A techno-economic and socio-environmental planning of wind farms for sustainable development and transition to a decarbonized scenario: Pakistan as a case study

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Session 2020-22

Supervised by

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June 2022

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by **Mr. Mohammad Uzair Shah** (Registration No. **00000329241**), of U.S.-Pakistan Center for Advanced Studies in Energy has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within the similarity indices limit and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Certificate

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DEDICATION

To everyone we hold dear.

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This project would not have been possible without the help that came in all shapes and forms from many people including, but not limited to, Dr. Sehar Shakir, Dr. Saeeda Khanum, Dr. Adeel Waqas, Mr. Abdul Kashif Janjua, my parents, and teachers.

Thank You.

Mohammad Uzair Shah

Abstract

Wind energy is one of the rapidly growing fields of renewable energy in the world. In Pakistan, despite having a tremendous potential, the installed capacity of wind energy is stalled at 1,287 MW which is around 0.37% of the total available potential. The following study investigates potential locations throughout Pakistan at provincial level with high suitability for wind farm deployment. The assessment of wind resource at each location is performed by utilizing GIS wind speed and power density data. Twenty locations all over Pakistan, with 3 to 5 sites in each province of Pakistan, are selected. In order to evaluate the feasibility at each selected site, SAM is utilized to model 50 MW wind farm and perform techno-economic analysis. Sites are also prioritized depending on their estimated net energy yield, capacity factor, NPV, LCOE and payback period. RETScreen is utilized to determine the net reduction in carbon equivalent emissions and liters of gasoline saved from combustion. Social impact assessment is also an integral part of the study which is performed to evaluate the public's opinion and perception about wind turbines. It is carried out by conducting survey and interviews in Khuzdar, Baluchistan and Jhimpir, Sindh. It is investigated that Sothgun, Washuk in Baluchistan demonstrated the most suitable techno-economic feasibility. The net annual electricity yield at Sothgun came out to be 287,766 MWh with a simple payback period of 4.2 years. The net reduction in CO_{2e} emissions was evaluated to be 105,808 tons per year with 45,463,165 liters of gasoline not consumed. The results of social assessment suggest that the government of Pakistan should include public awareness and participation schemes, financial incentives, efficient feed-in-tariffs and indigenization of wind technology into the next energy policy of Pakistan.

Keywords: Wind energy; Techno-economic analysis; social impact assessment; SAM; RETScreen

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1. **A techno-economic and socio-environmental planning of wind farms for sustainable development and transition to a decarbonized scenario: Pakistan as a case study**

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   Under review in Sustainable Energy Technologies and Assessments.

List of Abbreviations

AQI	Air Quality Index
AEDB	Alternate Energy Development Board
CSR	Corporate Social Responsibility
GIS	Graphing Information System
GHG	Greenhouse Gas
HAWT	Horizontal Axis Wind Turbine
KPK	Khyber-Pakhtunkhwa
LCOE	Levelized Cost of Electricity
NREL	National Renewable Energy Laboratory
NPC	Net Present Cost
NPV	Net Present Value
PCRET	Pakistan Council of Renewable Energy Technology
PM	Particulate Matter
PV	Photovoltaic
R&D	Research and Development
RERs	Renewable Energy Resources
RETs	Renewable Energy Technologies
SAM	System Advisor Model
SPP	Simple Payback Period
T&D	Transmission and Distribution
WRA	Wind Resource Assessment
VAWT	Vertical Axis Wind Turbine

Chapter 1: Introduction

1.1 Global energy scenario

Nowadays, energy is considered as the key element for the development of a nation. It plays an important role in the economic, industrial and social growth of a country and its population. Considering the global energy scenario, around 80% of the total global energy needs are fulfilled by fossil fuels [1]. The current level of fossil fuels consumption has resulted in a sharp decline in the global fossil fuel reserves. According to the studies, at the current level of fossil fuel combustion, the reserves will completely exhaust by 2060 [2]. By digging deeper into this, it is found that oil can last up to 50 years, natural gas up to 53 years, and coal up to 114 years approximately at the current level of consumption [3]. Apart from the decline in the reserves, burning of fossil fuels produces a plenty of harmful exhaust gases such as Oxides of Carbon (carbon dioxide and monoxide – CO_x), Oxides of Nitrogen (NOx), Oxides of Sulphur (SO_x) and Particulate Matter (PM) [4]. The emission of these gases has caused multiple environmental issues such as global warming, acid rain, smog, and so on. Climate change is the most prominent threat of today. It is considered as the slow poison for the life on Earth and has the potential to impact human life cycle in a terrible manner.

The following rate of decline in fossil fuel reserves and related environmental impacts have gotten the attention of many scientists, energy engineers and politicians to look for more sustainable means for energy. The goal is to look for energy resources which are cleaner and do not deplete, so providing energy security and independence to the country [5]. Considering the following situation, Renewable Energy Resources (RERs) are considered as the potential candidate to solve the mentioned problems. RERs are the energy resources which do not deplete and get replenished over finite period in human lifetime. Moreover, harnessing energy from RERs do not significantly add Greenhouse Gas (GHG) emissions into the environment. In the past few decades, a tremendous growth in RERs has been observed because of improved institutional framework and economic policy measures. RETs are regarded as a best possible solution to meet the global energy needs in a most sustainable way. Along with providing energy sustainability and environmental stability, it provides energy security and independence to the energy sector of a country The most widely used Renewable Energy Technologies (RETs) are given as:

- Hydel Energy
- Solar Energy
- Wind Energy
- Bioenergy
- Geo-thermal Energy
- Tidal Energy

Hydel energy utilizes dams to store huge water bodies at some elevation and then the water is released in a regulated way to run the turbines. Simply, in hydel energy, the potential energy of the stored water body is converted into electricity by the means of turbines. In solar energy, the energy in the sunlight (solar radiation) is converted into electricity. Solar energy has two means to convert solar energy into electricity. First, it utilizes solar PV modules to convert sunlight into electricity through optical means and second, it is converting solar energy to electricity through thermal means. Commercially, solar PV is most cost effective and commonly used commercially. Similarly, as the name refers, wind energy utilizes energy of the incoming wind to generate electricity using the wind turbines. Bioenergy utilizes biomass content to produce biofuels. Geothermal energy utilizes heat energy present in the deeper layers of earth surface while on the other hand, tidal energy utilizes energy of the incoming tides which are actually because of gravitational pull of moon. These technologies are called renewables because of their non-depleting, replenishable nature. In addition, they are clean source of energy which do not produce harmful GHG emissions while their general operation [6]. The study reveals that the share of renewable energy technologies increased from year 2012 to 2020. The transition in the percentage share of each technology from year 2012 to 2018 is clearly demonstrated in Figure 1-1. It shows a decline in the consumption of fossil fuels for energy needs and increase in the share of RETs by time.

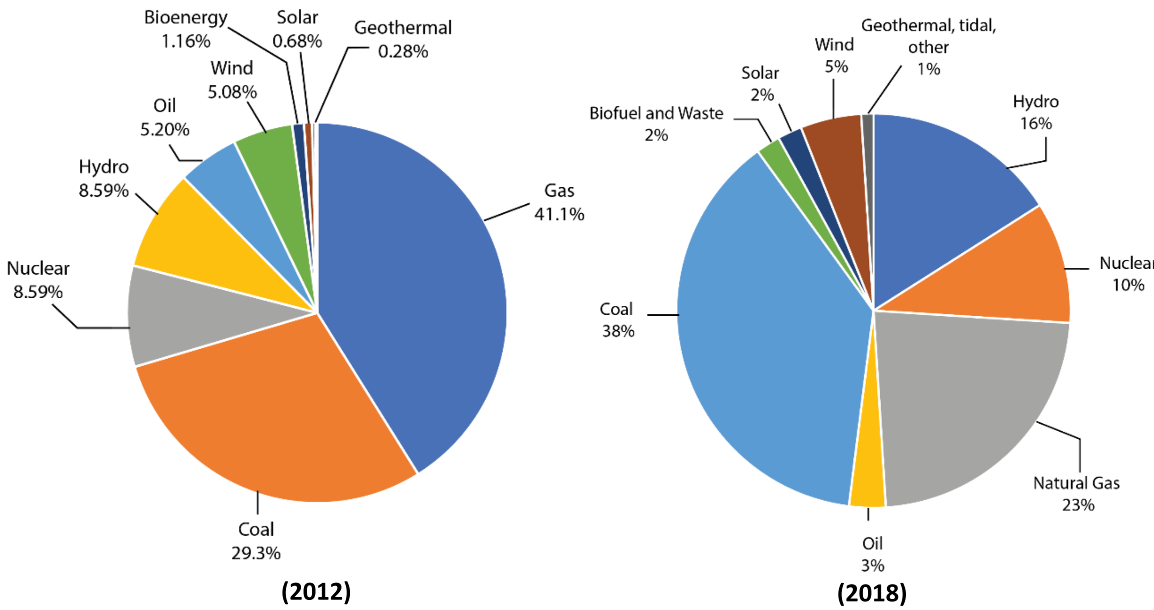

Figure 1-1: Share of energy technologies in global energy in year 2012 and 2018 [7], [8]

In the renewable energy regime, wind energy constitutes the major share in the global energy mix as predicted for year 2050. In addition, it shows that after wind energy, solar PV will be widely used technology. It shows a high potential for the deployment of wind and solar energy in the future global energy mix. The following information is described in detail in Figure 1-2.

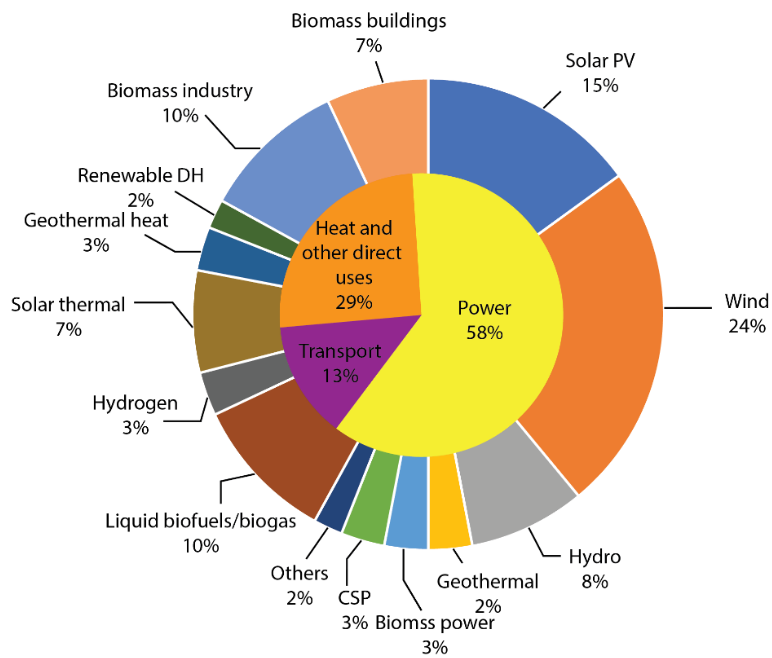

Figure 1-2: Energy scenario of renewable technologies in year 2050 [5]

1.2 Energy situation in Pakistan

Pakistan is one of the developing countries in the world which are facing a worst electricity shortfall. The escalating energy shortfall has severely impacted the economy of Pakistan while stunting the growth of industrial, agricultural and residential sector. The total energy mix of Pakistan consists of 4% nuclear, 29% hydro, 61% fossil-based fuels, and 6% others [8]. The following Figure 1-3 shows the energy mix of Pakistan in year 2020.

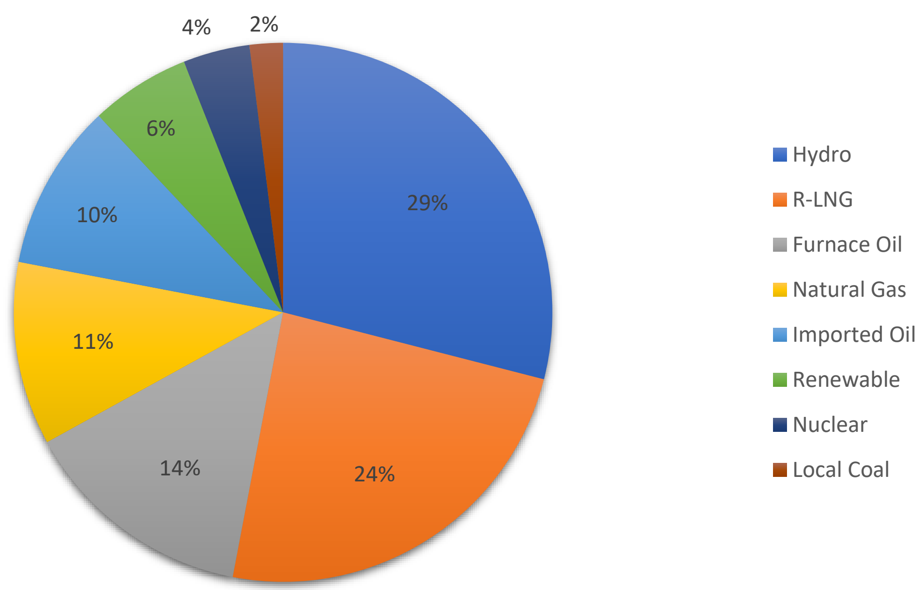

Figure 1-3: Energy mix of Pakistan in year 2020 [8]

It is evident that Pakistan's energy mix is mainly dependent on fossil fuels such as natural gas, petroleum oil, coal and so on. The percentage of renewable technologies is only 6% of the total share which is very underutilized as compared to the available potential [8]. In addition to this, the combustion of fossil fuels for energy activities has created severe environmental issues like smog and acid rain in major cities like Lahore, Karachi, Faisalabad and Multan. The conventional central distribution grid system is outsourced and needs adequate expansion to meet the current and rising energy demand which requires huge amount of investment, but it is making it impossible for economically weak countries like Pakistan.

According to the ministry of Energy in Pakistan, the energy shortfall has reached to 1500 MW. The average AQI in Faisalabad has reached to 161 (considered harmful), 149 in Bahawalpur and 137 in Lahore whereas it went to peak 256 in Lahore during winter days [9], [10]. $PM_{2.5}$ concentration in Pakistan air is currently 5 times above WHO exposure recommendation. Considering the current situation, 26% of the population of Pakistan is still devoid of electricity supply. Currently, the electricity generation capacity has reached 37000 MW while the distribution sector is stalled at 22000 MW with a demand of 25000 MW on consumer side [11].

According to literature, Pakistan has an estimated gross wind power potential of around 346,000 MW [12], [13]. Considering the following energy crisis, availability of resources, local and regional environmental issues, installation of wind farms seems like a most feasible solution. Therefore, our study will be focused on wind energy and its efficient deployment in Pakistan by keeping in view the techno-socio-economic perspective.

1.3 Working of wind turbines

Wind energy is one of the most commercially utilized technology to generate electricity. Wind energy converts kinetic energy of incoming wind to electricity by utilizing wind turbine. Wind turbine manly consists of rotor, blades, gears and generator to convert the kinetic energy of the wind to rotational energy of the rotor and then finally to electricity using the generator. Wind turbines are generally classified into two types:

1- Horizontal Axis Wind Turbine (HAWT)
2- Vertical Axis Wind Turbine (VAWT)

HAWT are the wind turbines which have the blades rotating in an axis parallel to ground while VAWT has blades which are rotating in an axis perpendicular to the ground. In HAWT, the generator and gearbox assembly are set at a certain height which is also referred as tower or hub height. In contrary, in VAWT the gearbox and generator are at ground. The following Figure 1-4 shows the comparison and components of wind turbines [14]. Therefore, it can be evaluated that vertical axis wind turbines are easier to install and are less complex in structure, on the other HAWT have higher costs and complexity to install. But HAWT gives better efficiency, generational and structural stability as compared to VAWT. Considering the cost and benefits of both the turbine types, HAWTs are generally utilized on a commercial level. Similarly, the wind turbines can also be classified into on-shore and off-shore wind turbines. On-shore wind turbines are installed on land while off-shore wind turbines are installed on the shore. Both of these wind turbines have their advantages and disadvantages. Off-shore wind turbines receive higher and stable level of winds but are expensive to install as compared to on-shore wind turbines [15]. They also face the issue of extra cost of electricity transmission. On the other hands, onshore wind turbines are subjected to lower level of winds but have lower installation costs as well. Therefore, on-shore wind turbines provide better levelized Cost of Electricity (LCOE) as compared to off-shore wind turbines [16]. Considering all these parameters, our study will be focused on onshore wind turbines.

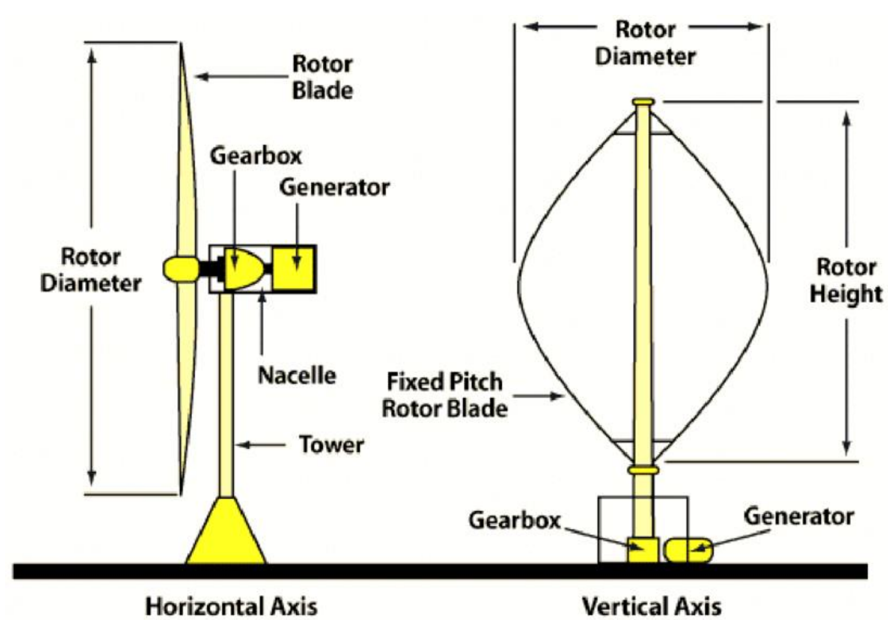

Figure 1-4: Comparison between HAWT and VAWT [14]

The following Equation 1 shows the theoretical energy generated from a wind turbine.

$$Power, P = \frac{1}{2}\rho A v^3 C_p \qquad (Equation\ 1)$$

where ρ is the density of air, A is the swept area of turbine, v is the velocity of wind and C_p is the coefficient of performance of wind turbine. It shows that the power generated from a wind turbine is dependent on density of air, swept area, velocity of incoming wind and coefficient of performance. It is important to mention that generated power is highly dependent on the available wind speed because power is directly proportional to the cube of velocity. Furthermore, the coefficient of performance is dependent on multiple variables including aerodynamic efficiency of blades, mechanical efficiency of turbine, and so on. It advocates that installation of wind turbines is very site specific and a careful wind resource assessment should be performed for a site before wind turbine installation. The net section discusses wind resource assessment in details. It should also be noted that electricity generation capacity is also dependent on and restricted to the power curve of wind turbine. A wind turbine cannot produce power more than its rated power limit. It means that every wind turbine operates at a minimum and a maximum wind speed to generate electricity. The wind turbine will not generate any electricity if the wind speed is not between these limits. In addition, wind turbine works at its maximum rated power at a rated wind speed. The following Figure 1-5 shows the power curve of a wind turbine discussing optimal operating variables.

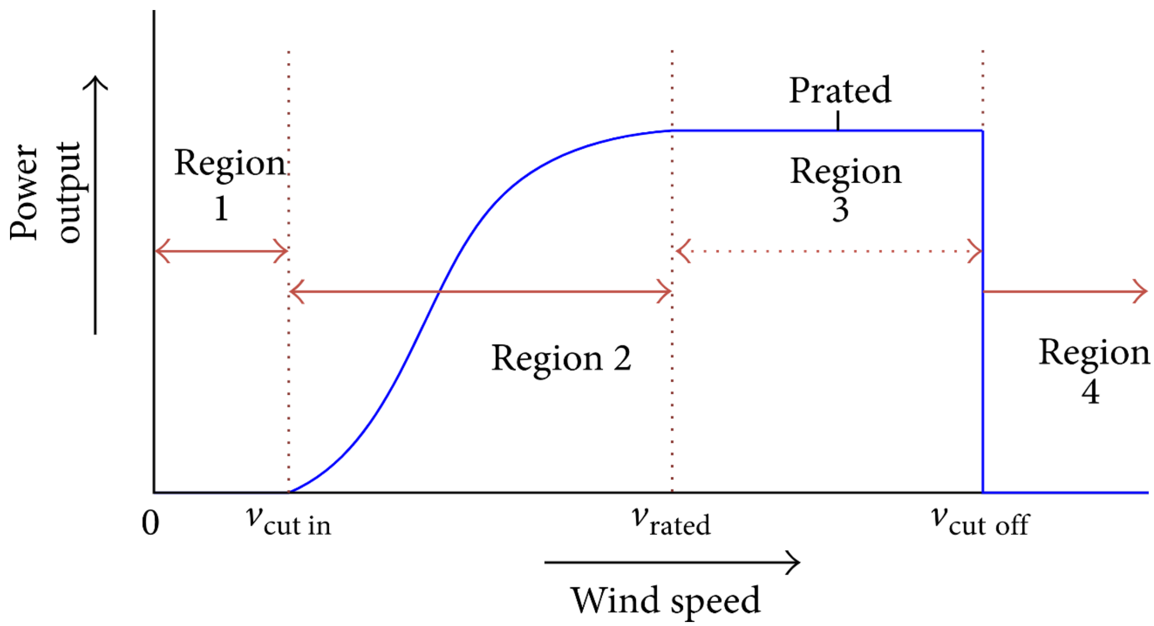

Figure 1-5: Power curve of a wind turbine [17]

The other important parameter while discussing the theory of wind turbines is the efficiency of wind turbines. The maximum efficiency achieved in a wind turbine is 59.3% which is also known as Betz Limit. It means that it is impossible to achieve efficiency above 59.3%. Nowadays, commercially available wind turbines have reached an efficiency of approximately 50%. So, it can be stated that the designing of wind turbines is at a relatively mature stage [18].

1.4 Wind resource assessment

The assessment and characterization available wind resource is a crucial factor for the development and operation of a wind farm. The wind resource assessment generally includes measurement of a of wind speed and direction at a specific location. There are weather stations which generally have the appropriate equipment to measure the wind speed and direction. The wind speed is measured by a device named as anemometer. A typical anemometer has a spinning wheel which rotates according to the windblown on it. The stronger the wind blows, the faster the spinning wheel rotates. Ultimately, the number of rotations (rpm) of the spinning wheel allows to calculate the wind speed. Generally, anemometers are also coupled with wind vanes to determine the direction of the incoming wind. The wind speed and direction data for a minimum of whole year is collected with a resolution of one hour (8760 total readings) to make a decision about the feasibility of a site for wind turbine or farm installation. The following Figure 1-6 shows the working of an anemometer [19].

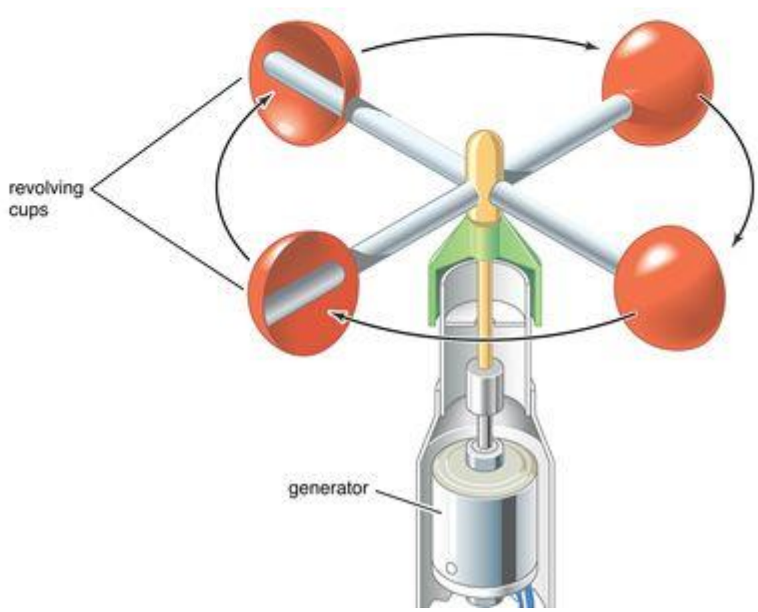

Figure 1-6: Working of a cup-anemometer [19]

To determine the wind speed at a particular location, the anemometer is generally installed at a height of 10 m from the ground [20]. But it should be noted that wind turbines are usually installed at a higher hub height around 100m, so wind speed at heights above 10m is determined empirically using power law. The following Equation 2 shows the mathematical form of power law.

$$v\,(z) = v(ref) * \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad (Equation\ 2)$$

In following Equation2, *v(z)* represents wind speed at required height *z*, *v(ref)* is the wind speed measured by anemometer at a given height, z_{ref} and α is the power law exponent related to the surface roughness. Therefore, the power law exponent is smaller for smooth areas while its value increases as the resistance in the topography increases. It is important to mention that anemometer gives a real-time wind speed data for a specific site. Moreover, it is difficult to get real-time data for a site which is in some remote area because of technical limitations. In this case, satellites data can help in providing preliminary wind speed and direction data to determine the technical viability of a site. There are GIS tools which help in determining the average speed and likelihood of various wind speeds at the required location. Global Wind Atlas is an online resource, developed by University of Denmark, which utilizes the satellite data to determine the average wind speed at a location along with giving the probability factor for the wind speed [21]. The probability of wind speed is determined by Weibull probability density function. The Weibull distribution is a two variable function which is used to fit the wind speed frequency distribution. In this way, Weibull distribution function helps in fitting the wind speed data in a frequency function. It tells about the possibility of a wind speed to occur for a certain number of hours in a year. In this way, it helps in analyzing the feasibility of a site for the development of wind farm. The following Equation 3 shows the empirical for of Weibull distribution function [22].

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^{k}\right) \qquad (Equation\ 3)$$

In following Equation 3, *f(v)* represents the probability density function, *c* represents scale factor, *k* represents the shape factor and *v* represents the given wind speed. In this, k determines the variability in the wind speed from actual data. It has value ranging between 1 to 3. The lower value of k represents more variability from the actual data while higher value of k demonstrates less variable wind. Furthermore, the scale factor is a measure of wind speed characteristics of the time series and is proportional to the mean wind speed. The following Figure 1-7 shows the Weibull probability density function [23].

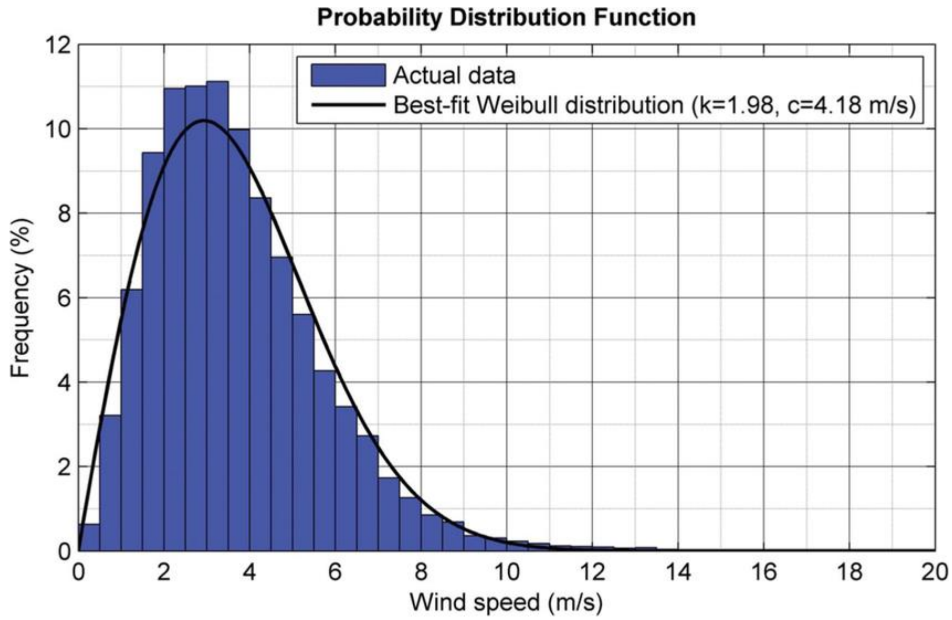

Figure 1-7: Weibull distribution function of wind speed [23]

Literature suggests that the development of RETs and specially, wind farm is highly impacted by four major parameters: technical, economic, environmental and social. It is crucial to keep these parameters in mind while determining the feasibility of a wind project. The assessment of these parameters in reference to wind turbine development is discussed in the next sections.

1.5 Technical assessment of wind farm

The working of a wind turbine is assessed by its net yield of electricity. The net energy yield of a wind turbine is dependent on the wind profile and turbine characteristics. Therefore, it is extremely important to select a turbine which matches the wind profile of the given site. There are various tools such as System Advisory Model (SAM) and RETscreen which can help in modeling the system and selecting the right turbine for the location [24]–[26]. The power curve of the selected turbine should match the wind profile of the site. The following Figure 1-8 elaborates the match of wind profile with the power curve of the wind turbine.

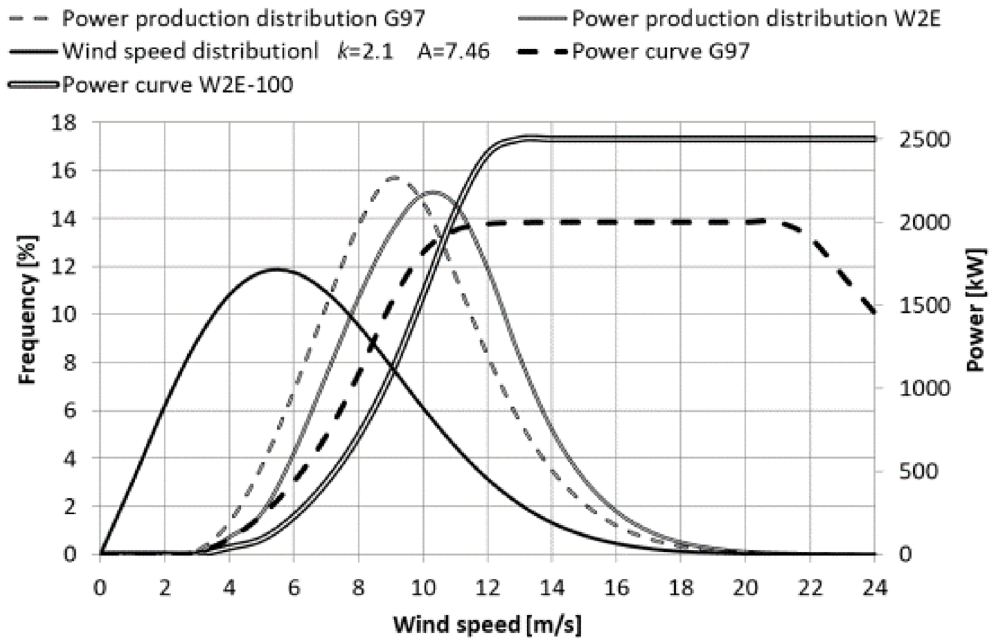

Figure 1-8: Power curve of wind turbine versus wind profile at a site [27]

Capacity factor is one of the most important parameters which helps in determining the performance of a wind turbine at a specific location. Capacity factor is the measure of how often a wind turbine runs for a particular period of time. It is obtained by dividing the actual output from a wind turbine to the total maximum power output possible. The following Equation 4 shows the mathematical form of capacity factor. The net yield of electricity and capacity factor are the two important parameters determining the technical feasibility of a wind project.

$$Capacity\ factor = \frac{Actual\ Energy\ Production\ (kWh)}{Nameplate\ capacity\ (kW) * Time\ (h)} \qquad (Equation\ 4)$$

1.6 Economic assessment of wind farm

According to literature, the development of wind farm is constrained because of high capital requirement. The determination of economic feasibility of the wind project is extremely important because only an economically viable project can attract more investments. The economic viability of a wind project is generally determined by three major parameters: Payback period, LCOE and NET Present Value (NPV). The lower the payback period, better will the feasibility of the project. Similarly, lower the LCOE of the project, the better the wind project will be. In the end, greater the NPV, the more feasible will be the project [28]. The following Equation 5 demonstrates the formula for calculating Payback period.

$$Payback\ period = \frac{Initial\ investment}{Total\ annual\ cashflow} \qquad (Equation\ 5)$$

Similarly, the following Equation 6 shows the empirical relation for calculating the NPV of a project.

$$NPV = \frac{R_t}{(1+i)^t} \qquad (Equation\ 6)$$

where R_t is the net cash flow at time t, t is time of the cashflow and i is the discount rate. In the end, the empirical relation for determining the LCOE is given in following Equation 7.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+i)^t}}{\frac{E_t}{(1+i)^t}} \qquad (Equation\ 7)$$

where I_t is the investment expenditure in year t, M_t is operations and maintenance expenditures in year t, F_t is the fuel expenditures in year t, E_t is the electricity generation in year t and n is the life of the system. The following economic parameters can also be determined in simulation tools such SAM and RETscreen [24]–[26].

1.7 Environmental assessment of wind farm

Nowadays, environmental impacts are of a great concern while designing an energy system. The global GHG emission laws are pushing the countries to limit their carbon emissions. Global policies like Kyoto Protocol and Paris Agreement have put a limit on countries to limit their carbon emissions and given the concept of carbon credits. Therefore, considering the following, wind farms can help in reducing the carbon emissions. The reduction in emissions is generally represented by tons of CO_2-equivalent. In other words, it tells how much emissions can be avoided from adding into the atmosphere if the electricity is produced from traditional energy resources. It usually includes a conversion factor for converting the net annual yield of electricity from wind turbines to CO_{2e} reduction. The value of this conversion factor is determined by the alternate fuel being used to supply electricity at a certain location. It is advocated that wind turbines help in significantly decreasing GHG emissions and ultimately, assisting to tackle the eminent threat of climate change [29]. The following Equation 8 shows the empirical relation to determine the annual CO_{2e} reduction.

$$Annual\ emission\ reduction = Conversion\ factor\ * Net\ annual\ yield\ (Equation\ 8)$$

1.8 Social assessment of wind farm

It is a common practice in most of the engineering projects to neglect the social impacts of the project. Whereas, in reality, the success and realization of a project is closely tied with its social acceptance. The social acceptance of a project is related to many factors such as employment, economics, accessibility, and so on. It is necessary to determine the impact of each social variable on the acceptability of the project. The similar case can be translated to the acceptability of the wind farms. There are several positive and negative social impacts of wind farms. Increase in the employment opportunities, electricity accessibility, social dynamics and so on, are the potential positive impacts of wind farms [30], [31]. On the other hand, noise, shadow flickers and visual impacts are the negative impacts of the wind farm. It is essential to determine the social acceptability of the wind farms in an area under study where wind project is decided to be installed. It is important as these social studies help in developing efficient policies for the success of project.

In social sciences, there are three major methods through which the social impact assessment is performed [32], [33]. These methods are given as follows:

1- Quantitative method approach
2- Qualitative method approach
3- Mixed method approach

Quantitative method approach involves the data collection, analyzation, interpretation and writing process. The methods which are generally used in this approach are surveys and experimental research that relate to identification of sample and population, specification of the design type, presentation and interpretation of results, and writing the outcomes which are consistent to the survey and experimentation. Quantitative method approach involves the data collection, analyzation, interpretation and writing process which are different from the quantitative. It includes purposeful sampling, collecting open end data analyzing texts and images, representing the data in tables and figures and personal interpretation of the outcomes. In contrary, mixed method approach includes quantitative and qualitative data in the study [32], [34].

1.9 Problem statement

The escalating energy shortfall has severely impacted the economy of Pakistan while stunting the growth of industrial, agricultural and residential sector. The combustion of fossil fuels for energy activities has created severe environmental issues like smog and acid rain in major cities like Lahore, Karachi, Faisalabad and Multan. The conventional central distribution grid system is outsourced and needs adequate expansion to meet the current/rising energy demand which requires huge amount of investment – making it impossible for economically weak countries like Pakistan. In order to solve the energy crisis issue, the sustainable development of wind farms is impeded by the lack of holistic R&D to incorporate techno-economic and socio-environmental feasibility analysis at provincial level in Pakistan. In the light of current situation, the development of integrated wind farms seems like a viable solution towards mitigating the issue of energy shortfall, carbonization, hazardous emissions and electricity supply in remote areas. It needs technical, financial and economic planning for ensuring the feasibility and optimal harvest of energy from a specific wind turbine by keeping the wind resource assessment of a certain area in view. Moreover, it requires social and environmental impact assessment of the wind farms to determine their acceptability in neighborhood and get public's opinion about various variables linked with the wind farms.

1.10 Aim of research

The aim of the following research is to perform wind resource assessment throughout the country and identify sites at provincial level in Pakistan with an excellent potential to support wind farm deployment. It involves data acquisition and transformation of wind speed data to select various sites. Furthermore, it is also aimed to perform techno-economic analysis of 50 MW wind farms at the selected sites and determine capacity factor, net annual yield, NPV, LCOE and payback period for the wind farms. It also involves determining the effect of various wind turbines on the techno-economic output of the wind farm at each site. In addition, the following research, also targets to determine the environmental impacts of the wind farms and their individual role in reducing the GHG emissions. In the end, social impact assessment is also aimed to be performed to get the public's perception and acceptance about wind farms.

1.11 Challenges and limitations

Research challenges

The few challenges of the research are given as follows:

- Wind speed data acquisition
- Conduction of survey
- Site interviews

Research limitations

The limitations of the research are given as follows:

- Utilization of GIS-based wind speed data because of unavailability of actual surface data.
- Small sample size for online social survey because of limited time.
- Small sample size for site interview because of resource constraints.

1.12 Thesis objectives

These are the following objectives of the research:

1- To perform wind resource assessment for potential areas at provincial level in Pakistan and suggesting potential sites for microgrid wind farms.

2- To perform technical and economic analysis to figure out the optimal and feasible installation of microgrid wind turbines at provincial level.

3- To assess social and environmental impacts (positive and negative) of wind turbines at local and regional level.

1.13 Scope of thesis

This research will work as a guiding path for the governmental and private wind farm investors to develop wind farms at the suggested locations. Until now, there has not been any country wind resource assessment performed and this research will fill this gap and suggest 20 locations at provincial level with maximum potential for wind farm deployment. Moreover, this research will evaluate the techno-economic benefits of 50 MW wind farm at each site and prioritize them in accordance with the maximum and least benefit-to-cost ratio. Moreover, considering the global policies for GHG emission reduction, this research will provide an estimate about the annual GHG emissions by the installation of wind farm at each. In the end, this research will perform social impact assessment to determine public's acceptance and perception about wind farms. Therefore, it will provide a holistic information to the policy makers to develop effective policies.

1.14 Thesis outline

Chapter 01 provides a brief introduction of the global energy mix and part of RETs in it. The energy generation and crisis in Pakistan are discussed along with reviewing the wind energy as a potential candidate. The available policies regarding RETs in Pakistan are discussed.

Chapter 02 summarizes the literature review conducted on WRA in Pakistan and describes the potential ways and methods to do it. In addition, different potential methods to perform technoeconomic assessment of wind farms are discussed along with reviewing the environmental impact assessment studies of wind farms. In the end, materials and methods for conducting online social surveys and site interviews are also summarized to provide social perspective to the research.

In **Chapter 03**, techniques specific to the data acquisition of wind speed, computer-based modeling, techno-economic analysis, optimization and environmental analysis of wind farms are briefly discussed. In addition, the qualitative and quantitative methods to perform social impact assessment such as site surveys, online surveys and interviews are discussed along with the associated statistics. Furthermore, it also represents the data acquisition, computer-based modeling, technoeconomic, environmental and social impact analysis techniques used in this research.

In **Chapter 04**, results and discussion about the obtained results of the research are included. The WRA throughout Pakistan is performed and potential locations with good to superb potential for wind farms are identified. In addition to this, the corresponding techno-economic and environmental analysis results are included in this chapter. In the end, the results of social surveys and interviews are also added.

Chapter 05 includes the conclusion of the research along with the recommendations for future work.

Summary

The chapter provides global energy scenario and the part of RETs in the global energy mix. The share of each RE technology in the global energy mix is analyzed. As a case study, the electricity generation and crisis situation of Pakistan and discussed and potential solutions based on RE technology are identified. Considering the availability of excellent potential and underutilization of wind energy in Pakistan, the integration of wind farms in the energy mix of the country is suggested. Furthermore, various basic theoretical concepts of wind energy including types of wind turbines, data acquisition, data processing, technoeconomic and environmental analysis, and so on are discussed. It also includes various statistical and empirical methods to determine the techno-economic outputs of a wind farm. In the end, the importance of social analysis in the development of wind farms is discussed along with reviewing various methods to perform social impact assessment. Therefore, the main objective of the research is to perform country wide WRA to identify the potential sites highly suitable for wind farm installation and also determining their techno-economic, environmental and social feasibility.

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Chapter 2: Literature review

2.1 Prospects of wind energy in Pakistan

Wind energy is characterized into two major technologies depending on its type of application which includes on-shore and off-shore wind turbines [1]. According to literature, globally on-shore wind turbines contribute to greater proportion as compared to off-shore wind turbines. The reason for higher penetration of on-shore wind turbines is its better benefit to cost ratio as compared off-shore wind turbines. Off-shore wind turbines add additional Transmission and Distribution (T&D) cost which decreases the benefit to cost ratio. Therefore, on-shore wind turbines provide better Net Present value (NPV), payback period and levelized cost of electricity (LCOE) [2], [3]. The increase in global total installed capacity of wind energy is given in Figure 2-1.

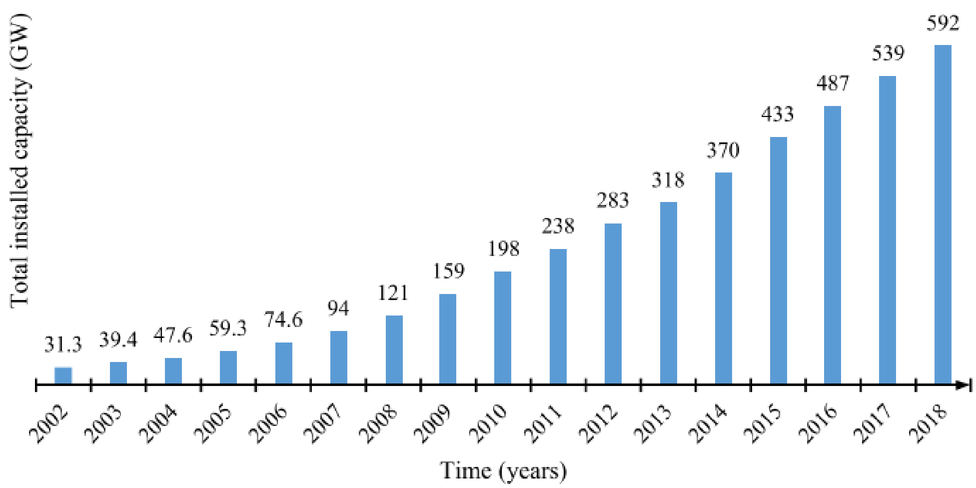

Figure 2-1: Global installed wind capacity from 2002 to 2018 [4]

Pakistan is blessed with multiple wind corridors which enables a significant potential to harness energy from wind. Almost all of the provinces in Pakistan demonstrate an adequate potential for wind farm installation while Sindh and Baluchistan exhibit stronger and steadier winds as compared to rest of the provinces. Wind Resources Assessment (WRA) is the first to step to investigate the viability of a site for windfarm deployment. Nasir et al. worked on analyzing the wind power potential by performing WRA at four locations in Pakistan including Lahore, Peshawar, Quetta and Karachi in year 1980 to 1984 [5]. They targeted one city in each province of Pakistan and their study verified that

Karachi and Quetta demonstrated better wind potential than Lahore and Peshawar. The study performed by [6] also performed WRA at few locations in Baluchistan in 1990 and concluded that majority of the locations in Baluchistan has the potential to support wind energy development. The following research also suggested the installation of wind farms to support the scattered, remote and rural population of Baluchistan.

In 1994, the studies performed by Abro et al. claimed the feasibility of wind farm installation near coastline, arid lands, and hilly terrains in Pakistan [7]. Arid and semi-arid lands in Pakistan demonstrate the best potential for solar and wind applications because of less cloudy and steadier wind condition. According to surveys, around two-third land in Pakistan is categorized as arid and semi-arid which makes it highly suitable for wind development. Mirza et al. and Wazir et al. [8], [9] also supported the potential of northern mountainy and southern coastal region of Pakistan to efficiently harness wind energy. [10,11] also supported the feasibility of wind farm installation in coastal areas of Pakistan In 2011, studies performed by Harijuan et al. [12] forecasted the penetration of wind energy into energy sector of Pakistan and concluded that wind energy has the capability to support the socio-economic growth, reduction in oil import pressure and protection of environment from hazardous emissions. Daim et al. also supported the feasibility of wind farm installation in Pakistan [13].

2.2 Challenges of wind energy in Pakistan

As rest of the RETs, wind energy is also challenged by various factors. The study performed by Shami et al. [14] show that the major challenges to the wind energy development are the lack of infrastructure which includes unavailability of proper network for transmission, road-ways and inaccessibility to the isolated areas. Their study also revealed that one of the reasons behind inadequate inclusion of wind energy into the energy mix of the country is the lack of studies performed on the environmental, social, and political aspects for integrating wind power into the energy sector of Pakistan. The research performed by Bhutto et al. [15] reveals that the technical development of wind turbine technology is at a comparatively mature stage and does not need a significant improvement while the real challenge is the grid integration of wind turbines and wind farms. They further add that the infrastructure of the existing grid needs major reforms in order to support integration of wind energy into Pakistan’s energy mix.

The inefficacy of the national energy policies is also one of the significant reasons for hindering the progress of RETs in Pakistan. The low level of R&D research on the development of wind energy has obstructed the efficient development of wind energy in Pakistan [10]. Further diving into the literature, it is studied that the policy and regulatory barriers, institutional barriers, market-based challenges, technical and informational barriers, fiscal and financial barriers and in the end social barriers are obstructing the growth of wind energy in Pakistan [16]. [17]–[20] studied that development of wind energy is obstructed in Pakistan due to set of challenges which are lacking management, conventional grid synchronization, locality issue, financial crisis, landscape and land use and variability of the power sources.

2.3 Feasibility studies for wind energy in Pakistan

It is crucial to determine the feasibility of a location to support wind farm deployment. Rashid et al. [4] performed the feasibility analysis for four sites including Karachi, Pasni, Gwadar ad Ormara and carried out a comparative analysis by varying wind turbine designs, geographical, operational, installation and financial parameters. They concluded that Karachi showed the highest capacity factor of 46% while Pasni showed the least capacity factor of 29.3%. Similarly, Karachi demonstrated the best economic feasibility among the four selected locations. Zeeshan et al. [21] also performed feasibility analysis or 12 selected locations in Pakistan by utilizing average wind speed data and fitting it over Weibull distribution function. In their study, Sujawal, Sanghar, Tando Ghulam Alai and Umerkot demonstrated the best potential for wind farm installation. Jahangiri et al. [22] utilized the GIS based wind speed data to identify the potential sites. The following concept of WRA using GIS-based data is also performed by Baseer et al. [23]. They also performed preliminary techno-economic feasibility analysis depending on the GIS data. The wind resource assessment of northern areas of Pakistan is also performed in literature and it is identified that multiple locations in northern region of Pakistan has the potential for small scale wind applications [24].

[10], [11] suggested wind farm installation to solve the electricity crisis issue in Karachi. Ali et al. also supported the application of wind energy in combination with other RETs to offset the peak electricity demand in Karachi [25]. Shami et al. [14] also performed feasibility analysis of various cities in Baluchistan and evaluated that Baluchistan has

almost 12,00 sq. km of area which be utilized to produce power up to 64,000 MW. Ashfaq et al. [26] also advocated the utilization of wind energy to solve the energy crisis issue in Pakistan and suggested that deployment of 10.4 MW of wind farms along with 882 MW of solar farms can significantly help in meeting the national electricity needs. Similar, Ullah et al. [27] used surface-based wind data to determine feasibility of south-eastern coast sits of Pakistan and determined the average speed to be 7.159 m/s with a power density of 414W/m^2 at 50m altitude. The following study is also performed by Khahro et al. [28] for Gharo, Sindh in which they utilized 5-year wind speed data to analyze the techno-economic feasibility for the site. The evaluated most probable wind speed to be 9.356 m/s with a power and energy density of 260 W/m^2 and 2300 kWh/m^2 respectively. In their result, for Gharo, Sindh, GE45.7 gave the best capacity factor of 56% with LCOE of 0.0255 UUSD/kWh. Mirza et al. also performed WRA for Gharo and Jhimpir, Sindh and their study provided benchmark wind speed data to determine the annual electricity production [29]. [30] also performed WRA for Gharo and supported its techno-economic feasibility for wind farm installation.

According to literature, the growth of wind energy at global level is obstructed due to requirement of higher capital and other financial constraints [16], [31]. The studies performed by Adnan et al. [32] majorly focused on economic feasibility of wind farms in Sujawal and Umerkot. The power density for Sujawal and Umerkot is also determined to be 414.18 W/m2 and 303.86 W/m2 with LCOE of 0.074 USD/kWh and 0.056 USD/kWh respectively. The payback period for both these locations was estimated to be 7 years. Zhang et al. [33] performed the WRA and economic feasibility analysis at 18 locations in Pakistan and determined that 6 locations including Karachi, Hyderabad, Sanghar, Umerkot, Tando Ghulam and Sajawal exhibited a potential of generation 22 GWh electricity annually with a marginal investment of 1100 USD/kW. The top three sites showed LCOE of 0.0366–0.0733 USD/kWh, 0.0388–0.0776 USD/kWh, and 0.039–0.0790 USD/kWh which is much lower than the average electricity tariff provided by WAPDA. [10], [34] advocated the economic feasibility of wind farms in Jamshoro, Sindh. Shah [35] also supported the development of wind energy in Sindh and Baluchistan.

In contrary, Imran et al. [36] worked on determining the techno-economic feasibility of hybrid renewable energy systems for Gilgit-Baltistan region and suggested that a combination of wind, solar and diesel engine can work best for the specified site for urban and rural electrification. The following concept of hybrid energy resources with a part of wind energy is also supported by [37], [38]. Considering the policy perspective, Ullah et al. revealed that the penetration of RETs in Pakistan's energy mix can be increased by providing financial incentives to get cheaper electricity. The following proposition of bringing incentives into the field of RETs is also supported by the studies performed by Malik et al., Perwez et al. and Mirjat et al. [39]–[41]. Computer modeling techniques are important in determining the techno-economic feasibility of wind farms. [36], [42]–[44] utilized System Advisory Model (SAM), developed National Renewable Energy Laboratory (NREL), to determine the techno-economic feasibility of RE systems including wind farm. Similarly, HOMER Pro is also utilized to determine the techno-economic viability of RE based systems [45]–[47]. In contrast, [48], [49] used RETScreen for analyzing the technical, economic and environmental feasibility of RETs.

2.4 Environmental and social impacts of wind energy

The current global policies and regulation for the GHG emissions, as set by Paris Agreement, have made wind energy even more attractive. Nazir et al. [17] proposed that RETs can significantly in lowering the hazardous pollutants caused by burning fossil fuels. [48], [49] utilized computer-based modeling techniques to determine the techno-economic feasibility of wind farms along with quantifying the annual reduction in GHG emission by the installation of wind farms at a specified site. In their study, they used RETScreen which is developed by Government of Canada to analyze the techno-economic viability as well as environmental feasibility of RETs including wind farms. It is also important to mention that 85 to 90% materials utilized to manufacture wind turbines can be recycled after the completion of project life [50], [51]. It is essential to determine the social impacts of RETs in order to develop efficient and effective energy policies. Social analysis is crucial to evaluate the public's awareness and acceptance of an energy project [52].

There are different techniques being utilized in literature to determine the social impacts. Quantitative and qualitative analysis are the two major types of social analysis. In literature, surveys are usually conducted in order to get quantitative results whereas interviews are conducted to perform qualitative social analysis [53]–[55]. The quantitative social analysis is performed by Radun et al. and Rafique et al. [56], [57] while the qualitative social analysis is performed by Abu-Salma et al. and Hinrichs et al. [58], [59]. The social impact assessment of wind farms is very limited and only a little research has been done in this field. Martínez-Mendoza et al. performed quantitative social analysis to determine the social impacts of wind energy in the Isthmus of Tehuantepec, Mexico using Likert-Fuzzy statistical method [60]. Similarly, the qualitative social impact assessment is also performed for US rural counties and Switzerland in literature as well [61], [62]. The health effects of wind turbine and noise impacts are also determined using social impact assessment techniques [56].

In the light of studied literature, it is clear that major portion of Pakistan needs WRA to identify the potential locations suitable for wind farm deployment. In literature, most of the WRA and techno-economic feasibility analysis study is performed for some specific cities in Sindh only. It leaves a gap for a holistic study which includes WRA of country wide sites and performing techno-economic analysis to determine benefit to cost ratio of potential sites in Pakistan. In addition, there has been no research performed to identify potential locations in each province of Pakistan along with their techno-economic outputs.

Similarly, a little research, in the past, has been performed to evaluate the environmental impacts of wind farms in Pakistan. In the end, there has been no research performed to analyze the social impacts of wind farms. Therefore, in order to fill these research gaps, the following study performs country wide GIS data-based WRA to identify potential sites for wind farm installation in each province of Pakistan and determine their techno-economic feasibilities. Further, the following research determines the environmental as well as social impacts of the wind farms in Pakistan through both quantitative and qualitative social impact analysis. This research is need of time and will definitely help the investors, decision and energy policy makers to develop efficient policies in Pakistan to promote the development of wind energy. The following Table 2-1 and Table 2-2 presents summary of different methodologies used for technoeconomic and socio-environmental analysis.

Table 2-1: Summary of techno-economic analysis of windfarms

Sr. No.	Year	Methodology	Location	Ref.
1	2021	Weibull distribution function for WRA	Umerkot and Sajwal, Pakistan	[32]
2	2021	HOMER Pro and SAM simulation	Gilgit, Pakistan	[36]
3	2021	Surface based wind data fitted with Weibull distribution function	Sindh and Baluchistan, Pakistan	[39]
4	2021	Artificial Intelligence optimization (Kolmogorove-Smirnov statistic model) for determining Weibull parameters	Pakistan	[40]
5	2020	SWOT Analysis and Fuzzy Analytical Hierarchy Process	Sindh and Baluchistan, Pakistan	[29]
6	2019	Six comparative techniques of Weibull analysis for WRA	Northern areas, Pakistan	[28]
7	2017	GIS wind speed data	Saudia Arabia	[23]
8	2016	Techno-economic statistical tools	Southern coast, Pakistan	[22]

Table 2-2: Summary of socio-environmental analysis methods

Sr. No.	Year	Methodology	Location	Ref.
1	2021	Environmental taxation through numerical energy system model	Norway	[41]
2	2021	Life cycle assessment	Global	[47]
3	2020	GIS MCDA model	Israel	[43]
4	2017	RETScreen	Changming county, China	[49]
5	2021	Qualitative social impact assessment by interviews	Global	[56], [57]
6	2021	Site survey and thematic analysis	USA	[62]
7	2020	Survey conduction and result analysis with Likert-fuzzy	Global	[60]
8	2020	Interview with content analysis technique	Switzerland	[61]
9	2017	Quantitative impact assessment by surveys	Mexico	[58], [59]

Summary

The following chapter includes a literature review of the wind energy situation around the world and specifically in Pakistan. It compares the application of wind energy in global energy mix and in energy mix of Pakistan. The following chapter includes summary of research conducted on the WRA and techno-economic feasibility analysis of wind farms in Pakistan from 1980s to until now. The techno-economic feasibility analysis performed throughout the country and the approaches utilized by the researchers are discussed in this chapter. Similarly, potential locations suggested for wind farm deployment suggested by the literature are also discussed. Furthermore, the methods and computer-based modeling techniques opted by various researchers to obtain techno-economic as well as environmental results of the wind farms are discussed and summarized. In the end, various techniques to evaluate social impacts of the wind farms are discussed and implications of each method are discussed in detail.

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Chapter 3: Methodology

3.1 Research procedure

The development of wind farms is greatly impacted by four variables including technical, economic, environmental and social. Therefore, the following research will take all of these variables into account. The first step in the research involves the acquisition of wind speed data. Wind speed data can be taken from various sources depending on the availability of resources. The second step of the research is to model the wind farm on a software tool and simulate the system to the techno-economic results from the farm. The third step in the research is the assessment of environmental impacts of the wind farms. It includes determination of reduction of GHG emissions. The final step of the research is to determine the social impacts of the wind farms. The following Figure 3-1 shows the procedure of research in graphical form.

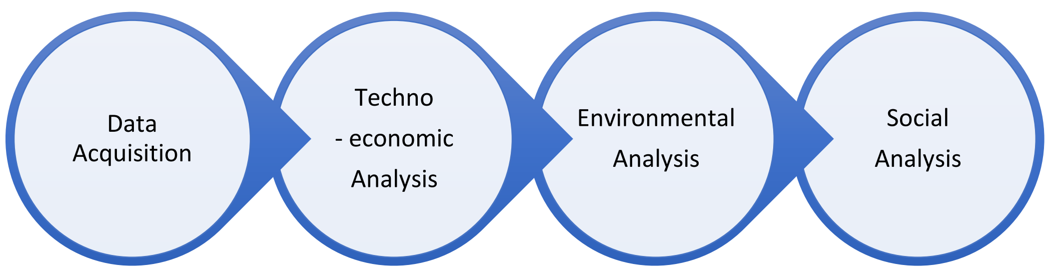

Figure 3-1: Experimental procedure of the research

3.2 Materials

In order to perform the techno-economic and environmental analysis, SAM and RETScreen software were utilized. In addition to perform, the online social survey about wind farm, google form service was utilized.

3.3 Data Acquisition

The following research is mainly dependent on wind speed data acquisition throughout Pakistan to identify potential sites with adequate potential to support wind farms. The wind speed data can be gathered from various sources depending on resource availability. There are two major sources for wind speed data acquisition.

3.3.1 Surface based data

The surface-based data is real-time wind speed data which is gathered using wind measuring device called anemometer. The wind speed data is gathered throughout the year, at least, to determine the hourly wind speed data at a specific site. The following data is difficult to obtain as it requires a lot of financial and technical resources along with time of at least a year. But it as a benefit that it provides accurate results. Weather stations have usually anemometers installed, so they can provide surface-based wind speed data. But the availability of weather stations for all the sites is not possible. The following Figure 3-2 shows example of a typically surface measured wind speed data.

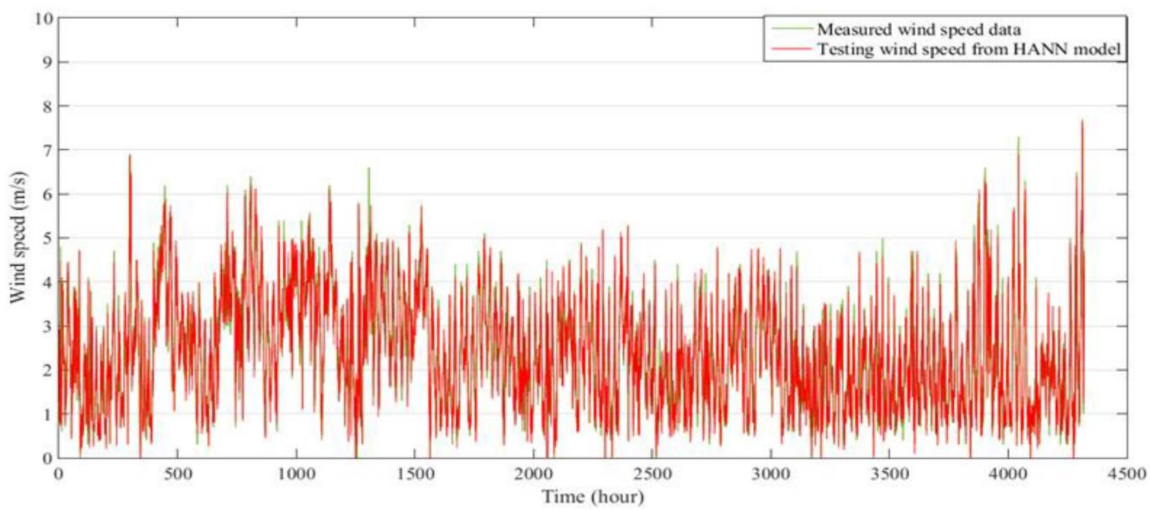

Figure 3-2: Typical surface-based wind speed data [1]

3.3.2 Satellite based data

The second method to acquire wind speed data through GIS data. GIS data is collected by the satellite and averaged throughout the years of acquired wind data. Global Wind Atlas is an online available resource which helps the researchers in getting in adequately accurate wind speed data for various locations. Therefore, helps in preliminary WRA at a site. It should also be noted that GIS based wind speed is not as accurate as surface-based data. The following Figure 3-3 shows example of GIS wind speed data from Global Wind Atlas.

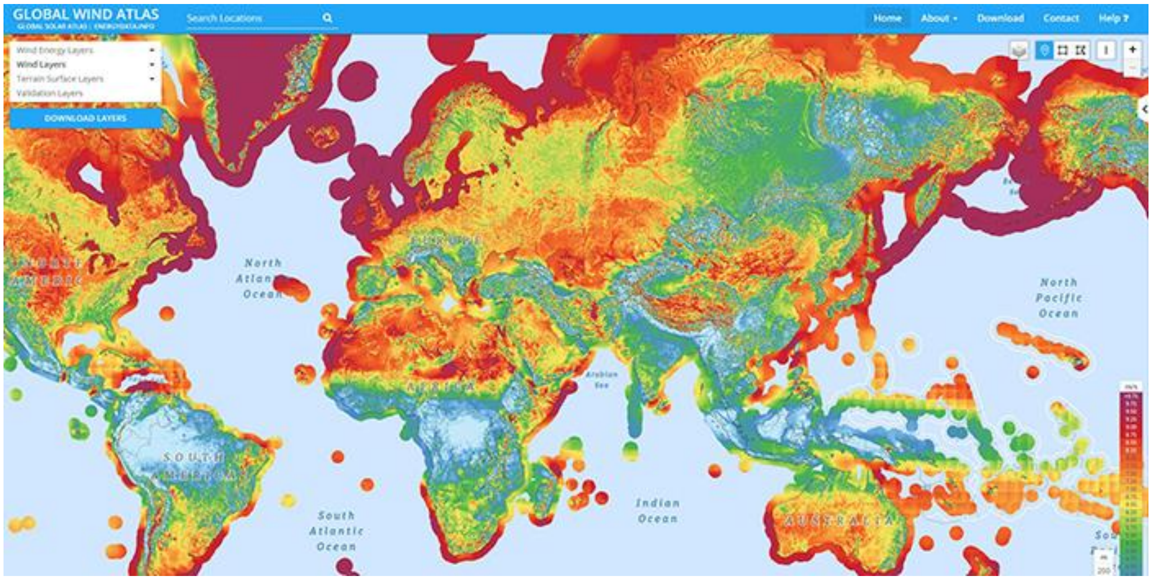

Figure 3-3: GIS wind speed data from Global Wind Atlas [2]

3.4 Techno-economic simulation

The techno-economic simulation is performed by moeling the wind farm on software tools and inserting te required input data. SAM, RETScreen, Ihoga, HOMER Pro are some of the wiely used energy modleing software. In our research, SAM will be mainly focused to model th system. System Advisory Model (SAM), developed by National Renewable Energy Laboratory (NREL), is a software tool designed to model and analyze the techno-economic parameters of RE systems [3]–[6]. It allows users to get hourly energy generation and load demand data in graphical form and provides a complete cashflow statement which is not possible in other energy system analysis software such as iHOGA and RETScreen. It has the capability to model the wind farm and analyze the techno-economic parameters in detail along with providing hourly and monthly graphical results.

Furthermore, the software helps in optimizing the layout of the wind farm and therefore, selecting the optimal configuration for the wind farm. Therefore, the optimal configuration and turbine type is selected for each identified site. SAM has a built-in database to provide information about the characteristics of commercially available wind turbines. Hence, SAM is utilized to analyze the performance of commercially available wind turbines and select the best performing wind turbine. Capacity factor and net annual energy yield are the deciding factors for the selection of wind turbine. SAM also enables the users to input financial details of the wind farm and determines the economic outcomes of the wind project.

3.5 Environmental simulation

The environmental impacts of the wind farm can be obtained by modeling the system on software tools such as RETScreen. RETScreen is an online available tool for energy modeling and analysis which is developed by the Government of Canada. It provides a platform that allows carbon planning, implementation, monitoring and reporting possible. It has a strong tool for determining the environmental impacts of RE projects which are not possible in SAM. In our study, RETScreen Expert is utilized to determine the impact of wind farms on the reduction filters of gasoline consumed [4], [7], [8]. Moreover, the amount of crude oil saved from being combusted is also determined through the software. The following Figure 3-4 provides an overlook of environmental analysis on RETScreen software.

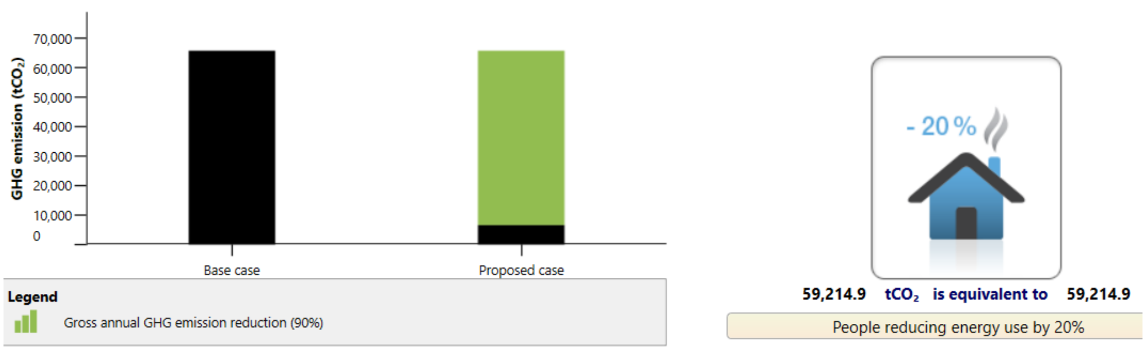

Figure 3-4: An overlook of environmental analysis on RETScreen

3.6 Social impact assessment

The study of social impacts is a crucial element for the success of a project. There are three major approaches to analyze the feasibility of project in the perspective of social sciences. In social sciences, there are three major methods through which the social impact assessment is performed [9,10]. These methods are given as follows:

1- Quantitative method approach
2- Qualitative method approach
3- Mixed method approach

Quantitative method approach involves the data collection, analyzation, interpretation and writing process. The methods which are generally used in this approach are surveys and experimental research that relate to identification of sample and population, specification of the design type, presentation and interpretation of results, and writing the outcomes which are consistent to the survey and experimentation. Quantitative method approach involves the data collection, analyzation, interpretation and writing process which are different from the quantitative. Moreover, qualitative studies are based upon narrative research, phenomenology, grounded theory, ethnographies and case studies. It includes purposeful sampling, collecting open end data analyzing texts and images, representing the data in tables and figures and personal interpretation of the outcomes. In contrary, mixed method approach includes quantitative and qualitative data in the study [9], [11]. The following Figure 3-5 shows the comparison between qualitative, quantitative and mixed method approach.

Figure 3-5: Comparison between qualitative, quantitative and mixed method approach

3.7 Technical analysis

The first step in the technical assessment of the wind farm is to perform WRA of the site. The global focus on the growth of wind energy has expanded the word wide performance of WRA of multiple locations. World Bank and Denmark Technical University (DTU) have developed an online software application for the global WRA which is named as Global Wind Atlas. It facilitates the policy makes, energy engineers and developers to select a particular site with adequate wind potential. In addition to this, DTU registered software named as WAsP is also available for academic as well as commercial use to analyze wind data and estimate the energy output of the wind projects. Due to the technical constraints, real-time wind resource data is not readily available for different regions of Pakistan.

Therefore, in order to provide a preliminary WRA, Global Wind Atlas can facilitate in providing reliable wind resource data to perform the analysis [12], [13]. The initial goal of study is to identify 3 to 6 potential locations in each province of Pakistan suitable for the wind farm installation. Therefore, using the Global Wind Atlas, average wind speed, power density, and wind rose can be extracted. The locations with the maximum wind speeds and power density are identified and noted for further analysis. Using the Global Wind Atlas, WRA is performed and total 20 locations all over Pakistan are identified with the largest potential to support the wind farm installation.

In literature, the wind resources in Pakistan are categorized into seven classes (see Table 3-1). These classes are standardized according to universal units to assess the wind power potential at a site. Sites which lie under wind class 3 or above are suitable for different utility-scale wind energy harnessing. Table 3-1 shows all the seven classes along with associated wind speeds and power density at an altitude of 10m and 100m. Energy modeling and simulation software generally utilize annual wind speed data or statistical wind resource to carry out the simulation of wind farms. The mostly utilized statistical wind data is Weibull distribution function. The empirical relation for the Weibull distribution function [15], [16].

Table 3-1: Wind power class categorization [14]

Wind class	Potential	10 m height		100 m height	
		Wind speed (m/s)	Power density (W/m^2)	Wind speed (m/s)	Power density (W/m^2)
1	Poor	0-4.4	0-100	0-5.4	0-200
2	Marginal	4.4-5.1	100-150	5.4-6.2	200-300
3	Moderate	5.1-5.6	150-200	6.2-6.9	300-400
4	Good	5.6-6.0	200-250	6.9-7.4	400-500
5	Excellent	6.0-6.4	250-300	7.4-7.8	500-600
6	Outstanding	6.4-7.0	300-400	7.8-8.6	600-800
7	Superb	>7.0	>400	>8.6	>800

In our study, the average wind speed, shape and scale factors are extracted by the Global Wind Atlas. It provides average wind speed, k and c factors at different heights such as 10m, 50m, 100m and 150m. The following data for 100 m height is inserted into the simulation software. System Advisory Model (SAM), developed by National Renewable Energy Laboratory (NREL), is a software tool designed to model and analyze the techno-economic parameters of RE systems [3]–[6]. It allows users to get hourly energy generation and load demand data in graphical form and provides a complete cashflow statement which is not possible in other energy system analysis software such as iHOGA and RETScreen. It has the capability to model the wind farm and analyze the techno-economic parameters in detail along with providing hourly and monthly graphical results.

Furthermore, the software helps in optimizing the layout of the wind farm and therefore, selecting the optimal configuration for the wind farm. Therefore, the optimal configuration and turbine type is selected for each identified site. SAM has a built-in database to provide information about the characteristics of commercially available wind turbines. Hence, SAM is utilized to analyze the performance of commercially available wind turbines and select the best performing wind turbine. Capacity factor and net annual energy yield are the deciding factors for the selection of wind turbine. By utilizing eq (4), capacity factor is determined. The losses in the system are estimated to be between 10% to 12% depending on the already done studies. For the analysis, the built-in loss model of SAM for the wind farms is utilized [3]. For the load profiling, it is difficult to obtain the actual load data due to resource constraints therefore, minimal load was assumed for the site and estimated that 50 MW micro-grid wind farm having utility connected configuration can provide electricity to the facility. It is also suggested that the installed micro-grid wind farms are connected to the residential and commercial area which have a peak load demand of 50 MW.

3.8 Economic analysis

The development of wind farms is highly affected by the economic and financial constraints as they require high capital investments. As far as developing countries like Pakistan are concerned, the financial parameters play a vital role in the efficient deployment of wind projects. The projects with better economic feasibility attract more investments and support from the government. It validates the need of economic analysis for the viable deployment of wind farm. SAM also enables the users to input financial details of the wind farm and determines the economic outcomes of the wind project. In our research, the installed, operational and management cost of the wind farm is determined through literature studies performed in Pakistan. For the simulation, $2400/kW installed cost was estimated with an O&M cost of $37/kW [17]. The cost of the micro-grid is also added into the installed cost of the system which was estimated to be around $1400/kW [18], [19]. Water and Power Development Authority (WAPDA) data was utilized to input the electricity tariff in the software. The average electricity rate used for the simulation is taken to be 0.156 ¢/kWh [17]. Similarly, the inflation rate was set to be 2.5% with a total discount rate of 9% [20]. The total life of the project is estimated to be 25 years. The economic outcomes of the simulation include NPV, Simple Payback Period (SPP) and LCOE [21]–[23].

3.9 Environmental analysis

The current environmental concerns have increased the need to include environmental impacts of an energy system into the study. In addition, the present global policies have made it a crucial element for the analysis of energy systems. The global GHG emission laws are pushing the countries to limit their carbon emissions. Wind farms can significantly help in reducing the GHG emissions. The reduction in emissions is generally represented by tons of CO_2-equivalent. It is usually determined through a conversion factor (having a unit of kg of CO_{2e} per kWh) for converting the net annual yield of electricity from wind turbines to CO_{2e} reduction. The value of this conversion factor is determined by the alternate fuel being used to supply electricity at a certain location. It is advocated that wind turbines help in significantly decreasing GHG emissions and ultimately, assisting to tackle the eminent threat of climate change. In our study, the conversion factor is estimated to be 0.23 kgCO_2/kWh when all types of fuels (oil, natural gas and coal) are being used as an alternate fuels to generate electricity [4], [24], [25].

RETScreen is an online available tool for energy modeling and analysis which is developed by the Government of Canada. It provides a platform that allows carbon planning, implementation, monitoring and reporting possible. It has a strong tool for determining the environmental impacts of RE projects which are not possible in SAM. In our study, RETScreen Expert is utilized to determine the impact of wind farms on the reduction filters of gasoline consumed [6,19,20]. Moreover, the amount of crude oil saved from being combusted is also determined through the software.

3.10 Social impact analysis

The study of social impacts is a crucial element for the success of a project. It is a common practice to neglect the social impacts of wind farms while assessing the feasibility of the wind farms. The study of social sciences can help the government and policymakers to improve the existing policies and consider the social impacts while developing new energy policies for the country. There are three major approaches to analyze the feasibility of project in the perspective of social sciences. It includes quantitative, qualitative and mixed method approach [10], [26]. It is important to mention that the following research includes technical, economic and environmental analysis of wind farm at 20 locations spread all across the country. Due to lack of resources, it is impossible to carry out social assessment at all the identified location. Therefore, in the following study, the social impact assessment is divided into three sections. The first section involves online survey to get the opinion of general public. For the second section, interviews are conducted in Khuzdar, Baluchistan considering it has an excellent potential for wind farm installation.

The third section includes conducting interviews in Jhimpir, Sindh where there already exist wind farms. In this way, the qualitative comparison can be drawn between the two sites where wind farm is planned to install and where wind farm already exists. Therefore, it can help the policy makers and wind farm developers to include social benefits according to the public's opinion while installing new wind farms at the suggested locations. It can also help the industrialists to include Corporate Social Responsibility (CSR) program benefits according to the public's needs and expectations.

3.10.1 Section A: Conduction of online survey

The advancement of technology has enabled the researchers to perform the social surveys through online resources. Google form provides the facility to perform online surveys with ease, especially when limited resources are available. In the following section, google forms service is utilized to conduct surveys and get quantitative aspect of the social impacts of wind farms [27]–[29]. The survey was conducted within a time frame of 30 days and 151 participants responded to the questions. Before the survey, participants were provided with a consent form which elaborated the purpose of study and confidentiality of the data. Participants were also given the option to leave the online survey anytime while filling the form. The survey was divided into 4 categories: demographic, social, environmental and economic questionnaires. The following Table 3-2 shows questions for the online survey and the options. In the following scaled questions, "1" represents "Strongly Disagree" and "5" represents "Strongly Agree."

The statistical consistency of the survey is validated by the sample size, n. The sample size estimated for the research is 150. According to literature, the error of sampling, e is usually estimated between 1 to 10% [30]. For our survey, the error estimated to be 8%. Similarly, obtained population proportion is estimated to be 5% and utilizing the normal distribution table, the Z value is derived against the required confidence level (i.e. corresponding to the chosen alpha level – for 0.05 is 1.96). Similarly, the rule of thumb is that the number of respondents for a survey should be more than 3 time the number of questionnaires in the survey. As the total number of questionnaires in the survey are 19 and according to the rule, the number of respondents should be equal to or more than 57 to provide statistical validity. In addition, the greater the number of respondents, greater will be the accuracy of the survey [28].

Table 3-2: Questionnaires for the online survey

Category	**ID**	**Item**	**Options**
Demographic	QA1	What is your age?	Under 18 years old 18-30 years old 30-40 years old 40-50 years old More than 50 years old
	QA2	What is your gender?	Male Female Prefer not to say
	QA3	What is your education level?	No schooling completed Under matriculation Matriculation or equivalent Intermediate or equivalent Bachelor’s degree Master’s degree Doctorate degree
	QA4	Which region/province of Pakistan do you belong?	Punjab Sindh Khyber Pakhtunkhwa Baluchistan Islamabad Capital Territory Gilgit-Baltistan Azad and Jammu Kashmir
Social	QA5	Do you know what a wind turbine is?	Yes No
	QA6	Have you ever seen an operational wind turbine?	Yes No
	QA7	I believe Pakistan is facing the issue of electricity shortfall	1 to 5 scale
	QA8	I believe wind farms can help in solving the issue of electricity shortfall	1 to 5 scale
	QA9	In your opinion, what is the biggest reason of electricity shortfall in Pakistan?	Conflicted benefits of politicians Inconsistent and incompetent energy policy

			Lack of financial capability Underutilization of RETs Lack of fossil fuel resources
	QA10	In your opinion, how can the energy crisis in Pakistan be solved?	Utilization of RETs such as wind, solar, etc. Developing better energy policy and infrastructure Reducing electricity consumption by incentivizing energy efficient products in market Importing more fossil fuels and petroleum products More taxation on electricity prices
Economic	QA11	I believe wind farms can help in reducing electricity prices	1 to 5 scale
	QA12	I believe wind farms can bring new employment opportunities to the country I believe wind farms can help in improving economic situation of the country	1 to 5 scale
	QA13	I would be willing to invest in the installation of wind farms if I get a reasonable return (for example, cheaper electricity tariffs, bill compensation, monthly profit share, etc.)	1 to 5 scale
	QA14	What benefits would you expect from the wind farm if the government decides to install a wind farm in your neighborhood? (It means you would be directly affected by noise and visual impacts). Please select the option in terms of priority	Employment quota for neighborhood community Cheaper electricity tariff for neighborhood community No load-shedding for the neighborhood community

Environmental	QA15	I believe Pakistan is facing environmental issues	1 to 5 scale
	QA16	I believe wind farms can help in reducing environmental issues (like smog, pollution, etc.) in Pakistan	1 to 5 scale
	QA17	I believe climate change is real and impacting Pakistan	1 to 5 scale
	QA18	I believe wind farms are aesthetically pleasing	1 to 5 scale
	QA19	Wind turbines produce noise, however the intensity of which decreases with distance. What noise level (in terms of equivalence) is acceptable to you if government plans to install a wind farm in your neighborhood?	Noise equivalent to blender (20 m away from wind turbine) Noise equivalent to vacuum cleaner (40 m away from wind turbine) Noise equivalent to mid-size air cooler (100 m away from wind turbine) Noise equivalent to refrigerator (400 m away from wind turbine) I would prefer no installation of wind farm in my neighborhood because of noise issue.

3.10.2 Section B: Interview from Khuzdar, Baluchistan

Khuzdar is a city in Baluchistan Province and is considered as one the majorly underdeveloped areas in Pakistan. The interview was taken from the local residents in their local language. The participants were well explained about the purpose of the interview and a consent form was signed by the participants. It was specifically mentioned that the collected data would be treated as strictly confidential and only used for the research purpose. In addition to this, participants were given the option to leave the interview anytime without providing any reason. Moreover, before the interview, they were shown a short video showing the working of a wind turbine along with standardized noise and visual impacts of the turbines to give a clear perspective to the local participants about the wind farms [9], [31]. In the following research, 7 people were interviewed. The following Table 3-3 shows the main interview questions.

Table 3-3: Interview questions from Khuzdar, Baluchistan

	Item
Central question	How do you think wind farms can help in alleviating the socio-economic and electricity shortfall issues from the community?
Sub-questions (ID)	
QB1	What do you know about wind farms and their working?
QB2	What is the level of electricity shortage in your area? How do you think it can be solved?
QB3	What is your opinion about the role of wind farms in solving the issue of electricity crisis and rural electrification? Do you think it can work in your area?
QB4	What do you think about the effect of wind farms on employment opportunities for the community? Will it increase or decrease the employment opportunities?
QB5	What socio-economic benefits do you expect from the installation of wind farms? Do you want better electricity supply, cheaper tariffs, employment opportunities or education?
QB6	What is your opinion about the visual impacts and noise created by the wind farms? Why do you think it is an issue for you? Will it be okay if it is equivalent to noise made by a refrigerator?
QB7	What do you think about investing in the installation of wind farm in your community? What benefits will you expect then?

3.10.3 Section C: Interview in Jhimpir, Sindh

Jhimpir, Sindh has an excellent potential for wind farm installation and therefore, there exist multiple wind farms with varying capacity. Interview was taken from the local community members of Jhimpir in their local language and the results were compared to the responses taken in interview from Khuzdar. Therefore, qualitative comparative analysis is drawn from the results. Due to resource limitations, interview was taken from 9 participants. In addition, the participants were sufficiently explained about the purpose of the interview and a consent form was signed by the participants. Participant of the interview were assured about the confidentiality of data and its utilization for research purpose only. In addition to this, participants were given the option to leave the interview anytime without providing any reason.

It is proposed that the following study will help in getting public's opinion from an area where already exists a wind farm and comparing it with people's perspective where there is a potential of wind farm installation in future. Furthermore, it will assist in understanding which can be taken to increase the public acceptance and participation in wind farms. It will also help the policy makers to develop better policies to ensure appropriate incentivization for promoting economic and social well-being of the impacted community [31]. The following Table 3-4 shows questions of the interview.

Table 3-4: Interview questions from Jhimpir, Sindh

	Item
Central question	How has the wind farm helped in alleviating the socio-economic issues from the community?
Sub-questions (ID)	
QC1	What do you know about wind farms and their working?
QC2	What do you think about the role of wind farms in reducing electricity shortfall (load-shedding)? How do you think wind farm has helped in solving the issue of load-shedding?
QC3	What do you think about the role of wind farms in reducing electricity prices? Do you think it has or it will reduce prices?
QC4	What is your opinion about the noise and visual impacts of wind farms? Have you experienced any noise in the past?
QC5	What do you think about the effect of wind farms on employment opportunities for the community? Did you experience any improvement in employment opportunities with the installation of wind farm?
QC6	What socio-economic benefits did you get from the installation of wind farms? What socio-economic benefits did you expect from the installation of wind farms?
QC7	What do you think about making an investment for the construction of wind farm in your community? What benefits will you expect then?

3.10.4 Limitations

The following social surveys and interviews have some limitations. Even though the sample size for our quantitative analysis is according to the theoretically determined sample size but still diverse range of cultural backgrounds were not covered. However, in order to increase the accuracy of the survey results, and eventually decrease the error term, the sample size should be increased. In our case, due to resource limitation, we were not able to cover wide range of cultural and regional backgrounds. The online survey form was subjected to availability of internet and understanding of English language. As majority of the population in Pakistan does not have access to proper internet and understanding of English language, therefore, one can argue that it limits the generalization of our results. Nevertheless, the protocols are documented step by step, therefore, results can be reproduced with participants in different cultural and regional backgrounds. Similarly, in Khuzdar, Baluchistan and Jhimpir, Sindh, the conduction of interview from diverse group of people was not possible because of resource constraint. In Khuzdar, majority of the people were uneducated and did not understand the purpose of interview. Moreover, the participants were not given reward for participating in the interview due to financial constraints of the study. It reduced the incentive for the people to participate in the study. The same resource constraint affected the generalization of interviews in Jhimpir. By taking a greater sample size, data from participants with diverse socio-cultural-economic background can be collected to have more generalized results.

Summary

The following chapter summarizes the method and materials available for data collection of wind speed, techno-economic feasibility analysis, environmental impact analysis and social impact assessment of wind farms. It is investigated that wind speed for a site can be determined through surface- and GIS-based data depending on the available resources and accuracy requirement. Furthermore, the application of Global Wind Atlas for determining the average windspeed and power density for various sites is also briefly discussed. The software used for modeling the renewable energy system, such SAM and RETScreen are discussed. The functionality and applications of both the software tools are also discussed and compared. The environmental tool of RETScreen is also included into the discussion to analyze its applicability in investigating environmental impacts of wind farms. In the end, various methods to perform social impact analysis is also discussed. Interviews, case studies, site surveys and online surveys are considered as the potential candidates to perform social impact assessment of wind farms in Pakistan.

Furthermore, it is stated that GIS-based wind speed data from Global Wind Atlas can provide accurate enough data to perform preliminary WRA. Moreover, the following data can be utilized to perform techno-economic feasibility analysis of the wind farm at the particular site. Moreover, for the computer-based modeling and simulation of wind farms, SAM is utilized for technical and economic analysis to determine capacity factor, net electructy yield, LCOE, NPV and payback period. RETScreen is utilized to determine the environmental impacts of the wind arms. The net reduction in carbon emissions is determined through simulation on RETScren. in order to do this social impact assessment, the research was divided into two major sections. It includes qualitative and quantitative analysis. In quantitative analysis, online survey was conducted to determine public's perception and awareness about wind farms. In the end, qualitative analysis was conducted by performing interviews at Khuzdar and Jhimpir. The interview responses are suggested to be analyzed through content analysis technique.

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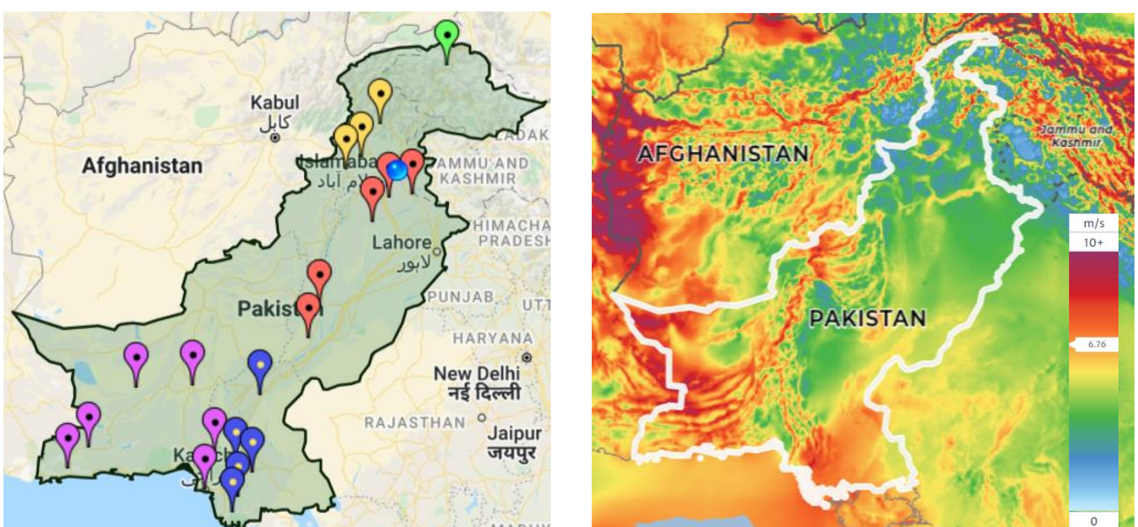
Chapter 4: Results and Discussion

4.1 Wind resource assessment

The results for the wind data are obtained through Global Wind Atlas using GIS data. 5 sites in Punjab, 5 sites in Sindh, 6 sites in Baluchistan, 3 sites in KPK and one site is identified in Gilgit depending on the average wind speed, power density and shape parameter of Weibull distribution function. The position of each site on map (a) along with a wind speed contrast map (b) is represented in Figure 4-1. In this, red, blue, purple, yellow and green markers represent sites in Punjab, Sindh, Baluchistan, KPK and Gilgit respectively. It is evident that locations are more widely spread and diverse in Baluchistan while in Sindh and KPK locations are relatively concentrated along a specific region. On the other hand, in Punjab, the sites are concentrated at two distinct regions. One on the upper Punjab and second in the lower Punjab region. It can also be evaluated that Baluchistan and Sindh has a better wind potential as compared to Punjab, KPK and Gilgit. Wind speed is generally lower in Punjab while on the other higher wind speeds exist in KPK and Gilgit in hilly terrains with concentrated wind hotspots.



(a) (b)

Figure 4-1: (a) Identified sites for wind farm installation; (b) Wind speed contrast map [1]

After carefully identifying the sites, WRA is performed for all the sites. In WRA, average wind speed, average power density, Weibull shape and scale parameters are determined using the data provided by Global Wind Atlas. The following Table 4-1 shows average wind speed, power density and wind class of the location based on both wind speed and power density. The wind class is assigned depending on the information given in Table 4-1 for altitude of 100m.

Table 4-1: WRA of the identified sites

Province	Location	Coordinates (Lat, Long)	Average Wind Speed, m/s	Power density, W/m^2	Wind class w.r.t wind speed	Wind class w.r.t power density
Punjab	Rajanpur Tribal Area	29.18°, 69.86°	7.78	412	5	4
	DGK	30.10°, 70.06°	7.31	592	4	5
	Khushab	32.60°, 72.54°	7.11	714	4	6
	Chakwal	32.68°, 73.01°	6.94	439	4	4
	Tehsil Dina, Jhelum	32.83°, 73.41°	8.52	859	6	7
Sindh	Manzoorabad, Jamshoro	25.73°, 67.90°	9.64	1013	7	7
	Shah Bander, Sajawal	24.92°, 67.60°	6.98	420	4	4
	Badin	24.31°, 67.83°	6.93	473	4	4
	Khairpur, Sanghar	24.45°, 68.55°	7.2	530	4	5
	Hyderabad	26.52°, 69.43°	7.4	509	5	5
Baluchistan	Dureji, Lasbela	25.22°, 68.40°	8.43	698	7	6
	Shaha Nooran, Khuzdar	25.52°, 67.14°	11.65	1738	7	7
	Shahrak, Kech	26.02°, 66.91°	10.15	1178	7	7
	Panjgur	26.12°, 63.63°	11.17	1242	7	7
	Gwadar South	26.53°, 63.49°	9.29	905	7	7
	Sothgun, Washuk	25.44°, 62.55°	11.97	1652	7	7
KPK	Shangla	27.34°, 63.37°	11.18	2110	7	7
	Nowshera	34.83°, 72.79°	8.87	921	7	7
	Darra Adam Khel	33.83°, 71.92°	10.25	1314	7	7
Gilgit	Hunza Nagar	33.63°, 71.55°	8.77	983	7	7

The wind speed ranged between 6.98 to 8.42 m/s, 6.93 to 9.64 m/s, 8.43 to 11.97 m/s, 8.87 to 11.18 m/s in Punjab, Sindh, Baluchistan and KPK respectively. It is evident from the wind data that Baluchistan has the largest potential for wind farm installation. All of the sites in Baluchistan demonstrated a wind power class of 7 which is considered as superb. Similarly, locations selected in KPK and Gilgit also came under wind class 7 category. In contrary, sites in Sindh and Punjab demonstrated a wind class ranging from 4 to 7 which ranges between good to superb wind potential. Therefore, it advocated that the selected sites have a significant potential for supporting wind farm development. It is also noted that some sites have higher wind speed but have a lower power density. In this case, to make a more conservative analysis, the wind class assigned by power density will be considered. Figure 4-2 represents the wind speed and power density for each site.

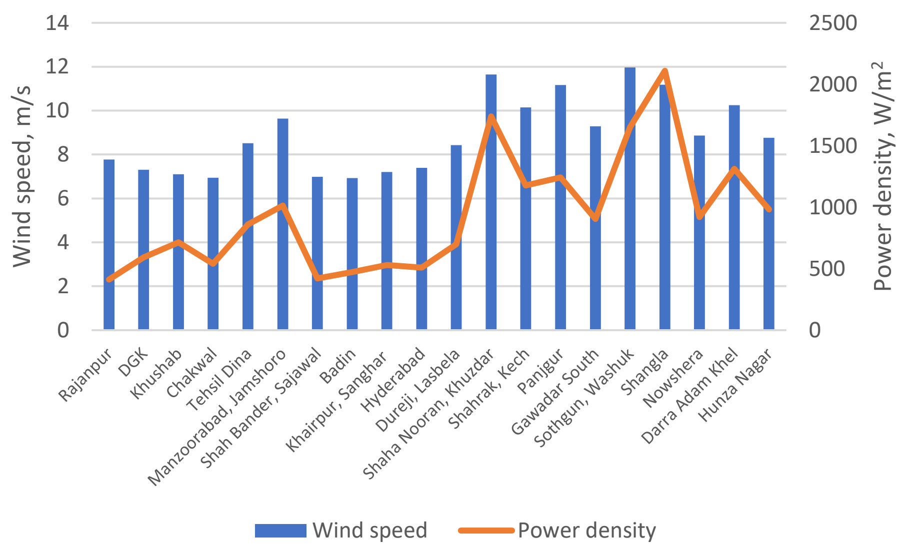


Figure 4-2: Wind speed and power density for the selected sites

The next step in WRA involves the determination of the Weibull distribution factors to determine the distribution of wind at the given site. For the Weibull parameters, Global Wind Atlas provides k and c for each month [2], [3]. In order to get annual values for k and c factors, average is taken and presented in Table 4-2. The shape factor, k represents variability, and it has value ranging between 1 to 3. The lower value of k represents more variability from the actual data while higher value of k demonstrates less variable wind. Most of the sites in Baluchistan and Sindh demonstrated k factor greater than 2 which represents a more stable and less variable wind profile. In contrary, Punjab (except

Rajanpur), KPK and Gilgit showed k factor lower than 2 which indicates that wind profile in these sites is more deviated from the actual wind speed data. The maximum k factor of 2.56 came out to be for Shah Bander while Hunza Nagar exhibited the lowest k factor of 1.387. It elaborates that wind data for Hunza Nagar is prone to variability as compared to rest of the sites.

Table 4-2: Shape and scale factors of Weibull wind distribution for selected sites

Province	**Location**	**k parameter**	**c parameter**
Punjab	Rajanpur Tribal Area	2.360	7.108
	DGK	1.867	5.638
	Khushab	1.695	4.888
	Chakwal	1.799	5.207
	Tehsil Dina, Jhelum	1.828	5.223
Sindh	Manzoorabad, Jamshoro	2.054	6.458
	Shah Bander, Sajawal	2.595	6.955
	Badin	2.442	6.618
	Khairpur, Sanghar	2.107	6.383
	Hyderabad	2.622	6.603
Baluchistan	Dureji, Lasbela	2.000	6.002
	Shaha Nooran, Khuzdar	1.972	5.807
	Shahrak, Kech	2.187	7.255
	Panjgur	2.249	7.676
	Gwadar South	1.870	6.179
	Sothgun, Washuk	2.207	7.592
KPK	Shangla	1.431	4.636
	Nowshera	1.682	4.583
	Darra Adam Khel	1.771	5.173
Gilgit	Hunza Nagar	1.387	4.628

The average wind speed values provided in Table 4-1 and shape and scale factors provided in Table 4-2 are utilized to plot the Weibull speed distribution for each site using Eq. (1).

The Weibull distribution plots for each site are given in Figure 4-3. The plots show that sites with higher shape factor values have a steeper and sharper curve which demonstrates less variability in the wind speed. On the other hand, sites with lower shape factor values showed a broader curve demonstrating higher variability form the mean wind speed.

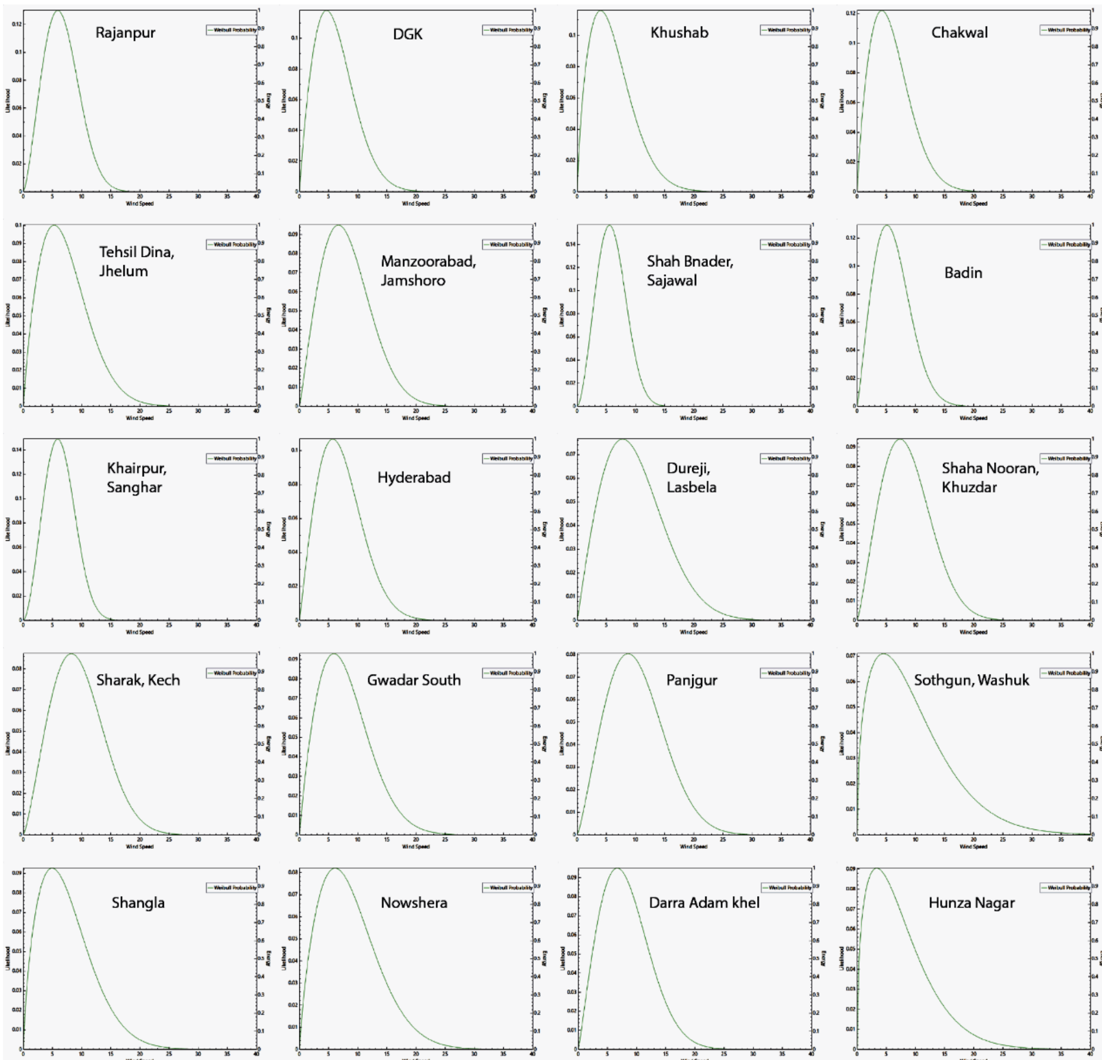


Figure 4-3: Weibull Speed distribution plots for each site

4.2 Simulation through SAM

4.2.1 Technical feasibility analysis

The first step in the simulation involves the determination of right turbine which has a power curve suiting best with the wind profile of the site. The simulation is performed by varying 7 commercially available wind turbines lying within the power range of 1.5 MW to 2.3 MW. The selected wind turbines include: Gamesa G114 2 MW, NREL 2000KW, Siemens 2.3 MW 108m, Vensys 82 m 1500kW, Enercon E82 2 MW, Vestas V90-2.0 and Nordex N90 2300. The power curves of these wind turbines are already available in SAM's database [4], [5]. The capacity factor with each selected wind turbine at each site in given in Figure 4-4. It shows that installation of Gamesa G114-2-MW wind turbine provided the maximum capacity factor at most of the locations. NREL 2000-kW wind turbine also provides a capacity factor close to the Gamesa G114-2-MW. While Nordex-N90-2300 wind turbine gave the minimum capacity factor. Therefore, it is recommended to install Gamesa G114-2-MW and NREL 2000-kW at the selected sites.

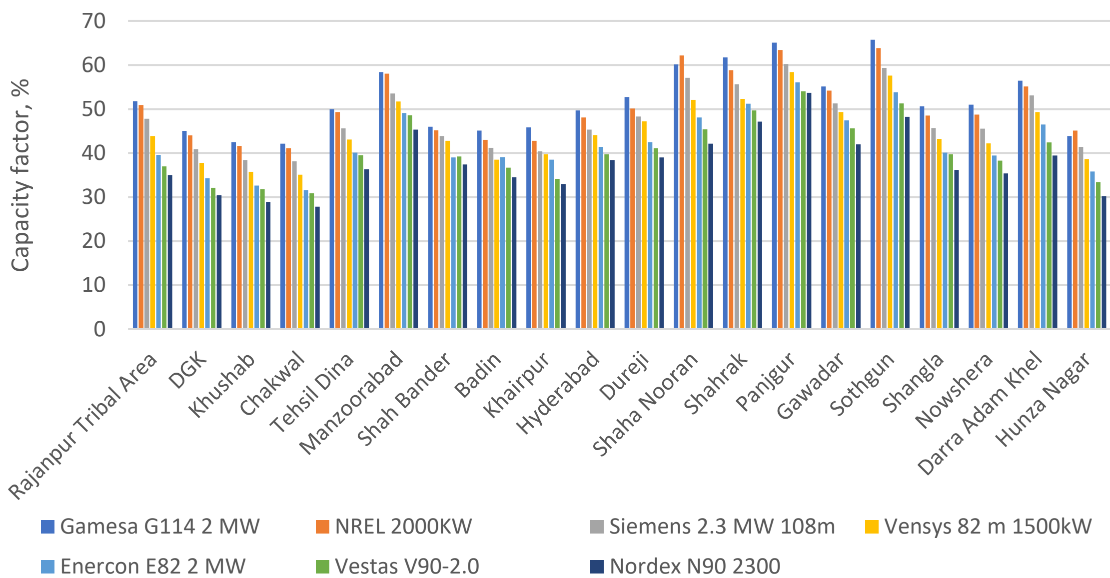


Figure 4-4: Comparison of various turbine performance

The results of the simulation (shown in Figure 4-4) demonstrate that sites in Baluchistan have the highest capacity factor. It means that sites in Baluchistan will generate the maximum annual electricity. The maximum capacity factor came out to be for Sothgun, Washuk (65.7%) which is followed by Panjgur. In contrary, out of 20 selected sites, the lowest capacity factor came out to be for Khushab (42.5%). The simulation results are represented in graphical form in Figure 4-5. These results advocate the technical feasibility of 50 MW wind farm installation at these sites. Moreover, priority should be given to sites with higher capacity factors. The results of the simulation support the installation of wind farms in Baluchistan, but it is restricted due to the geographical and ecological constraints. In addition, to provide electricity to the central grid, more profound T&D system should also be included. The following Table 4-3 shows detailed technical results from simulation. It includes detailed energy production from 50 MW wind farm each year along with their estimated capacity factors. Ina addition to this, the commercially available wind turbines which demonstrated the most efficient working are also included in the Table 4-3.

Table 4-3: Technical results from simulation of wind farms

Location	**Turbine Type**	**Annual production, MWh**	**Capacity factor, %**
Rajanpur Tribal Area	Gamesa G114 2 MW	226,884	51.8
DGK	Gamesa G114 2 MW	197,100	45
Khushab	Gamesa G114 2 MW	186,150	42.5
Chakwal	Gamesa G114 2 MW	184,398	42.1
Tehsil Dina, Jhelum	Gamesa G114 2 MW	219,000	50
Manzoorabad, Jamshoro	Gamesa G114 2 MW	255,792	58.4
Shah Bander, Sajawal	Gamesa G114 2 MW	201,480	46
Badin	Gamesa G114 2 MW	197,538	45.1
Khairpur, Sanghar	Gamesa G114 2 MW	200,604	45.8
Hyderabad	Gamesa G114 2 MW	217,686	49.7
Dureji, Lasbela	Gamesa G114 2 MW	230,826	52.7
Shaha Nooran, Khuzdar	NREL 2000 kW	272,436	62.2
Shahrak, Kech	Gamesa G114 2 MW	270,246	61.7
Panjgur	Gamesa G114 2 MW	285,138	65.1
Gawadar South	Gamesa G114 2 MW	241,338	55.1
Sothgun, Washuk	Gamesa G114 2 MW	287,766	65.7
Shangla	Gamesa G114 2 MW	221,628	50.6
Nowshera	Gamesa G114 2 MW	223,380	51
Darra Adam Khel	Gamesa G114 2 MW	247,032	56.4
Hunza Nagar	NREL 2000 kW	197,687	45.1

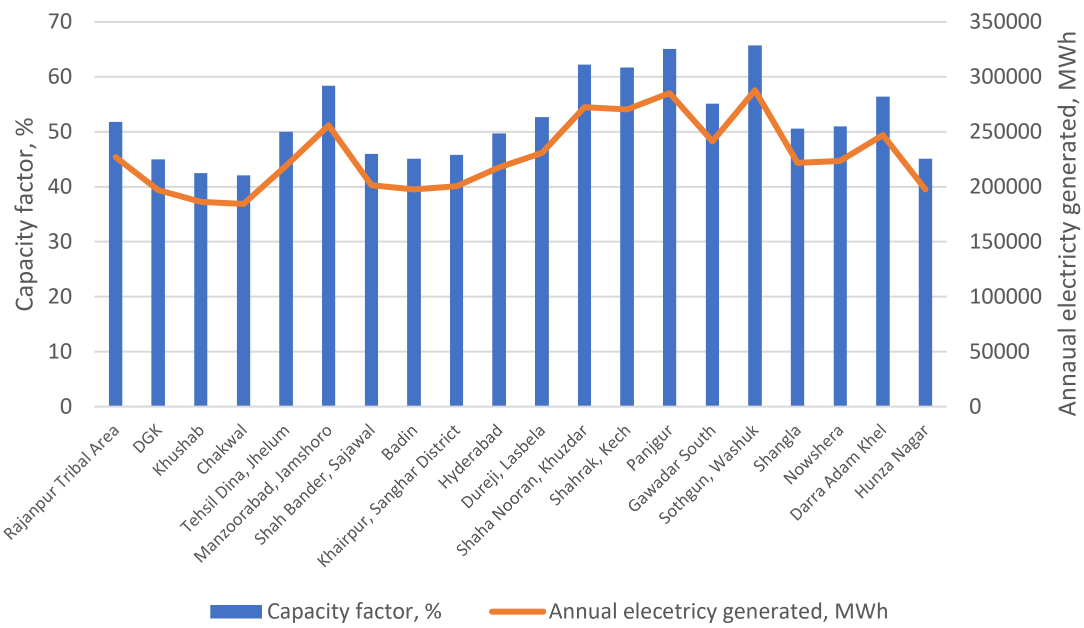


Figure 4-5: Graphical results showing the technical feasibility at each site

4.2.2 Economic feasibility analysis

Along with performing the technical analysis on SAM, economic analysis is also conducted. The results of the simulation are provided in Table 4-4. The results show that all of the sites demonstrated an excellent economic feasibility. NPV, LCOE, SPP are considered as the major parameters to determine the economic viability of the wind project. The net present cost (NPC) of the wind farms is estimated to be $19000000 for 50 MW wind farm. From the results, it is evident that all of the sites have a LCOE lower than the electricity tariff available in Pakistan (12 ¢/kWh). The average real LCOE comes out to be 3.21¢/kWh while the average nominal LCOE comes out to be 4.02¢/kWh. Similarly, the average discounted payback period (DPP) comes out to be 6.86 years while the average SPP comes out to be 5.2 years. Furthermore, the lowest LCOE came out to be for Manzoorabad, Jamshoro and highest LCOE came out to be for Chakwal. Similarly, the lowest SBP came out to be 4.4 years for Khuzdar and Jamshoro. The positive NPV also demonstrates the economic viability of the projects. Greater the NPV value for a project, greater the economic feasibility of the project. Therefore, Sothgun shows the maximum economic feasibility as far as NPV is considered. In comparison to this, Chakwal showed the least NPV.

Table 4-4: Economic results from the simulation of wind farms

Location	SPP (years)	DPP (years)	NPV ($)	LCOE (nominal), ¢/kWh	LCOE (real), ¢/kWh
Rajanpur Tribal Area	5.1	6.6	156,708,000	3.77	3
DGK	5.5	7.3	128,377,632	4.17	3.31
Khushab	6.3	9.3	87,918,920	5.2	4.2
Chakwal	6.4	9.5	86,244,480	5.25	4.24
Tehsil Dina, Jhelum	5.4	7.2	118,465,672	4.41	3.56
Manzoorabad, Jamshoro	4.4	5.2	203,234,576	3.06	2.43
Shah Bander, Sajawal	5.7	7.8	126,151,960	4.43	3.52
Badin	5.8	8	121,735,968	4.52	3.59
Khairpur, Sanghar	5.7	7.9	125,208,776	4.45	3.52
Hyderabad	5.3	7	113,576,992	4.1	3.26
Dureji, Lasbela	5	6.5	157,223,728	3.87	3.07
Shaha Nooran, Khuzdar	4.4	5.3	199,945,238	3.29	2.61
Shahrak, Kech	4.4	5.3	189,545,243	3.31	2.62
Panjgur	4.2	5	214,667,952	3.13	2.49
Gawadar South	4.9	6.1	168,202,453	3.7	2.94
Sothgun, Washuk	4.2	5	217,618,320	3.1	2.46
Shangla	5.2	6.8	147,279,792	4.03	3.2
Nowshera	5.2	6.8	149,053,874	4	3.18
Darra Adam Khel	4.8	5.9	174,108,325	3.62	2.87
Hunza Nagar	6	8.7	94,824,912	5.11	4.12

4.2.3 Environmental feasibility analysis

Considering the global policies and laws about GHG emissions control, it is crucial to determine the environmental impacts of the energy project. In case of wind farms, it is essential to determine the tonnes of CO_2 equivalent emissions reduction. In our case, RETScreen software is utilized to model the 50 MW wind farm at each site. The conversion factor is estimated to be 0.44 tCO_2/MWh by assuming every sort of fossil fuel is being utilize in the country to provide electricity to the central grid [6]–[8]. Therefore, the net reduction in CO_2 emissions by the installation of wind farm at each site is determined (see Figure 4-6). Moreover, the equivalent liters of gasoline not consumed by the addition of these individual wind farms is also provided in Figure 4-6. The results show that Shangla showed the best potential to reduce CO_{2e} emissions and consequently, the largest amount of gasoline saved from combustion. On the other hand, Chakwal showed the least CO_{2e} reduction from rest of the sites. It can be stated that all of the sites demonstrated a high potential to reduce carbon emissions.

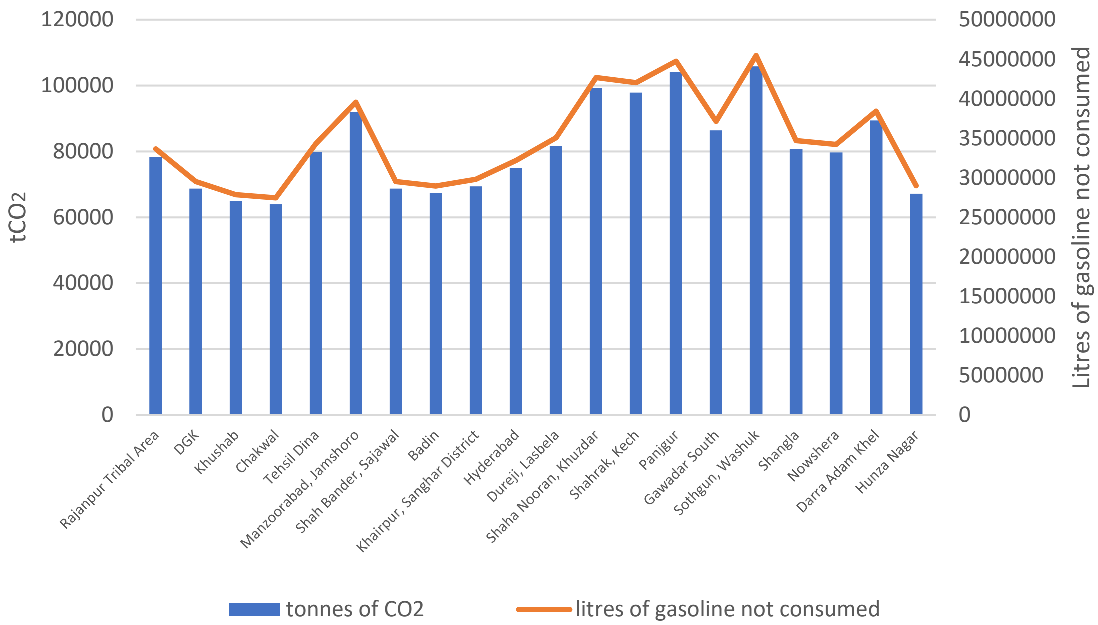


Figure 4-6: Reduction in carbon emissions by the installation of wind farm at each site

4.2.4 Social impact assessment

4.2.4.1 Section A: Online survey results

4.2.4.1.1 Demographic profile of the survey

The respondents were asked about their age, gender, level of education and the region where they belong in Pakistan (see Table 4-5 for detailed demographic composition of participants). In the survey, total 151 participants responded to the survey (n = 151). The result of the survey shows that majority of the study participants (n=91, 60.3%) were male while 58 (38.4%) females responded to the survey. The majority of the participants were also young adults (n =120, 79.5%) which lied within the age bracket of 18 to 30 years old, 20 participants (13.2%) lied within the age bracket of 30 to 40 years, 7 participants (4.6%) belonged to the age group of 40 to 50 years old, and 4 (2.6%) participants were under 18.

Similarly, majority of the participants (n=109, 72.2%) were from Punjab region. In addition, majority of the participants (64, 42.2%) were with a master's degree which was followed by 62 (41.1%) participants having bachelor's degree. So, it can be stated that most of the participants had higher qualification level and better understanding of the wind farms.

Table 4-5: Demographic composition of participants

SN		**Frequency**	**Percentage (%)**
QA1	Age bracket		
	Under 18 years old		2.6
	18-30 years old	120	79.5
	30-40 years old	20	13.2
	40-50 years old	7	4.6
	More than 50 years old	0	0
QA2	Gender		
	Male	91	60.3
	Female	58	38.4
	Prefer not to say	2	1.3
QA3	Education level		
	No schooling	0	0
	Under matriculation	2	1.3
	Matriculation or equivalent	6	4
	Intermediate or equivalent	13	13
	Bachelor's degree	62	41.1
	Master's degree	64	42.4
	Doctorate degree	4	2.6
QA4	Region in Pakistan		
	Punjab	109	72.2
	Sindh	8	5.3
	Khyber Pakhtunkhwa	9	6
	Baluchistan	8	5.3
	Islamabad Capital Territory	8	5.3
	Gilgit-Baltistan	5	3.3
	Azad and Jammu Kashmir	4	2.6

4.2.4.1.2 Survey results – Social category

The results of the survey show that major participants (n=144, 95.4%) were aware about the wind turbines and farms while only 7 participants were not aware of the wind turbines. Further, it is noted that around half of the participants have seen an operational wind turbine while half have not seen an operational wind turbine. The results from questionnaire QA7 to QA10 are given in Table 4-6. In addition, column and pie charts of the responses are given in Figure 4-7. It shows that majority of the participants strongly agreed that Pakistan is having an electricity shortfall situation while majority agreed that the following issue of electricity shortfall can be solved by the integration of wind turbines.

In addition, majority of the participants (n=65) were of the opinion that major issue of energy crisis is incompetent and inconsistent national energy polices while 21% of the participants considered conflicted benefits of politicians to be the reason of electricity shortage in Pakistan. 20.5% percent participants agreed that underutilization of renewables is the reason for energy shortfall in Pakistan. Similarly, in the response to QA10, majority of participants suggested that the energy shortfall in Pakistan can be resolved by developing better policies and infrastructure (n=69, 45.7%) and 65 participants agreed that inclusion of RETs into the energy mix can significantly help in tackling the energy issue. In short, majority of the participants suggested that national energy policy should be developed in a way to promote the inclusion of RETs into the national energy mix.

Table 4-6: Results of the survey from social category

ID		Frequency	Percentage (%)
QA7	Perspective about existence of electricity shortfall		
	Strongly disagree – 1 Disagree – 2 Neutral – 3 Agree – 4 Strongly Agree – 5	5 14 20 53 59	3.3 9.2 13.2 35.1 39
QA8	Perspective about wind farms		
	Strongly disagree – 1 Disagree – 2 Neutral – 3 Agree – 4 Strongly Agree – 5	3 7 23 67 51	1.9 4.6 15.2 44.3 33.7
QA9	Reason for electricity crisis		
	- Conflicted benefits of politicians - Inconsistent and incompetent energy policy - Lack of financial capability - Underutilization of RETs - Lack of fossil fuel resources	32 65 19 31 4	21.2 43 12.5 20.5 2.6
QA10	Solution for electricity crisis		
	- Utilization of RETs - Developing better energy policy and infrastructure - Reducing electricity consumption by incentivizing energy efficient products in market - Importing more fossil fuels and petroleum products - More taxation on electricity prices	65 69 7 6 4	43 45.7 4.6 4 2.6

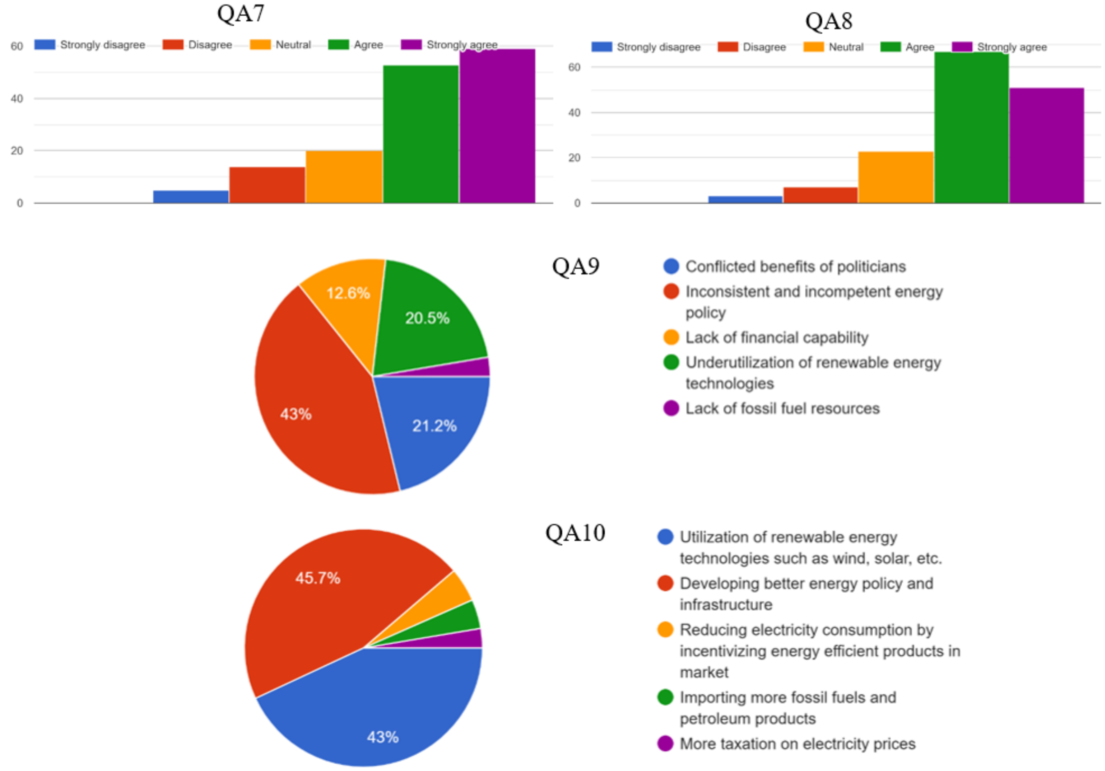


Figure 4-7: Charts for participant responses in social category of survey

4.2.4.1.3 Survey results – Economic category

The results of the survey for economic category are given in Table 4-7 with graphical results in Figure 4-8. The results of the survey show that majority of the participants (n=68)) ‘agreed’ that wind farms can help in reducing the electricity prices while 50 participants ‘strongly agreed’ for the part of wind farms in reducing electricity prices. For QA12, most of the participants (n=62) agreed that wind farms can bring new employment opportunities into the country with 56 participants strongly agreeing with the mentioned statement. It is also evaluated that majority of the participants, which was 71 respondents, agreed to invest in wind farm development if they were provided with market competitive returns on their investments. The returns can be in the form of monthly profit, reduction in electricity prices for the investors, feed-in-tariffs, and so on. It demonstrates that majority of the public is inclined towards participating and investing in wind farm projects if government or any other private company provides adequate returns to the people. As a response to QA14, majority of the participants opted cheaper electricity tariffs for the neighboring community of the wind farms (which are affected by the wind farms) as their first and second priority. It was followed by no load shedding and then employment quota for the neighboring community as their priority.

Table 4-7: Results of the survey from economic category

ID		**Frequency**	**Percentage (%)**
QA11	Reduction in electricity prices		
	Strongly disagree – 1	4	2.6
	Disagree – 2	7	4.6
	Neutral – 3	22	14.5
	Agree – 4	68	45
	Strongly Agree – 5	50	33.1
QA12	Employment		
	Strongly disagree – 1	1	0.6
	Disagree – 2	5	3.3
	Neutral – 3	27	17.8
	Agree – 4	62	41
	Strongly Agree – 5	56	37
QA13	Investment and public participation		
	Strongly disagree – 1	5	3.3
	Disagree – 2	6	3.9
	Neutral – 3	30	19.9
	Agree – 4	71	47
	Strongly Agree – 5	39	25.8
QA14	Expected benefits (1st ,2nd ,3rd priority)	(1st ,2nd ,3rd priority)	
	- Employment quota for neighborhood community	47, 39, 65	31, 25.8, 43
	- Cheaper electricity tariff for neighborhood community	56, 73, 22	37, 48.2, 14.4
	- No load-shedding for the neighborhood community	48, 39, 64	31.7, 25.8, 42.4

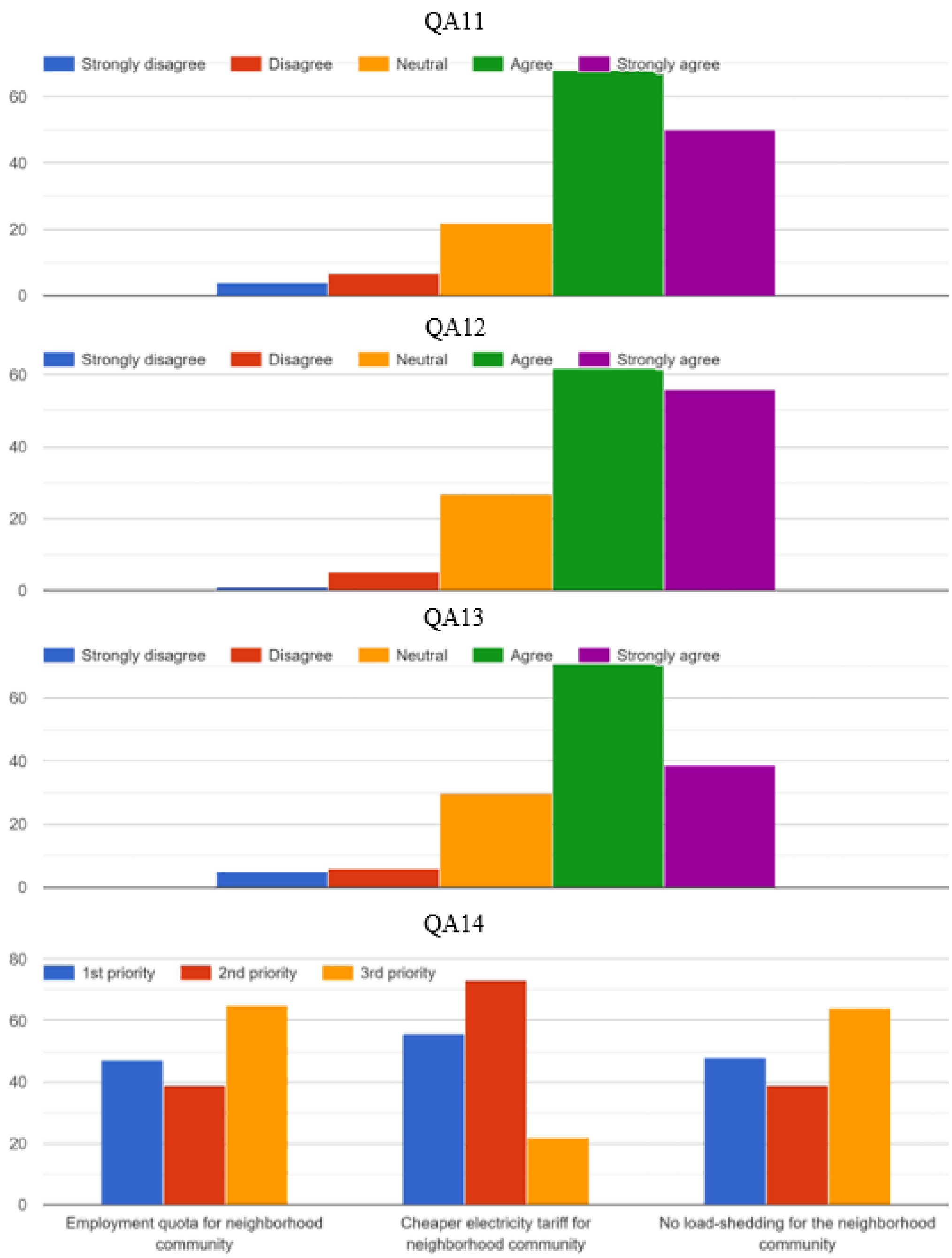


Figure 4-8: Charts for participant responses in economic category of survey

4.2.4.1.4 Survey results – environmental category

The survey results for environmental category (see Table 4-8 and Figure 4-9) demonstrate that majority of the participants (n=90) strongly agreed about the existence of environmental issues in Pakistan. Only 6 participants strongly disagreed to the existence of environmental issues in Pakistan. Similarly, in the answer to QA16, majority of the participants strongly agreed that the issue of environmental issues in Pakistan like smog, acid rain and so on, can be resolved by the inclusion of wind farm in the energy sector. Majority of the participants believed that wind farms are clean source of energy and can contribute to solving the environmental issues. As a response to QA17, majority of the participants strongly agreed about the existence of climate change and agreed that Pakistan is getting impacted by it. It means that majority of the population in Pakistan is aware of the global issue of climate change and believe that wind energy can help in solving the issue.

Considering the aesthetics of the wind farms, majority of the participants agreed that wind farms are aesthetically pleasing which was followed by 43 participants staying neutral on the aesthetical impact of wind farms. Cumulative of 14 participants disagreed about the aesthetic nature of wind farms. In the end, in the answer to QA19, majority of the participants (n=64) agreed that wind farm's noise level equivalent to refrigerator is acceptable to them. In contrary, 33 participants agreed for noise level equivalent to mid-size air cooler and 33 participants preferred zero noise level in their neighborhood because of wind farm. It can be deduced that while installing the wind farms, the distance from the closest neighboring community should be at least 400 m (for noise equivalent to refrigerator). Moreover, in the reference from QA14, the impacted community should be provided benefits in terms of cheaper electricity tariffs and excluding them from load-shedding as compensation for the noise and visual impacts.

Table 4-8: Results of the survey from environmental category

ID		Frequency	Percentage (%)
QA15	Perspective about environmental issues		
	Strongly disagree – 1	6	3.9
	Disagree – 2	2	1.2
	Neutral – 3	13	8.6
	Agree – 4	38	25.2
	Strongly Agree – 5	90	59.6
QA16	Contribution of wind farm in environmental issues		
	Strongly disagree – 1	5	3.3
	Disagree – 2	3	1.9
	Neutral – 3	26	17.2
	Agree – 4	54	35.7
	Strongly Agree – 5	63	41.7
QA17	Perspective about climate change		
	Strongly disagree – 1	5	3.3
	Disagree – 2	4	2.7
	Neutral – 3	15	9.9
	Agree – 4	38	25.1
	Strongly Agree – 5	89	58.9
QA18	Aesthetics		
	Strongly disagree – 1	4	2.7
	Disagree – 2	10	6.6
	Neutral – 3	43	28.4
	Agree – 4	59	39
	Strongly Agree – 5	35	23.1
QA19	Noise		
	Noise equivalent to blender (20 m away from wind turbine)	12	7.9
	Noise equivalent to vacuum cleaner (40 m away from wind turbine)	9	6
	Noise equivalent to mid-size air cooler (100 m away from wind turbine)	33	21.9
	Noise equivalent to refrigerator (400 m away from wind turbine)	64	42.4
	I would prefer no installation of wind farm in my neighborhood because of noise issue.	33	21.9

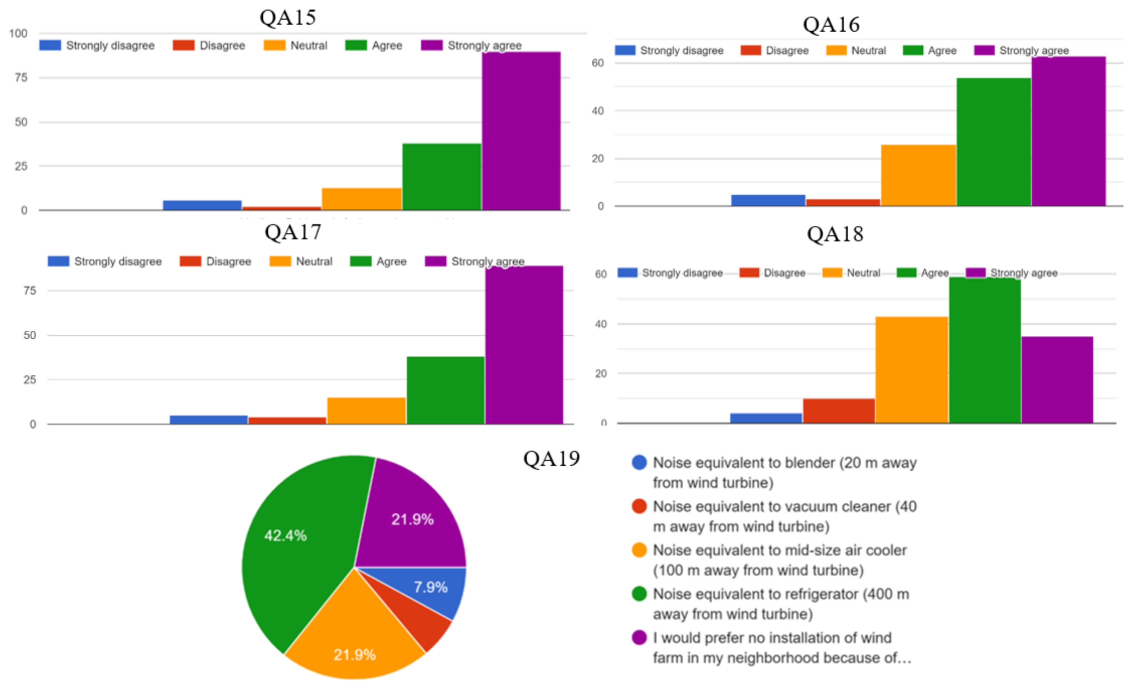


Figure 4-9: Charts for participant responses in environmental category of survey

4.2.4.2 Section B: Interview from Khuzdar, Baluchistan

In this section, key emerging and repeating themes were identified and analyzed across the interviews. In addition to this, it is also presented that how many participants mentioned each theme in order to indicate a frequency and theme distribution throughout participants. But it should be noted that the objective of qualitative research is to investigate the depth of the phenomenon instead of producing quantitative results. Furthermore, both inductive and deductive analysis were utilized to determine the themes. From the interview, electricity shortfall situation, perception about wind energy, misconceptions about the wind farms, and reasonings were identified. The themes extracted from the interviews are given below.

4.2.4.2.1 Familiarity with RETs

Through our survey, we identified that 3 out of 7 participants were aware about the wind farms, their working and application. In contrary, rest of the 4 participants were unaware of the wind farms and their applicability before the working of wind turbine was demonstrated to them through the video. Majority of the participants mentioned the concept of wind farms to be ‘interesting’ and ‘beneficial.’ Participants were also asked about the availability of other renewable resources in their area. All of the participants were aware of the solar PV technology and further added that all of them utilizing solar energy in their homes. One of the participants also commented about the extent of awareness about solar PV that even shepherds use portable solar PV modules to charge batteries. In order to identify the reason of greater penetration of solar PV into the region, probe questions were asked. All of the participates mentioned that government provided 2 solar panels each home in their region which helped in increasing the awareness about the technology. It was also noted that majority of the participants were unaware of the total wattage of the solar panels provided.

4.2.4.2.2 Level of electricity shortfall

All of the participants agreed that their area is having severe electricity shortage. Whereas the electricity shortage was divided into two regions: city and rural peripheries. Majority of the participants added that cities get on average 12 to 14 hours of electricity per day from WAPDA while rural peripheries get average 8 to 7 hours of electricity in a day. Some of the participants commented that the following long-term unavailability of electricity has increased the share of solar PV in their region. According to participants, the inclusion of solar PV has helped in solving their daily energy needs as electricity from WAPDA is highly unreliable.

4.2.4.2.3 Reasons for electricity Shortall

The participants were asked about the reasons of the electricity shortage and participants responded with a variety of reasons while some participants (two) were unaware of the reasons. They added that Baluchistan does not have their independent power plants and electricity mainly comes from Dadu and Sakkur, Sindh, therefore, they are having electricity shortage. Some of the participants said WAPDA is discriminating against them and not providing them enough electricity. On the other hand, two of the participants added that T&D lines are incapacitated and cannot transport enough electricity from Sindh to Baluchistan.

4.2.4.2.4 Potential solutions for electricity shortage

The participants were probe questioned about the potential solutions for alleviating the issue of electricity shortfall in their area to get a perspective of local community members. Majority (4 participants) of the participants suggested an installation of fossil fuel-based power plant in their area to have reliable electricity. While some of the participants suggested more inclusion of solar PV into their area. They further added that government should provide cheaper solar panels because current rates of solar panels are high, and they could not afford it. According to them, subsidizing the price of solar panels could help in solving the issue of electricity crisis in their area.

4.2.4.2.5 Role of wind farms

The participants were asked about their perspective about the deployment of wind farms in their area. They were inquired about their opinion on the role of wind farms to alleviate the issue of electricity shortfall in their area. 5 out of 7 participants agreed that wind farms can help in producing electricity. They compared it to the solar technology that electricity can be produced from "free" resources as compared to thermal power plants. One of the participants discussed about the wind availability at the valley and named it as the "bottleneck" for incoming wind. Therefore, they supported the applicability of wind farms in Khuzdar.

4.2.4.2.6 Employment opportunities

Participants were asked about the employment opportunities in their area and majority of the participants (6 out of 7) commented that employment situation in their area is bad. They further added that they have to move to Sindh for work. Some of the participants were currently working in Sindh. One participant stated that they have their own business of rice distribution, so they are unaware of the employment situation. On further questioning about the impact of wind farms on employment, all of the participants agreed that installation of wind farms is going to bring employment in their area. They accepted that wind farms are going to help in social and economic growth of their community.

4.2.4.2.7 Public participation

Interview was carried out from participants having different socio-economic backgrounds. During the interview, they were asked whether they would invest in the wind farm installation in their community if they were given adequate returns on their investment. Majority of the participants agreed to invest in the wind farm if government or any other private company sells share of wind turbines. Participants were asked about the expected benefits of their investment, so their responses included the following benefits: compensated electricity units (kWhs), cheaper electricity tariff, no load-shedding and employment. Majority of the participants expected compensated electricity units in return of their investments. While some opted cheaper electricity tariffs in return of their investment. One of the participants asked for employment in wind farm with compensated electricity tariffs. 2 of the participants asked for no load-shedding in return of their investment. So, all of the participants agreed to participate in the development of wind farms with suitable benefits in return. In addition to this, participants were asked about the total amount they could invest in the wind farm while getting market competitive returns. The amount of investment can be divided into two ranges depending on responses. Some of the participants were interested to invest around 70,000 to 100,000 PKR while some other participants were interested in investing 300,000 to 400,000 PKR.

4.2.4.2.8 Noise and visual impact

All of the participants were informed about the noise and visual impact of the wind farm and asked about their acceptability. Majority of the participants agreed to have the visuals impact of the wind farm. No one showed any objection to the visual impact of wind farm. Similarly, when asked about the noise, 3 participants said noise could be an issue for them but if it is within reasonable range, they would be comfortable with it as long as they get benefits in terms of cheaper electricity or employment quota for directly affecting community. While 4 participants said they would be comfortable with noise if they get reliable electricity in return. They were probed with a question of noise level equivalent to refrigerator for wind farm. All of the participants agreed to bear that level of noise if they get reliable electricity in return.

4.2.4.3 Section B: Interview from Jhimpir, Sindh

In this section, interview is taken from participants who live near or work at wind farm. After the interviews, statements of the participants were formulated, and major emerging and recurring themes were identified and analyzed. Similar to the previous section (section B interviews), it is also described that how many participants mentioned each theme in order to indicate a frequency and theme distribution throughout participants. The major themes extracted from the interview are given below:

4.2.4.3.1 Awareness about wind farms

Participants were asked about the wind farms and their working to get a view about their level of understanding. It was noted that all of the participants knew about the basic working principle of wind farms. In contrary, majority (6 out of 9) of the participants responded that they did not know about the concept of wind farms before the installation of wind farm in their neighborhood. While rest of the participants commented that they knew about the concept of wind farm but have never seen an operational wind turbine when probe questioned. It can be reflected that participants had negligible awareness about the wind farms before its actual installation.

4.2.4.3.2 Impacts of wind farm on load-shedding

Participants were questioned about the impacts of wind farm on load shedding. 5 out of 9 participants clearly agreed to the reduction of load-shedding after the installation of wind farm. They further added that before the installation of wind farm, they used to have 8 to 10 hours of load-shedding every day but after the installation of wind farm, it has reduced to 5 to 7 hours approximately. On the other hand, 2 out of 9 participants stated that there was no significant effect of wind farm on load-shedding. The frequency of load-shedding is almost the same. In the end, remaining 2 participants stayed neutral about this question as they were unaware of the past load-shedding hours. It can be inferred that majority of the participants agreed to reduction in load-shedding hours due to installation of wind farm.

4.2.4.3.3 Electricity price reduction

Financial incentives are one of the biggest drivers for transitioning to RETs. All of the participants were inquired about the impact of wind farm on electricity prices. Majority of the participants (7out of 9) refused to have any economic benefits from the wind farm even though they were directly impacted. 2 out of 9 participants agreed that the electricity prices were reduced after the installation of wind farm. Participants were further asked about the role of wind farms in reducing the electricity price in future. In response, 6 out of 9 predicants considered wind farms to be an expensive way of generating electricity.

Few of the participants mentioned wind farms to be inefficient. Further questioning about their opinion, 4 participants supported development of more dams of getting reliable and cheap electricity while 2 participants supported thermal energy for cheaper electricity. They mentioned Pakistan has wide reserves of coal which should be utilized. In contrast, 3 out of 9 participants agreed that wind farms can help in getting cheaper electricity if government invests more in their development.

4.2.4.3.4 Noise and visual impacts

Noise and visual impact are the two major parameters which affect the neighboring communities. Considering the visual impacts, no single participant had any objective about the visual impact of wind turbines. In contrary, when asked about the noise, participants who were working at the wind farm and staying near to wind farms strongly objected to the noise created by wind farm. They further mentioned it to be very uncomfortable. While the participants living in the nearby areas, commented that they only hear low noise during night which is quite acceptable. They further verified that local community is not having any problem with the noise impacts of the wind farm.

4.2.4.3.5 Employment

Participants were investigated about the improvement of employment opportunities after the installation of wind farms. All of the participants agreed that the development of wind farms improved the employment situation in their region. Before the installation of wind farms, people usually had to move to Hyderabad and Karachi to look for employment but the deployment of wind farms in Jhimpir has helped in improving employment rate and ultimately economic growth of the region. Further, majority of the participants commented that betterment of the employment situation is the only socio-economic benefit their local community received.

4.2.4.3.6 Investment

Public participation is an important factor to raise investments for the development of wind farms. Globally, there are various governmental policies to support public participation in RET based power plants but in Pakistan the following policies are lacking. In this interview, participants were asked about their decision to invest in the wind farms installation. Majority of the participants agreed to buy shares for the wind farm if they get enough return from their investment. Further questioning about the type and extent of returns, majority of the participants asked for compensation in the electricity bills until the life of the project. There were participants who asked for cheaper electricity tariff depending on their extent of investment. In the end, one participant expected share in the equity of the wind farm depending on number of shares bought for the wind farm.

4.2.5 Analysis of the survey and interviews

The results from the online survey advocate that majority of the people who use social media are aware of wind turbines and their working. Furthermore, it is evident that most of the people recognize that Pakistan is having environmental and climate change issues and wind farms can help in solving the mentioned issues. Similarly, major part of the participants showed their acceptance for wind farms as a potential solution to solve electricity crisis in Pakistan and supported that it can help in improving economic situation of the country. It is implied that maximum participants expected cheaper electricity tariffs if a wind farm gets installed in their neighborhood as their first priority. The underutilization of renewables and inefficient energy policies of Pakistan are the top issues selected by the participants as the key reason for energy crisis in Pakistan. In the end, considering the public participation, participants agreed to invest in buying the shares of wind farms if they get market competitive returns. Majority of the participants expected compensation in electricity tariff prices and certain amount of monthly free electricity in return of their investment. Most of the participants expected cheaper tariffs or provision of specific amount of electricity unit compensation in return of their investment in wind farms. The results from the interview also depicted that public awareness schemes should be initiated by the government to change the public's perception about RETs and especially wind turbines. Similarly, in order to improve participation and capital raising, policies should be developed to provide shares of the wind turbines in a wind farm to the general public. Moreover, it is also advised that wind farms should be at an optimal distance (at last 400 m) from the neighboring community. The comparison between interviews from Jhimpir and Khuzdar show that majority of the people from local community are getting employment in wind farms at Jhimpir, therefore it indicates that wind farm in Khuzdar can also help in improving the employment situation.

Summary

it is summarized through the technoeconomic analysis that Sothgun, Baluchistan depicted largest capacity factor of 65.1% while DGK demonstrated the least capacity factor of 45% among the selected 20 locations. The LCOE ranged between 2.43 to 3.59 ¢/kWh with Manzoorabad showing the least LCOE and Badin showing the maximum LCOE. Similarly, payback period ranged between 4.2 (Sothgun) to 6.4 years (Chakwal) among the 20 selected locations. Sothgun also demonstrated maximum reduction in equivalent carbon emissions. The results from the online survey advocate that majority of the people who use social media are aware of wind turbines and their working. Furthermore, it is evident that majority of the people recognize that Pakistan is having environmental and climate change issues and wind farms can help in solving the mentioned issue. Similarly, majority of the people showed their acceptance for wind farms as a potential solution to solve electricity crisis in Pakistan. Furthermore, majority of the participants agreed that wind farms can help in improving economic situation of the country as electricity is considered as the key variable driving the development of a country. Majority of the participants expected compensation in electricity tariff prices and certain amount of monthly free electricity in return of their investment. The following point of public participation is also validated by the interviews conducted in Jhimpir and Khuzdar. Majority of the participants expected cheaper tariffs or provision of specific amount of electricity unit compensation in return of their investment in wind farms. The results from the interview also depicted that public awareness schemes should be initiated by the government to change the public’s perception about RETs and especially wind turbines. The comparison between interviews from Jhimpir and Khuzdar show that majority of the people from local community are getting employment in wind farms at Jhimpir, therefore it indicates that wind farm in Khuzdar can also help in improving the employment situation.

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Chapter 5: Conclusions and future recommendations

5.1 Conclusions

The integration of RETs is considered as a crucial step for assuring independence and security of the energy sector of Pakistan. The following study focused on identification of potential sites at provincial level in Pakistan which are suitable for wind farm deployment. After performing WRA using GIS-based wind speed and power density data, 20 locations (3 to 5 locations in each province of Pakistan) with most suitable potential for wind farms installation are identified. Further, performing the computer-based modeling of the wind farms at the specified sites and performing the techno-economic analysis, it is evaluated that Sothgun, Baluchistan depicted largest capacity factor of 65.1% while Chakwal demonstrated the least capacity factor of 42.1% among the selected 20 locations. The real LCOE ranged between 2.43 to 4.24 ¢/kWh with Manzoorabad showing the least LCOE and Chakwal showing the maximum LCOE. Similarly, payback period ranged between 4.2 (Sothgun) to 6.4 years (Chakwal) among the 20 selected locations. Sothgun also demonstrated maximum reduction in equivalent carbon emissions. The results of the social survey demonstrated that public awareness schemes should be introduced to improve public participation and perception about wind energy. The interviews also demonstrated that public does not mind visual and noise impacts (equivalent to refrigerator) as long as they get consistent and cheaper electricity. Majority of the public showed inclination toward investing in wind farms if they get returns in form of consistent and cheaper electricity. Moreover, employment benefits should also be provided to the local population. GoP should redevelop energy policy to include FIT and enhance public participation. Moreover, the energy policy should also include sufficient financial incentives for the general public and investors to improve the penetration of RETs in energy mix of Pakistan.

5.2 Recommendations and future research

In the light of obtained techno-economic, environmental and social feasibility results, it can be stated that Pakistan has an excellent potential of wind energy which is still untapped. All of the 20 identified locations demonstrated excellent techno-economic feasibility and supported the installation of wind farms. But it should be noted that the following research is performed using GIS-based wind speed data which might deviate from the actual surface data. Therefore, it is recommended that anemometers would be installed at the identified locations to get the real-time annual wind speed data. It will help in lowering the error in the calculated techno-economic outputs and provide better, consistent and accurate results. Similarly, for the social surveys and interviews, interview was conducted for only two locations because of resource constraints. The online survey was also stopped at 151 participants because of time constraint. In order to get a holistic social impact assessment, country wide social surveys should be conducted to get more diversified results. It is also recommended the GoP should redesign the energy policies of Pakistan. The ARE 2019 policy does not have adequate incentives for the private sector to invest in the RET based projects. It is suggested that the energy policy should be redesigned in order to incorporate enhanced incentives, reduction of subsidies on fossil fuels, indigenization of technology, improved Research and Development (R&D) and reduced import taxes to enhance the penetration of wind power in energy sector of Pakistan. Furthermore, GoP should initiate schemes to increase public awareness about wind energy and other RETs. The Pakistan's energy policy is also lacking Feed-in-tariff (FIT) and proper measures should be taken in order to include FIT into the policy. It will help in improving public participation and ultimately, increase the share of wind in energy mix.

Appendix A: Journal Paper

A techno-economic and socio-environmental planning of wind farms for sustainable development and transition to a decarbonized scenario: Pakistan as a case study

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Abstract

Wind energy is one of the rapidly growing fields of renewable energy in the world. The following study investigates potential locations throughout Pakistan at provincial level with high suitability for wind farm deployment. The assessment of wind resource at each location is performed by utilizing Geographic Information System (GIS) wind data. Twenty locations all over Pakistan, with 3 to 5 sites in each province, are selected. System Advisor Model is utilized to model 50 MW wind farm and perform techno-economic feasibility analysis while RETScreen is utilized to quantify the environmental impacts. Social impact assessment is also an integral part of the study which is carried out by conducting online survey and site interviews. It is investigated that Sothgun, Washuk in Baluchistan demonstrates most suitable techno-economic feasibility. The net annual electricity yield came out to be 287,766 MWh with a simple payback period of 5 years. The net reduction in CO_{2e} emissions was evaluated to be 105,808 tons per year with 45,463,165 liters of gasoline not consumed. The results of social assessment suggest that the government of Pakistan should include public awareness and participation schemes, financial incentives, efficient feed-in-tariffs and indigenization of wind technology into the next energy policy.

Keywords: Wind energy; Techno-economic analysis; Social impact assessment; Environmental analysis; System Advisor Model