AHSAN MEHBOOB

ANALYSIS OF WIND ENERGY POTENTIAL IN SELECTED REGIONS IN PAKISTAN

MASTER THESIS

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NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF MECHANICAL ENGINEERING

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January, 2023

Approval

We certify that we have read the thesis submitted by Ahsan Mehboob titled **"(ANALYSIS OF WIND ENERGY POTENTIAL IN SELECTED REGIONS IN PAKISTAN)"** 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.

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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.

Ahsan Mehboob

31/01/2023

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Ahsan Mehboob

Abstract

Analysis of wind energy potential in selected regions in Pakistan

Mehboob, Ahsan
MA, Department of Mechanical Engineering
January, 2023, 87 pages

The Weibull Distribution is used assessing wind speed observations and calculating wind energy potential. Wind density, speed, and energy potential may all be anticipated using the Weibull probability density function.. Measurements were gathered for wind speed at the height of 10m of 100 different locations across whole Pakistan from the year 1981 to year 2021. during this study; mean monthly wind speed, wind power density, energy , and the scale (c) and shape (k) parameters are calculated for all these cities using Weibull distribution , for the future research , academics and investing in renewable energy specially wind potential study of this paper can be helpful. NASA Satellite data is used at the selected location for wind speed data. Finally, it is determined that utilizing small-scale renewable energy systems will aid in lowering the usage of fossil fuels, reducing the impact of global warming, and advancing the nation's sustainable technological advancement. And global wind atlas map is used just to see the wind power density and mean wind speed in Pakistan

Keywords*:* Pakistan, Wind energy potential, NASA software, renewable energy, wind power density.

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List of Abbreviation

PDF:	Probability Density Function
CDF:	Cumulative Distribution Function
WPD:	Wind Power Density
NASA:	National Aeronautics and Space Administration
RE:	Renewable Energy
RES:	Renewable Energy Sources
HAWT:	Horizontal Axis Wind Turbines
VAWT:	Vertical Axis Wind Turbines
USD:	United States of America Dollar

CHAPTER I

Introduction

This chapter includes the background, purpose of the study, limitations related descriptions of the research

Background

With an increasing population, demand for energy also increases .we cannot ignore the use of energy. Continuing the advancement in industrialized countries and to develop the standard of living in developing countries whole world all the countries are looking for different options and ways to overcome the energy crises which they are facing.

Fossil fuels are the leading source for the energy which cannot be ignored. The usage of it have an adverse effect on the ecosystem and will be ended soon. So there is an urge need to make a plan and system for the usage of renewable energy

The demand for energy is growing fast. From 63 thousand terawatt-hours (TWh) to 173 thousand TWh between the years 1969 to 2019, the world's yearly energy consumption almost boosted 3 times.

Electricity consumption

About 60 percent of the world electricity comes from burning fossil fuels, including coal, gas and oil

Figure 1

Global Electricity Production

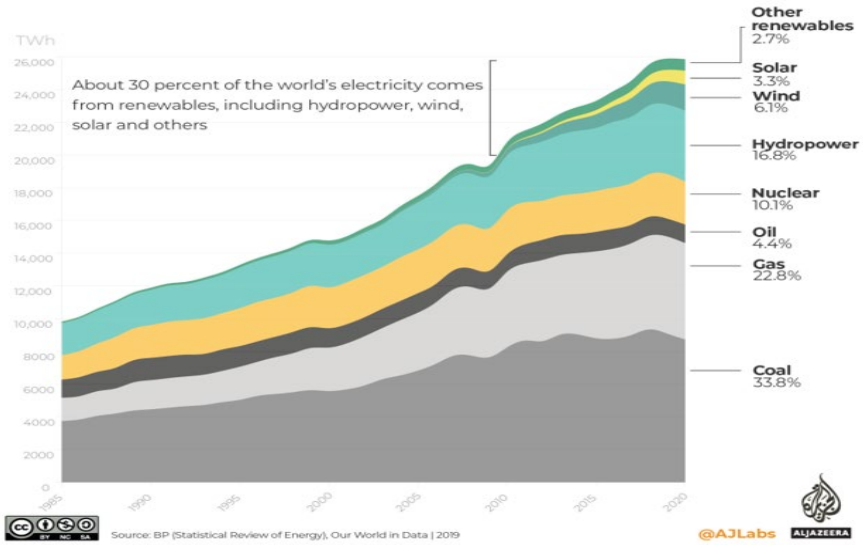


Figure 2

Electricity of Continents

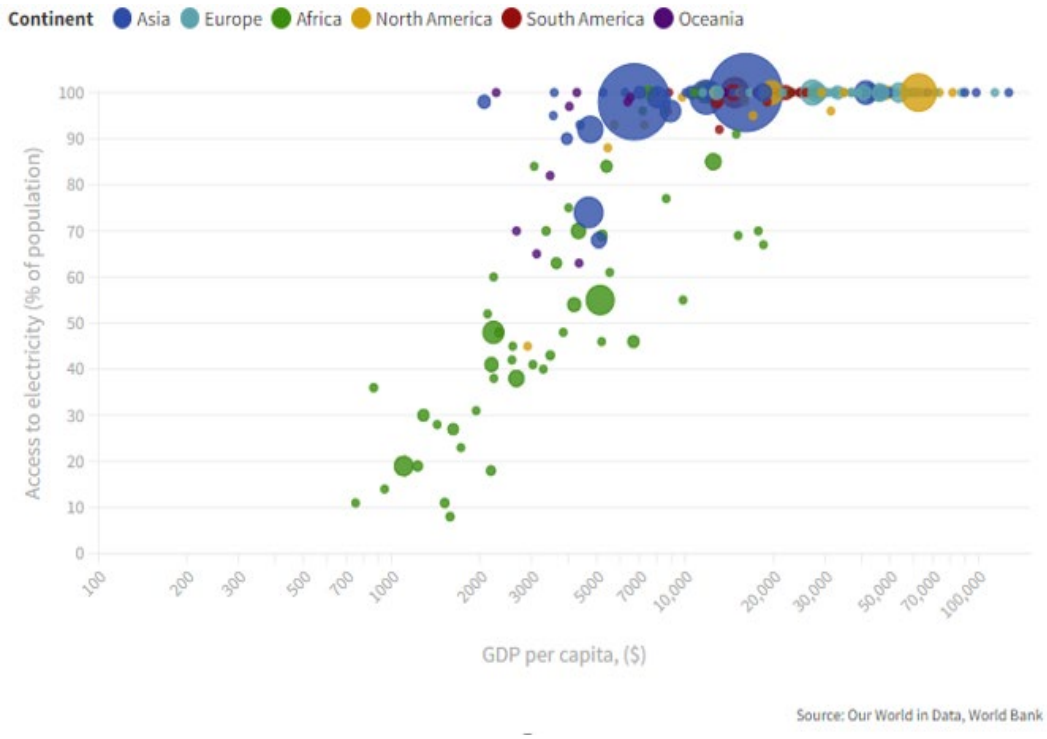


Figure 2 shows the electricity consumption of different countries combined on the basis of components. Fossil fuel is the main reason for the making energy, around 89 percent are met by non- renewable fossils fuels which includes gas, coal, oil. 9% is renewable energy and remaining is nuclear power in 2014

Economic analysis

In last 10 years, there is an increase in the investment of renewable energy worldwide (2007 to 2017). It was estimated to be $104 billion in 2007, but by 2017 it had increased to $279.8 billion. The installed renewable power generation capacity expanded to more than double from 1070 GW in 2007 to 2195 GW in 2017, thanks to this sharp increase. For sustainable vitalization and a pollution-free environment, this tendency is likely to continue. As a result, several nations have set ambitious goals for the field of renewable energy for the future years. It is necessary to develop a plan or algorithm for renewable energy sources' (RES) efficient integration into power systems due to the instability and unpredictability of meteorological conditions. In order to do this, various research articles (Amamra et al., 2017) and (Denholm et al., 2018) have been released recently.

Over $2.6 trillion was invested in renewable energy between 2010 and 2019. In two-thirds of the world, solar and wind is now more cheaper when compared with gas and coal options. Investment has increased wind and solar energy to almost 9% and more than 8%, respectively, of the world's producing capacity. (Eric Roston, Mira Rojanasakul, Paul Murray, Brittany Harris & Rutkoff, 2019).

Data released by the International Renewable Energy Agency (IRENA) states that new renewable energy project is around 163 gigawawtts much higher than any other coal options in 2021 in G20. According to IRENA usage of R.E will lower the production cost of energy globally for around 55 billion usd, the price of fossil fuel remains high .

A severe environmental issue that compromises life on Earth's surface is global warming (L. D. Burton, 2019). Another name for this process is global warming. It signifies that the planet is warming considerably and becoming more like a greenhouse, retaining heat and raising its surface temperature (Daniels, 2009). Since the middle of the 20th century, this phenomena has been plainly seen, and major efforts have been made to develop measures to stop it and lessen its detrimental effects (Caglayan et al., 2019)

Types of energies

The universe cannot exist without energy. Energy is divided into 2 categories, normal and abnormal sources. Normal energy that depends on normal sources, and abnormal energy, which depends on abnormal sources but develops over time and is influenced by a number of different elements. (Nazir et al., 2019; Paletto et al., 2019; Topcu & Tugcu, 2020). The extraction and exploitation of all of these forms of energy for human advantage requires the development of unique mechanisms, apparatus, and methods. We shall discuss renewable energy and all of its connected topics in this research topic.

R.E is energy that is utilized from the environmentals natural sources and never finishes. Wind sun and water are some options for sustainable energy. Petroleum and fossil fuels causes global warming, and also have disposable problems that causes danger to all living organisms on the earth causing them to experience numerous health issues and the emergence of numerous diseases that were not previously present, renewable energy is an environmentally friendly source of energy. Fossil fuels are the primary source of energy demand and are essential to the

global energy supply. Fossil fuels, on the other hand, have a harmful impact on the environment and are few. Therefore, it is crucial to use renewable energy sources and manage energy sources carefully. (Aynur.U 2010)

If a proper infrastructure implementation is chosen as a prospective alternative, similar to those of Ireland and Denmark, Pakistan offers a huge potential for usage of R.E sources. (Lund & Salgi, 2009) and (Lund, 2007)

U.N and world bank are working together for many years, trying to finish scarcity and reduce change of the climate around globe by using Sustainable Energy (United Nations, 2020), Here, it is evaluate how the making of non-hydro renewable sources influences the usage of nuclear power and fossil fuels and nuclear power in electrical sector, statistics of 109 countries (between 1960 to2015) is used to determine the trajectory of world where it is , it discovered that the use of fossil fuels has been only very slightly impacted by renewable energy, with an growth of 5 units of R.E being required on average to replace one unit of fossil energy. (Greiner et al., 2022).

Details of fossil fuel (What are fossil fuel)

Decomposition of animals and plants makes up the fossil fuel, found inside the core of the earth that are used to make energy. Its types are natural gas coal and oil. Coal is presented in the growth of silty rock (mixture of rock, dead plant and animal materials). In coal at least half or more must be a plant material (fossilized). Shale is another rock which have oil in its natural form after heating it we get the thick layer of gasoline. Name of natural gas is methane. (Society, 2022)

Purpose of study

Grid-connected systems are a desirable option to enhance electricity output from renewable energy sources, in addition to lowering electricity use and dependency on utility power. Examples of sustainable energy sources for home power include solar and wind energy. The results of the literature review show that Pakistani individuals hardly ever use wind and solar power.

Despite having a severe energy problem, Pakistan is one of the Asia-Pacific countries with a high wind power potential. The daily gap is thought to be between 4500 and 5500 MW despite an estimated daily demand for power of over 20,000 MW. There is a critical need for energy sources like wind energy given the widening

energy deficit, rising import costs for fossil fuels, and deteriorating air quality. Therefore, it's important to study wind energy availability, a potentially interesting source of R.E.

Aim of Study

This paper investigates wind potential for 100 cities all across Pakistan that are also densely to better grasp the possible applications for wind energy. wind speeds data were collected for a height of 10 meter. wind speed statistics (hourly), which is converted to mean monthly data and gathered throughout from 1990–2021, to examine wind speed characteristics. In addition, wind power densities were utilized to categorize wind energy means in the locations that were chosen.

In Pakistan there are huge reserves of wind potentials that needs to be studied in detail. This thesis targets to research, estimate and explain the following research objectives

- At particular location Wind potential and speeds
- Wind speed features based on the data of months and years.
- Is wind energy a good option for a given location?

CHAPTER II

Literature Review

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

Types of energy resources

Types of energies are renewable and non renewable energy as we already talked about the non renewable energies in which fossil fuels plays an important part in meeting energy demand for most of the countries but in this chapter we will be seeing different types of the renewable energies which are as follow

Solar energy

Energy produced by the sun is termed as solar energy. We can utilize it in many ways. Solar panels are placed at the open area (rooftop) to get more sunlight for making electricity.

Figure 3

Solar panel in Germany (Turgeon & Morse, 2022)

Wind energy

Transformation of kinetic energy by means of wind to electrical energy for generating power is the function of wind turbines. Blades of the wind turbine rotates which converts K.E to rotational energy. Circular motion is transformed into electricity by a shaft that is connected to the generator

Factors which effect the electricity production through wind are

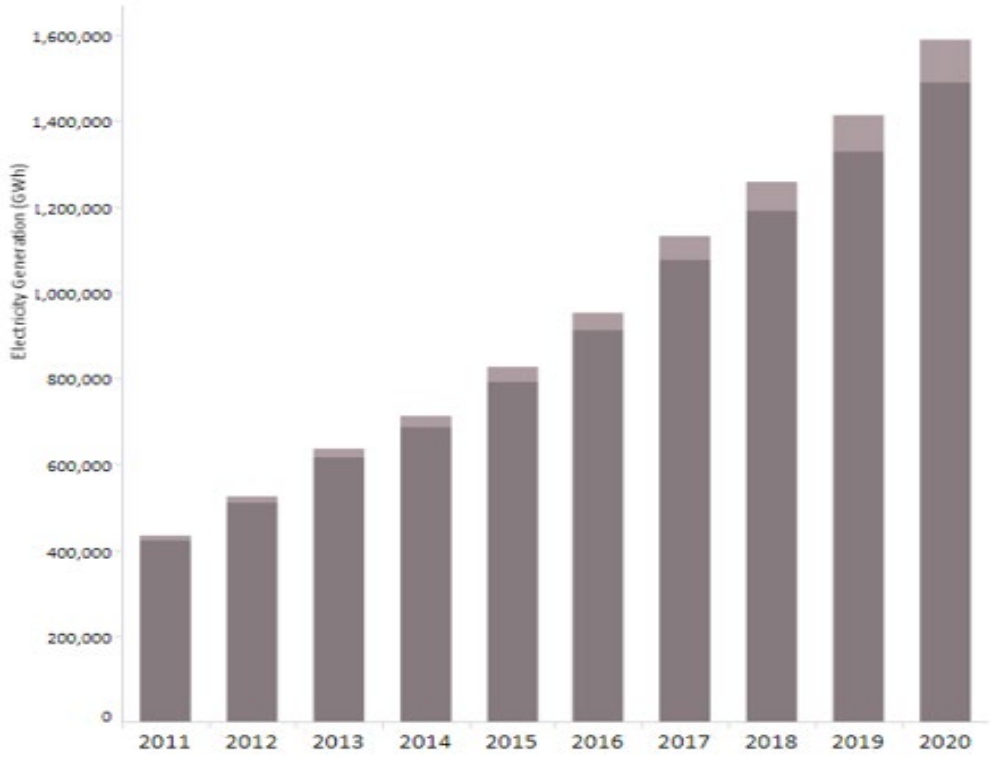
1) Length of the blades

2) Size of turbine

Final outcome is inversely proportional to both wind speed and size of the rotor. Hypothetically, a doubling of wind speed results in an eight-folding increase in the wind power potential .(Agency, 2020)

Figure 4

Electricity generation trend in energy



Types of wind power used in past were sails, windmills and wind pumps but now they are used for electricity production

Figure 5

Wind Turbine

Types of wind turbine

Wind turbines are machines that use mechanical and then electrical energy to transform from wind energy. (Horizontal axis wind turbines) HAWT and (vertical axis wind turbines) VAWT are the two forms into which they fall.

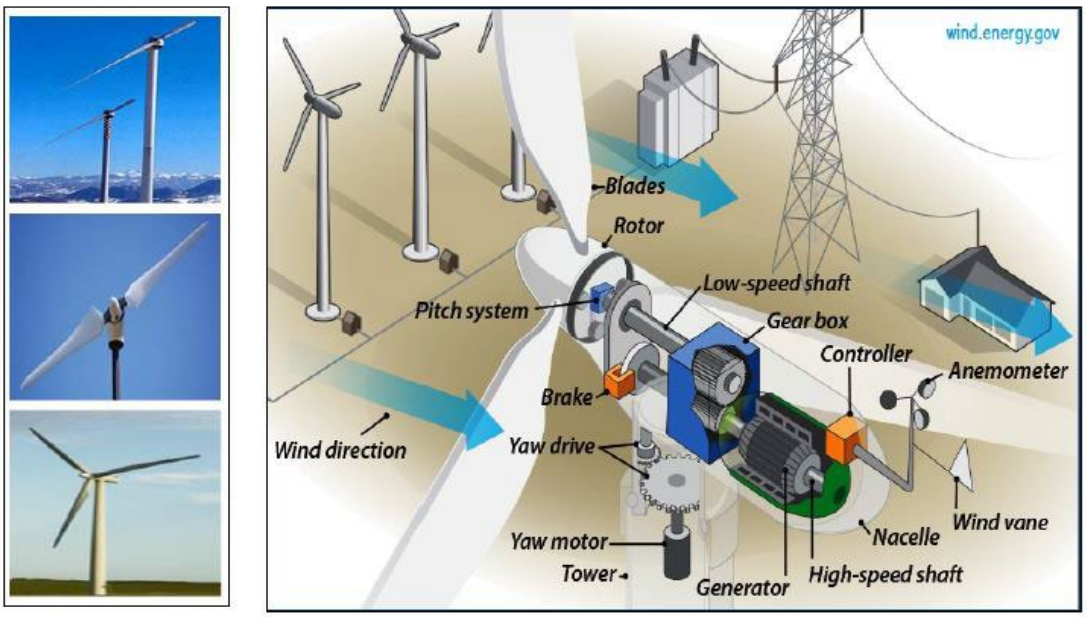
(Horizontal axis wind turbine) HAWT

A mechanism with 1, 2 or more revolving blades is known as (HAWT). The hub assembly, which connects to a low speed shaft, has the blades attached to it. (Sørensen, 2016). As demonstrated in Figure 2.4, speed of the shaft is increased from

low to high by the rotation from the gearbox linked to the generator which coverts it into electricity (Sørensen, 2016). Backing system plays an important role to start the machine when wind speed data is received by a controller. In HAWT maximum output power angles of blade are adjusted by pitch mechanism whereas function of yaw is to position it according to direction of wind. A typical horizontal turbine fixed on a 60 meter elevated tower and 70 meter diameter. At a wind of about 5.36 m/s generates 1.6 Mega-Watt, with the highest output power occurring in the range between 12.52 ms^{-1} to 13.41 ms^{-1}. When wind speed hits 22.35 ms^{-1}, it stops the rotation of turbine Figure 6 shows the separation distance for HAWTs in a farm in the crosswind and downwind directions. (Sørensen, 2016)

Figure 6

Wind turbine mechanism



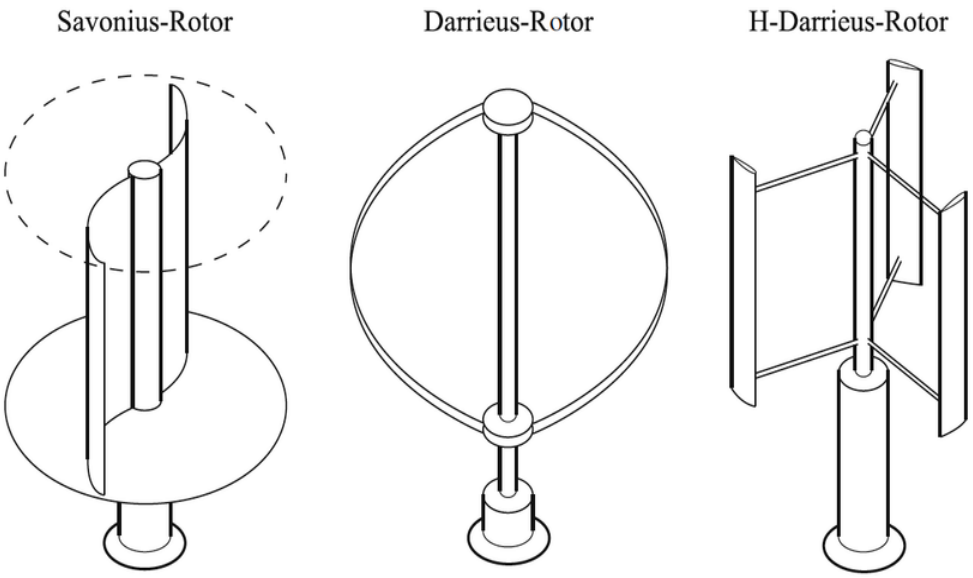
VAWT

In vertical axis wind turbines (VAWT) spinning shafts are fixed vertically, and all the other parts are placed at the bottom of the turbine (T. Burton et al., 2011). In this type gear box and generator are on the surface so its easy to repair and maintain, Because VAWTs don't need to be directed into the wind, wind sensor and orientation systems are unnecessary. 3 types of turbine are given below(T. Burton et

al., 2011)However, drag type VAWTs (Savonius turbines) in high turbulence it shows more significant advantages

Figure 7

Different Types of VAWTs



Biomass and biogas

What is biomass?

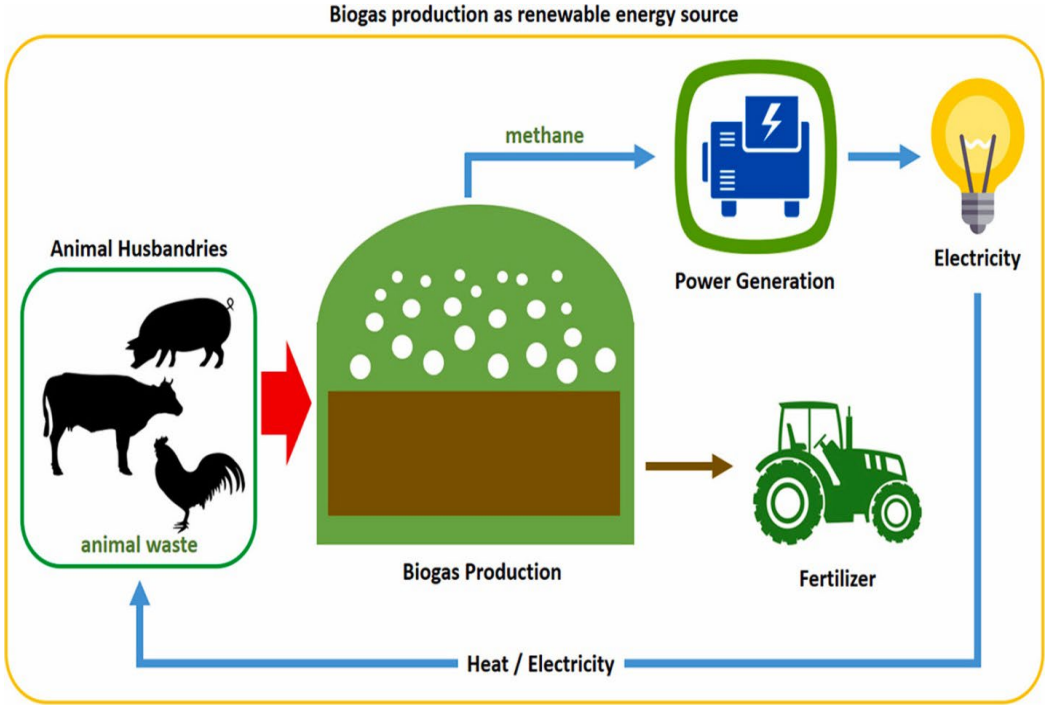
Solid biofuels are collectively referred to as biomass. It usually comes from crop waste, wood, and particular resources that have been grown to burn in the presence of oxygen to provide energy. Using biomass is known as biomass energy. Biomasses are heated for the production of liquid fuel, heat and electricity when utilizing biomass energy.

What is biogas?

One type of renewable energy is biogas. It is produced directly as a result of turning organic waste into energy and is a sustainable method of doing so as it is environmental friendly As the name suggests, It is a biofuel that is gaseous in form. It is a byproduct of the anaerobic digestion (AD) process, which converts organic waste—including food waste—in the absence of oxygen into energy.

Figure 8

Biogas production cycle



Animal dung, blood, and rumen content are all major sources of animal organic waste that might be used to produce a vast number of resources for biogas.In Indonesia also waste of the animals used for energy production (BioteCH4, 2020; M. Khalil et al., 2019)

Geothermal energy

Geothermal energy is the energy found inside the earth in the form of heat. It can be used for,

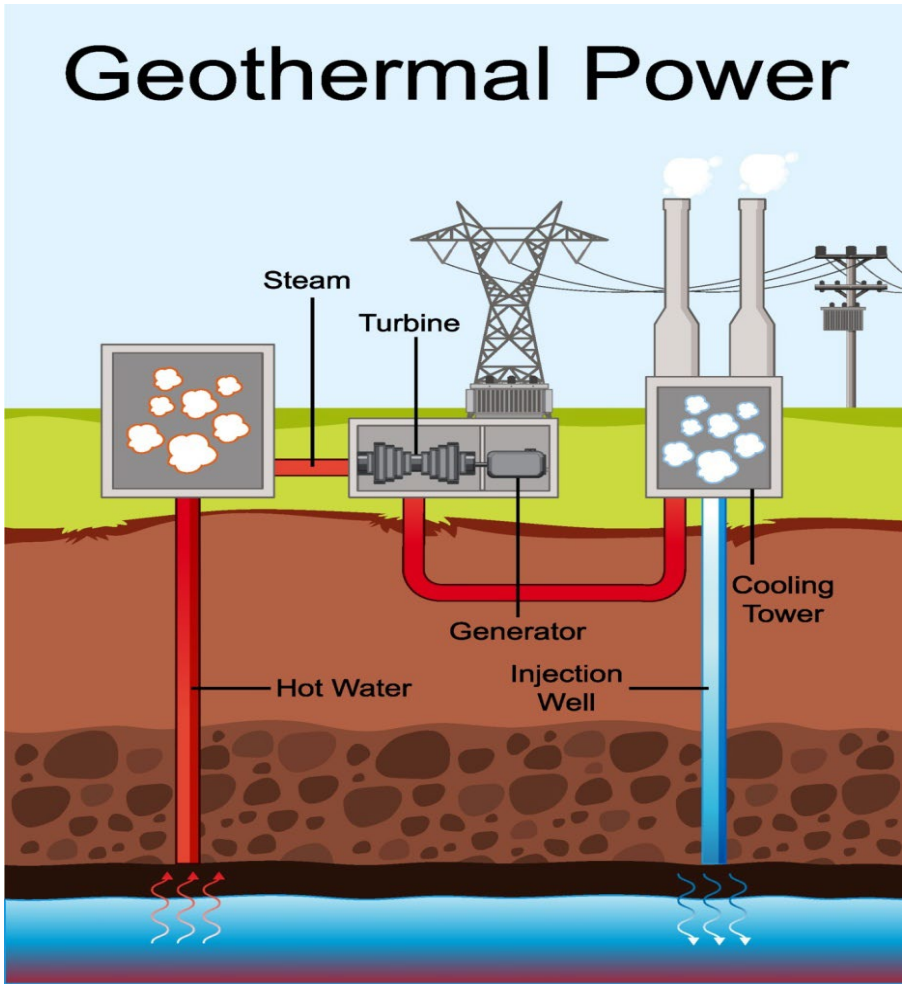
a) simple heating and cooling

b) for producing electricity.

Only a few amount of this type of energy is used but has a great potential future potential (Dickson & Fanelli, 2013). It is a renewable energy source, which could be used to solve current worldwide energy and environmental issues. (Muñoz et al., 2014)

Figure 9

Geothermal mechanism



Pakistan population, area covered and energy resources consumption

Pakistan is a country situated in Asia at a southern side, with a people living are of more than $180x10^6$. Around 22,800 MW of installed power generation capacity is currently available, with a mixture of mostly hydro, thermal, and nuclear sources. Due to a number of reasons, the power generation by the plants are very low and reaching a minimum of 9000 Mega Watt, whereas the usage is between 16.5Mega-Watt during summer time and 10,000 Mega-Watt in cold period. Pakistan have 4 provinces: 1)Punjab, 2)Sindh, 3)Balochistan, 4)Khyber Pakhtun Khwa (KPK), and Punjab. With almost 56% of the nation's population, Punjabs population is maximum as compared to provinces. Lahore serves as Punjab's capital. Punjab is home to almost 100 million people and covers more than 205 thousand km^2.so there

is a more need of energy in this area. Kalarkahar area is around 20 km in width and 250km in length which has the maximum wind energy potential but average wind potential is not good in this area. Population of this area is very low, but has more forests and deserted areas. This region uses different types of energy resources like hydro energy, wind energy and solar energy to produce energy, this area is good for wind turbine on small scale (Shami et al., 2016). Pakistan is an evolving state that needs a lot of energy to meet its industrial and residential needs as well as to continue the nation's economic growth. However, the nation is having trouble ensuring a steady supply of electricity and is currently dealing with its biggest energy crisis ever.

Researchers calculated the country's theoretical RE potential (Ghafoor et al., 2016) (Raheem et al., 2016) (Mirza, Umar K. & Maroto-Valer, M. Mercedes & Ahmad, 2003) (Sheikh, 2010) (Sheikh, 2009) (Asif, 2009) and its application to capture the useful form of energy utilizing a variety of methods. The majority of them were solar energy-focused but also discussed the methodological probability for producing electricity from other sources like wind, biomass, solar, and hydro.

There has been concern and pressure to reduce the negative effects of carbon emissions while maintaining national development initiatives, particularly in developing countries. Let's utilize Pakistan as an example, a developing nation that can be used as a case study in disclosing some recorded facts about energy. In Pakistan, power outages can last up to 18 hrs in rural areas and 8 to 10 hrs in city areas (J. Khan & Arsalan, 2016). There is a difference between demand and supply which is causing these disruptions. With the growth in population, the need is also rising. By the end of 2016, gas (37.9%) and oil (34.4%) accounted for the majority of Pakistan's energy resources, which are based on fossil fuels, Therefore, less than 1% of the energy mix was made up of the power generated by renewable energy sources. (M.A, Sheikh, 2003)

According to reports, Pakistan produces 53.4 percent of its power from coal, 22.6 percent from hydropower, 10.6 percent from gas, 2.8 percent from atomic energy, 0.6 percent from oil, and 10 percent from nonconventional resources. It is essential to promote renewable energies as an additional energy resources in order to lower the supply of energy and its demand. The new revolution that has brought about new resolutions in today's industries and technology world is mostly to blame for the rise in energy demand. And because the usage of nonrenewable energy

sources contributes to the depletion of fossil fuels, the globe is now converting to this new technology.

The United Nations estimates Pakistan's population to be 229,489,000 up till July 2022, or 2.87 percent of the world's population source. Total data for Pakistan's electricity consumption in 2021 was given as 116,816,000 GWh. This is an increase from the prior figure for 2020 of 108,371.000 GWh. Pakistan Electricity Consumption: Over the period of June 1991 to June 2021, there were 31 observations, and the total data is updated yearly. The statistics peaked in 2021 at 116,816 GWh and the lowest in 1991 at 31,534 GWh. Pakistan's total electricity usage is reported by the Ministry of Finance and has an active status in CEIC. The information is arranged under Pakistan's Table PK.RB006: Electricity Generation and Consumption in the Global Database. (Finance, 2021)

Wind potential analysis in Pakistan

A thorough understanding of the local wind patterns and winds speed distribution is necessary for the effective consumption of wind energy. Installing a wind energy transformation system requires consideration of a number of variables, including speed, power, type of generator, and a achievability assessment. Researchers had carried out several studies on features of wind and wind potential in numerous nations across world.

For an instance, in (Ullah et al., 2010)The Weibull functions were utilized to examine viability of wind energy at Pakistan's Kati Bandar. They determined that this location, with an typical power density of around 410 (W/m^2) at 50 meters above ground, is graded as excellent (Shami et al., 2016) investigated the features of wind speed in several Pakistani areas (Jiwani region, KPK Province, Sindh Province). The result showed that Pakistan's plans to produce electricity through wind farm projects could be advantageous.

Pakistan is one of the Asia-Pacific nations with one of the emerging market for wind power despite having a serious energy crisis.Daily electricity consumption is anticipated to be around 20000 Mega-Watt, with an everyday shortage of average 5000 Mega-Watt. immediate need of alternate energy resource is required for example wind, that is necessary due to the significant disparity between the supply and demand of electricity, rising import costs for fossil fuels, and deteriorating air

pollution(Shoaib et al., 2017). Thus, it’s essential for researchers to study wind energy availability as a potentially appealing renewable energy source.

Pakistan is capable of producing electricity through wind. Utilizing wind energy resources can assist Pakistan in achieving its ecological and policies related to energy with lowering energy imports.

Pakistan has a very large wind potential to produce energy, particularly in 3 provinces: Khyber Pakhtunkhwa (KPK), Sindh, Baluchistan,Wind energy potential is quite limited in the fourth Punjab province. These four cities—Gujranwala, Khanewal, Multan, and Sialkot—are all in the Punjab region. Punjab's Provence has relatively little potential for wind energy and is therefore not a viable option.

Focus is on wind energy. Pakistan has good wind potential

Wind is R.E source with no emissions. It also relies less on fossil fuels. 3

Benefits:

- It is an economical source of energy;
- Does not require large area;
- It may be used whenever there is wind.

Cons:

- Blades are harmed by centrifugal forces.
- Without wind, there can be no power production;

CHAPTER III

Methodology

This chapter provides information about the research design, participants/sample, data collection and analysis procedures as well as how the findings are analysed

Material and method

No study has been done which uses 100 location from 1981 until 2021. This research selected the 100 location based on the population and Nasa data is used to see the average daily wind speed of different cities which were then converted to monthly wind potential at 100 locations in Pakistan and used the nasa data to do further calculations and find the wind power density by using mathematical equations to predict the wind power class.

Pakistan has great wind potential only if we consider 10% of the maximum windy areas so the mean wind speed there is around 7.87ms^{-1}

Figure 10

Map of Pakistan

The above map of Pakistan shows all the locations which is studied in this paper and data collected from the satellite for a long period of time

Pakistan is generating power at some areas in Sindh through wind (e.g at keti Bandar, BinQasim, Gharo and Jimphir. Near Karachi FFEC constructed a wind power plant of 50MW. 347,190km2 is the land area of Balochistan which makes it the largest province accordind to area wise which is 44 percent of Pakistan's area. Here population density due to uneven mountains, hills and shortage of water is very low. Notably, Balochistan have a quite suitable locations for the wind corridors for wind farms. These are more efficient and around 50% better matched to that of the project at Gharo in Sindh

Wind Energy Potential in Pakistan

Figure 11

Mean Wind Power Density of Pakistan

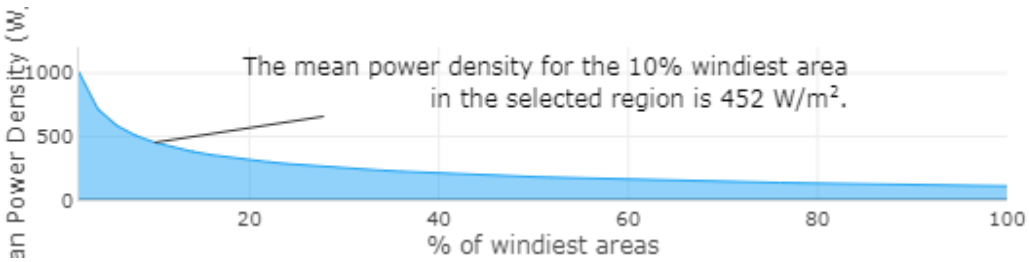


Figure 12

Pakistan wind frequency rose

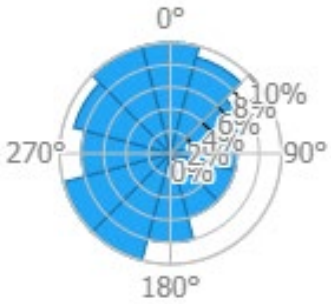


Figure 13

Mean wind speed

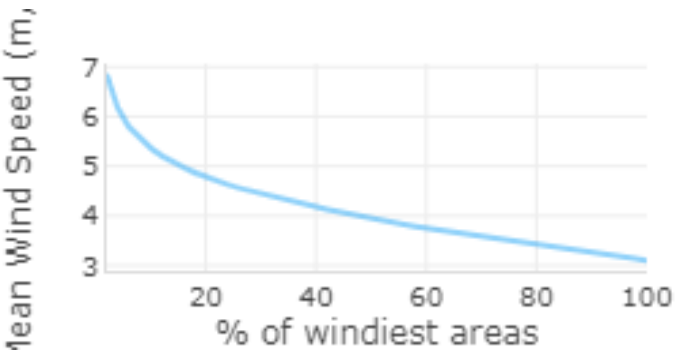


Figure 14

Wind speed rose of Pakistan

Figure 15

Baluchistan wind speed rose

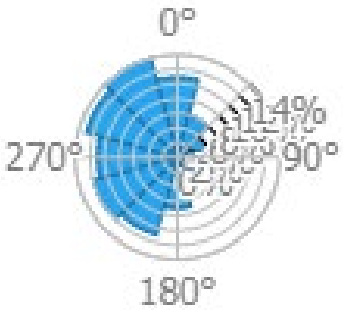


Figure 16

NWFP wind speed rose

Figure 17

Punjab wind speed rose

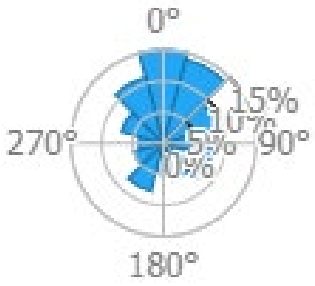


Figure 18

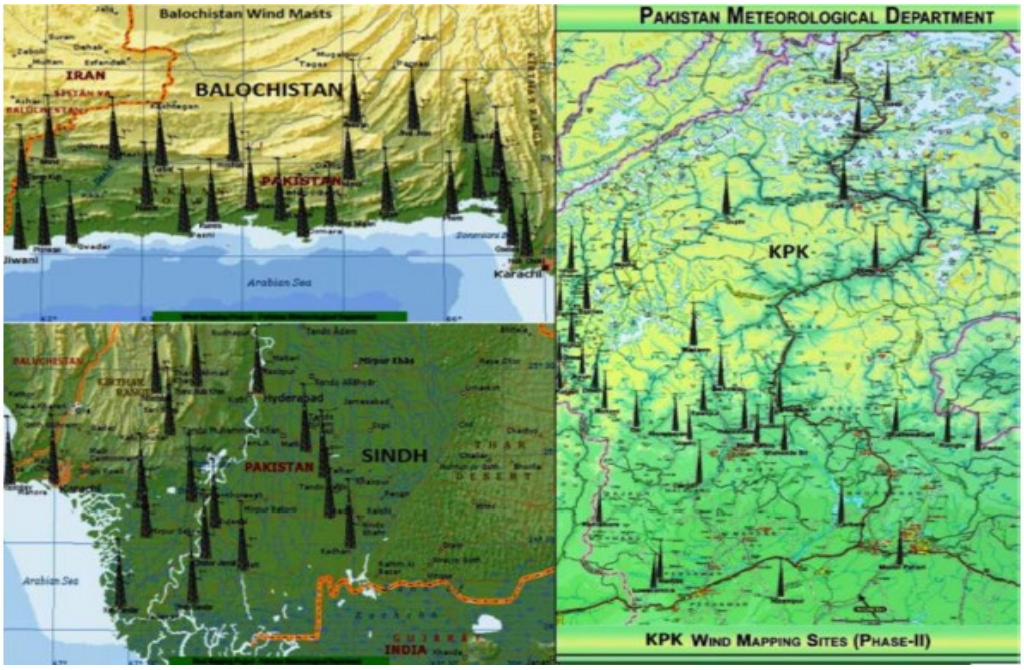
Sindh wind speed rose

Total 26 papers on Pakistan in which different type of renewable energies are dicussed at different location in Pakistan which are summarized in the table 1 Having different types of renewable energies when compared, so the wind energy was the most beneficial. The country has in total 346,000 MW installable wind power potential capacity (M. Z. Malik et al., 2020).

According to the research done by paper in (M. Baloch et al., 2017) they predicted that by 2030 Pakistan's wind power potential would be around 40 to 70 % , different types of method, techniques and tools are used to gather wind data.

Figure 19

Installed wind masts in three provinces of Pakistan



Weathers in Pakistan and wind potential

NREL carried out the assessment of wind resource around the whole country using GST.If we exclude the area covered by water so the over-all area of land is around 7.7 x 10^5 km^2 out of the total area of Pakistan 796,095 km^2. 5MW wind power plant can be installed in the areas where wind potential is maximum. (NREL, 2015) global wind atlas data is just used to see the wind potential of whole Pakistan

shown in the diagram, with that we can also see the 12 stations that are place at the location, the scale on the diagram shows the wind speed across whole Pakistan.

Wind speed data for 100 cities in Pakistan is taken out online from nasa website and utilizes that data to find different parameter. Pakistan has variable temperature, weather and climates; on seashore it is usually dry and hot and around river but cooler at upper area. 4 different weathers can be seen

- A chill and dry winter.
- A hot and dry spring.
- Hot rainy season.
- Decreasing rainy season.

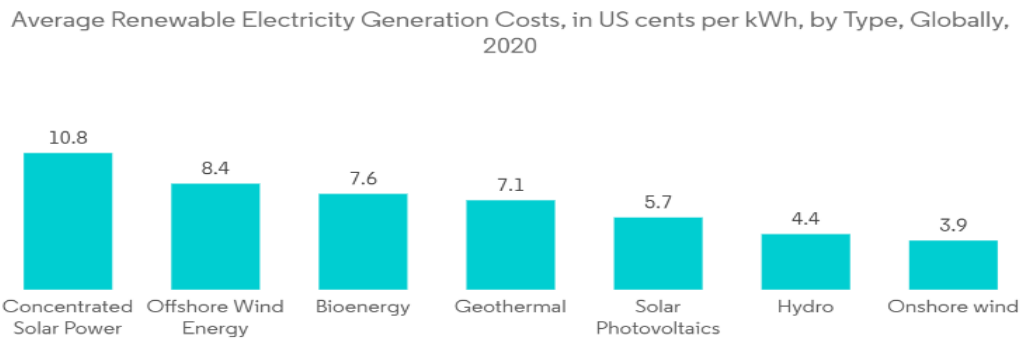
In evaluation with all renewable energies, wind is the most cheapest way to produce energy, claimed by IRENA. The mean cost of producing electricity using onshore wind energy was USD 0.039/kWh in 2020.

Pakistan offers a wealth of natural resources, including wind corridors with sufficient and constant wind speeds. For instance, the Gharo-Jhimpir wind corridor in Sindh has a total potential for wind energy of 43000 MW over an area of 9700 square kilometers. Phase 2 of the renewable energy mapping project, which will discover new wind energy-harnessing corridors, will begin in January 2022.

Additionally, Din Energy Pvt. Limited began operating the Jhimpir wind power station commercially in March 2022. The project's overall cost was USD 65 million, and the power plant has the ability to produce 50 MW of electricity. Thus, technological advancements that are resulting in reduced wind energy costs and higher efficiency,

Figure 20

Average renewable electricity generation cost in U.S in 2020

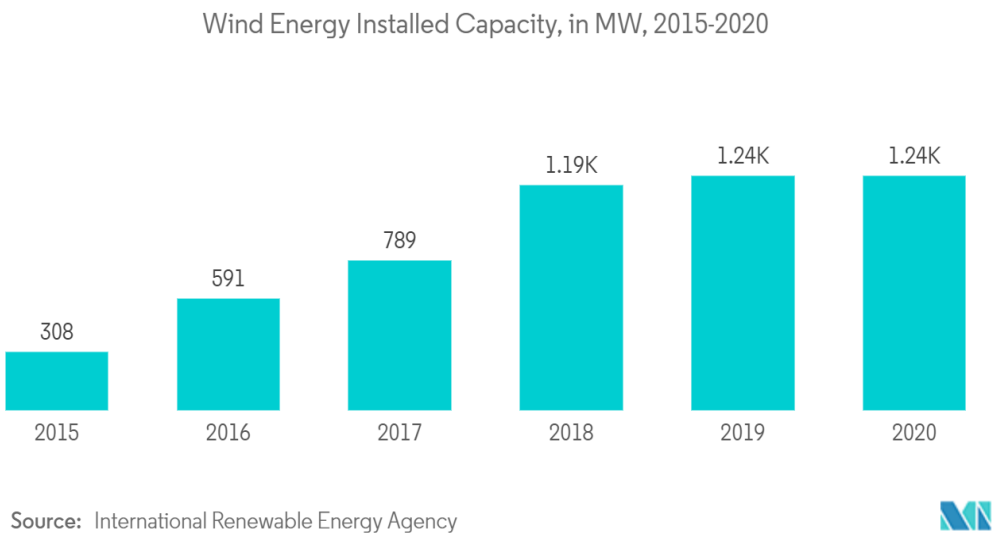


Source: International renewable energy market

Until 2022 national grid was provided with 1,335MW of energy from wind by plants, Whereas 10 more wind plants are currently in progress to provide around 500MW of power

Figure 21

Wind energy installed capacity in MW from 2015-2020



In addition, numerous researchers uses NASA information to project several potential locations for wind farms. For example, (Arreyndip et al., 2016) he uses NASA data from (1983–2013) to assess the potential for wind in various Cameroonian locations and build wind farms.

(Rafique et al., 2018) RETScreen software was used to research the viability for 100 Mega-Watt wind farms joined with grid station in Saudi Arabia. Additionally, utilizing NASA's average mean wind speed data many papers describes the wind speed features for chosen locations. For example, (Gökçeku¸s et al, 2019). Examined 8 different locations of Lebanon and gathered data, real data and NASA's average monthly wind statistics from 1982 until 2019. These data were made available through NASA's data

Mathematical equations

The WPD numbers are computable assessment for the amount of wind power that is accessible somewhere uses to find wind potential, other factors of wind speed are as follows:

wind speed forecast (Vmp):

$$V_{mp} = c\left(1 - \frac{1}{k}\right)^{1/k} \tag{3.1}$$

Maximum energy-carrying wind speed (VmaxE):

$$V_{maxE} = c\left(1 + \frac{2}{k}\right)^{1/k} \tag{3.2}$$

WPD shows information about wind (Mohammadi et al., 2017). It is expressed as:

$$\frac{P}{A} = \frac{1}{2}\rho v^3 \tag{3.3}$$

$$\frac{P}{A} = \frac{1}{2}\rho v^3 f(v) \tag{3.4}$$

Furthermore, considering a Weibull it can be computed as a function of the Weibull factors it can be written as the equation (Keyhani et al., 2010):

$$\left(\frac{P}{A}\right)_W = \int_0^\infty \frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right). \tag{3.5}$$

Furthermore, Equation (5) is used to find mean WPD (Keyhani et al., 2010):

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho \bar{v}^3 \tag{3.6}$$

where P is WPD in Wattm^{-2}, $\bar{P}$ is the average WPD in Wattm^{-2} , A is the area in m^2, ρ is air density in kgm^{-3} and $\bar{v}^3$is the average wind speed (ms^{-1}).

The Weibull is like a probability distribution which can be used to see product analyze life statistics, dependability and failure rate. It may also accommodate a broad range of data from numerous other disciplines, including engineering sciences, hydrology, biology, and economics.

As mentioned earlier shape and scale values also effects the distribution in many ways like how the curve will look, how much reliable it is and it's failing ratio. The Weibull slope is another name for the Weibull shape parameter which can also be called Weibull slope

Pakistan electricity prices

Table 1

Price per unit

Pakistan electricity prices	**Household, kwh**	**Business, kwh**
Pakistan Rupee	12.100	35.910
U.S Dollar	0.054	0.160

The energy cost of Pakistan in March 2022 was compared between normal consumers like household utilization and for industrialize areas. Table 1 above shows the tariffs, but the prices for day times were different 0.146 USD was fixed for consumers and 0.140 USD for business.

The information in Table 6 displays the average daily usage hours, watt ratings, and annual electricity consumption in kWh for various appliances. The majority of respondents acknowledged that they only use air conditioning during the summer (May to September), whereas ceiling fans are still in use from April to October. (Amber et al., 2021)

During the summer, water coolers are used in homes without air conditioning. Washing machines are typically used for 7 hours per week, or 1 hour per day. Following is how the annual electricity consumption was determined:

Annual Usage Hours x (Watt/1000) x 0.75 (1), where "0.75" denotes the scaling factor, indicating that appliances operate at 75% of their capacity. (Amber et al., 2021)

Domestic connection per unit rate

Tariffs for the electricity solely depends upon the amount of units you consume and at what hours they are consumed sometimes peak hour unit consumption of electricity is more table below shows the breakdown of units consumed and accordingly there price

Table 2

Units usage rate

Number of Units	**Rate per 1 Unit (kwh)**
1-50	Rs. 2
1-100	Rs. 7.36
101-200	Rs. 9.68
201-300	Rs. 12.15
301-700	Rs. 20.82
Above 700	Rs. 23.92

The most recent money per liter of octane-95 gasoline, diesel and other fuels are shown in the table below, these prices are of pump level that includes all the fees and taxes, the prices ae updated weekly

Per kWh electricity rates are shown in the table below, mean annual household electricity utilization and for business, 1000 000 kWh consumption is used

Table 3

Fuel price

Fuels, price per liter	**Date**	**PKR**	**USD**
Gasoline price	10.10.2002	224.8	1.035
Diesel price	10.10.2002	235.3	1.084
Kerosene price	10.10.2002	202.02	0.93

Per kWh electricity rates are shown in the table below, mean annual household electricity utilization and for business, 1000 000 kWh consumption is used

Table 4

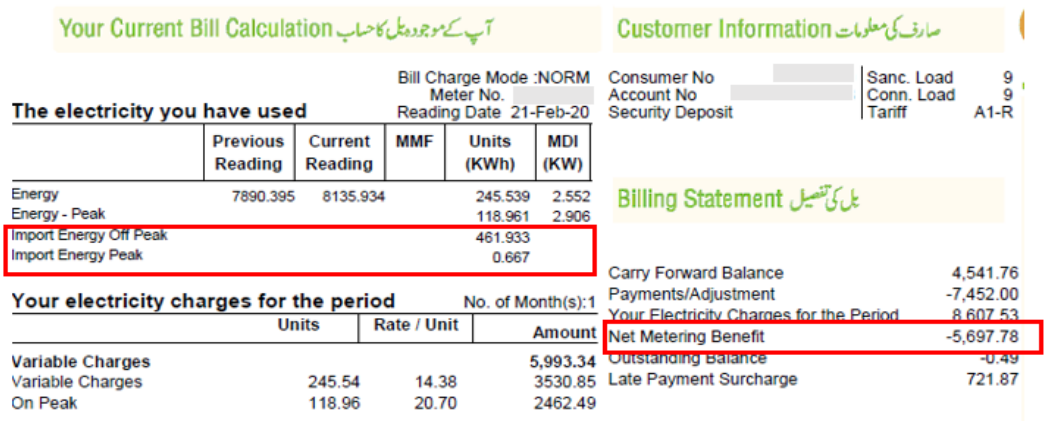
Bill tariff contribution

Total Bill	**8498**
Units:	433
Cost of electricity	6245.15
A(QTA/dmc)	697.13
FC-surcharge	186.19
Total Tariff Charges	7232.6042
Ele. Duty 1.5% of cost of electricity	104.1342
G.S.Tax @ 17%	1230
PTV-Fee	35
Meter Rent	0
Service Rent	0

The table above shows how the different expenses contributes towards the total bill

Figure 22

Actual bill



CHAPTER IV

Findings and Discussion

This chapter presents the findings based on the collected data.

Mean wind speed

Range of wind speed of Pakistan which can be concluded from the nasa data lies between 1.7 to 7.06 ms^{-1} for location that was selected

Mimimum average speed of wind was found in Peshawar, nowshera, mardan, charsadda in the month of October which is around 1.70878 m/s by nasa data

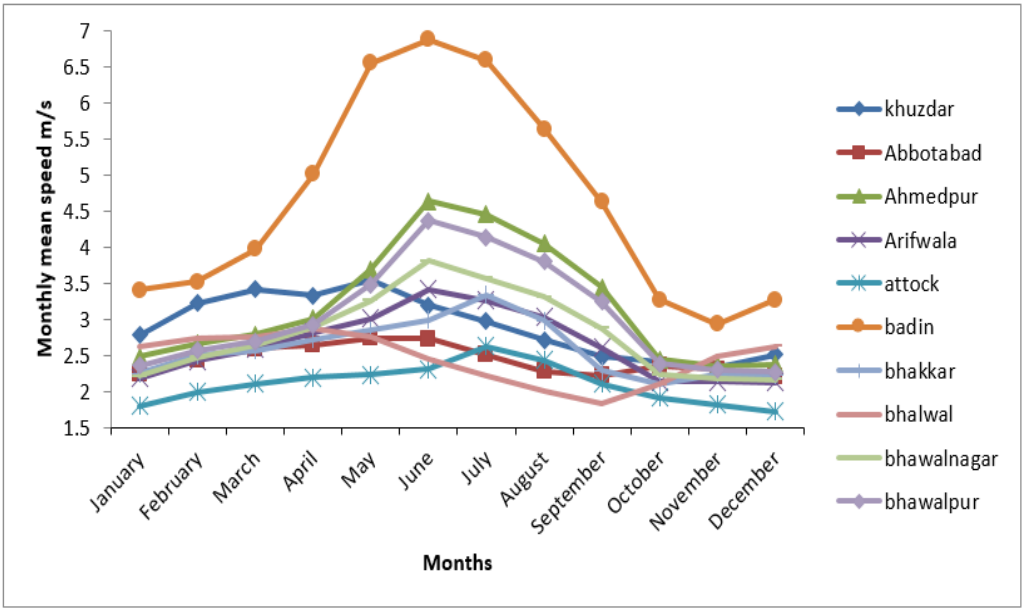
Maximum average which was recorded at height of 10 meter in Pakistan is 7.063171 m/s of Hyderabad in the month of june.

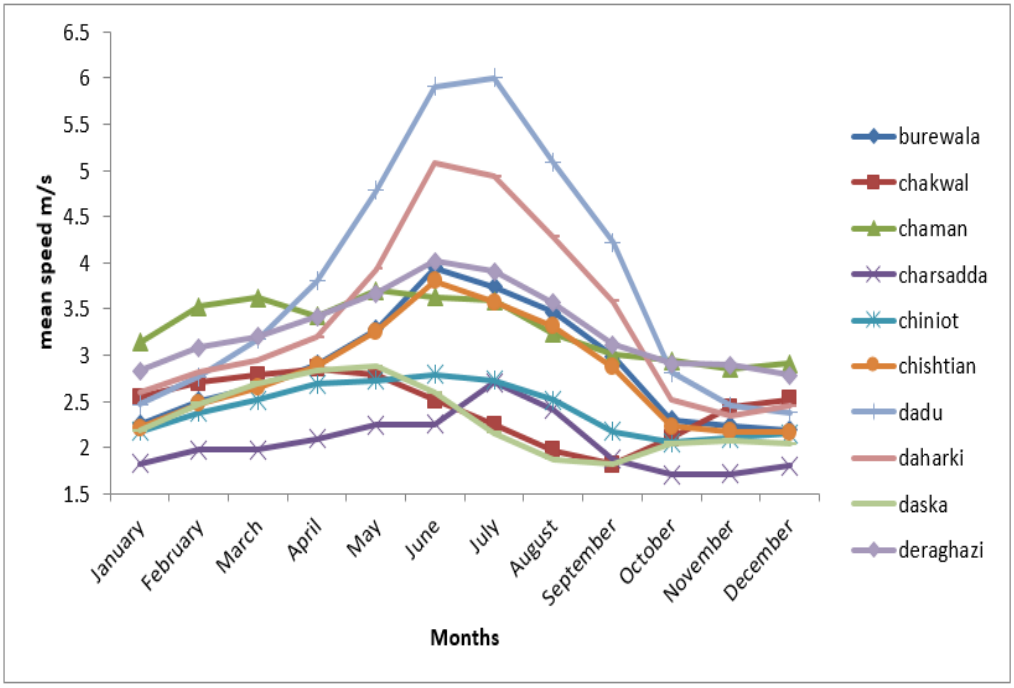
From the nasa source it could be concluded that on average basis speed of wind in Pakistan is around 2.9 m/s on monthly basis

Figure below shows the graphical representation of monthly wind speed of different locations

Figure 23

Monthly mean speed of different cities




mean speed m/s
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4.5
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3.5
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2.5
2
1.5
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February
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April
May
June
July
August
September
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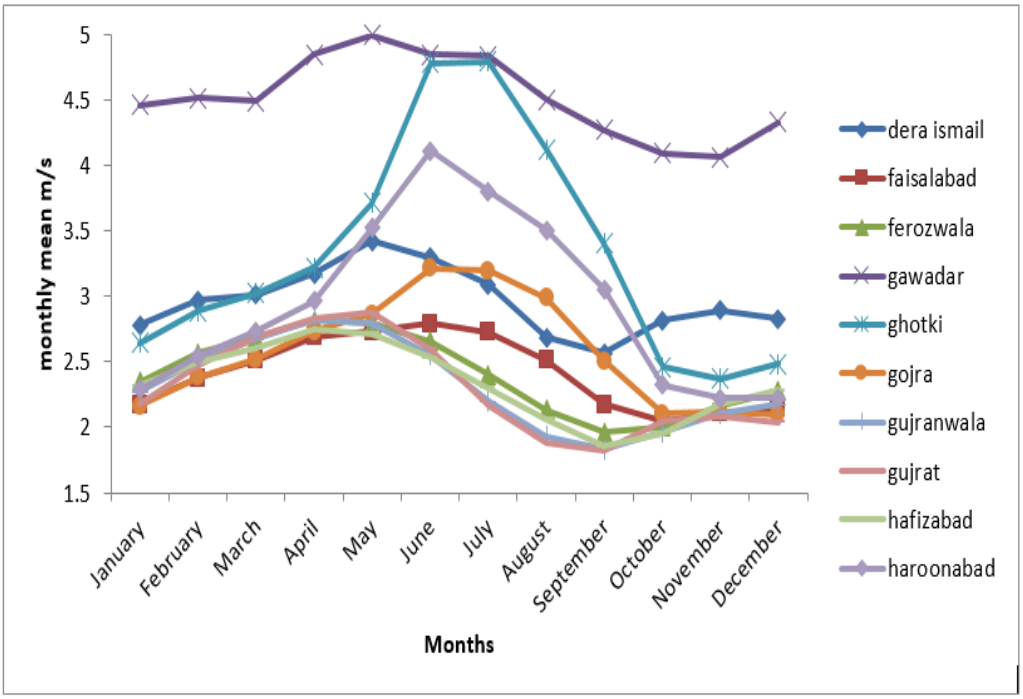
November
December
Months
burewala
chakwal
chaman
charsadda
chiniot
chishtian
dadu
daharki
daska
deraghazi


monthly mean m/s
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October
November
December
Months
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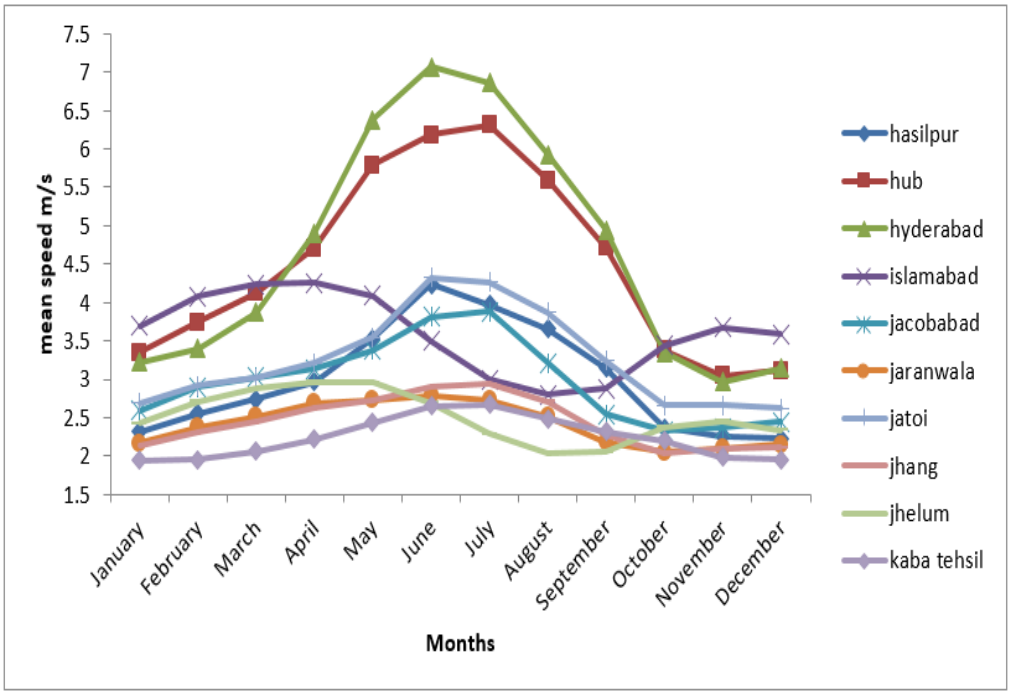
faisalabad
ferozwala
gawadar
ghotki
gojra
gujranwala
gujrat
hafizabad
haroonabad


mean speed m/s
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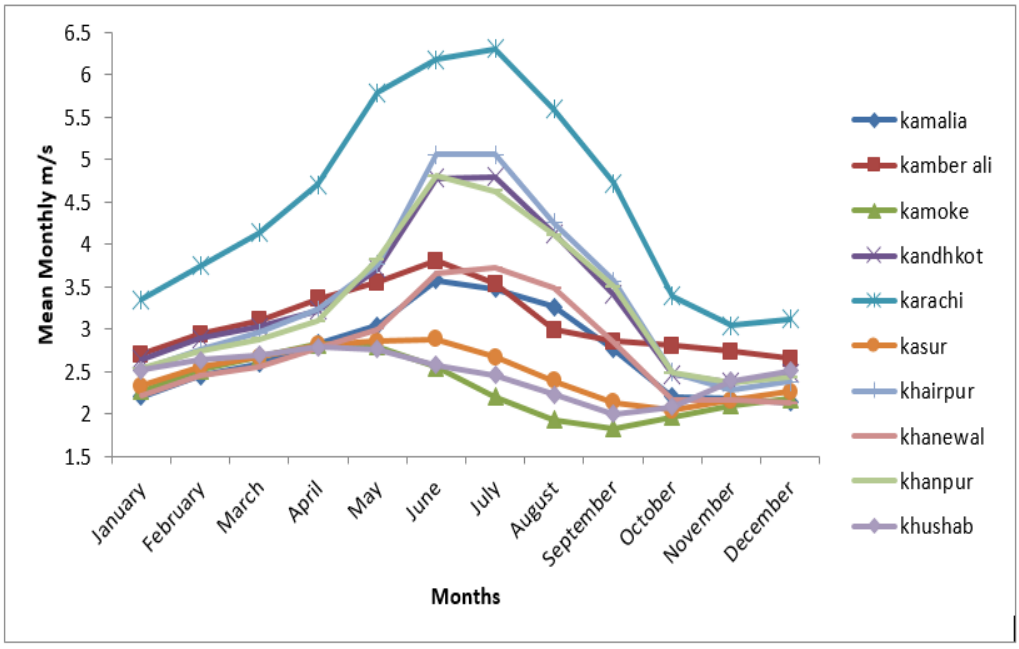
Months
hasilpur
hub
hyderabad
islamabad
jacobabad
jaranwala
jatoi
jhang
jhelum
kaba tehsil


Mean Monthly m/s
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Months
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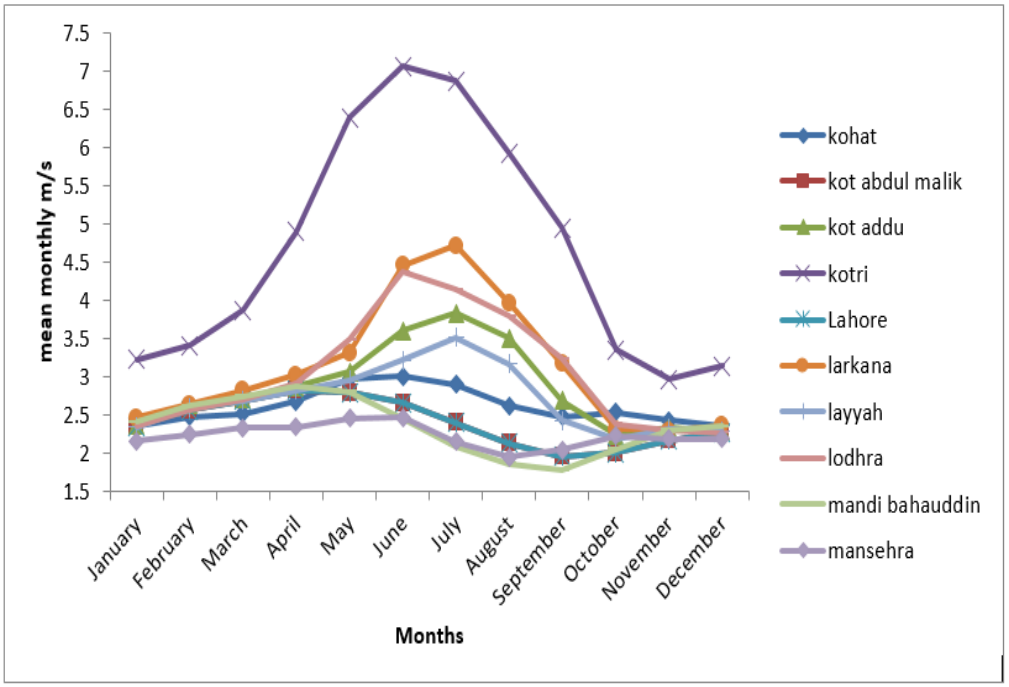
kamber ali
kamoke
kandhkot
karachi
kasur
khairpur
khanewal
khanpur
khushab


mean monthly m/s
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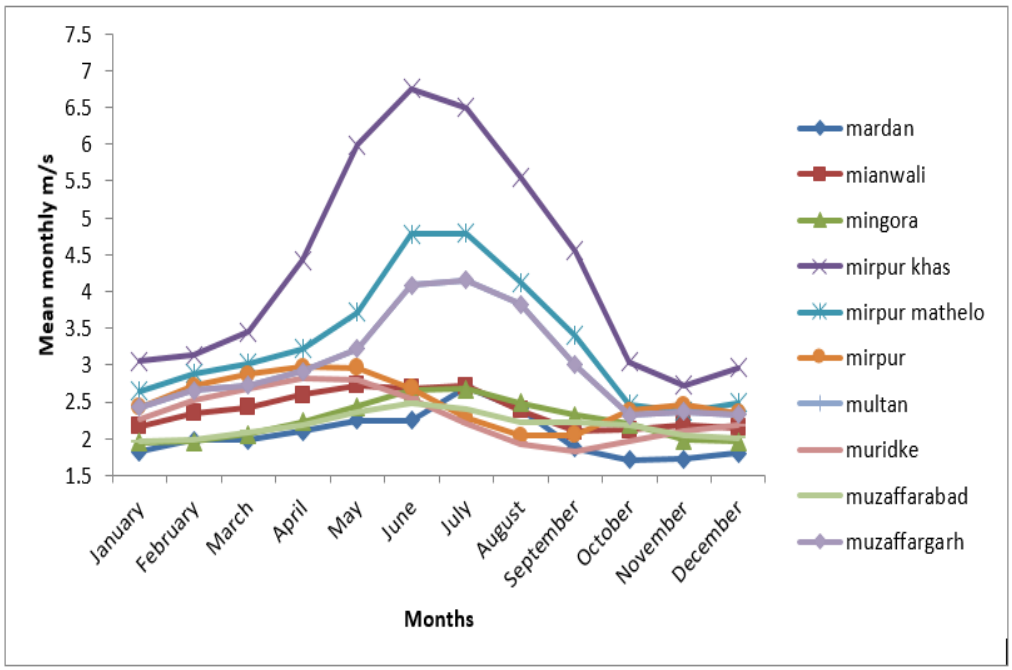
Months
kohat
kot abdul malik
kot addu
kotri
Lahore
larkana
layyah
lodhra
mandi bahauddin
mansehra


Mean monthly m/s
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Months
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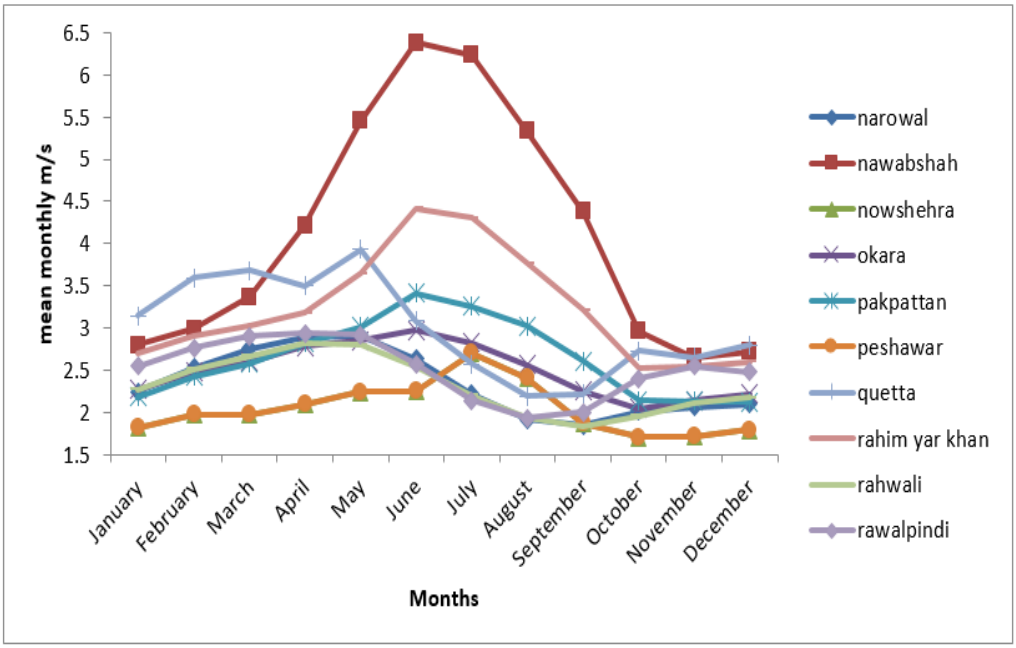
mianwali
mingora
mirpur khas
mirpur mathelo
mirpur
multan
muridke
muzaffarabad
muzaffargarh


mean monthly m/s
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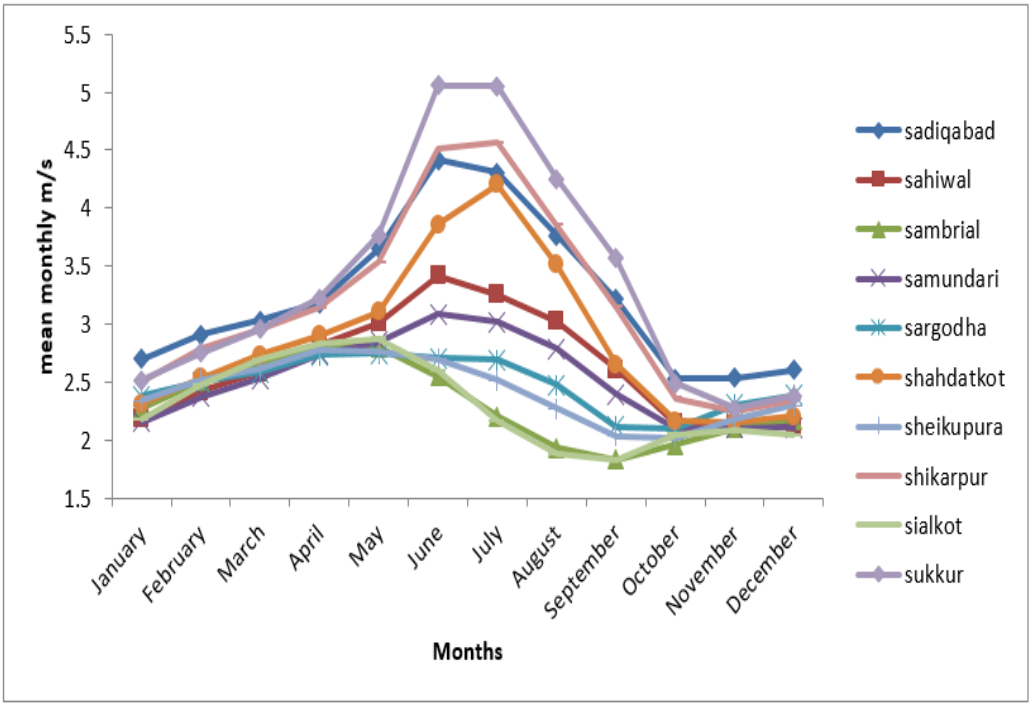
November
December
Months
narowal
nawabshah
nowshehra
okara
pakpattan
peshawar
quetta
rahim yar khan
rahwali
rawalpindi


mean monthly m/s
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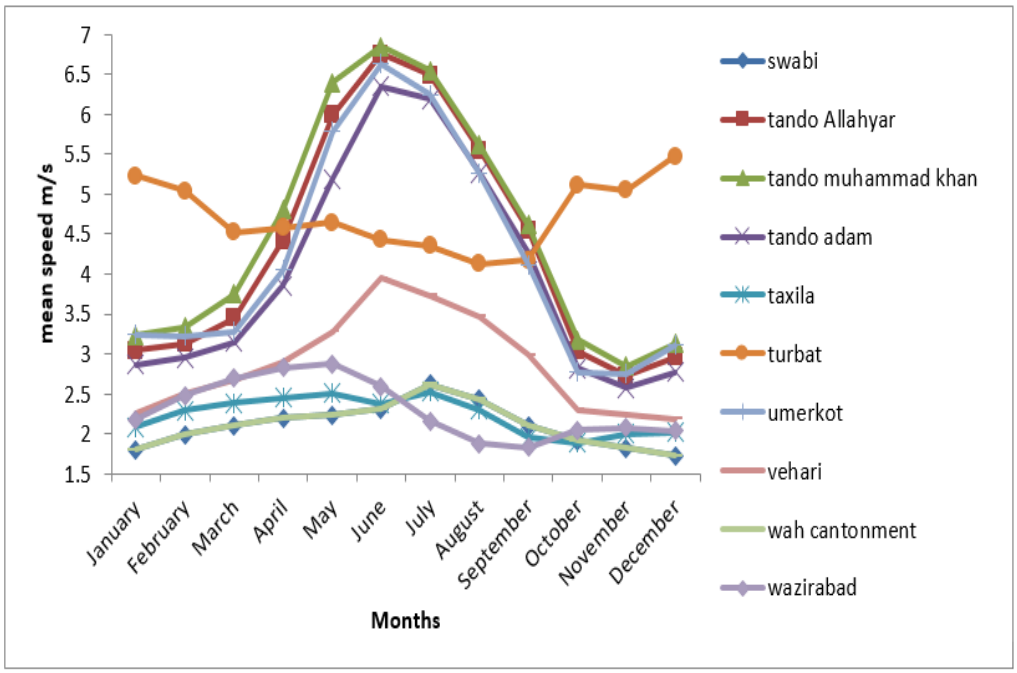
sadiqabad
sahiwal
sambrial
samundari
sargodha
shahdatkot
sheikupura
shikarpur
sialkot
sukkur



On the basis of monthly mean speed for every location maximum and minimum value for each city is summed up in the table 8 below, most cities wind speed has the value greater than 2 m/s reaching to the maximum as around 8 m/s

Table 5

Minimum and Maximum wind speed

Location	MIN	MAX
khuzdar	2.326098	3.534634
Abbotabad	2.202927	2.744146
Ahmedpur	2.354878	4.636585
Arifwala	2.12439	3.414878
attock	1.723415	2.623659
badin	2.93561	6.879512
bhakkar	2.106829	3.334878
bhalwal	1.833415	2.860732
bhawalnagar	2.163902	3.80439
bhawalpur	2.266098	4.368293
burewala	2.19122	3.946098

Table 5 (Continue)

location	MIN	MAX
chakwal	1.818537	2.85439
chaman	2.857805	3.700732
charsadda	1.70878	2.707073
chiniot	2.052439	2.791951
chishtian	2.163902	3.80439
dadu	2.383171	6.003659
daharki	2.342683	5.077073
daska	1.826098	2.876829
deraghazi	2.783171	4.015122
dera ismail	2.566341	3.42
faisalabad	2.052439	2.791951
ferozwala	1.960976	2.817317
gawadar	4.061463	4.993659
ghotki	2.369512	4.793415
gojra	2.099268	3.213902
gujranwala	1.828293	2.816341
gujrat	1.826098	2.876829
hafizabad	1.856585	2.747317
haroonabad	2.220488	4.10878
hasilpur	2.230488	4.23561
hub	3.043415	6.309512
hyderabad	2.966829	7.063171
islamabad	2.801463	4.259756
jacobabad	2.323902	3.883659
jaranwala	2.052439	2.791951
jatoi	2.619756	4.320488
jhang	2.041951	2.937317
jhelum	2.042439	2.969512
kaba tehsil	1.945122	2.673902
kamalia	2.12878	3.573659

Table 5 (continued)

location	MIN	MAX
kamber ali	2.650244	3.807561
kamoke	1.828293	2.816341
kandhkot	2.369512	4.793415
karachi	3.043415	6.309512
kasur	2.035854	2.879512
khairpur	2.273902	5.057317
khanewal	2.124146	3.717805
khanpur	2.370488	4.80122
khushab	1.993659	2.788537
kohat	2.362683	2.999268
kot abdul malik	1.960976	2.817317
kot addu	2.237073	3.826098
kotri	2.966829	7.063171
Lahore	1.960976	2.817317
larkana	2.297561	4.71878
layyah	2.187561	3.515366
lodhra	2.266098	4.368293
mandi bahauddin	1.773659	2.873659
mansehra	1.942439	2.461707
mardan	1.70878	2.707073
mianwali	2.095854	2.721707
mingora	1.945122	2.673902
mirpur khas	2.725854	6.752439
mirpur mathelo	2.369512	4.793415
mirpur	2.042439	2.969512
multan	2.312439	4.153171
muridke	1.828293	2.816341
muzaffarabad	1.960732	2.480732
muzaffargarh	2.312439	4.153171
narowal	1.847317	2.907073

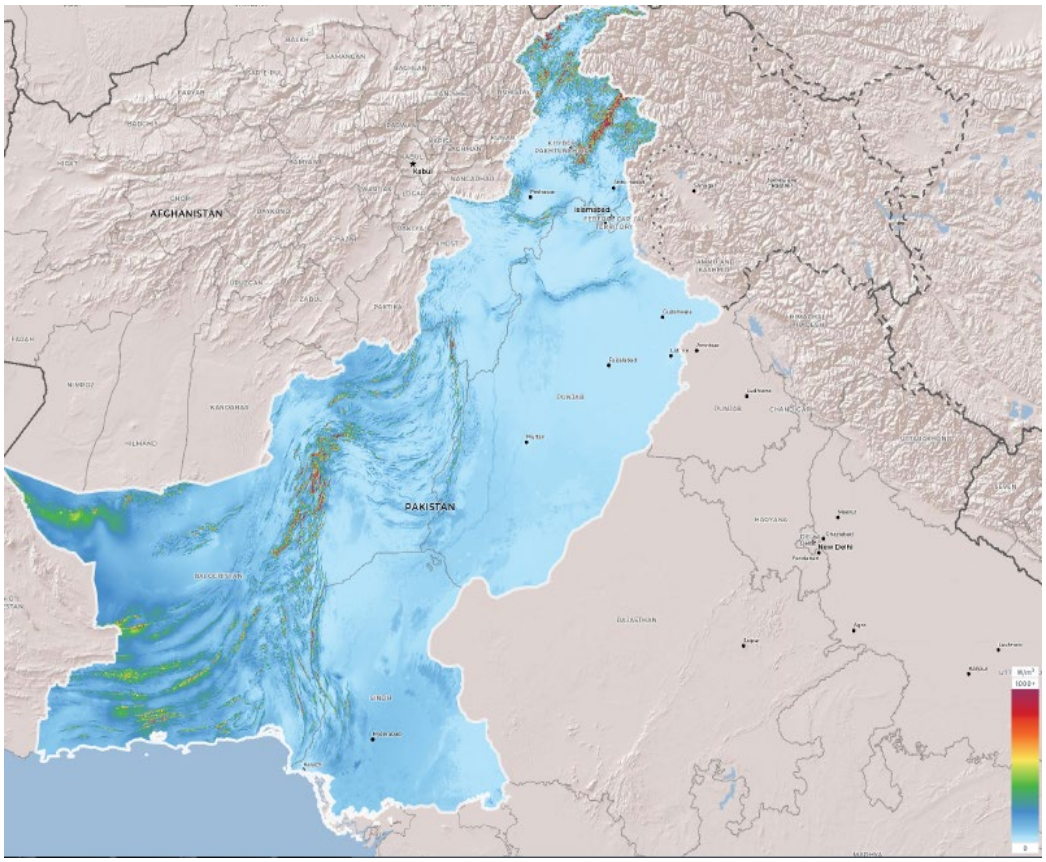
Table 5 (continued)

Location	MIN	MAX
nawabshah	2.650244	6.382439
nowshehra	1.70878	2.707073
okara	2.049024	2.974146
pakpattan	2.12439	3.414878
peshawar	1.70878	2.707073
quetta	2.190488	3.927805
rahim yar khan	2.530976	4.417805
rahwali	1.828293	2.816341
rawalpindi	1.937561	2.935366
sadiqabad	2.530976	4.417805
sahiwal	2.12439	3.414878
sambrial	1.828293	2.816341
samundari	2.091463	3.088293
sargodha	2.100732	2.743902
shahdatkot	2.15561	4.204634
sheikupura	2.022927	2.775854
shikarpur	2.243171	4.566098
sialkot	1.826098	2.876829
sukkur	2.273902	5.057317
swabi	1.723415	2.623659
tando Allahyar	2.725854	6.752439
Tando muhammad khan	2.848537	6.847073
tando adam	2.569024	6.346585
taxila	1.882439	2.525854
turbat	4.130488	5.471707
umerkot	2.753415	6.634634
vehari	2.19122	3.946098
wah cantonment	1.723415	2.623659
wazirabad	1.826098	2.876829

Wind power density and parameters analysis

Figure 24

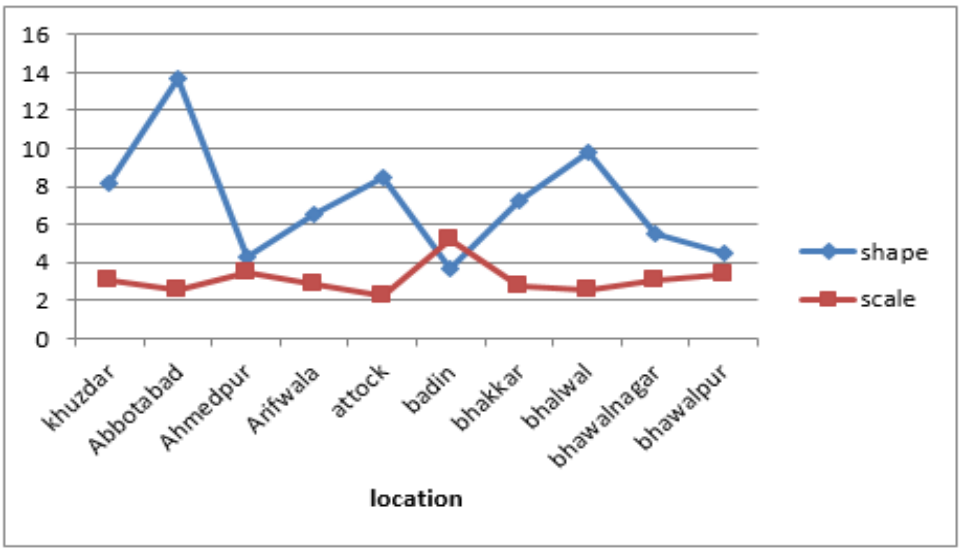
Mean wind power density at 10m

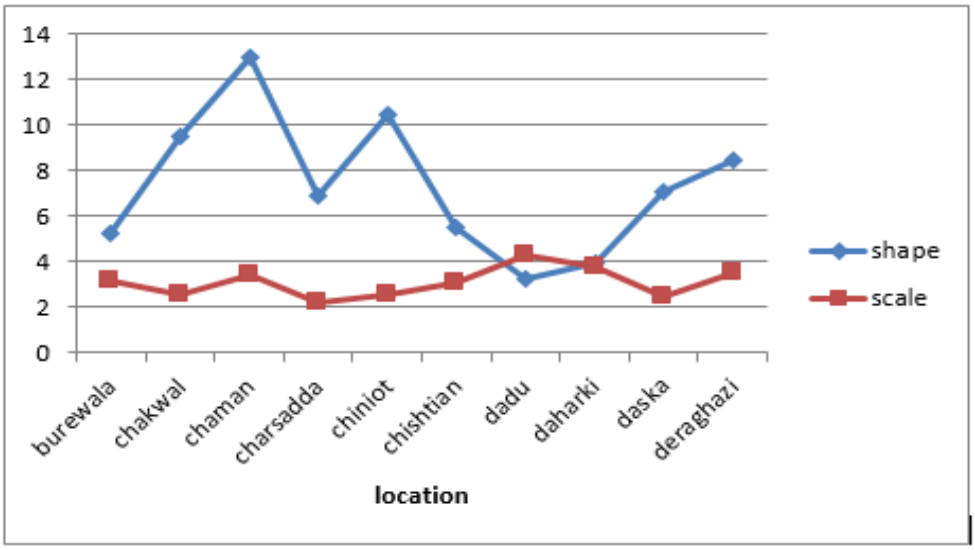


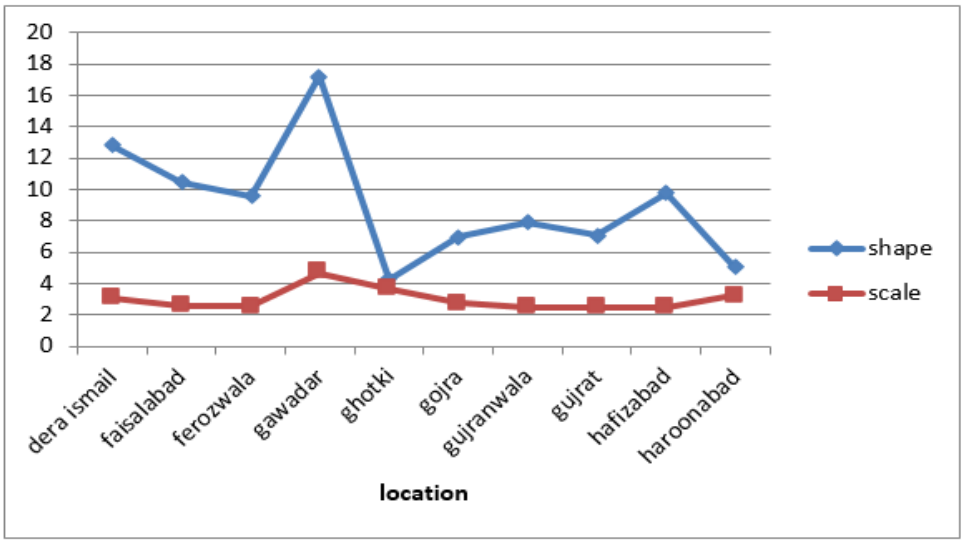
Minitab software computed the values for shape and scale parameter, on the basis of monthly mean speed for all the cities which is shown by the graphical representation below shows how the values of shape and scale parameters are changing simultaneously for all the cities selected the shape parameter is all the time greater than the scale parameter. Shape and scale parameter can be easily compared for different cities

Figure 25

Shape and scale comparison of cities



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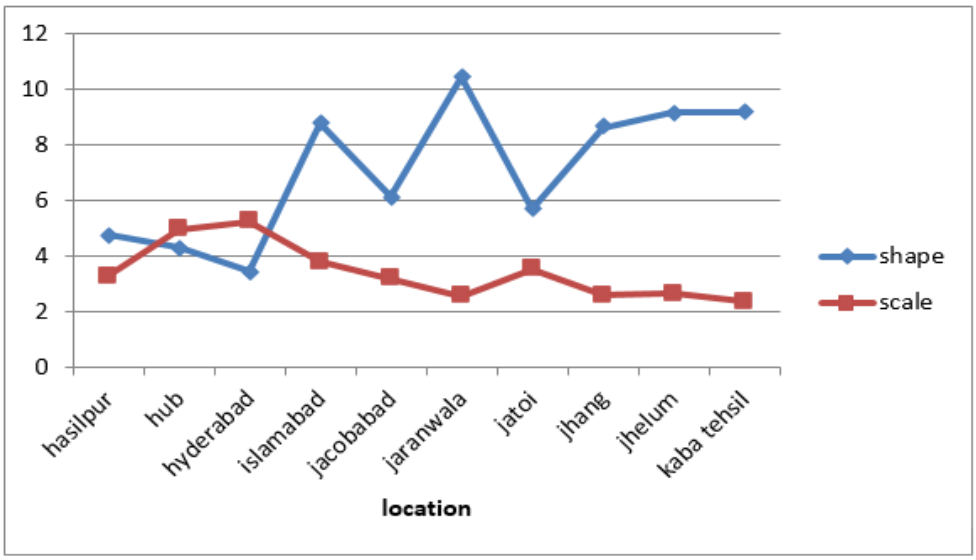
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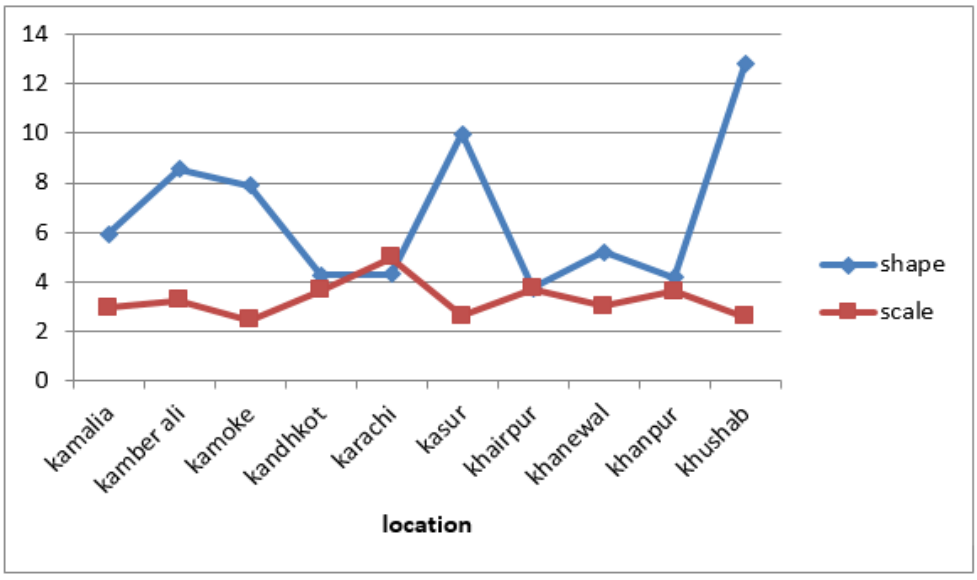
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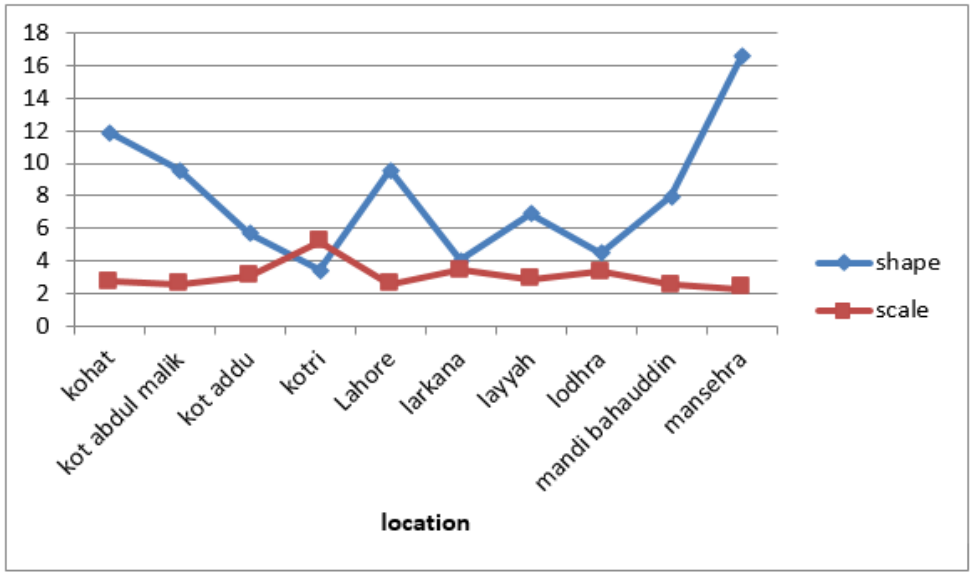
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Lahore
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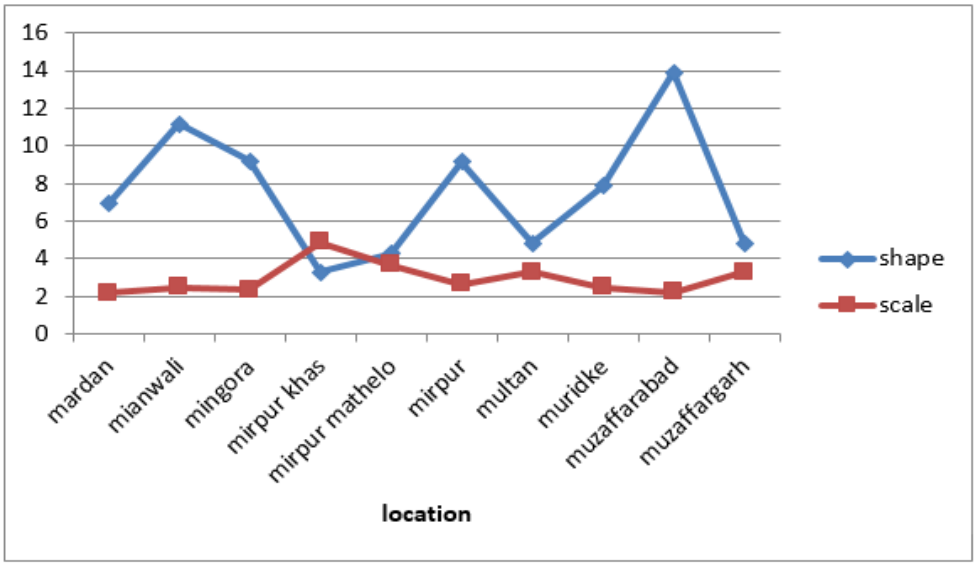
lodhra
mandi bahauddin
mansehra
location
shape
scale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mirpur mathelo
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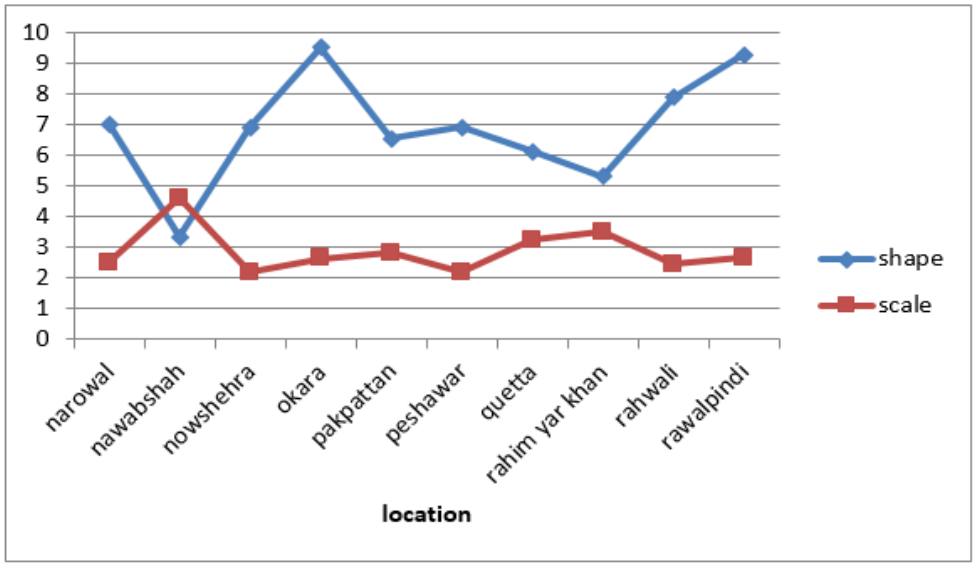
muridke
muzaffarabad
muzaffargarh
location
shape
scale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narowal
nawabshah
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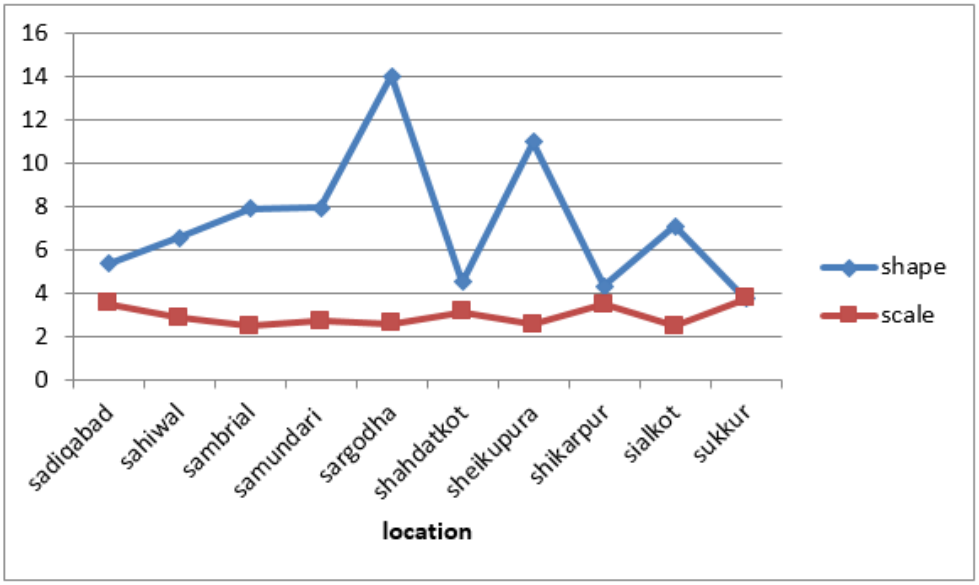
peshawar
quetta
rahim yar khan
rahwali
rawalpindi
location
shape
scale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sadiqabad
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sambrial
samundari
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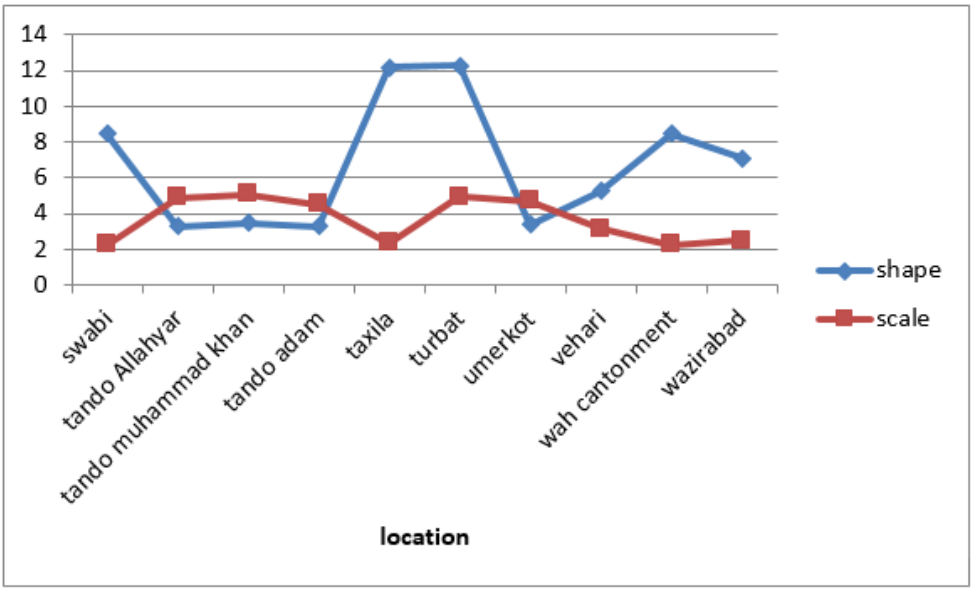
shahdatkot
sheikupura
shikarpur
sialkot
sukkur
location
shape
scale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swabi
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tando adam
taxila
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umerkot
vehari
wah cantonment
wazirabad
location
shape
scale

Table 6

Shape and scale parameters

Locations	**Shape**	**Scale**	**Locations**	**Shape**	**Scale**
khuzdar	8.145	3.085	jhang	8.637	2.586
Abbotabad	13.68	2.529	jhelum	9.167	2.654
Ahmedpur	4.29	3.514	kaba tehsil	9.187	2.36
Arifwala	6.558	2.834	kamalia	5.922	2.935
attock	8.453	2.221	kamber ali	8.565	3.255
badin	3.664	5.155	kamoke	7.884	2.463
bhakkar	7.272	2.753	kandhkot	4.259	3.653
bhalwal	9.77	2.589	karachi	4.304	4.96
bhawalnagar	5.48	3.032	kasur	9.99	2.606
bhawalpur	4.519	3.331	khairpur	3.744	3.719
burewala	5.232	3.119	khanewal	5.19	2.998
chakwal	9.494	2.578	khanpur	4.19	3.61
chaman	12.97	3.436	khushab	12.81	2.575
charsadda	6.934	2.181	kohat	11.93	2.715
chiniot	10.45	2.537	kot abdul malik	9.583	2.529
chishtian	5.48	3.032	kot addu	5.677	3.065
dadu	3.225	4.28	kotri	3.465	5.21
daharki	3.902	3.746	Lahore	9.583	2.529
daska	7.094	2.462	larkana	4.052	3.444
deraghazi	8.465	3.468	layyah	6.931	2.893
dera ismail	12.8	3.075	lodhra	4.519	3.331
faisalabad	10.45	2.537	mandi bahauddin	7.95	2.511
ferozwala	9.583	2.529	mansehra	16.59	2.297
gawadar	17.18	4.657	mardan	6.934	2.181
ghotki	4.259	3.653	mianwali	11.15	2.491
gojra	6.999	2.75	mingora	9.187	2.36
gujranwala	7.884	2.463	mirpur khas	3.302	4.857
gujrat	7.094	2.462	mirpur mathelo	4.259	3.653

Table 6 (continued)

Locations	Shape	Scale	Locations	Shape	Scale
hafizabad	9.773	2.461	mirpur	9.167	2.654
haroonabad	5.018	3.201	multan	4.824	3.27
Hasilpur	4.772	3.272	muridke	7.884	2.463
hub	4.304	4.96	muzaffarabad	13.9	2.225
hyderabad	3.465	5.21	muzaffargarh	4.824	3.27
islamabad	8.799	3.813	narowal	7.029	2.504
jacobabad	6.14	3.193	nawabshah	3.34	4.611
jaranwala	10.45	2.537	nowshehra	6.934	2.181
jatoi	5.71	3.508	okara	9.517	2.634
pakpattan	6.558	2.834			
peshawar	6.934	2.181			
quetta	6.142	3.239			
rahim yar khan	5.334	3.505			
rahwali	7.884	2.463			
rawalpindi	9.302	2.655			
sadiqabad	5.334	3.505			

Table 6 shows the values of (shape) k and (scale) c of Pakistan's 100 densely populated areas

Minimum value of shape is 3.225 of dadu Location: Latitude 26.7325 Longitude 67.7792 and maximum value is 17.18 of Gwadar Location: Latitude 25.1264 Longitude 62.3225

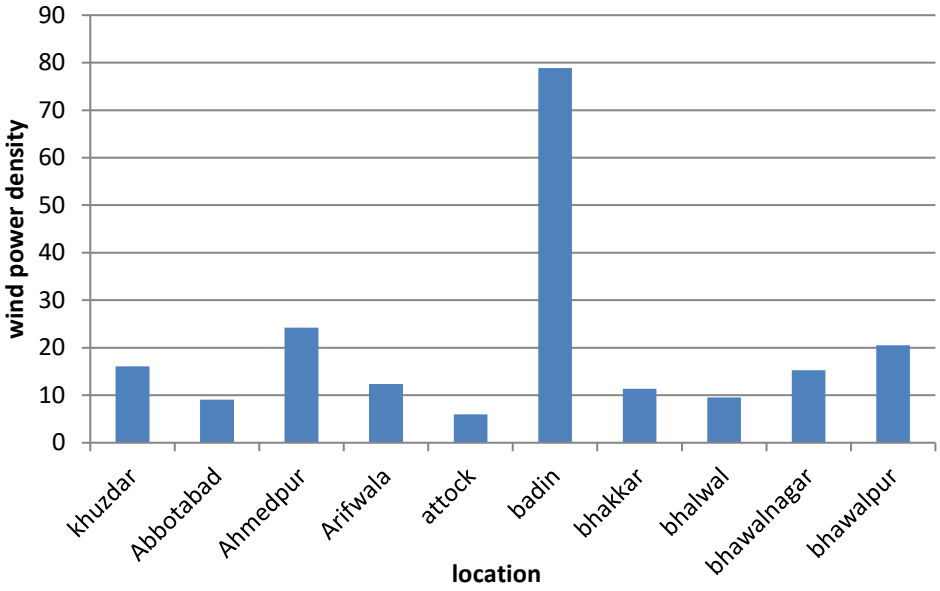
Minimum value of scale is Peshawar 2.181 Location: Latitude 34.0144 Longitude 71.5675 and maximum value is 5.21 Kotri Location: Latitude 25.374 Longitude 68.3013 and Hyderabad

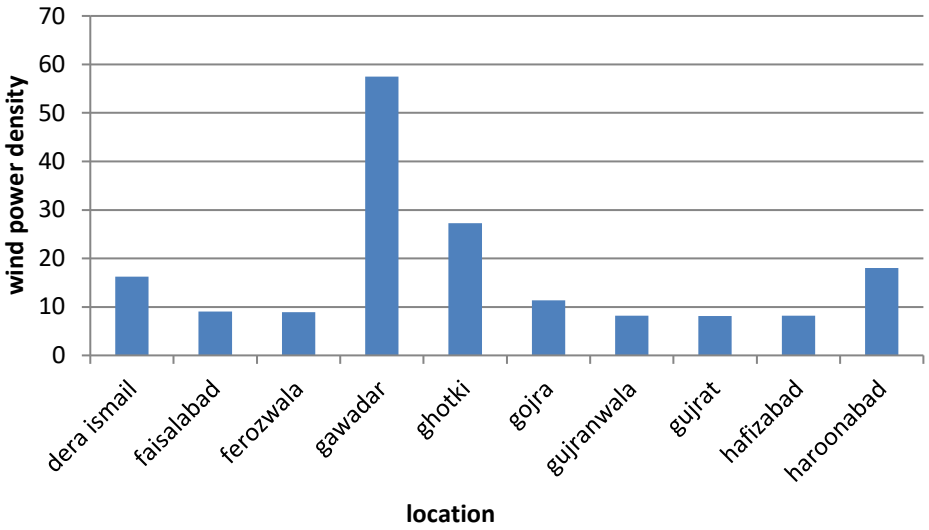
Furthermore, the bar charts below shows WPD of selected cities calculated from WPD equation Values fluctuates around 5.65274448 ms^{-1} to 82.66915 ms^{-1}

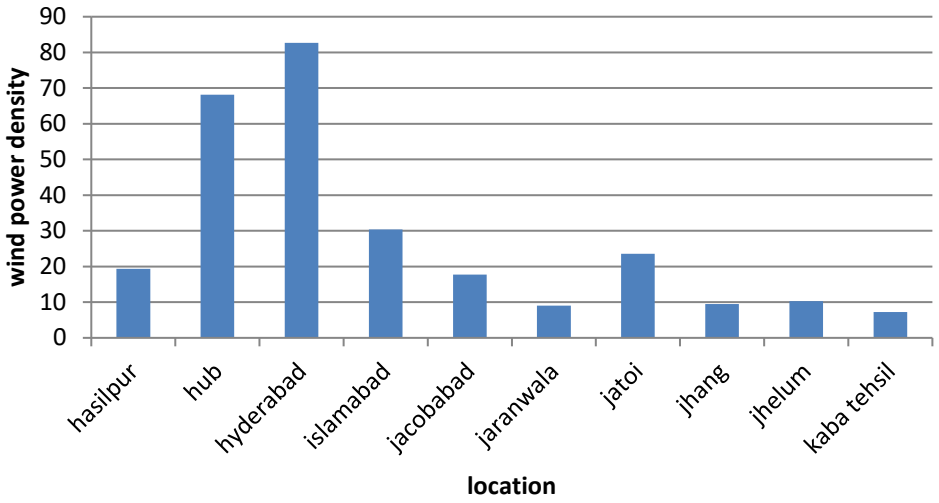
Minimum mean wind power density were seen in the cities like Peshawar, nowshera, mardan and charsadda., Maximum mean wind power density was seen in region of kotri

Figure 26

Wind power density of different cities






wind power density
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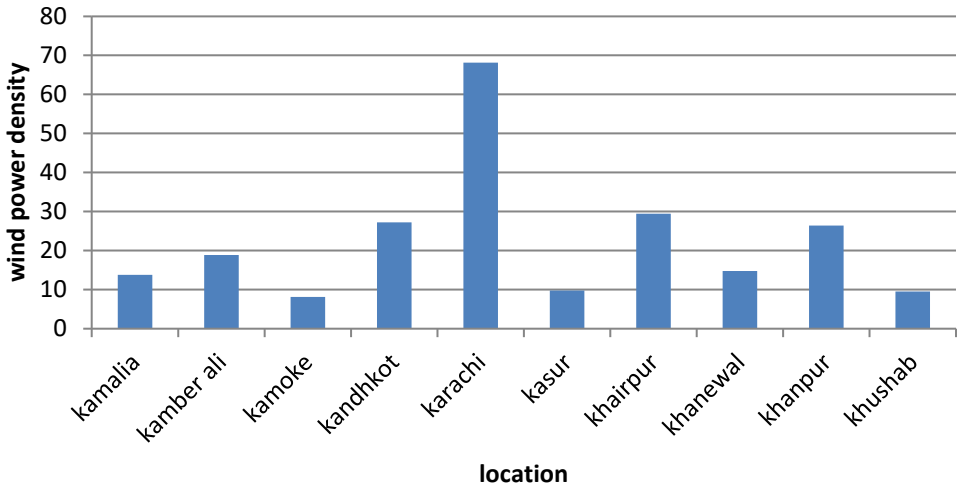
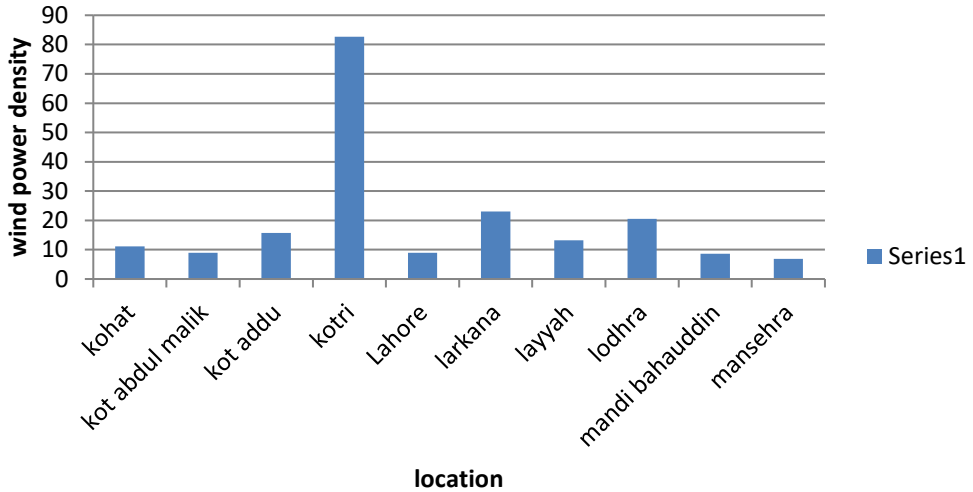
80
70
60
50
40
30
20
10
0
hasilpur
hub
hyderabad
islamabad
jacobabad
jaranwala
jatoi
jhang
jhelum
kaba tehsil
location


wind power density
80
70
60
50
40
30
20
10
0
kamalia
kamber ali
kamoke
kandhkot
karachi
kasur
khairpur
khanewal
khanpur
khushab
location


wind power density
90
80
70
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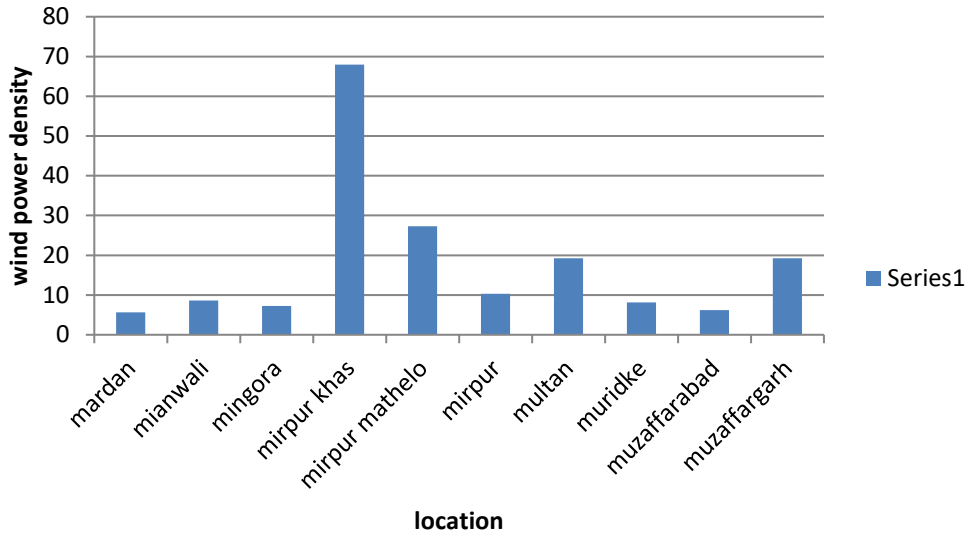
40
30
20
10
0
kohat
kot abdul malik
kot addu
kotri
Lahore
larkana
layyah
lodhra
mandi bahauddin
mansehra
location
Series1


wind power density
80
70
60
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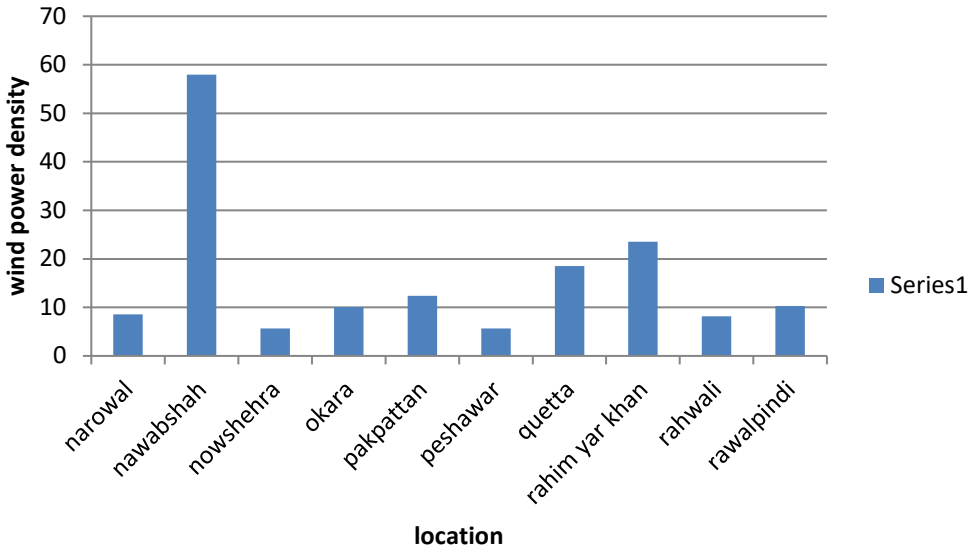
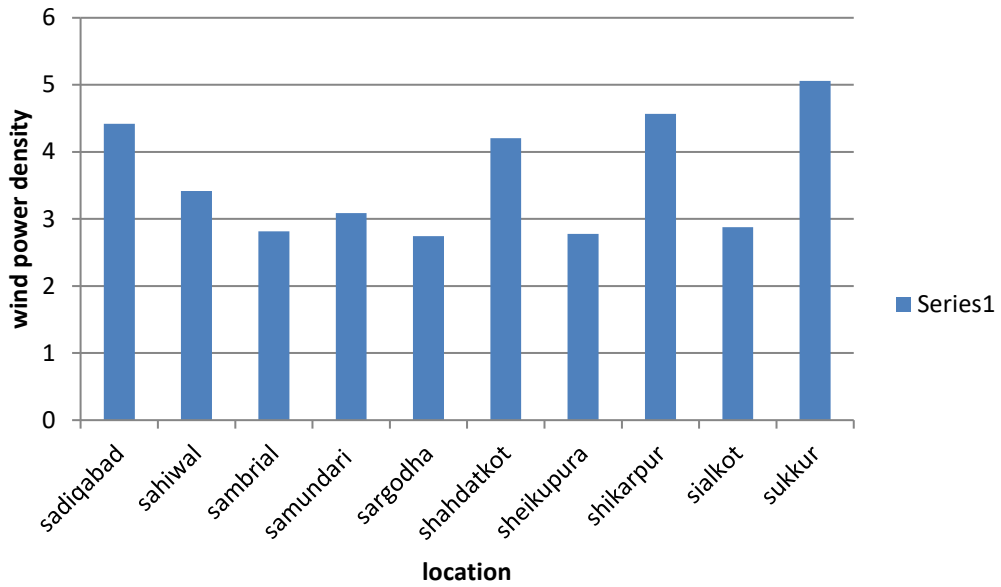
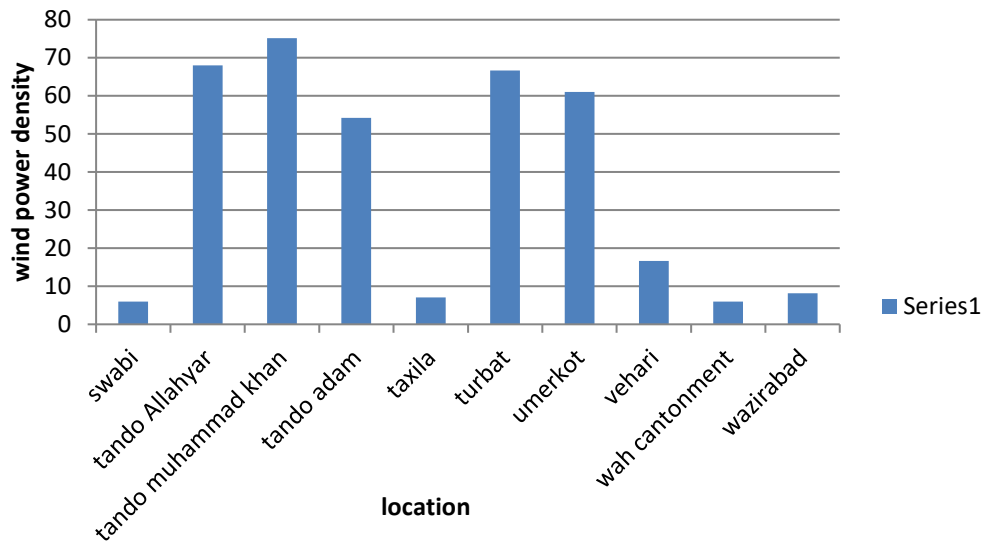
0
mardan
mianwali
mingora
mirpur khas
mirpur mathelo
mirpur
multan
muridke
muzaffarabad
muzaffargarh
location
Series1


wind power density
70
60
50
40
30
20
10
0
narowal
nawabshah
nowshehra
okara
pakpattan
peshawar
quetta
rahim yar khan
rahwali
rawalpindi
location
Series1


wind power density
6
5
4
3
2
1
0
sadiqabad
sahiwal
sambrial
samundari
sargodha
shahdatkot
sheikupura
shikarpur
sialkot
sukkur
location
Series1



About 18 wind Independent Power Projects (IPPs) have received land allocations from AEDB for 50 MW each of wind power producing projects. Most of these distributions are in the Sindh province especially in the villages of interior Sindh. Feasibility studies for 12 wind plants, each with a 50 Mega-Watt capacity, For eight wind plants (NEPRA) gives the approval and a license. Additionally, NEPRA has released information about the tariffs for four IPPs that use wind energy (Green Power, Dawood Power, Zorlu Enerji Pakistan, and Arabian Sea. One IPP, Fauji Fertilizer Company Ltd., is seeking authorization of its tariff petition). Additionally, reports on feasibility from other IPPs have been provided. This development suggests that the province of Sindh's wind potential is close to being utilized.

Wind energy potential of KPK

A significant amount of wind energy is present in Pakistan's KPK province's northwest (e.g Sakhakot, Totakan and Batkhela). Area of KPK is around 74,500 square kilometers. Table 3 KPK portion shows that 15.71% of the land is classified as having wind power which can be classified in moderate and some have excellent class. KPK is producing around 58,545 MW of power. Not many concrete steps have been taken so far to exploit the wind power potential in KPK. To take advantage of the tremendous potential wind energy here, effective efforts must be made immediately.

Wind potential of Balochistan

Balochistan province in Pakistan's southwest has a significant amount of wind power potential. Balochistan has an overall 347 thousand square kilometers area of land. Balochistan has an excellent wind potential which could be categorized in class 6 and 7. Unfortunately, no significant action has been taken to date to fully use this enormous potential area. Currently wind power plants which are in class 4 (good) are producing 63,700 MW of energy. Due to its isolated border location and the unstable and insecure political situation, this high potential windy area may have been overlooked. Exploring and using all locations with stron g wind potential is urgently needed given the nation's ongoing energy problem. Jiwani in Balochistan

Table7 shows different classes according to average wind speed and wind power density at the height of 10 meter.

Table 7

International wind power generation classification at 10m height

number	**Resource class**	**Speed (m/s)**	**WPD (W/m^2)**
1	poor	0-4.4	0-100
2	marginal	4.4-5.1	100-150
3	moderate	5.1-5.6	150-200
4	Good	5.6-6.0	200-250

CHAPTER V
Conclusion

Due to the country's expanding industrial sector and population, the demand for power has been rising quickly. Therefore, using renewable energy, such as wind and solar energy, can help to reduce GHG emissions and may be the greatest way to address the country's energy challenges.

Therefore, the purpose of this study was to look into the possibilities for wind energy in 100 different location in Pakistan

The features of wind speed were examined using the Weibull distribution function for the estimation of the wind energy potential. Furthermore, at a height of 10 meters, Weibull parameters and then WPD were calculated. Small-scale wind turbines may be viable for generating electricity in the regions, according to the report.

Future research will decide if it is necessary to also look at how financial factors like discount rates and inflation rates affect investment. In order to comprehend the impact, it is also important to investigate how the distribution and wind turbine system interact.

With this, price for the electricity will also decrease, for small scale systems where electricity is not reached or other sources are not feasible for power production

References

Agency, I. R. E. (2020). *Wind energy*. https://www.irena.org/Energy-Transition/Technology/Wind-energy

Ali, S. M. H., Zuberi, M. J. S., Tariq, M. A., Baker, D., & Mohiuddin, A. (2015). A study to incorporate renewable energy technologies into the power portfolio of Karachi, Pakistan. *Renewable and Sustainable Energy Reviews*, *47*, 14–22. https://doi.org/10.1016/j.rser.2015.03.009

Amamra, S.-A., Meghriche, K., Cherifi, A., & Francois, B. (2017). Multilevel Inverter Topology for Renewable Energy Grid Integration. *IEEE Transactions on Industrial Electronics*, *64*(11), 8855–8866. https://doi.org/10.1109/TIE.2016.2645887

Amber, K., Ahmad, R., Farmanbar, M., Bashir, M., Mehmood, S., Khan, M., & Saeed, M. (2021). Unlocking Household Electricity Consumption in Pakistan. *Buildings*, *11*(11), 566. https://doi.org/10.3390/buildings11110566

Amjad, F., & Shah, L. A. (2020). Identification and assessment of sites for solar farms development using GIS and density based clustering technique- A case of Pakistan. *Renewable Energy*, *155*, 761–769. https://doi.org/10.1016/j.renene.2020.03.083

Arreyndip, N. A., Joseph, E., & David, A. (2016). Wind energy potential assessment of Cameroon's coastal regions for the installation of an onshore wind farm. *Heliyon*, *2*(11), e00187. https://doi.org/10.1016/j.heliyon.2016.e00187

Asif, M. (2009). Sustainable energy options for Pakistan. *Renewable and Sustainable Energy Reviews*, *13*(4), 903–909. https://doi.org/10.1016/j.rser.2008.04.001

Baloch, M., Abro, S., Sarwar Kaloi, G., Mirjat, N., Tahir, S., Nadeem, M., Gul, M., Memon, Z., & Kumar, M. (2017). A Research on Electricity Generation from Wind Corridors of Pakistan (Two Provinces): A Technical Proposal for Remote Zones. *Sustainability*, *9*(9), 1611. https://doi.org/10.3390/su9091611

Baloch, M. H., Kaloi, G. S., & Memon, Z. A. (2016). Current scenario of the wind energy in Pakistan challenges and future perspectives: A case study. *Energy Reports*, *2*, 201–210. https://doi.org/10.1016/j.egyr.2016.08.002

BioteCH4. (2020). *What is the Difference Between Biomass & Biogas?*

Burton, L. D. (2019). *Agriscience: Fundamentals and Applications* (6th editio).

Delmar Cengage Learning.

Burton, T., Jenkins, N., Sharpe, D., & Bossanyi, E. (2011). *Wind Energy Handbook*. Wiley. https://doi.org/10.1002/9781119992714

Caglayan, D. G., Ryberg, D. S., Heinrichs, H., Linßen, J., Stolten, D., & Robinius, M. (2019). The techno-economic potential of offshore wind energy with optimized future turbine designs in Europe. *Applied Energy*, *255*, 113794. https://doi.org/10.1016/j.apenergy.2019.113794

Daniels, P. (2009). *The new solar system: ice worlds, moons, and planets redefined*. Washington, D.C. : National Geographic Society, [2009.

Denholm, P., Brinkman, G., & Mai, T. (2018). How low can you go? The importance of quantifying minimum generation levels for renewable integration. *Energy Policy*, *115*, 249–257. https://doi.org/10.1016/j.enpol.2018.01.023

Dickson, M. H., & Fanelli, M. (2013). *Geothermal Energy*. Routledge. https://doi.org/10.4324/9781315065786

Eric Roston, Mira Rojanasakul, Paul Murray, Brittany Harris, D. P. and A. T., & Rutkoff. (2019). *Global Trends in Renewable Energy Investment 2019*. https://www.bloomberg.com/graphics/climate-change-data-green/investment.html?leadSource=uverify wall

Finance, M. of. (2021). *Pakistan Electricity Consumption*.

Ghafoor, A., Rehman, T. ur, Munir, A., Ahmad, M., & Iqbal, M. (2016). Current status and overview of renewable energy potential in Pakistan for continuous energy sustainability. *Renewable and Sustainable Energy Reviews*, *60*, 1332–1342. https://doi.org/10.1016/j.rser.2016.03.020

Greiner, P. T., York, R., & McGee, J. A. (2022). When are fossil fuels displaced? An exploratory inquiry into the role of nuclear electricity production in the displacement of fossil fuels. *Heliyon*, *8*(1), e08795. https://doi.org/10.1016/j.heliyon.2022.e08795

Kamran, M. (2018). Current status and future success of renewable energy in Pakistan. *Renewable and Sustainable Energy Reviews*, *82*, 609–617. https://doi.org/10.1016/j.rser.2017.09.049

Kamran, M., Fazal, M. R., & Mudassar, M. (2020). Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis. *Renewable Energy*, *146*, 543–558. https://doi.org/10.1016/j.renene.2019.06.165

Keyhani, A., Ghasemi-Varnamkhasti, M., Khanali, M., & Abbaszadeh, R. (2010). An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. *Energy*, *35*(1), 188–201. https://doi.org/10.1016/j.energy.2009.09.009

Khalil, H. B., & Zaidi, S. J. H. (2014). Energy crisis and potential of solar energy in Pakistan. *Renewable and Sustainable Energy Reviews*, *31*, 194–201. https://doi.org/10.1016/j.rser.2013.11.023

Khalil, M., Berawi, M. A., Heryanto, R., & Rizalie, A. (2019). Waste to energy technology: The potential of sustainable biogas production from animal waste in Indonesia. *Renewable and Sustainable Energy Reviews*, *105*, 323–331. https://doi.org/10.1016/j.rser.2019.02.011

Khan, J., & Arsalan, M. H. (2016). Solar power technologies for sustainable electricity generation – A review. *Renewable and Sustainable Energy Reviews*, *55*, 414–425. https://doi.org/10.1016/j.rser.2015.10.135

Khan, K. S., & Tariq, M. (2018). Wind resource assessment using SODAR and meteorological mast – A case study of Pakistan. *Renewable and Sustainable Energy Reviews*, *81*, 2443–2449. https://doi.org/10.1016/j.rser.2017.06.050

Lund, H. (2007). Renewable energy strategies for sustainable development. *Energy*, *32*(6), 912–919. https://doi.org/10.1016/j.energy.2006.10.017

Lund, H., & Salgi, G. (2009). The role of compressed air energy storage (CAES) in future sustainable energy systems. *Energy Conversion and Management*, *50*(5), 1172–1179. https://doi.org/10.1016/j.enconman.2009.01.032

M.A, Sheikh. (2003). *Pakistan energy yearbook: hydrocarbon development Institute of Pakistan. Ministry of Petroleum and Natural Resources*.

Makkawi, A., Tham, Y., Asif, M., & Muneer, T. (2009). Analysis and inter-comparison of energy yield of wind turbines in Pakistan using detailed hourly and per minute recorded data sets. *Energy Conversion and Management*, *50*(9), 2340–2350. https://doi.org/10.1016/j.enconman.2009.05.017

Malik, M. Z., Ali, A., Kaloi, G. S., Soomro, A. M., Baloch, M. H., & Chauhdary, S. T. (2020). Integration of Renewable Energy Project: A Technical Proposal for Rural Electrification to Local Communities. *IEEE Access*, *8*, 91448–91467. https://doi.org/10.1109/ACCESS.2020.2993903

Malik, S. N., & Sukhera, O. R. (2012). Management of natural gas resources and

search for alternative renewable energy resources: A case study of Pakistan. *Renewable and Sustainable Energy Reviews*, *16*(2), 1282–1290. https://doi.org/10.1016/j.rser.2011.10.003

Mirza, Umar K. & Maroto-Valer, M. Mercedes & Ahmad, N. (2003). Status and outlook of solar energy use in Pakistan. *Renewable and Sustainable Energy Reviews,* 501–514. https://ideas.repec.org/a/eee/rensus/v7y2003i6p501-514.html

Mirza, I. A., Khan, N. A., & Memon, N. (2010). Development of benchmark wind speed for Gharo and Jhimpir, Pakistan. *Renewable Energy*, *35*(3), 576–582. https://doi.org/10.1016/j.renene.2009.08.008

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

Muñoz, Y., Guerrero, J., & Ospino, A. (2014). Evaluation of a hybrid system of renewable electricity generation for a remote area of colombia using homer software. *TECCIENCIA*, *9*(17), 57–67. https://doi.org/10.18180/tecciencia.2014.17.6

Nazir, M. S., Mahdi, A. J., Bilal, M., Sohail, H. M., Ali, N., & Iqbal, H. M. N. (2019). Environmental impact and pollution-related challenges of renewable wind energy paradigm – A review. *Science of The Total Environment*, *683*, 436–444. https://doi.org/10.1016/j.scitotenv.2019.05.274

NREL. (2015). *Geospatial Data Science*.

Paletto, A., Bernardi, S., Pieratti, E., Teston, F., & Romagnoli, M. (2019). Assessment of environmental impact of biomass power plants to increase the social acceptance of renewable energy technologies. *Heliyon*, *5*(7), e02070. https://doi.org/10.1016/j.heliyon.2019.e02070

Rabbani, R., & Zeeshan, M. (2020). Exploring the suitability of MERRA-2 reanalysis data for wind energy estimation, analysis of wind characteristics and energy potential assessment for selected sites in Pakistan. *Renewable Energy*, *154*, 1240–1251. https://doi.org/10.1016/j.renene.2020.03.100

Rafique, M., Rehman, S., Alam, M., & Alhems, L. (2018). Feasibility of a 100 MW Installed Capacity Wind Farm for Different Climatic Conditions. *Energies*, *11*(8), 2147. https://doi.org/10.3390/en11082147

Raheem, A., Abbasi, S. A., Memon, A., Samo, S. R., Taufiq-Yap, Y. H., Danquah, M. K., & Harun, R. (2016). Renewable energy deployment to combat energy crisis in Pakistan. *Energy, Sustainability and Society*, *6*(1), 16. https://doi.org/10.1186/s13705-016-0082-z

Saulat, H., Khan, M. M., Aslam, M., Chawla, M., Rafiq, S., Zafar, F., Khan, M. M., Bokhari, A., Jamil, F., Bhutto, A. W., & Bazmi, A. A. (2021). Wind speed pattern data and wind energy potential in Pakistan: current status, challenging platforms and innovative prospects. *Environmental Science and Pollution Research*, *28*(26), 34051–34073. https://doi.org/10.1007/s11356-020-10869-y

Shah, S. A. A., & Solangi, Y. A. (2019). A sustainable solution for electricity crisis in Pakistan: opportunities, barriers, and policy implications for 100% renewable energy. *Environmental Science and Pollution Research*, *26*(29), 29687–29703. https://doi.org/10.1007/s11356-019-06102-0

Shaikh, F., Ji, Q., & Fan, Y. (2015). The diagnosis of an electricity crisis and alternative energy development in Pakistan. *Renewable and Sustainable Energy Reviews*, *52*, 1172–1185. https://doi.org/10.1016/j.rser.2015.08.009

Shakeel, S. R., Takala, J., & Shakeel, W. (2016). Renewable energy sources in power generation in Pakistan. *Renewable and Sustainable Energy Reviews*, *64*, 421–434. https://doi.org/10.1016/j.rser.2016.06.016

Shami, S. H., Ahmad, J., Zafar, R., Haris, M., & Bashir, S. (2016). Evaluating wind energy potential in Pakistan's three provinces, with proposal for integration into national power grid. *Renewable and Sustainable Energy Reviews*, *53*, 408–421. https://doi.org/10.1016/j.rser.2015.08.052

Sheikh, M. A. (2009). Renewable energy resource potential in Pakistan. *Renewable and Sustainable Energy Reviews*, *13*(9), 2696–2702. https://doi.org/10.1016/j.rser.2009.06.029

Sheikh, M. A. (2010). Energy and renewable energy scenario of Pakistan. *Renewable and Sustainable Energy Reviews*, *14*(1), 354–363. https://doi.org/10.1016/j.rser.2009.07.037

Sher, H. A., Murtaza, A. F., Addoweesh, K. E., & Chiaberge, M. (2015). Pakistan's progress in solar PV based energy generation. *Renewable and Sustainable Energy Reviews*, *47*, 213–217. https://doi.org/10.1016/j.rser.2015.03.017

Shoaib, M., Siddiqui, I., Amir, Y. M., & Rehman, S. U. (2017). Evaluation of wind

power potential in Baburband (Pakistan) using Weibull distribution function. *Renewable and Sustainable Energy Reviews*, *70*, 1343–1351. https://doi.org/10.1016/j.rser.2016.12.037

Society, N. G. (2022). *Fossil fuels*.

Sørensen, J. N. (2016). *The General Momentum Theory* (pp. 43–58). https://doi.org/10.1007/978-3-319-22114-4_4

Stökler, S., Schillings, C., & Kraas, B. (2016). Solar resource assessment study for Pakistan. *Renewable and Sustainable Energy Reviews*, *58*, 1184–1188. https://doi.org/10.1016/j.rser.2015.12.298

Tahir, Z. R., & Asim, M. (2018). Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review. *Renewable and Sustainable Energy Reviews*, *81*, 2839–2861. https://doi.org/10.1016/j.rser.2017.06.090

Tahir, Z. ul R., Azhar, M., Blanc, P., Asim, M., Imran, S., Hayat, N., Shahid, H., & Ali, H. (2020). The evaluation of reanalysis and analysis products of solar radiation for Sindh province, Pakistan. *Renewable Energy*, *145*, 347–362. https://doi.org/10.1016/j.renene.2019.04.107

Topcu, M., & Tugcu, C. T. (2020). The impact of renewable energy consumption on income inequality: Evidence from developed countries. *Renewable Energy*, *151*, 1134–1140. https://doi.org/10.1016/j.renene.2019.11.103

Turgeon, A., & Morse, E. (2022). *solar energy*. https://education.nationalgeographic.org/resource/solar-energy

Ullah, I., Chaudhry, Q.-Z., & Chipperfield, A. J. (2010). An evaluation of wind energy potential at Kati Bandar, Pakistan. *Renewable and Sustainable Energy Reviews*, *14*(2), 856–861. https://doi.org/10.1016/j.rser.2009.10.014

United Nations. (2020). *Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All*. https://www.seforall.org/who-we-are.

Wakeel, M., Chen, B., & Jahangir, S. (2016). Overview of Energy Portfolio in Pakistan. *Energy Procedia*, *88*, 71–75. https://doi.org/10.1016/j.egypro.2016.06.024

APPENDICES

Appendix A

Table 8 summary of renewable energies in Pakistan

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(Asif, 2009) Sustainable energy options for Pakistan.	5 projects in Punjab	Hydropower Solar Biomass	In last two eras only hydropower power plant produces 1450MW of energy After that solar has also a good potential then comes biogass with minimum of wind potential
The evaluation of reanalysis and analysis products of solar radiation for Sindh province, Pakistan (Z. ul R. Tahir et al., 2020)	Karachi, Hyderabad	Solar radiation	Results were better in clear sky months. In summer the results were better as compared to winters. The clearness indices was matched with Karachi and Hyderabad Some changes need to be made in climate topology for better solar energy

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(Kamran et al., 2020) Towards empowerment of the renewable energy sector in Pakistan for sustainable energy evolution: SWOT analysis	Wind at 50m height is around 7ms^{-1} at coast of Sindh and balochistan. Good results were at Jamshoro, Mirpur Sakro, Keti-Bandar, Thatta, Shah Bandar, Gharo, Nooriabad, Kotri, Thar, Hyderabad, and Matli. However, in Baluchistan, Gawadar, Ormara, Chowki, Pasni, Liari, Gadani, Jiwani, and Hub are the best sites of wind potential	Wind energy	with better aerodynamics. By using mini and micro wind turbines, off-grid wind energy system can be best PCRET has installed 155 small wind turbines of capacity 161 kW.
	Operational bagasse based project Mainly Punjab area	Bio energy	Can be used for heating and cooking purposes. The by-product of the biogas is asource of fertilizer, anaerobic can increase the efficiency by 60%

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
	The micro-hydro potential is mostly available on canal falls, natural falls and canal flow in Gilgit Baltistan, Punjab and Khyber Pakhtun Khawa	Hydro power	9 micro/small hydro projects of cumulative capacity 98.41MWare operational.
(Amjad & Shah, 2020) Identification and assessment of sites for solar farms development using GIS and density based clustering technique- A case of Pakistan	solar irradiance in Killa Saifullah and Kalat districts with a size of 10 km^2, Muslim Bagh, and Surab Town near Kharan Similarly, Panjgur, Mangocher, Kalat, between Panjgur and Nag, and halfway between Surab and Besima, respectively. Prominent among the solar farm sizes is 289 km2 near Nag village	Solar energy	Complete scanning of the data (1466 solar sites) yielded 23 dense clusters of sizes in the range of 10 km^2 to 289 km^2 uses solar irradiance and terrain ruggedness to reduce the development cost of the solar farm, a terrain ruggedness criterion was applied

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(Sheikh, 2009) Renewable energy resource potential in Pakistan	In 2007, the annual power densities of Khungipayan (Dir/NWFP) and Shaheed Gali (AJK) remained 27.49 W/m^2 and 208.19 W/m^2 with highest wind speed of 2.61 m/s and 6.53 m/s respectively Jamshoro, Katibandar, Nooriabad Thatta and Gharo are some locations	Wind energy	The survey of coastal areas of Pakistan has indicated that tremendous potential exists for harnessing wind energy .
(Sheikh, 2010) Energy and renewable energy scenario of Pakistan	Kohat (NWFP), D.G. Khan, Rawalpindi (Punjab), Tharparkar (Sindh), Turbat/Kalat (Balochistan),	Solar energy	providing 80Wpanel with lighting system to each house hold. PCRET electrified more than 500 schools, mosques, houses through PV power with total generation capacity of more than 80 kW

Table 8 (continued)

Reference	City	Type of energy	Result, conclusion, suggestion
	4 MW grid interactive wind power station at Gharo, Sindh gul muhammad village in sindh	Wind energy	PCRET installed 130 units of total generating capacity of 143 kW with wind turbines of 0.5–10 kW capacity/unit while electrifying 1430 houses.
	at Azad Jammu and Kashmir. -at Northern Areas.	Hydropower	AEDB is having financial and technical co-operation with Agha Khan Foundation, UNDP, GEF, ADB and GTZ, etc. for its hydropower projects. PCRET has installed microhydel power plants of total generation capacity more than 5 MW through units of 5–50 kW each

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
	Biogas plants are gaining high popularity among farmers of Punjab province especially in Bahawalpur area.	Biogas	AEDB is working on biogas project at Landhi cattle colony, Karachi (NZAID). project will generate 250 kW of electricity through biogas whereas generation capacity will be extended to 30MW along with production of 1500 ton of organic fertilizer per day Another biogas power generating plant with a capacity of 8.25 MW is under construction in Shakarganj Mill with the technical assistance of AEDB.

Table 8 (continued

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(S. N. Malik & Sukhera, 2012) Management of natural gas resources and search for alternative renewable energy resources: A case study of Pakistan	The four large Hydro Dams are: (i) Kalabagh – 3800 MW, (ii) Bhasha – 4600 MW, (iii) Bunji – 5400 MW, (iv) Dasu – 3800 MW	Hydro power/ Hydro energy	development of medium scale projects requiring low gestation period and low capital cost, hydel stations having characteristics to generate more power during April to June and development of small hydel projects for isolated areas
(H. B. Khalil & Zaidi, 2014) Energy crisis and potential of solar energy in Pakistan	China power investment crop (CPI Group) has shown keen interest in four power projects. Projects of 660 MW and 300 MW will be installed in Lahore and Bahawalpur respectively Gilgit–Baltistan Lahore, Faisalabad, Sialkot, Islamabad, gilgit, Karachi,	Solar energy	solar energy better than wind energy in major cities of Pakistan. In over all conditions the wind turbines are not feasible and produced sufficient energy in most of the cities. Wind turbines are only applicable in coastal and desert areas of Baluchistan.

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(Ali et al., 2015) A study to incorporate renewable energy technologies into the power portfolio of Karachi, Pakistan	Karachi	Wind And solar	It is suggested to offset 10% of the total power output for the peak load condition using a power portfolio that includes a 2.9% and 4.4% share of PV and PTC, a 2.0% share of wind and 0.7 % share of biomass.
(Sher et al., 2015) Pakistan's progress in solar PV based energy generation	deserts of Sindh, Cholistan desert of Punjab and Balochistan offers exquisite possibilities of installing mega solar PV power plants. In these areas the sun shines in the range of 2300–2700h per year	Solar energy	Peak load management during day time can be accomplished by efficiently utilizing the solar PV based systems. Shifting lighting load of public parks and street lights on solar PV is also recommended.

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(Shaikh et al., 2015) The diagnosis of an electricity crisis and alternative energy Development in Pakistan	desert area of Cholistan in the Punjab province QASPC project, and in the cities of Lodhran (30 MW), Cholistan (50 MW), Kasur (10 MW) and Muzaffurgarh (50 MW Concentrated Solar Power)	Solar	large hydro and nuclear power plants can be sustainable and secure energy options for the long-term energy needs of the country. The potential of roof top solar projects for electricity and heating purposes. The potential of the Bagasse-basedco-generation of electricity from sugarmills in the country should be studied.

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
(Shakeel et al., 2016) Renewable energy sources in power generation in Pakistan	Generally discussed about the different provinces sindh, balochistan and punjab	Solar, wind, hydro	Sixty per cent electricity from hydel sources Cheap and emissions free electricity generation The matter of load shedding can be resolved by addressing the issue of circular debt and upgrading the transmission network on the priority basis. T&D losses ought to be brought down, revenue collection must be increased, and the investment should be made in the transmission infrastructure.

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Wind resource assessment using SODAR and meteorological mast – A case study of Pakistan (K. S. Khan & Tariq, 2018)	Kallarkahar region of Pakistan Sardi Chakwal	Wind energy	Wind farm deployment is moving from flat to complex terrains because of the availability of stronger winds there. SODAR being a cheaper option as compared to expensive mast installation methods. In the end, the wind energy community also needs to define standard parameters for Accuracy checks.
Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review (Z. R. Tahir & Asim, 2018)	The solar potential of Pakistan (especially Sindh and Baluchistan provinces) is among the second highest around the world.	Solar energy	Some of the locations have high solar potential

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, coclusion, suggestion**
Current status and future success of renewable energy in Pakistan (Kamran, 2018)			The view of ongoing projects and accelerated R&D in RE organizations RE will get grounds in the future energy mix of Pakistan making it dominant with solar, wind and biomass energy and accordingly will mitigate energy import bills and the generation of CO_2 in the atmosphere.
Overview of energy portfolio in Pakistan (Wakeel et al., 2016)	Punjab especially Sialkot, Jung etc. Some biomass plants, for example SSJD (12MW) in Sindh, Lumen Energy (12MW) Shahkot, Biomass power generation limited in Faisalabad in Punjab and in Mardan in KPK,	solar, wind biogas and small hydropower.	According to this report, coastal belt of Sindh and Baluchistan has more than 50,000MW Wind Baluchistan and Sindh are also used for water pumping at small levels. There is also a great potential of renewable energy,

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Current scenario of the wind energy in Pakistan challenges and future perspectives: A case study (M. H. Baloch et al., 2016)	Pakistan has around 1100 kilometers (km) coastal line for the wind energy potential, but in this manuscript, we have chosen one of the most suitable wind corridors of the southern part of the country selected wind corridor of Jamshoro city	Wind energy	a German company GmbH constructed a wind turbine Bonus 600/44MKIV type, if wind speed ranges in between 7.2–8 m/s and 8–8.8 m/s at 30 m and 50 m height that would be an excellent zones for installing wind turbines respectively. Thermal/gas power plants are too old and their efficiency is <15% such as Uch Power Plant located in Punjab Province having capacity is around 800 MW, but due to aging it generates only few MW.

Table 8 (continued)

Reference	City	Type of energy	Result, conclusion, suggestion
Analysis and inter-comparison of energy yield of wind turbines in Pakistan using detailed hourly and per minute recorded data sets (Makkawi et al., 2009)	wind speed data have been measured over a period of 4 years at a minute's frequency for Southern Pakistan at Gharo. The period of measurement was May 2002–June 2006.	Wind energy	sea breeze is the prime source of wind resource in monsoon months. producing the most significant energy yields.
An evaluation of wind energy potential at Kati Bandar, Pakistan (Ullah et al., 2010)	Kati bandar a small village east of Karachi on the coast of Sindh.	Wind energy	The site is class 4 wind power site likely to be suitable for wind farms as well as small, stand-alone systems. Rayleigh and Weibull distributions are considered to be the most suitable for representing wind speed variations. In addition, the air density, the height of the turbine tower, and the design of turbine affect the power

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Renewable energy deployment to combat energy crisis in Pakistan (Raheem et al., 2016)	Balochistan= swat Thar , cholistan two solar plants in Gawadar, Bunji (7100 MW), Tarbela fourth extension (1399 MW), Kohala (1095 MW), Lower Palas Valley (660 MW), Mahl (599 MW), and Lower spat Gah (495 MW) large-scale reservoir projects (dams) including Diamer Basha (4400 MW), Dasu (4250 MW), Munda (735 MW), Kurram-Tangi (80 MW), and Kalabagh dam (KB) (3600 MW).	Wind Solar Hydropower	significant wind speeds were identified in the costal part of Baluchistan, particularly in Swat and some of the Northern areas. Out of 42 examined sites, seven have a capacity factor ranging from 10 to 18 % and are appropriate for Bonus wind turbines (Model 600/44 MK IV). Solar desalination is a new and cost-effective technology that can be used Sindh is endowed with wind potential in the South, Baluchistan is rich with solar potential in the West, and Khyber Pakhtunkhwa is rich with hydro in the northeast area

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Exploring the suitability of MERRA-2 reanalysis data for wind energy estimation, analysis of wind characteristics and energy potential assessment for selected sites in Pakistan (Modern-Era Retrospective analysis for Research and Applications) (Rabbani & Zeeshan, 2020)	Bahawalpur, Punjab Chakri, Punjab Gwadar, Balochistan Haripur, KPK Peshawar, KPK Quaidabad, Punjab Quetta, Balochistan Sadiqabad, Punjab Sanghar, Sindh Sujawal, Sindh Tando Ghulam Ali, Sindh Umerkot, Sindh	Wind	Four locations with high wind power densities, namely Sujawal, Sanghar, Tando Ghulam Ali and Umerkot showed good potential to add wind share to global energy mix. Assuming a Vestas 2MWturbine, and without the consideration of losses, the annual energy production per turbine were calculated. The energy output values for S10, S9 and S11 were found to be 10,082 MWh, 9753 MWh and 9154 MWh per year per turbine, which were considerably higher than those for the rest of sites.

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Wind speed pattern data and wind energy potential in Pakistan: current status, challenging platforms and innovative prospects (Saulat et al., 2021)	South-eastern area of Sindh province, northwestern area of Khyber Pakhtunkhwa (KPK) province and south western area of Balochistan province hold a great potential for harnessing wind energy Karachi	Wind energy	South-eastern area of Sindh province, northwestern area of Khyber Pakhtunkhwa (KPK) province and south western area of Balochistan province hold a great potential for harnessing wind energy. Wind power production capacity of 88460 MW exists in the province of Sindh with potential sites like Hyderabad, Kotri, Jerruck, Gharo, Jhimpir, Lakha, Khuttikun and Bhambore, Wind power park in Karachi has been announced by AEDB having a capacity of 2500MW

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
A sustainable solution for electricity crisis in Pakistan: opportunities, barriers, and policy implications for 100% renewable energy (Shah & Solangi, 2019)	Pakistan	Biomass (biogass)	Sugarcane residue produces an estimate of more than 18 million tons of bagasse every year, high-pressure cogeneration plants at 84 sugar mills in the country can produce 1844 MW.
		Solar energy	The 10-year averaged data of Pakistan shows that the average insolation in the country varies from 5 to 7 kWh/m2/day, whereas 30% of areas in Pakistan receive solar insolation of more than 6 kWh/m2/day the government of

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Solar resource assessment study for Pakistan (Stökler et al., 2016)	Northern part of balochistan	Solar energy	There are 8–10 mean hours of sunshine a day, equating to 15 × 1014 kWh solar radiation annually. These values are enough to harness 1600 GW power in a year. In March 2015, the World Bank conducted a solar assessment survey of Pakistan and determined that almost 90% of areas receive 2000 kWh/m2 of global horizontal irradiance annually.

Table 8 (continued)

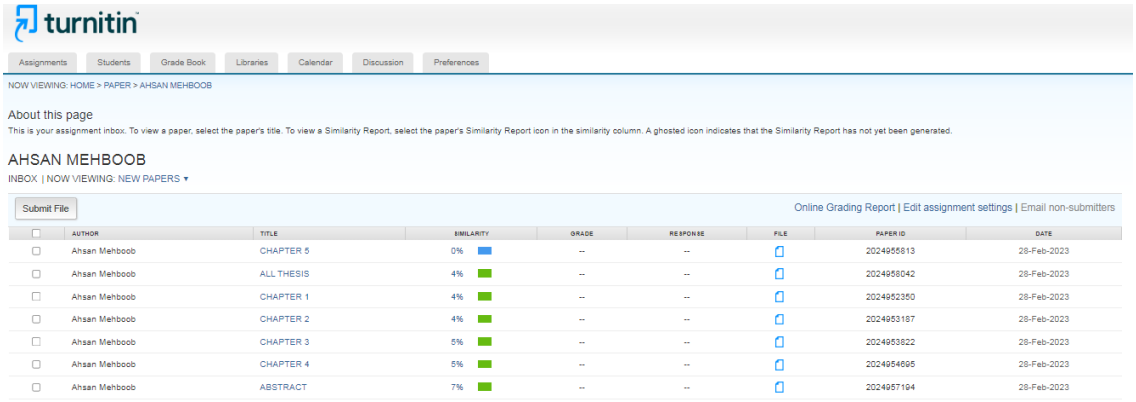
Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Development of benchmark wind speed for Gharo and Jhimpir, (Mirza et al., 2010)	Gharo, jimphir. The wind power projects currently being pursued lie in (i) the area between towns of Gharo and Mirpur Sakro, and (ii) Jhimpir area. The land allocated to wind power project developers in Gharo area is in two clusters, Bhambore and Khuttikun.	Wind energy	The trend of wind speeds cannot be predicted without having long term reliable wind speed data. The project developers find it difficult to make power production estimates and calculation of financial returns without analyzing wind speeds and knowing wind power density. Wind farm developers can make their financial models considering the annual energy production (AEP) on benchmark wind speed values. The wind risk approach has minimized the financial risks

Table 8 (continued)

Reference	**City**	**Type of energy**	**Result, conclusion, suggestion**
Evaluating wind energy potential in Pakistan's three provinces, with proposal for integration into national power grid (Shami et al., 2016)	southeastern region of Pakistan located in Sindh has high wind power potential. This region includes coastal areas of Sindh as well as some locations in interior Sindh. Some of the cities/towns located within the windy region with their geographic locations are: Hyderabad, kotri, jerruck wind power potential exists in southwestern region of Pakistan located in the province of Balochistan Koh-i-Dalil, Tozghi, Juzzak, Jiwani	Wind energy	Balochistan has the highest wind power potential among the three provinces evaluated About 12,000 sq. km area is available in Balochistan with good-to-excellent wind power classes for power generation of up to 64,000 MWafter meeting all area utilization constraints. small scale micro grids can be powered up through wind farms like that of 50 MW Gharo wind corridor in Sindh.

Appendix X

Similarity Report



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