.31	0.45
CV	15.37	10.14	14.05
Min.	2.32	2.44	2.54
Max.	3.51	3.45	4.03
S	0.03	-0.56	0.52
K	-1.46	-0.26	-0.19
Variable	**Kfardebian**	**Qaraoun**	
Mean	3.48	2.86	
SD	0.41	0.19	
CV	11.66	6.52	
Min.	3.04	2.51	
Max.	4.22	3.08	
S	0.82	-0.54	
K	-0.75	-0.81	
Variable	**Khiam**	**Hekr El Dahri**	
Mean	2.81	2.91	
SD	0.18	0.30	
CV	6.52	10.14	
Min.	2.47	2.36	
Max.	3.03	3.34	
S	-0.54	-0.56	
K	-0.81	-0.26	

Variable	**Ain ed Dabaa**	**Mqaybleh**
Mean	4.90	2.91
SD	0.53	0.30
CV	10.79	10.14
Min.	4.00	2.36
Max.	5.82	3.34
S	-0.15	-0.56
K	-0.41	-0.26

Figure 4.1

Mean Monthly Wind Speed at a Height of 10m



Determination of Weibull parameters

Using the maximum likelihood approach, the Weibull distribution parameters for the selected locations were determined based on monthly wind speed data collected from meteorological services.

Figure 4.2 presents the calculated shape (k) and scale (c) for all selected locations at a height of 10m, with the value of k ranging from 5.99 to 15.45 and an average of 10.49. Additionally, the annual value of c was estimated to be within the range of 2.88-5.04m/s with an average value of 3.32m/s.

The mean wind speed and standard deviation (SD) of the wind speed were also calculated using Eq. (3.3) and Eq. (3.4) and shown in Figure 4.3. It can be observed that the mean wind speed and SD ranged from 2.78-4.8m/s and 0.22-0.63m/s, respectively.

Furthermore, the PDF illustrates the frequency of observing different levels of wind speed and can be used to estimate the prevailing wind speed at a given location. The wind speed at which the distribution curve peaks represent the most frequently observed wind speed for the location. Figure 4.4 displays the PDF for all selected locations.

Figure 4.2

Weibull Parameters for all Selected Locations at a Height of 10m.

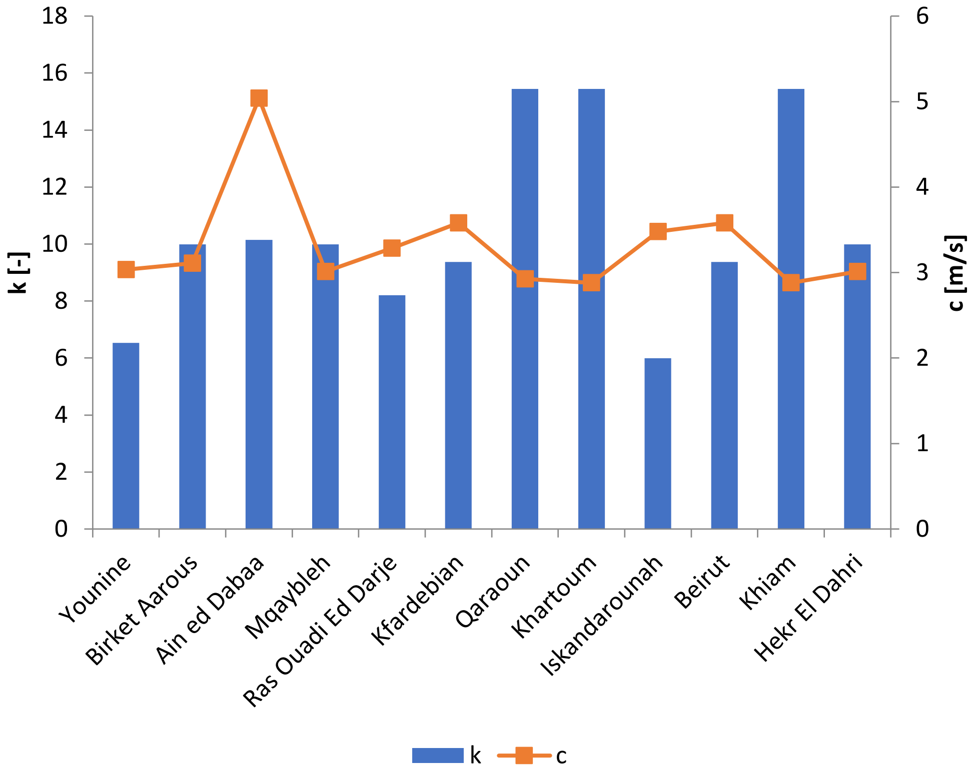


Figure 4.3

Mean Wind Speed and Standard Deviation.

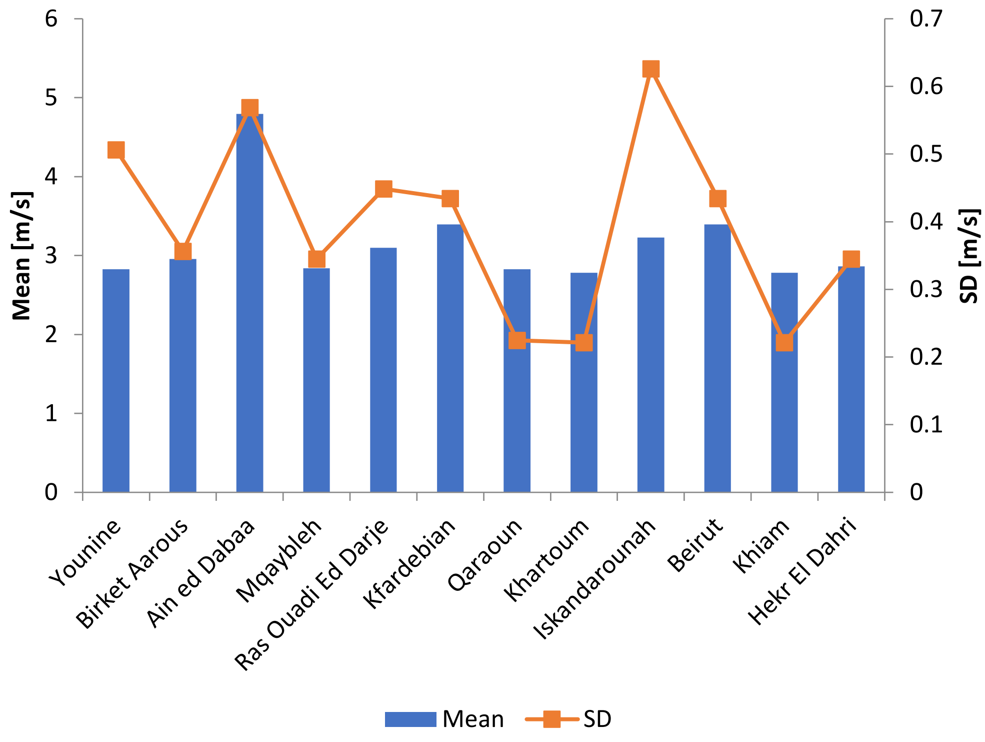
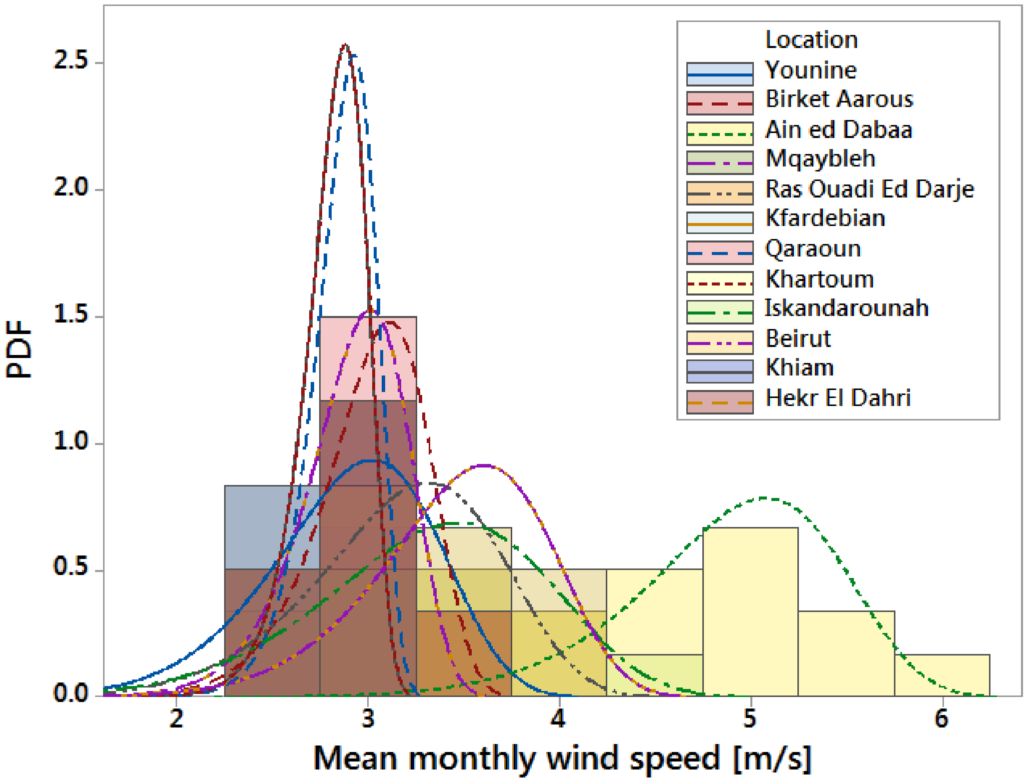


Figure 4.4

The Probability Density Function for all Selected Locations.



Wind power density

In order to assess the wind potential of the selected locations, the annual wind power density was calculated using Eq. (3.7). The results of the WPD calculation for each location are presented in Figure (4.5), with values ranging from 13.18W/m2 to 67.44W/m2 and an average value of 21.03W/m2. Based on these values, the wind energy generation potential of these locations falls into the class 1 (Poor) category, as shown in Table (4.2). Therefore, small-scale wind turbines would be suitable for harnessing the available wind energy potential in these areas. However, it can be concluded that high-capacity wind turbines (MWs) with a height of 90m or more may be appropriate for collecting the wind energy potential in the selected locations. This was investigated using the power-law method, whereby the data collected at a height of 10m was extrapolated to a height of 90m, which is the height at which most 1MW or larger wind turbines are installed.

Figure 4.5

The Annual Value of Wind Power Density for all Selected Locations.

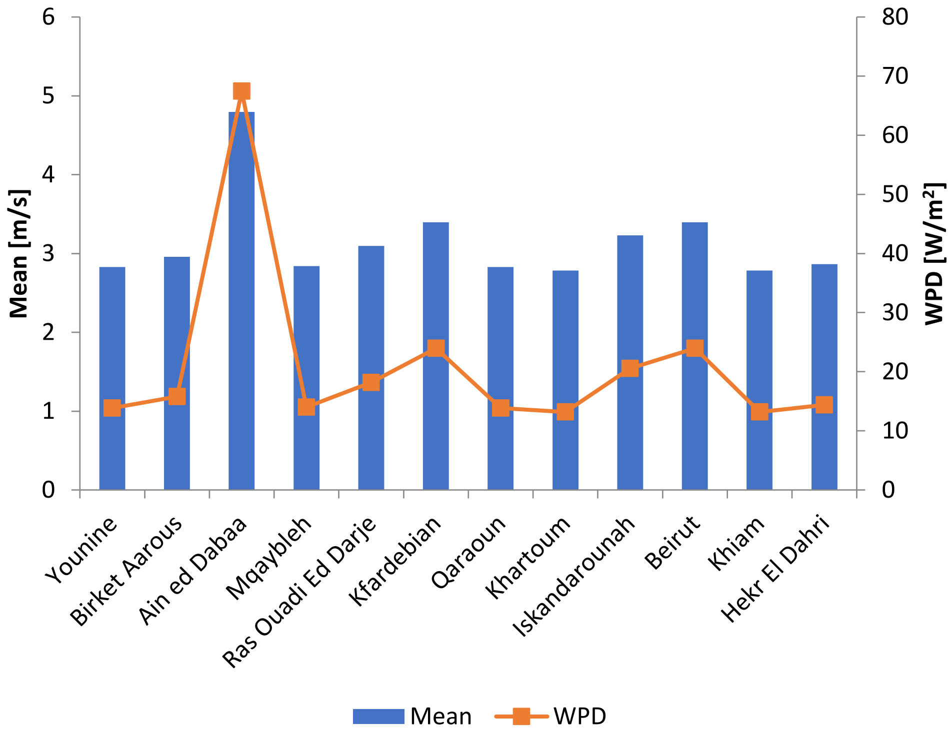


Table 4.2

Classification of Wind Power at a Hight of 10m.

Power class	$\bar{P}$**[W/m²]**
1 (Poor)	≤100
2 (Marginal)	≤150
3 (Moderate)	≤200
4 (Good)	≤250
5 (Excellent)	≤300
6 (Excellent)	≤400
7 (Excellent)	≤1000

Economic analysis

In the previous discussion, a total of nine wind turbines with differing characteristics were chosen, and the wind speed at different hub heights was calculated with the help of Eq. (3.11). For instance, Figures (4.6) to (4.8) portrays the wind speed's monthly variation at various hub heights for three selected locations Younine, Ain ed Dabaa and Khartom, respectively. The graph illustrates that as the hub height of the wind turbine increases, the wind speed also increases.

The main objective is to analyse the effectiveness of wind energy in Sudan's regions, and to accomplish this, nine wind turbines with varying rated power were chosen. The goal is to find the best match between the wind regime and the chosen turbines. In order to determine the economic feasibility, the cost of electricity per kilowatt-hour in Lebanon, the annual interest rate, the capital cost of acquisition, operation, and maintenance expenses of wind turbines, as well as the turbines' lifespan, are all important factors. These values were obtained from previous research studies, global petrol prices, and trading economics.

Furthermore, the selected turbine's annual energy production (AEP) and capacity factor (CF) were computed using Eqs. (3.12) and (3.15), respectively. Additionally, the electricity generated cost (EGC) and simple payback period (SPP) were calculated using Eqs. (3.16) and (3.17), respectively.

Figure 4.6

Monthly Average Wind Speed for Younine at Various Hub Heights.

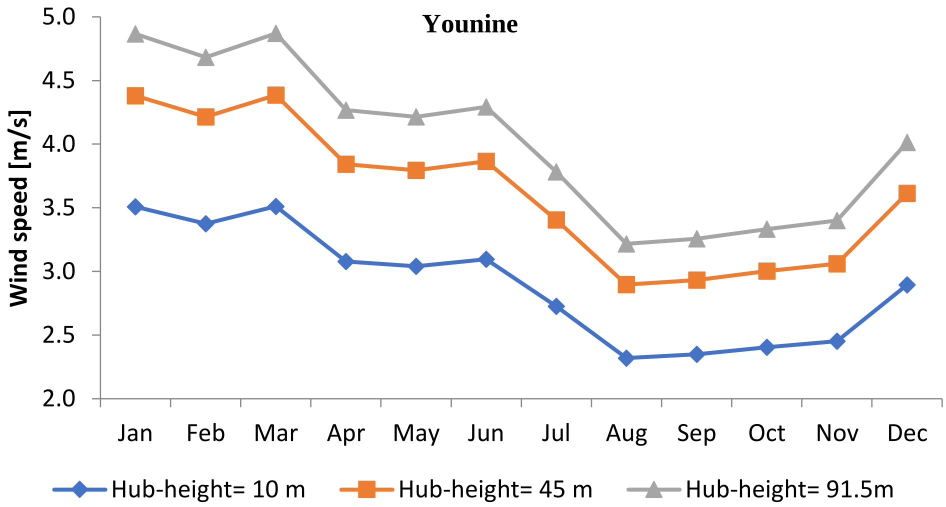


Figure 4.7

Monthly Average Wind Speed for Ain ed Dabaa at Various Hub Heights.

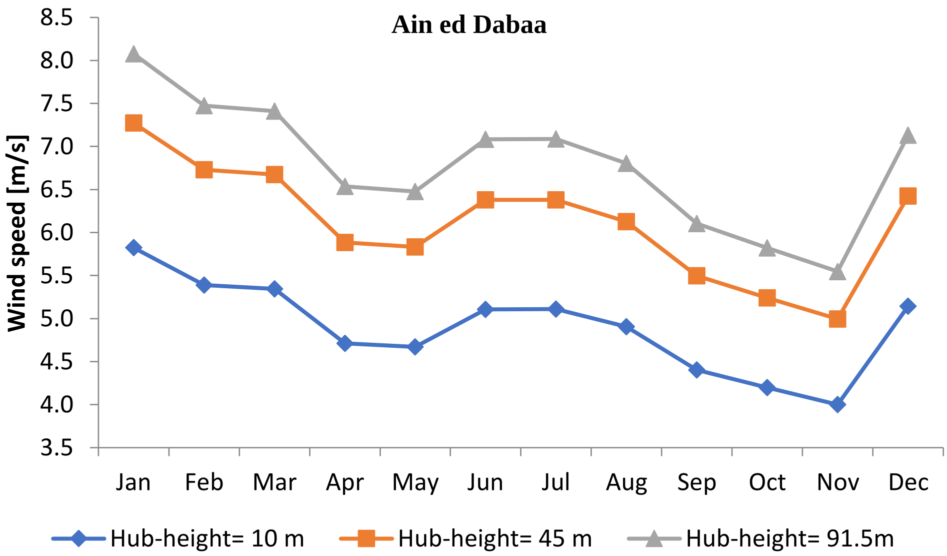
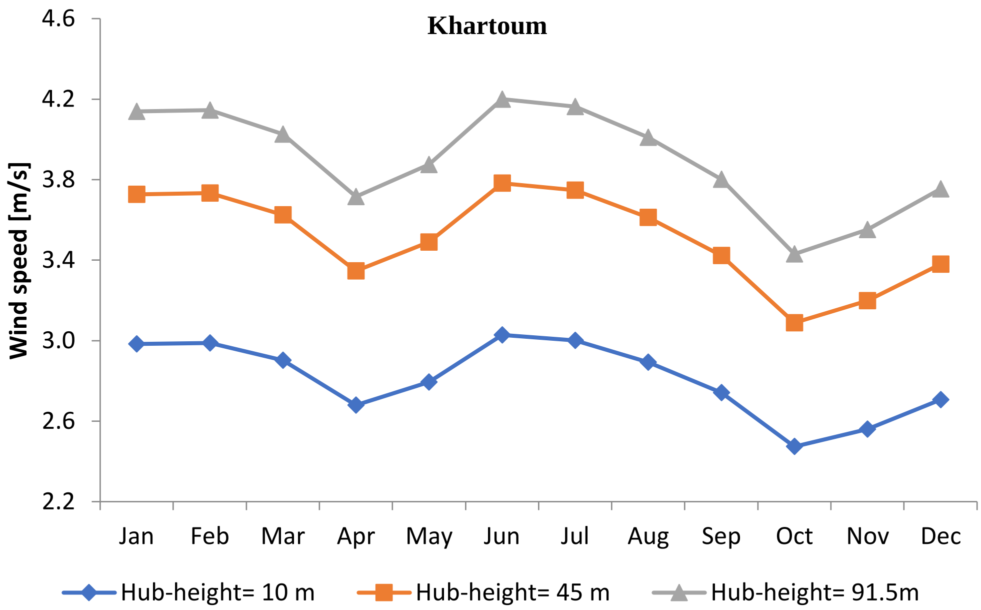


Figure 4.8

Monthly Average Wind Speed for Khartom at Various Hub Heights.



In Figures (4.9) to (4.12), the annual energy production (AEP), capacity factor (CF), electricity generated cost (EGC), and simple payback period (SPP) for all the chosen locations are shown, respectively. The estimated results indicate that the AEP values range from 339.55MWh to 5017.35MWh, with an average value of 1241.875MWh. The highest and lowest AEP values were found in Ain ed Dabaa and Khartoum, respectively, for a hub height of 91.5m (Model#6) and 55m (Model#2).

Figure 4.9

The Estimated Results of AEP for all Selected Locations.

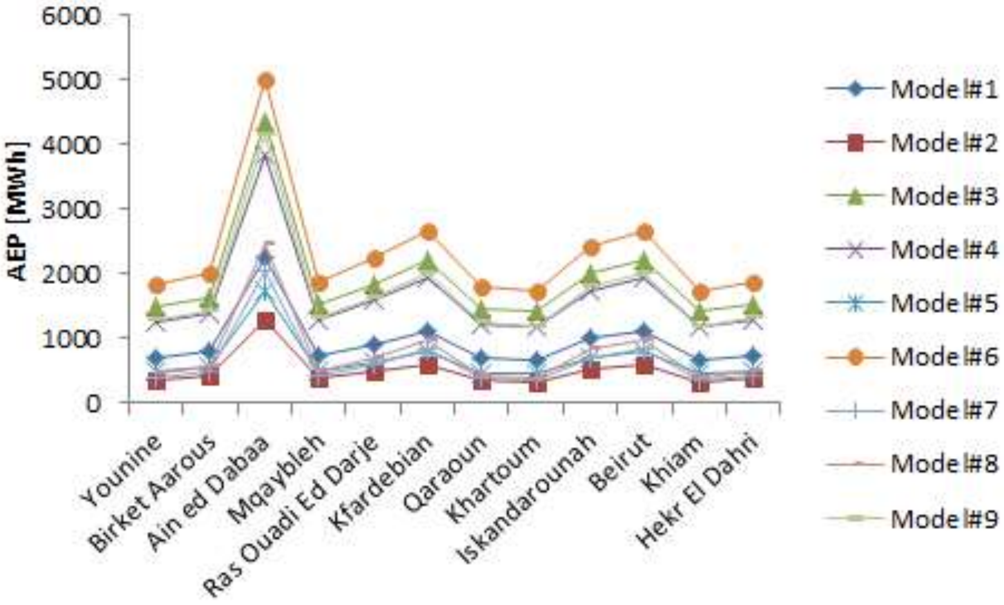


Figure 4.10

The Estimated Results of CF for all Selected Locations.

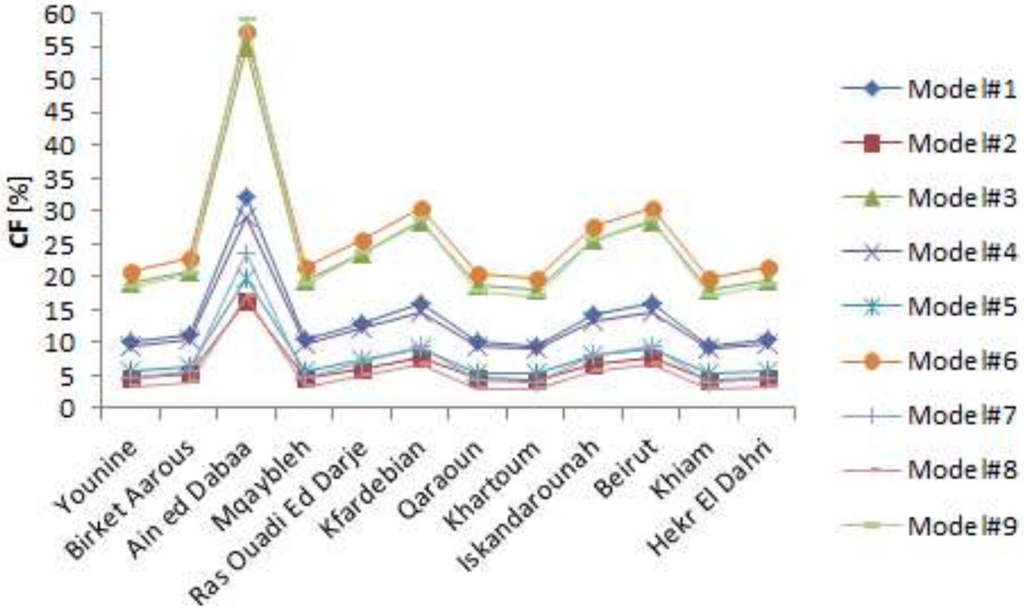


Figure 4.11

The Estimated Results of EGC for all Selected Locations.

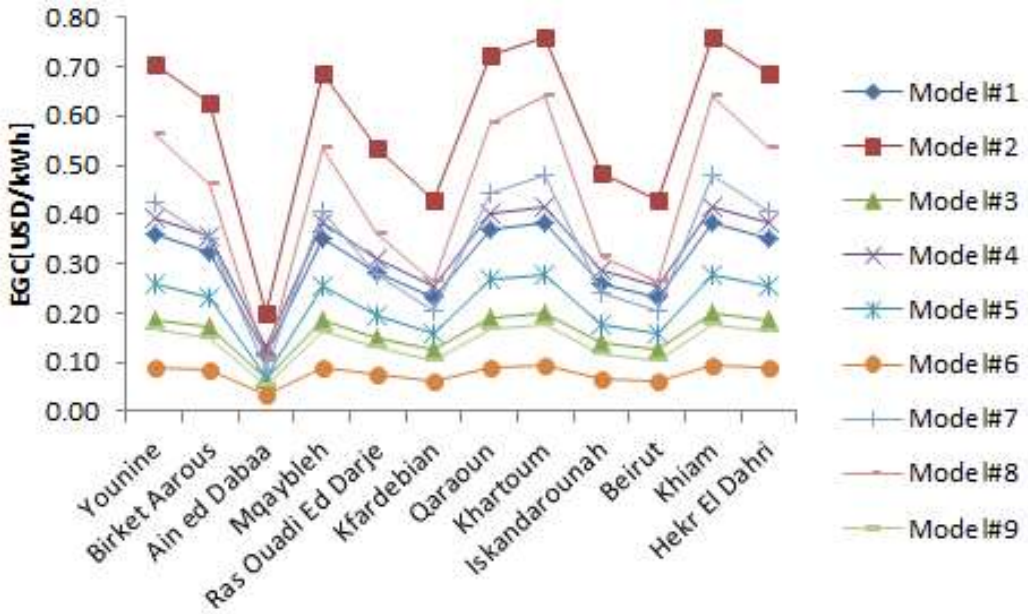
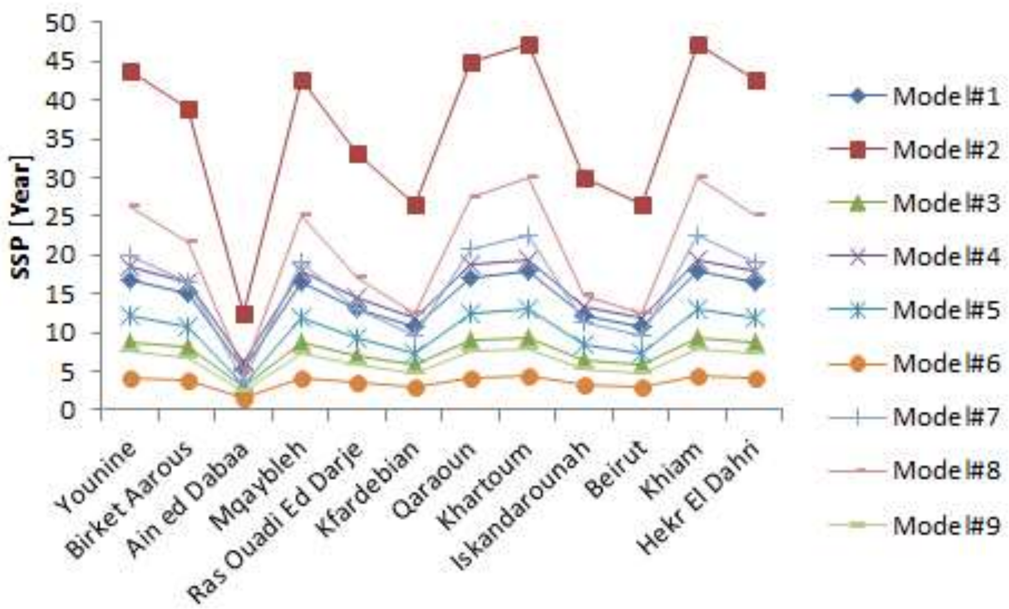


Figure 4.12

The Estimated Results of SSP for all Selected Locations.



In the study, the highest and lowest values of capacity factor (CF) were found to be 59.23% (Ain ed Dabaa) and 2.79% (Khiam), respectively, with an average value of 14.28%. The energy generation cost (EGC) values were found to be in the range of 0.033-0.761 USD/kWh, with an average value of 0.287 USD/kWh. The shortest payback period of 1.54 years was observed at Ain ed Dabaa for a hub height of 91.5m (Model#6). Allouhi et al. (2020) have analysed wind farm performance and have found similar results. For instance, the CF values ranged from 31.1-49% and 37.3-56.6% for 50m and 75m hub-height turbines, respectively, and the payback period for different wind farms with a capacity of 100MW ranged from 6.34-27.3 years.

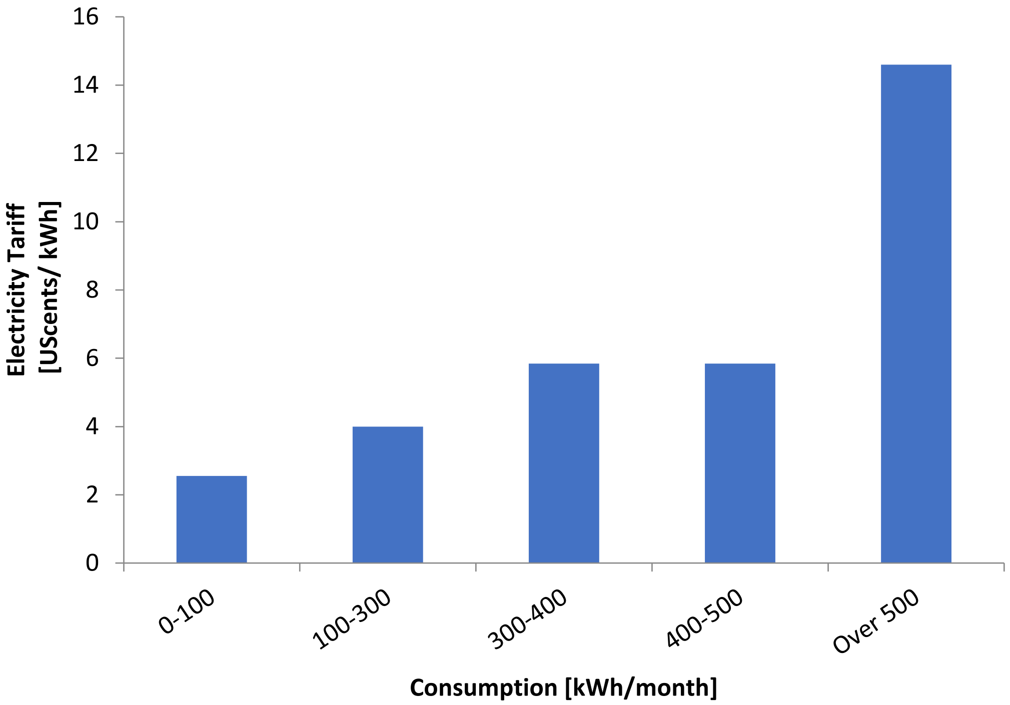
Rehman et al. (2018) concluded that when the value of specific power production (SPP) exceeds the assumed lifetime of the wind turbine, it is not economically viable to install wind turbines in that location for that particular wind turbine model. SPP values for small and medium-scale wind turbines are generally within the range of 5-12 years.

Based on these results, and Adeyeye et al. (2021) that BWTs are competitive compared to CWTs, especially at locations with low wind conditions. Although Model#6 has a lower EGC in all selected locations, Model#9 has a robust design and a wider range of applications for all classes of wind resources, making it more cost-effective in the long run.

The study also suggests that FWWT technology is a strong candidate for increasing the availability of economic, green, and sustainable energy in Lebanon according to Ucar et al. (2019). Finally, the developed systems provide valuable insight into the economic feasibility of wind energy in Lebanon, and wind energy could help alleviate the chronic lack of electricity and reduce the electricity bill in the country.

Figure 4.13

The Electricity Tariff in Lebanon.



CHAPTER V

Conclusion and Recommendations

This study investigated the potential and validity of wind power in 11 selected locations in Lebanon. Lebanon is currently facing a severe crisis in both water and electricity supply, and the government's efforts to provide affordable and accessible electricity are being outpaced by the growing challenges faced by the population and energy sectors.

In order to address this issue, wind energy has emerged as a potential alternative solution for household electricity supply. To this end, it is crucial to develop roadmaps that can help reduce the impact of global warming and promote sustainable technological development.

This research also presents a techno-economic model that assesses wind energy in twelve locations in Lebanon, comparing the performance of the Barber wind turbine (Model#9), a new wind technology, to conventional wind turbines under the same economic conditions. The study finds that the Barber wind turbine (Model#9) is highly competitive for low wind speed conditions when compared to eight commercial wind turbines, which can encourage stakeholders in the renewable energy sector to provide support mechanisms for the adoption of large-scale and small-scale wind systems in the country.

The adoption of wind energy can have numerous benefits for Lebanon beyond addressing the current electricity crisis. For one, it can help reduce the country's reliance on fossil fuels, which are not only a major contributor to global warming but also subject to price volatility in the international market. Additionally, the development of wind energy infrastructure can create job opportunities and stimulate local economic growth. Furthermore, wind energy can increase energy security, particularly in remote or rural areas where grid connection may not be feasible or cost-effective. By diversifying the country's energy mix and reducing its dependence on imported fossil fuels, wind energy can also help Lebanon achieve its climate commitments and contribute to global efforts to combat climate change.

However, there are also challenges that need to be addressed in the development of wind energy in Lebanon. One major obstacle is the lack of a supportive policy framework, including feed-in tariffs and other incentives to encourage investment in renewable energy. The absence of clear regulations and procedures for obtaining permits and licenses can also hinder the development of wind energy projects. Additionally, there is a need to address issues related to the integration of wind energy into the existing electricity grid, including system stability and reliability.

Overall, the adoption of wind energy has the potential to provide numerous benefits for Lebanon, from addressing the current electricity crisis to promoting sustainable economic growth and reducing the country's reliance on fossil fuels. However, it is important for policymakers to address the challenges and provide a supportive environment for the development of wind energy infrastructure.

Limitations and Future work

In this study, it is essential to acknowledge the limitations of this work. First, the financial parameters were assumed based on historical values in the literature. Second, Limited Wind Resources: One of the major limitations for wind energy farms in Lebanon is the availability of suitable wind resources. The country's topography and geographical location result in varied wind patterns, making it challenging to identify optimal sites for wind farms. Future work could focus on conducting extensive wind resource assessments using advanced modelling techniques and deploying anemometer towers at potential locations to gather accurate wind data for informed decision-making.

Grid Integration Challenges: Integrating wind energy into the existing power grid presents another limitation. The Lebanese electricity grid infrastructure may require significant upgrades and modifications to accommodate the intermittent nature of wind power. Future research could investigate grid integration strategies, including the development of energy storage systems, smart grid technologies, and demand-response mechanisms to enhance the stability and reliability of the power system.

References

Fang, H., Li, J., & Song, W. (2018). Sustainable site selection for photovoltaic power plant: An integrated approach based on prospect theory. Energy conversion and management, 174, 755-768.
https://doi.org/10.1016/j.enconman.2018.08.092

Shorabeh, S. N., Firozjaei, M. K., Nematollahi, O., Firozjaei, H. K., & Jelokhani-Niaraki, M. (2019). A risk-based multi-criteria spatial decision analysis for solar power plant site selection in different climates: A case study in Iran. Renewable Energy, 143, 958-973.
https://doi.org/10.1016/j.renene.2019.05.063

Tercan, E., Eymen, A., Urfalı, T., & Saracoglu, B. O. (2021). A sustainable framework for spatial planning of photovoltaic solar farms using GIS and multi-criteria assessment approach in Central Anatolia, Turkey. Land use policy, 102, 105272.
https://doi.org/10.1016/j.landusepol.2020.105272

Memon, B., Baloch, M. H., Memon, A. H., Qazi, S. H., Haider, R., & Ishak, D. (2019). Assessment of wind power potential based on Raleigh distribution model: an experimental investigation for coastal zone. Engineering, Technology & Applied Science Research, 9(1), 3721-3725.

Kassem, Y., Gökçekuş, H., & Lagili, H. S. A. (2021). A techno-economic viability analysis of the two-axis tracking grid-connected photovoltaic power system for 25 selected coastal mediterranean cities. Engineering, Technology & Applied Science Research, 11(4), 7508-7514.
https://doi.org/10.48084/etasr

Elmahmoudi, F., Abra, O. E. K., Raihani, A., Serrar, O., & Bahatti, L. (2020). Elaboration of a wind energy potential map in morocco using gis and analytic hierarchy process. Engineering, Technology & Applied Science Research, 10(4), 6068-6075. https://doi.org/10.48084/etasr

Olabi, A. G., & Abdelkareem, M. A. (2022). Renewable energy and climate change. Renewable and Sustainable Energy Reviews, 158, 112111.https://doi.org/10.1016/j.rser.2022.112111

Yadav, S. K., & Bajpai, U. (2018). Performance evaluation of a rooftop solar photovoltaic power plant in Northern India. Energy for Sustainable Development, 43, 130-138. https://doi.org/10.1016/j.esd.2018.01.006

El Khchine, Y., Sriti, M., & Elyamani, N. E. E. K. (2019). Evaluation of wind energy potential and trends in Morocco. Heliyon, 5(6), e01830. https://doi.org/10.1016/j.heliyon.2019.e01830

Mansouri Kouhestani, F., Byrne, J., Johnson, D., Spencer, L., Hazendonk, P., & Brown, B. (2019). Evaluating solar energy technical and economic potential on rooftops in an urban setting: the city of Lethbridge, Canada. International Journal of Energy and Environmental Engineering, 10(1), 13-32. https://doi.org/10.1007/s40095-018-0289-1

AlQdah, K. S., Alahmdi, R., Alansari, A., Almoghamisi, A., Abualkhair, M., & Awais, M. (2021). Potential of wind energy in Medina, Saudi Arabia based on Weibull distribution parameters. Wind Engineering, 45(6), 1652-1661. https://doi.org/10.1177/0309524X211027356

Chahine, R. B. Energy Strategy to Supply Electric Demands in Politically Unstable Developing Countries (Lebanon Case Study).

Council for Development and Reconstruction. (2016). Physical Infrastructure - Electricity Sector Over- view. http://www.cdr.gov.lb/eng/progress_reports/pr102016/Eelec.pdf

Wehbe, N. (2020). Optimization of Lebanon's power generation scenarios to meet the electricity demand by 2030. The Electricity Journal, 33(5), 106764. https://doi.org/10.1016/j.tej.2020.106764

Farhat, R. A., Mahlooji, M., Gaudard, L., El-Baba, J., Harajli, H., Kabakian, V., & Madani, K. (2020). A Multi-attribute Assessment of Electricity Supply Options in Lebanon. In Food-Energy-Water Nexus Resilience and Sustainable Development (pp. 1-27). Springer, Cham. https://doi.org/10.1007/978-3-030-40052-1_1

Kassem, Y., Gökçekuş, H., & Janbein, W. (2021). Predictive model and assessment of the potential for wind and solar power in Rayak region, Lebanon. Modeling Earth Systems and Environment, 7(3), 1475-1502. https://doi.org/10.1007/s40808-020-00866-y

Kinab, E., & Elkhoury, M. (2012). Renewable energy use in Lebanon: Barriers and solutions. Renewable and Sustainable Energy Reviews, 16(7), 4422-4431. https://doi.org/10.1016/j.rser.2012.04.030

Moore, H. L., & Collins, H. (2020). Decentralised renewable energy and prosperity for Lebanon. Energy Policy, 137, 111102. https://doi.org/10.1016/j.enpol.2019.111102

Al Zohbi, G., Hendrick, P., & Bouillard, P. (2015). Wind characteristics and wind energy potential analysis in five sites in Lebanon. International journal of hydrogen energy, 40(44), 15311-15319. https://doi.org/10.1016/j.ijhydene.2015.04.115

Kassem, Y., Gökçekuş, H., & Zeitoun, M. (2019). Modeling of techno-economic assessment on wind energy potential at three selected coastal regions in Lebanon. Modeling Earth Systems and Environment, 5(3), 1037-1049. https://doi.org/10.1007/s40808-019-00589-9

Elkhoury, M., Nakad, Z., & Shatila, S. (2010). The assessment of wind power for electricity generation in Lebanon. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 32(13), 1236-1247. https://doi.org/10.1080/15567030802706754

El-Ali, A., Moubayed, N., & Outbib, R. (2007, October). Comparison between solar and wind energy in Lebanon. In 2007 9th International Conference on Electrical Power Quality and Utilisation (pp. 1-5). IEEE. https://doi.org/ 10.1109/EPQU.2007.4424155

Kassem, Y., Gökçekuş, H., & Janbein, W. (2021). Predictive model and assessment of the potential for wind and solar power in Rayak region, Lebanon. Modeling Earth Systems and Environment, 7(3), 1475-1502. https://doi.org/ 10.11648/j.ajme.20160205.12

Elkhoury, M., Nakad, Z., & Shatila, S. (2010). The assessment of wind power for electricity generation in Lebanon. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 32(13), 1236-1247. https://doi.org/10.1080/15567030802706754

Al Zohbi, G., Hendrick, P., & Bouillard, P. (2018). Assessment of wind energy potential in Lebanon. Research In Marine Sciences, 3(4), 401-414.

Gökçekuş, H., Kassem, Y., & Al Hassan, M. (2019). Evaluation of wind potential at eight selected locations in Northern Lebanon using open-source data. Int J Appl Eng Res, 14(11), 2789-2794.

Kassem, Y., Çamur, H., Abdalla, M. A. H. A., Erdem, B. D., & Al-ani, A. M. R. (2021). Evaluation of wind energy potential for different regions in Lebanon based on NASA wind speed database. In IOP Conference Series: Earth and Environmental Science (Vol. 926, No. 1, p. 012093). IOP Publishing. https://doi.org/10.48084/etasr

Serban, A., Paraschiv, L. S., & Paraschiv, S. (2020). Assessment of wind energy potential based on Weibull and Rayleigh distribution models. Energy Reports, 6, 250-26 https://doi.org/10.1016/j.egyr.2020.08.048

Guarienti, J. A., Almeida, A. K., Neto, A. M., de Oliveira Ferreira, A. R., Ottonelli, J. P., & de Almeida, I. K. (2020). Performance analysis of numerical methods for determining Weibull distribution parameters applied to wind speed in Mato Grosso do Sul, Brazil. Sustainable Energy Technologies and Assessments, 42, 100854.
https://doi.org/10.1016/j.seta.2020.100854

Kassem, Y., Al Zoubi, R., & Gökçekuş, H. (2019). The possibility of generating electricity using small-scale wind turbines and solar photovoltaic systems for households in Northern Cyprus: a comparative study. *Environments*, 6(4), 47.
https://doi.org/10.3390/environments6040047

Kassem, Y., Çamur, H., & Aateg, R. A. F. (2020a). Exploring solar and wind energy as a power generation source for solving the electricity crisis in libya. *Energies*, 13(14), 3708. https://doi.org/10.3390/en13143708

Alayat, M. M., Kassem, Y., & Çamur, H. (2018). Assessment of wind energy potential as a power generation source: A case study of eight selected locations in Northern Cyprus. Energies, 11(10), 2697.
https://doi.org/10.3390/en11102697

Bilir, L., İmir, M., Devrim, Y., & Albostan, A. (2015). An investigation on wind energy potential and small-scale wind turbine performance at İncek region–Ankara, Turkey. Energy Conversion and Management, 103, 910-923.
https://doi.org/10.1016/j.enconman.2015.07.017

Rehman, S., Alam, M. M., Alhems, L. M., & Rafique, M. M. (2018). Horizontal axis wind turbine blade design methodologies for efficiency enhancement—A review. Energies, 11(3), 506.
https://doi.org/10.3390/en11030506

American Wind Energy Association. (2012). Size specifications of common industrial wind turbines. Technical Specifications of Common Large Wind Turbines.

Kassem, Y., Gökçekuş, H., & Zeitoun, M. (2019). Modeling of techno-economic assessment on wind energy potential at three selected coastal regions in Lebanon. *Modeling Earth Systems and Environment*, 5(3), 1037-1049. https://doi.org/10.1007/s40808-019-00589-9

Adeyeye, K. A., Ijumba, N., & Colton, J. S. (2021). A Techno-Economic Model for Wind Energy Costs Analysis for Low Wind Speed Areas. Processes, 9(8), 1463. https://doi.org/10.3390/pr9081463

Ucar, A., & Balo, F. (2009). Investigation of wind characteristics and assessment of wind-generation potentiality in Uludağ-Bursa, Turkey. Applied energy, 86(3), 333-339. https://doi.org/10.1016/j.apenergy.2008.05.001

Khan, M. A., Çamur, H., & Kassem, Y. (2019). Modeling predictive assessment of wind energy potential as a power generation sources at some selected locations in Pakistan. *Modeling Earth Systems and Environment*, 5(2), 555-569. https://doi.org/10.1007/s40808-018-0546-6

Tester, J. W., Drake, E. M., Driscoll, M. J., Golay, M. W., & Peters, W. A. (2012). Sustainable energy: choosing among options. MIT press.

Langodan, S., Viswanadhapalli, Y., Dasari, H. P., Knio, O., & Hoteit, I. (2016). A high-resolution assessment of wind and wave energy potentials in the Red Sea. *Applied energy*, 181, 244-255.
https://doi.org/10.1016/j.apenergy.2016.08.076

Allouhi, A., Zamzoum, O., Islam, M. R., Saidur, R., Kousksou, T., Jamil, A., & Derouich, A. (2017). Evaluation of wind energy potential in Morocco's coastal regions. Renewable and Sustainable Energy Reviews, 72, 311-324.
https://doi.org/10.1016/j.rser.2017.01.047

Alsaad, M. A. (2013). Wind energy potential in selected areas in Jordan. Energy Conversion and Management, 65, 704-708. https://doi.org/10.1016/j.enconman.2011.12.037

Masseran, N. (2015). Evaluating wind power density models and their statistical properties. *Energy*, 84,533-541. https://doi.org/10.1016/j.energy.2015.03.018

Ammari, H. D., Al-Rwashdeh, S. S., & Al-Najideen, M. I. (2015). Evaluation of wind energy potential and electricity generation at five locations in Jordan. Sustainable Cities and Society, 15, 135-143.

Mohammadi, K., Alavi, O., & McGowan, J. G. (2017). Use of Birnbaum-Saunders distribution for estimating wind speed and wind power probability distributions: A review. *Energy Conversion and Management*, 143,109-122. https://doi.org/10.1016/j.enconman.2017.03.083

Boccard, N. (2009). Capacity factor of wind power realized values vs. estimates. energy policy, 37(7), 2679-2688.
https://doi.org/10.1016/j.enpol.2009.02.046

IRENA, I. (2019). Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects. Abu Dhabii.

Ayodele, T. R., Jimoh, A. A., Munda, J. L., & Agee, J. T. (2014). Viability and economic analysis of wind energy resource for power generation in Johannesburg, South Africa. International Journal of Sustainable Energy, 33(2), 284-303. https://doi.org/10.1080/14786451.2012.762777

American Wind Energy Association. (2022). How a Wind Turbine Works. https://www.awea.org/wind-101/how-do-wind-turbines-work

National Renewable Energy Laboratory. (2022). Wind Energy Basics. https://www.nrel.gov/wind/wind-energy-basics.html

Union of Concerned Scientists. (2022). How Do Wind Turbines Work? https://www.ucsusa.org/resources/how-do-wind-turbines-work

Vestas. (2022). Wind Turbines. https://www.vestas.com/products/wind-turbines

Pallabazzer, R. (2003). Parametric analysis of wind siting efficiency. *Journal of Wind Engineering and Industrial Aerodynamics*, 91(11), 1329-1352. https://doi.org/10.1016/j.jweia.2003.08.002

Ohunakin, O. S., Oyewola, O. M., & Adaramola, M. S. (2013). Economic analysis of wind energy conversion systems using levelized cost of electricity and present value cost methods in Nigeria. *International Journal of Energy and Environmental Engineering*, 4(1),1-8. https://doi.org/10.1186/2251-6832-4-2

Ouarda, T. B., Charron, C., Shin, J. Y., Marpu, P. R., Al-Mandoos, A. H., Al-Tamimi, M. H., ... & Al Hosary, T. N. (2015). Probability distributions of wind speed in the UAE. *Energy conversion and management*, 93, 414-434. https://doi.org/10.1016/j.enconman.2015.01.036

Riahi, K., Van Vuuren, D. P., Kriegler, E., Edmonds, J., O'neill, B. C., Fujimori, S., ... & Tavoni, M. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Globalenvironmentalchange*, 42,153-168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

VijayaVenkataRaman, S., Iniyan, S., & Goic, R. (2012). A review of climate change, mitigation and adaptation. *Renewable and Sustainable Energy Reviews*, 16(1), 878-897. https://doi.org/10.1016/j.rser.2011.09.009

Appendices

Appendix A

Appendix X

Turnitin Similarity Report