Wind Energy in Saudi Arabia Opportunities and Challenges

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Abstract

Wind energy has been recognized as one of the fastest-growing energy sources in world and as a key role in reducing greenhouse gas emissions, reducing dependence on oil, diversifying energy supply, and providing electricity at a low cost. In its 2030 Vision, the Kingdom of Saudi Arabia has recently set ambitious targets to move away from oil dependency and redirect the efforts towards more higher-value exploitation of oil and gas, mainly meeting 10 percent of its energy demand through renewable energy sources. This paper attempts to explore the feasibility of using wind turbine machines for energy generation in Saudi Arabia by presenting a study of the opportunities and challenges that can arise while installing these machines. The paper also highlights several technical challenges and gaps that have been anticipated for this design motivation. Observations and upcoming trends show that by 2030 renewable energy, including solar and wind, will provide up to 50% of electricity production in the Kingdom.

Keywords
Wind Energy, Opportunities, Challenges, Saudi Arabia.

1. Introduction
The negative impact of consuming fossil fuels such as natural gas and oil has been a growing concern for policymakers worldwide due to the adverse effect on human and environmental health (Anon 2006). The necessity for transforming the complete power generation process to meet people's needs has been a critical concern for almost every country. The use of renewable energy sources is perceived to be the most feasible solution. The United States, China, and several other European countries are already adopting renewable energy generation methods, and wind energy is the major contributor here (Caldera, Bogdanov, and Afanasyeva 2018). Several other countries, including Saudi Arabia, have been trying to shift to using wind energy as the primary energy source because of its abundance. However, diverse challenges impair the progress rate massively.

Due to Saudi Arabia's vital role in the Middle Eastern region, it is poised to be a major contributor to wind energy use as the primary source of power generation. The recently announced "Vision 2030" transformation plan (Anon 2006) by Saudi Arabia can prove decisive in promoting the importance and relevance of wind energy as the government looks toward exploring renewable sources of energy for sustained growth. The Vision 2030 program includes increasing the power generation capabilities of KSA to 16GW using wind energy, therefore confirming the countries' pledge to reduce the global carbon footprints (Anon 2006). However, the move will require Saudi Arabia to undertake massive reforms in understanding the feasibility of using the appropriate technology and scientific means to achieve the target realistically. It also presents a significant opportunity to the technological firms, turnkey project owners, suppliers, and other related parties to increase their capabilities for designing the equipment and resources required for tapping into the natural resource effectively (Boretti et al. 2020).

This paper attempts to investigate the feasibility of using wind turbine machines to generate electricity in Saudi Arabia, by examining the opportunities and challenges arising from the installation of such devices. The paper also highlights several technical difficulties and gaps for the design motivation anticipated.

2. Literature Review

Wind technology was commercially adopted in the 1970s, which has been made more efficient in the current times through periodic modifications over the decades (Anon 2006). However, the turbine's basic working concept remains the same, with a horizontal axis generator placed on the top of a vertical tower and three blades rotating on a vertical plane. Several wind turbine machines, usually hundreds, are located in the most feasible location, known as a wind energy farm, to produce enough power that can be converted into commercial electricity (Anon 2006). The wind towers' size varies according to the economic and landscape limitations, although they can sometimes be over 150m in height (Watch 2021). Although the technology produces minimal pollutants and is deemed to be among the cleanest forms of energy, it might cause some negative impact on the ecological balance, especially near wind farms. The sound and electromagnetic vibrations that are produced while operating these turbines can harm aquatic life (Knowlton 2019). The height and scale of the wind towers can cause animal mortality due to collision-related incidents. In this paper's context, understanding the risks of wind farms harming environmental conservation and ecology is critical. Harnessing wind energy by installing wind farms can impact many regional and migratory species of animals, resulting in short or long-term implications for those animals. The construction of these farms can lead to natural disturbance and degradation of the habitat of the species existing in the area. These might include avian lives such as birds and bats, mammals such as indigenous animals and marine life, and aquatic species like fishes. The installation can also impact the vegetation of the locality, including the marine life due to heavy machinery and the erection of turbine towers. During the installation and even during the operational stages, birds and bats can collide with the rotating turbines, which might cause a depletion in their population drastically. Since the location and local habitat could be diverse, having a generalized idea about the actual impact can only be made upon assessing the location. Also, considering steps like guarding the farm with fences to avoid land or airborne animals, or building artificial coral reefs for aquatic life could be undertaken to avoid flora and fauna losses.

The global community has committed to reducing the impact of greenhouse gases by cutting down on their consumption (Frankel 1AD). Fossil fuels are the major contributor to these gases; therefore, decreasing their emissions is crucial to achieving a cleaner environment. Moreover, one of the major uses of oil is in electricity production in various countries. Countries are taking cognizance of the issue and trying to come up with alternative solutions. The over-reliance on oil for power generation reduces gradually, although the rate is noticeably low (Anon 2006).

One of the alternative routes for reducing oil consumption is to rely more on renewable energy. Saudi Arabia generates the majority of its power using oil, making it the largest oil consumer to produce electricity. The country generates 42% of the power using oil, while natural comprises 57.8% using natural gas. Saudi Arabia has committed to reducing the massive use of oil by 2030 under its Vision 2030 program. The Kingdom aims to make 50% of production from natural gas, while the rest from renewable energy. The country has already installed 397MW of renewable energy facilities by the end of the year 2019 and targets 6GW of power generation using renewables by 2030. Hence, there is a noticeable difference between the number of facilities that need to be installed to fulfill the commitment.

Despite utilizing renewable energy sources, the technical, economic, and environmental outcomes have proved to be a barrier in coming up with a practical scenario until recent times. Because of its topography, Saudi Arabia has enjoyed an abundance of solar and wind energy. However, harnessing its power could become challenging (Anon 2006). An increase in the output depends primarily on the input, but the management, storage, and transmission of the power generated can create an issue. Smaller installations can handle this issue as the energy generated can be stored in batteries in a power station, which can be transmitted as per need for use. However, these batteries' size is limited, and generating more power would create an issue in storing such a massive amount. Subsequently, transmitting the energy could be a significant problem. Understanding the scope of installing the wind turbines would depend on the turbines' capabilities and provide a sustainable flow of power for consumption. Hence, researching the capacities of different types of turbines, the environmental background required for their operations, the economic impact of the technology installed, including power stations' capacities for distribution, and the overall feasibility of establishing the turbines need a thorough examination. The turbines' technical aspects of understanding the ecological impact also need to be considered to avoid any unnecessary deterioration of the environment.

Leung et al. (2012) conducted an in-depth study on the history of wind energy evolution. The study mentioned that wind energy usage dates back to over 3000 years ago, where Egyptians were the first to use windmills to pump water. Chinese farmers used vertical axis wind wheels to drain rice farms for several centuries before windmills emerged in Europe. In 1887, the first windmill harnessed to generate electricity was invented by Prof. James Blyth in Scotland (Anon 2006).

Pointed out the keen interest in exploiting renewable energy resources, including wind energy, to replace crude oil is because of the oil crisis in the 1970s (Salah, Abo-khalil, and Praveen 2021a). Added that the dire weather conditions and CO2 emission during the last centuries motivated the developed countries to consider and adopt clean energy sources(Alnaser et al. 2008). Believed that the world's conventional oil reserves might deplete in the coming decades (Bentley 2002, Goodstein 2005). Few researchers like claimed that the crude oil would not start depleting for at least 50 to 60 years (Anon 2006; Owen and King 2010). Anticipated that the world would face the predicament of maintaining power production compensating for the increasing decline in the existing oil production (Höök et al. 2014).

According to the United Nations (2017), the Saudi population growth rate will be 16.7% as of 2018; thus, the estimated population of the Kingdom will be 39.1 million in 2030. The rise in population will be accompanied by an increase in energy demand with a growth rate of 8% per year based on the analysis of 2004-2017 electricity data of Saudi Arabia (Salah et al. 2021). Currently, the electricity sources in Saudi Arabia are Saudi Electricity Company (SEC) that generates approximately electricity of 79 GW, and Saline Water Conversion Corporation (SWCC), which contributes by generating 12% of the total power (Al Garni et al. 2016). Addressed the Gulf Cooperation Council's agreement to establish an interconnecting power station in 2001, making up an additional electricity source to the Kingdom. However, the speculations imply that the existing electricity generating methods will fall short to meet the Kingdom's future energy demand (Anon 2006). Highlighted that Saudi Arabia could be an oil importer by 2038 if it does not take prompt action (Lahn, Stevens, and Royal Institute of International Affairs 2011). Therefore, in response to the rapid rise in energy demand and drop in the oil reserves, Saudi Arabia launched the Saudi 2030 Vision Plan, which is a comprehensive plan that aims to reduce the Kingdom's dependence on oil, and exploit the potential natural sources of sustainable and clean energy (Salah et al. 2021a). The promising Saudi candidate energy sources to replace fossil fuels are solar and wind energy because of the nature and geographical location of the Kingdom. Besides, their zero harmful gas emissions, fast technology developments, and decreasing costs making them suitable alternatives (Slootweg and Kling 2003; Yang and Chengzhi 2009).

Various researches have been conducted to localize the best locations within the Kingdom for wind turbine installation. Those studies' analyses are based on several factors such as mean wind speed and cumulative frequency distribution (CFD) (Salah et al. 2021). The north-western region is the best for wind turbines (Anon 2006; Salah et al. 2021). Believed that Yanbu, Dhahran, and four more cities could generate wind energy to reach 1000MWh per month (Salah et al. 2021a). The study showed that Taif city is a potential place for hosting wind energy (Shaahid, Al-Hadhrami, and Rahman 2014). The research showed that the leading wind turbine manufacturers in the world are Goldwind and Vestas (Anon 2006). They mentioned that the selection of suitable wind turbine types depends on wind speed characteristics in the targeted regions. They concluded that Vestas is a suitable turbine choice for a city like Yanbu, whose average wind speed is approximately over eight m/s (Anon 2006; Salah et al. 2021a), (Shaahid et al. 2014).

Diverse, sophisticated wind forecasting, and load management models have been developed, such as the wind speed predictive model designed by More et al. (2003), predicting wind speed data daily in India using Artificial Neural Network. A Support Vector Machine (SVM) based model was discussed to find hourly mean wind speed forecasting (Botha and van der Walt 2017). Brahimi (Brahimi 2019) proposed using the artificial neural networks (ANNs) method to predict daily wind speed in a number of locations in the Kingdom of Saudi Arabia based on multiple local meteorological measurement data provided by K.A.CARE.

The fluctuations in the environmental factors affecting wind energy can cause a rapid and sometimes unpredicted decrease or increase in energy production. It is also hard to make a long-term prediction even with the advanced wind forecasting tools the world has right now. Therefore, to overcome this issue of emphasized the importance of solar-wind hybrid energy systems, where the weaknesses of one source can be compensated by the other (Anon 2006; Yang et al. 2009). Researcher highlights another challenge related to large turbines to find the feasibility of up-scaling wind turbines from technical and economic perspectives. The study results showed that up-scaling turbines with the existing designs and typical heavy materials currently used negatively affect design and cost, and large rotors are the major challenge. Therefore, the study suggested altering the overall wind turbine concepts and designing a two-bladed downwind turbine with lightweight materials (Al Garni et al. 2016).

The Saudi Ministry of Energy (2021) launched the National Renewable Energy Program (NREP) to use the Kingdom's renewable energy sources. Also, it looks forward to stimulating and stabilizing the economic development for the fulfillment of the 2030 Vision and the country's commitment to reduce CO2 emission. The 2030 Vision's goal is to have 20% of the total power production from solar and wind energy (Anon 2006). NREP comprises three rounds where a set of solar and wind energy projects across the Kingdom will be completed in each round. In the first round, 700MW power generating projects were tendered successfully, including the biggest wind farm in the Middle East, Dumat Al Jandal, in the Al-Jouf region. Dumat Al Jandal has a power capacity of 400MW and is expected to be in commercial operation. According to the Ministry of Energy, the Dumat Al Jandal farm project will create eight hundred jobs in the construction stage and a hundred and fifty more jobs in the operation stage. The country is now working towards achieving rounds 2 and 3 (Anon 2006).

3. Methodology

Our study took the data of Saudi Arabia weather forecast from the KAPSARC website (Anon 2006). We used the data between 2018 and 2019 to study the latitude, Longitude, wind direction angle, and wind speed rate. These data are used to see the potential of wind energy in the Kingdom. Table 1 showed the weather forecast for 2018 (Anon 2018). The collected information will study wind energy potential in Saudi Arabia to explore all opportunities and challenges. Table 2 is showing the latitude, Longitude, wind direction angle, and wind speed rate data in Saudi Arabia at 2019-01-01 from (000:00:00 +03:00 am) to (2:00:00 +03:00 am).

In our analysis, we focused on using peak-time which has highest wind speed data in 2018. The peak time was in December 2018 at 16:00. Table 3 has the data the maximum wind speed point in Saudi Arabia during December 2018 at 16:00. Also, we studied the air temperature and air temperature dew points, the saturation point temperature of the cool air at pressure, and the water vapor constant. Also, we studied the air temperature and air temperature dew points, the saturation point temperature of the cool air at pressure, and the water vapor constant.

Table 1. Wind in KSA, KAPSARC(Anon 2006)

	…	latitude	longitude	elevation	Wind direction angle	Wind speed rate (m/s)	sky ceiling height (m)	Visibility distance (m)	…	Atmospheric sea level pressure	GEOPOINT
1	…	17.611	44.419	1,213.71	140	5.1	900	10,000	…	9,999.90	17.611436, 44.419169
2	…	17.611	44.419	1,213.71	120	3.1	900	10,000	…	9,999.90	17.611436, 44.419169
3	…	17.611	44.419	1,213.71	120	3.1	914	9,999	…	9,999.90	17.611436, 44.419169
4	…	17.611	44.419	1,213.71	110	3.1	99,999	10,000	…	9,999.90	17.611436, 44.419169
5	…	17.611	44.419	1,213.71	100	2.1	99,999	10,000	…	9,999.90	17.611436, 44.419169

Table 2. Latitude, Longitude, Wind direction angle, and Wind speed rate Data Jan, 2019, KAPSARC

station name	observation date	Latitude	Longitude	Wind direction angle	Wind speed rate
KING KHALED AB	2019-01-01 02:00:00+03:00	18.297286	42.803536	999	0
KING ABDULAZIZ INTL	2019-01-01 02:00:00+03:00	21.679564	39.156536	310	1.5

HAIL	2019-01-01 02:00:00+03:00	27.437917	41.686292	999	0
SHARURAH	2019-01-01 02:00:00+03:00	17.466875	47.121431	80	4.1
AL AHSA	2019-01-01 02:00:00+03:00	25.285306	49.485189	330	3.6
GASSIM	2019-01-01 02:00:00+03:00	26.3	43.7666666	70	2.1
ARAR	2019-01-01 02:00:00+03:00	30.906589	41.138217	170	3.1
KING ABDULAZIZ AB	2019-01-01 02:00:00+03:00	26.265417	50.152027	350	2.6
QAISUMAH	2019-01-01 02:00:00+03:00	28.335192	46.125069	999	0
TABUK	2019-01-01 02:00:00+03:00	28.365417	36.618889	140	4.1
WADI AL DAWASIR	2019-01-01 02:00:00+03:00	20.504275	45.199556	110	1
:	:	:	:	:	:

Table 3. Saudi Arabia Wind Speed at Peak Time

Station name	Wind Speed (m/s)
NEJRAN	4.1
PRINCE SALMAN BIN ABDULAZIZ	9.3
HAIL	6.2
AL AHSA	5.1
ABHA	7.7
DAMMAM (KING FAHD INT. AIRPORT)	3.6
KING KHALED AB	4.1
PRINCE ABDULMAJEED BIN ABDULAZIZ AIRPORT	7.2
KING ABDULLAH BIN ABDULAZIZ	5.1
TURAIF	2.1
YENBO	10.3
WEJH	5.1
ARAR	8.2
AL JOUF	2.6
TAIF	9.3
RAFHA	6.2
KING KHALED INTL	3.6
WADI AL DAWASIR	6.2
SHARURAH	0
KING ABDULAZIZ INTL	5.1
TABUK	4.1
QAISUMAH	8.2
GASSIM	2.6
PRINCE MOHAMMAD BIN ABDULAZIZ	4.1

Also, we used the framework KAPSARC tool to see CO2 emissions (Table 1, Table 2 and Table 3). This analysis used old data and estimated data to find the effect of increasing the usage of renewable energy by 20% as follows (Anon 2006).

4. Results

The wind speed characteristics and the energy potential in Saudi Arabia use case measured wind speed at 10m. The researchers used the data to calculate the power density of wind stations in Saudi Arabia. This use for evaluating the suitability of each site for the installation of different types of wind turbines (Salah et al., 2021). A research case studied closing the gap between wind energy targets and implementation for emerging countries. Other research determined the area near the Gulf of Aqaba is the most cost-effective for wind harvesting, with turbines having a moderate specific rating (350 W m2) and a low hub height (75 m) (Giani et al. 2020).

Figure 1 shows the percentage data of the air temperature and air temperature dew points(Anon 2006.). Figure 2 shows the calculated scenario of CO2 emissions by increasing the usage of renewable energy by 20%. Figure 3-4 is showing wind direction angle and wind speed-rate potential in Saudi Arabia. The outcomes demonstrate the strategy's effectiveness in assisting power system operators in ensuring optimal energy dispatch. According to Figure 5, the following cities showed the highest records of wind speed: Yenbo, Taif, Prince Salman bin Abdulaziz station, and Qaisuma. Referring to Figure 6, Haql city showed great potential for generating wind power due to the power density higher than 200 W/m2 for 11 months. The wind power density in Yanbu is higher than 100 W/m2 for six months (Salah et al. 2021). Although, there is a variety in wind speed during the year, which affects the output power from wind turbines. We realized that Yenbo, Taif, Qaisumah, and Haql have the highest potential in generating wind energy.

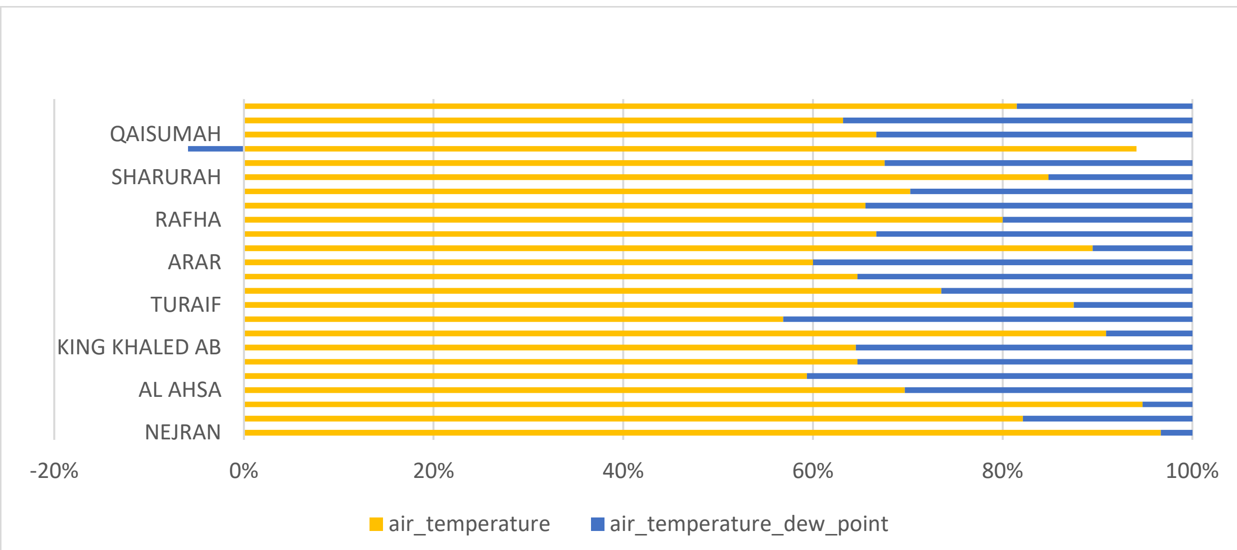

Figure 1. Air Temperature and Air Temperature dew point in Saudi Arabia (Anon 2020b)

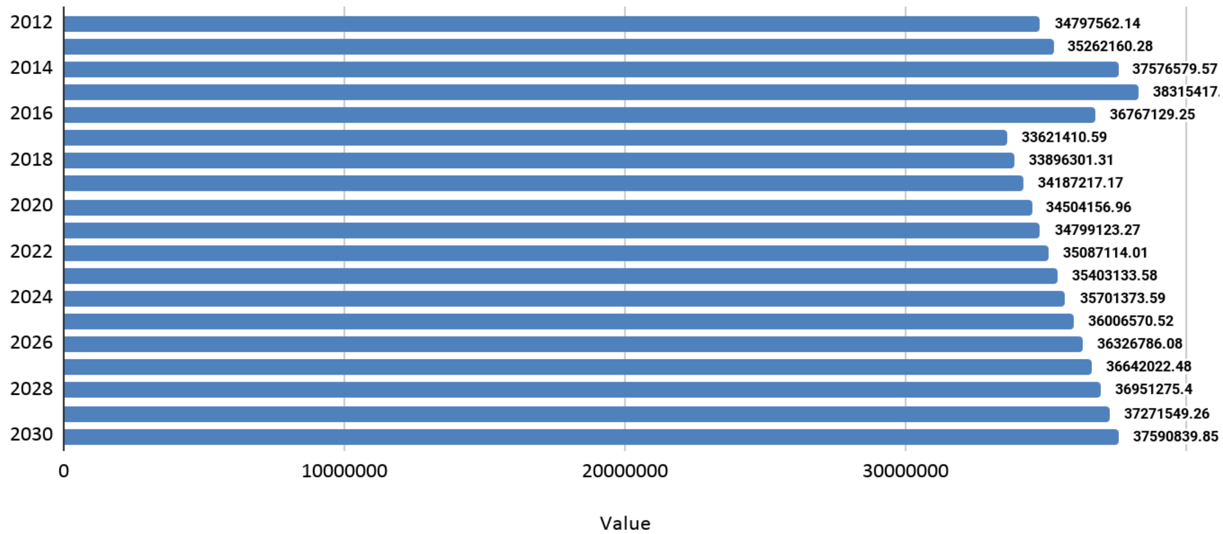

Figure 2. Scenario Analysis - CO2 emissions (Tons) Data, KAPSARC (Anon 2020b)

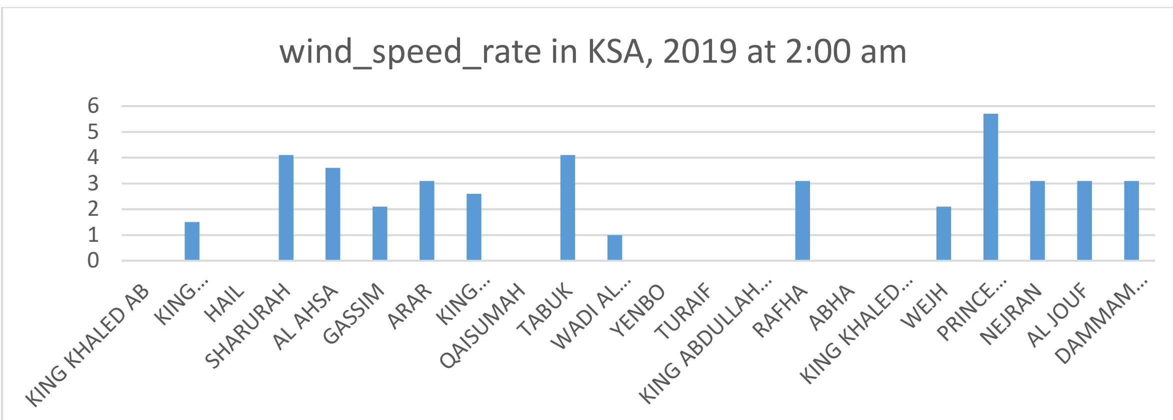

Figure 3. wind Speed Rate in KSA, 2019 at 2:00 am

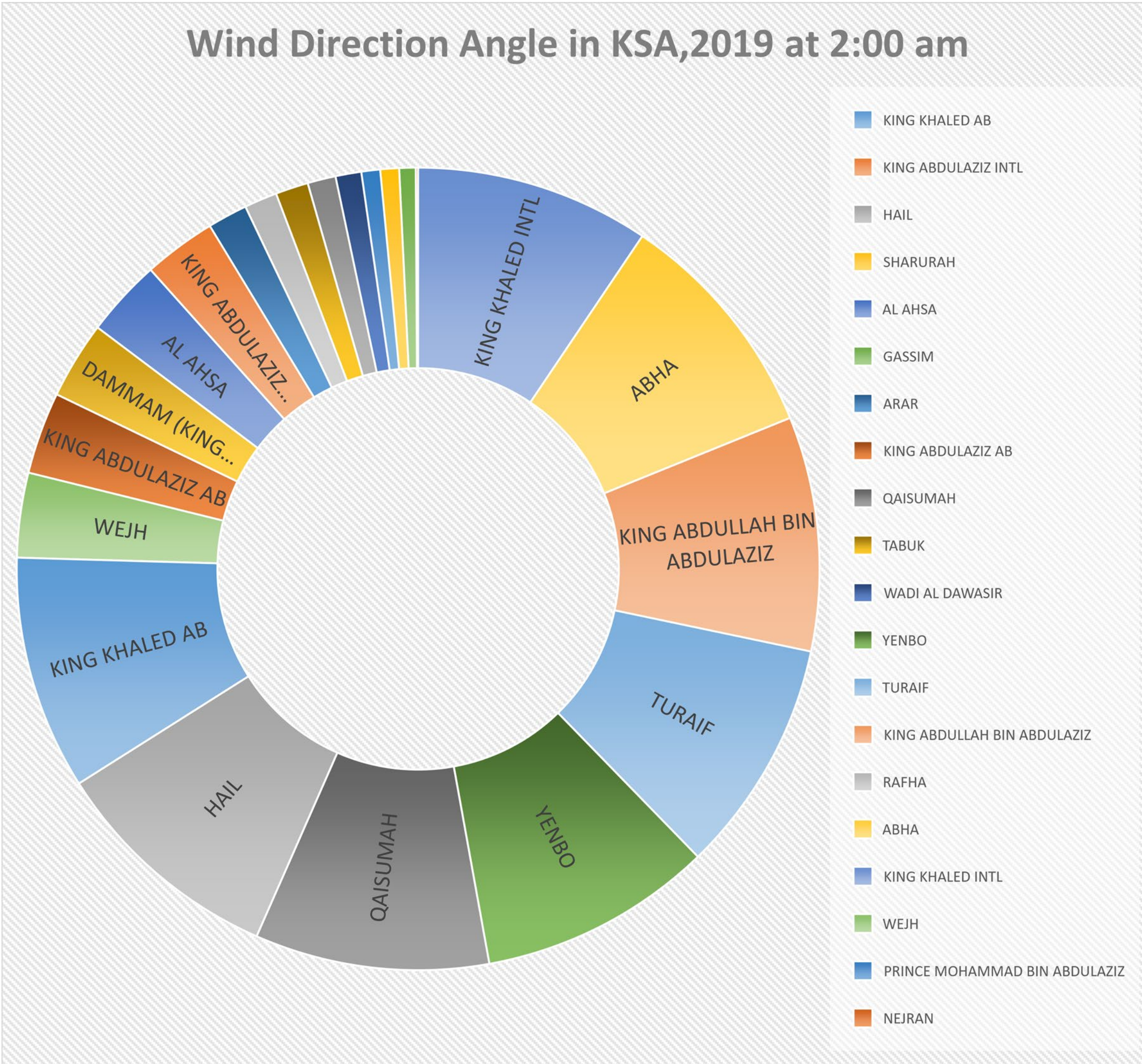

Figure 4. Wind Direction Angle in KSA,2019 at 2:00 am

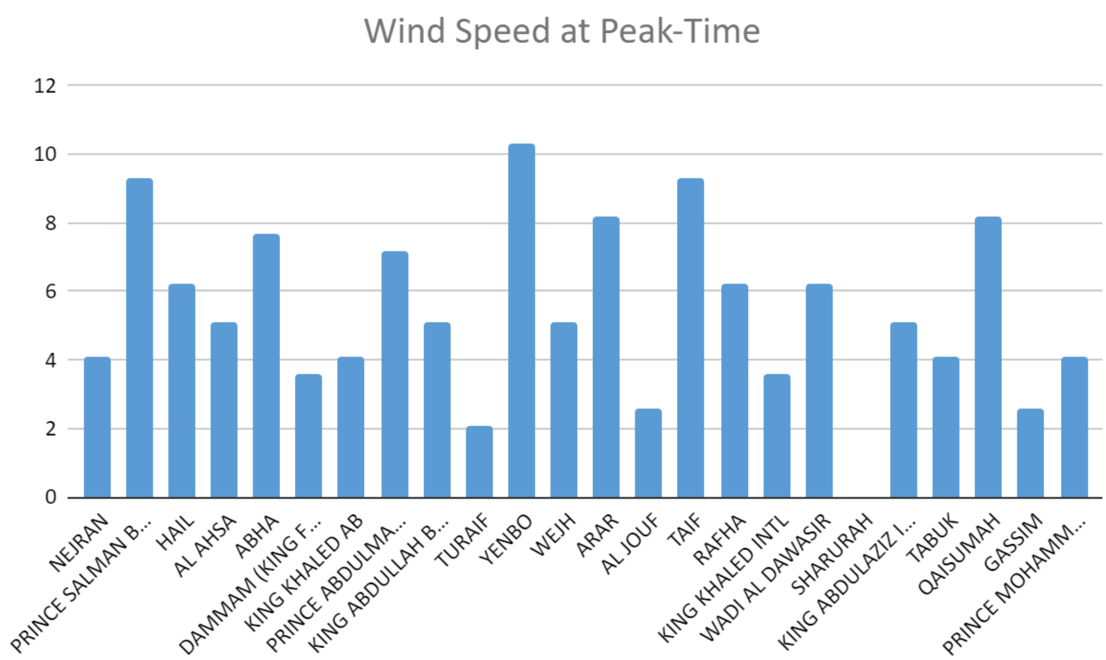

Figure 5. Saudi Arabia Wind Speed at Peak Time (Anon 2020b.).

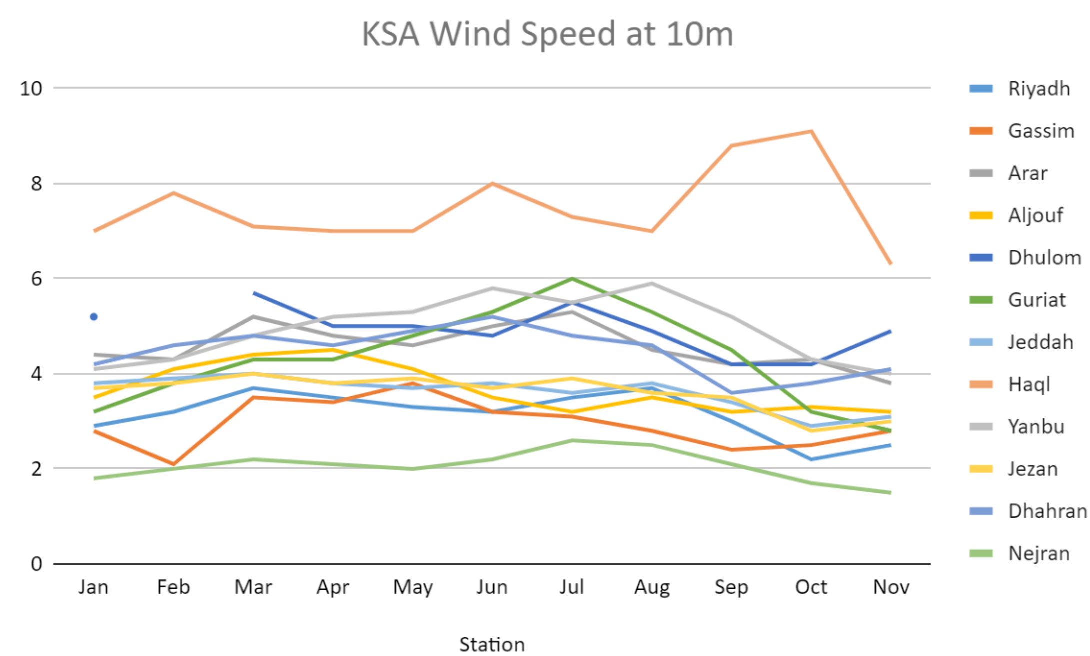

Figure 6. Wind Speed at 10m height KSA Use Case (Salah et al. 2021b)

5. Conclusion

The weather forecast Saudi Arabia from KAPSARC showed the latitude, Longitude, wind direction angle, and wind speed-rate data between 2018 and 2019 and its great potential of wind energy in the Kingdom. According to wind speed and Air temperature analysis at peak-time, wind energy challenges showed the potential and challenges of using wind energy in Saudi Arabia during the time since wind speed has different reading during the year. The outcomes demonstrate the wind data to find the potential of using wind turbines in Saudi Arabia. According to wind speed at peak period, the following cities showed the highest records Yenbo, Taif, Qaisumah, and Haql. Haql and Yanbu cities showed great potential for generating wind power during the year. The main challenges of installing wind turbines summarized as following:

- The estimated cost of installing wind turbines with the variety of power and energy ratings.
- The changeable wind speed during the year.

However, Saudi Arabia is minimizing the gap between wind energy targets and the installed systems. As a future goal, we guarantee that Yenbo, Taif, Qaisumah, and Haql have the highest potential in generating wind energy. Furthermore, we predict installing a wind turbine in these cities will improve the dependency on renewable energy.

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