The Impact of Off-shore Wind Farms on Kuwait's Electrical Grid

by

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ABSTRACT

Kuwait is committed to implementing the Kyoto Protocol in "Vision 2035" to reduce greenhouse gas emissions by shifting to the use of wind and solar energies [1]. The specific goal of the Vision 2035 is for renewables to comprise 15% of Kuwait's electrical generation by 2030. Wind and solar are abundant in Kuwait and can easily provide 15% of the total electrical generation. However, there are three significant obstacles. The first is Kuwait currently depends heavily on rapidly diminishing fossil fuels which are the major sources of CO_2, NOx, and SOx emissions. Unfortunately, current plans are to build two conventional power stations by 2024. The purpose is to cover the energy needs for growing population. The second problem is that Kuwait has a very small land area. Consequently, there is limited space to build new utility-scale renewable power stations. The third issue is the low electricity tariff provides little incentive for the population to save energy. Offshore wind farms have the potential to provide thousands of GWh/yr to accomplish the goals of Vision 2035. Kuwait has a vast untapped supply of offshore wind energy. Specifically, there are eight offshore locations in which 50 turbines could be built each, for a total of 400 turbines. Using 4.2 MW turbines, this would provide 1.68 GW of wind energy, and increase the renewable portion of the electrical energy production to 13.93% (including Shagaya renewable park). Installing battery storage with the proposed wind turbines could provide fast ramp response which would serve to complement existing power production on Kuwait's grid. In this work, six different turbines with different sizes are considered from 2.5 MW to 4.2 MW (from well-known manufacturers, such as, *Nordex* and *Vestas*), but ultimately 4.2 MW turbines are recommended. Data for this study has been supplied by: A) Civil

Aviation -- temperature and wind speed, B) Ministry of Electricity and Water (MEW) -- electricity data, and C) Public Authority for Civil Information -- population data.

I am grateful to many people around me who helped me with my school life. My father and my mother overwhelmed me with their constant prayers all the time and asking about me, my brothers and sisters, who always encouraged me to be a good student. My wife, the amazing woman who stood by my side and carried with me this heavy task, and without my wife I wouldn't have gotten this far, she cared at home and children and was always encouraging me and from which I draw strength and my children who push me to be a great example of a successful father. To my colleague and great friend, who had all the credit from the beginning to the writing of the paper, Dr. Muhammad Bin Salama, who works hard to help me when I was in Kuwait and never wavered in my advice and assistance at all times. Many thanks to the wonderful Dr. Hassan Dashti, the Director of Meteorology, for providing me with advice and providing important data that helped me in my research. I thank all those who have given me confidence and it consider as the Medal of Honor. Long live with love and peace.

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TABLE OF CONTENTS

CHAPTER Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

Kuwait is located in the eastern part of the Middle East and specifically on the northeast of the Arabian Peninsula bordered to the north and northwest by Iraq and to the south and southwest by Saudi Arabia. The Arabian Gulf is located to the east, and is the only outlet to the sea. Kuwait has several ports which play an important role in trade, both in the past, and the present. The area of Kuwait is very small with a total of 17,818 km^2 (6,879.6 mi^2). The coastal length of Kuwait, including islands, is approximately 496 km. Kuwait's territorial waters include 7,611 km^2 (2,938.6 mi^2), with a maximum depth of 30 m [2][3]. The land of Kuwait is arid, covered with sand, and mostly flat (except some low height hills). The population of Kuwait at the end of 2019 reached 4.78 million [4], where ex-pats make up about 70% which is 3.35 million, and the rest are Kuwaitis, 1.43 million, equivalent to 30%. Kuwait has eight conventional power stations with a capacity of 19,353 MW and one renewable energy park with a capacity of 70 MW with a total of 19,423 MW until the end of 2019. Kuwait is rich in oil and gas fields, and these are spread throughout the country. However, Kuwait is also rich in renewable resources such as solar and wind. Kuwait Vision 2035 proposes that renewable energies will comprise 15% of total electricity production, in compliance with the Kyoto Treaty on climate change. Kuwait has a large proportion of cloudless days, and has relatively energetic coastal winds. The strong winds often loft particulates and create less blue skies which is an evidence of abundant winds.

Population growth puts great pressure on the electrical network. Consequently, the government is eager to provide additional electrical capacity to meet the increasing needs of the population. It is possible to both address the impeding the electrical shortage and to contribute to Vision 2035 -- by adding renewable energy capacity. Energy conservation can also alleviate the problem, and this can be encouraged economically by increasing consumer costs for electrical energy closer to production costs. Continuing to operate existing stations requires only marginal costs. However, if new capacity must be built, installation costs are also incurred. This provides an opportunity to allocate those funds instead toward renewable energy power stations. Without either increased production or better conservation, shortages could occur soon.

There are major reasons for transferring to renewable energy and to stop burning fossil fuel. First, Kuwait relies mainly on burning fossil fuels of all kinds which are the main source of greenhouse gases such as CO_2, NOx, and SOx which pollute the environment and exacerbates the problem of global warming, especially the local air where Kuwait has a small area. Second, oil and gas are considered the core wealth of Kuwait and must be wisely used to preserve value for future generations. Also, diversifying the economy enhances stability for the citizens for Kuwait. Oil and gas prices are volatile, which makes conventional power stations less attractive compared to renewable energy. In addition to the value of the price stability of the ‘fuel’ (wind and sunlight), renewable energy does not produce greenhouse gases [5].

The government has demonstrated serious and growing intent to build renewable energy power stations. For example, the Kuwait Institute for Scientific Research created a master plan for Shagaya renewable park to be the first renewable power station in the country. The current sustainable energy production in Shagaya Renewable Energy Park is 70 MW which consists of 10 MW wind, 10 MW photovoltaic, and 50 MW concentrated solar power. It started to produce energy in 2016 with 20 MW and then increased to 70 MW in 2018. According to the plan of the government, they are working to produce energy from the sun on a very large scale called Debdebah project that will be the largest solar energy project in the country with a capacity of 1,500 MW. This project will produce 1,570 MW in all three energy types by 2022 and it is mainly PV. By 2030, the PV will raise to 2,710 MW, CSP will raise to 250 MW, and wind will be 110 MW with total power production of 3,070 MW. The wind energy portion is very little in relation to the huge potentials that can be extracted from the wind on land, not to mention the sea. The renewable capacity by 2030 is 3,070 MW of the total 33,981 MW which makes the share of 9.03%. The need to build offshore wind farms is to achieve the desired goal with a capacity of 1,680 MW with 4.2 MW wind turbine size to raise the renewable share to 13.32%. The available spaces in Kuwait are very limited and small in relation to building sustainable stations. Therefore, offshore areas are vast and untapped and would benefit energy production on a large scale if optimally exploited. Unfortunately, Kuwait consumes large quantities of natural gas to produce energy, as local production is not enough, so it always seeks to import to fill the shortage in supply, and this constitutes a huge burden financially. The search for a clean alternative, such as solar and wind energies, will have an effect on mitigating, if not eliminating, the demand for natural gas from abroad, thus preserving the strength of the financial structure of the country that will affect the gross domestic product. Eight marine locations were chosen to study their productive feasibility and impact on the national network; five are beach places and three are deep in the sea.

The purpose of the research is to find clean and sustainable alternative energy to reduce dependence on fossil fuels in addition to make use of abundant wind energy, especially offshore. According to data from the MEW, all upcoming projects until 2030 are solar photovoltaic, CSP, and onshore wind projects. Notably missing from the upcoming plans is offshore wind energy which could help meet future energy demand while conserving valuable land space for other purposes. The fastest solution for immediate needs of energy by the government is by building another two conventional power stations with a total capacity of 5,400 MW by 2025 which even worsens the problem. This increase in consumption devours a large amount of fuel, especially natural gas, which constitutes a huge loss as Kuwait's wealth depends on selling crude oil. Since the trend in energy production is limited on-land, so the equivalent solution is offshore production, as it will later be seen that it contains the largest unexploited area for energy production in the country. The problem with the land is that it is very limited, so building power stations is limited only to the west of the country in narrow areas due to oil and gas fields in addition to reserved residential areas and that's why the cost of offshore land is much lower than the cost of onshore land. Usually, the renewable energy power stations, PV and wind, occupied a very large area on the utility-scale which makes it not preferable for small or limited areas as Kuwait. Wind energy is defined as a form of energy in which the turbines convert the kinetic energy of the wind into mechanical or electrical energy that can be used to generate energy; and it is an indirect form of solar energy. Kuwait has a good average annual wind speed throughout the year on land and sea locations. By harvesting winds, it can generate several thousand gigawatts annually, which reflects a positive reflection on the delivery of electrical energy [6][7]. Statistics of wind energy globally confirmed an increase in the installed capacity in 2017, 2018, and 2019 by 10.19%, 9.6%, and 16.3% respectively, and of those for offshore energy by 31.34%, 25.44%, and 19.8% respectively. This is an indication of the high demand for wind energy globally [8]. Another statistical report showed that the offshore wind market installation jumped from 3,382 MW in 2015 to 6,145 MW in 2019. The share of offshore wind to the total installation in 2019 is 10.12% and the total installations of offshore wind to the total wind installation is 4.48% [9].

PERSONAL MOTIVATION

The demand for energy in Kuwait is very high compared to the rest of the world due to the low tariff and this is the main reason that made the consumers indifferent to maintaining it. The government pays billions of KD annually to maintain the efficiency of the network from interruptions and collapses. I think it was my duty towards my country to search for a feasible and cheap alternative compared to producing fossil fuels that cost the country financially and environmentally, besides, easier to build and maintain.

AIM AND OBJECTIVES

The aim of the research is to provide and encourage the Kuwait government to generate energy from permanent and clean energies and to reduce the dependency on fossil fuel. There are multiple of objectives, the first one is testing eight offshore locations by getting the wind speed and density for evaluation in addition to the temperatures to calculate the cost of energy which is the Levelized Cost Of Energy (LCOE) to ease the decision making where the economic factor is the main driver in any project. Eight offshore locations were chosen to study the feasibility of producing electric energy, five of which are coastal and the rest are deep in the sea. Six wind turbines were chosen from two of the best wind turbine manufacturers in the world due to the availability of the sizes required to build them in the previous locations, namely, Vestas which is a Danish company, and Nordex which is a German company. All selected wind turbines have an energy curve to enable electrical power to be calculated for any period. The cost of Vestas wind turbine is $0.753 million/MW [10] and for Nordex is $0.695 million/MW [11] depending on the currency in late December 2019 [12]. The unit price chosen is $0.98 million/MW for Vestas and $0.904 million/MW for Nordex including 30% for transportation cost. It has been found that Vestas V112/3000 is the least cost while MHI Vestas V117/4200 is about 28% more energy generation with 7.05% more LCOE at most which makes it the best choice. The second one is to install backup batteries with wind turbines in addition to gas turbines would smooth the ramp-ups and cover all ramp-ups without complications. The third one is forcing the consumers to reduce their electrical consumption by increasing the electricity tariff for a fair value.

STUCTURE OF THE THESIS

This work will be divided into four chapters. Starting with chapter 1 which is the introduction followed by chapter 2 which is the literature review and then chapter 3 is the results and discussion and the last chapter which is conclusion and recommendation. After that, references followed by the appendices from A to D for descriptive tables figures.

CHAPTER 2

LITERATURE REVIEW

By 2100, most of the energy would be generated from wind, photovoltaic, solar heat, geothermal, hydro, and biomass. From 2017 to 2025, the growth of wind energy predicted to jump from 600 GW to 1750 GW. The aim in the US is to produce energy from wind 35 % of the total energy demand by 2050. Many countries in the European Union such as Germany, Denmark, and others tend to build more offshore than onshore due to the usage of the land including USA. Offshore windmill has some advantages over onshore, higher speed, smooth operation due to less turbulence, and less noise pollution. “It is predicted that the offshore wind turbines, installed near major coastal cities in shallow coastal waters would become more attractive in the future” Sheridan et al. [13].

By 2050, 80% of the world's energy generation would come from renewable sources and wind energy would play a main role in electricity generation, related to the Intergovernmental Panel on Climate Change (IPCC). Many international studies proven that the offshore generation is becoming cost effective compared to onshore. The wind power generation cost in Shagaya renewable power project in Kuwait is about USD 5.98 ¢/kWh according to current economic analysis. The main energy consumption per capita in Kuwait is 577 million Btu/person while the world's average is 75. According to Al-kandari et al study, the average wind speed in Kuwait territorial waters at 50 m elevation does not fall below 6 m/s with turbines of up to 2 MW can be utilized. The coastal of Kuwait can produce 69 TWh/year from wind with 2 MW turbine. Most of the wind in Kuwait is coming from North West (NW). Table 3 shows the monthly means and maximums of wind speeds and gust speeds for the period 1957 – 2002 from Kuwait international airport at 10 m and 30 m height. Also, Table 3 shows that wind speed is higher outside the city and on the sea because of the flatness of the surface. Table 4 shows the monthly wind power density for different stations at 30 m Height (W/m^2). Table 5 illustrates the wind power density distribution for all months for all the eight different marine locations in Kuwait. The information found to be useful as follows: 1. The wind density at its peak in the summer where the demand is the highest. 2. The highest marine location is Beacon N6 which is 3 km away from the land. 3. The marine locations close to the land are good during the summer season and marine locations far from land are food during the winter season. The economic part of this journal is not mentioned here. There is a plan to build thermal power stations by MEW until year 2023 with a cost of $1650/kW. Table 6 shows the cost details involving the project to build 25 wind turbines at Beacon 6N south of Boubyan island. Table 7 illustrate of operation cost per year [3].

Six locations were studied in Kuwait and their annual average wind speed is 3.7 – 5.5 m/s with a mean wind power density of 80 – 167 W/m^2 at 10 m height. The maximum potential wind power was found during the summer season where the highest electrical demand. Because of the growth of population, the demand on fossil fuel increases proportionally due to the need for energy. The approach of this study is to use ArcGIS software to find the best spatial location to harvest wind power among of many locations in Kuwait. The criteria used in the study are: 1) The average annual wind speed, 2) Land use, 3) Topography of land, 4) Distance from the main road networks, 5) Urban areas, and 6) Distance from sensitive areas as military, oil fields, and natural reserves. The average wind speed is a crucial factor for generating electricity from wind. Wind speed with 4 m/s and above, consider excellent, so most of the country is rated in excellent range. The result showed the best locations to build wind farm which are Al-Shagaya, Al-Dabdaba, and Al-Salmi are the most recommended locations followed by Al-Abdali farm area in second place then Umm al-Hayman area in third place and forth place came North Wafra and Al-Shaqeeq [14].

The approach is to use statistical methods to analyze the wind speed data at three main islands in Kuwait which are Mubarak port (at Boubyan Island), Failaka Island and Umm Almaradim Island. Wind speed is a main factor to produce electricity from wind. The use of renewable energy is increasing due to fossil fuel use limitation and carbon dioxide emission in addition to the population growth which needs energy. The mean wind speed over 37 years on three locations on 30 m height as it follows: Mubarak port at Boubyan Island is about 4.5 m/s, Failaka Island is about 4.46 m/s, and Umm Almaradim is about 4.66 m/s, in addition that in June; the wind speed is the highest while in October is the lowest. The average wind density for the same locations are 150 W/m^2 for Mubarak port at Boubyan Island and 175 W/m^2 for Failaka Island and Umm Almaradim. Cut-out speed is more important because the speed of the wind could damage the turbine [15].

Arabian Gulf is bordered by Oman, UAE, Qatar, Bahrain, Saudi Arabia, Kuwait, Iraq, and Iran. The depth of the Arabian Gulf is shallow with more than 100 m on the Iranian side. A study by apricum showed maybe the cost of wind and solar cheaper than oil and gas which is less than 10¢/kWh. The electricity consumption growth rate of GCC is 3.15% per year between 2005 – 2009 where 2.2% for the world and 0.5% for the U.S. The average W/person in GCC in 2005 was 1,149 W which is much higher than world average of 297 W/person but less than USA average of 1,460 W/person. The purpose of this study is to build a complete wind map for the Arabian Gulf. The higher the altitude, the higher wind speed due to lower in pressure. It appears from the result that the central of the Arabian Gulf is most wind region compared to the northern and southern region, while the southern region has the lower wind speed [16].

Wind energy, compared to other sources of renewable energy, is low in term of cost. Well-designed wind turbines can cope some negative environmental impacts like the noise, visual quality, bird hits, etc. In 2016, the investment in the wind energy mostly was in 10 countries which are China, USA, Germany, India, Brazil, France, Turkey, Netherlands, United Kingdom, and Canada. In 2016, the Middle East and Africa increased their total wind energy capacity to 3.9 GW by added only 418 MW wind energy which falls way behind other regions. There is an estimation of 12.2 GW to added by 2021 in the region. 80% of energy produced from renewable energy comes from wind resource by 2050. As a matter affect, 20% of the supplied oil is consumed locally. During 2000 – 2015, the generation and export of electrical energy in Kuwait increased by 106% according to the MEW where the population reached 4.44 million. In June, Al-Wafra station (south of Kuwait) found to have the maximum mean wind power density (WPD) of 555.65 W/m^2. In the northern, northwestern, and southern parts of the country are found to have higher WPD due to open flat desert areas. Wind energy potential is determined by speed, direction, continuity, and availability. The approach of this study is to assess the wind energy potential and identify the hub height of the windmills in coastal and offshore locations in Kuwait. The offshore has some advantages over onshore which are wind speed, wind availability, lower turbulence, less noise, public objections, and impact on the natural beauty of lands. It was found, according to the data, that offshore is 32.35 – 35.2% higher than onshore. The formula is used to calculate different elevation $V_z=V_{10}$ (Z/10)^α, where

V_z is the wind speed at the desired elevation in m/s, V_{10} is the measured wind speed at elevation 10 m in m/s, z is the desired elevation in meter, and α is a dimensionless coefficient depends on the surface roughness and 1/7 for offshore. From the calculation, it showed that the wind speed is directly proportional with height. According to the classification of the wind power by The US Department of Energy, at this elevation in Kuwait falls in ranges between marginal (class 2) to excellent (class 5) based on annual average wind speeds. The wind turbine has cut-in and cut-out speed, the cut-out speed is more important because the wind speed can damage the turbine. The cut-in speed is 3 – 5 m/s and the cut-out speed is 25 m/s [5].

There are couple of reasons to build offshore wind farm, one of them is the great backup of the gas turbine, Kuwait has more than 5000 MW of gas turbines which the needed time to be connected to the grid at most around 15 min. Any ramp up or loss in the offshore wind farm energy will be backed up in matter of minutes to cover that ramp or loss. In addition to solar park with 1500 MW will be another great factor to backup. So, offshore wind farm and solar park will integrate each other to improve stability and reliability of the national grid. The time period of the sun in known but the wind is unpredicted. According to the wind analysis previously, Kuwait is windy all the time all the year and extremely rare to reach zero speed. Solar park will produce energy during the day regardless the cloud and the dust, wind park will produce energy all day and all night according to the data.

Kuwait is a small country and have very limited land. The land mainly used for building houses for living and for agriculture to supply food for the population. As of the increase in population, searching for new areas for building getting more difficult where another challenge appear which is some areas contain oil field and natural gas also military bases. Building an onshore wind farm may be preferable nowadays than offshore but in the near future to search for land to build wind farm will be very hard to find and very costly. There are couple of cities are in the building phase recently such as South Sabah Alahmad city, Khiran city, almutla city, South Khaitan, and South Abdullah Almubarak. These cities combined make up more than 50 thousand houses according to Public Authority for Housing Welfare [17].

The highest wind speed on land at elevation of 10 m is in June and July months from Northwest direction with 5.7 m/s and 5.3 m/s respectively and for elevation of 30 m, 6.7 and 6.2 respectively (Al Nassar et al. 2005) [18].

In this journal, they calculate the energy production for four locations which are Altaweel, Ras As-Subiyah, Umm Omara and Alwafra for (1998-2002) data with 19.94 GWh/yr with capacity factor less than 25%. In Alsalmi location, the capacity factor is 40% according to KISR data [19].

CHAPTER 3

RESULTS AND DISCUSSION

Power and Energy Capacity

This research utilizes data analysis because many tables provided from the MEW and Department of Meteorology ranged from three years to more than 20 years. Electrical energy has a large and influential role in people's lives and is the main component of any society because it includes all aspects of modern city life (health, education, security ... etc), and it is difficult to live without it. Globally, energy consumption increases annually due to the increase in population which is the main driver. The Kuwaiti government is serious about providing energy to all sectors in the country-- residential, agricultural, governmental, commercial, and industrial-- by building power stations if needed. The residential sector is the most energy consuming sector, followed by the commercial sector, where together they constitute more than 80% of the total consumption [20]. The MEW is concerned with providing energy and water to all sectors of the country. Kuwait Vision 2035 is to reach 15% of electric energy production from sustainable energies (PV, CSP, and Wind) by 2030 [1]. All upcoming renewable energy comes from solar energy due to the high availability of the Sun annually. Until the beginning of 2020, there were no wind farms scheduled to be built shortly, as Kuwait has a good amount of average monthly wind speed that can help raise the renewable percentage in Kuwait's vision 2035. The only two renewable projects, Alshagaya and Alabdalia, employ mostly solar energy while the wind energy only a small fraction. The plan for Alshagaya farm is to produce 2,000 MW by 2019, but in reality, it produced only 70 MW at the beginning of 2020 which means the target is not met and Kuwait is falling way behind. Alabdalia project, still under study, is entirely solar energy and is a partnership between the public and private sectors. According to a document from the MEW, the upcoming projects until 2030 are mainly photovoltaic (PV) and concentrated solar power (CSP) in addition to a small portion of wind energy of 100 MW + 10 MW present. All projects are onshore while offshore has a very high untapped potential for energy production, especially wind power. Until the beginning of 2020, the renewable energy capacity was 98 MW including the residential, private sectors, and some government buildings which are 28 MW. Today, Kuwait depends on oil and natural gas to run the power stations to produce electricity and water. Multiple factors are encouraging the Kuwait government to transfer from using fossil fuel resources to permanent resources like wind and solar for energy and water production. The consumption of oil and natural gas increases every year for local consumption and the country depends on these resources for wealth; also, the prices of oil and gas fluctuate which makes the government think seriously about transferring to renewable energy. Some of the renewable energy is found to be very cost-efficient compared to fossil fuel resources, not to mention the huge amount of greenhouse gas emissions that cause global warming such as carbon dioxide and other harmful gases into the atmosphere. The dependency on one resource as the fossil fuel will lead to an unsteady situation to provide future needs of energy. Governments are making policies to enforce taxes on the carbon burned and put pressure on the companies and energy utilities to reduce and eliminate burning carbon-based fuel [21]. Kuwait has eight conventional power stations to produce electricity and desalination water, and they are all located on the Arabian Sea – east of the country – because of the need for water in large quantities, in addition to renewable ones located to the west. As it is known, the thermal power station produces water in parallel with the electricity to increase its efficiency as the highest efficiency recorded in all power stations is about 42%. Most power stations consist of steam and gas turbines, some of which work as a combined cycle.

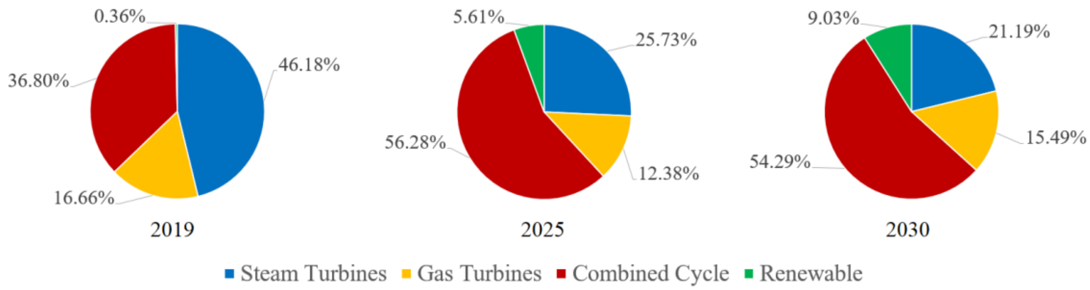

Figure 1: Percentage share of the four fossil fuel types for 2019, 2025, and 2030.

Fig. 1 shows the percentage share of type of unit in 2019, 2025, and 2030. The reason for choosing these years is because of the important change that took place there. Steam turbines dominate the fleet by 46.18%, followed by the combined cycle at 36.80%, and gas turbines account for 16.66% and operate only in emergencies and during peak loads due to their low thermal efficiency and high operating costs. 0.36% is the share of renewable energy in 2019.

Table 1: Total power capacity per power station until 2019.

Power Station	Installation Capacity (MW)	Capacity Percentage %
Shuwaikh	252	1.30
Shuaiba North	875.5	4.51
Shuaiba South	720	3.71
Doha East	1122	5.78
Doha West	2541	13.08
Zour South	5805.8	29.89
Sabiya	6496.7	33.45
Zour North	1540	7.93
Shagaya Renewable Energy	70	0.36
Total	19423	100.00

In 2025, steam turbines dropped from 8,970 MW to 7,200 MW which decreased the share to 25.73%, and gas turbines increased slightly from 3,236 MW to 3,464 MW which decreased the share to 12.38% due to increase in other type's share. Combined cycle saw a huge jump from 7,147 MW to 15,747 MW which increased the share to 56.28%, and also a huge increase in renewable energy from 70 MW to 1,570 MW which increased the share to 5.61%. In 2030, the steam turbine will remain the same at 7,200 MW but the share decreased to 21.19%, and the gas turbines increased significantly from 3,464 MW to 5,264 MW which increased the share to 15.49%. The combined cycle increased from 15,747 MW to 18,447 MW but a slight decrease in the share to 54.29% and a huge increase in renewable energy from 1,570 MW to 3,070 MW. Shagaya renewable park will consist of 2,710 MW of PV, 250 MW of CSP (Concentrating Solar Power), and 110 MW of wind energy. The total installed capacity generation until the end of 2019 is 19,423 MW, each power station's capacity, and their corresponding percentage is shown in Table 1. It is clear that Zour South and Sabiya power stations are the most productive of all other plants, as the country mainly relies on them.

In fact, building a steam power station needs about 7 years from study to the first operation, and about 5 years for a gas turbine type, so it requires sufficient care and study in the case of wanting to build this type of power station. The generation capacity in Kuwait is more than 100 steam and gas turbines and will increase in the near future due to the construction of new residential areas. In terms of the electrical network, it can compensate for the double contingencies which reflect the robustness of the network, so the network can receive new units. Two power stations are on the line to be built on the south of Kuwait, Nuwaiseeb in 2023 and Khairan in 2024 with a capacity of 3,300 MW and 1,500 MW, respectively.

Table 2 illustrates the total power capacity installed from 1958 to 2019 for all power stations in Kuwait which are 9 including one renewable power station. The first energy production installation was in Shuwaikh power station with 70 MW, and the total power installed until the end of 2019 was 19,423 MW. The increase in capacity was high in pace from 1958 until 1988, then decreased slightly in 1991, and after that, stayed almost flat until 1997, and then, increased steeply until 2016 then stayed almost flat for 2017 and 2018, after that, increased slightly in 2019 demonstrated in Fig. 2. The percentage changes from 1959 until 2019 showed two big changes, in 1961 with 85.7% and 1965 with 87.5%. It is believed these jumps occurred because of the beginnings in energy production in Kuwait, where people needed electricity to operate various appliances, especially air conditioning.

Table 2: Power installation from 1958 to 2019 in Megawatts (MW).

Year	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Shagaya	Total Capacity	Chang Percentage %
1958	70									70	
1959	70									70	0.0
1960	70									70	0.0
1961	130									130	85.7
1962	160									160	23.1
1963	160									160	0.0
1964	160									160	0.0
1965	160	140								300	87.5
1966	160	210								370	23.3
1967	160	210								370	0.0
1968	160	280								440	18.9
1969	160	400								560	27.3
1970	160	400	134							694	23.9
1971	160	400	402							962	38.6
1972	160	400	536							1096	13.9
1973	160	400	536							1096	0.0
1974	160	400	804							1364	24.5
1975	160	400	804							1364	0.0
1976	242	400	804							1446	6.0
1977	364	400	804	300						1868	29.2
1978	324	400	804	600						2128	13.9
1979	324	400	804	1050						2578	21.1
1980	324	400	804	1050						2578	0.0
1981	324	400	804	1158						2686	4.2
1982	324	400	804	1158	600					3286	22.3
1983	324	400	804	1158	1200					3886	18.3
1984	324	400	804	1158	2400					5086	30.9
1985	324	400	804	1158	2400					5086	0.0
1986	324	400	804	1158	2400	300				5386	5.9
1987	324	400	804	1158	2400	1610				6696	24.3
1988	195.3	330	804	1158	2400	2511				7398.3	10.5
1989	208	330	804	1158	2400	2511				7411	0.2
1990	140	270	804	1158	2400	2511				7283	-1.7
1991		25	804	1158	2400	2511				6898	-5.3
1992			829	1158	2400	2511				6898	0.0
1993			829	1158	2400	2511				6898	0.0
1994			829	1158	2400	2511				6898	0.0
1995			829	1158	2400	2511				6898	0.0
1996			829	1158	2400	2511				6898	0.0
1997			829	1158	2400	2511				6898	0.0
1998			745	1158	2400	2511	600			7414	7.5
1999			720	1158	2400	2511	1500			8289	11.8
2000			720	1158	2400	2511	2400			9189	10.9
2001			720	1158	2400	2511	2400			9189	0.0
2002			720	1158	2400	2511	2400			9189	0.0
2003			720	1158	2400	2511	2400			9189	0.0
2004			720	1158	2400	3011	2400			9689	5.4
2005			720	1158	2400	3511	2400			10189	5.2
2006			720	1158	2400	3511	2400			10189	0.0
2007	252		720	1158	2400	3551	2400			10481	2.9
2008	252		720	1158	2484.6	4376	2650			11640.6	11.1
2009	252		720	1158	2512.8	4376	2900			11918.8	2.4
2010	252	875.5	720	1158	2541	4936	2900			13382.5	12.3
2011	252	875.5	720	1158	2541	4936	4220			14702.5	9.9
2012	252	875.5	720	1158	2541	4935.8	4866			15348.3	4.4
2013	252	875.5	720	1158	2541	5306	4866.7			15719.2	2.4
2014	252	875.5	720	1158	2541	5306	4866.7			15719.2	0.0
2015	252	875.5	720	1158	2541	5805.8	5366.7	1540		18259	16.2
2016	252	875.5	720	1158	2541	5805.8	5866.7	1540	20	18779	2.8
2017	252	875.5	720	1122	2541	5805.8	5866.7	1540	20	18743	-0.2
2018	252	875.5	720	1122	2541	5805.8	5866.7	1540	70	18793	0.3
2019	252	875.5	720	1122	2541	5805.8	6496.7	1540	70	19423	3.4

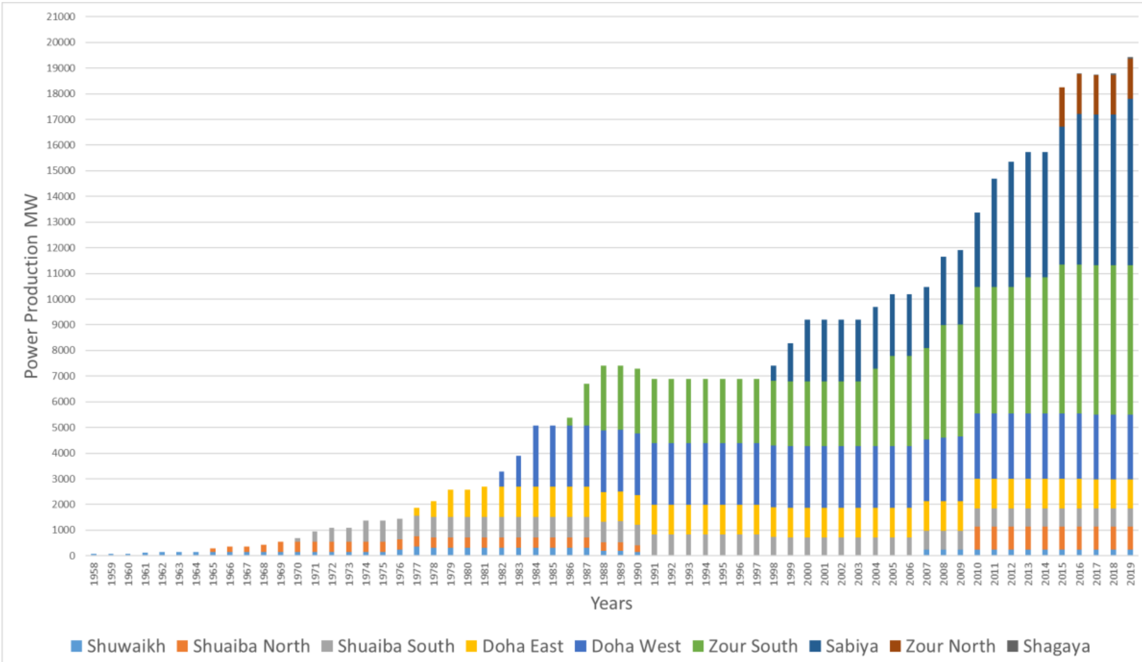

Figure 2: Total cumulative power installation from 1958 to 2019.

In some years, the change was zero which means the electricity production the year before was enough and covering the demand loads for the year after. Only three years were in the negative change and they are 1990 with (-1.7%), 1991 with (-5.3%), and 2017 with (-0.2%). 1990 and 1991 was in negative change because of the Iraq invasion of Kuwait which affected the whole country in all fields. The small negative change in 2017 – clearly appeared in Table 2 – is due to the shutdown of some old turbines that were not economically feasible to maintain. The global demand rate rose by 2.3% in 2018 which made it the highest growth in the last decade and Kuwait recorded higher than the global average [22].

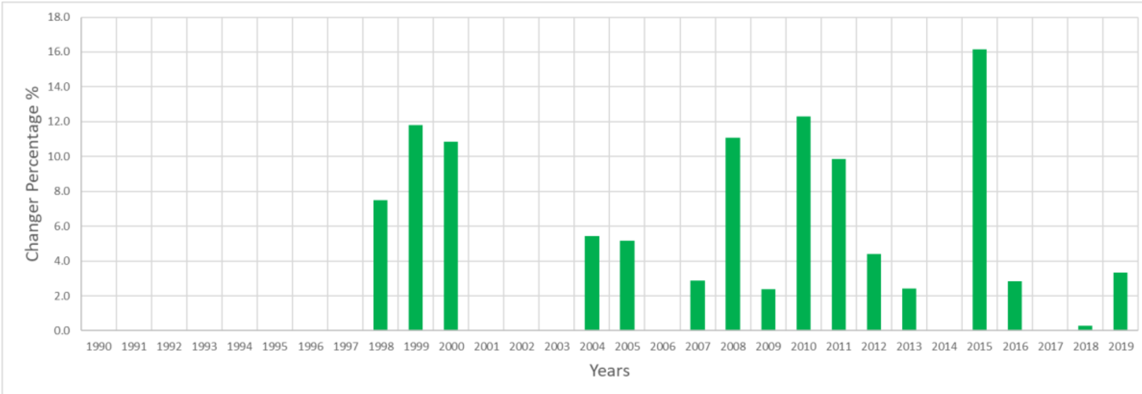

Figure 3: Change percentage installation from 1990 to 2019.

The production plan from 2016 to 2030 is shown in Fig. 4, and it is observed that there is an increase between 2021 and 2024 with 7,158 MW, and this is the largest future increase to meet the increase in loads with the construction of new residential areas. In 2016, the production was 18,279 MW and in 2030 will be about 33,981 MW with an average annual increase approximately 1,122 MW. This increase is very large due to the increase in consumption and failure to consider the high costs that are spent on producing electricity by the consumers. The average annual increase means one power station every

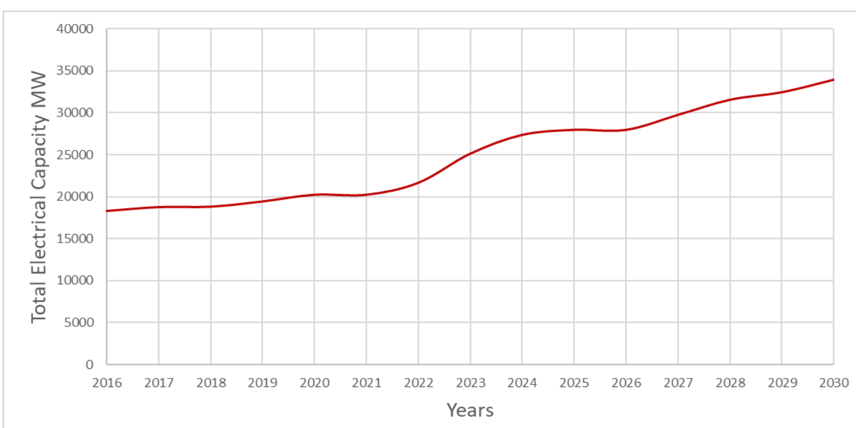

Figure 4: Total power installation with future plan from 2016 to 2030.

two years which puts a lot of pressure on the Kuwait economy because of the gas consumption and due to its price. As it is known, all power stations in Kuwait are thermal plants that use crude oil, heavy oil, gas oil, and natural gas, and in the future, the share of crude oil and heavy oil will decrease and replace them with natural gas for its properties that are less harmful to nature. Because of the lack of documentation, some data has not been available for many years, so the total energy generated, the lowest recorded load, and the highest recorded load starts from the year 1997 as in Table 3.

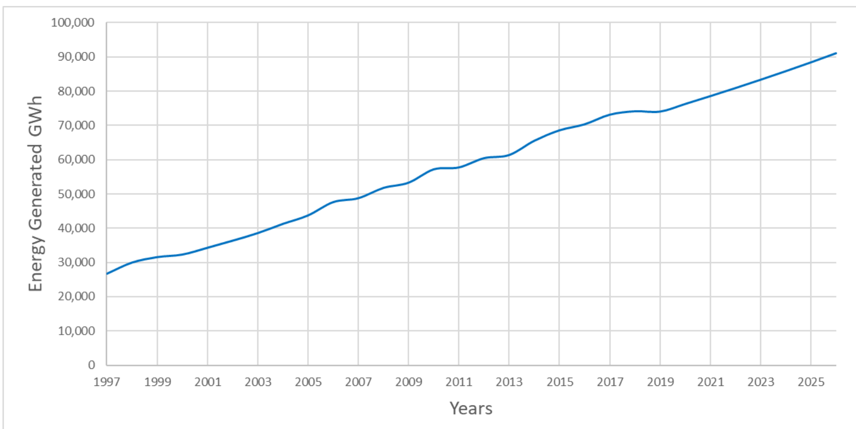

Figure 5: Annual energy generated from 1997 to 2019 and future prediction to 2026.

Table 3: Annual load and total energy generated with their corresponding change percentage from 1997 to 2026.

Year	Minimum Load Recorded (MW)	Maximum Load Recorded (MW)	Total Energy Generated (GWh)	Change Percentage %
1997	1,430	5,360	26,724	
1998	1,580	5,800	29,984	12.2
1999	1,650	6,160	31,576	5.3
2000	1,830	6,450	32,323	2.4
2001	1,880	6,750	34,299	6.1
2002	1,950	7,250	36,362	6.0
2003	2,110	7,480	38,577	6.1
2004	1,880	7,750	41,257	6.9
2005	2,480	8,400	43,734	6.0
2006	2,710	8,900	47,605	8.9
2007	2,650	9,070	48,754	2.4
2008	2,980	9,710	51,749	6.1
2009	3,140	9,960	53,277	3.0
2010	3,250	10,890	57,160	7.3
2011	3,450	11,220	57,720	1.0
2012	3,640	11,660	60,418	4.7
2013	3,720	12,060	61,335	1.5
2014	3,910	12,410	65,501	6.8
2015	4,100	12,810	68,536	4.6
2016	4,230	13,350	70,295	2.6
2017	4,280	13,770	73,095	4.0
2018	4,470	13,910	74,088	1.4
2019	4,445	14,420	73,996	-0.1
2020	4,578	14,853	76,216	3.0
2021	4,716	15,298	78,502	3.0
2022	4,857	15,757	80,857	3.0
2023	5,003	16,230	83,283	3.0
2024	5,153	16,717	85,781	3.0
2025	5,308	17,218	88,355	3.0
2026	5,467	17,735	91,005	3.0

The average total energy generated is 4.8% from 1997 to 2019, and the shaded in blue are future years where the average is calculated based on 3% due to the decline in the last few years. The total energy generated from 1997 to 2026 is represented in Fig. 5. As noted, the line progresses almost straight and the future is predictable according to the steady increasing rate. Table 4 is very interesting as it shows the minimum recorded load and its time as well as the maximum recorded load from 2009 to 2019. The minimum recorded load was 7 times in January, 4 times in February, and once in March. Usually, the reading is recorded in the early morning when the load is at its lowest usage at 5 am. Surprisingly, in 2012 the minimum load occurred on March 3 at 8 am which is unusual. The maximum recorded load was 4 times in June, 5 times in July, and 4 times in August. Usually, the reading is recorded in the afternoon when the load at its highest usage 3 - 4 pm. This data gives the impression that it is easy to predict the future of minimum and maximum loads, which makes the energy production supply easy.

Table 4: Minimum and maximum recorded load from 2009 to 2019.

Years	Minimum Load Recorded (MW)	Time Minimum Load Recorded	Maximum Load Recorded (MW)	Time Maximum Load Recorded
2009	3,140	Feb. 14 (5 - 6 am)	9,960	Jun. 28 (4 pm) Jul. 13 (4 pm)
2010	3250	Feb. 14 (5 am)	10890	Jun. 15 (3 - 4 pm)
2011	3450	Jan. 25 (5 am) Jan. 30 (5 am)	11220	Jul. 27 (4 pm)
2012	3640	Mar. 3 (8 am)	11660	Aug. 1 (3 pm)
2013	3720	Jan. 2 (5 am)	12060	Jul. 17 (4 pm)
2014	3910	Jan. 23 (5 - 6 am)	12410	Jun. 11 (4 pm)
2015	4100	Feb. 1 (5 am)	12810	Aug. 30 (4 pm)
2016	4230	Feb. 9 (4 am)	13350	Aug. 17 (3 pm)
2017	4280	Jan. 25 (3 am)	13770	Jul. 26 (2 pm) Aug. 1 (3 pm)
2018	4470	Jan. 20 (4 am)	13910	Jul. 10 (4 pm)
2019	4490	Jan. 28 (4 am)	14420	Jun. 27 (2 pm)

As noticeable, the peak of demand is increasing slowly every year. In 2009, the peak demand load barely reached 10,000 MW while in 2019 it reached more than 14,000 MW due to the increase in population. According to this growing percentage of demanding loads, the Kuwaiti government is keen to build more power stations to cover the need for energy. The demand curve for 2017 is shown in Fig. 6 and has the highest level during the summer season with approximately 14,000 MW and the lowest level during the winter season with approximately 4,000 MW. See Appendix A for the years 2009 to 2019; the year 2019 is not complete due to lack of data.

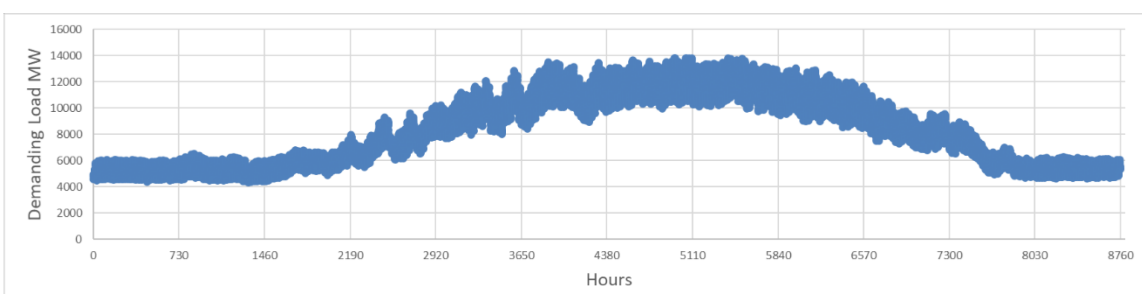

Figure 6: Load curve for 2017.

Fig. 7 and Fig. 8 represent the demand curves for a high-demand day in summer and the lowest-demand day in winter 2019. The winter demand curve is almost flat with a minimum of 4,500 MW and a maximum of 6,000 MW with a difference of 1,500 MW. In the summer, early morning demand is low, at around 11,000 MW, and in the afternoon its peak is more than 14,000 MW with a difference of more than 3,000 MW. These loads are still acceptable and can be supplied with energy.

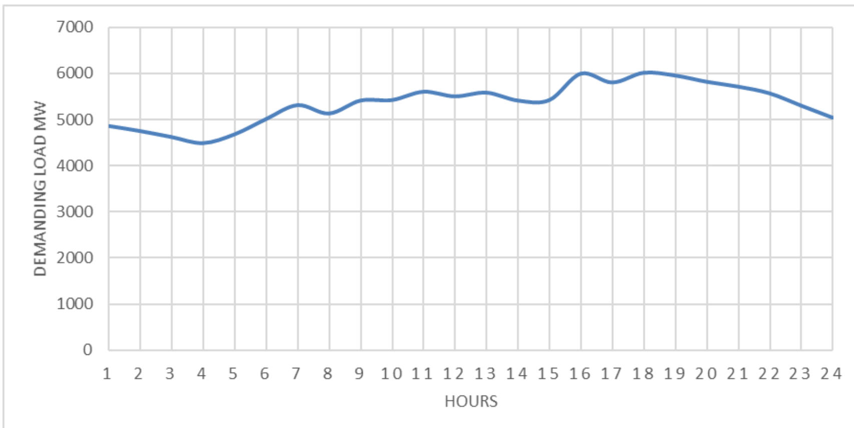

Figure 7: Demand for the lowest day in 2019.

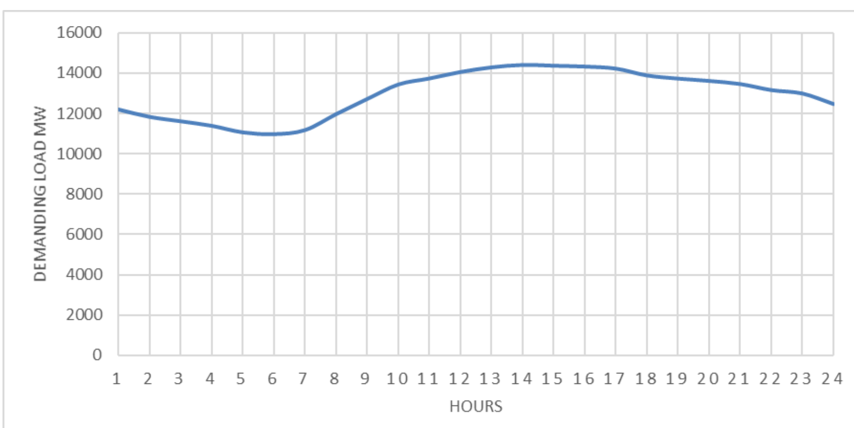

Figure 8: Demand for the highest day in 2019.

Population and Demand

Table 5: Population, peak Demand, and per capita consumption from 1996 to 2019.

Year	Population	Change %	Peak Demand (MW)	Change %	Per Capita Consumption KWh/person	Change %
1996	1,781,411		5,200		12,201	4.4
1997	1,837,450	3.1	5,360	3.1	12,441	2.0
1998	2,066,759	12.5	5,800	8.2	12,461	0.2
1999	2,148,032	3.9	6,160	6.2	12,552	0.7
2000	2,231,908	3.9	6,450	4.7	12,305	-2.0
2001	2,309,102	3.5	6,750	4.7	12,677	3.0
2002	2,419,928	4.8	7,250	7.4	12,832	1.2
2003	2,546,684	5.2	7,480	3.2	12,992	1.2
2004	2,753,656	8.1	7,750	3.6	12,940	-0.4
2005	2,991,189	8.6	8,400	8.4	12,673	-2.1
2006	3,182,960	6.4	8,900	6.0	13,060	3.1
2007	3,399,637	6.8	9,070	1.9	12,526	-4.1
2008	3,441,813	1.2	9,710	7.1	13,142	4.9
2009	3,484,881	1.3	9,960	2.6	13,372	1.8
2010	3,582,054	2.8	10,890	9.3	14,010	4.8
2011	3,697,293	3.2	11,220	3.0	13,633	-2.7
2012	3,823,728	3.4	11,660	3.9	14,054	3.1
2013	3,960,364	3.6	12,060	3.4	13,530	-3.7
2014	4,091,993	3.3	12,410	2.9	14,062	3.9
2015	4,239,006	3.6	12,810	3.2	14,251	1.3
2016	4,411,124	4.1	13,350	4.2	14,036	-1.5
2017	4,500,476	2.0	13,770	3.1	14,413	2.7
2018	4,621,638	2.7	13,910	1.0	14,235	-1.2
2019	4,776,407	3.3	14,420	3.7		

The greater the population, the greater the consumption and demand for energy. Table 5 shows the three columns, namely population, peak demand, and per capita consumption from 1996 to 2019 with corresponding change percentages. Until 2019, the population consisted of 30% Kuwaiti and 70% foreign, so the overpopulation leads to great pressure on the grid to supply enough energy. The population doubled between 2001 and 2019; in parallel, the peak demand also doubled to equalize the increase in population which is normal. The percentage of population change over the years is precisely shown, with a maximum increase between 1997 – 1998 by 12.5%, between 2003 – 2004 by 8.1%, and between 2004 – 2005 by 8.6%. The smallest change occurred between 2007 – 2008 and between 2008 – 2009, by 1.2% and 1.3%, respectively. This increase occurred on the foreign side because, in these years, the country needed many workers for the major construction process that the country was going through at that time. The population and peak demand have almost the same slope, meaning the increase in population has a steady rate which makes it easy to predict the future in parallel to peak demand as in Fig. 9. In the period from 1997 to 1998, the increasing percentage was 12.5% which is the highest rate for more than 20 years.

The peak of demand increases every year with the increase in population, with the highest increase occurring in 2010 by 9.3%, and the lowest increase happening in 2018 by 1.0%. There is no clear reason for the increase in 2010 but in 2018 the increase was caused by a slight increase in the population. The increases before 2011 were higher than after it, due to the energy conservation campaign that the Kuwaiti government started in mid-2007, and it took many years to obtain the desired results in saving energy.

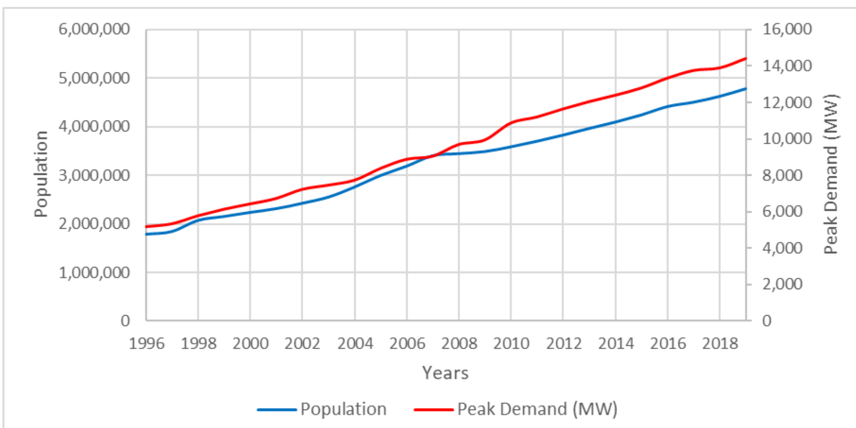

Figure 9: Population in comparison with peak demand from 1996 to 2019.

To accurately assess the situation, the period was divided into two 10-year halves, the first one from 1998 to 2008, and the second one from 2008 to 2018. The per capita consumption increased by 5.47% in the first period and by 8.32% in the second period, which is surprising, and it seems due to the lower tariff, which helps to increase unnecessary overconsumption. 12% increase happened between 2007 and 2010 which considered the highest in the whole period from 1996 to 2018. Overall, the increase within 20 years, was 13.79% in per capita consumption, found in Fig. 10.

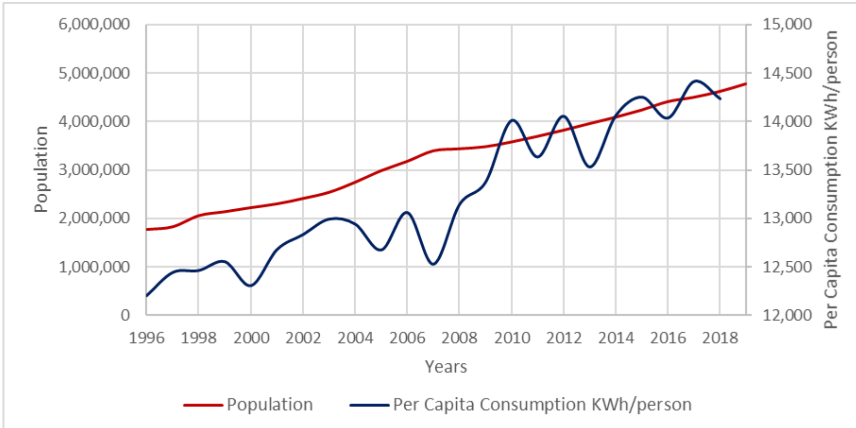

Figure 10: Population in comparison with per capita consumption from 1996 to 2019.

The sales revenue in Kuwaiti Dinars and US Dollars and its change percentage from 1997 to 2018 is demonstrated in Table 6. The sales revenue was fluctuating up and down from 1997 to 2005 and then began to rise from 2006 until 2018. A major jump occurred between 2011 and 2012 with a value of $126.539 million and a further jump between 2017 and 2018 worth $143.513 million. Less collection took place in 2011 with a value of $ 34.429 million lower than 2012, reflecting that many consumers had not paid their bills. The money collection system in Kuwait is not effective and not strict; otherwise, revenue would be more than the amount collected in 2018.

Table 6: Sales revenue from 1997 to 2018.

Years	Sales Revenue KWD (Million)	Sales Revenue USD (Million)	Change %
1997	26.143	85.749	
1998	24.002	78.726	-8.2
1999	31.541	103.454	31.4
2000	34.728	113.909	10.1
2001	26.702	87.583	-23.1
2002	36.581	119.987	37.0
2003	29.479	96.690	-19.4
2004	36.067	118.301	22.4
2005	32.789	107.549	-9.1
2006	33.877	111.116	3.3
2007	43.961	144.193	29.8
2008	47.082	154.427	7.1
2009	52.864	173.395	12.3
2010	51.495	168.903	-2.6
2011	56.654	185.825	10.0
2012	95.250	312.419	68.1
2013	84.753	277.990	-11.0
2014	94.941	311.407	12.0
2015	90.994	298.462	-4.2
2016	117.585	385.677	29.2
2017	108.627	356.297	-7.6
2018	152.381	499.810	40.3

Fuel Consumption and Cost

Kuwait's government is eager to build a robust infrastructure of fuel networks to supply all power stations, as needed, all types of fuel for electricity production and water desalination. Recently, Kuwait produced 4 million barrels daily and part of oil production goes to electricity and water production. The price of oil at the end of January 2020 was $63 per barrel [23][24].

Kuwait depends on oil and its products to generate electricity and water. The cost of kWh in Kuwait is $0.007 for the residential sector which makes it one of the cheapest in the world [25]. Natural gas consists mainly of methane and small amounts of other substances like carbon dioxide, nitrogen, hydrogen, and others. It is in the gas form and occurs naturally. Gas oil also known as fuel oil, heavy oil, marine fuel, or furnace oil, is heavier than crude oil and mostly used in heating or generating power. Crude oil is a yellowish-black liquid found in the deep of the Earth. This type is the mother of all types like diesel, benzene, kerosene, other fuel types. Heavy fuel oil is the residual of crude oil after extraction of other useful fuel types and it is a thick black liquid-like tar. The reason to use this type of fuel is to reduce the cost of fuel for electricity and water production [26].

Fuel Consumption

Natural Gas

Table 7: Annual cost of the natural gas consumption for all power stations from 2005 to 2018.

Year	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2005	7,757,900		37,274,985	10,570,446	6,556,919	24,427,454	4,067,993		90,655,697
2006	8,367,758		38,059,615	17,073,703	15,373,667	39,024,679	5,620,774		123,520,196
2007	15,374,809		31,322,251	16,572,725	7,453,756	45,094,349	12,637,558		128,455,448
2008	19,775,985		36,148,029	17,208,312	11,437,687	38,966,263	20,586,670		144,122,946
2009	10,785,168		40,619,207	18,394,118	12,405,781	51,662,222	16,256,950		150,123,446
2010	16,360,674	23,782,066	37,632,412	19,107,940	15,911,569	68,868,053	28,092,931		209,755,645
2011	9,081,556	29,023,067	38,890,234	17,942,988	27,902,850	87,969,135	30,480,219		241,290,049
2012	8,356,254	30,180,949	38,577,566	16,703,453	33,761,106	88,090,041	48,410,796		264,080,165
2013	7,357,870	28,162,742	39,460,518	14,431,748	14,882,305	97,629,275	51,511,871		253,436,329
2014	6,992,779	18,044,383	37,898,270	18,719,063	26,603,572	130,026,154	75,629,318		313,913,539
2015	8,341,558	30,291,973	36,786,720	14,121,889	18,262,293	113,419,497	104,953,104	24,759,022	350,936,056
2016	9,678,796	38,016,457	36,671,781	15,345,401	21,366,390	103,055,039	105,126,015	49,250,877	378,510,756
2017	8,404,287	34,209,963	36,566,085	19,723,726	19,097,669	67,987,908	89,824,480	99,124,791	374,938,909
2018	8,302,139	38,230,721	37,120,311	15,364,480	26,335,319	79,969,129	93,561,130	104,531,677	403,414,906

Beginning with the first fossil fuels, which is natural gas, is considered the least harmful to nature. Currently, Kuwait is heading to rely more on natural gas than other types. Natural gas is measured in thousand cubic feet (MCF) which is approximately equal to 1,000,000 Btu (British thermal units) where M is the roman number for thousand. Table 7 shows the details of the consumption of all eight power stations for the years 2005 to 2018. The Shuaiba North power station has been out of service since 1992 for renovation and installation of new gas turbines as it started using natural gas from 2010. The Zour North a new power station, entered service in the year 2015. Since 2015, all power stations use natural gas, and as it is noticed, the consumption increases every year as consumption in 2018 exceeds 4 times the consumption in 2005. Fig. 11 clearly shows the consumption curve since 2005, and it is observe that it is increasing at a rapid pace. There was a decrease in consumption in 2013 and 2017 due to the increase in heavy oil consumption in 2013 and crude oil in 2017. Consumption will increase in the future in large part due to power stations that will be built from 2019 and beyond by more than 10,000 MW.

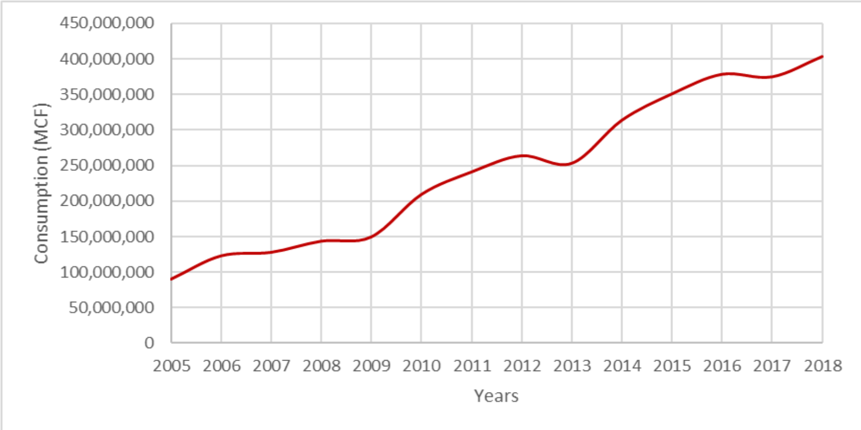

Figure 11: Natural gas consumption from 2005 to 2018.

Gas Oil

The second type of fossil fuel type is gas oil which is used by seven power stations out of eight. Table 8 illustrates the details of the consumption of these power stations for the years 2005 to 2018.

Table 8: Annual cost of the gas oil consumption for all power stations from 2005 to 2018.

Year	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2005				3,965		742,311	36,424		782,700
2006				29,284		4,294,090	8,141		4,331,515
2007				165		3,903,707	40,718		3,944,590
2008				733	147,499	6,786,413	26,522		6,961,167
2009			600,939	10,460	368,300	8,157,489	1,701,741		10,838,929
2010			342,167	12,237	12,149	6,894,948	1,826,115		9,087,616
2011			221,560	12,026		4,186,879	5,826,434		10,246,899
2012		193,114	316,979	462	152,218	2,036,850	9,214,006		11,913,629
2013		97,637		393		2,730,951	6,408,325		9,237,306
2014		1,130,334		170		1,797,857	8,225,301		11,153,662
2015		1,335,149		307		1,702,108	5,242,855	290,030	8,570,449
2016		333,040	129,208	356	15,181	1,061,018	4,074,153	118,802	5,731,758
2017		431,409		272		1,179,731	3,563,158	20,291	5,194,861
2018		183,698		225	14,034	470,503	2,853,202	102,096	3,623,758

Shuwaikh power station does not use this type of fuel because it is not designed for it. Shuaiba South power station consumes gas oil on a non-continuous period, four years in a row starting in 2009 by 600,939 barrels and stopping in 2012 with 316,979 barrels then consumed only in 2016 with the lowest consumption with 129,208 barrels. Similarly, Doha West power station consumes the fuel for three years in a row starting in 2008 with 147,499 barrels and stopping in 2010 with 12,149 barrels then in 2012, only 152,218 barrels. In 2016 the consumption equated to 15,181 barrels, and 2018 with 14,034 barrels. Shuaiba North power station started to consume in 2012 with 193,114 barrels and reached its maximum in 2015 with 1,335,149 barrels then drops back in 2018 with 183,698 barrels. Zour North is the newest power station that started in 2015 were entered the service with 290,030 barrels then reached its minimum in 2017 with 20,291 barrels then increased again in 2018 to 102,096 barrels. Doha East, Zour South, and Sabiya are the only power stations consuming for the whole period where Zour South and Sabiya were the most dominant in consumption among others. Zour South was dominating from 2005 until 2010 then Sabiya took the lead from 2011 until 2018 that formed 78.74% of the 2018 consumption. Doha East is the lowest consumption among them; it started by 3,965 barrels and peaked in 2006 with 29,284 barrels then ended with very low consumption in 2018 at 225 barrels. The total consumption of gas oil is shown in Fig. 12. It started with 782,700 barrels in 2005 and peaked in 2012 at 11,913,629 barrels then went down to 3,623,758 barrels in 2018. In the future, the consumption might fall due to more gas turbines being in the line.

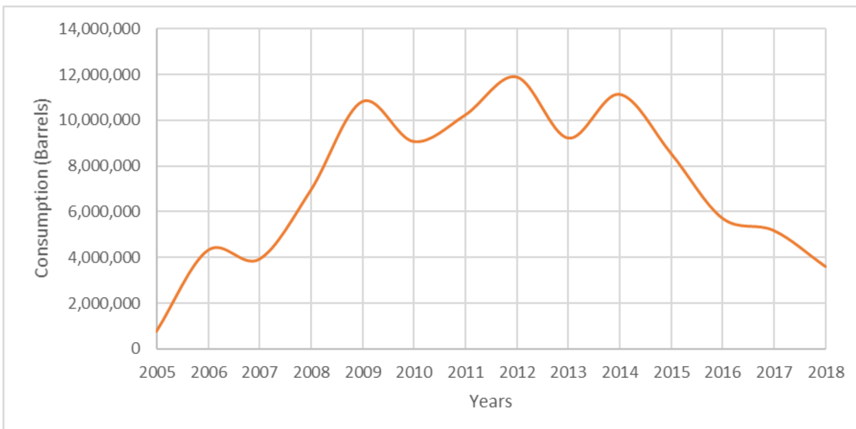

Figure 12: Gas oil consumption from 2005 to 2018.

Crude Oil

The third fossil fuel type is crude oil which is used by only four power stations out of eight. Table 9 demonstrates the details of the consumption of these power stations for the years 2005 to 2018.

Table 9: Annual cost of the crude oil consumption for all power stations from 2005 to 2018.

Year	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2005				6,429,035		9,991,908	2,902,451		19,323,394
2006				5,695,984			4,677,187		10,373,171
2007				5,342,286		8,349,147	2,883,040		16,574,473
2008				5,014,463			4,450,004		9,464,467
2009				5,274,117	864,581	9,237,311	4,715,051		20,091,060
2010				5,553,888	1,546,813	9,966,099	896,522		17,963,322
2011				4,974,937		11,378,668	3,093,819		19,447,424
2012				4,677,387		10,765,875	1,123,632		16,566,894
2013				3,925,377		7,314,672	83,806		11,323,855
2014				3,429,396		9,840,633	1,139,064		14,409,093
2015				4,360,599			488,838		4,849,437
2016				3,416,227	331,609	213,033	97,075		4,057,944
2017				3,141,491		4,396,030	1,657,144		9,194,665
2018				114,417	5,317,716	133,478	671,377		6,236,988

Doha West used the crude oil for only 4 years in the whole period starting in 2009 with 864,581 barrels and ending by 2018 with its maximum consumption of 5,317,716 barrels. Zour South stopped using crude oil only for three in the whole period, 2006, 2008, and 2015. The maximum consumption in Zour South was in 2011 at 11,378,668 barrels and the minimum was in 2018 with 133,478 barrels. Doha East and Sabiya power stations have used this type of fuel for the whole period. Doha East reached its maximum consumption in 2005 with 6,429,035 barrels and its minimum in 2018 at 114,417 barrels. Sabiya reached its maximum consumption in 2009 at 4,715,051 barrels and its minimum in 2013 with 83,806 barrels. Doha East consumption was decreasing over the years while Sabiya consumption was higher before 2012 than after. Doha West consumption was 85.26% of the total consumption in 2018. The total consumption is described in Fig. 13 and it is fluctuating until 2009 which is the maximum of 20,091,060 barrels then it started to decrease until its minimum in 2016 with 4,057,944 barrels. In the future, consumption may decrease due to the increase in the number of gas turbines in the line in addition to its value, which is considered wealth for Kuwait.

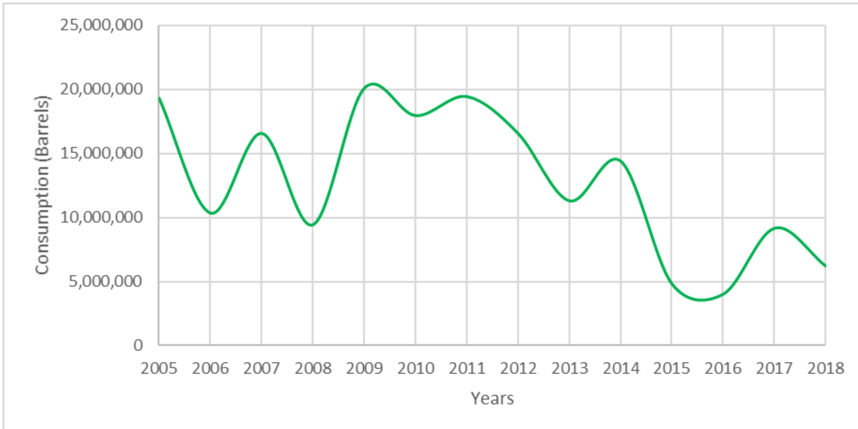

Figure 13: Crude oil consumption from 2005 to 2018.

Heavy Oil

The fourth fossil fuel type is a heavy oil that is used by only four power stations out of eight. Table 10 shows the details of the consumption of these power stations for the years 2005 to 2018.

Table 10: Annual cost of the heavy oil consumption for all power stations from 2005 to 2018.

Year	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2005				2,601,741	20,405,489	12,144,583	11,197,548		46,349,361
2006				2,589,983	19,724,915	20,299,799	10,380,467		52,995,164
2007				2,560,744	19,720,126	12,533,832	13,648,802		48,463,504
2008				2,454,033	19,524,590	21,096,708	12,680,044		55,755,375
2009				1,656,098	18,917,408	11,236,457	12,489,738		44,299,701
2010				2,277,143	16,606,922	10,273,879	14,744,615		43,902,559
2011				2,308,145	15,399,739	7,991,806	13,235,404		38,935,094
2012				2,699,098	14,079,998	7,449,045	14,329,417		38,557,558
2013				3,288,258	17,907,206	8,961,373	16,810,264		46,967,101
2014				3,081,905	15,725,837	7,271,372	11,875,568		37,954,682
2015				3,145,653	15,891,758	15,325,014	12,360,071		46,722,496
2016				2,852,384	16,227,534	17,458,499	11,921,925		48,460,342
2017				2,696,066	15,398,758	12,278,507	11,218,052		41,591,383
2018				6,136,383	8,394,951	17,024,229	11,400,802		42,956,365

Four power stations out of eight are using this type of fuel for the whole period. Doha East consumption reached its minimum in 2009 with 1,656,098 barrels and its maximum in 2018 at 6,136,383 barrels. Doha West started with high consumption at 20,405,489 barrels and decreasing until it reached its minimum in 2018 with 8,394,951 barrels. Zour South consumption reached its minimum in 2014 at 7,271,372 barrels and its maximum in 2008 with 21,096,708 barrels. Sabiya had its minimum in 2006 at 10,380,467 barrels and its maximum in 2013 with 16,810,264 barrels. The reason to consume heavy oil specifically in these four power stations is that they were modified to use this type in addition to its lower cost compared to gas oil and crude oil. Doha East had an increasing rate and Doha West had a fluctuating rate from 2009 and after. Zour South was a kind of flat consumption between 2009 and 2014 and after that, its consumption increased. Sabiya is fluctuating from 2005 to 2013 then went to about flat rate from 2013 and after. The total consumption is in Fig. 14 is varied between 37 million and 55 million barrels.

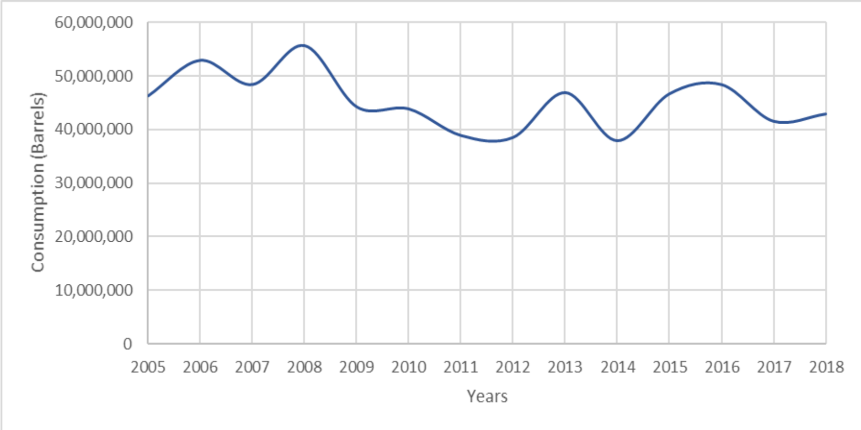

Figure 14: Heavy oil consumption from 2005 to 2018.

This kind of fuel is the worst because it is heavy and thick, and it needs heat and pressure to move into the pipes to be consumed in the power stations. The rate of consumption will decrease because Doha East power station will be shut down in 2024 and will be replaced with gas turbines and other power stations might stay at the same rate of consumption. The consumption quantity of the three fossil fuel types is demonstrated in Fig. 15, and heavy oil is dominant over the others.

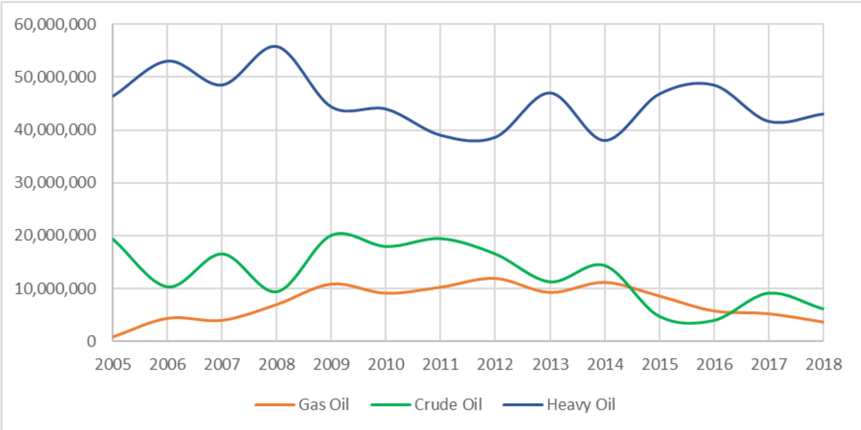

Figure 15: Gas oil, crude oil, and heavy oil consumption curves from 2005 to 2018.

For a follow-up, Fig. 16 pinpoints the total quantity of the three types of fuel consumed to produce electricity from 2005 to 2018 to compare it with the total oil production. It is noted that there are two increase rates in 2009 and 2013 where the supply of natural gas wasn't enough in Fig. 11. These data are confirming the trend of the Kuwait government to slowly switch to natural gas. According to the Organization of the Petroleum Exporting Countries (OPEC), Kuwait oil production was 2,736.6 thousand barrels per day (tb/d) in 2018 and the domestic demand was 352.9 (tb/d) which is 12.9% of total production [27]. The problem here is the internal production of natural gas is not enough so they import to meet the needs.

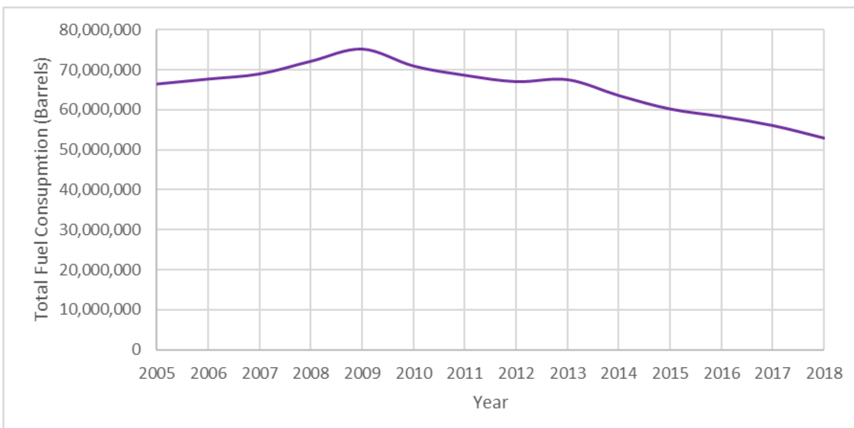

Figure 16: Total consumption of gas oil, crude oil, and heavy oil combined from 2005 to 2018.

Fuel Costs

The total cost of fossil fuel has been reviewed in Table 11 for eight power stations from 2012 to 2018. The orange color represents the most expensive and the green one represents the least expensive.

Table 11: Total cost of all types of fossil fuel in all power stations from 2012 to 2018.

Year	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2012	$48,324,022	$223,390,736	$86,515,821	$779,569,488	$1,465,721,402	$2,429,731,286	$2,720,082,461		$7,753,335,216
2013	$39,628,874	$145,408,349	$91,829,104	$762,174,787	$1,614,964,730	$2,253,406,797	$2,542,065,510		$7,449,478,150
2014	$55,781,392	$241,671,510	$262,786,880	$678,985,485	$1,459,294,381	$2,643,443,923	$2,450,234,838		$7,792,198,410
2015	$34,950,483	$209,332,877	$40,967,328	$392,152,528	$744,701,034	$1,252,530,128	$1,328,942,704	$119,539,523	$4,123,116,605
2016	$32,294,221	$141,846,378	$40,956,061	$276,567,450	$628,427,702	$1,017,394,352	$951,559,786	$145,771,667	$3,234,817,616
2017	$35,061,296	$172,672,246	$45,656,976	$348,791,229	$808,328,858	$1,138,754,643	$1,203,565,066	$369,345,133	$4,122,175,446
2018	$45,580,093	$229,515,549	$53,300,765	$462,058,669	$1,010,072,877	$1,580,898,906	$1,524,748,403	$514,612,352	$5,420,787,613

Shuwaikh power station is the lowest in fuel cost compared to others; the lowest was in 2016 with over $32 million and the highest was in 2014 with more than $55 million. The second-lowest one after Shuwaikh is Shuaiba South; the lowest cost was in 2016 with more than $40 million and the highest was in 2014 with over $262 million. Like Shuaiba South, Shuaiba North reached its highest in 2014 with more than $241 million and its lowest cost in 2016 with less than $142 million. Doha East started in 2012 with the highest cost by more than $779 million, then decreased until its lowest in 2016 by slightly more than $276 million after that increased again. Doha West is the third most costly power station with more than $1.6 billion at its maximum in 2013 and its minimum by slightly less than $629 million in 2016. Zour South and Sabiya are the most fuel-costly among others due to their huge capacity. The highest cost for Zour South was in 2014 with more than $2.5 billion and the lowest cost was in 2016 with more than $1 billion. The highest cost of Sabiya was in 2012 with more than $2.7 billion and the lowest was in 2016 with less than $1 billion. Zour North entered the service in 2015 with $119 million and then increased every year until 2018 with more than $500 million. In total, the most expensive year was 2014 at $7.79

billion and the least expensive was in 2016 at $3.23 billion. There is no clear reason for such costs in these certain years.

Table 12: Total cost of all types of fossil fuel in all power stations from 2016 to 2018.

Year	Fuel Type	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2016	Natural Gas	$32,294,221	$123,751,712	$36,045,904	$47,776,275	$67,621,466	$380,852,051	$340,956,435	$139,388,979	$1,168,687,043
	Gas Oil		$18,094,666	$4,910,157	$17,430	$687,472	$55,148,394	$206,892,938	$6,382,688	$292,133,744
	Crude Oil				$130,940,269	$13,110,624	$10,271,773	$3,387,072		$157,709,738
	Heavy Oil				$97,833,475	$547,008,141	$571,122,134	$400,323,341		$1,616,287,091
	Total	$32,294,221	$141,846,378	$40,956,061	$276,567,450	$628,427,702	$1,017,394,352	$951,559,786	$145,771,667	$3,234,817,616

Year	Fuel Type	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2017	Natural Gas	$35,061,296	$146,371,014	$45,656,976	$74,189,299	$75,289,542	$303,361,152	$369,423,533	$368,120,451	$1,417,473,264
	Gas Oil		$26,301,232		$18,349		$71,647,622	$218,547,280	$1,224,682	$317,739,165
	Crude Oil				$144,036,419		$177,388,595	$78,921,027		$400,346,042
	Heavy Oil				$130,547,162	$733,039,315	$586,357,274	$536,673,226		$1,986,616,976
	Total	$35,061,296	$172,672,246	$45,656,976	$348,791,229	$808,328,858	$1,138,754,643	$1,203,565,066	$369,345,133	$4,122,175,446

Year	Fuel Type	Shuwaikh	Shuaiba North	Shuaiba South	Doha East	Doha West	Zour South	Sabiya	Zour North	Total
2018	Natural Gas	$45,580,093	$214,193,984	$53,300,765	$73,781,328	$128,188,570	$470,992,874	$536,654,112	$506,082,333	$2,028,774,058
	Gas Oil		$15,321,565		$17,792	$1,207,536	$39,139,882	$241,214,525	$8,530,019	$305,431,318
	Crude Oil				$7,046,496	$373,968,819	$9,741,802	$43,678,317		$434,435,434
	Heavy Oil				$381,213,053	$506,707,952	$1,061,024,349	$703,201,450		$2,652,146,803
	Total	$45,580,093	$229,515,549	$53,300,765	$462,058,669	$1,010,072,877	$1,580,898,906	$1,524,748,403	$514,612,352	$5,420,787,613

Unfortunately, the detailed data for fossil fuel costs are only available for three years. Table 12 shows Shuwaikh power station consumed only natural gas for the three years, while Shuaiba South consumed natural gas and gas oil in 2016 then switched to only natural gas in 2017 and 2018. Shuaiba North and Zour North power stations consumed natural gas and gas oil for the three years. Doha East, Doha West, Zour South, and Sabiya consumed all types of fuel for the three years except for Doha West which stopped consuming gas oil and crude oil in 2017 due to economic issues.

To have a solid vision of the percentage of fuel cost in 2016, 2017, and 2018 for all types of fuels, is clearly explained in Fig. 17. The heavy oil is the predominant of all types followed by the natural gas then the crude oil and last is the gas oil. Heavy oil shared 50% in 2016 and decreased by 2% to 48% in 2017, then raised by 1% to 49% in 2018. The natural gas followed the same trend as heavy oil; it shared 36% in 2016 and decreased by 2% to 34% in 2017, then increased by 3% to 37% in 2018. The gas oil is the most expensive fuel type of all which is consumed in a very narrow usage in peak loads; for example, it formed only 9% in 2016 and decreased by 1% to 8% in 2017, then decreased once more by 2% to 6%. The crude oil shared 5% in 2016 then increased by 5% to reach 10% in 2017 and that is due to supply issues of other fuel types, then the percentage decreased by 2% to reach 8% in 2018.

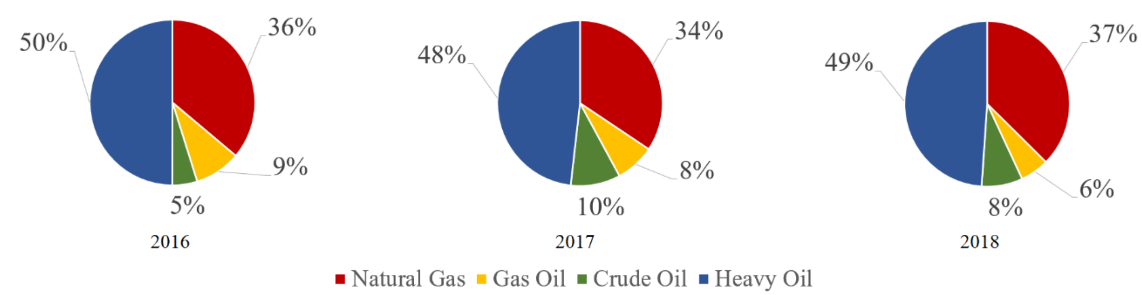

Figure 17: Share percentage of all four fossil fuel types in 2016, 2017, and 2018.

To find the average prices of all fuel types mentioned previously, a simple calculation has been done by taking the total cost of the fuel divided by its quantity. The prices are on the average basis for the whole year because it is very difficult to find the daily prices of them. Surprisingly, the average prices increased annually from 2016 to 2018 with significant value for crude oil and heavy oil by 53.6% and 54.4% respectively, 65.1% for gas oil, and 60.8% for natural gas. Convert a cubic foot of natural gas to a barrel for a clear approximation that 1-barrel equals 5.615 cubic feet as the cost of natural gas at the end of January 2020 reached $1.90 per cubic foot [23].

Table 13: Per-unit cost for all four fossil fuel types from 2016 to 2018.

Year	Natural Gas ($/MCF)	Gas Oil ($/Barrel)	Crude Oil ($/Barrel)	Heavy Oil ($/Barrel)
2016	$3.34	$54.33	$34.89	$33.58
2017	$4.17	$60.97	$47.62	$47.84
2018	$5.49	$83.41	$65.06	$61.68

If one barrel of crude oil costs $63, the barrel of natural gas will cost $10.67 which makes it a cheaper option to run the power stations compared to the crude oil. So, natural gas is the cheapest and the best for the environment while heavy oil is the worst for the environment and gas oil is the most expensive fuel among other types so this is the reason to be used in emergency cases. The fluctuating oil and gas prices make this type of fuel not attractive especially in high prices which makes the government find another clean energy substitution. The cost of energy USD/kWh is oscillating because it is related to global pricing so, in 2019, the cost of energy was 0.0406 KD/kWh equals 0.133 USD/kWh including depreciation of assets and operation and maintenance in addition to the transmission and distribution. The cost of the fuel only would be 0.01884 KD/kWh equal to 0.062 USD/kWh; by converting to MWh, the cost would be 40.6 KD/MWh equal to 133 USD/MWh which is the total, and the fuel only would be 18.84 KD/MWh equal to 62 USD/MWh [20].

Wind and Temperatures Analysis

Temperatures Analysis

Kuwait is known to have hot weather in summer and cool in winter, with temperatures reaching approximately 50 ° C (122 ° F) in summer in open areas in the desert and somewhat less in cities. Also, winter temperatures drop to zero degrees Celsius and sometimes less. Likewise, the temperatures in the islands and in the depths of the sea decrease due to the water vapor that softens the surrounding atmosphere. In this research, eight marine locations were chosen to measure the temperatures and their suitability with the installation of wind farms to produce electrical energy from wind. The locations are as follows, the first location is Beacon M28 located in the southeast of the Boubyan island, about 27 km, which is the largest Kuwaiti island. The second location is Beacon N6 in the south of Boubyan island and east of Ras Al-Sabiya. The third location is South Dolphin located about 3 km north of the downtown in Kuwait Bay. The fourth location is Salmiya located in the northeast of the Salmiya area about 3 km. The fifth location is Ahmadi Oil Pier located onshore approximately 5 km east of the Mangaf area. The sixth location is Sea Island Buoy located approximately 20 km northeast of the Mangaf area. The seventh location is Juliaa Port located on the east coast of Juliaa area. The eighth and last location is Umm Almaradim Island located approximately 25 km east of Alkhiran Resort [28][29].

The monthly and annual average temperatures measured in Celsius for the eight locations demonstrated in Table 14 for 2008, and for years 2009 – 2014 as seen in Appendix B. Six of these locations have data from 2008 to 2017 while Beacon M28 has data from 2007 to 2014 and Sea Island Buoy has data from 2008 to 2016 so the common years have been considered. Some months contain zero values and that is due to either the station being under maintenance or the sensor being defective in addition to some odd values that have been neglected. The summer months of June, July, August, and September are the hottest months with more than 30°C while the winter months of January, February, and December are the coldest months with less than 20°C shown in Fig. 18.

Table 14: The monthly and annual average temperatures for eight marine locations from 2008.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	11.9	14.4	20.0	24.5	29.0	32.2	33.8	34.4	33.2	28.1	21.5	16.3	24.9
	Sea Island Buoy	12.2	13.9	19.7	24.3	28.8	31.4	0.0	29.7	33.4	28.8	22.4	17.0	23.5
	Ahmadi Oil Pier	11.7	14.6	22.2	26.7	31.4	36.4	37.6	36.9	34.3	29.1	21.5	16.0	26.5
2008	Beacon N6	10.1	13.1	20.5	25.3	30.0	33.6	35.1	34.8	33.1	27.3	20.1	14.4	24.8
	Juliaa Port	11.6	14.1	20.8	25.3	30.0	34.1	35.2	35.3	33.4	28.3	21.2	15.6	25.4
	Salmiya	11.6	14.1	21.5	26.2	30.7	34.8	36.5	36.2	34.1	28.8	21.7	16.0	26.0
	South Dolphin	11.2	13.9	21.0	25.7	30.2	33.2	35.1	35.5	33.7	28.2	21.2	15.7	25.4
	Umm Almaradim	13.2	14.8	19.8	24.0	28.8	32.3	34.0	34.4	33.6	29.3	23.2	18.1	25.5

Ahmadi Oil Pier recorded the highest temperatures at 38.5°C in July 2009 while Beacon M28 recorded the lowest temperature at 10.1°C in January in the same year for the whole period. Ahmadi Oil Pier is the hottest during the summer whereas Umm Almaradim Island is the hottest during the winter. In addition, Beacon M28 is the coldest during the summer where Beacon N6 is the coldest during the winter which led to the least average annual temperatures for Beacon N6 followed by Beacon M28 and it might be because those are located furthest North to the other locations. The annual average temperature for all locations ranged from 24.8°C to 27.9°C (Sea Island Buoy were removed due to zeros) which are very acceptable temperatures for installing wind farms.

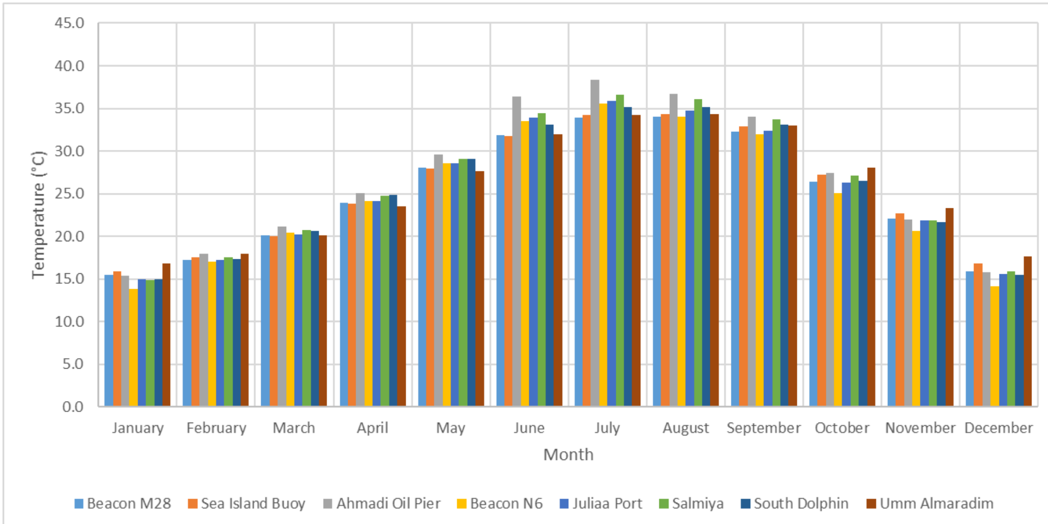

Figure 18: Monthly average temperatures in Celsius of the eight marine locations.

Wind Analysis

The wind is an indirect form of solar energy, where the wind is caused by large-scale movements of global air masses in the atmosphere. Initially, these air movements are created by heating the sun to the Earth's atmosphere, heating the air, making it lighter and less dense, rising to high altitudes, and then the air begins to cool and descend because the cold air is denser and heavier. The places of hot air are places of high pressure and places of cold air are places of low pressure, so the air masses travel from high pressure to low pressure, which in turn determines the speed and direction of wind movement. The higher the pressure, the higher the wind speed and produce effective force due to the Earth's rotation. Wind in open areas is more stable than cities that have tall buildings and trees, where they are considered obstacles and windbreaks, so their speed changes and becomes unstable [30][6].

Table 15: The monthly and annual average wind speed (m/s) for eight marine locations at 10 m elevation for 2008.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
2008	Beacon M28	5.6	5.7	5.1	4.4	4.5	5.9	4.7	4.4	5.3	4.9	5.0	4.3	5.0
	Sea Island Buoy	5.2	5.4	4.4	3.7	3.8	5.8	0.0	3.7	4.9	5.1	5.3	5.5	4.8
	Ahmadi Oil Pier	4.8	5.6	5.0	4.6	4.7	7.2	5.4	4.5	5.1	4.9	4.9	5.2	5.1
	Beacon N6	4.5	5.4	5.1	4.8	4.9	6.6	5.4	4.4	5.0	4.6	4.5	4.7	5.0
	Juliaa Port	4.8	5.5	5.1	4.4	4.6	6.1	4.8	4.3	5.0	4.9	5.0	5.2	5.0
	Salmiya	4.1	4.6	4.0	3.4	3.4	4.3	3.5	3.3	4.0	3.8	3.6	4.0	3.8
	South Dolphin	5.0	5.7	4.9	4.8	4.4	6.2	4.9	4.2	4.9	5.0	5.1	5.3	5.0
	Umm Almaradim	5.7	6.2	5.2	4.2	4.5	5.3	4.0	4.1	5.0	5.4	6.3	6.4	5.2

The marine locations have been analyzed to know the wind speed and wind density as well. The monthly and annual average wind speed at 10 m height for 2008 is pinpointed in Table 15, for years 2009 – 2014 as seen in Appendix B. The analysis found that four locations have winds available during summer and winter seasons which reflect a good indication of wind availability which are Beacon M28, Sea Island Buoy, Juliaa Port, and Salmiya. Umm Almaradim Island is windy during the winter while Beacon N6 and Ahmadi Oil Pier are windy during the summer. South Dolphin location is windier during the summer with a significant amount in winter. The highest annual average wind speed for the period of 2008 to 2014 occurred in Umm Almaradim Island with a speed of 5.3 m/s followed by South Dolphin with a speed of 5.0 m/s then Beacon N6 with a speed of 4.9 m/s. Ahmadi Oil Pier recorded a wind speed of 4.7 m/s and then Sea Island Buoy and Juliaa Port have an average wind speed of 4.6 m/s. The wind speed of Salmiya is 4.4 m/s and the lowest went for Beacon M28 with an average wind speed of 4.3 m/s.

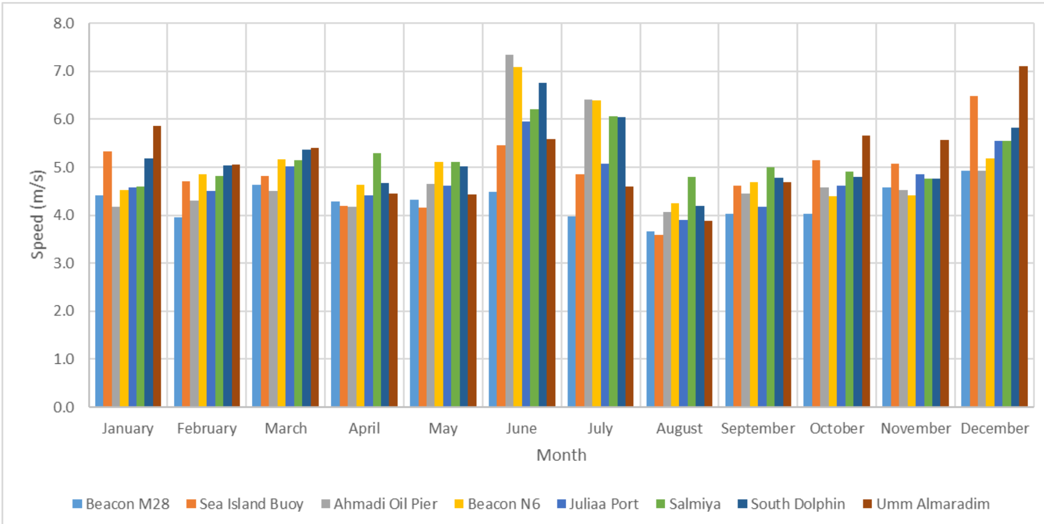

Figure 19: Monthly average wind speed in (m/s) of the eight marine locations.

The monthly average wind speed of the eight locations shown in Fig. 19 that some are windy during the summer season and others are windy during the winter season. All wind speed has been measured on the height of 10 m and the Power Law has been used to calculate different elevated wind speed:

$$\frac{v_1}{v_2} = [\frac{h_2}{h_1}]^{\alpha}$$

where v_1 and v_2 are average wind speed at heights h_1 and h_2 respectively. α is the wind shear exponent which depends on the roughness of the surface. h_1 is 10 m and α is 1/7 or 0.1429 for sea surface [3]. Increasing in elevation would results in higher in the wind speed and wind density as observed. Beginning with the reference elevation at 10 m, wind speed ranges from 3.6 m/s to 6.1 m/s, according to the classification of wind power in Table 16 falls in between 1 to 2 (poor to marginal) and that is suitable for tiny wind turbines couple of 10 kW. At 50 m elevation, the wind speed ranges from 4.6 m/s to 7.7 m/s which falls between 1 to 5 (poor to excellent) and that is suitable for a couple of 100 kW to MW. At 80 m and higher, the range of the wind speed from 4.9 m/s to 8.3 m/s, with over than 9 m/s for 160 m, falls in between 1 to 6 (poor to outstanding) makes it very suitable for multiple MW turbines to harvest more power at a utility-scale.

The reason to calculate more than 120 m elevations is that some wind turbine manufacturers reached higher elevation to harvest more wind for more power output as Siemens, Vestas, GE, Enercon, and Nordex. Table 16 illustrates the class quality corresponding to wind speed and wind power density (WPD) [31][5]. It is a very useful tool to know the status of WPD for deciding the proper wind elevation and corresponding wind turbines for ultimate efficiency.

Table 16: Wind power classes at 50 m height.

Class Quality	Wind Speed (m/s)	Wind Power Density (W/m2)
1 (Poor)	0 - 5.6	0 - 200
2 (Marginal)	5.6 - 6.4	200 - 300
3 (Fair)	6.4 - 7.0	300 - 400
4 (Good)	7.0 - 7.5	400 - 500
5 (Excellent)	7.5 - 8.0	500 - 600
6 (outstanding)	8.0 - 8.8	600 - 800
7 (Superb)	> 8.8	> 800

WPD is a quantitative measure of the available wind energy and is calculated by the average available power per square meter annually of the surveyed area of the turbine and varies with different heights. Wind density is influenced by two factors directly: wind speed and air density [32].

Table 17: The monthly and annual average WPD (W/m^2) for eight marine locations at 10 m elevation for 2008.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
2008	Beacon M28	205.4	213.5	158.7	98.5	106.6	239.0	123.5	98.8	171.6	138.2	142.8	91.6	143.5
	Sea Island Buoy	164.5	180.0	97.3	57.8	62.4	229.3	0.0	60.0	135.1	151.1	176.1	198.1	125.9
	Ahmadi Oil Pier	130.2	206.2	143.7	113.6	118.2	442.1	182.6	105.9	154.9	134.4	136.8	160.2	158.9
	Beacon N6	106.6	183.5	152.8	127.8	134.1	330.8	179.3	96.4	146.5	111.5	103.1	122.2	143.5
	Juliaa Port	133.3	199.8	155.5	98.3	115.3	265.5	131.7	92.8	144.8	135.2	147.7	165.7	144.4
	Salmiya	78.4	112.6	77.1	44.9	45.1	94.8	51.0	42.7	74.5	63.1	53.7	76.5	66.1
	South Dolphin	145.7	218.6	138.7	131.8	102.5	274.3	139.3	86.5	138.5	149.4	151.3	170.7	149.0
	Umm Almaradim	220.4	282.1	165.7	87.1	106.1	173.5	74.7	81.6	150.4	186.2	285.6	306.2	163.9

The formula used to calculate the wind power density is:

$$P_{\text{avg}}/A = \frac{1}{2}\rho\left(v^3\right)_{\text{avg}}$$

where P_{avg} is the average power, ρ is the wind density of 1.225 kg/m^3, and v_{avg}^3 is the average wind speed cubed. Similarly to wind speed, Table 17 illustrates the monthly and annual average wind power density in W/m^2 at 10 m height for 2008 and years 2009 – 2014 as seen in Appendix B. Starting with the highest annual average wind density recorded occurred in Umm Almaradim Island with 182.4 W/m^2 followed by South Dolphin with 145.4 W/m^2 then Beacon N6 and Ahmadi Oil Pier with 134.9 W/m^2. Juliaa Port has recorded 116.8 W/m^2 then Sea Island Buoy with 111.3 W/m^2 after that, the wind density of Salmiya is 104.2 W/m^2 and the least went for Beacon M28 with an average wind density of 94.2 W/m^2. Noted here that the wind density starts passing 1000 W/m^2 from 80 m and above.

Temperatures and wind speed correlation

An evaluation was made to know the relation between temperature and wind speed during the summer and winter seasons, as well as the correlation between the eight locations based on the effect of wind movement between them.

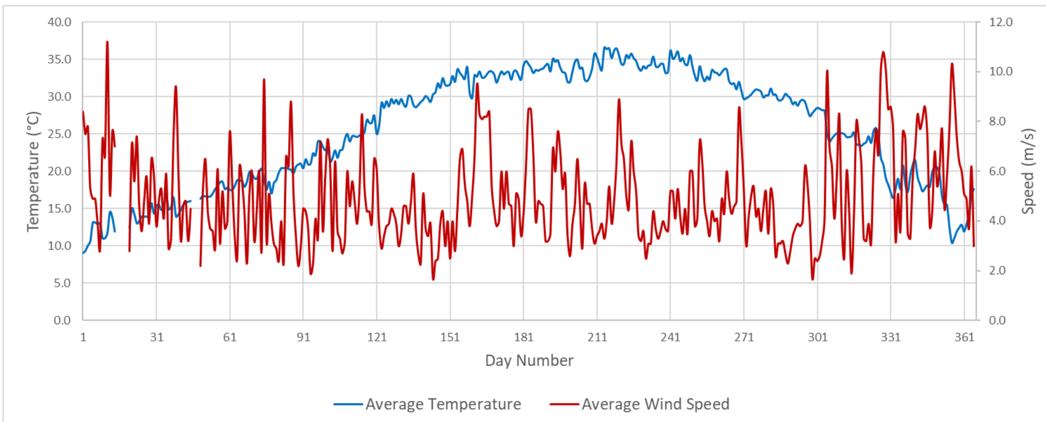

Figure 20: Temperature versus wind speed during a year for Beacon M28 location.

Usually on land in Kuwait, in the summer season during the day when the temperature is high, it raises the wind speed in parallel, and when the night comes, the wind slows down. What happened in some of these locations is the opposite case and it might be because they are marine locations. Fig. 20 demonstrates the average temperature versus average wind speed in the whole year of Beacon M28 and for other locations as seen in Appendix C. It shows that the wind speed is slightly higher during the winter season where the temperatures are low, which makes the wind blows in the whole year, similarly, are Sea Island Buoy, Juliaa Port, and Salmiya with small variations. Ahmadi Oil Pier, Beacon N6, and South Dolphin are windy during the summer season with a considerable amount in the winter for the South Dolphin location. The final location is Umm Almaradim Island which is windy during the winter season and low wind speed during the summer season.

Wind correlation analysis has been evaluated and what found is all locations are correlated to each other to some degree. Ahmadi Oil Pier, Sea Island Buoy, Juliaa Port, and Umm Almaradim Island locations are found to be highly correlated, whereas Beacon N6, South Dolphin, and Salmiya location are found to be correlated most of the time. Beacon M28, Beacon N6, and Umm Almaradim Island locations found to be partially correlated. Most of the distances within a few tens of kilometers range, so the result is not abnormal while in the long distances the correlation will be different. A similar evaluation has been done for the temperatures, as shown in Fig. 18, that all locations have a strong correlation.

Weibull Distribution

To estimate the wind speed of each location, Weibull distribution has been used. The Weibull formula used is:

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

Where *k* is shape parameter, *c* is the scale parameter, which controls the width of the curve, and *v* is the wind speed. For *k* = 1, the wind is mostly at the slow speed, and the curve takes the shape of exponential decay, which means the location is not good for wind turbines. For *k* = 2, the wind blows at relatively steady speed, and in some periods, blows faster and slower, the curve takes the shape of a wide bell shape. For *k* = 3, the wind blows in high rate speed most of the time, and the curve shape takes the narrow bell shape as seen in Fig. 21 [6].

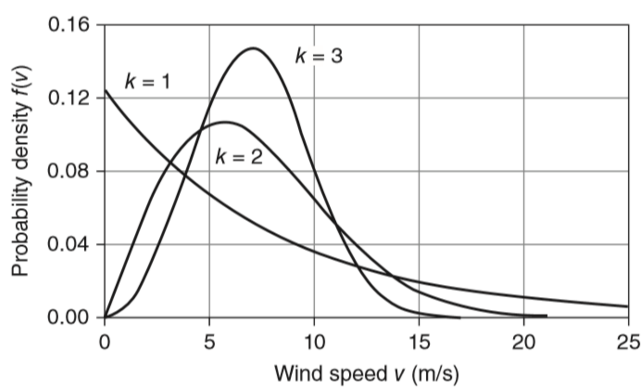

Figure 21: Weibull probability density function with shape parameter k = 1, 2, and 3.

Fig. 22 demonstrates the measured wind speed in comparison with Weibull pdf, in addition to cumulative Weibull for Beacon M28 location for seven years of the period 2007 – 2014 and for the other locations, as seen in Appendix C.

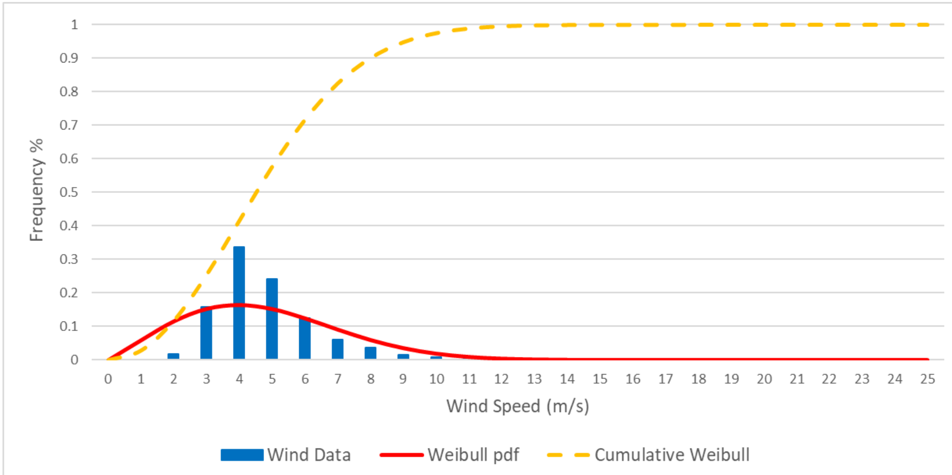

Figure 22: Measured wind speed and Weibull distribution of Beacon M28 location.

Unfortunately, all Weibull pdf does not match the wind speed data, and that is because the wind speed is a daily basis, only one reading per day. At least a sample per hour or more would be great to make a good match to the Weibull pdf. The parameters of Weibull distribution shape and scale for each location including annual wind power density, have been shown in Table 18. The shape parameter *k* is varied between 1.95 to 3.0 and scale parameter *c* is varied between 4.757 to 5.798.

Table 18: Weibull distribution shape *k*, scale *c* parameters with corresponding WPD.

Station	*v* (m/s)	*k*	*c* (m/s)	Annual WPD (W/m^2)
Beacon M28	4.757	2.1	5.368	94.2
Sea Island Buoy	5.017	2.0	5.661	111.3
Ahmadi Oil Pier	5.173	2.05	5.837	124.7
Beacon N6	5.315	1.95	5.997	134.9
Juliaa Port	5.080	3.0	5.732	116.8
Salmiya	4.802	2.1	5.418	104.2
South Dolphin	5.432	2.0	6.129	145.4
Umm Almaradim	5.798	2.0	6.542	182.4

The shape *k* parameter values are reasonable except for Juliaa Port, which is 3.0, appears from the wind analysis section that it is windy all year but not high rate and constant, and that is due to the low sampling rate. The Kuwait map is taken from the Google

Maps website, which shows that the Arabian Gulf is located on the eastern side and is the only place to build marine wind farms all the way from north to south shown in Fig. 23.

The red squares represent the wind farm areas as a spatial approximation, the black lines are underwater (submarine) cables, and the brown squares are a backup system that consists of massive batteries to recover energy in the event of power loss. Shaqaya Renewable Energy Park is the only clean power station in the country to the west. This is a rough outline of what will be built in the future for wind farms, including the rapid response system. It also appears that most of the locations are located near residential areas, other than Shaqaya renewable park, and this is an advantage.

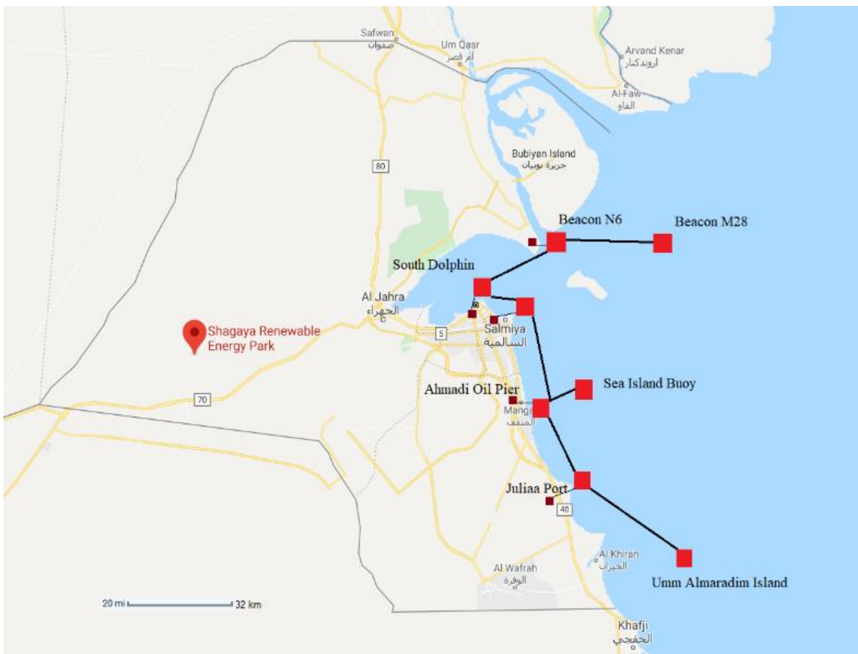

Figure 23: All eight marine locations including Shagaya renewable park.

Wind Turbines

Wind turbine manufacturers around the world are many, and it was difficult to find manufacturers that make offshore turbines as the percentage of offshore turbine manufacturers compared to onshore is very low. The best offshore turbine manufacturers in the world were chosen because they have long experience and also, for the high quality of their products. Table 19 contains six offshore turbine sizes, and the reason for choosing six turbines is to give a wide range of options to the appropriate turbine installations for each location to produce better energy compared to its costs [33]. Nordex is a German company with two turbines, and Vestas is a Danish company with four turbines. All turbines in the table were chosen to be offshore turbines to meet the required specifications. The size of the turbines started from 2.3 MW to 4.2 MW, where these sizes were chosen to be close to the sizes in the Shaqaya renewable park which consists of five 2 MW. Vestas V112/3000, Vestas V112/3300, and MHI Vestas V117/4200 turbines start producing power from 3 m/s while the rest starts from 4 m/s. The V112/3000 turbine reaches its rated capacity at 12 m/s while the others reach either 13 m/s or 14 m/s.

After analysis of the wind bins and their corresponding of Weibull pdf and hours per years, also the power and energy for each wind turbine brand and size for all stations, the results were obtained. The annual energy production for 2.3 MW turbines is the lowest and increasing gradually until 4.2 MW, which is the highest. The interesting thing here is 3.45 MW turbine is not the second-highest annual energy after 4.2 MW turbine, but it falls in the fourth place after 3.3 MW and 3.0 MW turbines. According to the energy curves in Table 19, a 3.45 MW turbine exceeds the 3.0 MW turbine and 3.3 MW when the wind speed reaches 10 m/s and more, which makes it retreat behind them, especially in these eight locations, while in other locations with higher wind speeds, it will make the energy production higher.

Table 19: Power of the six sizes of offshore wind turbines from Nordex, Vestas, and MHI Vestas manufacturers with their corresponding of wind bins.

Brand & Type	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Power (kW)	2300	2500	3000	3300	3450	4200
Diameter (m)	90	90	112	112	112	117
Swept Area (m^2)	6362	6362	9852	9852	9852	10751
Wind Speed (m/s)						
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	19	22	0	70
4	35	62	122	134	42	197
5	175	188	303	302	144	394
6	352	363	554	552	380	742
7	580	599	953	906	736	1160
8	870	912	1375	1370	1226	1693
9	1237	1299	1955	1950	1894	2343
10	1623	1744	2498	2586	2719	3073
11	2012	2149	2936	3071	3306	3793
12	2230	2389	3000	3266	3442	4175
13	2300	2492	3000	3298	3450	4200
14	2300	2500	3000	3300	3450	4200
15	2300	2500	3000	3300	3450	4200
16	2300	2500	3000	3300	3450	4200
17	2300	2500	3000	3300	3450	4200
18	2300	2500	3000	3300	3450	4200
19	2300	2500	3000	3300	3450	4200
20	2300	2500	3000	3300	3450	4200
21	2300	2500	3000	3300	3450	4200
22	2300	2500	3000	3300	3450	4200
23	2300	2500	3000	3300	3450	4200
24	2300	2500	3000	3300	3450	4200
25	2300	2500	3000	3300	3450	4200

The highest average annual energy produced found to be related to Umm Almaradim Island with about 4.5 MWh/yr to about 9 MWh/yr followed by South Dolphin with about 4 MWh/yr to about 8 MWh/yr and then Beacon N6 with about 3.7 MWh/yr to about 7.4 MWh/yr. The lowest average locations are Beacon M28 and Juliaa Port with about 2.5 MWh/yr to about 5.3 MWh/yr. To this extent, the picture is not complete because choosing a wind turbine according to the total annual energy production is a wrong approach, there is an essential factor more important which is the economic factor. That important factor determines the cost of energy at which the turbine is chosen which is best for the specified location.

Table 20 is the most important table which have great details to determine for the best wind turbines according to the economic factor; for other locations, see Appendix D. Table 20 shows the average power and average energy with related efficiency and capacity factor in addition to the installation cost, total annual energy produced, and levelized variable cost (LVC) to resolve for the levelized cost of energy (LCOE).

Table 20: Electric details including the LCOE for six wind turbines of Beacon M28 location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	801	801	1241	1241	1241	1354
Average Energy (kWh/yr)	7,017,323	7,017,323	10,867,321	10,867,321	10,867,321	11,859,276
Average Efficiency (%)	0.36	0.39	0.38	0.38	0.32	0.45
Capacity Factor (CF)	0.13	0.12	0.16	0.14	0.11	0.15
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	2557	2724	4160	4178	3438	5358
Levelized Variable Cost (LVC) $/MWh	25					
Levelized Cost of Energy (LCOE) $/MWh	94.45	95.82	85.34	91.08	108.95	90.58

The average power formula used is:

$$\bar{P} = \frac{6}{\pi} \cdot \left(\frac{1}{2} \rho A \bar{v}^3 \right)$$

where $\bar{P}$ is the average power in watt, ρ is the air density of 1.225 kg/m^3, A is the swept area of the blades in meters, and $\bar{v}$ is the average wind speed for the whole period in (m/s). The average energy is the multiplication of the hours in one year 8760 h/yr by the average power $\bar{P}$. Average efficiency is the total energy from all wind bins divided by the average energy. The capacity factor is the total energy from all wind bins divided by the multiplication of the rated power of the turbine by 8760 h/yr. The cost of the turbine is measured by $/MW. The annual energy is the total energy from all wind bins. The levelized variable cost (LVC) includes fuel, labor, and any variable operation and maintenance costs [34].

The levelized cost of energy (LCOE) is the cost of producing per unit energy in \$/MWh or \$/kWh. The formula used for LCOE is:

$$LCOE = \left(\frac{TIC \times r}{1-(1+r)^{-T}} \div Q \right) + LVC$$

where the total installed cost *TIC* in \$, *r* is the interest rate, *Q* is the total energy produced MWh/yr, *T* is the time in years, and *LVC* in \$/MWh or \$/kWh.

LCOE is an essential tool for comparing different types of wind turbines and their sizes to determine which is a better choice. The average power calculation is according to Rayleigh probability density where the shape parameter $k = 2$ and the reason to choose that value is that the wind speed in these locations is moderate. Most of the shape parameter is around the value of 2 in Table 18 but because of one sample per day which made it not quite exact.

The cost of Vestas turbines is \$0.753 million/MW [10] and \$0.695 million/MW for Nordex turbines [11]. Including 30% for the transportation to give it a reasonable price, the price increases to \$0.98 mil/MW for Vestas wind turbine and \$0.904 million/MW for Nordex because the number of turbines would be ordered in smaller quantities similar to Shagaya Renewable Park. The cheapest turbine is 2.3 MW at \$2,080,000 and the most expensive one is 4.2 MW at \$4,116,000 including transportation for both. LVC is \$15/MWh for the five shore locations, \$20/MWh for Sea Island Buoy location around 20 km of the shore, and two locations with \$25/MWh for Umm Almaradim Island located around 25 km and around 35 km for Beacon M28 of the shore. According to the average efficiency, the highest turbine is the MHI Vestas V117/4200 ranged between 37% in Juliaa

Port and 46% in Ahmadi Oil Pier and Beacon N6 while the lowest turbine is the Vestas V112/3450 ranged between 24% in Juliaa Port and 36% in Umm Almaradim Island. In terms of the capacity factor, the highest turbine is the Vestas V112/3000 ranged between 16% in Beacon M28, Juliaa Port, and Salmiya, and 27% in Umm Almaradim Island while the lowest turbine is the Vestas V112/3450 ranged between 10% in Juliaa Port and 22% in Umm Almaradim Island. These low capacity factors are due to low reading samples and must be around 40% similar to the wind turbines in Shagaya renewable park at least. The least LCOE among of these turbines is Vestas V112/3000 ranged from $55.28/MWh in South Dolphin to $85.34/MWh in Beacon M28 where the most expensive LCOE is Vestas V112/3450 ranged from $64.95/MWh in South Dolphin to $108.95/MWh in Beacon M28. The result declares the best turbine to choose for all locations is assigned for the Vestas V112/3000 with the lowest LCOE. Whereas, in terms of energy production, MHI Vestas V117/4200 produces more annual energy with about 28% more than Vestas V112/3000 with a slight difference in cost ranged from 5.26% to 7.05% more which encourages the decision makers to choose this size over others. It is believed that more samples would reduce the LCOE even more to be more realistic which results in fewer errors. The LCOE calculation reveals able to reveal that the biggest turbines are the not best choice as seen above, it depends on the location's wind speed. As an example, Vestas V112/3300 in Umm Almaradim is cheaper than MHI Vestas V117/4200 while in Juliaa Port, MHI Vestas V117/4200 is cheaper than Vestas V112/3300. The cost of offshore wind dropped 32% for the past year and dropped even more since the first half of 2019 for 12%. The drop since the first half of 2019 for onshore wind is 6% and solar for 12%. Worldwide, the prices for energy are $78/MWh for offshore wind, $47/MWh for onshore wind, and $51/MWh for solar. Massachusetts could reach the lowest offshore in the U.S. for $64/MWh for the Vineyard Wind project [35].

According to the data presented, there are three factors to decide the most favorable of these eight locations due to either wind density, energy production, or cost of energy. The economic factor is the most effective factor for any project. Table 21 illustrates the order of the eight locations affected by these factors. According to the wind density, usually the windy location is more favorable due to wind availability and what is shown is Umm Almaradim Island is the best location followed by South Dolphin then Beacon N6 all the way down to the least favorable location which is Beacon M28. For the energy production factor, the order is switched for the last four locations where the first four were the same as in the wind density factor. The cost of energy factor shows that South Dolphin is the best location followed by Umm Almaradim Island then Beacon N6 until the least favorable location related to Beacon M28.

Table 21: Locations order according to wind density, energy production, and LCOE factors.

No.	Wind Density W/m^2	Energy Production kWh/yr	LCOE $/MWh
1	Umm Almaradim Island	Umm Almaradim Island	South Dolphin
2	South Dolphin	South Dolphin	Umm Almaradim Island
3	Beacon N6	Beacon N6	Beacon N6
4	Ahmadi Oil Pier	Ahmadi Oil Pier	Ahmadi Oil Pier
5	Juliaa Port	Sea Island Buoy	Sea Island Buoy
6	Sea Island Buoy	Salmiya	Salmiya
7	Salmiya	Beacon M28	Juliaa Port
8	Beacon M28	Juliaa Port	Beacon M28

Offshore Wind Farms

Building offshore wind farms has many advantages, steady-state wind speed, less turbulence, less turbine noise, no need for land to occupy which is proper for small countries and very expensive lands, less environmental impact, more safety from direct engagement, and the temperature of offshore is lower than on land. The wave exceeds 1 m for only one month in a year. Also, the tides vary from 1.5 m to 4 m, and the maximum water speed between 0.5 to 1 m/s. So, the Kuwait environment is suitable to build offshore wind farms. There are many wind farm layouts [36][37][38], 5D × 10D is the common one that has been chosen as seen in Fig. 24 for 30 onshore wind turbines, where D is the diameter of the swept area of the turbine. As seen, the total area recommended for the onshore wind turbines is 65D × 40D including the buffer area surrounding the whole wind farm. The main purpose of the buffer area is to allow the wind to gain speed to be able to turn the turbine's blades. offshore wind farms do not need the buffer area because the sea is open in all directions which makes it advantageous over the onshore wind farms, and the total recommended area will then be 45D × 20D.

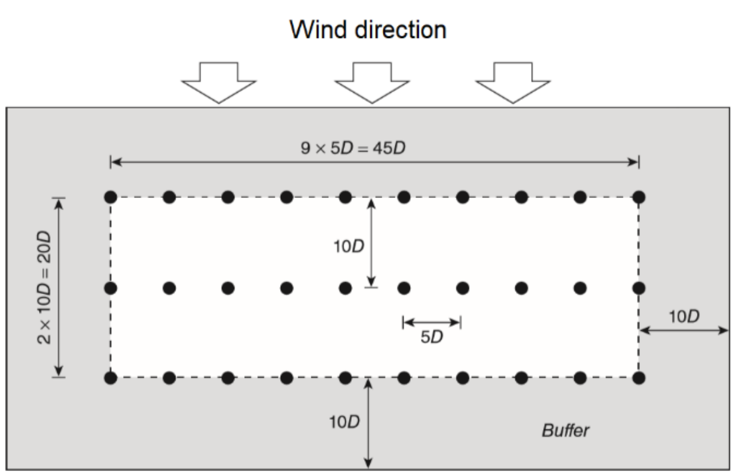

Figure 24: Onshore wind farm layout and size.

Calculating the area of the turbine, offshore and onshore for comparison, and their corresponding power density for all wind turbines assigned allow for a clear idea about the effect of the area occupied for these wind turbines, as demonstrated in Table 22.

Table 22: Comparison between offshore and onshore wind turbines for the six turbines.

		Offshore		Onshore	
No.	Turbine Type	Turbine Area km^2	Total Power Density MW/km^2	Turbine area with buffer zone km^2	Total Power Density MW/km^2
1	Nordex N90/2300	7.29	9.47	21.06	3.28
2	Nordex N90/2500	7.29	10.29	21.06	3.56
3	Vestas V112/3000	11.29	7.97	32.61	2.76
4	Vestas V112/3300	11.29	8.77	32.61	3.04
5	Vestas V112/3450	11.29	9.17	32.61	3.17
6	MHI Vestas V117/4200	12.32	10.23	35.59	3.54

The results show that the area occupied by the offshore turbines is 34.6% of the area occupied by the onshore turbines. The highest power density for offshore turbines goes for Nordex N90/2500 with 10.29 MW/km^2 and followed closely by MHI Vestas V117/4200 with 10.23 MW/km^2 then the lowest is Vestas V112/3000 with 7.97 MW/km^2. Similar to the onshore, the highest power density goes for Nordex N90/2500 with 3.56 MW/km^2 and followed nearly by MHI Vestas V117/4200 with 3.54 MW/km^2 then the lowest is Vestas V112/3000 with 2.76 MW/km^2. The total power density of the onshore turbines decreased due to the occupied area that includes the buffer zone, and this indicates that the buffer is very consuming for the land as it is neglected in the sea. For offshore turbines, Vestas V112/3000 has the least power density and the least cost of energy. In some locations, Vestas V112/3300 and MHI Vestas V117/4200 are interchangeably more favorable according to the LCOE but MHI Vestas V117/4200 has the highest power density of all of them. Vestas V112/3450 falls in the fourth place on the total power density and last position on the LCOE which makes it the least preferable. Vestas V112/3000 is the most preferable due to its lowest LCOE whereas MHI Vestas V117/4200 is the most preferable due to the balance between LCOE and power density compared to V112/3000.

To make a comparison between Vestas V112/3000 and MHI Vestas V117/4200 turbines, assume that all locations are ready for wind farms to decide the best choice. Installing thirty wind turbines of Vestas V112/3000 in all locations with a total of 240 turbines would give a power of 720 MW. In 2020, the conventional generation is 20,153 MW with Shagaya renewable park of 70 MW, the total generation combined is 20,943 MW where the renewable energy share is 3.77%. The similar calculation for MHI Vestas V117/4200 type with a total of 1,008 MW would increase the share of renewable energy to 5.08%. In 2022, the conventional generation will be 20,081 MW with Shagaya renewable park of 1,570 MW, the total generation combined will be 22,371 MW where the renewable energy share is 10.24% and for MHI Vestas V117/4200 type with a total of 1,008 MW would increase the share of the renewable energy to 11.38%. According to previous results, MHI Vestas V117/4200 is the best choice considering all aspects, annual generation, LCOE, power density, and higher renewable share percentage.

Land Limitation

Building cities around the country limits the chances to build renewable energy farms where the locations of the residential areas, at the present and in the future, scattered in the North, South, and mostly in the middle to the east where Kuwait City is as seen in Fig. 25. A parallel problem appeared which is the locations of the oil and gas fields all over Kuwait where they are so restricted to be nearby, shown in Fig. 26. Onshore wind farms have very limited locations, where west of Kuwait is the only option available now; besides, the wind speed is the highest in the west and that is advantageous. Obtaining building permits is another problem, as obtaining them is prolonged due to lack of land.

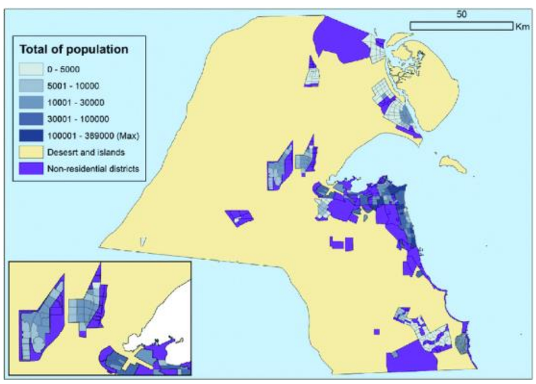

Figure 25: Residential and agricultural areas.

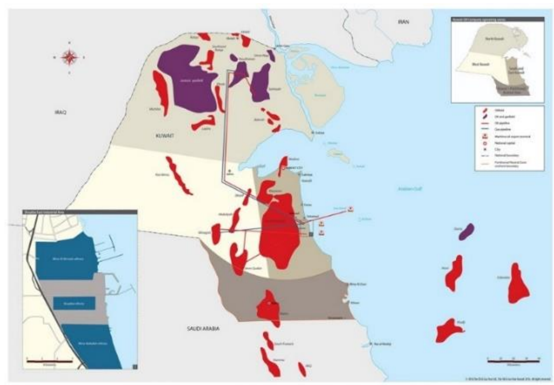
Figure 26: Oil and natural gas fields.

On the contrary, Kuwait possesses vast unexploited areas of the sea, which enables building offshore wind farms anywhere except near to the oil tankers located in Ahmadi port, and thus raising the proportion of renewable share production to the total production also does not need to reserve land for wind farms. The new technologies can make offshore wind farms a better choice for energy production by a continuous plummet in the price not to mention the size of some turbines which now exceeds 10 MW by some the world leaders' manufacturers as GE Haliade-X 12 MW and Siemens Gamesa 14 MW that allows harvesting energy even from locations with slower wind.

Battery Storage as Backup Power

The map of Kuwait in Fig. 23 shows the battery storage as backup power for better options in parallel with gas turbines. Kuwait has 2,800 MW of gas turbine in 2020 and will increase to 4,600 MW by 2028 and will be ready to be connected to the grid for at most 15 min; according to the MEW. The electricity data from 2009 to 2019 found that the highest ramp-up happened twice for 1,450 MW, one on the second of September 2012 in one hour and the second one on the 27th of May 2015, where the generation dropped 1,010 MW and then jumped 1,450 MW in 2 hours. So, the amount of energy that gas turbines produce can cover these ramp-ups in case of occurrence. Table 23 pinpoints the ramp-ups' power on an hourly basis and their corresponding frequencies. Every year the ramp-ups frequency increase, the majority of the frequency in 2009 happened for 600 MW and lower and only twice above it, while in 2019 the majority happened for 900 MW and lower with only nine times above it. One of the best advantages of the backup battery is the ability to connect to the grid in a few seconds, 100 MW in 0.1 seconds in the U.K., which is way faster than the 15-min gas turbines [40]; also, they do not produce greenhouse gases as gas turbines do. We can use both systems for backing up; low outages can be covered by batteries and high outages can be covered by gas turbines. This hybrid storage system will reduce the dependence on gas turbines which results in reducing the fossil fuel emission on air. More than 96% of the ramp-ups happened in the range of 500 MW and less in 2018, so using the backup batteries will result in smoothing the load curve [39]. In December 2017, Australia built the Hornsdale power reserve with a capacity of 100 MW/129 MWh with a cost of $0.5 mil/MW and they will increase its capacity to 150 MW/193.5 MWh in 2020 [41]. It is very useful to transfer this experience to Kuwait.

If the 500 MW ramp-ups are covered by the batteries and over that by the gas turbines, the Hornsdale power reserve can be used as an example to calculate the total cost of the backup batteries. The cost of energy varies; the longer the storage lasts, the lower the MWh cost because of the inverters and other hardware consumed due to the short period of the discharge phase [42].

Table 23: The annual frequency of the ramp-ups happened from 2009 to 2019.

MW	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
100	6491	6370	6379	6305	6285	6233	6260	6213	6230	6237	5595
200	1069	1091	983	956	988	989	907	886	852	877	758
300	720	728	763	765	723	691	726	703	638	645	536
400	367	417	403	443	456	464	431	460	467	435	383
500	100	128	175	206	213	270	272	280	299	264	277
600	10	22	45	74	71	84	124	167	159	181	183
700	1	3	9	8	19	23	31	42	68	88	94
800	0	0	2	1	2	4	6	7	30	23	46
900	1	0	0	0	2	1	1	1	13	7	14
1000	0	0	0	0	0	0	0	0	2	2	4
1100	0	0	0	0	0	0	0	0	0	0	4
1200	0	0	0	0	0	0	0	0	0	0	0
1300	0	0	0	0	0	0	0	0	1	0	1
1400	0	0	0	0	0	0	0	0	0	0	0
1500	0	0	0	1	0	0	1	0	0	0	0

Installing 100 MW battery system in each of the 5 locations on the map for a total of 500 MW with a total cost of $250 million = KD 78 million for the whole backup batteries according to the first half of 2018 prices. Fluence battery manufacturer has the ability to dump 500 MW on the grid as low as 20 minutes; also, their battery life is up to 25 years. Greg Perkins et al assumed that half of the original storage capacity is replaced after 10 years [43]. Pacific Gas and Electric Company (PG&E) in California recently got approved for four storage battery projects will be built on or near Moss Landing Power Plant by the

end of 2020 with a total capacity of 567.5 MW/2270 MWh supplied by Tesla, Vistra/Dynegy, Hummingbird Energy Storage LLC, and Micronoc Inc. [41][44]. The Manatee Energy Storage Center storage battery project for Florida Power and Light Co. (FPL) will be built in 2021 is with a capacity of 409 MW/900 MWh, which is considered the largest storage battery in the world supplied by NexEra Energy Inc. [41].

CHAPTER 4

CONCLUSION AND RECOMMENDATIONS

Conclusion

The world is trying hard to reduce the consumption of depleted fossil fuels, especially in energy production because it is the main source of carbon dioxide emissions, nitrogen oxide, and sulfur oxide, leading to global warming and its accompanying consequences. The goal of Kuwait Vision 2035, following up on the Kyoto Protocol, is to reduce dependence on fossil fuel sources as much as possible to make production capacity from permanent and clean sources to 15% of the total energy produced by 2030. Due to the increase in population, Kuwait is planning to build two additional conventional power stations to the existing eight to make a total of ten with a capacity of 26,981 MW and a renewable capacity of 1,570 MW representing 5.61% of the total generation by 2025. This percentage considered very low compared to the possibilities that Kuwait has. By 2030, the total generation will be 33,981 MW where renewable energy consists of 9.03% of which 3,070 MW and still far from the stated goal. The increase in the consumption of natural gas is not surprising, due to the increase in the installation of additional new gas turbines for the current fleet, and as a result, the consumption of the other types of fuel is reduced, except for heavy oil, as it will continue at the same pace. Average temperatures in all eight locations are between the lowest of 15°C and the highest of less than 40°C. Wind density at altitudes of 80 m and above is very suitable for energy production on a utility-scale as some locations reach more than 1000 W/m^2. The results indicated that there is a somewhat correlation between these locations due to the short distances where they are affected by each other due to the change of wind speeds. Onshore wind farms are only limited in western Kuwait due to residential areas and oil and gas fields that cover most of Kuwait's land, which made them far from populated areas, located mostly on the east, while offshore farms located near the populated areas are more beneficial. Because the coastline of Kuwait is about 494 km and a water area of about 7,611 km^2, with a maximum depth reaches 30 m, makes it an ideal place to build offshore wind farms besides that transferring energy is very advantageous because of the small area of Kuwait. Six wind turbines were selected for evaluation from well-known manufacturing companies to reach the best results, on which the optimal decision is taken. The results showed that the Vestas V112/3000 turbine is the least LCOE followed by MHI Vestas V117/4200, while Vestas V112/3450 turbine is the costliest. A comparison has been done to differentiate between the first and the second turbines and found that MHI Vestas V117/4200 is the ideal option for all locations, according to the balance between energy cost and the annual energy production. The least expensive location found to be is South Dolphin, followed by Umm Almaradim Island, while Beacon M28 is the most expensive. The combination between gas turbines and backup batteries is an ideal solution to cover any ramp-ups where batteries are for low ramp-ups. The rest can be covered by the gas turbines because it was found that over 96% of the frequency of the ramp-ups was 500 MW and less in 2018, and it is increasing every year due to increase in energy production. Hornsdale Energy Reserve, Moss Landing Power Plant, and the Manatee Energy Storage Center storage battery projects are replacing the peaker power stations, which is a strong proof that some countries around the world are serious about transferring from fossil fuel to clean energy therefore, it is useful transferring this experience to Kuwait because it is an ideal solution for rapid response to increase the reliability of the system. Kuwait provides significant subsidies for electricity, water, and fuel for power stations and also for transportation. According to the ministry of finance report of the fiscal year 2019/2020, the subsidy for electricity, water, and power stations fuel reached more than 1.5 billion KD which equivalent to more than $4.92 billion [45]. Sadly, the subsidy data for transportation fuel is not available and according to the Ministry of Interior, the number of registered cars in Kuwait is more than two million in 2017. The expenses incurred by Kuwait are very large and that can be saved in the case of relying on renewable energy especially offshore and the savings can be directed to beneficial projects.

Recommendations

Three actionable recommendations will benefit the Kuwaiti electric grid, which increases its reliability and dependability. The first recommendation is the speedup in starting of the construction of offshore wind farms in the eight locations immediately to generate clean energy and raise its share to the total energy generated to achieve the Kuwait vision 2035. Also, it can avoid, or at least postpone, the construction of the two conventional power stations that help reduce the consumption of fossil fuels, especially imported natural gas because domestic supply is insufficient. Vestas V112/3000 turbine is the cheapest in terms of LCOE, whereas the MHI Vestas V117/4200 turbine is better in terms of annual energy productivity with about 28% more than V112/3000 turbine with a slight difference in cost with no more than 7.05% at most, which makes MHI Vestas V117/4200 turbine the best choice, in addition, helping to reach the specific goal faster.

Beginning with only eight turbines in a configuration of two rows in each location for evaluation similar to Shagaya renewable park, we will then increase them to 50 turbines for production with a total of 400 turbines, and as a result, it will raise the renewable share to 7.99% in 2020 and 13.93% in 2022 because of the additional PV, which is very close to the desired goal. Building the new two conventional power stations will delay reaching the desired goal and it may not be reached because the capacity of both is 5,400 MW. The second recommendation is to build backup batteries in parallel with gas turbines and use them to overcome all ramp-ups. Due to the rapid response that characterizes the batteries, it can initially enter the grid to cover the beginning of the ramp-ups which is up to 500 MW and then followed by gas turbines for higher ramping. Also, the gas turbines can be used as spinning reserve. The third recommendation, which is the most important and has a direct and significant impact on the previous recommendations, is to raise the electricity tariff in parallel with reducing subsidies gradually to urge consumers to reduce their consumption. The results showed that there has been an increase in per capita consumption since 1996, and this indicates that consumers are taking advantage of low tariff which is supported by high subsidy to increase their unjustified consumption. Another consequence of consumption reduction is there will be an abundance in energy and hence the urgent need to build power stations will diminish, which will reflect on the stability of the network and lessen the sharpening of the ramps.

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APPENDIX A

LOAD CURVES

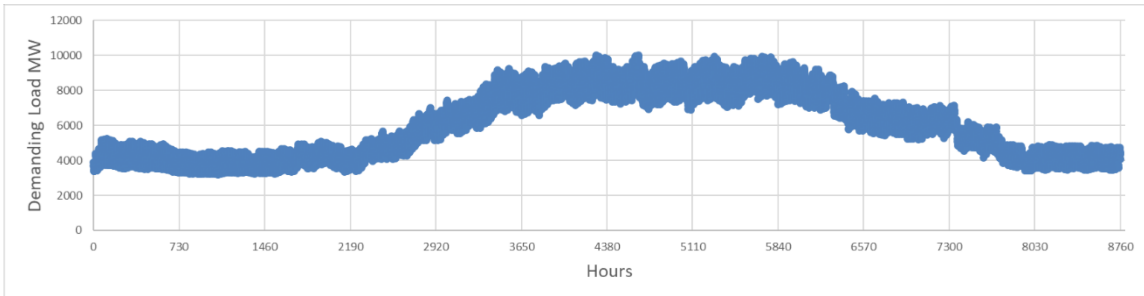

Figure A.1: Load curve for 2009.

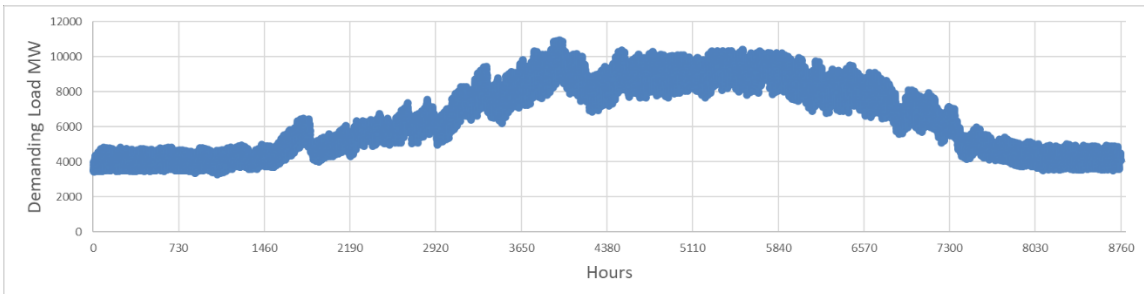

Figure A.2: Load curve for 2010.

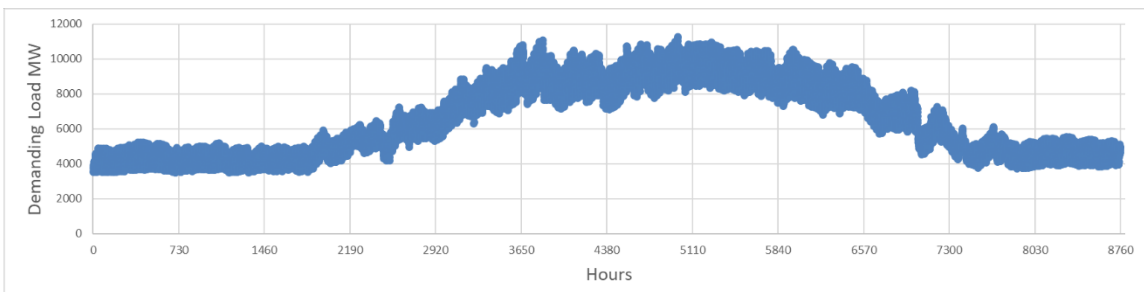

Figure A.3: Load curve for 2011.

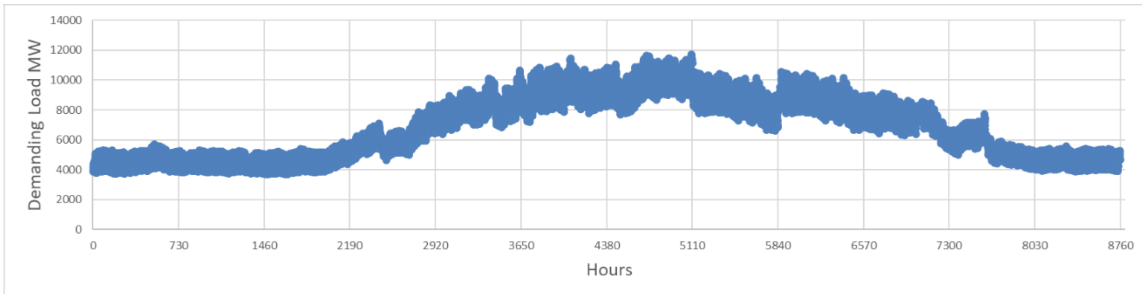

Figure A.4: Load curve for 2012.

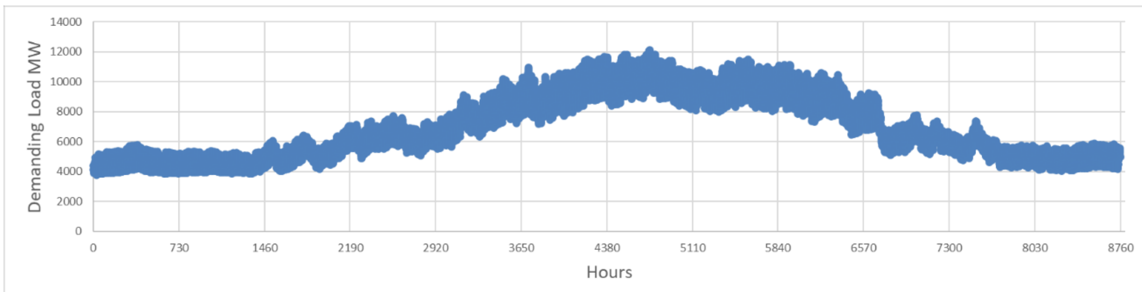

Figure A.5: Load curve for 2013.

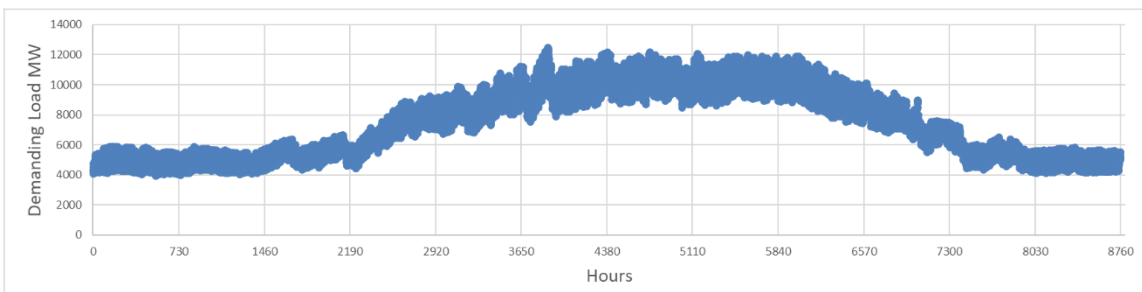

Figure A.6: Load curve for 2014.

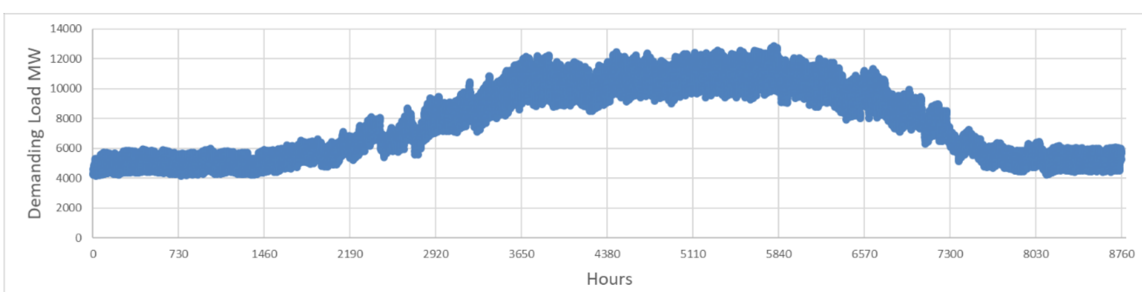

Figure A.7: Load curve for 2015.

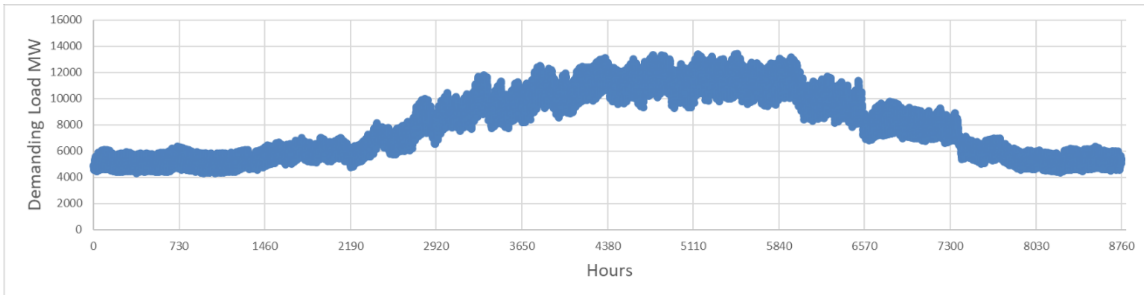

Figure A.8: Load curve for 2016.

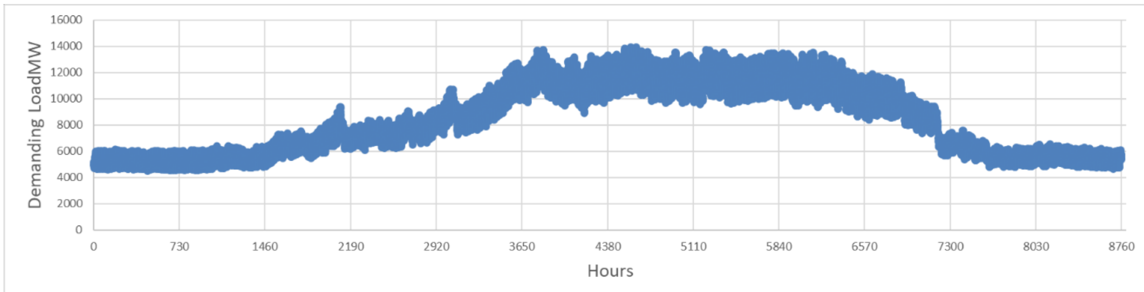

Figure A.9: Load curve for 2018.

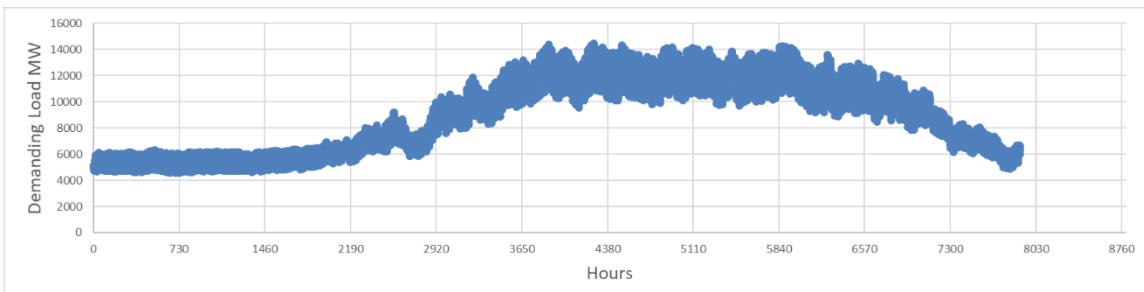

Figure A.10: Load curve for 2019.

APPENDIX B

TEMPERATURE, WIND SPEED AND DENSITY AT ELEVATIONS 50M-160M

Table B.1: The monthly and annual average temperatures for eight marine locations from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	13.1	16.6	18.9	22.4	28.9	33.3	34.2	33.9	32.3	28.8	22.9	18.3	25.3
	Sea Island Buoy	13.8	16.8	18.7	22.1	28.4	32.8	34.3	34.2	32.8	29.3	23.4	19.0	25.5
	Ahmadi Oil Pier	13.2	17.4	19.7	23.5	31.3	36.2	38.5	37.1	34.2	29.8	22.8	18.2	26.8
2009	Beacon N6	11.6	16.4	18.8	22.8	30.1	33.9	35.5	34.8	32.0	27.9	21.5	16.8	25.2
	Juliaa Port	12.8	16.9	18.9	22.7	29.8	34.4	36.2	35.5	33.1	28.9	22.8	18.2	25.9
	Salmiya	13.3	17.0	19.5	23.3	30.7	35.5	36.9	35.9	33.4	29.7	22.7	18.1	26.3
	South Dolphin	12.7	16.8	19.3	23.3	30.3	34.6	35.1	34.8	32.8	28.9	22.3	17.7	25.7
	Umm Almaradim	15.1	18.1	19.1	22.2	28.4	33.3	34.7	34.7	33.2	29.6	24.2	19.6	26.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	17.5	17.5	20.9	24.7	29.2	33.0	34.1	35.0	33.7	29.6	23.1	18.2	26.4
	Sea Island Buoy	17.8	17.7	21.1	24.4	29.0	33.4	34.3	34.9	34.8	29.3	24.2	19.4	26.7
	Ahmadi Oil Pier	17.2	18.1	22.4	26.1	31.5	36.9	37.7	36.3	35.5	31.0	23.6	18.4	27.9
2010	Beacon N6	16.9	16.9	21.2	25.3	30.3	34.9	35.1	35.4	33.5	29.1	21.6	16.4	26.4
	Juliaa Port	17.3	17.8	21.7	25.4	30.4	35.2	36.0	35.3	34.1	29.7	22.2	17.4	26.9
	Salmiya	17.2	17.7	21.9	25.7	30.9	35.8	36.2	36.4	35.2	30.6	23.4	18.3	27.4
	South Dolphin	17.0	17.6	21.9	25.8	30.5	34.8	35.4	36.2	34.4	30.0	22.7	17.7	27.0
	Umm Almaradim	18.4	18.3	21.2	24.3	28.9	33.3	34.5	35.0	34.5	31.0	25.0	20.1	27.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	15.1	15.4	18.6	23.3	29.0	33.1	33.9	34.7	32.9	27.8	20.0	14.9	24.9
	Sea Island Buoy	15.7	15.8	19.1	23.3	29.0	33.1	34.0	35.1	33.7	28.5	21.1	15.8	25.4
	Ahmadi Oil Pier	15.1	15.9	19.9	25.0	31.5	37.4	37.5	37.7	35.4	28.5	19.8	15.0	26.6
2011	Beacon N6	13.7	14.8	18.8	24.2	30.4	34.9	35.3	35.4	32.8	26.7	18.3	13.0	24.9
	Juliaa Port	15.0	15.5	18.9	23.9	30.1	35.0	35.3	35.7	33.5	27.8	19.7	14.1	25.4
	Salmiya	15.0	15.7	19.6	24.5	30.8	35.9	36.6	36.7	34.4	28.5	19.8	14.9	26.0
	South Dolphin	14.6	15.3	19.1	24.3	30.2	34.5	35.4	36.0	33.6	28.1	19.4	14.3	25.4
	Umm Almaradim	16.7	16.7	19.2	23.0	28.8	33.4	34.3	35.3	34.1	29.3	21.7	16.8	25.8

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	14.5	14.8	16.9	23.0	29.5	32.6	34.5	35.1	32.4	29.8	22.9	17.7	25.3
	Sea Island Buoy	15.0	15.2	17.0	22.9	29.1	32.4	34.3	35.2	33.7	0.0	0.0	17.8	25.1
	Ahmadi Oil Pier	14.5	15.3	18.2	24.8	31.7	36.9	38.0	38.3	34.9	30.3	23.1	17.7	27.0
2012	Beacon N6	13.0	14.2	17.0	24.1	30.5	34.2	35.5	36.0	32.5	28.8	21.6	16.3	25.3
	Juliaa Port	14.0	15.0	17.3	23.8	30.3	34.5	36.0	36.3	33.1	29.2	22.5	17.6	25.8
	Salmiya	14.2	15.0	17.7	24.3	30.9	35.4	36.8	36.9	34.1	30.1	23.0	17.5	26.3
	South Dolphin	14.0	14.8	17.5	24.4	31.0	34.3	36.0	36.1	33.3	29.7	22.6	17.3	25.9
	Umm Almaradim	16.1	16.0	17.4	22.7	28.9	32.9	34.8	35.6	33.7	30.7	24.4	19.3	26.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	15.5	17.3	20.1	24.0	28.1	31.8	33.9	34.0	32.3	26.4	22.1	15.9	25.1
	Sea Island Buoy	15.9	17.6	20.0	23.8	28.0	31.8	34.2	34.3	32.9	27.3	22.7	16.8	25.4
	Ahmadi Oil Pier	15.4	18.0	21.2	25.1	29.6	36.4	38.4	36.7	34.1	27.4	22.0	15.8	26.7
2013	Beacon N6	13.9	17.0	20.4	24.1	28.6	33.5	35.6	34.0	31.9	25.0	20.7	14.1	24.9
	Juliaa Port	14.9	17.3	20.2	24.2	28.6	33.9	35.9	34.7	32.4	26.3	21.9	15.5	25.5
	Salmiya	14.9	17.5	20.8	24.8	29.1	34.5	36.6	36.1	33.7	27.1	21.9	15.8	26.1
	South Dolphin	15.0	17.3	20.6	24.9	29.1	33.1	35.2	35.2	33.1	26.5	21.6	15.5	25.6
	Umm Almaradim	16.8	17.9	20.2	23.5	27.6	32.0	34.2	34.3	33.0	28.0	23.3	17.6	25.7

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	14.2	15.4	19.9	24.5	29.7	32.9	34.3	34.0	33.3	28.9	21.6	18.2	25.6
	Sea Island Buoy	14.7	15.7	19.9	24.3	28.9	0.0	34.7	34.1	33.7	29.5	22.4	18.9	24.8
	Ahmadi Oil Pier	14.3	15.8	20.6	26.1	31.6	36.3	38.0	36.5	35.2	29.8	21.5	18.1	27.0
2014	Beacon N6	13.0	14.8	20.1	25.1	30.4	33.8	35.4	34.6	33.1	27.8	19.7	16.6	25.4
	Juliaa Port	14.1	15.1	20.0	25.0	30.2	34.1	35.8	35.0	33.5	28.9	21.0	17.3	25.8
	Salmiya	14.0	15.7	20.5	25.6	31.1	35.3	36.8	35.9	34.7	29.3	21.5	18.0	26.5
	South Dolphin	13.9	15.4	20.5	25.5	30.8	34.2	35.4	35.1	34.0	29.0	21.1	17.6	26.0
	Umm Almaradim	15.7	16.1	19.9	24.0	29.0	32.8	34.5	34.4	34.0	30.1	23.1	19.4	26.1

Table B.2: The monthly and annual average wind speed (m/s) for eight locations at 10 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	4.1	4.5	4.3	3.9	3.9	4.0	4.1	4.3	4.3	4.1	4.8	4.2	4.2
	Sea Island Buoy	4.3	4.6	4.2	3.7	3.8	3.6	4.3	4.6	4.5	4.3	5.3	4.7	4.3
	Ahmadi Oil Pier	4.7	5.0	4.8	4.4	4.8	4.6	6.4	5.8	4.8	4.1	4.7	4.2	4.9
2009	Beacon N6	4.4	4.8	4.8	4.4	4.8	4.9	6.1	5.9	4.9	4.2	4.4	3.8	4.8
	Juliaa Port	4.9	5.1	4.8	4.4	4.5	4.3	5.1	4.9	4.3	4.1	4.8	4.5	4.6
	Salmiya	3.6	3.7	3.6	3.5	3.5	3.6	4.0	4.3	3.7	3.4	4.0	3.5	3.7
	South Dolphin	5.0	4.8	5.0	4.5	4.5	4.8	5.9	5.7	5.0	4.5	4.9	4.4	4.9
	Umm Almaradim	5.9	6.1	4.7	4.4	4.4	4.0	4.9	5.0	4.9	4.9	5.7	5.4	5.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	4.7	4.1	4.5	4.2	3.9	4.2	4.2	4.0	3.8	3.9	3.8	3.8	4.1
	Sea Island Buoy	5.2	4.2	4.6	4.0	3.8	4.2	4.3	3.7	4.4	4.3	4.7	4.7	4.4
	Ahmadi Oil Pier	4.5	4.1	4.6	4.3	4.4	5.2	5.6	3.6	4.2	4.2	3.8	4.0	4.4
2010	Beacon N6	5.0	4.1	5.0	4.7	4.9	5.5	5.3	4.0	4.2	4.3	4.1	4.0	4.6
	Juliaa Port	4.8	4.4	4.7	4.6	4.3	4.5	4.9	3.9	4.2	4.2	4.1	4.1	4.4
	Salmiya	4.5	3.5	4.0	3.8	3.4	3.9	3.9	3.4	3.4	3.5	3.0	3.3	3.6
	South Dolphin	5.6	4.4	5.1	4.9	4.6	5.3	5.4	4.0	4.4	4.6	4.3	4.5	4.8
	Umm Almaradim	6.2	5.9	6.0	5.0	5.3	5.9	6.1	5.1	5.7	6.3	6.9	6.7	5.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	4.4	4.3	4.4	4.9	3.8	4.3	3.9	3.9	3.9	4.7	4.8	4.0	4.3
	Sea Island Buoy	5.4	4.8	4.6	4.5	3.4	4.9	4.0	4.1	4.0	5.6	6.0	5.4	4.7
	Ahmadi Oil Pier	4.3	4.4	4.8	4.6	4.0	6.4	4.9	4.8	4.4	4.8	5.0	4.5	4.7
2011	Beacon N6	4.5	4.6	5.1	5.4	4.6	6.3	5.1	5.1	4.5	4.8	4.9	4.6	5.0
	Juliaa Port	4.8	4.5	4.5	5.0	4.1	5.4	4.5	4.2	3.8	5.1	5.4	4.4	4.6
	Salmiya	3.8	3.7	3.6	4.1	3.1	4.1	3.6	3.6	3.2	4.2	4.6	5.2	3.9
	South Dolphin	4.9	5.1	5.3	5.2	4.2	6.1	4.8	5.1	4.4	5.2	5.7	5.1	5.1
	Umm Almaradim	6.9	5.9	5.7	5.6	5.1	6.9	5.8	5.8	5.8	7.1	6.9	6.1	6.1

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	4.2	4.9	4.5	3.9	4.1	4.2	3.9	4.2	3.9	4.5	4.5	4.5	4.2
	Sea Island Buoy	4.8	5.3	4.8	3.5	3.6	4.4	3.8	4.6	4.4	0.0	0.0	5.2	4.4
	Ahmadi Oil Pier	4.2	4.9	4.7	3.9	4.1	5.8	4.8	5.6	4.6	4.3	4.5	4.4	4.7
2012	Beacon N6	4.3	5.4	5.4	4.4	4.5	5.9	5.0	5.6	4.7	4.3	4.6	4.3	4.9
	Juliaa Port	4.4	5.0	5.0	4.0	4.4	4.9	4.3	4.8	4.1	4.4	4.6	4.9	4.6
	Salmiya	4.8	5.4	5.7	5.0	5.3	6.5	6.1	6.0	5.3	5.5	4.8	4.8	5.4
	South Dolphin	4.5	5.8	5.5	4.6	4.3	5.8	5.0	5.7	4.7	4.8	5.0	4.8	5.0
	Umm Almaradim	5.7	6.4	6.0	4.0	4.5	4.7	4.1	4.6	4.5	5.3	5.6	5.9	5.1

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	4.4	4.0	4.6	4.3	4.3	4.5	4.0	3.7	4.0	4.0	4.6	4.9	4.3
	Sea Island Buoy	5.3	4.7	4.8	4.2	4.2	5.5	4.9	3.6	4.6	5.1	5.1	6.5	4.9
	Ahmadi Oil Pier	4.2	4.3	4.5	4.2	4.7	7.3	6.4	4.1	4.5	4.6	4.5	4.9	4.8
2013	Beacon N6	4.5	4.9	5.2	4.6	5.1	7.1	6.4	4.3	4.7	4.4	4.4	5.2	5.1
	Juliaa Port	4.6	4.5	5.0	4.4	4.6	6.0	5.1	3.9	4.2	4.6	4.9	5.6	4.8
	Salmiya	4.6	4.8	5.2	5.3	5.1	6.2	6.1	4.8	5.0	4.9	4.8	5.6	5.2
	South Dolphin	5.2	5.0	5.4	4.7	5.0	6.8	6.0	4.2	4.8	4.8	4.8	5.8	5.2
	Umm Almaradim	5.9	5.1	5.4	4.5	4.4	5.6	4.6	3.9	4.7	5.7	5.6	7.1	5.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	4.0	4.3	4.0	4.0	3.5	4.1	4.4	4.2	3.8	4.8	4.1	3.2	4.0
	Sea Island Buoy	4.5	4.9	4.2	3.9	3.5	0.0	4.6	4.4	4.1	4.9	5.1	4.8	4.5
	Ahmadi Oil Pier	4.0	4.5	4.0	4.0	4.0	5.6	6.0	5.0	4.2	4.4	4.3	4.1	4.5
2014	Beacon N6	4.0	5.0	4.6	4.5	4.4	5.9	5.9	5.3	4.7	4.5	4.2	4.3	4.8
	Juliaa Port	4.3	4.6	4.6	4.3	3.8	4.9	4.9	4.6	4.0	4.9	4.6	4.1	4.5
	Salmiya	4.1	4.8	4.4	4.7	4.7	5.7	5.6	5.7	4.7	4.7	4.4	4.1	4.8
	South Dolphin	4.5	5.4	4.9	4.5	4.4	5.6	5.7	5.2	4.6	4.4	4.7	4.7	4.9
	Umm Almaradim	5.4	5.3	4.8	4.4	3.7	4.5	4.6	4.6	4.3	5.5	5.7	5.2	4.8

Table B.3: The monthly and annual average wind speed (m/s) for eight locations at 50 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	7.0	7.1	6.5	5.5	5.7	7.4	5.9	5.5	6.6	6.2	6.2	5.4	6.3
	Sea Island Buoy	6.5	6.7	5.5	4.6	4.7	7.3	0.0	4.7	6.1	6.4	6.7	7.0	6.0
	Ahmadi Oil Pier	6.1	7.1	6.3	5.8	5.9	9.1	6.8	5.7	6.4	6.1	6.2	6.5	6.5
2008	Beacon N6	5.7	6.8	6.4	6.0	6.1	8.3	6.7	5.5	6.3	5.7	5.6	5.9	6.3
	Juliaa Port	6.1	7.0	6.4	5.5	5.8	7.7	6.1	5.4	6.3	6.1	6.3	6.6	6.3
	Salmiya	5.1	5.8	5.1	4.2	4.3	5.4	4.4	4.2	5.0	4.8	4.5	5.1	4.8
	South Dolphin	6.3	7.2	6.2	6.1	5.6	7.8	6.2	5.3	6.2	6.3	6.4	6.6	6.3
	Umm Almaradim	7.2	7.8	6.6	5.3	5.7	6.7	5.0	5.2	6.4	6.8	7.9	8.1	6.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.1	5.7	5.4	5.0	4.9	5.0	5.2	5.4	5.4	5.2	6.0	5.3	5.3
	Sea Island Buoy	5.5	5.8	5.3	4.7	4.7	4.5	5.4	5.8	5.6	5.4	6.6	6.0	5.4
	Ahmadi Oil Pier	5.9	6.3	6.0	5.6	6.0	5.8	8.0	7.2	6.0	5.2	5.9	5.3	6.1
2009	Beacon N6	5.6	6.0	6.1	5.5	6.1	6.1	7.7	7.4	6.1	5.3	5.6	4.8	6.0
	Juliaa Port	6.1	6.4	6.1	5.5	5.6	5.4	6.4	6.1	5.4	5.1	6.1	5.6	5.8
	Salmiya	4.5	4.7	4.6	4.4	4.4	4.5	5.0	5.4	4.6	4.3	5.1	4.4	4.6
	South Dolphin	6.3	6.1	6.2	5.7	5.7	6.0	7.4	7.2	6.3	5.6	6.2	5.5	6.2
	Umm Almaradim	7.4	7.7	6.0	5.5	5.6	5.0	6.1	6.3	6.2	6.2	7.1	6.8	6.3

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.9	5.1	5.6	5.3	5.0	5.3	5.3	5.0	4.8	4.9	4.8	4.8	5.2
	Sea Island Buoy	6.6	5.3	5.8	5.0	4.8	5.3	5.4	4.7	5.6	5.4	5.9	5.9	5.5
	Ahmadi Oil Pier	5.7	5.2	5.8	5.4	5.6	6.5	7.0	4.5	5.2	5.2	4.8	5.0	5.5
2010	Beacon N6	6.2	5.2	6.3	5.9	6.1	7.0	6.7	5.0	5.3	5.5	5.2	5.1	5.8
	Juliaa Port	6.1	5.5	6.0	5.7	5.5	5.7	6.1	4.9	5.3	5.3	5.1	5.2	5.5
	Salmiya	5.6	4.4	5.0	4.7	4.3	4.9	4.9	4.3	4.3	4.4	3.7	4.1	4.6
	South Dolphin	7.0	5.6	6.5	6.1	5.7	6.7	6.8	5.0	5.6	5.8	5.4	5.7	6.0
	Umm Almaradim	7.8	7.4	7.6	6.3	6.7	7.4	7.7	6.4	7.2	7.9	8.7	8.4	7.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.5	5.5	5.6	6.1	4.8	5.4	4.9	4.9	4.9	5.9	6.1	5.1	5.4
	Sea Island Buoy	6.8	6.1	5.8	5.7	4.3	6.1	5.1	5.2	5.1	7.0	7.6	6.8	6.0
	Ahmadi Oil Pier	5.4	5.5	6.0	5.8	5.1	8.1	6.2	6.0	5.5	6.0	6.3	5.6	6.0
2011	Beacon N6	5.6	5.8	6.5	6.8	5.8	7.9	6.5	6.4	5.7	6.0	6.2	5.8	6.2
	Juliaa Port	6.0	5.7	5.7	6.3	5.2	6.8	5.6	5.3	4.7	6.4	6.8	5.5	5.8
	Salmiya	4.8	4.6	4.6	5.2	3.9	5.1	4.5	4.5	4.0	5.2	5.8	6.5	4.9
	South Dolphin	6.2	6.5	6.6	6.6	5.3	7.6	6.0	6.4	5.5	6.6	7.2	6.5	6.4
	Umm Almaradim	8.7	7.4	7.2	7.1	6.4	8.7	7.2	7.3	7.2	8.9	8.6	7.7	7.7

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.2	6.1	5.6	4.9	5.1	5.2	4.9	5.2	4.8	5.6	5.6	5.7	5.3
	Sea Island Buoy	6.1	6.7	6.0	4.4	4.5	5.5	4.8	5.8	5.5	0.0	0.0	6.5	5.5
	Ahmadi Oil Pier	5.3	6.1	5.9	4.9	5.2	7.4	6.1	7.1	5.8	5.4	5.7	5.5	5.9
2012	Beacon N6	5.4	6.7	6.8	5.6	5.6	7.4	6.3	7.1	5.9	5.5	5.7	5.4	6.1
	Juliaa Port	5.6	6.2	6.3	5.0	5.5	6.2	5.4	6.1	5.2	5.6	5.8	6.1	5.7
	Salmiya	6.0	6.8	7.1	6.3	6.6	8.2	7.6	7.6	6.7	7.0	6.0	6.0	6.8
	South Dolphin	5.7	7.3	6.9	5.7	5.4	7.3	6.2	7.1	5.9	6.0	6.3	6.1	6.3
	Umm Almaradim	7.2	8.1	7.6	5.0	5.7	5.9	5.2	5.7	5.7	6.7	7.1	7.5	6.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.6	5.0	5.8	5.4	5.4	5.7	5.0	4.6	5.1	5.1	5.8	6.2	5.4
	Sea Island Buoy	6.7	5.9	6.1	5.3	5.2	6.9	6.1	4.5	5.8	6.5	6.4	8.2	6.1
	Ahmadi Oil Pier	5.2	5.4	5.7	5.3	5.9	9.2	8.1	5.1	5.6	5.8	5.7	6.2	6.1
2013	Beacon N6	5.7	6.1	6.5	5.8	6.4	8.9	8.0	5.4	5.9	5.5	5.6	6.5	6.4
	Juliaa Port	5.8	5.7	6.3	5.6	5.8	7.5	6.4	4.9	5.3	5.8	6.1	7.0	6.0
	Salmiya	5.8	6.1	6.5	6.7	6.4	7.8	7.6	6.0	6.3	6.2	6.0	7.0	6.5
	South Dolphin	6.5	6.3	6.8	5.9	6.3	8.5	7.6	5.3	6.0	6.0	6.0	7.3	6.6
	Umm Almaradim	7.4	6.4	6.8	5.6	5.6	7.0	5.8	4.9	5.9	7.1	7.0	8.9	6.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.0	5.3	5.0	5.0	4.4	5.1	5.6	5.3	4.8	6.0	5.1	4.0	5.1
	Sea Island Buoy	5.7	6.1	5.3	5.0	4.4	0.0	5.8	5.6	5.1	6.2	6.4	6.0	5.6
	Ahmadi Oil Pier	5.1	5.7	5.0	5.1	5.0	7.1	7.5	6.3	5.3	5.5	5.4	5.1	5.7
2014	Beacon N6	5.1	6.4	5.8	5.7	5.6	7.4	7.5	6.7	5.9	5.7	5.3	5.5	6.0
	Juliaa Port	5.4	5.8	5.8	5.4	4.8	6.1	6.1	5.8	5.0	6.1	5.8	5.2	5.6
	Salmiya	5.2	6.0	5.5	5.9	5.9	7.1	7.1	7.2	5.9	5.9	5.5	5.1	6.0
	South Dolphin	5.7	6.8	6.2	5.6	5.5	7.0	7.2	6.5	5.7	5.5	6.0	5.9	6.1
	Umm Almaradim	6.8	6.6	6.0	5.5	4.7	5.7	5.8	5.8	5.4	6.9	7.2	6.6	6.1

Table B.4: The monthly and annual average wind speed (m/s) for eight locations at 80 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	7.5	7.6	6.9	5.9	6.1	7.9	6.4	5.9	7.1	6.6	6.7	5.8	6.7
	Sea Island Buoy	7.0	7.2	5.9	4.9	5.1	7.8	0.0	5.0	6.6	6.8	7.2	7.4	6.4
	Ahmadi Oil Pier	6.5	7.5	6.7	6.2	6.3	9.7	7.2	6.0	6.9	6.5	6.6	6.9	6.9
2008	Beacon N6	6.1	7.3	6.8	6.4	6.5	8.8	7.2	5.9	6.7	6.1	6.0	6.3	6.7
	Juliaa Port	6.5	7.5	6.9	5.9	6.2	8.2	6.5	5.8	6.7	6.6	6.8	7.0	6.7
	Salmiya	5.5	6.2	5.4	4.5	4.5	5.8	4.7	4.5	5.4	5.1	4.8	5.4	5.2
	South Dolphin	6.7	7.7	6.6	6.5	6.0	8.3	6.6	5.6	6.6	6.8	6.8	7.1	6.8
	Umm Almaradim	7.7	8.4	7.0	5.7	6.0	7.1	5.4	5.5	6.8	7.3	8.4	8.6	7.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.5	6.1	5.8	5.3	5.2	5.4	5.6	5.8	5.8	5.6	6.5	5.7	5.7
	Sea Island Buoy	5.8	6.2	5.7	5.0	5.1	4.8	5.7	6.2	6.0	5.8	7.1	6.4	5.8
	Ahmadi Oil Pier	6.3	6.7	6.5	5.9	6.4	6.2	8.6	7.7	6.4	5.5	6.3	5.7	6.5
2009	Beacon N6	6.0	6.4	6.5	5.9	6.5	6.5	8.2	8.0	6.5	5.7	6.0	5.2	6.4
	Juliaa Port	6.6	6.9	6.5	5.9	6.0	5.8	6.8	6.6	5.8	5.5	6.5	6.0	6.2
	Salmiya	4.8	5.0	4.9	4.7	4.7	4.8	5.4	5.8	4.9	4.6	5.4	4.7	5.0
	South Dolphin	6.7	6.5	6.7	6.1	6.1	6.4	7.9	7.7	6.7	6.0	6.6	5.9	6.6
	Umm Almaradim	8.0	8.2	6.4	5.9	5.9	5.4	6.6	6.7	6.6	6.6	7.6	7.3	6.8

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.3	5.5	6.0	5.7	5.3	5.6	5.7	5.4	5.1	5.3	5.1	5.1	5.5
	Sea Island Buoy	7.0	5.7	6.2	5.4	5.1	5.6	5.8	5.0	6.0	5.7	6.3	6.3	5.9
	Ahmadi Oil Pier	6.1	5.6	6.2	5.7	6.0	7.0	7.5	4.8	5.6	5.6	5.1	5.3	5.9
2010	Beacon N6	6.7	5.6	6.7	6.3	6.6	7.5	7.2	5.4	5.6	5.8	5.5	5.4	6.2
	Juliaa Port	6.5	5.9	6.4	6.1	5.8	6.1	6.6	5.2	5.7	5.6	5.5	5.6	5.9
	Salmiya	6.0	4.7	5.3	5.1	4.6	5.3	5.3	4.6	4.6	4.7	4.0	4.4	4.9
	South Dolphin	7.5	5.9	6.9	6.5	6.1	7.1	7.2	5.4	6.0	6.2	5.8	6.1	6.4
	Umm Almaradim	8.3	8.0	8.1	6.7	7.2	7.9	8.3	6.8	7.7	8.5	9.3	9.0	8.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.9	5.8	5.9	6.5	5.1	5.8	5.2	5.3	5.2	6.3	6.5	5.4	5.8
	Sea Island Buoy	7.2	6.5	6.2	6.1	4.5	6.6	5.4	5.6	5.4	7.5	8.1	7.3	6.4
	Ahmadi Oil Pier	5.8	5.9	6.4	6.2	5.4	8.7	6.6	6.4	5.9	6.4	6.8	6.0	6.4
2011	Beacon N6	6.0	6.2	6.9	7.3	6.2	8.5	6.9	6.8	6.1	6.4	6.6	6.2	6.7
	Juliaa Port	6.4	6.1	6.0	6.7	5.5	7.3	6.0	5.6	5.1	6.8	7.3	5.9	6.2
	Salmiya	5.1	4.9	4.9	5.5	4.2	5.5	4.9	4.8	4.3	5.6	6.3	7.0	5.2
	South Dolphin	6.6	6.9	7.1	7.0	5.7	8.2	6.5	6.9	5.9	7.0	7.7	6.9	6.9
	Umm Almaradim	9.4	7.9	7.7	7.6	6.9	9.3	7.7	7.8	7.7	9.6	9.2	8.3	8.3

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.6	6.6	6.0	5.2	5.5	5.6	5.2	5.6	5.2	6.0	6.0	6.1	5.7
	Sea Island Buoy	6.5	7.2	6.5	4.7	4.9	5.9	5.2	6.2	5.9	0.0	0.0	7.0	5.9
	Ahmadi Oil Pier	5.6	6.5	6.3	5.2	5.6	7.9	6.5	7.6	6.2	5.8	6.1	5.9	6.3
2012	Beacon N6	5.7	7.2	7.3	6.0	6.0	7.9	6.7	7.6	6.3	5.8	6.1	5.8	6.5
	Juliaa Port	5.9	6.7	6.7	5.4	5.9	6.7	5.8	6.5	5.5	6.0	6.2	6.6	6.1
	Salmiya	6.4	7.2	7.6	6.8	7.1	8.8	8.2	8.1	7.2	7.5	6.4	6.4	7.3
	South Dolphin	6.1	7.8	7.4	6.1	5.8	7.8	6.7	7.6	6.3	6.4	6.7	6.5	6.8
	Umm Almaradim	7.7	8.7	8.1	5.4	6.1	6.3	5.5	6.1	6.1	7.1	7.6	8.0	6.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.9	5.3	6.2	5.8	5.8	6.0	5.4	4.9	5.4	5.4	6.2	6.6	5.8
	Sea Island Buoy	7.2	6.3	6.5	5.6	5.6	7.3	6.5	4.8	6.2	6.9	6.8	8.7	6.6
	Ahmadi Oil Pier	5.6	5.8	6.1	5.6	6.3	9.9	8.6	5.5	6.0	6.2	6.1	6.6	6.5
2013	Beacon N6	6.1	6.5	7.0	6.2	6.9	9.5	8.6	5.7	6.3	5.9	5.9	7.0	6.8
	Juliaa Port	6.2	6.1	6.8	5.9	6.2	8.0	6.8	5.2	5.6	6.2	6.5	7.5	6.4
	Salmiya	6.2	6.5	6.9	7.1	6.9	8.4	8.1	6.5	6.7	6.6	6.4	7.5	7.0
	South Dolphin	7.0	6.8	7.2	6.3	6.8	9.1	8.1	5.6	6.4	6.5	6.4	7.8	7.0
	Umm Almaradim	7.9	6.8	7.3	6.0	6.0	7.5	6.2	5.2	6.3	7.6	7.5	9.6	7.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.3	5.7	5.3	5.3	4.7	5.5	6.0	5.7	5.2	6.5	5.5	4.3	5.4
	Sea Island Buoy	6.0	6.6	5.7	5.3	4.7	0.0	6.2	6.0	5.5	6.7	6.9	6.4	6.0
	Ahmadi Oil Pier	5.4	6.1	5.4	5.4	5.4	7.6	8.1	6.8	5.7	5.9	5.8	5.5	6.1
2014	Beacon N6	5.4	6.8	6.2	6.1	5.9	7.9	8.0	7.2	6.3	6.1	5.7	5.8	6.5
	Juliaa Port	5.8	6.2	6.2	5.7	5.1	6.5	6.6	6.2	5.4	6.5	6.2	5.6	6.0
	Salmiya	5.5	6.5	5.9	6.3	6.3	7.6	7.5	7.7	6.3	6.3	5.9	5.5	6.4
	South Dolphin	6.1	7.3	6.6	6.0	5.9	7.5	7.7	7.0	6.1	5.9	6.4	6.3	6.6
	Umm Almaradim	7.3	7.1	6.4	5.9	5.0	6.1	6.2	6.2	5.8	7.4	7.7	7.0	6.5

Table B.5: The monthly and annual average wind speed (m/s) for eight locations at 100 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	7.8	7.9	7.1	6.1	6.3	8.2	6.6	6.1	7.3	6.8	6.9	5.9	6.9
	Sea Island Buoy	7.2	7.4	6.1	5.1	5.2	8.1	0.0	5.2	6.8	7.0	7.4	7.7	6.6
	Ahmadi Oil Pier	6.7	7.8	6.9	6.4	6.5	10.0	7.5	6.2	7.1	6.8	6.8	7.2	7.1
2008	Beacon N6	6.3	7.5	7.1	6.6	6.8	9.1	7.4	6.0	7.0	6.3	6.2	6.5	6.9
	Juliaa Port	6.7	7.7	7.1	6.1	6.4	8.5	6.7	6.0	6.9	6.8	7.0	7.2	6.9
	Salmiya	5.6	6.4	5.6	4.7	4.7	6.0	4.9	4.6	5.5	5.2	5.0	5.6	5.3
	South Dolphin	6.9	7.9	6.8	6.7	6.2	8.6	6.8	5.8	6.8	7.0	7.0	7.3	7.0
	Umm Almaradim	8.0	8.6	7.2	5.8	6.2	7.4	5.6	5.7	7.0	7.5	8.7	8.9	7.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.7	6.3	6.0	5.5	5.4	5.5	5.8	6.0	6.0	5.8	6.7	5.9	5.9
	Sea Island Buoy	6.0	6.4	5.9	5.1	5.2	4.9	5.9	6.4	6.2	6.0	7.3	6.6	6.0
	Ahmadi Oil Pier	6.5	7.0	6.7	6.1	6.6	6.4	8.9	8.0	6.7	5.7	6.5	5.8	6.7
2009	Beacon N6	6.2	6.7	6.7	6.1	6.7	6.7	8.4	8.2	6.7	5.9	6.2	5.3	6.7
	Juliaa Port	6.8	7.1	6.7	6.1	6.2	5.9	7.1	6.8	6.0	5.7	6.7	6.2	6.4
	Salmiya	5.0	5.2	5.1	4.9	4.8	5.0	5.5	5.9	5.1	4.7	5.6	4.8	5.1
	South Dolphin	6.9	6.7	6.9	6.3	6.3	6.6	8.2	8.0	6.9	6.2	6.8	6.1	6.8
	Umm Almaradim	8.2	8.5	6.6	6.1	6.1	5.5	6.8	7.0	6.8	6.8	7.9	7.5	7.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.5	5.6	6.2	5.9	5.5	5.8	5.9	5.6	5.3	5.4	5.3	5.3	5.7
	Sea Island Buoy	7.3	5.9	6.4	5.6	5.3	5.8	6.0	5.2	6.2	5.9	6.5	6.5	6.1
	Ahmadi Oil Pier	6.3	5.7	6.4	5.9	6.2	7.2	7.7	5.0	5.8	5.8	5.3	5.5	6.1
2010	Beacon N6	6.9	5.8	6.9	6.5	6.8	7.7	7.4	5.6	5.8	6.0	5.7	5.6	6.4
	Juliaa Port	6.7	6.1	6.6	6.3	6.0	6.3	6.8	5.4	5.9	5.8	5.6	5.7	6.1
	Salmiya	6.2	4.9	5.5	5.2	4.8	5.4	5.4	4.7	4.7	4.8	4.1	4.6	5.0
	South Dolphin	7.7	6.1	7.1	6.7	6.3	7.4	7.5	5.5	6.2	6.4	5.9	6.3	6.6
	Umm Almaradim	8.6	8.2	8.4	6.9	7.4	8.2	8.5	7.1	7.9	8.8	9.6	9.3	8.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.1	6.0	6.1	6.8	5.3	6.0	5.4	5.5	5.4	6.5	6.7	5.6	5.9
	Sea Island Buoy	7.5	6.7	6.4	6.3	4.7	6.8	5.6	5.8	5.6	7.7	8.4	7.5	6.6
	Ahmadi Oil Pier	6.0	6.1	6.7	6.4	5.6	9.0	6.9	6.6	6.1	6.6	7.0	6.2	6.6
2011	Beacon N6	6.2	6.4	7.1	7.5	6.4	8.7	7.1	7.0	6.3	6.6	6.8	6.4	6.9
	Juliaa Port	6.6	6.3	6.2	6.9	5.7	7.5	6.2	5.8	5.2	7.0	7.5	6.1	6.4
	Salmiya	5.3	5.1	5.0	5.7	4.4	5.6	5.0	5.0	4.4	5.8	6.5	7.2	5.4
	South Dolphin	6.9	7.1	7.3	7.3	5.9	8.4	6.7	7.1	6.1	7.3	8.0	7.1	7.1
	Umm Almaradim	9.7	8.2	7.9	7.8	7.1	9.6	8.0	8.0	8.0	9.9	9.5	8.5	8.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.8	6.8	6.2	5.4	5.7	5.8	5.4	5.8	5.4	6.2	6.2	6.3	5.9
	Sea Island Buoy	6.7	7.4	6.7	4.8	5.0	6.1	5.3	6.4	6.1	0.0	0.0	7.2	6.1
	Ahmadi Oil Pier	5.8	6.7	6.5	5.4	5.7	8.1	6.7	7.8	6.4	6.0	6.3	6.1	6.5
2012	Beacon N6	5.9	7.5	7.5	6.2	6.2	8.2	6.9	7.8	6.5	6.0	6.3	6.0	6.8
	Juliaa Port	6.1	6.9	6.9	5.5	6.1	6.9	6.0	6.7	5.7	6.2	6.4	6.8	6.3
	Salmiya	6.6	7.5	7.9	7.0	7.3	9.1	8.4	8.3	7.4	7.7	6.6	6.6	7.5
	South Dolphin	6.3	8.1	7.6	6.3	6.0	8.0	6.9	7.9	6.5	6.6	6.9	6.7	7.0
	Umm Almaradim	7.9	9.0	8.4	5.6	6.3	6.6	5.7	6.3	6.3	7.4	7.8	8.2	7.1

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.1	5.5	6.4	5.9	6.0	6.2	5.5	5.1	5.6	5.6	6.4	6.8	5.9
	Sea Island Buoy	7.4	6.5	6.7	5.8	5.8	7.6	6.7	5.0	6.4	7.1	7.1	9.0	6.8
	Ahmadi Oil Pier	5.8	6.0	6.3	5.8	6.5	10.2	8.9	5.7	6.2	6.4	6.3	6.9	6.7
2013	Beacon N6	6.3	6.7	7.2	6.4	7.1	9.8	8.9	5.9	6.5	6.1	6.1	7.2	7.0
	Juliaa Port	6.4	6.3	7.0	6.1	6.4	8.3	7.0	5.4	5.8	6.4	6.8	7.7	6.6
	Salmiya	6.4	6.7	7.2	7.4	7.1	8.6	8.4	6.7	6.9	6.8	6.6	7.7	7.2
	South Dolphin	7.2	7.0	7.5	6.5	7.0	9.4	8.4	5.8	6.7	6.7	6.6	8.1	7.2
	Umm Almaradim	8.1	7.0	7.5	6.2	6.2	7.8	6.4	5.4	6.5	7.9	7.7	9.9	7.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.5	5.9	5.5	5.5	4.8	5.6	6.2	5.9	5.3	6.7	5.6	4.4	5.6
	Sea Island Buoy	6.2	6.8	5.8	5.5	4.9	0.0	6.4	6.1	5.7	6.9	7.1	6.6	6.2
	Ahmadi Oil Pier	5.6	6.3	5.5	5.6	5.5	7.8	8.3	7.0	5.9	6.1	6.0	5.7	6.3
2014	Beacon N6	5.6	7.0	6.4	6.3	6.1	8.2	8.3	7.4	6.5	6.3	5.9	6.0	6.7
	Juliaa Port	6.0	6.4	6.4	5.9	5.3	6.8	6.8	6.4	5.5	6.7	6.4	5.8	6.2
	Salmiya	5.7	6.7	6.1	6.5	6.5	7.9	7.8	8.0	6.5	6.5	6.1	5.7	6.7
	South Dolphin	6.3	7.6	6.8	6.2	6.1	7.8	7.9	7.2	6.3	6.1	6.6	6.5	6.8
	Umm Almaradim	7.5	7.3	6.6	6.1	5.2	6.3	6.4	6.4	6.0	7.6	7.9	7.2	6.7

Table B.6: The monthly and annual average wind speed (m/s) for eight locations at 120 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	8.0	8.1	7.3	6.3	6.4	8.4	6.7	6.3	7.5	7.0	7.1	6.1	7.1
	Sea Island Buoy	7.4	7.6	6.2	5.2	5.4	8.3	0.0	5.3	6.9	7.2	7.6	7.9	6.8
	Ahmadi Oil Pier	6.9	8.0	7.1	6.6	6.6	10.3	7.7	6.4	7.3	6.9	7.0	7.4	7.3
2008	Beacon N6	6.4	7.7	7.2	6.8	6.9	9.4	7.6	6.2	7.1	6.5	6.3	6.7	7.1
	Juliaa Port	6.9	7.9	7.3	6.2	6.6	8.7	6.9	6.1	7.1	6.9	7.2	7.4	7.1
	Salmiya	5.8	6.5	5.8	4.8	4.8	6.2	5.0	4.7	5.7	5.4	5.1	5.7	5.5
	South Dolphin	7.1	8.2	7.0	6.9	6.3	8.8	7.0	6.0	7.0	7.2	7.2	7.5	7.2
	Umm Almaradim	8.2	8.9	7.4	6.0	6.4	7.5	5.7	5.9	7.2	7.7	8.9	9.1	7.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.8	6.4	6.2	5.6	5.5	5.7	5.9	6.2	6.1	5.9	6.9	6.0	6.0
	Sea Island Buoy	6.2	6.6	6.0	5.3	5.4	5.1	6.1	6.5	6.4	6.2	7.5	6.8	6.1
	Ahmadi Oil Pier	6.7	7.1	6.9	6.3	6.8	6.6	9.1	8.2	6.8	5.9	6.6	6.0	6.9
2009	Beacon N6	6.3	6.8	6.9	6.2	6.9	6.9	8.7	8.4	6.9	6.1	6.3	5.5	6.8
	Juliaa Port	7.0	7.3	6.9	6.3	6.4	6.1	7.2	6.9	6.1	5.8	6.9	6.4	6.6
	Salmiya	5.1	5.3	5.2	5.0	5.0	5.1	5.7	6.1	5.2	4.8	5.7	4.9	5.3
	South Dolphin	7.1	6.9	7.1	6.4	6.4	6.8	8.4	8.2	7.1	6.4	7.0	6.2	7.0
	Umm Almaradim	8.4	8.7	6.7	6.2	6.3	5.7	7.0	7.1	7.0	7.0	8.1	7.7	7.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.7	5.8	6.4	6.0	5.6	6.0	6.0	5.7	5.5	5.6	5.4	5.4	5.8
	Sea Island Buoy	7.4	6.1	6.6	5.7	5.5	6.0	6.1	5.3	6.3	6.1	6.7	6.7	6.2
	Ahmadi Oil Pier	6.5	5.9	6.5	6.1	6.3	7.4	7.9	5.1	5.9	5.9	5.5	5.7	6.2
2010	Beacon N6	7.1	5.9	7.1	6.7	7.0	7.9	7.6	5.7	6.0	6.2	5.9	5.7	6.6
	Juliaa Port	6.9	6.3	6.8	6.5	6.2	6.4	7.0	5.6	6.0	6.0	5.8	5.9	6.3
	Salmiya	6.3	5.0	5.6	5.4	4.9	5.6	5.6	4.9	4.8	5.0	4.2	4.7	5.2
	South Dolphin	7.9	6.3	7.3	6.9	6.5	7.6	7.7	5.7	6.3	6.5	6.1	6.4	6.8
	Umm Almaradim	8.8	8.4	8.6	7.1	7.6	8.4	8.8	7.3	8.1	9.0	9.8	9.5	8.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.3	6.2	6.3	6.9	5.4	6.2	5.5	5.6	5.5	6.6	6.9	5.8	6.1
	Sea Island Buoy	7.7	6.9	6.5	6.5	4.8	7.0	5.7	5.9	5.8	7.9	8.6	7.7	6.7
	Ahmadi Oil Pier	6.1	6.3	6.8	6.5	5.7	9.2	7.0	6.8	6.2	6.8	7.2	6.4	6.8
2011	Beacon N6	6.4	6.5	7.3	7.7	6.6	9.0	7.3	7.2	6.5	6.8	7.0	6.6	7.1
	Juliaa Port	6.8	6.5	6.4	7.1	5.8	7.7	6.4	6.0	5.4	7.2	7.7	6.3	6.6
	Salmiya	5.4	5.2	5.2	5.8	4.5	5.8	5.1	5.1	4.5	5.9	6.6	7.4	5.6
	South Dolphin	7.0	7.3	7.5	7.4	6.1	8.7	6.8	7.3	6.3	7.4	8.2	7.3	7.3
	Umm Almaradim	9.9	8.4	8.2	8.0	7.3	9.9	8.2	8.3	8.2	10.1	9.8	8.8	8.8

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.9	6.9	6.4	5.5	5.8	5.9	5.6	5.9	5.5	6.4	6.4	6.4	6.1
	Sea Island Buoy	6.9	7.6	6.8	5.0	5.1	6.2	5.5	6.6	6.2	0.0	0.0	7.4	6.3
	Ahmadi Oil Pier	6.0	6.9	6.7	5.5	5.9	8.3	6.9	8.0	6.6	6.1	6.4	6.2	6.6
2012	Beacon N6	6.1	7.6	7.7	6.3	6.4	8.4	7.1	8.0	6.7	6.2	6.5	6.2	6.9
	Juliaa Port	6.3	7.1	7.1	5.7	6.2	7.1	6.1	6.9	5.9	6.3	6.6	6.9	6.5
	Salmiya	6.8	7.7	8.1	7.2	7.5	9.3	8.6	8.6	7.6	7.9	6.8	6.8	7.7
	South Dolphin	6.5	8.3	7.8	6.5	6.1	8.2	7.1	8.1	6.7	6.8	7.1	6.9	7.2
	Umm Almaradim	8.2	9.2	8.6	5.7	6.5	6.7	5.9	6.5	6.5	7.6	8.0	8.4	7.3

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.3	5.6	6.6	6.1	6.2	6.4	5.7	5.2	5.7	5.8	6.5	7.0	6.1
	Sea Island Buoy	7.6	6.7	6.9	6.0	5.9	7.8	6.9	5.1	6.6	7.3	7.2	9.3	6.9
	Ahmadi Oil Pier	5.9	6.1	6.4	6.0	6.6	10.5	9.1	5.8	6.4	6.5	6.5	7.0	6.9
2013	Beacon N6	6.5	6.9	7.4	6.6	7.3	10.1	9.1	6.1	6.7	6.3	6.3	7.4	7.2
	Juliaa Port	6.5	6.4	7.2	6.3	6.6	8.5	7.2	5.6	6.0	6.6	6.9	7.9	6.8
	Salmiya	6.6	6.9	7.4	7.5	7.3	8.9	8.6	6.9	7.1	7.0	6.8	7.9	7.4
	South Dolphin	7.4	7.2	7.7	6.7	7.2	9.6	8.6	6.0	6.8	6.8	6.8	8.3	7.4
	Umm Almaradim	8.4	7.2	7.7	6.3	6.3	8.0	6.6	5.5	6.7	8.1	7.9	10.1	7.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.7	6.1	5.7	5.6	5.0	5.8	6.3	6.0	5.5	6.8	5.8	4.5	5.7
	Sea Island Buoy	6.4	7.0	6.0	5.6	5.0	0.0	6.6	6.3	5.8	7.1	7.3	6.8	6.4
	Ahmadi Oil Pier	5.7	6.4	5.7	5.8	5.7	8.0	8.5	7.2	6.1	6.2	6.2	5.8	6.4
2014	Beacon N6	5.8	7.2	6.6	6.5	6.3	8.4	8.5	7.6	6.7	6.5	6.0	6.2	6.9
	Juliaa Port	6.1	6.5	6.5	6.1	5.5	6.9	7.0	6.5	5.7	6.9	6.6	5.9	6.4
	Salmiya	5.9	6.9	6.2	6.7	6.7	8.1	8.0	8.2	6.7	6.7	6.3	5.8	6.8
	South Dolphin	6.5	7.8	7.0	6.4	6.3	8.0	8.1	7.4	6.5	6.2	6.8	6.7	6.9
	Umm Almaradim	7.7	7.5	6.8	6.2	5.3	6.5	6.6	6.6	6.1	7.8	8.1	7.4	6.9

Table B.7: The monthly and annual average wind speed (m/s) for eight locations at 140 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	8.2	8.3	7.5	6.4	6.6	8.6	6.9	6.4	7.7	7.2	7.2	6.2	7.2
	Sea Island Buoy	7.6	7.8	6.4	5.4	5.5	8.5	0.0	5.4	7.1	7.4	7.8	8.1	6.9
	Ahmadi Oil Pier	7.0	8.2	7.2	6.7	6.8	10.5	7.9	6.5	7.4	7.1	7.1	7.5	7.5
2008	Beacon N6	6.6	7.9	7.4	7.0	7.1	9.6	7.8	6.3	7.3	6.7	6.5	6.9	7.2
	Juliaa Port	7.1	8.1	7.4	6.4	6.7	8.9	7.0	6.3	7.3	7.1	7.3	7.6	7.3
	Salmiya	5.9	6.7	5.9	4.9	4.9	6.3	5.1	4.8	5.8	5.5	5.2	5.9	5.6
	South Dolphin	7.3	8.3	7.2	7.0	6.5	9.0	7.2	6.1	7.2	7.3	7.4	7.7	7.3
	Umm Almaradim	8.4	9.1	7.6	6.1	6.6	7.7	5.8	6.0	7.4	7.9	9.1	9.3	7.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.9	6.6	6.3	5.7	5.7	5.8	6.0	6.3	6.2	6.0	7.0	6.1	6.1
	Sea Island Buoy	6.3	6.7	6.2	5.4	5.5	5.2	6.2	6.7	6.5	6.3	7.7	6.9	6.3
	Ahmadi Oil Pier	6.8	7.3	7.0	6.4	7.0	6.8	9.3	8.4	7.0	6.0	6.8	6.1	7.1
2009	Beacon N6	6.5	7.0	7.1	6.4	7.0	7.1	8.9	8.6	7.1	6.2	6.5	5.6	7.0
	Juliaa Port	7.1	7.4	7.1	6.4	6.5	6.2	7.4	7.1	6.3	5.9	7.1	6.5	6.8
	Salmiya	5.2	5.4	5.3	5.1	5.1	5.2	5.8	6.2	5.4	4.9	5.9	5.0	5.4
	South Dolphin	7.3	7.0	7.2	6.6	6.6	7.0	8.6	8.4	7.3	6.5	7.1	6.4	7.2
	Umm Almaradim	8.6	8.9	6.9	6.4	6.4	5.8	7.1	7.3	7.2	7.1	8.2	7.9	7.3

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.8	5.9	6.5	6.2	5.7	6.1	6.2	5.8	5.6	5.7	5.5	5.5	6.0
	Sea Island Buoy	7.6	6.2	6.7	5.8	5.6	6.1	6.3	5.4	6.5	6.2	6.8	6.8	6.4
	Ahmadi Oil Pier	6.6	6.0	6.7	6.2	6.5	7.5	8.1	5.2	6.1	6.1	5.6	5.8	6.4
2010	Beacon N6	7.2	6.0	7.3	6.8	7.1	8.1	7.8	5.8	6.1	6.3	6.0	5.9	6.7
	Juliaa Port	7.0	6.4	6.9	6.7	6.3	6.6	7.1	5.7	6.1	6.1	5.9	6.0	6.4
	Salmiya	6.5	5.1	5.8	5.5	5.0	5.7	5.7	5.0	5.0	5.1	4.3	4.8	5.3
	South Dolphin	8.1	6.4	7.5	7.1	6.7	7.7	7.8	5.8	6.5	6.7	6.2	6.6	6.9
	Umm Almaradim	9.0	8.6	8.8	7.3	7.8	8.6	9.0	7.4	8.3	9.2	10.1	9.7	8.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.4	6.3	6.4	7.1	5.6	6.3	5.6	5.7	5.6	6.8	7.0	5.9	6.2
	Sea Island Buoy	7.8	7.0	6.7	6.6	4.9	7.1	5.9	6.0	5.9	8.1	8.8	7.9	6.9
	Ahmadi Oil Pier	6.3	6.4	7.0	6.7	5.9	9.4	7.2	7.0	6.4	7.0	7.4	6.5	6.9
2011	Beacon N6	6.5	6.7	7.5	7.9	6.8	9.2	7.5	7.4	6.6	7.0	7.2	6.8	7.2
	Juliaa Port	7.0	6.6	6.5	7.2	6.0	7.9	6.5	6.1	5.5	7.4	7.9	6.4	6.7
	Salmiya	5.6	5.3	5.3	6.0	4.6	5.9	5.3	5.2	4.6	6.1	6.8	7.6	5.7
	South Dolphin	7.2	7.5	7.7	7.6	6.2	8.9	7.0	7.5	6.4	7.6	8.4	7.5	7.4
	Umm Almaradim	10.1	8.6	8.3	8.2	7.4	10.1	8.4	8.4	8.4	10.4	10.0	9.0	8.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.1	7.1	6.5	5.6	5.9	6.1	5.7	6.1	5.6	6.5	6.5	6.6	6.2
	Sea Island Buoy	7.0	7.8	7.0	5.1	5.3	6.4	5.6	6.7	6.4	0.0	0.0	7.5	6.4
	Ahmadi Oil Pier	6.1	7.1	6.9	5.7	6.0	8.5	7.0	8.2	6.7	6.3	6.6	6.4	6.8
2012	Beacon N6	6.2	7.8	7.9	6.5	6.5	8.6	7.3	8.2	6.9	6.3	6.6	6.3	7.1
	Juliaa Port	6.4	7.2	7.2	5.8	6.4	7.2	6.3	7.0	6.0	6.5	6.7	7.1	6.7
	Salmiya	6.9	7.8	8.3	7.3	7.7	9.5	8.8	8.8	7.8	8.1	6.9	6.9	7.9
	South Dolphin	6.6	8.5	8.0	6.6	6.3	8.4	7.2	8.2	6.8	6.9	7.3	7.0	7.3
	Umm Almaradim	8.3	9.4	8.8	5.8	6.6	6.9	6.0	6.6	6.6	7.7	8.2	8.6	7.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.4	5.8	6.8	6.2	6.3	6.5	5.8	5.3	5.9	5.9	6.7	7.2	6.2
	Sea Island Buoy	7.8	6.9	7.0	6.1	6.1	8.0	7.1	5.2	6.7	7.5	7.4	9.5	7.1
	Ahmadi Oil Pier	6.1	6.3	6.6	6.1	6.8	10.7	9.3	5.9	6.5	6.7	6.6	7.2	7.1
2013	Beacon N6	6.6	7.1	7.5	6.7	7.4	10.3	9.3	6.2	6.8	6.4	6.4	7.6	7.4
	Juliaa Port	6.7	6.6	7.3	6.4	6.7	8.7	7.4	5.7	6.1	6.7	7.1	8.1	7.0
	Salmiya	6.7	7.0	7.5	7.7	7.4	9.0	8.8	7.0	7.3	7.1	6.9	8.1	7.6
	South Dolphin	7.6	7.3	7.8	6.8	7.3	9.8	8.8	6.1	7.0	7.0	6.9	8.5	7.6
	Umm Almaradim	8.6	7.4	7.9	6.5	6.5	8.1	6.7	5.7	6.8	8.3	8.1	10.3	7.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.8	6.2	5.8	5.8	5.1	5.9	6.5	6.1	5.6	7.0	5.9	4.6	5.9
	Sea Island Buoy	6.6	7.1	6.1	5.8	5.1	0.0	6.7	6.4	6.0	7.2	7.4	6.9	6.5
	Ahmadi Oil Pier	5.9	6.6	5.8	5.9	5.8	8.2	8.7	7.3	6.2	6.3	6.3	5.9	6.6
2014	Beacon N6	5.9	7.4	6.8	6.6	6.4	8.6	8.7	7.8	6.9	6.6	6.2	6.3	7.0
	Juliaa Port	6.3	6.7	6.7	6.2	5.6	7.1	7.1	6.7	5.8	7.1	6.8	6.0	6.5
	Salmiya	6.0	7.0	6.4	6.8	6.8	8.3	8.2	8.4	6.8	6.8	6.4	5.9	7.0
	South Dolphin	6.6	7.9	7.1	6.5	6.4	8.1	8.3	7.5	6.6	6.4	6.9	6.9	7.1
	Umm Almaradim	7.9	7.7	7.0	6.4	5.5	6.6	6.8	6.7	6.3	8.0	8.3	7.6	7.0

Table B.8: The monthly and annual average wind speed (m/s) for eight locations at 160 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	8.3	8.4	7.6	6.5	6.7	8.8	7.0	6.5	7.8	7.3	7.4	6.4	7.4
	Sea Island Buoy	7.7	8.0	6.5	5.5	5.6	8.6	0.0	5.5	7.2	7.5	7.9	8.2	7.1
	Ahmadi Oil Pier	7.1	8.3	7.4	6.8	6.9	10.7	8.0	6.7	7.6	7.2	7.3	7.7	7.6
2008	Beacon N6	6.7	8.0	7.5	7.1	7.2	9.8	8.0	6.5	7.4	6.8	6.6	7.0	7.4
	Juliaa Port	7.2	8.2	7.6	6.5	6.9	9.1	7.2	6.4	7.4	7.2	7.5	7.7	7.4
	Salmiya	6.0	6.8	6.0	5.0	5.0	6.4	5.2	4.9	5.9	5.6	5.3	6.0	5.7
	South Dolphin	7.4	8.5	7.3	7.2	6.6	9.2	7.3	6.2	7.3	7.5	7.5	7.8	7.5
	Umm Almaradim	8.5	9.3	7.7	6.3	6.7	7.9	5.9	6.1	7.5	8.1	9.3	9.5	7.7

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.1	6.7	6.4	5.9	5.8	5.9	6.2	6.4	6.4	6.2	7.1	6.3	6.3
	Sea Island Buoy	6.4	6.9	6.3	5.5	5.6	5.3	6.3	6.8	6.6	6.4	7.8	7.0	6.4
	Ahmadi Oil Pier	7.0	7.4	7.1	6.6	7.1	6.9	9.5	8.5	7.1	6.1	6.9	6.2	7.2
2009	Beacon N6	6.6	7.1	7.2	6.5	7.2	7.2	9.0	8.8	7.2	6.3	6.6	5.7	7.1
	Juliaa Port	7.3	7.6	7.2	6.5	6.6	6.4	7.5	7.2	6.4	6.1	7.2	6.7	6.9
	Salmiya	5.3	5.5	5.4	5.2	5.2	5.3	5.9	6.4	5.5	5.0	6.0	5.1	5.5
	South Dolphin	7.4	7.2	7.4	6.7	6.7	7.1	8.8	8.5	7.4	6.7	7.3	6.5	7.3
	Umm Almaradim	8.8	9.1	7.0	6.5	6.6	5.9	7.2	7.4	7.3	7.3	8.4	8.0	7.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.9	6.0	6.6	6.3	5.9	6.2	6.3	5.9	5.7	5.8	5.7	5.7	6.1
	Sea Island Buoy	7.8	6.3	6.8	6.0	5.7	6.2	6.4	5.5	6.6	6.3	6.9	6.9	6.5
	Ahmadi Oil Pier	6.7	6.1	6.8	6.3	6.6	7.7	8.3	5.3	6.2	6.2	5.7	5.9	6.5
2010	Beacon N6	7.4	6.2	7.4	7.0	7.3	8.2	7.9	5.9	6.2	6.5	6.1	6.0	6.8
	Juliaa Port	7.2	6.5	7.1	6.8	6.5	6.7	7.2	5.8	6.3	6.2	6.0	6.1	6.5
	Salmiya	6.6	5.2	5.9	5.6	5.1	5.8	5.8	5.1	5.1	5.2	4.4	4.9	5.4
	South Dolphin	8.3	6.6	7.6	7.2	6.8	7.9	8.0	5.9	6.6	6.8	6.4	6.7	7.1
	Umm Almaradim	9.2	8.8	9.0	7.4	7.9	8.8	9.1	7.6	8.5	9.4	10.2	9.9	8.8

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.5	6.4	6.6	7.2	5.7	6.4	5.8	5.8	5.7	6.9	7.2	6.0	6.4
	Sea Island Buoy	8.0	7.2	6.8	6.7	5.0	7.2	6.0	6.2	6.0	8.3	9.0	8.1	7.0
	Ahmadi Oil Pier	6.4	6.5	7.1	6.8	6.0	9.6	7.3	7.1	6.5	7.1	7.5	6.6	7.0
2011	Beacon N6	6.6	6.8	7.6	8.0	6.9	9.3	7.6	7.5	6.7	7.1	7.3	6.9	7.4
	Juliaa Port	7.1	6.8	6.7	7.4	6.1	8.0	6.6	6.2	5.6	7.5	8.1	6.6	6.9
	Salmiya	5.7	5.5	5.4	6.1	4.7	6.0	5.4	5.3	4.7	6.2	6.9	7.7	5.8
	South Dolphin	7.3	7.6	7.8	7.8	6.3	9.0	7.1	7.6	6.5	7.8	8.5	7.6	7.6
	Umm Almaradim	10.3	8.8	8.5	8.4	7.6	10.3	8.6	8.6	8.6	10.6	10.2	9.1	9.1

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.2	7.2	6.6	5.8	6.0	6.2	5.8	6.2	5.7	6.6	6.7	6.7	6.3
	Sea Island Buoy	7.2	7.9	7.1	5.2	5.4	6.5	5.7	6.8	6.5	0.0	0.0	7.7	6.5
	Ahmadi Oil Pier	6.2	7.2	7.0	5.8	6.1	8.7	7.1	8.4	6.9	6.4	6.7	6.5	6.9
2012	Beacon N6	6.3	8.0	8.0	6.6	6.6	8.7	7.4	8.4	7.0	6.5	6.8	6.4	7.2
	Juliaa Port	6.6	7.4	7.4	5.9	6.5	7.4	6.4	7.1	6.1	6.6	6.8	7.2	6.8
	Salmiya	7.1	8.0	8.4	7.5	7.8	9.7	9.0	8.9	7.9	8.2	7.1	7.1	8.1
	South Dolphin	6.7	8.6	8.2	6.8	6.4	8.6	7.4	8.4	7.0	7.1	7.4	7.2	7.5
	Umm Almaradim	8.5	9.6	9.0	5.9	6.7	7.0	6.1	6.8	6.7	7.9	8.4	8.8	7.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	6.6	5.9	6.9	6.4	6.4	6.7	5.9	5.4	6.0	6.0	6.8	7.3	6.4
	Sea Island Buoy	7.9	7.0	7.2	6.2	6.2	8.1	7.2	5.3	6.9	7.6	7.5	9.6	7.2
	Ahmadi Oil Pier	6.2	6.4	6.7	6.2	6.9	10.9	9.5	6.0	6.6	6.8	6.7	7.3	7.2
2013	Beacon N6	6.7	7.2	7.7	6.9	7.6	10.5	9.5	6.3	7.0	6.5	6.6	7.7	7.5
	Juliaa Port	6.8	6.7	7.5	6.6	6.9	8.9	7.5	5.8	6.2	6.9	7.2	8.3	7.1
	Salmiya	6.8	7.2	7.7	7.9	7.6	9.2	9.0	7.1	7.4	7.3	7.1	8.3	7.7
	South Dolphin	7.7	7.5	8.0	6.9	7.5	10.0	9.0	6.2	7.1	7.1	7.1	8.7	7.7
	Umm Almaradim	8.7	7.5	8.0	6.6	6.6	8.3	6.8	5.8	7.0	8.4	8.3	10.5	7.7

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	5.9	6.3	5.9	5.9	5.2	6.0	6.6	6.3	5.7	7.1	6.0	4.7	6.0
	Sea Island Buoy	6.7	7.3	6.2	5.9	5.2	0.0	6.8	6.6	6.1	7.4	7.6	7.1	6.6
	Ahmadi Oil Pier	6.0	6.7	5.9	6.0	5.9	8.3	8.9	7.5	6.3	6.5	6.4	6.0	6.7
2014	Beacon N6	6.0	7.5	6.9	6.7	6.6	8.7	8.8	7.9	7.0	6.8	6.3	6.5	7.1
	Juliaa Port	6.4	6.8	6.8	6.3	5.7	7.2	7.2	6.8	5.9	7.2	6.9	6.2	6.6
	Salmiya	6.1	7.1	6.5	7.0	7.0	8.4	8.3	8.5	6.9	7.0	6.5	6.1	7.1
	South Dolphin	6.7	8.1	7.3	6.6	6.5	8.3	8.5	7.7	6.8	6.5	7.1	7.0	7.2
	Umm Almaradim	8.0	7.8	7.1	6.5	5.6	6.7	6.9	6.8	6.4	8.1	8.5	7.7	7.2

Table B.9: The monthly and annual average wind density (W/m^2) for eight marine locations at 10 m elevation from 2009 - 2014.

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
2009	Beacon M28	79.3	107.6	93.9	71.4	68.4	74.3	83.5	94.7	92.1	83.1	129.9	87.5	87.7
	Sea Island Buoy	95.4	114.7	87.9	59.1	62.4	52.6	90.9	112.2	104.4	94.3	171.2	124.7	93.6
	Ahmadi Oil Pier	120.0	146.9	129.6	101.0	127.8	116.4	302.5	222.6	128.5	81.8	118.1	86.7	133.7
	Beacon N6	103.0	128.2	132.3	97.4	131.5	134.0	263.0	241.1	133.9	89.3	101.5	66.5	128.7
	Juliaa Port	136.3	154.2	132.3	98.5	104.1	91.4	152.8	135.2	93.0	79.5	132.4	105.0	116.3
	Salmiya	53.1	59.6	56.7	51.3	49.2	53.7	74.0	91.8	57.9	45.3	76.0	48.5	58.9
	South Dolphin	145.1	131.1	142.9	106.8	107.5	128.0	239.5	222.2	144.4	105.2	136.5	96.9	138.9
	Umm Almaradim	241.1	265.5	123.7	96.7	100.5	73.9	135.5	147.1	139.1	137.4	211.7	184.5	147.6
2010	Beacon M28	118.7	78.5	103.7	88.5	71.7	85.4	88.9	75.1	65.4	70.1	64.4	64.4	80.4
	Sea Island Buoy	166.3	89.4	113.9	75.2	65.5	85.6	93.2	59.6	102.1	90.0	118.6	118.6	97.8
	Ahmadi Oil Pier	109.1	82.1	113.2	90.4	101.4	162.3	200.9	53.1	83.6	84.9	65.4	73.0	97.3
	Beacon N6	142.3	83.2	145.4	119.7	136.3	199.6	176.1	75.1	85.4	95.8	80.8	76.4	114.1
	Juliaa Port	130.4	99.4	125.0	111.2	95.8	106.8	135.7	69.2	87.5	85.9	77.9	82.6	99.3
	Salmiya	103.2	51.1	72.4	62.2	47.7	70.5	69.9	46.4	46.0	49.3	30.6	41.9	55.9
	South Dolphin	200.5	100.6	159.0	133.7	111.5	173.8	181.3	74.3	102.6	112.9	91.7	107.8	125.8
	Umm Almaradim	274.1	242.0	256.0	143.9	179.0	239.9	270.6	154.0	217.8	292.5	383.2	345.6	243.3
2011	Beacon M28	100.1	95.1	100.8	134.6	65.2	94.3	67.9	70.8	67.3	117.7	130.7	77.3	91.4
	Sea Island Buoy	180.9	131.4	113.2	108.8	45.1	135.4	75.6	83.5	77.5	201.2	257.4	187.5	123.9
	Ahmadi Oil Pier	92.4	100.1	128.3	111.9	76.0	312.9	140.6	127.6	97.0	127.8	150.1	103.4	124.4
	Beacon N6	104.3	112.5	159.0	182.9	116.3	289.7	158.1	152.3	108.5	127.6	138.2	116.3	142.8
	Juliaa Port	126.8	109.9	105.9	143.6	80.4	184.6	103.9	85.3	62.0	150.8	187.0	100.3	116.0
	Salmiya	64.5	57.7	55.8	80.4	36.1	78.5	54.7	54.4	37.5	84.9	117.1	163.9	69.4
	South Dolphin	140.4	158.8	171.3	166.4	89.7	262.5	129.4	156.4	99.9	166.6	221.2	159.3	155.8
	Umm Almaradim	392.5	240.3	218.5	208.8	154.3	391.6	223.0	226.7	222.8	419.3	378.8	271.5	270.4
2012	Beacon M28	84.5	135.0	103.4	68.0	78.7	84.8	69.1	83.9	66.8	103.7	105.7	107.3	89.4
	Sea Island Buoy	131.5	179.0	128.9	49.4	55.0	97.2	66.0	114.4	96.9	0.0	0.0	161.6	99.1
	Ahmadi Oil Pier	86.5	133.6	122.0	68.3	82.5	233.0	130.2	209.0	115.4	92.4	107.3	97.5	117.9
	Beacon N6	89.9	180.4	183.2	102.9	104.1	238.2	146.0	209.7	122.5	95.8	110.9	94.9	134.4
	Juliaa Port	100.8	142.6	143.4	74.5	97.0	141.6	92.8	130.2	80.8	103.0	113.4	135.2	111.2
	Salmiya	126.5	182.1	214.5	149.5	171.6	328.2	260.5	253.1	177.5	198.4	126.4	126.5	187.2
	South Dolphin	109.1	229.9	193.3	110.9	93.0	225.9	143.1	211.5	120.9	125.8	144.5	131.2	148.4
	Umm Almaradim	218.9	312.7	258.8	75.1	109.4	122.8	81.0	110.3	108.3	174.2	208.4	243.0	156.3
2013	Beacon M28	100.8	72.5	116.8	91.7	94.5	105.9	74.0	57.6	76.4	76.7	112.6	140.1	91.7
	Sea Island Buoy	177.7	122.0	130.4	86.1	83.9	190.4	133.6	54.0	114.6	158.7	153.1	319.4	135.1
	Ahmadi Oil Pier	84.7	93.2	107.5	85.0	117.7	462.0	308.1	78.7	103.8	112.7	108.3	140.4	133.0
	Beacon N6	108.2	133.8	161.1	115.9	155.8	416.4	304.4	89.9	120.2	98.8	100.3	163.6	151.2
	Juliaa Port	112.2	106.9	148.2	100.6	115.1	247.7	152.0	69.1	85.2	115.6	134.3	200.5	127.2
	Salmiya	113.4	130.5	160.2	173.2	155.5	279.7	259.7	129.6	145.7	137.6	126.4	200.2	163.3
	South Dolphin	162.7	149.7	180.9	119.4	148.5	359.8	258.9	86.5	128.3	128.9	126.4	230.9	165.0
	Umm Almaradim	236.0	151.9	183.9	103.1	101.4	203.6	114.1	68.9	119.9	212.6	202.2	418.1	163.8
2014	Beacon M28	73.4	89.8	72.7	72.1	49.6	77.9	101.4	87.7	65.9	129.1	78.5	37.4	75.7
	Sea Island Buoy	106.1	136.1	86.9	71.9	50.2	0.0	113.5	101.2	80.0	141.8	154.3	125.8	103.8
	Ahmadi Oil Pier	75.6	107.6	74.1	77.3	74.3	206.6	251.9	148.2	89.4	96.6	93.9	78.7	107.4
	Beacon N6	76.9	150.3	116.4	109.2	100.8	236.6	245.0	179.0	122.2	109.8	89.2	96.0	129.7
	Juliaa Port	92.4	111.8	112.9	90.9	65.5	134.6	135.7	112.2	73.9	133.9	116.6	82.9	103.3
	Salmiya	81.6	129.7	97.4	121.2	119.7	213.6	206.2	220.7	118.9	121.0	99.4	78.9	128.4
	South Dolphin	108.4	188.3	136.8	104.0	98.8	203.3	217.0	161.1	110.7	97.7	125.1	121.5	135.2
	Umm Almaradim	183.6	172.1	127.2	97.9	61.6	108.5	116.3	114.1	92.2	192.5	215.5	165.4	131.5

Table B.10: The monthly and annual average wind density (W/m^2) for eight marine locations at 50 m elevation from 2009 - 2014.

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	409.6	425.7	316.5	196.4	212.5	476.6	246.2	196.9	342.0	275.5	284.6	182.5	286.0
	Sea Island Buoy	327.9	358.9	193.9	115.3	124.4	457.2	0.0	119.7	269.4	301.2	351.2	394.9	250.9
	Ahmadi Oil Pier	259.5	411.1	286.5	226.5	235.7	881.5	364.0	211.2	308.8	267.9	272.7	319.5	316.7
2008	Beacon N6	212.5	365.9	304.7	254.7	267.4	659.4	357.5	192.2	292.1	222.3	205.5	243.6	286.1
	Juliaa Port	265.8	398.3	310.0	196.0	229.9	529.4	262.6	185.0	288.6	269.5	294.5	330.4	288.0
	Salmiya	156.2	224.5	153.6	89.5	89.9	188.9	101.7	85.1	148.5	125.7	107.0	152.5	131.8
	South Dolphin	290.4	435.9	276.6	262.8	204.4	546.9	277.7	172.4	276.1	297.8	301.6	340.3	297.0
	Umm Almaradim	439.3	562.4	330.4	173.6	211.6	345.9	148.9	162.7	299.8	371.2	569.4	610.5	326.7

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	158.1	214.6	187.1	142.3	136.3	148.2	166.5	188.8	183.7	165.7	259.0	174.4	174.8
	Sea Island Buoy	190.3	228.6	175.2	117.8	124.4	104.9	181.3	223.7	208.2	188.0	341.4	248.7	186.7
	Ahmadi Oil Pier	239.2	292.8	258.5	201.4	254.8	232.0	603.1	443.8	256.3	163.0	235.5	172.8	266.5
2009	Beacon N6	205.3	255.6	263.7	194.2	262.1	267.2	524.4	480.6	266.9	178.0	202.3	132.6	256.5
	Juliaa Port	271.7	307.4	263.7	196.4	207.5	182.2	304.7	269.5	185.4	158.5	263.9	209.3	231.8
	Salmiya	105.9	118.8	113.0	102.3	98.1	107.0	147.5	182.9	115.5	90.4	151.5	96.7	117.4
	South Dolphin	289.3	261.4	284.8	213.0	214.4	255.3	477.4	443.0	287.9	209.8	272.2	193.1	276.9
	Umm Almaradim	480.6	529.4	246.7	192.9	200.4	147.4	270.1	293.2	277.3	273.9	422.2	367.9	294.2

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	236.7	156.6	206.6	176.5	142.9	170.3	177.2	149.6	130.4	139.7	128.3	128.3	160.2
	Sea Island Buoy	331.6	178.1	227.0	150.0	130.6	170.7	185.9	118.8	203.5	179.5	236.5	236.5	195.0
	Ahmadi Oil Pier	217.6	163.7	225.6	180.3	202.2	323.5	400.5	105.9	166.7	169.2	130.4	145.6	194.1
2010	Beacon N6	283.7	165.8	289.9	238.6	271.7	398.0	351.0	149.6	170.3	190.9	161.1	152.3	227.4
	Juliaa Port	260.0	198.2	249.2	221.6	190.9	213.0	270.6	138.0	174.4	171.2	155.3	164.7	198.0
	Salmiya	205.8	101.8	144.3	124.0	95.1	140.5	139.4	92.5	91.7	98.3	61.1	83.6	111.5
	South Dolphin	399.8	200.6	317.1	266.6	222.3	346.6	361.4	148.2	204.6	225.1	182.9	214.9	250.8
	Umm Almaradim	546.4	482.5	510.3	286.9	356.8	478.2	539.5	307.0	434.2	583.2	764.0	689.0	485.1

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	199.6	189.6	200.9	268.3	129.9	188.0	135.3	141.1	134.1	234.7	260.6	154.0	182.2
	Sea Island Buoy	360.7	262.0	225.6	216.8	89.9	269.9	150.7	166.5	154.6	401.2	513.1	373.9	247.0
	Ahmadi Oil Pier	184.2	199.6	255.9	223.1	151.4	623.9	280.4	254.3	193.3	254.8	299.2	206.2	248.1
2011	Beacon N6	208.0	224.4	317.1	364.5	231.8	577.7	315.3	303.6	216.3	254.3	275.5	231.8	284.7
	Juliaa Port	252.8	219.2	211.2	286.3	160.4	367.9	207.1	170.0	123.7	300.7	372.7	200.0	231.4
	Salmiya	128.6	115.1	111.2	160.4	71.9	156.5	109.1	108.5	74.8	169.2	233.5	326.7	138.3
	South Dolphin	279.8	316.6	341.6	331.7	178.8	523.3	257.9	311.7	199.1	332.2	441.1	317.7	310.5
	Umm Almaradim	782.4	479.0	435.6	416.2	307.6	780.7	444.5	452.0	444.2	835.9	755.1	541.2	539.0

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	168.5	269.2	206.2	135.5	157.0	169.1	137.7	167.3	133.1	206.6	210.6	213.9	178.3
	Sea Island Buoy	262.1	356.8	256.9	98.6	109.7	193.8	131.6	228.0	193.2	0.0	0.0	322.2	197.6
	Ahmadi Oil Pier	172.4	266.4	243.1	136.2	164.6	464.5	259.5	416.7	230.0	184.2	214.0	194.3	235.1
2012	Beacon N6	179.2	359.6	365.3	205.1	207.5	475.0	291.0	418.1	244.2	190.9	221.1	189.2	268.0
	Juliaa Port	200.9	284.4	285.9	148.5	193.5	282.3	185.0	259.5	161.1	205.3	226.0	269.5	221.6
	Salmiya	252.3	363.1	427.5	298.0	342.2	654.4	519.4	504.6	353.8	395.6	252.1	252.3	373.2
	South Dolphin	217.6	458.3	385.3	221.1	185.4	450.4	285.4	421.7	241.1	250.7	288.1	261.6	295.9
	Umm Almaradim	436.3	623.3	516.0	149.6	218.1	244.7	161.5	219.9	215.9	347.2	415.5	484.5	311.6

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	200.9	144.5	232.8	182.9	188.4	211.1	147.5	114.8	152.3	152.9	224.6	279.3	182.7
	Sea Island Buoy	354.2	243.3	260.0	171.6	167.3	379.6	266.3	107.7	228.5	316.5	305.2	636.7	269.3
	Ahmadi Oil Pier	168.8	185.9	214.4	169.5	234.7	921.1	614.2	157.0	206.9	224.6	215.9	279.8	265.2
2013	Beacon N6	215.7	266.7	321.3	231.0	310.6	830.1	606.8	179.2	239.6	196.9	200.0	326.1	301.4
	Juliaa Port	223.7	213.0	295.5	200.5	229.4	493.8	303.0	137.7	169.9	230.4	267.7	399.8	253.7
	Salmiya	226.1	260.2	319.5	345.3	310.0	557.7	517.7	258.5	290.4	274.4	252.1	399.1	325.6
	South Dolphin	324.3	298.5	360.7	238.0	296.1	717.3	516.1	172.4	255.8	256.9	252.1	460.4	328.9
	Umm Almaradim	470.4	302.9	366.6	205.5	202.2	405.9	227.5	137.3	239.1	423.9	403.0	833.6	326.6

Year	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	146.4	179.0	145.0	143.7	98.9	155.3	202.2	174.8	131.4	257.4	156.5	74.6	150.8
	Sea Island Buoy	211.6	271.4	173.2	143.4	100.0	0.0	226.3	201.8	159.6	282.6	307.6	250.7	207.0
	Ahmadi Oil Pier	150.7	214.6	147.8	154.2	148.2	411.8	502.2	295.5	178.2	192.6	187.2	157.0	214.1
2014	Beacon N6	153.3	299.7	232.0	217.8	200.9	471.7	488.5	356.8	243.7	219.0	177.8	191.3	258.5
	Juliaa Port	184.2	222.8	225.1	181.2	130.6	268.3	270.6	223.7	147.4	266.9	232.5	165.3	205.9
	Salmiya	162.7	258.5	194.2	241.6	238.7	425.9	411.0	440.0	237.0	241.2	198.2	157.4	255.9
	South Dolphin	216.2	375.3	272.7	207.4	196.9	405.2	432.7	321.3	220.7	194.8	249.4	242.1	269.5
	Umm Almaradim	365.9	343.0	253.7	195.1	122.8	216.3	231.8	227.5	183.7	383.8	429.7	329.8	262.2

Table B.11: The monthly and annual average wind density (W/m^2) for eight marine locations at 80 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	501.0	520.7	387.1	240.3	260.0	583.0	301.1	240.9	418.4	337.0	348.1	223.3	349.9
	Sea Island Buoy	401.1	439.0	237.2	141.0	152.2	559.3	0.0	146.4	329.5	368.5	429.6	483.1	306.9
	Ahmadi Oil Pier	317.4	502.9	350.4	277.1	288.3	1078.2	445.2	258.3	377.7	327.8	333.6	390.8	387.4
2008	Beacon N6	260.0	447.5	372.7	311.6	327.1	806.6	437.3	235.1	357.3	271.9	251.4	298.0	350.0
	Juliaa Port	325.2	487.3	379.2	239.7	281.2	647.6	321.3	226.3	353.1	329.7	360.2	404.1	352.3
	Salmiya	191.1	274.6	187.9	109.5	109.9	231.1	124.4	104.0	181.7	153.8	130.9	186.6	161.2
	South Dolphin	355.2	533.2	338.3	321.5	250.0	669.0	339.6	210.9	337.7	364.3	368.9	416.3	363.3
	Umm Almaradim	537.4	687.9	404.1	212.4	258.9	423.1	182.1	199.0	366.7	454.1	696.5	746.8	399.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	193.4	262.5	228.9	174.1	166.7	181.2	203.7	230.9	224.7	202.7	316.8	213.3	213.9
	Sea Island Buoy	232.7	279.6	214.3	144.1	152.2	128.4	221.8	273.6	254.6	229.9	417.6	304.2	228.3
	Ahmadi Oil Pier	292.6	358.1	316.1	246.4	311.7	283.8	737.8	542.8	313.5	199.4	288.1	211.4	326.0
2009	Beacon N6	251.1	312.7	322.6	237.5	320.6	326.8	641.4	587.9	326.5	217.8	247.5	162.2	313.8
	Juliaa Port	332.3	376.1	322.6	240.3	253.9	222.9	372.7	329.7	226.8	193.9	322.8	256.1	283.5
	Salmiya	129.6	145.3	138.2	125.1	120.0	130.9	180.4	223.8	141.3	110.5	185.3	118.3	143.6
	South Dolphin	353.9	319.8	348.4	260.6	262.2	312.2	584.0	541.9	352.2	256.6	332.9	236.2	338.7
	Umm Almaradim	587.9	647.6	301.7	235.9	245.2	180.3	330.4	358.7	339.2	335.0	516.4	450.0	359.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	289.5	191.5	252.8	215.9	174.8	208.4	216.8	183.0	159.4	170.9	157.0	157.0	196.0
	Sea Island Buoy	405.6	217.9	277.7	183.5	159.8	208.9	227.3	145.3	248.9	219.5	289.3	289.3	238.6
	Ahmadi Oil Pier	266.2	200.2	275.9	220.6	247.3	395.8	489.9	129.6	203.9	207.0	159.4	178.1	237.4
2010	Beacon N6	347.0	202.9	354.6	291.8	332.3	486.8	429.4	183.0	208.4	233.5	197.1	186.3	278.1
	Juliaa Port	318.1	242.4	304.8	271.1	233.5	260.6	331.0	168.8	213.4	209.4	190.0	201.5	242.2
	Salmiya	251.7	124.6	176.5	151.7	116.3	171.9	170.5	113.1	112.1	120.3	74.7	102.2	136.4
	South Dolphin	489.0	245.4	387.9	326.1	271.9	423.9	442.0	181.3	250.3	275.4	223.7	262.9	306.8
	Umm Almaradim	668.3	590.2	624.2	350.9	436.5	584.9	660.0	375.6	531.1	713.4	934.5	842.8	593.3

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	244.1	232.0	245.7	328.2	159.0	230.0	165.5	172.6	164.1	287.1	318.8	188.4	222.8
	Sea Island Buoy	441.2	320.5	275.9	265.2	109.9	330.2	184.4	203.7	189.1	490.7	627.6	457.3	302.1
	Ahmadi Oil Pier	225.3	244.2	313.0	272.9	185.3	763.2	343.0	311.1	236.5	311.7	366.0	252.2	303.5
2011	Beacon N6	254.4	274.5	387.9	445.9	283.6	706.6	385.7	371.3	264.6	311.1	337.0	283.6	348.3
	Juliaa Port	309.2	268.1	258.3	350.2	196.1	450.1	253.3	208.0	151.3	367.8	455.9	244.6	283.0
	Salmiya	157.3	140.8	136.0	196.1	87.9	191.4	133.5	132.7	91.5	207.0	285.6	399.7	169.1
	South Dolphin	342.3	387.3	417.8	405.8	218.8	640.2	315.5	381.3	243.6	406.4	539.5	388.6	379.9
	Umm Almaradim	957.1	585.9	532.8	509.1	376.3	955.0	543.7	552.9	543.3	1022.5	923.7	662.1	659.3

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	206.1	329.3	252.2	165.8	192.0	206.9	168.4	204.6	162.8	252.8	257.7	261.7	218.1
	Sea Island Buoy	320.6	436.5	314.2	120.6	134.2	237.0	161.0	278.9	236.3	0.0	0.0	394.1	241.7
	Ahmadi Oil Pier	210.8	325.8	297.4	166.6	201.3	568.2	317.4	509.7	281.3	225.3	261.7	237.7	287.6
2012	Beacon N6	219.3	439.8	446.8	250.8	253.9	581.0	355.9	511.5	298.7	233.5	270.5	231.5	327.8
	Juliaa Port	245.7	347.8	349.8	181.7	236.7	345.3	226.3	317.4	197.1	251.1	276.5	329.7	271.1
	Salmiya	308.6	444.1	523.0	364.5	418.6	800.5	635.3	617.2	432.8	483.9	308.3	308.6	456.5
	South Dolphin	266.2	560.6	471.3	270.5	226.8	550.9	349.1	515.9	294.9	306.7	352.4	320.0	362.0
	Umm Almaradim	533.7	762.5	631.2	183.0	266.7	299.4	197.6	269.0	264.0	424.7	508.2	592.7	381.1

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	245.7	176.8	284.8	223.7	230.4	258.2	180.4	140.4	186.3	187.0	274.7	341.6	223.5
	Sea Island Buoy	433.3	297.6	318.1	209.9	204.6	464.4	325.8	131.7	279.5	387.1	373.3	778.8	329.4
	Ahmadi Oil Pier	206.5	227.4	262.2	207.4	287.1	1126.7	751.3	192.0	253.1	274.8	264.0	342.3	324.5
2013	Beacon N6	263.9	326.2	393.0	282.6	379.9	1015.4	742.2	219.3	293.1	240.9	244.7	398.9	368.7
	Juliaa Port	273.6	260.6	361.5	245.2	280.6	604.0	370.6	168.4	207.9	281.8	327.5	489.0	310.3
	Salmiya	276.5	318.3	390.8	422.3	379.2	682.1	633.3	316.1	355.2	335.6	308.3	488.1	398.2
	South Dolphin	396.7	365.1	441.2	291.2	362.2	877.4	631.3	210.9	312.9	314.2	308.3	563.2	402.3
	Umm Almaradim	575.4	370.6	448.4	251.4	247.3	496.6	278.3	168.0	292.4	518.5	493.0	1019.7	399.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	179.1	219.0	177.3	175.8	121.0	190.0	247.3	213.8	160.7	314.9	191.4	91.2	184.5
	Sea Island Buoy	258.9	332.0	211.9	175.4	122.3	0.0	276.8	246.8	195.2	345.7	376.2	306.7	253.1
	Ahmadi Oil Pier	184.4	262.5	180.8	188.6	181.3	503.7	614.3	361.5	218.0	235.6	228.9	192.0	261.9
2014	Beacon N6	187.5	366.6	283.8	266.4	245.7	577.0	597.5	436.5	298.1	267.9	217.5	234.1	316.2
	Juliaa Port	225.3	272.6	275.3	221.6	159.8	328.2	331.0	273.6	180.3	326.5	284.4	202.3	251.8
	Salmiya	199.0	316.2	237.5	295.6	292.0	521.0	502.8	538.3	289.9	295.0	242.5	192.5	313.0
	South Dolphin	264.5	459.1	333.6	253.7	240.9	495.7	529.2	393.0	269.9	238.2	305.1	296.2	329.6
	Umm Almaradim	447.6	419.6	310.3	238.6	150.3	264.6	283.6	278.3	224.7	469.5	525.6	403.4	320.7

Table B.12: The monthly and annual average wind density (W/m^2) for eight marine locations at 100 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	551.3	573.0	426.0	264.4	286.1	641.5	331.3	265.1	460.4	370.8	383.1	245.7	385.0
	Sea Island Buoy	441.4	483.1	261.0	155.2	167.5	615.4	0.0	161.1	362.6	405.5	472.7	531.6	337.7
	Ahmadi Oil Pier	349.3	553.4	385.6	304.9	317.3	1186.5	489.9	284.2	415.6	360.7	367.1	430.0	426.3
2008	Beacon N6	286.1	492.4	410.1	342.9	359.9	887.6	481.2	258.7	393.2	299.2	276.6	328.0	385.1
	Juliaa Port	357.8	536.2	417.2	263.8	309.4	712.6	353.5	249.0	388.5	362.8	396.4	444.7	387.6
	Salmiya	210.3	302.1	206.8	120.4	120.9	254.3	136.8	114.5	199.9	169.2	144.0	205.3	177.4
	South Dolphin	390.9	586.7	372.3	353.7	275.1	736.2	373.7	232.1	371.6	400.8	405.9	458.1	399.8
	Umm Almaradim	591.3	757.0	444.7	233.7	284.8	465.6	200.4	218.9	403.5	499.7	766.4	821.7	439.7

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	212.8	288.8	251.9	191.5	183.5	199.4	224.1	254.1	247.2	223.1	348.6	234.7	235.3
	Sea Island Buoy	256.1	307.7	235.8	158.6	167.5	141.2	244.0	301.1	280.2	253.0	459.5	334.7	251.2
	Ahmadi Oil Pier	321.9	394.1	347.9	271.1	343.0	312.3	811.8	597.3	344.9	219.4	317.0	232.6	358.7
2009	Beacon N6	276.3	344.1	354.9	261.4	352.8	359.6	705.8	646.9	359.3	239.6	272.3	178.5	345.3
	Juliaa Port	365.7	413.8	354.9	264.4	279.4	245.3	410.1	362.8	249.6	213.3	355.2	281.8	312.0
	Salmiya	142.6	159.9	152.1	137.7	132.0	144.0	198.5	246.2	155.5	121.6	203.9	130.2	158.0
	South Dolphin	389.4	351.9	383.4	286.7	288.5	343.6	642.6	596.3	387.6	282.4	366.3	259.9	372.7
	Umm Almaradim	646.9	712.6	332.0	259.6	269.8	198.4	363.5	394.7	373.3	368.6	568.2	495.2	396.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	318.6	210.8	278.1	237.6	192.3	229.3	238.5	201.4	175.5	188.1	172.7	172.7	215.6
	Sea Island Buoy	446.4	239.8	305.6	201.9	175.8	229.8	250.2	159.9	273.9	241.6	318.4	318.4	262.5
	Ahmadi Oil Pier	292.9	220.3	303.6	242.7	272.2	435.5	539.0	142.6	224.4	227.8	175.5	195.9	261.2
2010	Beacon N6	381.9	223.2	390.1	321.1	365.7	535.7	472.5	201.4	229.3	257.0	216.9	205.0	306.1
	Juliaa Port	350.0	266.8	335.4	298.3	257.0	286.7	364.3	185.8	234.8	230.5	209.1	221.7	266.5
	Salmiya	276.9	137.1	194.2	166.9	128.0	189.1	187.6	124.4	123.4	132.4	82.2	112.5	150.1
	South Dolphin	538.1	270.0	426.8	358.9	299.2	466.5	486.4	199.5	275.4	303.0	246.1	289.3	337.6
	Umm Almaradim	735.4	649.5	686.9	386.2	480.3	643.7	726.2	413.3	584.5	785.0	1028.3	927.4	652.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	268.6	255.2	270.4	361.1	174.9	253.1	182.1	189.9	180.6	316.0	350.8	207.3	245.2
	Sea Island Buoy	485.5	352.6	303.6	291.8	120.9	363.3	202.9	224.1	208.0	540.0	690.6	503.2	332.5
	Ahmadi Oil Pier	247.9	268.7	344.4	300.3	203.8	839.8	377.4	342.3	260.2	343.0	402.7	277.5	333.9
2011	Beacon N6	280.0	302.0	426.8	490.7	312.0	777.5	424.4	408.6	291.2	342.3	370.9	312.0	383.3
	Juliaa Port	340.2	295.0	284.2	385.4	215.8	495.3	278.8	228.9	166.4	404.7	501.7	269.2	311.4
	Salmiya	173.1	154.9	149.6	215.8	96.8	210.6	146.9	146.1	100.6	227.8	314.3	439.8	186.1
	South Dolphin	376.7	426.1	459.7	446.5	240.7	704.4	347.2	419.6	268.0	447.2	593.7	427.6	418.0
	Umm Almaradim	1053.2	644.8	586.3	560.2	414.1	1050.9	598.3	608.4	597.9	1125.1	1016.4	728.5	725.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	226.7	362.4	277.5	182.4	211.3	227.6	185.3	225.2	179.2	278.1	283.5	287.9	240.0
	Sea Island Buoy	352.8	480.3	345.8	132.7	147.7	260.8	177.1	306.9	260.0	0.0	0.0	433.6	266.0
	Ahmadi Oil Pier	232.0	358.5	327.3	183.4	221.5	625.3	349.3	560.9	309.6	247.9	288.0	261.6	316.4
2012	Beacon N6	241.3	484.0	491.7	276.0	279.4	639.3	391.7	562.8	328.7	257.0	297.7	254.7	360.8
	Juliaa Port	270.4	382.8	384.9	199.9	260.4	380.0	249.0	349.3	216.9	276.3	304.2	362.8	298.3
	Salmiya	339.5	488.7	575.5	401.1	460.6	880.8	699.1	679.2	476.3	532.5	339.3	339.5	502.3
	South Dolphin	292.9	616.9	518.6	297.7	249.6	606.2	384.1	567.7	324.6	337.5	387.7	352.1	398.3
	Umm Almaradim	587.3	839.0	694.6	201.4	293.5	329.4	217.4	296.0	290.5	467.4	559.2	652.2	419.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	270.4	194.5	313.4	246.1	253.6	284.2	198.5	154.5	205.0	205.8	302.3	375.9	245.9
	Sea Island Buoy	476.8	327.4	350.0	230.9	225.2	511.0	358.5	144.9	307.6	426.0	410.7	857.0	362.4
	Ahmadi Oil Pier	227.3	250.2	288.5	228.2	316.0	1239.8	826.7	211.3	278.5	302.4	290.5	376.7	357.0
2013	Beacon N6	290.4	358.9	432.4	310.9	418.0	1117.3	816.8	241.3	322.5	265.1	269.2	439.0	405.7
	Juliaa Port	301.1	286.8	397.8	269.9	308.8	664.6	407.8	185.3	228.7	310.1	360.4	538.1	341.5
	Salmiya	304.3	350.3	430.0	464.7	417.2	750.6	696.9	347.9	390.9	369.3	339.3	537.2	438.2
	South Dolphin	436.5	401.7	485.5	320.4	398.5	965.5	694.6	232.1	344.3	345.8	339.3	619.7	442.7
	Umm Almaradim	633.2	407.8	493.4	276.6	272.2	546.4	306.2	184.8	321.8	570.6	542.5	1122.1	439.7

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	197.1	241.0	195.1	193.5	133.1	209.1	272.2	235.3	176.8	346.5	210.6	100.4	203.0
	Sea Island Buoy	284.8	365.3	233.1	193.0	134.6	0.0	304.6	271.6	214.8	380.4	414.0	337.5	278.6
	Ahmadi Oil Pier	202.9	288.8	198.9	207.5	199.5	554.3	675.9	397.8	239.9	259.3	251.9	211.3	288.2
2014	Beacon N6	206.3	403.5	312.3	293.1	270.4	635.0	657.5	480.3	328.0	294.8	239.3	257.5	348.0
	Juliaa Port	247.9	299.9	302.9	243.8	175.8	361.1	364.3	301.1	198.4	359.2	312.9	222.6	277.1
	Salmiya	218.9	348.0	261.4	325.2	321.3	573.3	553.2	592.3	319.1	324.6	266.8	211.8	344.5
	South Dolphin	291.0	505.2	367.1	279.1	265.1	545.4	582.4	432.4	297.0	262.2	335.7	325.9	362.7
	Umm Almaradim	492.6	461.7	341.4	262.6	165.3	291.2	312.0	306.2	247.3	516.6	578.3	443.9	352.9

Table B.13: The monthly and annual average wind density (W/m^2) for eight marine locations at 120 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	596.1	619.6	460.6	285.9	309.3	693.6	358.3	286.6	497.8	400.9	414.2	265.7	416.3
	Sea Island Buoy	477.3	522.3	282.2	167.8	181.1	665.4	0.0	174.2	392.1	438.4	511.1	574.8	365.2
	Ahmadi Oil Pier	377.7	598.3	417.0	329.7	343.1	1282.9	529.7	307.3	449.4	390.0	396.9	465.0	460.9
2008	Beacon N6	309.3	532.5	443.5	370.7	389.2	959.7	520.3	279.8	425.2	323.5	299.1	354.6	416.4
	Juliaa Port	386.9	579.8	451.1	285.2	334.6	770.5	382.3	269.3	420.1	392.3	428.6	480.9	419.1
	Salmiya	227.4	326.7	223.6	130.2	130.8	274.9	148.0	123.8	216.2	183.0	155.8	222.0	191.8
	South Dolphin	422.7	634.4	402.5	382.5	297.5	796.0	404.1	250.9	401.8	433.4	438.9	495.3	432.3
	Umm Almaradim	639.4	818.5	480.9	252.7	308.0	503.5	216.7	236.7	436.3	540.3	828.8	888.5	475.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	230.1	312.3	272.3	207.1	198.4	215.6	242.3	274.8	267.3	241.2	377.0	253.8	254.5
	Sea Island Buoy	276.9	332.7	255.0	171.5	181.1	152.7	263.9	325.6	303.0	273.6	496.8	362.0	271.7
	Ahmadi Oil Pier	348.1	426.1	376.2	293.1	370.9	337.6	877.8	645.9	373.0	237.3	342.8	251.5	387.9
2009	Beacon N6	298.8	372.1	383.8	282.6	381.5	388.9	763.2	699.5	388.5	259.1	294.5	193.0	373.4
	Juliaa Port	395.4	447.5	383.8	285.9	302.1	265.2	443.5	392.3	269.9	230.7	384.1	304.7	337.4
	Salmiya	154.2	172.9	164.4	148.9	142.7	155.8	214.6	266.3	168.1	131.5	220.5	140.8	170.8
	South Dolphin	421.0	380.5	414.5	310.0	312.0	371.5	694.9	644.8	419.1	305.4	396.1	281.1	403.0
	Umm Almaradim	699.5	770.5	359.0	280.7	291.7	214.5	393.1	426.8	403.6	398.6	614.4	535.5	428.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	344.5	227.9	300.8	256.9	207.9	247.9	257.9	217.8	189.7	203.4	186.8	186.8	233.2
	Sea Island Buoy	482.7	259.3	330.4	218.3	190.1	248.5	270.5	172.9	296.1	261.2	344.2	344.2	283.9
	Ahmadi Oil Pier	316.7	238.3	328.3	262.4	294.3	470.9	582.8	154.2	242.6	246.3	189.7	211.9	282.4
2010	Beacon N6	412.9	241.4	421.9	347.2	395.4	579.3	510.9	217.8	247.9	277.9	234.5	221.6	330.9
	Juliaa Port	378.4	288.5	362.7	322.6	277.9	310.0	393.9	200.9	253.9	249.2	226.1	239.7	288.2
	Salmiya	299.5	148.2	210.0	180.4	138.4	204.5	202.9	134.6	133.4	143.1	88.9	121.6	162.3
	South Dolphin	581.8	292.0	461.5	388.1	323.5	504.4	525.9	215.7	297.8	327.6	266.1	312.8	365.0
	Umm Almaradim	795.2	702.2	742.7	417.6	519.3	696.0	785.3	446.9	632.0	848.8	1111.9	1002.8	706.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	290.4	276.0	292.4	390.5	189.1	273.7	196.9	205.4	195.2	341.7	379.3	224.2	265.1
	Sea Island Buoy	525.0	381.3	328.3	315.6	130.8	392.9	219.4	242.3	224.9	583.9	746.8	544.2	359.5
	Ahmadi Oil Pier	268.1	290.6	372.4	324.7	220.4	908.1	408.1	370.1	281.3	370.9	435.4	300.1	361.1
2011	Beacon N6	302.7	326.6	461.5	530.6	337.4	840.7	458.9	441.8	314.9	370.1	401.0	337.4	414.4
	Juliaa Port	367.9	319.0	307.3	416.7	233.4	535.5	301.4	247.5	180.0	437.6	542.5	291.1	336.7
	Salmiya	187.2	167.5	161.8	233.4	104.6	227.7	158.8	158.0	108.8	246.3	339.8	475.5	201.2
	South Dolphin	407.3	460.8	497.1	482.8	260.3	761.7	375.4	453.7	289.8	483.5	642.0	462.4	452.0
	Umm Almaradim	1138.8	697.2	634.0	605.8	447.7	1136.3	647.0	657.9	646.5	1216.6	1099.1	787.7	784.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	245.2	391.8	300.1	197.3	228.5	246.1	200.4	243.5	193.7	300.8	306.6	311.3	259.5
	Sea Island Buoy	381.5	519.3	373.9	143.5	159.7	282.0	191.5	331.8	281.2	0.0	0.0	468.9	287.6
	Ahmadi Oil Pier	250.9	387.7	353.9	198.3	239.5	676.1	377.7	606.5	334.7	268.1	311.4	282.8	342.2
2012	Beacon N6	260.9	523.3	531.7	298.5	302.1	691.3	423.5	608.6	355.4	277.9	321.9	275.4	390.1
	Juliaa Port	292.4	413.9	416.2	216.2	281.6	410.9	269.3	377.7	234.5	298.8	329.0	392.3	322.6
	Salmiya	367.1	528.4	622.3	433.7	498.0	952.5	755.9	734.4	515.0	575.8	366.9	367.1	543.2
	South Dolphin	316.7	667.1	560.8	321.9	269.9	655.5	415.4	613.8	350.9	364.9	419.2	380.7	430.7
	Umm Almaradim	635.1	907.2	751.0	217.8	317.4	356.2	235.1	320.1	314.2	505.4	604.7	705.2	453.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	292.4	210.3	338.8	266.1	274.2	307.3	214.6	167.0	221.6	222.6	326.8	406.5	265.9
	Sea Island Buoy	515.6	354.0	378.4	249.7	243.5	552.5	387.7	156.7	332.6	460.6	444.1	926.7	391.9
	Ahmadi Oil Pier	245.7	270.6	312.0	246.7	341.7	1340.5	893.9	228.5	301.2	327.0	314.2	407.3	386.1
2013	Beacon N6	314.0	388.1	467.6	336.2	452.0	1208.1	883.2	260.9	348.7	286.6	291.1	474.6	438.6
	Juliaa Port	325.6	310.1	430.1	291.8	333.9	718.7	441.0	200.4	247.3	335.3	389.7	581.8	369.2
	Salmiya	329.0	378.8	465.0	502.5	451.1	811.6	753.5	376.2	422.6	399.4	366.9	580.8	473.8
	South Dolphin	472.0	434.4	525.0	346.5	430.9	1044.0	751.1	250.9	372.3	373.9	366.9	670.1	478.7
	Umm Almaradim	684.7	440.9	533.6	299.1	294.3	590.8	331.1	199.9	348.0	617.0	586.6	1213.3	475.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	213.1	260.6	211.0	209.2	143.9	226.1	294.3	254.4	191.2	374.7	227.7	108.6	219.5
	Sea Island Buoy	308.0	395.0	252.1	208.7	145.5	0.0	329.3	293.6	232.2	411.3	447.6	364.9	301.2
	Ahmadi Oil Pier	219.4	312.3	215.1	224.4	215.7	599.3	730.9	430.1	259.4	280.4	272.4	228.5	311.7
2014	Beacon N6	223.1	436.3	337.6	317.0	292.4	686.6	711.0	519.3	354.7	318.7	258.8	278.5	376.2
	Juliaa Port	268.1	324.3	327.5	263.7	190.1	390.5	393.9	325.6	214.5	388.4	338.4	240.6	299.7
	Salmiya	236.7	376.3	282.6	351.7	347.4	619.9	598.2	640.5	345.0	351.0	288.5	229.0	372.5
	South Dolphin	314.7	546.3	396.9	301.8	286.6	589.8	629.7	467.6	321.2	283.5	363.0	352.4	392.2
	Umm Almaradim	532.6	499.3	369.2	283.9	178.8	314.9	337.4	331.1	267.4	558.6	625.3	480.0	381.6

Table B.14: The monthly and annual average wind density (W/m^2) for eight marine locations at 140 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	636.9	661.9	492.1	305.4	330.5	741.0	382.7	306.2	531.8	428.3	442.5	283.8	444.7
	Sea Island Buoy	509.9	558.0	301.5	179.3	193.5	710.9	0.0	186.1	418.9	468.4	546.0	614.0	390.1
	Ahmadi Oil Pier	403.5	639.2	445.5	352.2	366.5	1370.6	565.9	328.3	480.1	416.6	424.0	496.7	492.4
2008	Beacon N6	330.5	568.9	473.8	396.1	415.8	1025.3	555.8	298.9	454.2	345.6	319.6	378.8	444.9
	Juliaa Port	413.3	619.4	482.0	304.7	357.5	823.1	408.4	287.7	448.8	419.1	457.9	513.7	447.8
	Salmiya	242.9	349.0	238.9	139.1	139.7	293.7	158.1	132.2	230.9	195.5	166.4	237.2	204.9
	South Dolphin	451.6	677.7	430.0	408.6	317.8	850.4	431.7	268.1	429.3	463.0	468.9	529.1	461.8
	Umm Almaradim	683.1	874.4	513.7	270.0	329.0	537.9	231.5	252.9	466.1	577.2	885.4	949.2	508.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	245.8	333.6	290.9	221.2	211.9	230.4	258.9	293.6	285.6	257.7	402.7	271.2	271.9
	Sea Island Buoy	295.8	355.4	272.4	183.2	193.5	163.2	281.9	347.8	323.7	292.2	530.8	386.7	290.2
	Ahmadi Oil Pier	371.9	455.3	401.9	313.1	396.2	360.7	937.8	690.0	398.5	253.5	366.2	268.7	414.4
2009	Beacon N6	319.2	397.5	410.0	301.9	407.6	415.4	815.3	747.2	415.0	276.8	314.6	206.2	398.9
	Juliaa Port	422.5	478.0	410.0	305.4	322.7	283.3	473.8	419.1	288.3	246.4	410.3	325.5	360.4
	Salmiya	164.7	184.8	175.6	159.1	152.5	166.4	229.3	284.5	179.6	140.5	235.6	150.4	182.5
	South Dolphin	449.8	406.5	442.9	331.2	333.3	396.9	742.4	688.8	447.7	326.2	423.2	300.3	430.5
	Umm Almaradim	747.2	823.1	383.5	299.9	311.6	229.2	419.9	455.9	431.2	425.8	656.4	572.1	457.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	368.0	243.5	321.3	274.5	222.1	264.9	275.5	232.7	202.7	217.3	199.5	199.5	249.1
	Sea Island Buoy	515.6	277.0	353.0	233.3	203.1	265.5	289.0	184.7	316.3	279.0	367.8	367.8	303.3
	Ahmadi Oil Pier	338.3	254.5	350.8	280.4	314.4	503.1	622.7	164.7	259.2	263.1	202.7	226.3	301.7
2010	Beacon N6	441.1	257.9	450.7	370.9	422.5	618.8	545.8	232.7	264.9	296.8	250.6	236.8	353.6
	Juliaa Port	404.3	308.2	387.5	344.6	296.8	331.2	420.8	214.6	271.2	266.2	241.5	256.1	307.9
	Salmiya	319.9	158.4	224.3	192.8	147.9	218.4	216.7	143.8	142.5	152.9	95.0	129.9	173.4
	South Dolphin	621.6	311.9	493.0	414.6	345.6	538.9	561.9	230.4	318.1	350.0	284.3	334.1	389.9
	Umm Almaradim	849.5	750.2	793.5	446.1	554.8	743.5	838.9	477.4	675.1	906.8	1187.9	1071.3	754.2

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	310.3	294.8	312.3	417.1	202.0	292.4	210.4	219.4	208.6	365.0	405.3	239.5	283.2
	Sea Island Buoy	560.9	407.4	350.8	337.1	139.7	419.7	234.3	258.9	240.3	623.8	797.8	581.3	384.1
	Ahmadi Oil Pier	286.4	310.4	397.8	346.9	235.5	970.1	436.0	395.4	300.6	396.2	465.2	320.6	385.7
2011	Beacon N6	323.4	348.9	493.0	566.8	360.5	898.2	490.2	472.0	336.4	395.4	428.4	360.5	442.7
	Juliaa Port	393.0	340.8	328.3	445.2	249.3	572.1	322.0	264.4	192.3	467.5	579.5	311.0	359.7
	Salmiya	200.0	178.9	172.9	249.3	111.8	243.3	169.7	168.7	116.3	263.1	363.1	508.0	215.0
	South Dolphin	435.1	492.3	531.1	515.8	278.1	813.7	401.1	484.7	309.6	516.6	685.8	493.9	482.8
	Umm Almaradim	1216.6	744.8	677.3	647.2	478.3	1213.9	691.2	702.9	690.6	1299.7	1174.1	841.6	838.1

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	261.9	418.6	320.6	210.7	244.1	263.0	214.1	260.1	207.0	321.3	327.5	332.6	277.3
	Sea Island Buoy	407.6	554.8	399.4	153.3	170.6	301.3	204.6	354.5	300.4	0.0	0.0	500.9	307.3
	Ahmadi Oil Pier	268.0	414.2	378.1	211.8	255.9	722.3	403.5	647.9	357.6	286.4	332.7	302.2	365.5
2012	Beacon N6	278.7	559.1	568.0	318.9	322.7	738.5	452.4	650.2	379.7	296.8	343.9	294.2	416.7
	Juliaa Port	312.3	442.1	444.6	230.9	300.8	439.0	287.7	403.5	250.6	319.2	351.5	419.1	344.6
	Salmiya	392.2	564.5	664.8	463.4	532.1	1017.5	807.6	784.6	550.1	615.1	391.9	392.2	580.3
	South Dolphin	338.3	712.6	599.1	343.9	288.3	700.3	443.7	655.8	374.9	389.8	447.9	406.7	460.1
	Umm Almaradim	678.5	969.2	802.3	232.7	339.1	380.5	251.1	342.0	335.6	539.9	646.0	753.4	484.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	312.3	224.7	362.0	284.3	292.9	328.3	229.3	178.5	236.8	237.8	349.2	434.3	284.1
	Sea Island Buoy	550.8	378.2	404.3	266.8	260.1	590.3	414.1	167.4	355.3	492.1	474.5	990.0	418.7
	Ahmadi Oil Pier	262.5	289.0	333.3	263.6	365.0	1432.1	955.0	244.1	321.7	349.3	335.6	435.1	412.4
2013	Beacon N6	335.5	414.6	499.5	359.2	482.9	1290.7	943.5	278.7	372.5	306.2	311.0	507.1	468.6
	Juliaa Port	347.8	331.2	459.5	311.7	356.7	767.8	471.1	214.1	264.2	358.2	416.3	621.6	394.4
	Salmiya	351.5	404.7	496.7	536.8	482.0	867.1	805.0	401.9	451.5	426.7	391.9	620.5	506.2
	South Dolphin	504.2	464.1	560.9	370.1	460.4	1115.3	802.4	268.1	397.7	399.4	391.9	715.9	511.4
	Umm Almaradim	731.4	471.0	570.0	319.6	314.4	631.2	353.7	213.5	371.7	659.1	626.7	1296.2	507.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	227.6	278.4	225.4	223.5	153.8	241.5	314.4	271.8	204.3	400.3	243.3	116.0	234.5
	Sea Island Buoy	329.0	422.0	269.3	222.9	155.5	0.0	351.8	313.7	248.1	439.4	478.2	389.8	321.8
	Ahmadi Oil Pier	234.3	333.6	229.8	239.7	230.4	640.3	780.8	459.5	277.1	299.5	291.0	244.1	332.9
2014	Beacon N6	238.3	466.1	360.7	338.6	312.3	733.5	759.6	554.8	378.9	340.5	276.4	297.5	402.0
	Juliaa Port	286.4	346.4	349.9	281.7	203.1	417.1	420.8	347.8	229.2	415.0	361.5	257.1	320.1
	Salmiya	252.9	402.0	301.9	375.7	371.1	662.2	639.1	684.2	368.6	375.0	308.2	244.7	397.9
	South Dolphin	336.2	583.6	424.0	322.5	306.2	630.1	672.7	499.5	343.1	302.8	387.8	376.5	419.0
	Umm Almaradim	569.0	533.4	394.4	303.3	191.0	336.4	360.5	353.7	285.7	596.8	668.1	512.8	407.7

Table B.15: The monthly and annual average wind density (W/m^2) for eight marine locations at 160 m elevation from 2009 - 2014.

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	674.4	700.9	521.1	323.4	349.9	784.7	405.3	324.2	563.1	453.6	468.6	300.5	470.9
	Sea Island Buoy	540.0	590.9	319.3	189.8	204.9	752.8	0.0	197.1	443.5	496.0	578.2	650.2	413.1
	Ahmadi Oil Pier	427.3	676.9	471.7	373.0	388.1	1451.3	599.3	347.7	508.4	441.2	449.0	526.0	521.4
2008	Beacon N6	349.9	602.4	501.7	419.4	440.3	1085.7	588.6	316.5	481.0	366.0	338.4	401.2	471.1
	Juliaa Port	437.7	655.9	510.4	322.7	378.5	871.6	432.4	304.6	475.2	443.8	484.8	544.0	474.1
	Salmiya	257.2	369.6	253.0	147.3	147.9	311.0	167.4	140.0	244.5	207.0	176.2	251.2	217.0
	South Dolphin	478.2	717.6	455.4	432.7	336.6	900.5	457.2	283.9	454.6	490.3	496.5	560.3	489.0
	Umm Almaradim	723.3	925.9	544.0	285.9	348.4	569.6	245.2	267.8	493.6	611.2	937.5	1005.1	537.9

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	260.3	353.3	308.1	234.3	224.4	243.9	274.1	310.8	302.4	272.9	426.5	287.1	287.9
	Sea Island Buoy	313.3	376.4	288.5	194.0	204.9	172.8	298.5	368.3	342.7	309.5	562.1	409.5	307.3
	Ahmadi Oil Pier	393.8	482.1	425.5	331.6	419.6	382.0	993.0	730.7	421.9	268.4	387.8	284.5	438.8
2009	Beacon N6	338.0	420.9	434.2	319.7	431.6	439.9	863.4	791.3	439.5	293.1	333.1	218.3	422.4
	Juliaa Port	447.3	506.2	434.2	323.4	341.7	300.0	501.7	443.8	305.3	260.9	434.5	344.7	381.6
	Salmiya	174.4	195.6	186.0	168.4	161.5	176.2	242.8	301.2	190.2	148.8	249.5	159.2	193.3
	South Dolphin	476.3	430.4	469.0	350.7	353.0	420.3	786.1	729.4	474.1	345.4	448.1	318.0	455.8
	Umm Almaradim	791.3	871.6	406.1	317.5	330.0	242.7	444.7	482.8	456.6	450.9	695.1	605.8	484.4

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	389.7	257.8	340.2	290.6	235.2	280.5	291.8	246.4	214.6	230.1	211.3	211.3	263.8
	Sea Island Buoy	546.0	293.3	373.8	247.0	215.0	281.1	306.0	195.6	335.0	295.5	389.4	389.4	321.1
	Ahmadi Oil Pier	358.3	269.5	371.4	296.9	332.9	532.7	659.4	174.4	274.5	278.6	214.6	239.7	319.5
2010	Beacon N6	467.1	273.1	477.2	392.8	447.3	655.3	578.0	246.4	280.5	314.3	265.3	250.7	374.4
	Juliaa Port	428.1	326.3	410.3	364.9	314.3	350.7	445.6	227.2	287.2	281.9	255.7	271.2	326.0
	Salmiya	338.8	167.7	237.5	204.1	156.6	231.3	229.5	152.2	150.9	161.9	100.6	137.6	183.6
	South Dolphin	658.2	330.3	522.1	439.0	366.0	570.6	595.0	244.0	336.9	370.6	301.1	353.8	412.9
	Umm Almaradim	899.6	794.4	840.2	472.4	587.5	787.3	888.3	505.5	714.9	960.2	1257.9	1134.4	798.6

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	328.6	312.2	330.7	441.7	214.0	309.6	222.7	232.3	220.9	386.5	429.1	253.6	299.9
	Sea Island Buoy	593.9	431.4	371.4	357.0	147.9	444.5	248.2	274.1	254.5	660.5	844.8	615.6	406.7
	Ahmadi Oil Pier	303.3	328.7	421.3	367.3	249.4	1027.3	461.7	418.7	318.3	419.6	492.6	339.5	408.5
2011	Beacon N6	342.5	369.4	522.1	600.2	381.7	951.1	519.1	499.8	356.2	418.7	453.6	381.7	468.8
	Juliaa Port	416.2	360.9	347.7	471.4	264.0	605.8	341.0	279.9	203.6	495.0	613.7	329.3	380.9
	Salmiya	211.8	189.5	183.0	264.0	118.4	257.6	179.6	178.7	123.1	278.6	384.4	537.9	227.6
	South Dolphin	460.8	521.3	562.4	546.2	294.5	861.7	424.7	513.3	327.9	547.0	726.2	523.0	511.3
	Umm Almaradim	1288.2	788.7	717.2	685.3	506.5	1285.4	731.9	744.3	731.3	1376.3	1243.3	891.1	887.5

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	277.4	443.3	339.5	223.2	258.5	278.5	226.7	275.4	219.1	340.2	346.8	352.2	293.6
	Sea Island Buoy	431.6	587.5	423.0	162.3	180.6	319.0	216.7	375.4	318.1	0.0	0.0	530.4	325.4
	Ahmadi Oil Pier	283.8	438.6	400.3	224.3	271.0	764.9	427.3	686.1	378.7	303.3	352.3	320.0	387.1
2012	Beacon N6	295.1	592.0	601.4	337.6	341.7	782.0	479.1	688.5	402.1	314.3	364.1	311.5	441.3
	Juliaa Port	330.7	468.2	470.8	244.5	318.6	464.8	304.6	427.3	265.3	338.0	372.2	443.8	364.9
	Salmiya	415.3	597.8	703.9	490.7	563.4	1077.5	855.1	830.8	582.6	651.3	415.0	415.3	614.5
	South Dolphin	358.3	754.6	634.4	364.1	305.3	741.5	469.9	694.4	397.0	412.8	474.3	430.7	487.2
	Umm Almaradim	718.4	1026.3	849.6	246.4	359.0	403.0	265.9	362.1	355.4	571.7	684.1	797.8	513.0

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	330.7	238.0	383.3	301.1	310.2	347.6	242.8	189.0	250.7	251.8	369.7	459.9	300.8
	Sea Island Buoy	583.3	400.5	428.1	282.5	275.4	625.1	438.5	177.2	376.2	521.1	502.4	1048.3	443.4
	Ahmadi Oil Pier	278.0	306.1	353.0	279.1	386.5	1516.5	1011.2	258.5	340.7	369.9	355.4	460.8	436.7
2013	Beacon N6	355.2	439.1	529.0	380.3	511.3	1366.7	999.1	295.1	394.5	324.2	329.4	536.9	496.2
	Juliaa Port	368.3	350.8	486.5	330.1	377.7	813.0	498.8	226.7	279.8	379.3	440.8	658.2	417.7
	Salmiya	372.2	428.5	526.0	568.5	510.4	918.2	852.4	425.5	478.1	451.8	415.0	657.1	536.0
	South Dolphin	533.9	491.4	593.9	391.9	487.5	1181.0	849.7	283.9	421.2	423.0	415.0	758.0	541.5
	Umm Almaradim	774.5	498.8	603.6	338.4	332.9	668.4	374.6	226.1	393.6	698.0	663.6	1372.6	537.8

	Station	January	February	March	April	May	June	July	August	September	October	November	December	Annually
	Beacon M28	241.0	294.8	238.7	236.7	162.8	255.7	332.9	287.8	216.3	423.8	257.6	122.8	248.4
	Sea Island Buoy	348.4	446.9	285.2	236.1	164.6	0.0	372.6	332.2	262.7	465.3	506.4	412.8	340.7
	Ahmadi Oil Pier	248.2	353.3	243.3	253.8	244.0	678.0	826.8	486.5	293.4	317.1	308.2	258.5	352.6
2014	Beacon N6	252.4	493.5	382.0	358.6	330.7	776.7	804.3	587.5	401.2	360.6	292.7	315.0	425.6
	Juliaa Port	303.3	366.9	370.5	298.3	215.0	441.7	445.6	368.3	242.7	439.4	382.8	272.2	339.0
	Salmiya	267.8	425.6	319.7	397.8	393.0	701.2	676.7	724.5	390.3	397.1	326.4	259.1	421.4
	South Dolphin	356.0	618.0	449.0	341.4	324.2	667.2	712.4	529.0	363.3	320.7	410.7	398.7	443.7
	Umm Almaradim	602.5	564.8	417.6	321.2	202.2	356.2	381.7	374.6	302.5	632.0	707.4	543.0	431.7

APPENDIX C

TEMPERATURE AND WIND SPEED CORRELATION, AND WEIBULL PDF

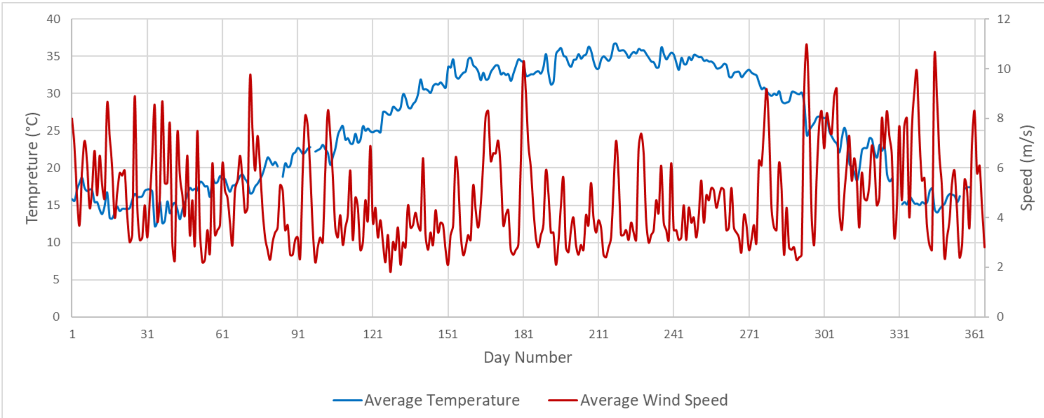

Figure C.1: Temperature versus wind speed during a year for Sea Island Buoy location.

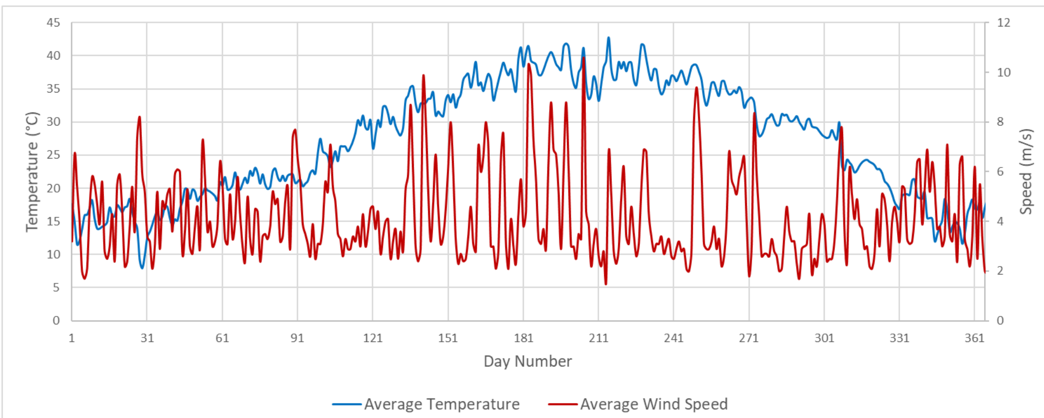

Figure C.2: Temperature versus wind speed during a year for Ahmadi Oil Pier location.

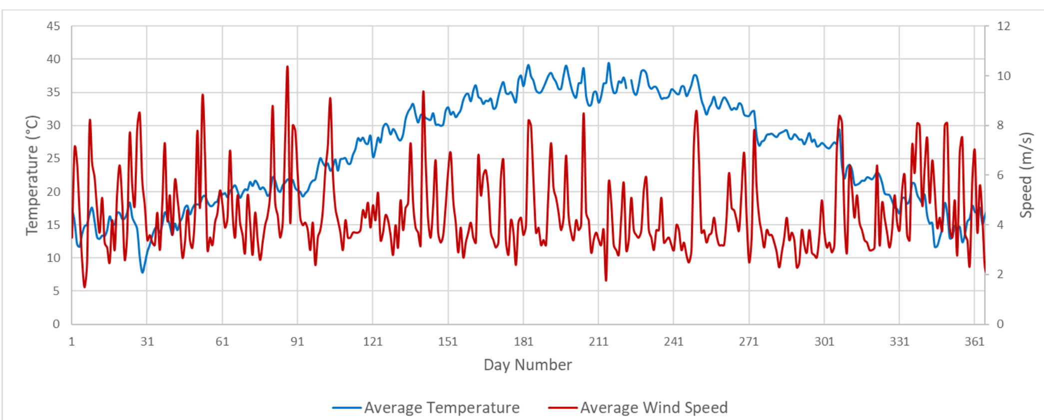

Figure C.3: Temperature versus wind speed during a year for Beacon N6 location

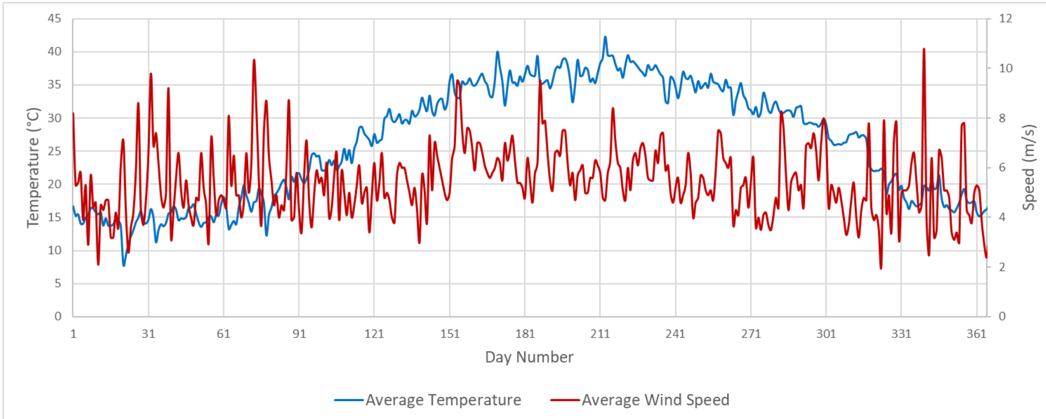

Figure C.4: Temperature versus wind speed during a year for Juliaa Port location.

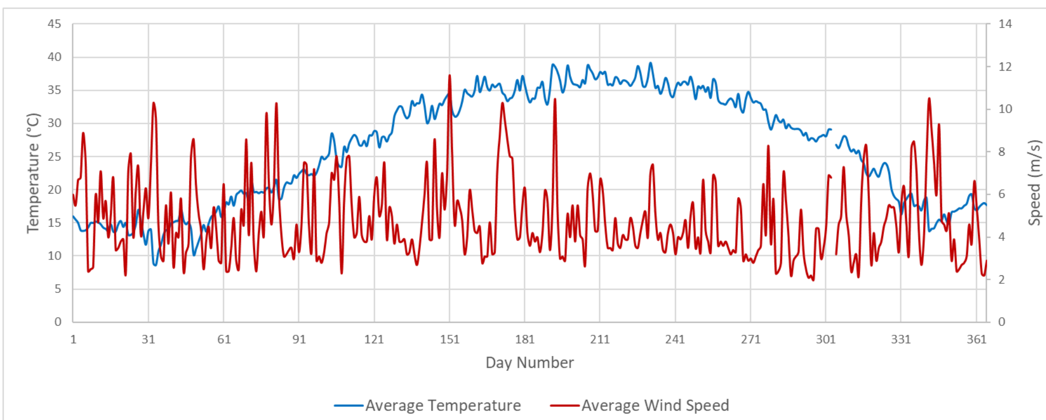

Figure C.5: Temperature versus wind speed during a year for Salmiya location.

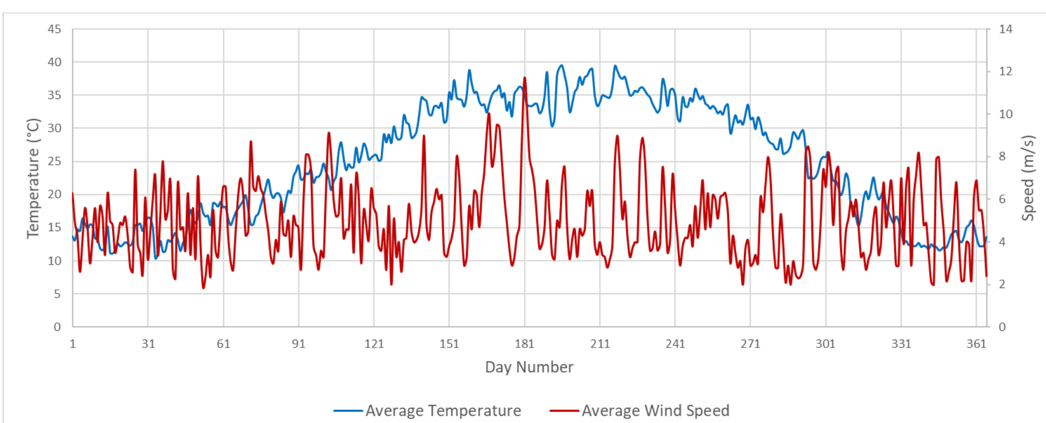

Figure C.6: Temperature versus wind speed during a year for South Dolphin location.

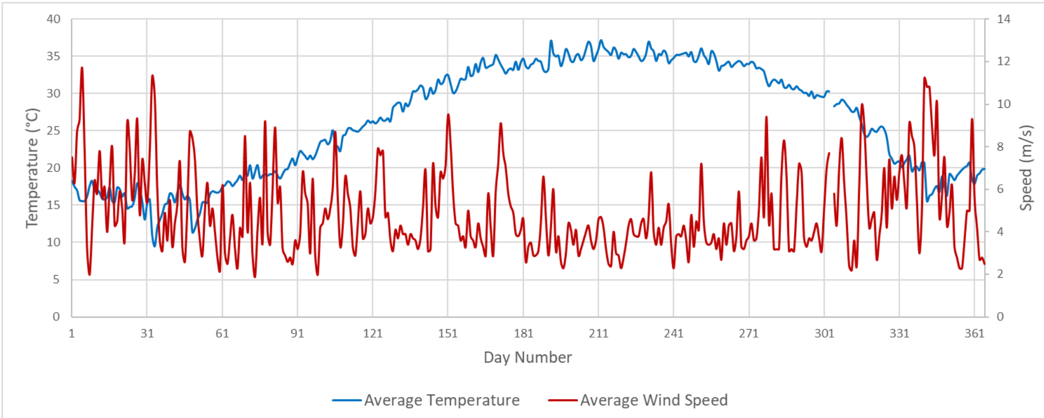

Figure C.7: Temperature versus wind speed during a year for Umm Almaradim Island location.

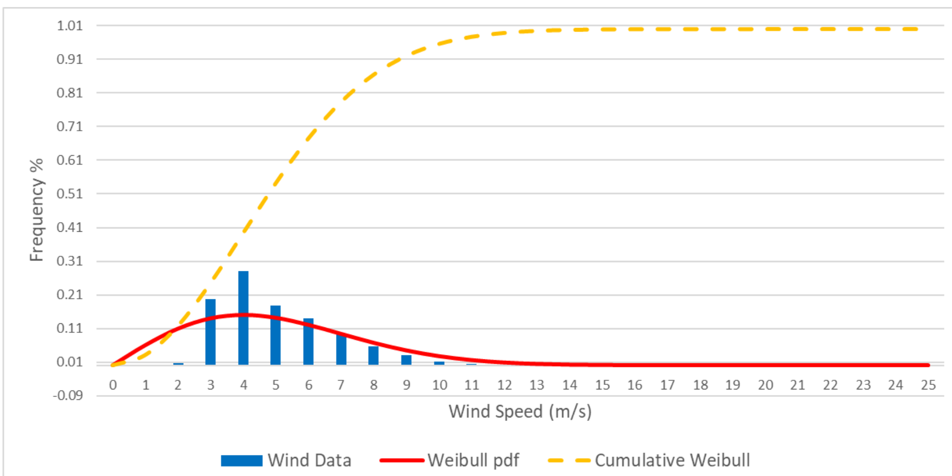

Figure C.8: Measured wind speed and Weibull distribution of Sea Island Buoy location.

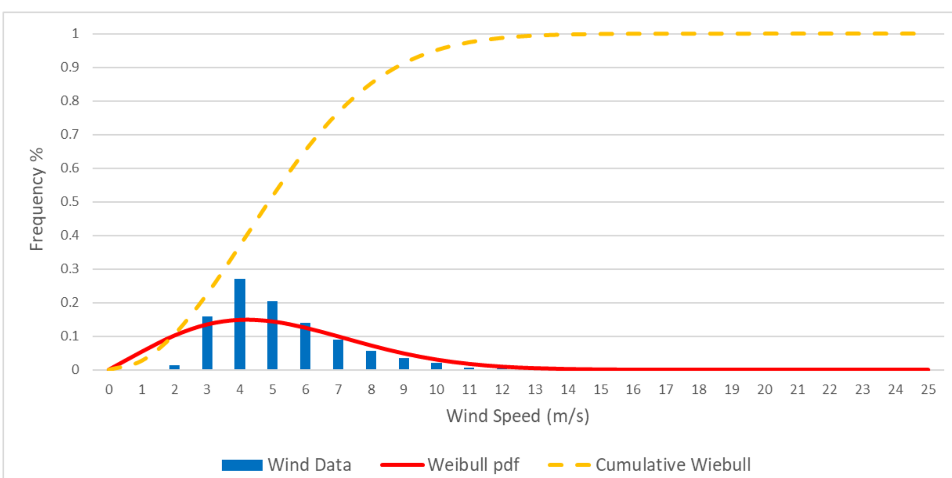

Figure C.9: Measured wind speed and Weibull distribution of Ahmadi Oil Pier location.

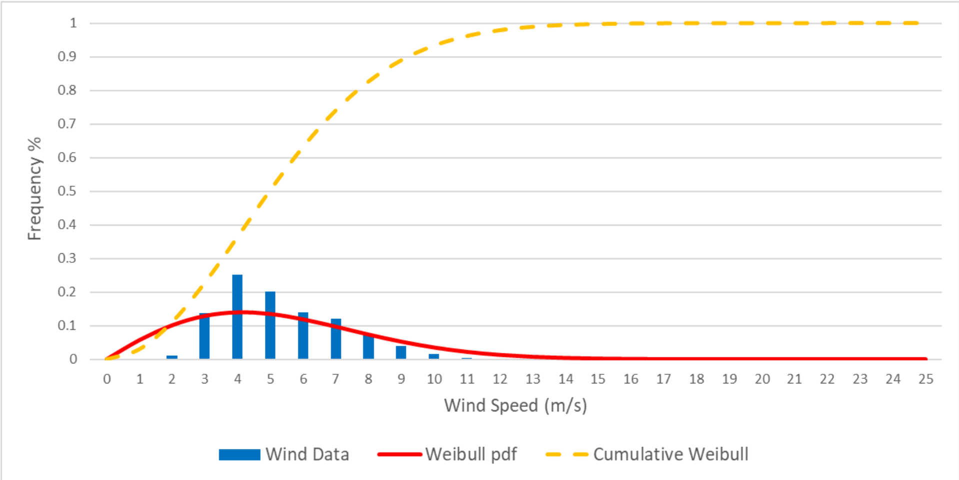

Figure C.10: Measured wind speed and Weibull distribution of Beacon N6 location.

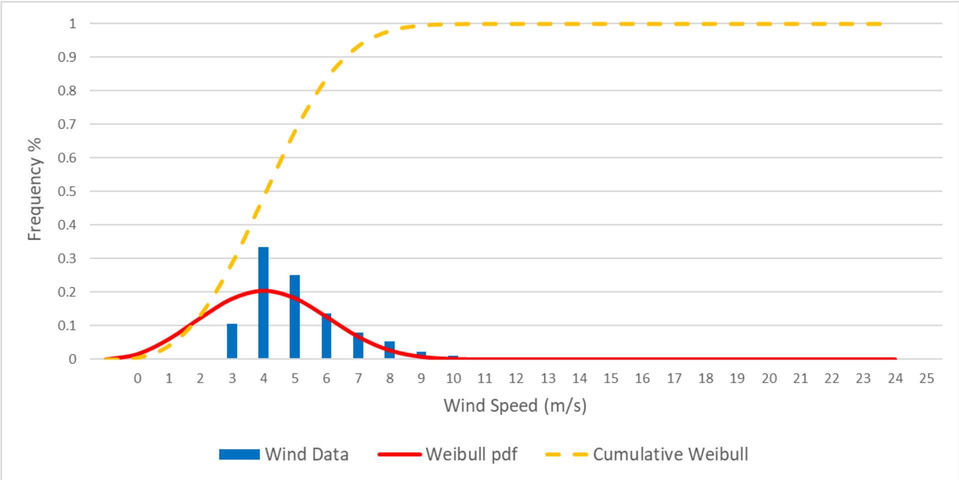

Figure C.11: Measured wind speed and Weibull distribution of Juliaa Port location.

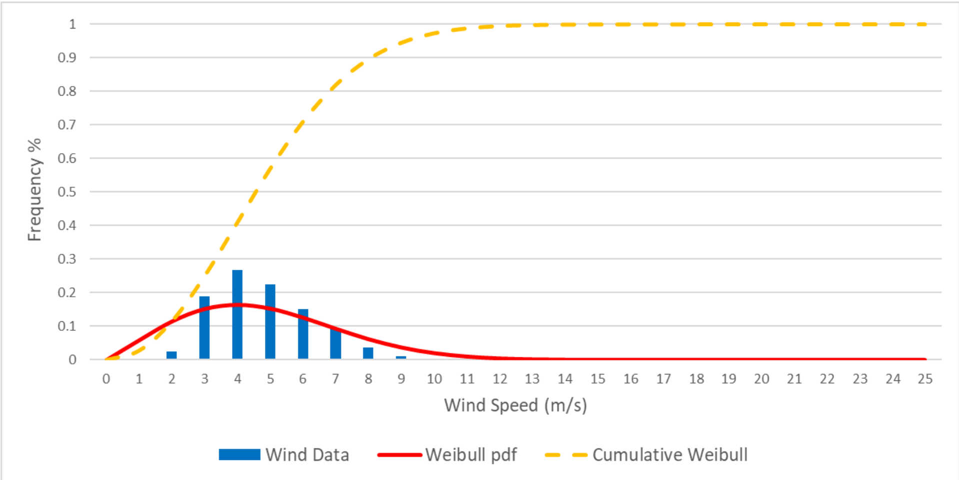

Figure C.12: Measured wind speed and Weibull distribution of Salmiya location.

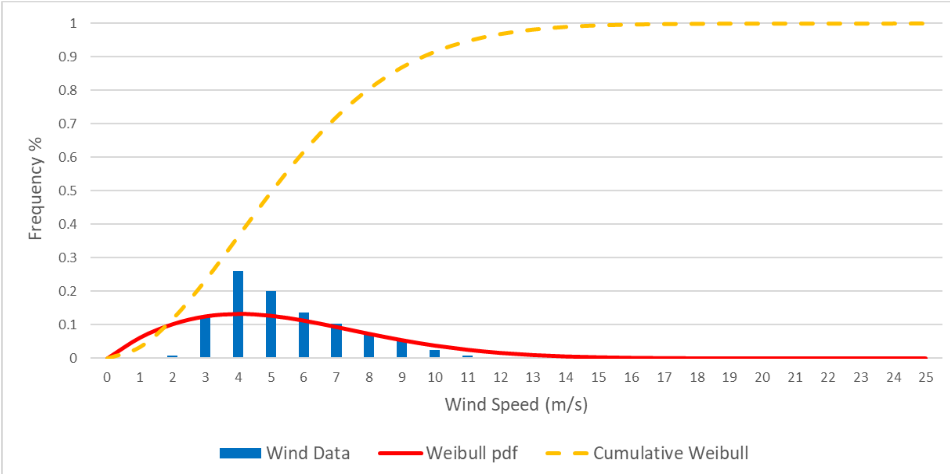

Figure C.13: Measured wind speed and Weibull distribution of South Dolphin location.

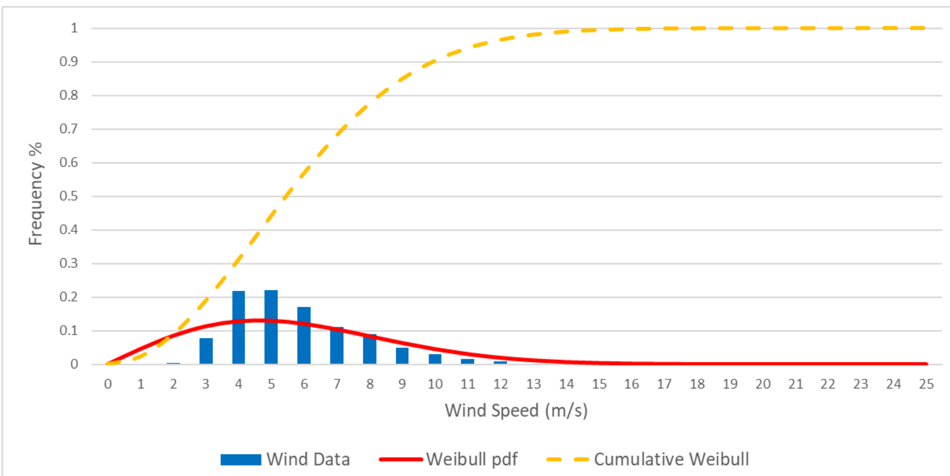

Figure C.14: Measured wind speed and Weibull distribution of Umm Almaradim Island location.

APPENDIX D

ELECTRIC AND LCOE DETAILS

Table D.1: Electric details including the LCOE for six wind turbines of Sea Island Buoy location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	940	940	1455	1455	1455	1588
Average Energy (kWh/yr)	8,230,579	8,230,579	12,746,219	12,746,219	12,746,219	13,909,678
Average Efficiency (%)	0.38	0.40	0.39	0.39	0.34	0.46
Capacity Factor (CF)	0.15	0.15	0.19	0.17	0.14	0.17
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	3107	3309	4954	5005	4313	6365
Levelized Variable Cost (LVC) $/MWh	20					
Levelized Cost of Energy (LCOE) $/MWh	77.15	78.32	70.67	75.16	86.93	75.21

Table D.2: Electric details including the LCOE for six wind turbines of Ahmadi Oil Pier location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	1030	1030	1595	1595	1595	1741
Average Energy (kWh/yr)	9,024,987	9,024,987	13,976,473	13,976,473	13,976,473	15,252,227
Average Efficiency (%)	0.37	0.39	0.38	0.38	0.33	0.45
Capacity Factor (CF)	0.17	0.16	0.20	0.19	0.15	0.18
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	3331	3545	5291	5349	4647	6788
Levelized Variable Cost (LVC) $/MWh	15					
Levelized Cost of Energy (LCOE) $/MWh	68.31	69.43	62.43	66.62	77.11	66.77

Table D.3: Electric details including the LCOE for six wind turbines of Beacon N6 location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	1117	1117	1731	1731	1731	1889
Average Energy (kWh/yr)	9,788,994	9,788,994	15,159,648	15,159,648	15,159,648	16,543,401
Average Efficiency (%)	0.38	0.40	0.38	0.39	0.35	0.45
Capacity Factor (CF)	0.18	0.18	0.22	0.20	0.17	0.20
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	3697	3937	5795	5888	5244	7448
Levelized Variable Cost (LVC) $/MWh	15					
Levelized Cost of Energy (LCOE) $/MWh	63.03	64.00	58.31	61.89	70.05	62.18

Table D.4: Electric details including the LCOE for six wind turbines of Juliaa Port location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	975	975	1510	1510	1510	1648
Average Energy (kWh/yr)	8,543,996	8,543,996	13,231,591	13,231,591	13,231,591	14,439,353
Average Efficiency (%)	0.30	0.31	0.32	0.31	0.24	0.37
Capacity Factor (CF)	0.13	0.12	0.16	0.14	0.10	0.15
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	2523	2678	4188	4158	3157	5389
Levelized Variable Cost (LVC) $/MWh	15					
Levelized Cost of Energy (LCOE) $/MWh	85.39	87.06	74.93	81.40	106.44	80.21

Table D.5: Electric details including the LCOE for six wind turbines of Salmiya location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	824	824	1276	1276	1276	1393
Average Energy (kWh/yr)	7,219,141	7,219,141	11,179,865	11,179,865	11,179,865	12,200,349
Average Efficiency (%)	0.36	0.39	0.38	0.38	0.32	0.45
Capacity Factor (CF)	0.13	0.13	0.16	0.15	0.12	0.15
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	2632	2804	4272	4293	3554	5499
Levelized Variable Cost (LVC) $/MWh	15					
Levelized Cost of Energy (LCOE) $/MWh	82.46	83.81	73.75	79.31	96.23	78.90

Table D.6: Electric details including the LCOE for six wind turbines of South Dolphin location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	1193	1193	1847	1847	1847	2016
Average Energy (kWh/yr)	10,449,019	10,449,019	16,181,790	16,181,790	16,181,790	17,658,843
Average Efficiency (%)	0.39	0.41	0.39	0.39	0.36	0.45
Capacity Factor (CF)	0.20	0.20	0.24	0.22	0.19	0.22
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	4025	4290	6231	6362	5778	8034
Levelized Variable Cost (LVC) $/MWh	15					
Levelized Cost of Energy (LCOE) $/MWh	59.12	59.97	55.28	58.40	64.95	58.74

Table D.7: Electric details including the LCOE for six wind turbines of Umm Almaradim Island location.

Turbine Brand & Size	Nordex N90/2300	Nordex N90/2500	Vestas V112/3000	Vestas V112/3300	Vestas V112/3450	MHI Vestas V117/4200
Average Power (kW)	1451	1451	2247	2247	2247	2452
Average Energy (kWh/yr)	12,709,195	12,709,195	19,681,993	19,681,993	19,681,993	21,478,539
Average Efficiency (%)	0.36	0.38	0.36	0.36	0.33	0.42
Capacity Factor (CF)	0.23	0.22	0.27	0.25	0.22	0.24
Total Installed Cost (TIC) $	2,080,000	2,260,000	2,940,000	3,234,000	3,381,000	4,116,000
Total Annual Energy (Q) (MWh/yr)	4542	4837	7009	7156	6556	9011
Levelized Variable Cost (LVC) $/MWh	25					
Levelized Cost of Energy (LCOE) $/MWh	64.10	64.89	60.81	63.58	69.03	64.00