ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

A POTENTIAL OFFSHORE WIND FARM ARRANGEMENT OFF THE BOZCAADA SHORES

M.Sc. THESIS

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BOZCAADA AÇIKLARINDA POTANSİYEL AÇIK DENİZ RÜZGAR ÇİFTLİĞİ TASARIMI

YÜKSEK LİSANS TEZİ

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Oğuzhan TURHANLAR, a M.Sc. student of ITU Graduate School of Science Engineering and Technology student ID 508151209, successfully defended the dissertation entitled "A POTENTIAL OFFSHORE WIND FARM ARRANGEMENT OFF THE BOZCAADA SHORES" which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

This dissertation thesis started from an urge to learn and research more about Turkey's and World's renewable offshore energy industry.

Firstly, I would like to thank my thesis advisor Prof. Dr. Serdar BEJİ for his valuable support and guidance over the course of this dissertation.

I would like to express my love and gratitude to my dear family and my beloved friend H. Gizem ÖZDEMİR for their endless support during my Master of Science education and completion of this dissertation.

December 2018

Oğuzhan TURHANLAR
(Shipbuilding and Ocean Engineer)

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ABBREVIATIONS

AC **:** After Christ
BC **:** Before Christ
DWEA **:** Danish Wind Energy Association
EMO **:** Chamber of Electrical Engineers
GW **:** Gigawatt
GWEC **:** Global Wind Energy Council
HAWT **:** Horizontal Axis Wind Turbine
MW **:** Megawatt
NNE **:** North North East (22.5°)
REUK **:** Renewable Energy United Kingdom
TLP **:** Tension Leg Platform
UK **:** United Kingdom
USA **:** United States of America
VAWT **:** Vertical Axis Wind Turbine
WEC **:** Wind Energy Converter
WWEA **:** World Wind Energy Association

SYMBOLS

a	**:** Wave Amplitude
c	**:** Wave Celerity
d	**:** Water Depth
E	**:** Wave Energy
F	**:** Fetch Distance
$\mathbf{F_i}$	**:** Inertia Force
$\mathbf{F_D}$	**:** Friction Force
$\mathbf{F_T}$	**:** Total Force
H	**:** Wave Height
Hs	**:** Significant Wave Height
k	**:** Wave Number
T	**:** Wave Period
Ts	**:** Significant Wave Period
$\mathbf{M_i}$	**:** Inertia Moment
$\mathbf{M_d}$	**:** Friction Moment
U	**:** Wind Velocity
$\mathbf{U_A}$	**:** Adjusted Wind Speed
ρ	**:** Sea Water Density
ω	**:** Angular Frequency
η	**:** Wave Profile
λ, **L**	**:** Wave Length

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A POTENTIAL OFFSHORE WIND FARM ARRANGEMENT OFF THE BOZCAADA SHORES

SUMMARY

Throughout the world, energy demand and the need for energy production is rising day by day. Fossil fuels are not compromising in the long run, due to the usage of them, there is an increase in pollution and CO_2 concentration in the atmosphere. The increase in CO_2 concentration causes the temperatures to rise in the atmosphere and the acidity to increase in the ocean. These changes are the main reasons of global warming.

Global warming causes the climates to change and the temperatures to raise around the globe.Raise in the temperature affects living creatures and their adaptation capabilities. In addition to that, due to the draught and temperature raise causes photosynthetic plants to decrease their O_2 production rates. Thus, accelerating the global climate change.

In order to reduce the adverse effects, of global warming, green energy demand is on the rise. Some of the developed countries (such as China, USA, Germany, UK, Denmark) have issued decisions on producing more green energy and supporting companies to use green energy and to build green energy plants. Governments give support to those companies, which chose to use green energy in their activities, and reduce the taxes on green energy to make it widely used. Even households are installing energy plants on top of their rooftops and governments buy excess produced energy.

Green energy is the energy, which comes from natural and renewable resources, such as sun, wind and water. Solar energy plants, hydroelectrical plants and wind farms are established around the world for specific locations according to efficiency of the renewable source.

Recent studies claimed that, amongst renewable energy sources, wind energy technology might be the most innovative and harmless answer for green energy supply of the future. A wind turbine is a structure, which converts the kinetic energy from winds to electricity. Especially, offshore wind energy farms have been considered as a solution, since offshore winds have no obstruction in front of them and thus, blow more steadily. However, one must consider the offshore conditions to construct such a structure to withstand for years. As mentioned priorly, Germany, China, USA, UK and Denmark are taking the lead amongst other countries on the power generating by offshore wind farms.

In order to arrange an offshore wind farm, first of all, wind map of planned location has been checked to find the initial wind farm location. Çanakkale offshore has been selected as starting point. After selecting the location, wind speed, wind direction, water depth, turbine type, turbine foundation, shipping and migration routes have

been checked to select the most proper location. Northeastern shores of Bozcaada have been selected for final location after evaluating aforementioned parameters.

Wave forces have been calculated by using Morrison's Equation on the second phase of this dissertation and results are included on the following pages of this paper.

BOZCAADA AÇIKLARINDA POTANSİYEL AÇIK DENİZ RÜZGAR ÇİFTLİĞİ TASARIMI

ÖZET

Günümüz dünyasında, enerji arzı ve enerjiye olan ihtiyaç günden güne artmaktadır. Gelişen teknoloji, artan nüfus ve tüketim kültürüyle birlikte artan enerji ihtiyacının karşılanması için dünya genelinde çoğunlukla fosil yakıtlar kullanılmaktadır.

Ölen canlıların milyonlarca yıl boyunca toprak içerisinde çözülmesi ve hidrokarbonlara dönüşmesi ile oluşan yakıt türüne fosil yakıt denir. Fosil yakıtlar, rezervlerinin sınırlı olması ve çevreye verdikleri zararlar sebebiyle uzun vadede gelecek vadetmemektedirler. Fosil yakıt kullanımı sonrasında ürün olarak ortaya çıkan CO_2 (karbondioksit), atmosferde birikmekte, ve biriken CO_2, güneşten gelen ısıyı atmosferde tutarak, öncelikle atmosferin, sonrasında yeryüzünün ısınmasına sebebiyet vermektedir. Buna, günümüzde küresel ısınma denmektedir.

Küresel ısınma, yeryüzü üzerinde iklimlerin değişmesine, sıcaklıkların artmasına, buzulların erimesine ve buna bağlı olarak da deniz seviyesinin yükselmesine sebebiyet vermektedir. Deniz seviyesinin yükselmesi, deniz seviyesinde olan veya deniz seviyesinden aşağıda kalan bölgeler için tehlike arz etmektedir. Artan sıcaklıklardan, belirli sıcaklık aralıkları içerisinde yaşamaya adapte olmuş canlılar ve bu canlıları besin olarak tüketen canlılar olumsuz etkilenmekte ve hatta bazılarının nesilleri tükenmektedir. Yeşil bitkilerin sıcaklık ve kuraklıktan dolayı fotosentez vasıtasıyla O2 üretimleri azalmakta ve buna bağlı olarak da atmosferdeki CO2 fazlalığının etkileri günden güne artmaktadır.

Küresel ısınmanın ve iklim değişikliklerinin ve daha önce bahsedilen benzer olumsuz etkilerin önüne geçebilmek adına yeşil enerji kaynaklarına yönelme eğilimi ortaya çıkmıştır. Özellikle, gelişmiş ve gelişmekte olan ülkeler yeşil enerji konusunda başı çekmekte ve küresel ısınmanın olumsuz etkilerini tersine çevirebilmek adına adımlar atmaktadırlar. Temel anlamda yeşil enerji kaynakları, güneş, rüzgar, su ve jeotermal kaynaklar olarak sıralanabilir. Bahsi geçen kaynakların varlığı ve yoğunluğu, dünya üzerinde coğrafik olarak değişiklik göstermekte ve hangisinin kullanılması gerektiğine, bulundukları konuma ve kurulum yapılması planlanan bölgede hangisinin veriminin en üst seviyede olduğuna göre karar verilmektedir. Günümüze kadar verim ve doğaya minimum olumsuz etki gibi alanlarda, sürdürülebilir enerji kaynakları üzerinde yapılan çalışmalar, bu kaynakların içerisinde en çok gelecek vaat eden kaynağın rüzgar olduğunu ortaya çıkarmıştır.

Rüzgar, temelde dünyanın dönüşü ve Coriolis etkisi ile, sıcak ve soğuk hava arasındaki basınç farklılıklarından dolayı oluşan hava akımıdır. Rüzgar, tarih boyunca tahıl öğütme, su çıkarma, su taşıma gibi sebeplerle kullanılagelmiştir. 19. yüzyıl sonlarında, bildiğimiz anlamdaki rüzgar enerji türbinleri üretilmiş ve ticari anlamda elektrik üretimine başlanmıştır.

Rüzgar türbini, rüzgar sayesinde dönen kanatlara ve rotora, ve bu dönüşten elde edilen kinetik enerjiyi, elektrik enerjisine dönüştüren bir jeneratöre sahip olan bir

yapıdır. Kanatları ve rotoru rüzgarın en ideal olduğu yükseklikte tutabilmek üzere, tüm ilgili donanımı içerisinde barındıran nacelle adı verilen kaporta, bir kule/direk üzerine oturtulur.

Açık deniz, rüzgarı önleyecek engellerin bulunmaması ve rüzgar türbini yerleşimi için geniş alana sahip olması sebebiyle, rüzgar enerji santrali kurulumu için ideal lokasyonları barındırmaktadır.

Açık deniz rüzgar türbinleri, kıyıdan 10 km veya daha açıkta, deniz yüzeyi üzerinde konumlandırılan türbinlere verilen isimdir. Deniz üzerinde esen rüzgarların, karada esen rüzgarlardan daha stabil ve sürekli olması, açık deniz rüzgar türbinlerinin veriminin ve kapasite faktörünün, kara üzerinde bulunan rüzgar türbinlerine göre fazla olmasına sebebiyet vermektedir. Bu sebeple, dünya üzerinde açık deniz rüzgar çiftliği kurulumu günden güne artmaktadır. Bununla birlikte, rüzgar çiftliği tasarımı yapılırken, deniz derinliği, bölgedeki rüzgar hızı, rüzgar yönü, canlıların göç yollarının olup olmaması, deniz yollarının bulunup bulunmadığı ve deniz dibinin jeofiziki durumu gibi açık koşullar da göz önüne alınmalıdır. Kurulumu yapılacak çiftliğin, yıllar boyu enerji üretimi sağlayabilmesi ve verimli olabilmesi için bu alanda belirlenen inşa ve güvenlik kurallarına ve sınırları içerisinde bulunduğu ülkenin düzenlemelerine uygun olması gerekmektedir.

Gelişmiş ülkeler, rüzgar enerjisini kullanım alanında ve karbon emisyonunu azaltmak konusunda ilerlemek amacıyla ülkelerine yatırım yapmaktadırlar. Yenilenebilir kaynaklar ile üretilen rüzgar enerjisi gibi enerji türleri, hem çevreye daha az veya sıfır karbon salınımı yapmakta, hem de ülke vatandaşlarına fosil yakıtlara oranla daha ucuz enerji sağlayabilmektedirler. Rüzgar enerjisini kullanım sıralamasında Almanya, Çin, Amerika Birleşik Devletleri, Birleşik Krallık ve Danimarka başı çeken ülkelerdir. Birleşik Krallık açık deniz rüzgar enerjisi kurulu güç sıralamasında Dünya genelinde ilk sırada yer almaktadır.

Üç tarafı denizlerle çevrili olan ülkemizde, Türkiye rüzgar atlası incelendiğinde, Ege Bölgesi ve Ege Denizi, rüzgar hızı açısından en çok gelecek vaat eden yerlerden biri olarak görülebilmektedir. Halihazırda, Ege Bölgesi, Çanakkale ve Balıkesir illeri çevresinde, kara üzerinde bulunan rüzgar çiftliklerine çokça rastlamak mümkündür. Ancak açık deniz rüzgar türbini kurulumuna henüz başlanmamıştır.

Bu çalışmada, öncelikle açık deniz rüzgar enerji santrallerinin kurulumundan önce seçilecek konum üzerinde incelenmesi gereken parametreler gözden geçirilmiş ve açıklanmıştır. Ardından, Türkiye rüzgar haritasına göre başlangıç bölgesi olarak Ege Bölgesi'nde Çanakkale ve çevresi seçilmiştir. Ardından Çanakkale ve çevresi için Meteoroloji Genel Müdürlüğü'nden alınan ortalama rüzgar hızı ve rüzgar yönü bilgileri incelenmiş ve Bozcaada çevresinin rüzgar çiftliği kurulumu için en uygun alan olduğu belirlenmiştir. Türbin sayısı, temel tipi ve türbin türü; deniz durumu, rüzgar hızı, deniz derinliği, dalga yükleri, çevreye ve yerleşimin deniz ulaşımına etkisi gibi koşullar göz önüne alınarak Bozcaada'nın kuzeydoğusu yerleşim alanı olarak seçilmiş ve potansiyel yerleşim çalışması tamamlanmıştır. Seçilen türbin tipine göre, türbin temeli (foundation) üzerine binebilecek dalga yükleri Morrison Denklemi ile hesaplanmıştır ve yapının, seçilen alandaki dalga yüküne dayanacağı görülmüştür. Ardından, ülkemizin ilgili makamlarınca belirlenen kurallar olup olmadığı ve varsa bu kurallara uygunluğu kontrol edilmiştir. Kurulum yapılacak bölgede, yerleşimi engelleyici bir deniz yolu veya hayvanların (özellikle uçan canlıların) göç yolu olmadığı teyit edilmiştir. Yerleşime etki edebilecek tüm parametreler kontrol edildikten sonra yerleşim çalışması tamamlanmıştır.

Rüzgar çiftliği yerleşimi için seçilen alandaki deniz parametrelerine göre yapılan hidrodinamik hesapları tezin ilerleyen bölümlerinde sunulmuştur.

1. INTRODUCTION

Throughout the history of humankind, the need for energy has always existed. Earlier, humans used their own power to obtain energy for daily tasks, and the demand for energy has been increased day by day with increasing population, improving technology and increasing consumption. Later on, fossil fuels and natural resources have been used to meet increasing energy demand. People burned coals to make weapons, built and used water mills/wheels on the rivers to grind grains. With the onset of the Industrial Revolution, natural resources and muschles replaced with engines and machinery. Due to the increasing fuel need of the machinery used in factories, countries have verged into searching for fuel and raw material around the world.

Until recent past, conventional energy sources mainly comprising of fossil fuels have been used as main source of energy. The reasons why the conventional energy sources were widely used are accessibility, continuous production, higher efficiency. On the other hand, conventional energy sources have been formed in millions of years and their reservoir are limited. Due to these reasons, conventional energy resources are depleting day by day. In addition to that, usage of conventional fuels harms environment mainly by polluting the air. Increasing CO_2 concentration in the atmosphere, causes air to heat up and in return, global warming and climate change occur.

Due to these reasons, a pursuit for cleaner energy was borned. On the contrary of conventional energy sources, renewable energy sources are environmentally friendly, have lower carbon emission and lower operational costs. Also, as the name implies itself, renewable energy sources replenish themselves and do not deplete.

Amongst the renewable energy sources, wind energy is the most promising one. Wind has been used many ways such as to navigate sailing ships, pump water inside wells or grind grains to obtain flour. As of the end of 2017, a total of 539 GW installed wind power capacity supplies 5% of global electricity needing (WWEA, 2017).

Offshore Wind Industry is a rapidly processing branch of Wind Energy Industry. Since there is no obstacles over the ocean, winds can blow faster and more regular than winds blowing over the land. According to reports of 2017, there are 18,8 GW of offshore wind power capacity globally. About 84% of the installed power generation (15,8 GW) are located off the coast of European countries (GWEC, 2017).

For Turkey, reports from end of the June 2018 states that, 58,3% of total energy generation comes from natural gas and fossil fuels, 23,3% comes from hydraulic sources, and 7,6% comes from the wind (EMO, 2018).

In order to become a developed country, security of supply of energy must be maintained at all times. To do that, resources of the country must be put forward and used. Thus, renewable energy sources and wind energy can be considered as essential sources of energy to ensure security of supply in a country. Analyses must be carried out to obtain maximum efficiency from a wind farm. To reach the maximum efficiency, offshore wind farms must be considered. In the harsh environment of the open ocean, selecting an optimum location for a wind farm is a difficult task. Engineers must look from a broad perspective to this objective. Turbine structure must be designed in a way that it must withstand wave and wind forces and must be designed as optimum as possible to obtain greatest power possible.

In this project, wind energy has been defined and explained, and a possible wind farm layout/arrangement have been carried out for an offshore wind farm off the coast of Bozcaada. At first, Gulf of Saros was selected. To ensure that Gulf of Saros is the proper location for a wind farm on Aegean Sea, tables of monthly mean and maximum velocity and direction of wind are obtained from General Directorate of Meteorology in Istanbul for the vicinity of Gulf of Saros. (Related data tables are attached in Annex-A.) At first selected locations for data tables were, Gökçeada, Bozcaada, Gallipoli, Lapseki and Çanakkale. After receiving the aforementioned information, Bozcaada nearshore is selected as the final location due to having a mean annual wind velocity as 6.09 m/s at 30 m altitude.

2. HISTORY OF WIND ENERGY

Winds form from the pressure differences due to heating and cooling of the Earth. Hot air rises up and cold air sinks, and this motion creates a air flow thus resulting in a horizontal flow called wind.

Babylonians used wind energy to irrigate their farms around 1500 B.C. This is known as the first usage of wind energy. In the 1st century A.C., a Greek engineer named Heron of Alexandria invented the first wind-driven wheel to power a machine. This is the first known wind-driven wheel mechanism. In 12th century, vertical axis windmills were used in Northwestern Europe and they were used to produce flour from grains (Figure 2.1). In 16th century, Dutch, used wind energy to pump ground water and create polders from the sea. In 1887, Prof James Blyth of Anderson's College, Glasgow (now known as Strathclyde University), created the first known wind turbine to produce electricity (Shahan, 2014).

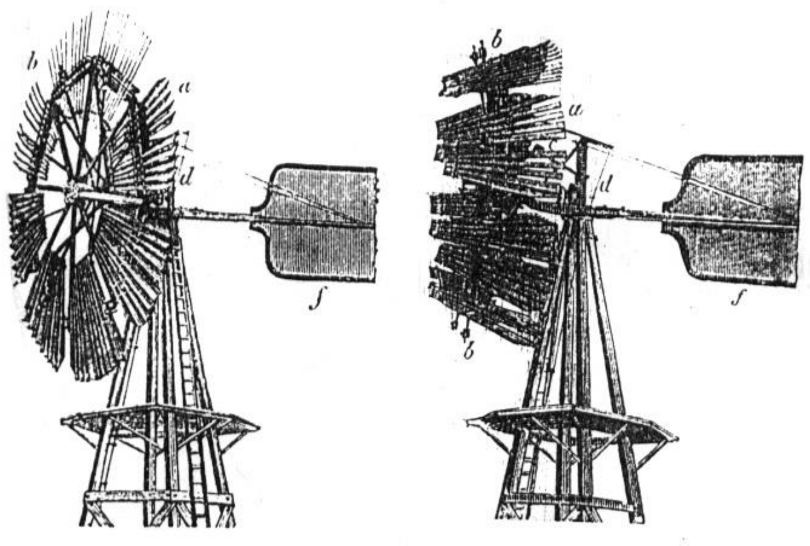

Figure 2.1 : A historical wind turbine.

Danish scientist, Poul La Cour was the inventor of modern electricity generating wind turbines (Figure 2.2). He managed to build wind turbines with electricity generating capacities of around 20 to 35 kW. (DWEA, 2003)

Figure 2.2 : Two of Poul La Cour's test wind turbines at 1897.

At 1919, a German physicist named Albert Betz calculated the power fraction, which can be extracted from an ideal wind stream as 59.3%. This number is called Betz's Limit.

2.1 Wind Turbines - Introduction

A modern wind turbine is a structure, which converts kinetical wind energy to electrical energy. Nowadays, with the help of developing technology, they are mainly used for producing energy. Generated electricity is connected to grid circuit. They are called Wind Energy Converter (WEC), Wind Power Plant or Wind Turbine (Figure 2.3). With the help of developing technology, power generation of wind turbines increased from 30 kW to 12 MW from the beginning of past century to 2018.

Figure 2.3 : A modern wind turbine.

2.2 Types of Wind Turbines

There are many design variations of wind turbines and they can be categorized according to their orientation of their rotation axis, there are two basic types of wind turbines. First and less commonly used type is Vertical Axis Wind Turbine (VAWT). Vertical axis wind turbines have lower efficiency and their rotors are too close to ground, hence they can not reach high speed wind profiles at certain heights.

Second and more commonly used wind turbine type is Horizontal Axis Wind Turbine (HAWT). Their rotor rotates around a horizontal axis and they have better efficiency and suitable for many different power classes. 3 bladed HAWTs (also called as Danish Model) are the most commonly used wind turbine type around the world. (Lehtomäki, 2015)

2.2.1 Horizontal axis wind turbines

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed towards the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most of the HAWTs have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. A horizontal axis wind turbine can be seen in Figure 2.4.

Figure 2.4 : An offshore wind turbine.

2.2.2 Vertical axis wind turbines

Vertical-axis wind turbines have the main rotor shaft arranged vertically. They can be operated with relatively slower winds, therefore can produce electricity within a greater wind speed range. Two of the most known and common vertical wind turbine types are Savonius (Fig.2.5) and Darrieus (Fig.2.6) Wind Turbines (REUK, 2015). They are mainly used for pumping water and electricity generation. They are easy to use and easy to maintain and have low noise level (especially Savonius type). VAWTs can be operated by lower wind speeds, due to this feature, they can even be used inside cities where the wind is constantly blocked by buildings (University of Vaasa, 2016). However, due to their lower efficiency and smaller scaled application, they are not commercially used.

Figure 2.5 : Savonius type wind turbine.

Figure 2.6 : Darrieus type wind turbine.

2.3 Components of a Wind Turbine

Components of a wind turbine can be seen in Figure 2.7.

Rotor: Blades and hub together form the rotor. Blades and hub are the most essential components of a wind turbine with regards to performance and cost aspects. Many of today's turbines have 3 blades. Power increase is provided by using longer blades. However, longer blades means less strength and more weight to the structure. In order to obtain a perfect design, blades are generally made from composite materials.

Anemometer: Measures the wind speed and transmits wind speed data to controller to turn pitch control on or off according to measured wind speed.

Pitch control: Changes pitch angle of the blades according to wind direction/speed.

Mechanical transmission components: Gearbox connects low speed shaft to the high speed shaft and it increases the rotational speeds to obtain more power from lower wind speeds. Generator produces electricity by rotation of high speed shaft. If the wind blows faster than turbine limits or a problem occurs on turning parts, brake will stop the rotor mechanically, electrically or hydraulically.

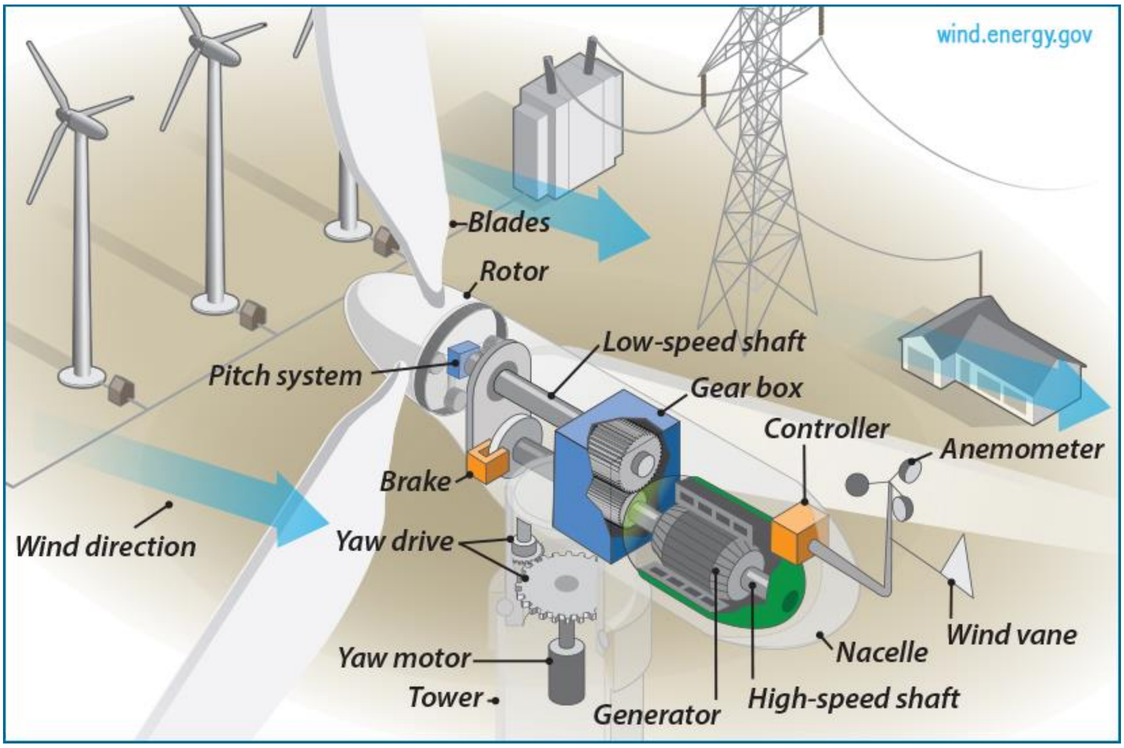

Figure 2.7 : Components of a wind turbine.

Wind vane: measures the wind direction and transmits data to yaw drive to rotate the turbine according to wind direction. Yaw drive orients the turbine to the upwind direction with the help of yaw motor.

Nacelle and tower: are the two main structural components where nacelle is the case which holds all electrical, mechanical and/or hydraulic equipment safe from physical impacts and the tower holds the nacelle in a designated height safely. (Department of Energy, 2018)

Foundation holds all of the turbine in place and it needs to be strong enough to stand the weight of the structure and the components and it should withstand the loads causing by the rotation.

3. OFFSHORE WIND ENERGY

According to wind energy literature, beyond 10 kilometers off a shoreline is called offshore region. Thus, if a wind turbine or wind farm is located 10 km off from the shore, then they are called offshore wind turbine or offshore wind farm. Near-shore term is used for wind turbines, which are located 3 kilometers, and less from a shoreline. Furthermore, near-shore wind turbines can be located on land as well.

For now, onshore wind turbines are more common due to the economical reasons, where it is cheaper to build and maintain an onshore wind farm than building one offshore. However, with the help of developing technology, offshore wind farms are conquering the renewable energy world with reducing construction and maintenance costs and increasing efficiencies of the turbines.

The main reasons why offshore wind farms becoming more common is that there are no obstacles over the ocean to decelerate the wind and the wideness of the ocean fields which can be appropriate for wind farm construction. In other words, the wind blows faster and steadier over the oceans and there are a huge number of fields to build offshore wind farms.

3.1 Wind Profile

As stated priorly, in general, winds blowing over oceans are steadier and faster than the ones blowing over land. Consequently, offshore wind turbines produce energy at their maximum capacity for longer periods and due to the steadiness of the winds, strength of the turbine is not overly affected.

3.2 Foundation Types, Water Depth, Seabed Profile

Offshore wind turbines can be installed up to 45 meters of water depth. With the developing technology, companies are installing floating wind farms on deeper ocean waters. Statoil, a Norwegian renewable energy company previously was in oil& gas business, achieved to be the first company to install a wind farm, which is called

Hywind Scotland, consisting of five 6 MW floating type wind turbines. They are ballast stabilized and anchored to the seabed. The water depth at installed location is about 100 meters (Equinor, 2018).

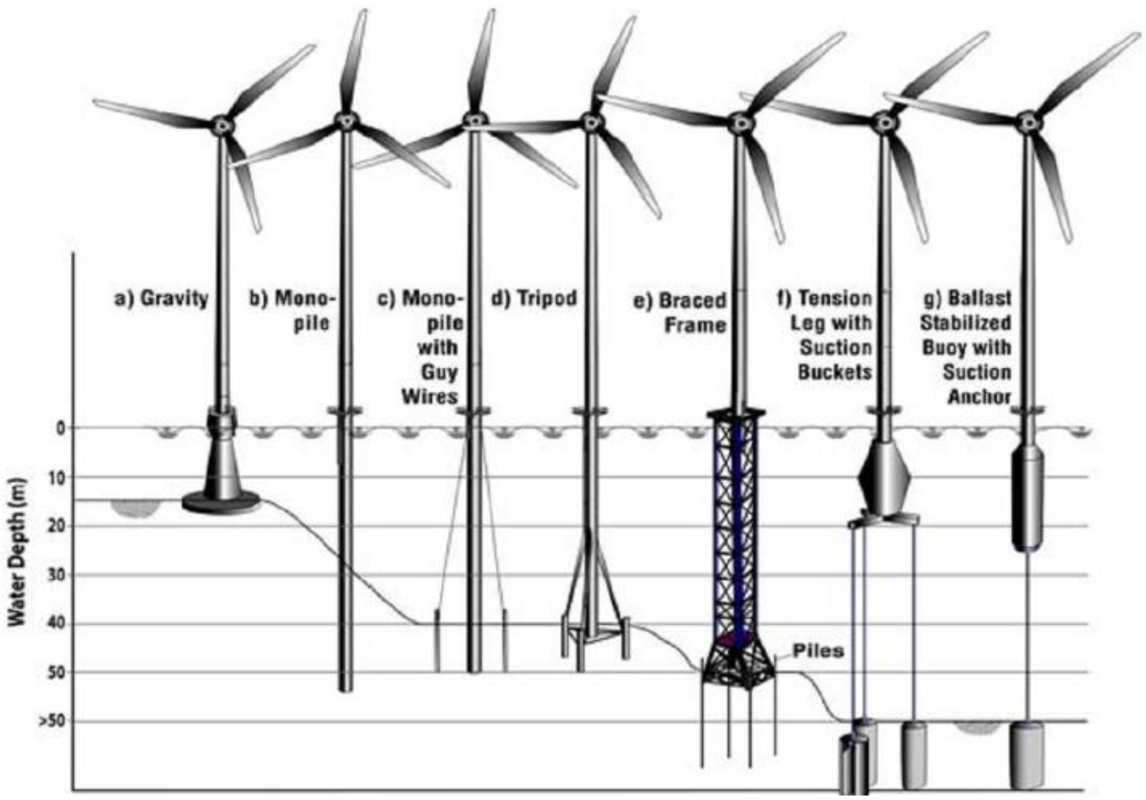

Figure 3.1 : Wind turbines foundation comparison for water depth(Malhotra, 2011).

Common foundation types for offshore wind turbines can be seen in the figure 3.1 above.

For water depths up to 30 meters, monopile and gravity foundation types are used. A monopile consists of a steel pile, which is driven into the seabed. Typical installation method for this foundation is to float the structure into designated point and then to drive piles into the seabed using hydraulic hammers (Malhotra, 2011). In order to carry out these operations, an Offshore Windfarm Installation Vessel or specially designed barges should be used to carry and install the piles and turbine structure itself. Related installation process is the same for monopile and tripod foundations.

A gravity type foundation is used in shallower waters. A concrete block is constructed at a near dock or a shipyard and then the block is carried to designated position and sunk inside to the pocket prepared for the foundation to sit on.

With increasing depth, the cost of production and installation of wind turbines increases. 50 meters and deeper waters require a different set of foundations which are, braced frame, TLP (mooring line stabilized), and SPAR (ballast stabilized) buoy types.

Braced frame foundation is a frame structure consisting of trusses connecting each other. In order to fix it onto seabed, there are piles, which are to be driven into seabed with similar processes as monopile and tripod foundation installation.

When it comes to deeper waters, where it is not applicable to directly connect with the seabed, the Tension Leg Platform (TLP) and SPAR (ballast stabilized) foundation types are used.

Tension Leg and SPAR type foundations are used in waters deeper than 50 meters. Foundation is floated to installation point by an offshore support vessels or a barge. For Tension Leg, mooring lines are connected to the foundation structure and to the pontoons or suction pockets which are fixed onto seabed. After positioning the foundation over installation point, mooring lines stretched in a way to pull the structure inside water and the tension on the lines holds the structure in place.

For SPAR type foundation, it is floated to installation point and seawater is pumped inside the tanks of foundation buoy. The weight of the ballast water stabilizes the structure upright and then mooring lines are tied to holds it into place. As mentioned before, the first floating wind farm in the world, Hywind Scotland wind farm, consists of five ballast stabilized wind turbines at around 100 meters water depth.

3.3 Layout, Installation and Location

Oceans cover about 75% of the surface of the earth. Thus, it is safe to say that, there are more possible wind farm areas than there is on land. Carrying wind turbine components on land, requires special considerations, such as, blocking the traffic or opening new roads, moving road signs, and using specifically designed transportation vehicles. In addition to that, in offshore areas there are no obstructions for transportation and installation of the wind turbines and its components, other than weather.

Due to specifically designed offshore wind farm installation vessels, crane capacity for offshore installation is relatively bigger than onshore cranes'. Wind turbine components can be transported to the installation site without confronting problems. Wind turbines can be installed with the help of aforementioned wind turbine installation vessels or with the support of offshore platforms which specifically designed for offshore installation jobs. A picture from an offshore wind farm installation site can be seen in figure 3.2 below.

Figure 3.2 : Wind turbine installation site.

There are other limiting factors which should be checked while considering a site for wind farm installation, these factors can be listed as: Sea routes, navy bases, anchoring points, living creatures, and their migration routes.

Distance of the wind farm site from land, causes an increase in installation, operation and maintenance costs. Installation vessels are needed to take many rounds between the site and the land. Thus, increasing the distance they needed to travel is increasing the costs. In addition to that, distance directly affects the cabling length and costs.

During operation phase, maintenance crew should visit the wind farm periodically.

Rental costs of these vessels are greater than renting land cranes and their costs changes according to weather conditions and availability of the vessel.

Installing a wind farm which will be closer to land, would reduce the installation, operation and maintenance costs. In designing phase, wind farm location should be selected as near as possible to large settlements.

Salty sea weather causes near buildings and facilities to corrode. Offshore wind turbine foundations should be coated with anti-corrosive coatings to avoid corrosion. A special air conditioning system which pressurizes nacelle's inside, to avoid salty water/air, should be installed.

3.4 Impact on Living Creatures and Environment

In order to avoid encountering problems during permit phase, all migrating routes should be checked. Marine birds can try to fly through a rotating wind turbine and die. Bird kills can occur if the wind farm set up on a migration route (Snyder, 2009). These areas must be by-passed.

Another specific effect of wind turbines occurs during installation phase. During the hydraulic hammering of the foundation pins into the seabed, the noise can harm marine animals which communicate with acoustic signals. These drilling and hammering sounds can cause loss of hearing for these animals. In addition to this, operational (turning) sound of a wind turbine can be heard about 1 km away. (Snyder, 2009).

Aforementioned environmental impacts can be avoided by using foundation types, which can be quietly installed, such as, floating SPAR or TLP type, or gravity based types.

4. OFFSHORE WIND FARM DESIGN AND FEASIBILITY STUDIES

4.1 Location Selection According to Wind Map

First step of designing an onshore or offshore wind farm is to check wind map of the dedicated location. In order to select a windy region for an offhore wind farm, wind map of Turkey is given in below Figure 4.1.

Figure 4.1 : Wind map of Turkey (MGM, 2010).

Above wind map of Turkey has been created by 45 different meteorological measurement stations collecting wind data between the years 1989 - 1998 (MGM, 2010).

According to above wind map, Aegean Region has the largest wind potential on Turkey’s seas. For this reason, Gulf of Saros and its vicinity were chosen as a starting point.

General Directorate of Meteorology in Istanbul was visited to get meteorological data around mentioned area. Gökçeada, Bozcaada, Çanakkale, Gallipoli, Lapseki and Gulf of Saros were chosen from the map as the data collection points.

After receiving the data sets and analyzing annual maximum and annual mean wind speed and wind direction data, Bozcaada was chosen. Bozcaada region has annual maximum wind speed, annual mean wind speed and wind direction data which were collected from 1970 to 2016, and still continues to collect mentioned data. Annual mean wind speed was calculated throughout these 46 years and found as 6.09 m/s and maximum wind speed has been seen to go up to 31.2 m/s. These measurement has been taken from an altitude of 30 meters. Location of OMGI (Automatic Observation Station) can be seen in below figure 4.2. Related data set is attached in Annex A.

Figure 4.2 : Location of Bozcaada OMGI.

4.1.1 Bathymetry map

Commonly used foundation types such as monopile or gravity based foundations are usable up to a water depth of around 30 meters. After 30 meters, tripod, braced frame and floating foundations must be evaluated. However, shallower water directly connected with cheaper structure production and installation. Due to this reason, offshore wind farm designers must select shallowest and the most efficient area possible. Thus, for selected region, bathymetry map of Bozcaada shore can be seen in below Figure 4.3.

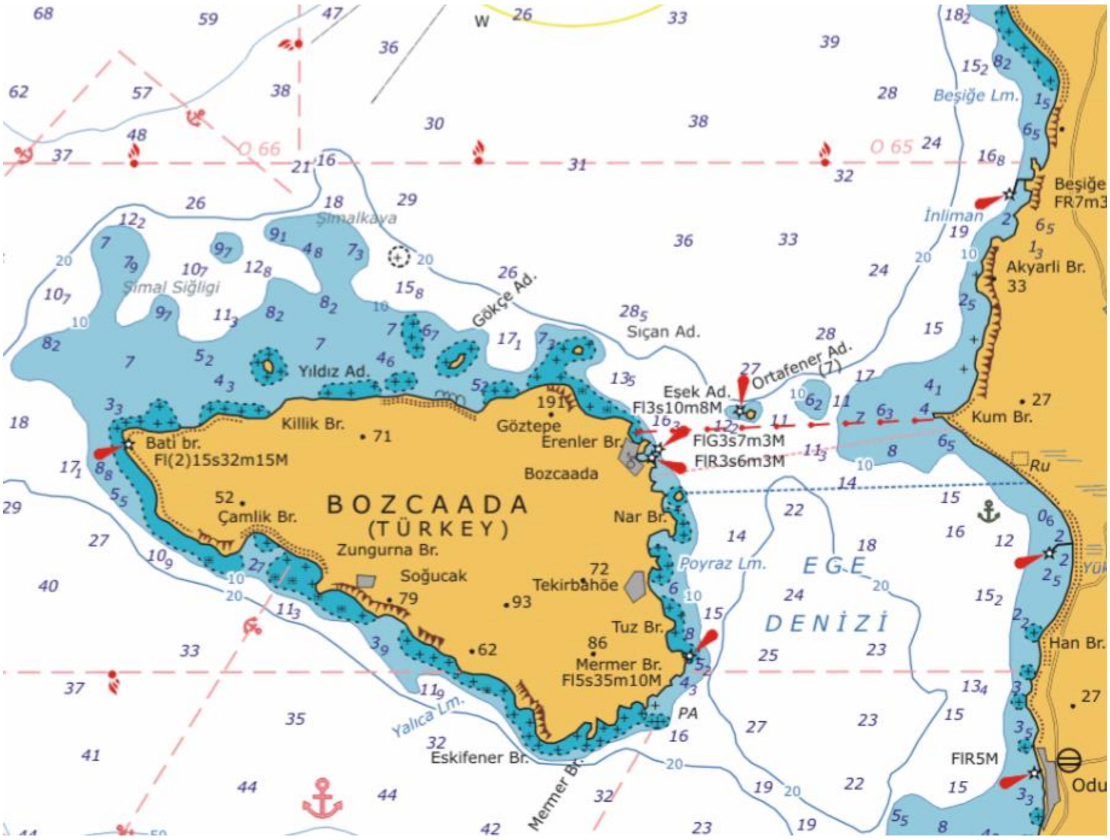

Figure 4.3 : Bathymetry map of Bozcaada shores.

4.1.2 National boundaries

In Aegean Sea, there are many Greek Islands which is closer to Turkey than they are to Greece. These islands, quasi expand the territorial waters of Greece. Because of this region, building a structure off the coast of Turkey can result in a problematic construction. However, there are no Greek islands off the coast of Çanakkale. There are only Gökçeada and Bozcaada, thus there will not be a problem with national boundaries.

4.1.3 Sea transportation routes

Sea is a bounding medium which connects the continents and transportation between the countries and between the islands are carried out by ships. Human transportation is essential in Aegaen Sea. Thus, there are a number of shipping routes over the Aegean Sea. Shipping and transportation routes must be avoided. There is only one shipping route from Çanakkale - Geyikli to Bozcaada and this route will be avoided during selection of turbine locations. Also, sea transportation routes have been checked through Marine Traffic software, and it has been seen that the selected wind farm location is not on the passage way of the ships coming out or going in the Dardanelles Strait.

4.1.4 Living creatures, migration routes

It is ecologically dangerous for marine species, especially marine birds, to build a wind farm near their nesting areas. It is important for offshore wind farm designers to check whether there are marine species or endangered species around potential wind farm area.

A huge number of marine animals communicate through acoustic signals. Wind farm installation process, especially hydraulical hammering of piles into the seabed, creates loud noise and this can cause hearing loss on marine animals or they can swim away from their nesting areas.

Electrical cables which are laid onto the seabed for electricity conduction, creates an electromagnetic field. This field can adversely effect species which use it to find their ways or preys.

Bozcaada and its vicinity have been checked for migration routes or for a nesting spaces of marine animals, migrating birds or endangered species. It has been seen that, there is no migration route, nesting area or endangered species around Bozcaada shores.

4.1.5 Grid connection

Cables coming from wind turbines, connected to an offshore substation and joined together to a shore conduction cable. Grid connection is the point on land, where the cables coming from the offshore wind farm substation will be connected to. Since, these connection cables are expensive and must be laid as short as possible, Grid connection location must be checked. This is an essential point while selecting location (Lützen, 2017).

For Bozcaada offshore wind farm, the grid connection on land has checked and the location has been selected as close as possible to the land.

4.2 Location Selection

Location of the wind farm has been selected according to above mentioned points and the location is shown in below Figure 4.4.

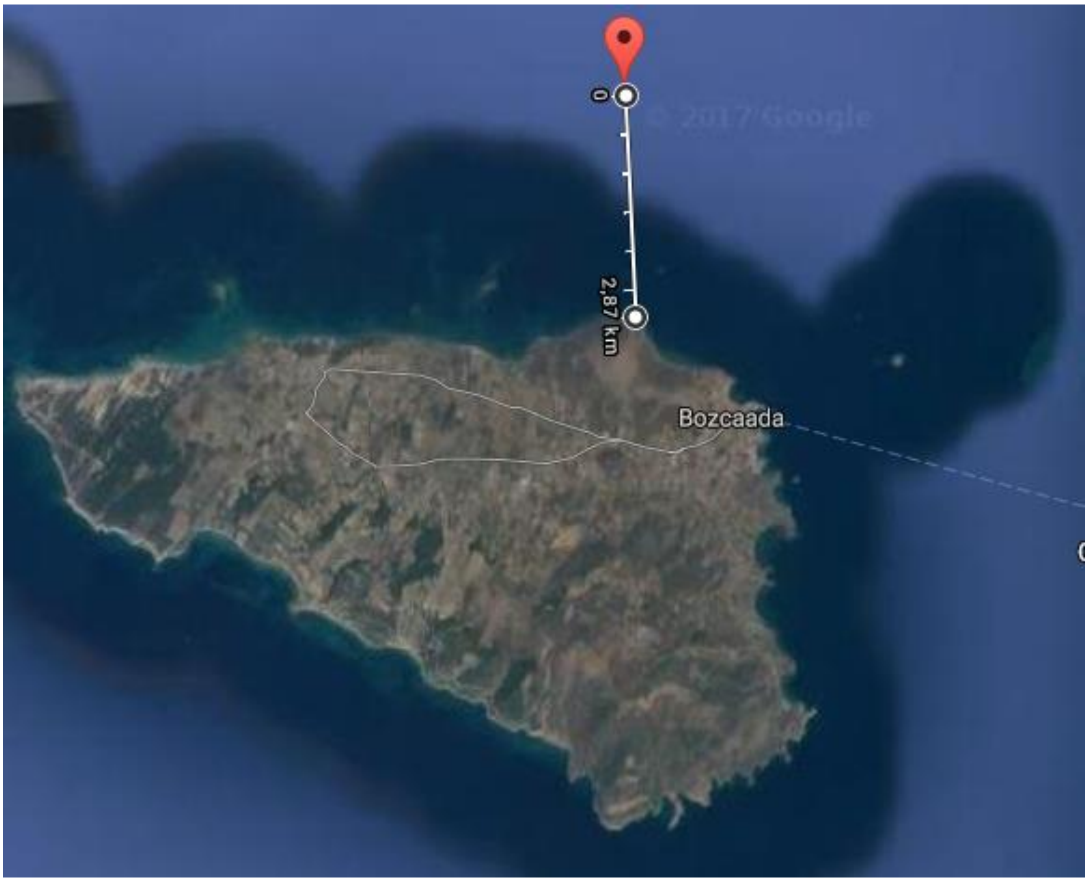

Figure 4.4 : Location of wind farm.

Selected location has a distance of 2.87 km to Bozcaada.

Coordinates: 39.872864 N, 26.054048 E

Choosing the location and the foundation type of a wind turbine is a successive process. Since water depth at this location is around 26 meters, which is suitable for a monopile type wind turbine, monopile foundation type has been chosen.

The reasons for selecting this location can be listed as below:

- Acceptable average wind speed and average wave height.

- Fairly close to Bozcaada center and have accessability to land. (grid connections, closer location means shorter route for repair and maintenance, etc.)
- Has a fair distance from shipping route of Geyikli-Bozcaada
- There are no endangered species or migration routes around potential wind farm location.

4.3 Wind Turbine Selection

A household consumes about 2500 kWh per year in Turkey according to below figure 4.5.

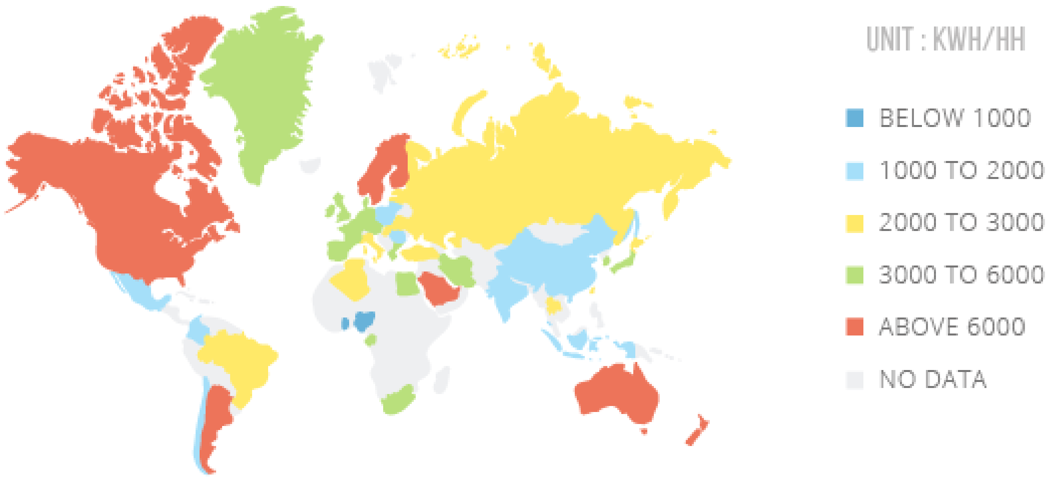

Figure 4.5 : Average electricity usage (Ovoenergy, 2014).

Siemens Gamesa, Vestas, Enercon and GE wind turbines have been examined and as a final decision, VESTAS - V116-2.0 MW IEC IIB type wind turbine has been selected (Vestas, 2017). The reason for selecting Vestas is that they are the top wind turbine provider around the world and they have a widely available service and maintenance network.

In practice, the distance between wind turbines is an essential parameter for turbine efficiency. There must be a 3 to 7 times of rotor diameter distance between each turbine according to their alignment. Therefore, 500 meter is selected as the distance between wind turbines.

For this dissertation, a total of 30 MW of power generation is aimed to reach.

For selected wind turbines, each turbine is able to produce 2.0 MW, thus wind farm can produce 15 x 2.0 MW = 30 MW in total. With an estimated 40% efficiency, this wind farm can produce 105.12 GWh/year.

According to the above potential power generation capacity of the wind farm, about 42000 households can be

4.4 Estimating the Wind Speed at Hub Height

The wind speed values received from General Meteorology Directorate of Istanbul, have been measured from an altitude of 30 meters. In order to correctly use wind speed at reference height, this value must be transferred to the hub height. For this dissertation, wind turbine has a rotor diameter of 116 meters, thus, a hub height of 80 meters will be sufficient.

$$V(h) = V(href)\{\frac{\ln\left(\frac{h}{z0}\right)}{\ln\left(\frac{href}{z0}\right)}\} \tag{4.1}$$

Where z_0 is the roughness length and it can be taken as 0,0002 for offshore, since there is no disturbances to slow down/obstruct winds.

$z_0 \sim 0.0002$ m

$h_{ref} = 30$ m

V(href) = 6.09 m/s at $h_{ref} = 30$ m

Hub height = h = 80 m

V(80m) = 6.09 (ln(80/0.0002) / ln(30/0.0002)) = 6.586 m/s

6.586 m/s is the expected average wind speed at the height of the hub.

With the help of this information, the estimated power output can be derived as well.

$$E = P = \frac{1}{2} \cdot \rho \cdot V^3 \cdot A \tag{4.2}$$

A is sweep area of the rotor (10568 m^2)

ρ is the air density. (taken as 1.2041 kg/m^3)

V is wind speed. (6.586 m/s)

P = 1,82 MW (As expected from Vestas Data Sheet)

4.5 Layout of the Wind Farm

Aforementioned parameters have been checked, and the layout of the windfarm has been arranged as shown in below figure 4.6 (not to scale). The figure shows the location and siting direction of the wind turbines.

There is a distance of 500 meters between each turbine, thus below figure shows the alignment of wind turbines with each other. In order to see the arrangement of the wind turbine with regards to the geographical position of the Bozcaada, layout of the windfarm has been magnified.

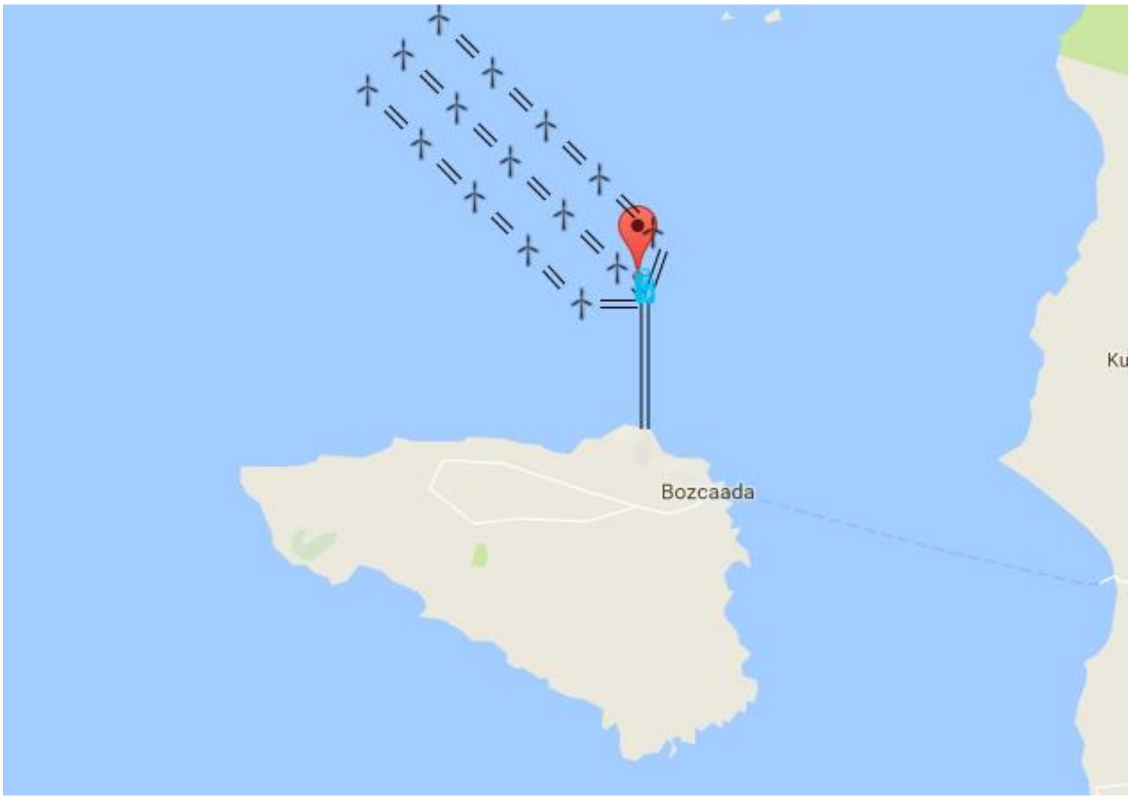

Figure 4.6 : Layout of the wind farm.

The dominant wind direction at the wind farm location is found to be NNE (North – North East) direction. Turbine locations selected to get maximum upright coming wind from NNE direction. Wind turbines have been aligned in three rows NE-SW direction, and five columns in NW-SE direction to allow maximum upright wind from N, NE and NNE directions.

Wind turbines arranged to face the wind without getting into each others's upwind direction. 500 meters distance is about 4.3 times longer than the rotor diameter of selected wind turbines (which is 116 meters), thus allowing the wind turbulence to get dampened and not affecting or reducing the speed and direction of each of the wind turbines' upwind.

5. DETERMINING WAVE PARAMETERS BY USING FETCH DISTANCE

Ocean engineering terminology is shown in Figure 5.1 and specified below.

H indicates the wave height which is the vertical distance between wave crest and trough.

L or λ indicates the wave length which is the horizontal distance between two wave crest or trough.

T is the period which is the time wave takes to travel its wavelength “L”.

U is the wind speed at designated area.

F is the fetch distance. Fetch is the area of the ocean where the wind blows steadily and at a constant direction, thus resulting in generating waves.

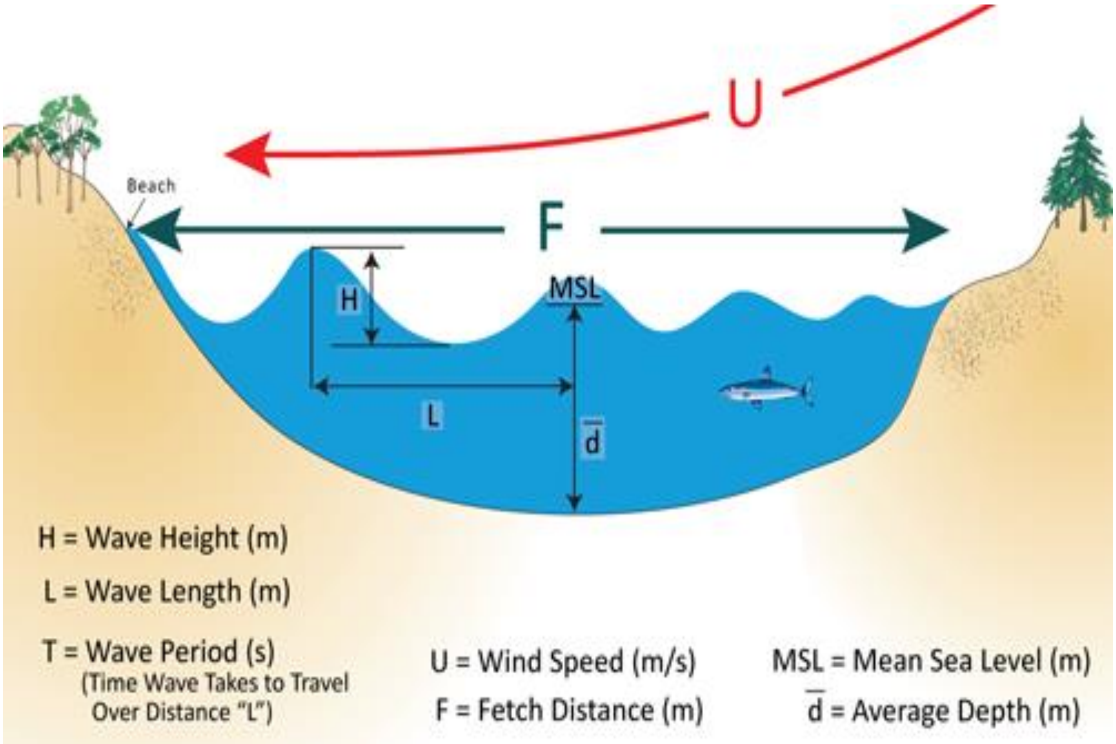

Figure 5.1 : Ocean engineering parameters.

5.1 Basic Equations

Basic wave equations can be found below.

$$k = 2\pi/\lambda \tag{5.1}$$

$$\omega = 2\pi/T \tag{5.2}$$

$$c = \lambda/T \tag{5.3}$$

$$\frac{H_s g}{U^2} = 0.283 tanh\left[0.0125\left(\frac{gF}{U_A^2}\right)^{0.42}\right] \tag{5.4}$$

$$\frac{gT_s}{2\pi U} = 1.2 tanh\left[0.077\left(\frac{gF}{U_A^2}\right)^{0.25}\right] \tag{5.5}$$

$$\frac{U_T}{U_{3600}} = 1.277 + 0.296th(0.9 * \log(\frac{45}{t}) \tag{5.6}$$

$$t = \frac{1609}{U_f} \tag{5.7}$$

$$U_A = 0.71U^{1.23} \tag{5.8}$$

5.2 Definitions and Calculations about Morrison's Equation

Morrison's Equation is an empirical equation to derive the inline forces acting on a body inside of a fluid. Calculation of wave forces on the foundation of the wind turbines by using Morrison's Equation will be carried out.

Morrison's Equation includes an inertia term and a drag term. Basically, these terms will be calculated by using fluid velocity, density of the fluid and C_D & C_M coefficients (Techet, 2004). Inertia and Drag terms will be calculated separetely and then will be added to find total wave forces acting on the foundation of the wind turbine.

Forces acting on a cylindirical foundation and related parameters are given in Figure 5.2.

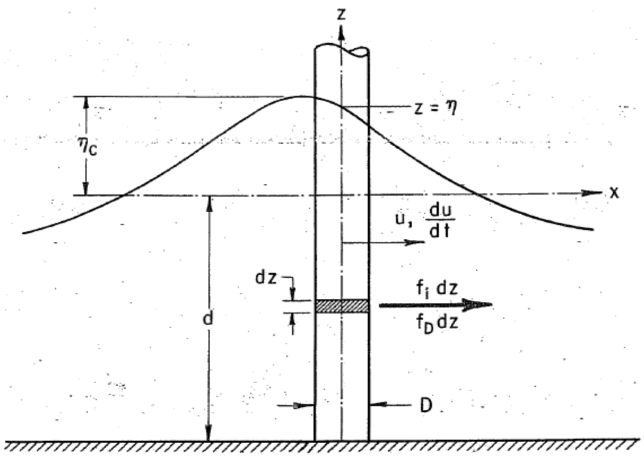

Figure 5.2 : Forces acting on a cylindirical foundation and related parameters

Monopile type of foundation has been previously selected. In order to basically commentate the situation of the wind turbine, it can be described as a cylinderical structure put inside the water and waves will periodically hit it throughout its lifetime. Morrison's equation comes in place to check how much of a wave force will affect the foundation structure.

$$F = F_i + F_D \tag{5.9}$$

$$F_i = \rho C_m V u \tag{5.10}$$

$$F_D = \frac{1}{2}\rho C_d A_u |u| \tag{5.11}$$

Morrison's Equation:

$$F = \underbrace{\rho C_m V u}_{F_i} + \underbrace{\frac{1}{2}\rho C_d A_u |u|}_{F_D} \tag{5.11}$$

In above formulae, "u" indicates the orbital velocity of waves. Horizontal direction defines the "x" axis and according to linear wave theory, the orbital velocity on the x axis is given as:

$$u = g\frac{H.T.coshk(h+z)}{2 * L\, cosh\, kh}\cos(\omega t - kx) \tag{5.12}$$

In the total acceleration, the non-linear term can be neglected so that the horizontal acceleration becomes:

$$\frac{du}{dt} \cong \frac{\delta u}{\delta t} - g\frac{\pi H \cosh k(h+z)}{L \cosh kh}\sin(\omega t - kx) \qquad (5.13)$$

5.3 C_D & C_M Coefficients

In 1957 Wiegel, Beebe and Moon obtained data from 6.625 inch diameter sized vertical cylinder. C_D and C_M coefficients are obtained by kinematic conditions, local forces and linear wave theory. Drag coefficient "C_D" and Inertia coefficient "C_M" are taken from Figure 5.3 and Figure 5.4 respectively.

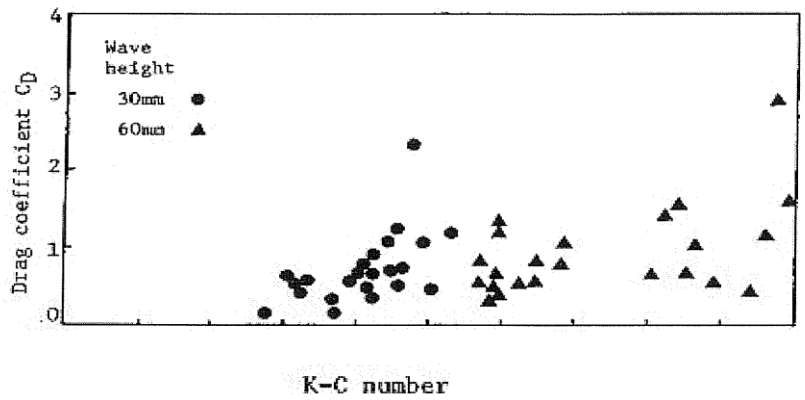

Figure 5.3 : C_D coefficients (Herbrich, 1990).

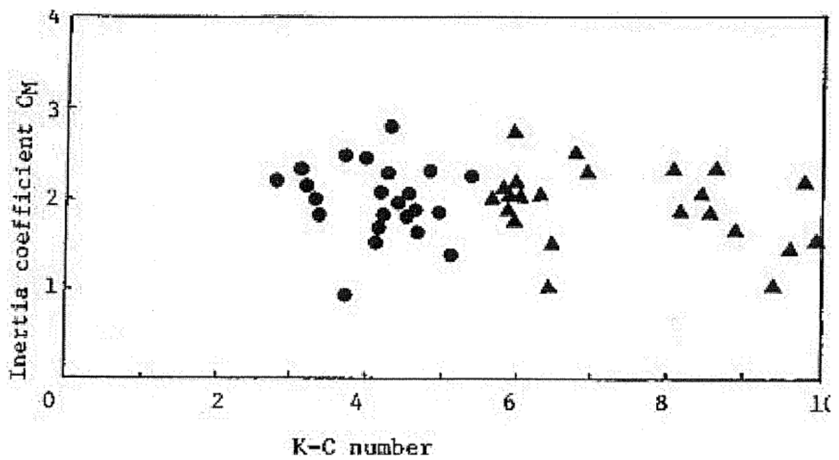

Figure 5.4 : C_M coefficients (Herbrich, 1990).

Generally for smooth circular cylinders C_D = 0.7 and C_M = 2 data accepted according to Handbook of Coastal Engineering. (Herbrich, 1990)

5.4 Obtaining Morrison's Equation for Wind Turbine Foundation

Below formulae are used to obtain Morrison's Equation to find total inertia and drag force and moment values by using dimensionless data.

$$F = \int_{-h}^{\eta} f_i dz + \int_{-h}^{\eta} f_d\, dz = -F_i sin\omega t + F_d (cos\omega t)^2 \tag{5.14}$$

$$M = \int_{-h}^{\eta} (z+h) f_i\, dz + \int_{-h}^{\eta} (z+h) f_d dz = -M_i sin\omega t + M_d (cos\omega t)^2 \tag{5.15}$$

$$F_i = C_m \rho g \frac{\pi D^2}{4} H K_i \tag{5.16}$$

$$Mi = C_m \rho g h \frac{\pi D^2}{4} HKiSi = hFiSi \tag{5.17}$$

$$F_d = C_D \frac{1}{2} \rho g D H^2 K_d \tag{5.18}$$

$$M_d = C_d \frac{1}{2} \rho g h D H^2 K_d S_d \tag{5.19}$$

$$K_i = \frac{1}{2} tanhkh \tag{5.20}$$

$$K_d = \frac{1}{8}\left(1 + \frac{2kh}{sinh2kh}\right) \tag{5.21}$$

$$S_i = 1 + \left(\frac{1 - coshkh}{sinh2kh}\right) \tag{5.22}$$

$$S_d = \frac{1}{2} + \frac{1}{8K_d}\left(\frac{1}{2} + \frac{1 - cosh2kh}{2khsinh2kh}\right) \tag{5.23}$$

5.5 Obtaining Maximum Forces

Inertia and Drag forces can not reach their maximum values at the same time. Thus, total force reaches its maximum value at the $\frac{dF}{dt} = 0$ condition.

$$F_{max} = \left(\frac{F_i^2}{2Fd}\right) + F_d(cos\theta_f)^2 \tag{5.24}$$

$$\omega t = \theta_f = -sin^{-1}\left(\frac{F_i}{2F_d}\right) \tag{5.25}$$

6. CALCULATIONS USING MORRISON'S EQUATION FOR BOZCAADA SHORES

In this project, a cylindirical submerged (monopile type) foundation will be calculated by the help of above mentioned formulae.

Fetch distance will be calculated by using maximum wind speed which previously obtained from General Meteorology Directorate in Istanbul. Maximum wind speed is used to check whether the structure will withstand worst case scenarios. 1 hour average wind speed will be used instead of maximum wind speed, since maximum wind speed is a single data. Average will be found by the help of empirical formula.

After checking the meteorological data for the year 2016, the fastest wind speed and direction were found as 31.2 m/s from N direction. Possible fetch distance was measured as 81 km.

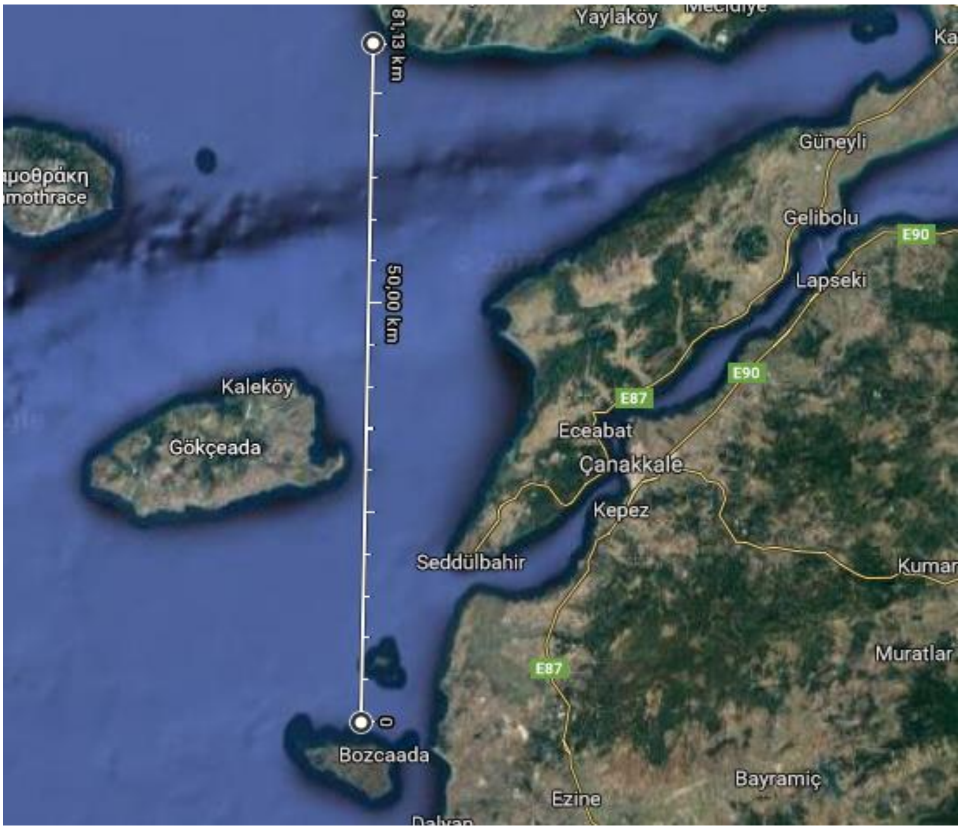

Figure 6.1 : Fetch distance demonstration for wind farm location.

$$t = \frac{1609}{31.2} = 51{,}57 \ sec$$

$$\frac{U_T}{U_{3600}} = 1.277 + 0.296th(0.9 * \log\left(\frac{45}{51.57}\right)) = 1{,}261$$

$$U_{3600} = 24{,}74 \, m/sec$$

$$U_A = 0.71 * U^{1.23}$$

$$U_A = 0.71 * 24{,}74^{1.23}$$

$$U_A = 36{,}74 \, m/s$$

$$F = 81120 \, meters$$

6.1 Calculation of Wave Data

$$\frac{H_s g}{U^2} = 0.283tanh\left[0.0125\left(\frac{gF}{U_A^2}\right)^{0.42}\right]$$

By using equation (5.4) the wave height is obtained as H_S=5,06 meters.

$$\frac{gT_s}{2\pi U} = 1.2tanh\left[0.077\left(\frac{gF}{U_A^2}\right)^{0.25}\right]$$

By using equation (5.5) the wave period is obtained as T_S=8,69 seconds

6.2 Obtaining Wave Length by Iterative Solutions

Dispersion relation can be used with the help of wave period data. This way, wave length can be found iteratively. According to equations (6.2) L is found as 117,8 meters. After iterating the equation (6.1), L (λ) is found as 58 meters.

$$\lambda = \lambda_O tanh\frac{2\pi h}{\lambda} \tag{6.1}$$

$$\lambda_O = 1.56131T^2 \tag{6.2}$$

6.3 Wave Number and Wave Celerity Data

Wave number and wave celerity can be obtained by using equations (5.1) and (5.3) respectively.

$$k = 2\pi/\lambda$$

k= 0,108098 rad/meters

$$c = \lambda / T$$

c= 6,69 meters/sec

6.4 Calculation of Dimensionless Data

K_i, K_d and S_d and S_i values can be obtained using equations below.

$$K_i = \frac{1}{2} tanhkh$$

K_i=0,4964

$$K_d = \frac{1}{8}\left(1 + \frac{2kh}{sinh2kh}\right)$$

K_d=0,1300

$$S_i = 1 + \left(\frac{1 - coshkh}{sinh2kh}\right)$$

S_i=0,6846

$$S_d = \frac{1}{2} + \frac{1}{8K_d}\left(\frac{1}{2} + \frac{1 - cosh2kh}{2khsinh2kh}\right)$$

S_d=0,8107

6.5 Calculation of Inertia and Friction (Drag) Forces

After calculating the dimensionless coefficients, Inertia and Friction forces can be calculated. Diameter of the monopile structure should be taken around 4.5 meters for the turbines used in this project, however for the sake of correct calculations and using correct coefficients (6.625 inches diameter was used while finding C_D and C_M

coefficients.), 0,5 meter diameter was used in below calculations.

$$F_i = C_m \rho g \frac{\pi D^2}{4} H K_i$$

$$F_i = 9919\ N$$

$$F_d = C_D \frac{1}{2} \rho g D H^2 K_d$$

$$F_d = 5863\ N$$

$$\omega t = \theta_f = -sin^{-1}\left(\frac{F_i}{2F_d}\right)$$

$$\omega t = -58°$$

This degree shows maximum intersection value of F_i and F_d forces.

6.6 Calculation of Inertia and Friction (Drag) Effect Points

For inertia force;

$$Mi = C_m \rho g h \frac{\pi D^2}{4} HKiSi = hFiSi$$

$$Mi = 176567{,}3\ N.m$$

$$x_i = \frac{M_i}{F_i}$$

$$x_i = \frac{176567{,}33}{9919{,}95} = 17{,}80\ meters$$

For friction force;

$$M_d = C_d \frac{1}{2} \rho g h D H^2 K_d S_d = 123589{,}94\ N.m$$

$$x_d = \frac{M_d}{F_d}$$

$$x_d = \frac{123589{,}94}{5863{,}16} = 21{,}08\ meters$$

6.7 Calculation of Total Force and Moment Values

This area is accepted as a deep water area and incident wave and diffraction wave data has been calculated, radiation wave data was neglected.

$$F = \int_{-h}^{\eta} f_i dz + \int_{-h}^{\eta} f_d \, dz = -F_i sin\omega t + F_d (cos\omega t)^2$$

$$F = -9919 * \sin(-58) + 5863(\cos(-58))^2$$

$$F = 10006{,}02 \; N$$

$$M = \int_{-h}^{\eta} (z+h) f_i \, dz + \int_{-h}^{\eta} (z+h) f_d dz = -M_i sin\omega t + M_d (cos\omega t)^2$$

$$M = -M_i sin\omega t + M_d (cos\omega t)^2$$

$$M = -176567\sin(-58) + 123589(cos(-58))^2$$

$$M = 180298{,}66 \; N.m$$

After total force and moment values have been calculated, effect point can be found as below:

$$x_t = \frac{M_t}{F_t}$$

$$x_i = \frac{180298{,}66}{10006{,}02} = 18{,}02 \; meters$$

Effect point values have been calculated from seabed.

7. CONCLUSIONS AND RECOMMENDATIONS

Renewable energy is trending around the world as a salvation from the domination of the conventional energy sources, for the sake of the Earth's future. Developed countries are investing their money and educating their youth to take the lead for renewable energy throughout the world.

Amongst the renewable energy sources, wind energy is taking the lead in the aspects of production, installation, operation and maintenance costs and efficiency factor. With the help of developing technologies and new installation techniques such as floating offshore wind turbine construction, offshore wind energy is on the rise. Offshore wind energy is the future of wind energy with its capacity factor and leading technology.

On offshore wind energy league, UK is on the lead, however Germany is a close second and Denmark, USA and China are following them. In order for them to be a pioneer they need to closely follow new technologies and researches on this topic. Denmark was first to experiment offshore wind turbines, and after it was seen that offshore wind energy is more promising than onshore wind, investment to offshore wind has been increased day by day.

An offshore structure should be designed and built in a way that it can withstand both wave and wind forces. To do that, wave forces must be evaluated in the selected region where wind farm will be located. While withstanding the harsh environment of offshore areas, an offshore wind turbine must produce energy and make profit from the energy it produced.

In this work, wind energy and wind energy parameters have been described. Afterwards, the details and basics of offshore wind energy have been given. Lastly, an example study has been carried out of a wind turbine off the Bozcaada shores.

While doing that, mean wind speed and dominant wind direction data sets have been obtained from General Directorate of Meteorology in Istanbul. These sets comprise of data collected from OMGI (automatic observation stations) between the 1970-

2016. According to data sets, Bozcaada has a mean wind speed of 6.09 m/s and the dominant wind direction is NNE.

Water depth off the Bozcaada shores, allows the installation of monopile type of foundation structure. Water depth fluctuates between 20 to 45 meters and which is reasonable for monopile foundation. Selected location has a water depth of 26 meters.

Turbine selection has been completed by checking wind profiles. Rotor diameters and power generation capacities have been checked while selecting appropriate wind turbine. After mentioned steps, VESTAS - V116-2.0 MW IEC IIB type wind turbine has been selected.

Fetch distance and empirical values were calculated. Morrison’s equation was used in this project for calculating the wave forces of the wind turbines off the Bozcaada Shores. Results appear to be realistic.

Bozcaada shores have the largest potential for installation of an offshore wind farm on Turkey’s seas. In this study, conducted calculations and potential arrangement works, set an example of the parameters to check for designing a potential offshore wind farm and what to expect from Bozcaada offshore area.

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APPENDICES

APPENDIX A: Dominant Wind Direction and Mean Wind Speed Data Set

APPENDIX A

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1970	1	N 10.0
17111	BOZCAADA	1970	2	S 10.9
17111	BOZCAADA	1970	3	NNE9.4
17111	BOZCAADA	1970	4	SSW7.1
17111	BOZCAADA	1970	5	N 6.2
17111	BOZCAADA	1970	5	SW 6.2
17111	BOZCAADA	1970	6	N 4.9
17111	BOZCAADA	1970	7	N 6.6
17111	BOZCAADA	1970	8	N 6.3
17111	BOZCAADA	1970	9	N 7.8
17111	BOZCAADA	1970	10	NNE9.8
17111	BOZCAADA	1970	11	NNE8.0
17111	BOZCAADA	1970	12	NNE8.3
17111	BOZCAADA	1971	1	NNE9.3
17111	BOZCAADA	1971	2	NNE11.1
17111	BOZCAADA	1971	3	SSE9.1
17111	BOZCAADA	1971	4	NNE7.9
17111	BOZCAADA	1971	5	N 5.4
17111	BOZCAADA	1971	6	N 4.9
17111	BOZCAADA	1971	7	N 7.1
17111	BOZCAADA	1971	8	N 7.6
17111	BOZCAADA	1971	9	N 7.2
17111	BOZCAADA	1971	10	N 7.9
17111	BOZCAADA	1971	11	S 8.7
17111	BOZCAADA	1971	12	NE 6.7
17111	BOZCAADA	1972	1	NNE9.7
17111	BOZCAADA	1972	2	NE 8.3
17111	BOZCAADA	1972	3	NNE10.9
17111	BOZCAADA	1972	4	N 7.3
17111	BOZCAADA	1972	5	N 5.9
17111	BOZCAADA	1972	6	N 5.2
17111	BOZCAADA	1972	7	N 4.6
17111	BOZCAADA	1972	8	N 6.3
17111	BOZCAADA	1972	9	NNW6.9
17111	BOZCAADA	1972	10	NNE6.2
17111	BOZCAADA	1972	11	NNE6.0
17111	BOZCAADA	1972	11	ENE6.0
17111	BOZCAADA	1972	12	NNE8.5
17111	BOZCAADA	1973	1	NNE7.6
17111	BOZCAADA	1973	2	SSE7.1

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1973	3	ENE5.9
17111	BOZCAADA	1973	4	SSW4.9
17111	BOZCAADA	1973	5	ENE4.3
17111	BOZCAADA	1973	6	NNE5.0
17111	BOZCAADA	1973	7	ENE5.2
17111	BOZCAADA	1973	7	NNE5.2
17111	BOZCAADA	1973	8	ENE7.4
17111	BOZCAADA	1973	9	ENE5.9
17111	BOZCAADA	1973	10	ENE8.0
17111	BOZCAADA	1973	11	E 6.9
17111	BOZCAADA	1973	12	SW 6.9
17111	BOZCAADA	1974	1	E 6.9
17111	BOZCAADA	1974	1	ENE6.9
17111	BOZCAADA	1974	2	NNE7.6
17111	BOZCAADA	1974	3	NNE7.5
17111	BOZCAADA	1974	4	NNE5.3
17111	BOZCAADA	1974	5	NNE6.2
17111	BOZCAADA	1974	6	NNE4.9
17111	BOZCAADA	1974	7	NNE5.9
17111	BOZCAADA	1974	8	NNE7.4
17111	BOZCAADA	1974	9	NNE6.4
17111	BOZCAADA	1974	10	SSW6.6
17111	BOZCAADA	1974	11	ENE6.3
17111	BOZCAADA	1974	12	ENE6.1
17111	BOZCAADA	1975	1	ENE7.7
17111	BOZCAADA	1975	2	ENE8.9
17111	BOZCAADA	1975	3	SSE5.7
17111	BOZCAADA	1975	3	SSW5.7
17111	BOZCAADA	1975	4	NNE4.8
17111	BOZCAADA	1975	4	NE 4.8
17111	BOZCAADA	1975	5	NE 3.3
17111	BOZCAADA	1975	6	NNE4.3
17111	BOZCAADA	1975	7	NNE6.1
17111	BOZCAADA	1975	8	NNE6.2
17111	BOZCAADA	1975	9	NE 6.2
17111	BOZCAADA	1975	10	ENE6.3
17111	BOZCAADA	1975	11	NE 7.5
17111	BOZCAADA	1975	12	ENE6.9
17111	BOZCAADA	1976	1	SSW7.7
17111	BOZCAADA	1976	2	NNE8.4
17111	BOZCAADA	1976	3	NNE6.8
17111	BOZCAADA	1976	4	NNW5.6

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1976	4	SSE5.6
17111	BOZCAADA	1976	5	NNW5.2
17111	BOZCAADA	1976	6	NNW5.8
17111	BOZCAADA	1976	7	NNW4.9
17111	BOZCAADA	1976	8	NNW5.1
17111	BOZCAADA	1976	9	NNW4.3
17111	BOZCAADA	1976	10	NNE6.1
17111	BOZCAADA	1976	11	NNE6.4
17111	BOZCAADA	1976	12	NNE8.0
17111	BOZCAADA	1977	1	NNE6.7
17111	BOZCAADA	1977	2	SSE7.0
17111	BOZCAADA	1977	3	NNE6.4
17111	BOZCAADA	1977	4	NNE5.9
17111	BOZCAADA	1977	5	NNW4.7
17111	BOZCAADA	1977	6	NNW4.5
17111	BOZCAADA	1977	7	NNW5.1
17111	BOZCAADA	1977	8	NNW6.2
17111	BOZCAADA	1977	9	N 7.1
17111	BOZCAADA	1977	10	N 6.4
17111	BOZCAADA	1977	11	S 6.0
17111	BOZCAADA	1977	12	N 9.3
17111	BOZCAADA	1978	1	N 8.0
17111	BOZCAADA	1978	2	N 7.1
17111	BOZCAADA	1978	3	N 7.3
17111	BOZCAADA	1978	4	NNW5.8
17111	BOZCAADA	1978	5	NNE5.8
17111	BOZCAADA	1978	6	NNW4.4
17111	BOZCAADA	1978	7	NNW6.1
17111	BOZCAADA	1978	8	NNW6.3
17111	BOZCAADA	1978	9	NNE5.1
17111	BOZCAADA	1978	10	NNE6.9
17111	BOZCAADA	1978	11	NNE8.8
17111	BOZCAADA	1978	12	NNE7.0
17111	BOZCAADA	1979	1	NNE8.3
17111	BOZCAADA	1979	1	SSE8.3
17111	BOZCAADA	1979	2	NNE9.2
17111	BOZCAADA	1979	3	NNE6.5
17111	BOZCAADA	1979	3	SSE6.5
17111	BOZCAADA	1979	4	NNE5.9
17111	BOZCAADA	1979	4	SSE5.9
17111	BOZCAADA	1979	5	NNW4.5
17111	BOZCAADA	1979	6	NNW5.1

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1979	7	NNW5.5
17111	BOZCAADA	1979	8	NNW5.4
17111	BOZCAADA	1979	9	NNE5.9
17111	BOZCAADA	1979	10	NNE7.1
17111	BOZCAADA	1979	12	NNE6.9
17111	BOZCAADA	1980	3	NNE6.5
17111	BOZCAADA	1980	4	NNE5.7
17111	BOZCAADA	1980	5	SSE4.6
17111	BOZCAADA	1980	6	NNE4.7
17111	BOZCAADA	1980	6	NNW4.7
17111	BOZCAADA	1980	7	NNW4.8
17111	BOZCAADA	1981	1	NNE9.3
17111	BOZCAADA	1981	2	NNE7.7
17111	BOZCAADA	1981	3	NNW5.9
17111	BOZCAADA	1981	4	NNW5.1
17111	BOZCAADA	1981	5	NNW5.9
17111	BOZCAADA	1981	6	NNW4.4
17111	BOZCAADA	1981	7	NNE6.0
17111	BOZCAADA	1981	8	NNE6.4
17111	BOZCAADA	1981	9	NNE5.8
17111	BOZCAADA	1981	10	NNE4.9
17111	BOZCAADA	1981	11	NNE5.7
17111	BOZCAADA	1981	11	ENE5.7
17111	BOZCAADA	1981	12	SSW8.4
17111	BOZCAADA	1982	1	NE 7.7
17111	BOZCAADA	1982	1	ENE7.7
17111	BOZCAADA	1982	2	NE 7.4
17111	BOZCAADA	1982	3	NNE7.1
17111	BOZCAADA	1982	4	NNE5.3
17111	BOZCAADA	1982	5	NNE5.6
17111	BOZCAADA	1982	6	NE 4.3
17111	BOZCAADA	1982	7	NNE5.1
17111	BOZCAADA	1982	8	NNE5.9
17111	BOZCAADA	1982	9	NNE6.4
17111	BOZCAADA	1982	10	NNE5.7
17111	BOZCAADA	1982	11	NNE6.7
17111	BOZCAADA	1982	12	SSW7.7
17111	BOZCAADA	1983	1	NE 6.9
17111	BOZCAADA	1983	2	NE 8.8
17111	BOZCAADA	1983	3	NE 7.5
17111	BOZCAADA	1983	4	NNE4.7
17111	BOZCAADA	1983	5	NNE4.9

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1983	6	NNE5.7
17111	BOZCAADA	1983	7	NNE5.1
17111	BOZCAADA	1983	8	NNE5.9
17111	BOZCAADA	1983	9	NNE5.8
17111	BOZCAADA	1983	10	NNE6.0
17111	BOZCAADA	1983	11	NNE7.4
17111	BOZCAADA	1983	11	NE 7.4
17111	BOZCAADA	1983	12	NE 6.6
17111	BOZCAADA	1984	1	SSW6.8
17111	BOZCAADA	1984	1	SSE6.8
17111	BOZCAADA	1984	2	ENE6.7
17111	BOZCAADA	1984	2	NE 6.7
17111	BOZCAADA	1984	3	ENE6.9
17111	BOZCAADA	1984	4	NNE5.2
17111	BOZCAADA	1984	5	SSW4.0
17111	BOZCAADA	1984	5	NNE4.0
17111	BOZCAADA	1984	6	NNE5.3
17111	BOZCAADA	1984	7	NNE6.0
17111	BOZCAADA	1984	8	NNE5.6
17111	BOZCAADA	1984	9	NNE5.3
17111	BOZCAADA	1984	10	NNE5.2
17111	BOZCAADA	1984	11	NNE6.6
17111	BOZCAADA	1984	12	ENE6.9
17111	BOZCAADA	1985	1	ENE8.9
17111	BOZCAADA	1985	2	ENE7.9
17111	BOZCAADA	1985	3	NNE6.7
17111	BOZCAADA	1985	4	NNE5.8
17111	BOZCAADA	1985	5	NNE4.2
17111	BOZCAADA	1985	6	NNE4.3
17111	BOZCAADA	1985	6	NNW4.3
17111	BOZCAADA	1985	7	NNE6.2
17111	BOZCAADA	1985	8	NNE6.6
17111	BOZCAADA	1985	9	NNE6.3
17111	BOZCAADA	1985	10	NNE7.2
17111	BOZCAADA	1985	11	NNE6.2
17111	BOZCAADA	1985	12	NNE6.1
17111	BOZCAADA	1985	12	ESE6.1
17111	BOZCAADA	1985	12	SSE6.1
17111	BOZCAADA	1986	1	SSW7.7
17111	BOZCAADA	1986	2	NNE8.1
17111	BOZCAADA	1986	3	ENE7.7
17111	BOZCAADA	1986	4	NNE4.8

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1986	5	NNE5.8
17111	BOZCAADA	1986	6	NNE5.1
17111	BOZCAADA	1986	7	NNE5.7
17111	BOZCAADA	1986	8	NNE7.2
17111	BOZCAADA	1986	9	NNE6.4
17111	BOZCAADA	1986	10	NNE7.1
17111	BOZCAADA	1986	11	NNE6.5
17111	BOZCAADA	1986	12	NNE7.0
17111	BOZCAADA	1987	1	NNE8.9
17111	BOZCAADA	1987	1	SSE8.9
17111	BOZCAADA	1987	2	NNW6.7
17111	BOZCAADA	1987	3	NNE7.6
17111	BOZCAADA	1987	4	NNW7.0
17111	BOZCAADA	1987	5	NNW4.8
17111	BOZCAADA	1987	5	SSE4.8
17111	BOZCAADA	1987	6	NNW5.2
17111	BOZCAADA	1987	7	NNE6.9
17111	BOZCAADA	1987	8	NNE5.9
17111	BOZCAADA	1987	9	NNE5.9
17111	BOZCAADA	1987	10	NNE7.6
17111	BOZCAADA	1987	11	SSW6.1
17111	BOZCAADA	1987	12	NE 6.6
17111	BOZCAADA	1988	1	ENE6.1
17111	BOZCAADA	1988	2	NNE7.2
17111	BOZCAADA	1988	3	SSW6.2
17111	BOZCAADA	1988	4	NNE5.5
17111	BOZCAADA	1988	5	NNE4.2
17111	BOZCAADA	1988	6	NNE3.3
17111	BOZCAADA	1988	7	NNE5.9
17111	BOZCAADA	1988	8	NNE6.6
17111	BOZCAADA	1988	9	NNE5.3
17111	BOZCAADA	1988	10	NNE7.8
17111	BOZCAADA	1988	11	NNE7.3
17111	BOZCAADA	1989	1	NNE8.1
17111	BOZCAADA	1989	2	NNE7.5
17111	BOZCAADA	1989	3	NNE6.1
17111	BOZCAADA	1989	4	NNE5.7
17111	BOZCAADA	1989	4	NNW5.7
17111	BOZCAADA	1989	5	NNE6.1
17111	BOZCAADA	1989	6	NNE2.9
17111	BOZCAADA	1989	7	NNE7.0
17111	BOZCAADA	1989	8	NNE6.4

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1989	9	NNE5.1
17111	BOZCAADA	1989	10	NNE7.7
17111	BOZCAADA	1989	11	NNE6.0
17111	BOZCAADA	1989	12	NNE6.4
17111	BOZCAADA	1990	1	NNE6.2
17111	BOZCAADA	1990	2	NNE7.9
17111	BOZCAADA	1990	3	NNE6.4
17111	BOZCAADA	1990	4	NNE5.1
17111	BOZCAADA	1990	4	ESE5.1
17111	BOZCAADA	1990	4	SSE5.1
17111	BOZCAADA	1990	5	NNE5.4
17111	BOZCAADA	1990	6	NNE5.2
17111	BOZCAADA	1990	7	NNE7.5
17111	BOZCAADA	1990	8	NNE7.6
17111	BOZCAADA	1990	9	NNE4.8
17111	BOZCAADA	1990	10	NNE6.5
17111	BOZCAADA	1990	11	S 6.5
17111	BOZCAADA	1990	11	SSE6.5
17111	BOZCAADA	1990	12	NE 6.6
17111	BOZCAADA	1991	1	NNE7.3
17111	BOZCAADA	1991	2	NNE7.2
17111	BOZCAADA	1991	3	NNE6.3
17111	BOZCAADA	1991	4	NE 5.7
17111	BOZCAADA	1991	5	SSW4.6
17111	BOZCAADA	1991	6	NNW4.6
17111	BOZCAADA	1991	7	NNE5.9
17111	BOZCAADA	1991	8	NNE6.7
17111	BOZCAADA	1991	9	NNE5.0
17111	BOZCAADA	1991	10	NNE5.7
17111	BOZCAADA	1991	11	NNE5.9
17111	BOZCAADA	1991	12	NNE8.6
17111	BOZCAADA	1992	1	NNE6.3
17111	BOZCAADA	1992	1	ENE6.3
17111	BOZCAADA	1992	2	ENE6.0
17111	BOZCAADA	1992	3	NNE6.7
17111	BOZCAADA	1992	4	SSE4.8
17111	BOZCAADA	1992	5	NNE6.8
17111	BOZCAADA	1992	6	NNW4.4
17111	BOZCAADA	1992	6	NNE4.4
17111	BOZCAADA	1992	7	NNE5.9
17111	BOZCAADA	1992	7	NNW5.9
17111	BOZCAADA	1992	8	NNE6.9

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1992	9	NNE6.2
17111	BOZCAADA	1992	10	SSE5.5
17111	BOZCAADA	1992	11	ESE6.3
17111	BOZCAADA	1992	12	NE 8.1
17111	BOZCAADA	1993	1	NNE7.1
17111	BOZCAADA	1993	2	NE 7.6
17111	BOZCAADA	1993	3	NNE6.5
17111	BOZCAADA	1993	4	NNE6.2
17111	BOZCAADA	1993	5	NNE4.3
17111	BOZCAADA	1993	6	NNE4.4
17111	BOZCAADA	1993	7	NNE5.9
17111	BOZCAADA	1993	8	NNE7.0
17111	BOZCAADA	1993	9	NNE5.0
17111	BOZCAADA	1993	10	NNE4.9
17111	BOZCAADA	1993	11	NE 7.7
17111	BOZCAADA	1993	12	S 6.4
17111	BOZCAADA	1994	1	NE 5.9
17111	BOZCAADA	1994	2	NNE6.6
17111	BOZCAADA	1994	3	NE 6.5
17111	BOZCAADA	1994	4	NNW4.9
17111	BOZCAADA	1994	5	NNE3.8
17111	BOZCAADA	1994	6	NNE4.6
17111	BOZCAADA	1994	7	NNE6.6
17111	BOZCAADA	1994	8	NNE5.3
17111	BOZCAADA	1994	9	NNE4.9
17111	BOZCAADA	1994	10	NNE5.2
17111	BOZCAADA	1994	11	NE 5.7
17111	BOZCAADA	1994	12	ESE5.5
17111	BOZCAADA	1995	1	SSE7.4
17111	BOZCAADA	1995	2	NNE6.1
17111	BOZCAADA	1995	3	SSE6.5
17111	BOZCAADA	1995	4	NNW4.7
17111	BOZCAADA	1995	4	N 4.7
17111	BOZCAADA	1995	5	N 5.6
17111	BOZCAADA	1995	6	NNW3.7
17111	BOZCAADA	1995	7	N 5.9
17111	BOZCAADA	1995	8	NNW5.2
17111	BOZCAADA	1995	9	N 4.1
17111	BOZCAADA	1995	10	N 5.8
17111	BOZCAADA	1995	11	ENE5.5
17111	BOZCAADA	1995	12	NE 6.4
17111	BOZCAADA	1996	1	NE 6.0

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	1996	2	NE 6.7
17111	BOZCAADA	1996	3	N 6.2
17111	BOZCAADA	1996	4	NNW3.9
17111	BOZCAADA	1996	5	NNW4.2
17111	BOZCAADA	1996	6	N 4.9
17111	BOZCAADA	1996	7	N 5.7
17111	BOZCAADA	1996	8	N 5.2
17111	BOZCAADA	1996	9	ESE4.2
17111	BOZCAADA	1996	10	NE 4.5
17111	BOZCAADA	1996	11	NNE5.4
17111	BOZCAADA	1996	12	NNE7.0
17111	BOZCAADA	1996	12	SSE7.0
17111	BOZCAADA	1997	1	NE 5.4
17111	BOZCAADA	1997	2	NE 5.6
17111	BOZCAADA	1997	3	NE 6.1
17111	BOZCAADA	1997	4	NNE5.2
17111	BOZCAADA	1997	5	NNE5.3
17111	BOZCAADA	1997	6	NNW3.3
17111	BOZCAADA	1997	7	NNW3.9
17111	BOZCAADA	1997	8	NNW5.1
17111	BOZCAADA	1997	9	NW 6.4
17111	BOZCAADA	1997	10	NE 6.4
17111	BOZCAADA	1997	11	NE 4.6
17111	BOZCAADA	1997	12	NNE7.0
17111	BOZCAADA	1998	1	ESE4.8
17111	BOZCAADA	1998	2	NNE5.9
17111	BOZCAADA	1998	3	NE 6.6
17111	BOZCAADA	1998	4	SSE6.0
17111	BOZCAADA	1998	5	NNW4.8
17111	BOZCAADA	1998	6	NNW5.0
17111	BOZCAADA	1998	7	N 5.7
17111	BOZCAADA	1998	7	NNW5.7
17111	BOZCAADA	1998	8	NNE6.0
17111	BOZCAADA	1998	9	NNE5.2
17111	BOZCAADA	1998	10	NNE5.2
17111	BOZCAADA	1998	11	NNE6.2
17111	BOZCAADA	1998	11	NE 6.2
17111	BOZCAADA	1998	12	NNE7.2
17111	BOZCAADA	1999	10	ENE5.6
17111	BOZCAADA	1999	11	NE 6.8
17111	BOZCAADA	1999	12	S 6.4
17111	BOZCAADA	2000	1	NE 7.2

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	2000	2	NE 6.2
17111	BOZCAADA	2000	3	NE 5.6
17111	BOZCAADA	2000	4	NNE4.2
17111	BOZCAADA	2000	5	NE 5.1
17111	BOZCAADA	2000	6	NNE6.5
17111	BOZCAADA	2000	7	NNE5.3
17111	BOZCAADA	2000	8	NE 7.4
17111	BOZCAADA	2000	9	NNE5.8
17111	BOZCAADA	2000	9	NE 5.8
17111	BOZCAADA	2000	10	NNE6.2
17111	BOZCAADA	2000	11	NE 3.9
17111	BOZCAADA	2000	12	ENE5.9
17111	BOZCAADA	2001	1	NE 6.9
17111	BOZCAADA	2001	2	ENE6.4
17111	BOZCAADA	2001	3	SSW6.3
17111	BOZCAADA	2001	3	ENE6.3
17111	BOZCAADA	2001	4	S 5.8
17111	BOZCAADA	2001	4	WSW5.8
17111	BOZCAADA	2001	5	NNE5.1
17111	BOZCAADA	2001	6	NNE5.7
17111	BOZCAADA	2001	7	NNE6.1
17111	BOZCAADA	2001	8	NNE7.4
17111	BOZCAADA	2001	9	NNE4.9
17111	BOZCAADA	2001	10	NNE7.1
17111	BOZCAADA	2001	11	ENE6.6
17111	BOZCAADA	2001	12	NE 10.2
17111	BOZCAADA	2002	1	ENE6.0
17111	BOZCAADA	2002	2	S 5.4
17111	BOZCAADA	2002	2	NE 5.4
17111	BOZCAADA	2002	2	ENE5.4
17111	BOZCAADA	2002	2	SSW5.4
17111	BOZCAADA	2002	3	NE 6.7
17111	BOZCAADA	2002	4	NE 5.9
17111	BOZCAADA	2002	5	NE 5.5
17111	BOZCAADA	2002	6	NNE5.9
17111	BOZCAADA	2002	7	NNE4.8
17111	BOZCAADA	2002	7	NE 4.8
17111	BOZCAADA	2002	8	NNE5.4
17111	BOZCAADA	2002	9	NNE4.0
17111	BOZCAADA	2002	10	ENE4.7
17111	BOZCAADA	2002	11	ESE4.4
17111	BOZCAADA	2002	12	ENE6.9

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	2003	1	SSW7.2
17111	BOZCAADA	2003	2	NE 9.6
17111	BOZCAADA	2003	3	NE 7.4
17111	BOZCAADA	2003	4	NNE5.7
17111	BOZCAADA	2003	5	NNE5.5
17111	BOZCAADA	2003	6	NNE5.8
17111	BOZCAADA	2003	7	NNE5.2
17111	BOZCAADA	2003	8	NNE6.4
17111	BOZCAADA	2003	9	NNE6.2
17111	BOZCAADA	2003	10	NE 6.2
17111	BOZCAADA	2003	10	SSW6.2
17111	BOZCAADA	2003	11	NE 5.5
17111	BOZCAADA	2003	12	NE 6.9
17111	BOZCAADA	2004	1	E 7.9
17111	BOZCAADA	2004	2	SSE7.2
17111	BOZCAADA	2004	3	ENE7.4
17111	BOZCAADA	2004	4	NNE6.4
17111	BOZCAADA	2004	5	NNE6.3
17111	BOZCAADA	2004	6	NNE4.6
17111	BOZCAADA	2004	7	NNE7.3
17111	BOZCAADA	2004	8	NNE4.9
17111	BOZCAADA	2004	9	NNE6.9
17111	BOZCAADA	2004	10	NNE5.5
17111	BOZCAADA	2004	10	ENE5.5
17111	BOZCAADA	2004	11	NNE6.4
17111	BOZCAADA	2004	12	N 6.1
17111	BOZCAADA	2005	1	N 6.9
17111	BOZCAADA	2005	2	N 8.2
17111	BOZCAADA	2005	3	N 5.8
17111	BOZCAADA	2005	4	N 7.8
17111	BOZCAADA	2005	4	S 7.8
17111	BOZCAADA	2005	5	NNW5.1
17111	BOZCAADA	2005	6	NNW5.9
17111	BOZCAADA	2005	7	N 5.7
17111	BOZCAADA	2005	8	N 5.2
17111	BOZCAADA	2005	9	N 5.0
17111	BOZCAADA	2005	10	NNE6.3
17111	BOZCAADA	2005	11	N 6.6
17111	BOZCAADA	2005	12	N 7.1
17111	BOZCAADA	2005	12	S 7.1
17111	BOZCAADA	2006	1	N 8.7
17111	BOZCAADA	2006	2	N 6.0

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	2006	3	S 6.8
17111	BOZCAADA	2006	4	N 5.1
17111	BOZCAADA	2006	5	N 5.3
17111	BOZCAADA	2006	6	N 5.3
17111	BOZCAADA	2006	7	N 8.3
17111	BOZCAADA	2006	8	N 4.5
17111	BOZCAADA	2006	9	N 6.1
17111	BOZCAADA	2006	10	N 6.2
17111	BOZCAADA	2006	11	NNE5.6
17111	BOZCAADA	2006	12	N 5.4
17111	BOZCAADA	2007	1	S 5.2
17111	BOZCAADA	2007	2	N 6.2
17111	BOZCAADA	2007	3	N 7.0
17111	BOZCAADA	2007	4	N 4.9
17111	BOZCAADA	2007	5	N 4.2
17111	BOZCAADA	2007	6	N 4.1
17111	BOZCAADA	2007	7	N 6.3
17111	BOZCAADA	2007	8	N 3.3
17111	BOZCAADA	2007	9	N 5.4
17111	BOZCAADA	2007	10	N 5.4
17111	BOZCAADA	2007	11	NNE1.9
17111	BOZCAADA	2007	12	NE 4.8
17111	BOZCAADA	2008	1	NE 6.1
17111	BOZCAADA	2008	2	NE 7.1
17111	BOZCAADA	2008	3	SSW5.4
17111	BOZCAADA	2008	4	SSW4.6
17111	BOZCAADA	2008	5	NNE4.1
17111	BOZCAADA	2008	6	NNE5.2
17111	BOZCAADA	2008	7	NNE6.0
17111	BOZCAADA	2008	8	NNE7.0
17111	BOZCAADA	2008	9	NNE5.9
17111	BOZCAADA	2008	10	NE 5.7
17111	BOZCAADA	2008	11	NE 5.7
17111	BOZCAADA	2008	12	NE 6.2
17111	BOZCAADA	2009	1	NE 6.6
17111	BOZCAADA	2009	2	NE 7.3
17111	BOZCAADA	2009	3	NNE4.9
17111	BOZCAADA	2009	3	SE 4.9
17111	BOZCAADA	2009	4	NNE5.2
17111	BOZCAADA	2009	5	NNE4.4
17111	BOZCAADA	2009	6	N 4.3
17111	BOZCAADA	2009	6	NE 4.3

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	2009	7	NNE5.4
17111	BOZCAADA	2009	8	NNE7.5
17111	BOZCAADA	2009	9	NNE6.1
17111	BOZCAADA	2009	10	NNE5.0
17111	BOZCAADA	2009	11	N 4.3
17111	BOZCAADA	2009	12	S 7.0
17111	BOZCAADA	2009	12	SSW7.0
17111	BOZCAADA	2009	12	NE 7.0
17111	BOZCAADA	2010	1	NE 7.6
17111	BOZCAADA	2010	2	SSW6.5
17111	BOZCAADA	2010	3	NE 5.4
17111	BOZCAADA	2010	4	NE 5.5
17111	BOZCAADA	2010	5	N 3.2
17111	BOZCAADA	2010	6	NNE4.1
17111	BOZCAADA	2010	7	NNE5.6
17111	BOZCAADA	2010	8	NNE5.8
17111	BOZCAADA	2010	9	NNE5.6
17111	BOZCAADA	2010	10	NE 5.7
17111	BOZCAADA	2010	11	SSW5.1
17111	BOZCAADA	2010	12	SSW7.2
17111	BOZCAADA	2011	1	NE 5.7
17111	BOZCAADA	2011	2	NE 6.9
17111	BOZCAADA	2011	3	NE 6.8
17111	BOZCAADA	2011	4	NNE6.6
17111	BOZCAADA	2011	4	NE 6.6
17111	BOZCAADA	2011	5	NNE5.1
17111	BOZCAADA	2011	6	NE 4.8
17111	BOZCAADA	2011	7	N 4.7
17111	BOZCAADA	2011	8	N 7.2
17111	BOZCAADA	2011	9	NNE6.8
17111	BOZCAADA	2011	10	NNE7.0
17111	BOZCAADA	2011	11	NNE7.4
17111	BOZCAADA	2011	12	N 5.6
17111	BOZCAADA	2012	1	NNE7.3
17111	BOZCAADA	2012	2	NNE6.6
17111	BOZCAADA	2012	3	NNE5.5
17111	BOZCAADA	2012	4	S 5.6
17111	BOZCAADA	2012	5	NNE4.1
17111	BOZCAADA	2012	6	N 5.9
17111	BOZCAADA	2012	7	N 6.3
17111	BOZCAADA	2012	8	NNE5.7
17111	BOZCAADA	2012	8	N 5.7

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	2012	9	N 5.9
17111	BOZCAADA	2012	10	N 5.5
17111	BOZCAADA	2012	11	NNE6.7
17111	BOZCAADA	2012	12	NNE6.5
17111	BOZCAADA	2013	1	NE 6.3
17111	BOZCAADA	2013	1	S 6.3
17111	BOZCAADA	2013	2	E 6.0
17111	BOZCAADA	2013	3	S 2.7
17111	BOZCAADA	2013	4	N 4.9
17111	BOZCAADA	2013	5	N 4.6
17111	BOZCAADA	2013	6	N 5.1
17111	BOZCAADA	2013	7	N 7.0
17111	BOZCAADA	2013	8	NNE6.9
17111	BOZCAADA	2013	8	N 6.9
17111	BOZCAADA	2013	9	N 3.8
17111	BOZCAADA	2013	10	NNE5.2
17111	BOZCAADA	2013	11	NNE5.5
17111	BOZCAADA	2013	11	ESE5.5
17111	BOZCAADA	2013	12	NNE6.2
17111	BOZCAADA	2014	1	N 5.1
17111	BOZCAADA	2014	2	NNE5.4
17111	BOZCAADA	2014	3	S 5.7
17111	BOZCAADA	2014	4	S 4.3
17111	BOZCAADA	2014	5	S 4.6
17111	BOZCAADA	2014	6	NNE4.4
17111	BOZCAADA	2014	7	N 5.2
17111	BOZCAADA	2014	8	N 5.5
17111	BOZCAADA	2014	9	NNE5.8
17111	BOZCAADA	2014	10	NNE6.4
17111	BOZCAADA	2014	11	NNE5.1
17111	BOZCAADA	2014	11	NE 5.1
17111	BOZCAADA	2014	12	NNE5.5
17111	BOZCAADA	2014	12	NE 5.5
17111	BOZCAADA	2014	12	S 5.5
17111	BOZCAADA	2015	1	S 7.1
17111	BOZCAADA	2015	2	NNE8.0
17111	BOZCAADA	2015	3	NNE5.8
17111	BOZCAADA	2015	4	N 5.2
17111	BOZCAADA	2015	5	N 4.6
17111	BOZCAADA	2015	6	N 6.0
17111	BOZCAADA	2015	7	N 6.3
17111	BOZCAADA	2015	8	N 6.6

STATION NO	STATION NAME	YEAR	MONTH	MONTHLY DOMINANT DIRECTION AND MEAN WIND SPEED
17111	BOZCAADA	2015	9	N 4.9
17111	BOZCAADA	2015	10	NNE6.4
17111	BOZCAADA	2015	11	N 5.2
17111	BOZCAADA	2015	12	NNE6.1
17111	BOZCAADA	2016	1	SE 5.9
17111	BOZCAADA	2016	2	S 5.6
17111	BOZCAADA	2016	2	SSW5.6
17111	BOZCAADA	2016	3	NNE5.2
17111	BOZCAADA	2016	3	S 5.2
17111	BOZCAADA	2016	4	NNE3.7
17111	BOZCAADA	2016	5	N 4.4
17111	BOZCAADA	2016	6	NNE6.1
17111	BOZCAADA	2016	7	NNE6.3
17111	BOZCAADA	2016	8	NNE7.1
17111	BOZCAADA	2016	9	NNE5.2
17111	BOZCAADA	2016	10	NNE5.1
17111	BOZCAADA	2016	11	NNE5.6
17111	BOZCAADA	2016	12	NNE6.7

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