ECONOMICAL, ENVIRONMENTAL OUTCOMES OF WIND ENERGY PRODUCTION IN TURKEY

An interactive qualifying project in fulfillment of the requirements for the degree of

Bachelor of Science

WORCESTER POLYTECHNIC INSTITUTE

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ABSTRACT

An interactive qualifying project presented on the energy demands of Turkish Republic and wind energy as an alternative for fossil fuel. In addition to that, future wind power plant sites, energy production estimation, economical and environmental outcomes are analyzed and interpreted.

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INTRODUCTION

This interactive qualifying project mainly focuses on using wind energy as a partial, alternative electrical energy resource in order to decrease the demand for fossil fuel. Project begins with describing the latest technology in wind power production as well as major components of a wind turbine. In addition to that, some information on wind turbine production and management companies are introduced in order to show the importance of wind energy throughout the world.

Project also focuses on the building of such large scale wind turbines, potential wind energy production areas around Turkey. Analysis of wind energy capacity, wind speed and average annual electrical energy production estimations are all based on REPA; Turkish wind energy potential atlas.

Feasibility and economical outcomes of wind energy are analyzed with the help of Ministry of Energy and Natural Resources Department's most recent report and Turkish Energy Market Organization reports. Detailed construction, transportation and grid stabilization engineering cost analysis are beyond the scope of this project and were kept as simple as possible.

Just like the other countries around the world, Turkey's energy demands are increasing as a result of population growth and industrial demands. Considering the fact that fossil fuel supplies in OPEC will last in the next century, energy industry must concentrate on alternative and reliable methods of supplying the demand. In addition to that, global warming is increasing proportionally with the fossil fuel usage for various demands related to energy.

CHAPTER 1 – BRIEF DESCRIPTION OF WIND TURBINES

HOW WIND TURBINES OPERATE

The main energy source for the wind turbines is air. Air is a fluid; it has its particles in the gas form instead of liquid form. When air moves quickly, its particles move fast, in the form of wind. Meaning of motion is derived from the kinetic energy, which can be easily captured and very easy to use. For instance, it is like the water can be captured by the turbines of a hydroelectric dam. In our case, the fluid is captured by a wind turbine. Speaking of wind power, it all starts from the sun. The wind is a form of solar energy: 1% to 2% of the solar energy is converted in wind. It's just air in motion which is caused by the rotation of the earth, the irregularities of the earth’s surface, irregularities of the temperature in the atmosphere. The wind is more important in coastal and mountainous regions due to the amplified effect of atmospheric pressure difference on wind velocity. When the sun heats up a certain area of land, the air around that land absorbs some of that heat coming from the sun. At a certain temperature, the hotter air begins to rise very quickly since the given volume of the hot air is lighter than the equal volume of the cooler air. Faster-moving (hotter) air particles exert more pressure than slower-moving particles, so it takes fewer of them to maintain the normal air pressure at a given elevation. At the time that lighter hot air suddenly rises, cooler air flows quickly in to fill the gap and the hot air leaves behind. That movement of air rushing to fill up the gap creates the wind. The job of the wind turbine is to convert the fluid flow and create energy. In more specific way, Wind Turbines converts the kinetic the kinetic energy from the wind to the mechanical energy, using generators and the created mechanical energy, wind turbines create electricity.

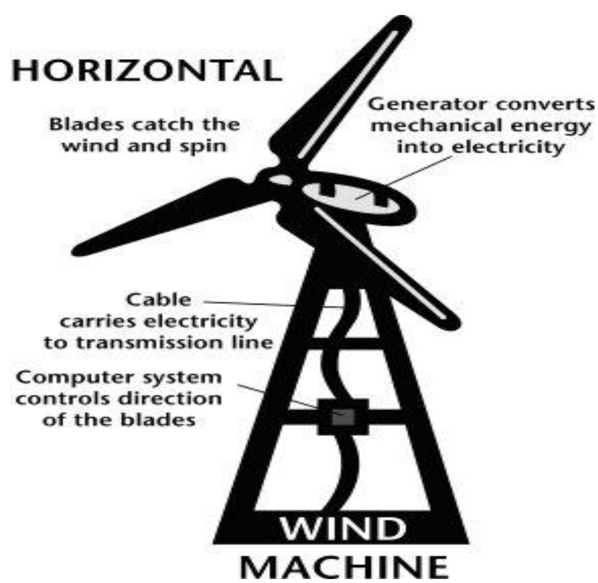

FIGURE 1-BASIC DESCRIPTION OF A WIND TURBINE

MAJOR COMPONENTS OF WIND TURBINES

Typical wind turbines consists of a nacelle, rotor blades (propeller blades), hub, low speed shaft, gearbox, high speed shaft with mechanical brake, electric generator, yaw mechanism, electronic controller, hydraulics system, cooling unit, tower, anemometer and wind vane. The tower of the wind turbine carries the nacelle and the rotor. Towers may be lattice or tubular towers. Tubular towers are safer but more expensive. They are more commonly used since production capabilities are higher and more efficient.

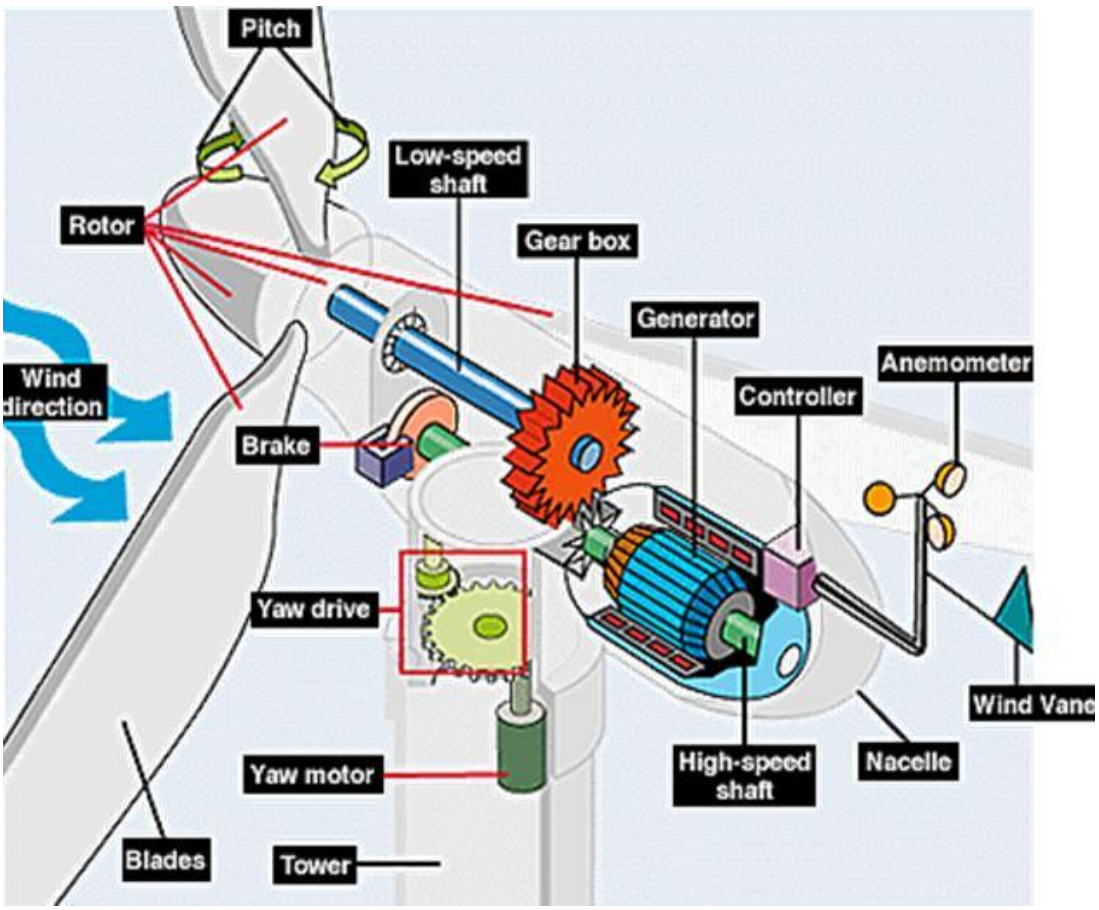

FIGURE 2-DETAILED COMPONENTS INSIDE THE TURBINE

ELECTRICITY PRODUCTION

Rotating turbines attached to electrical generators produce most commercially available electricity. Turbines are driven by a fluid (wind) which acts as a renewable, natural intermediate energy carrier. Wind flowing through the blades creating the aerodynamic effect results in a force turning the rotor. The wind turbine converts kinetic energy of the wind to mechanical energy. After that, the generator converts mechanical energy to electrical energy by connecting the low speed shaft to the generator which has a angular velocity controlled by a speed brake and a gearbox. Unlike other electricity generators, wind turbine generators are different; this distinction comes from the supplier which is the wind turbine rotor and other than that, torque.

TYPES OF WIND TURBINES

Classification of wind generators, or wind energy collectors (WECs), can be based onto the turbine rotation axes and the geological positioning of the structure. Whilst the former has two classes, horizontal-axis and vertical-axis turbines; the latter has three classes: off-shore, on-shore and near-shore.[1] Horizontal –axis wind turbines (HAWT) are much more common than Vertical-axis wind turbines (VAWT) due to better energy extracting properties that shall be discussed later.

Classification of wind generators on the geological positioning depends on distinct definitions of space and location. To clarify, off-shore wind generators must be positioned at least 10 kilometers or more off the shore. Near-shore turbines are positioned within 5 kilometers off the shore. On-shore turbines are positioned on the land.

HORIZONTAL AXIS WIND TURBINES (HAWT)

HAWTs have the rotor shaft and generator on top of the tower and they must be pointed into the wind to harvest electricity. Pointing process has been computerized thanks to wind sensors and servo motors to keep the wind hitting the blades at maximum angle and speed possible. However, the rotation caused by the wind itself isn't enough for production purposes, therefore; turbines include a gearbox for accentuating the rotation of the blades for generating electricity.

HAWTs are upwind turbines that convert the energy of the high winds. Being positioned upwind is crucial due to the turbulence created by the tower of the turbine. Downwind mechanisms have been made, however; fatigue problems had arisen due to turbulence which affected reliability. Modern HAWTs operate on three stiff blades with tip speeds as much as six hundred percent of that of the wind. Three-blade turbine structure has been adopted for commercial uses so widely that it has almost become synonymous with the turbine design since it features high efficiency and high reliability for energy production purposes.

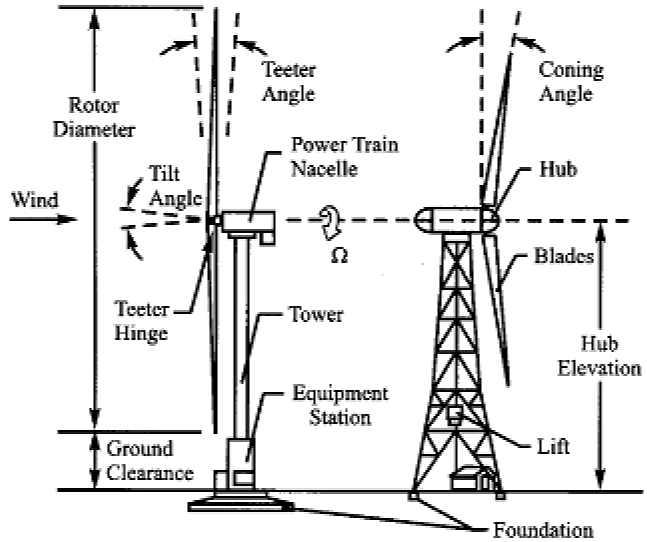

FIGURE 3-HAWT BLADE DESIGN

The blades are positioned to the side of the tower, aiding stability due to the proximity with the center of gravity. Also, this type of turbines self start, cutting the need (and the cost) of an auxiliary starting mechanism. Moreover, taller turbine towers, which are generally between 20 to 40m in height, give access to more energized, stronger winds. In some sites, 10m of altitude difference could mean %20 more wind power and %30+ more energy production. Just because of the same reason though, HAWTs are more prone to damages in storms and higher transportation/installation costs. Consequently, on-shore HAWT installations often raise controversies and fiery oppositions as they block or damage the land sight. Tower heights are subject to discussion in national security meetings in almost every country that utilize them since they do obstruct radar signals if they are placed near airfields or military bases.

VERTICAL AXIS WIND TURBINES (VAWT)

As the name suggests, in Vertical-Axis Wind Turbines, the rotor is horizontal to the ground, revolving around the `z` axis. The advantage of this layout is that turbine doesn't need to be above a high tower and the gearbox, with other mechanical devices such as the generator, can be placed near the ground. Another property of this layout is blades do not have to be pointed into the wind. However, vertically mounted `blades` create excessive drag whilst rotation in the wind. Moreover, rotation and torque aren't as smooth and linear as in the HAWTs, which seriously damage the internal of the turbine and hinter reliability.

HAWTs commonly have the three-bladed commercial turbine design, whereas VAWTs differ greatly in shape, size and function. Mainly they differ in function by how they capture the wind: Lift-type and Drag-type.[2] Drag-types are mostly simplified to three-cup anemometers, which can also be seen in WPI campus on the wall of Higgins Labs. What determines the differences is Tip Speed Ratio (TSR). In drag-type VAWTs, TSR can never exceed 1, and commonly will be less than 1, since the tip of the `cups` cannot exceed the speed of the wind. However, if TSR is greater than 1, it means there is some lift in the turbines, hence lift-type VAWTs. Lift-type turbines combine better efficiency and more power, therefore; are preferred over drag-type VAWTs.

Most common Drag-type VAWT is `the Savonius`. Having an S-shaped rotor, this turbine uses buckets, sails, drums and paddles to catch the wind and, if made well, can exceed a TSR of 1. However, these devices cannot be utilized for generating electricity as it cannot operate above 100RPMs. [1000 RPMs and more is required for efficient electricity generation.] They are mostly used in rural areas to grind grain and pump water.

Lift-Type VAWTs are generally known to be Darrieus Type, which is an eggbeater shaped shaft and blade design. The output of a lift-type VAWT is sinusoidal, having massive differences during the rotation due to the fact that each blade cuts the wind twice per rotation. Furthermore, long vertical blades each have various natural frequency of variation; thus those values must be avoided during rotation to keep the turbine and tower intact from damages.

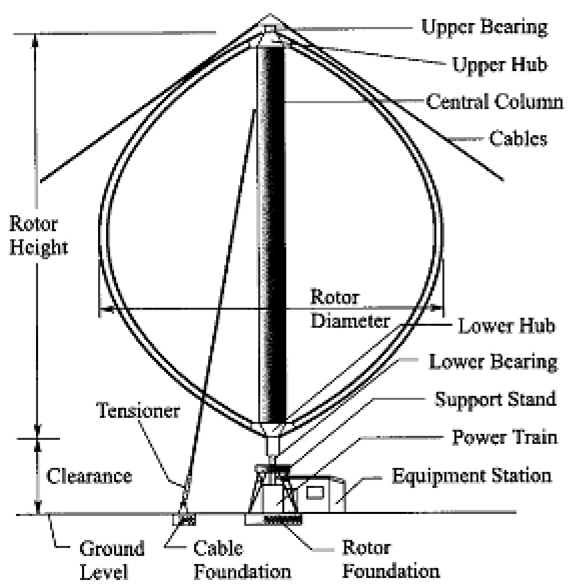

FIGURE 4-VAWT(LIFT-TYPE)[3]

VAWTs are almost impossible to mount on top of high towers, therefore; they deal with the lower, more turbulent winds. Hence their energy productions are much less than those of HAWTs.

OFF-SHORE WIND TURBINE LOCATIONS

Off-Shore zones are located more than 10 kilometers away from the shore and mostly preferred by the community since they are far less obtrusive than on-shore zones. One reason for this preference is off-shore wind turbines are much lower than the land ones as water has less surface roughness compared to land, making high speed, high energy winds possible at the sea surface.

Off-Shore wind power plants have an expense problem. First of all, available zones for wind turbine `farms` are far less than land options. Second, installation of corrosion protected towers to the sea floor is a highly expensive process, let alone the maintenance and power transmission costs. To send the electricity generated to the stations on land, underwater transmission cables must be used, which also add up on the cost list. Also, transmission of electric current must be alternated to high voltage direct current over long distances; therefore additional hardware is a must for off-shore farms.

So what makes off-shore wind turbines profitable? The answer is *average cost*. Off-shore farms often consist of hundreds of turbines, maybe more, which sums to colossal energy production volumes, thus reducing the average cost per watts. In addition to sheer volume of these farms, off-shore turbines usually are the largest turbines around, having much bigger blades and higher output values.

ON SHORE WIND TURBINE LOCATIONS

On-shore zones are mostly on top of hills or elevated lands that are almost 3 kilometers from the nearest shoreline. Theory behind this application is to obtain the maximum wind speed from the accelerating effect of hills and steep land on the coastal winds. Determining the exact location of greatest wind speed is crucial for maximizing output and the process is known as `micro-siting`. Detailed wind maps of the area are constructed with the help of anemometers since 20m of positioning difference could double or half the output numbers.

Like every engineering problem, on-shore turbine installation has a drawback that has to be considered: effect on local habitat. Hilltops and coastal areas are perfect to harvest the wind generated by the heating/cooling difference of land and sea, yet tall turbine towers often degrade the appearance. More in so, local winds are used for navigation by migrating birds so perfect location for a wind farm quite possibly be the perfect location for the birds also. Politically supported debates and oppositions usually arise for installation of wind farms on land in many countries.

NEAR SHORE WIND TURBINE LOCATIONS

Near-shore locations are described as a hybridization of distance parameters. They are mostly considered to be within 3 kilometers of inland and 10 kilometers of offshore. Near-shore farms also hybridize the thermodynamic and aerodynamic properties of offshore winds and onshore winds. Shores are ideal places for turbine installation due to strong convection winds. Moreover, winds on sea surface carry much more energy at the same speed than the winds over mountains and elevated landscapes since the density of wind is higher on sea surface.

WIND TURBINE SPECIFICATIONS

For commercial energy solutions, HAWTs with upwind rotor direction are usually chosen for their superior efficiency and output over VAWTs. Commercial HAWTs vary in output in regards to their rotor diameters. Energy output values with corresponding rotor diameters from eminent manufacturers of the industry are illustrated in Table 1.

Manufacturer	Rotor Diameter	Energy Output
Enercon Gmbh. E-33	33.4 m	330 kW
Enercon Gmbh. E-44	44.0 m	900 kW
Enercon Gmbh. E-48	48.0 m	800 kW
Enercon Gmbh. E-53	52.9 m	800 kW
Enercon Gmbh. E-71	71 m	2,300 kW
Enercon Gmbh. E-82	82 m	2,000 kW
Mitsubishi Heavy Industries MWT-1000	57 m	1,000 kW
Mitsubishi Heavy Industries MWT-1000A	61.4 m	1,000 kW
Mitsubishi Heavy Industries MWT-92/2.4	92 m	2,400 kW
Mitsubishi Heavy Industries MWT-95/2.4	95 m	2,400 kW
Siemens Power Generation SWT-1.3-62	62.0 m	1,300 kW
Siemens Power Generation SWT-2.3-82	82.4 m	2,300 kW
Siemens Power Generation SWT-2.3-93	93.0 m	2,300 kW
Siemens Power Generation SWT-3.6-107	107.0 m	3,600 kW
REpower Systems AG. MD77	76.5 m	1,500 kW
REpower Systems AG. MM70	70.0 m	2,000 kW
REpower Systems AG. MM82	82.0 m	2,000 kW
REpower Systems AG. MM92	92.5 m	2,000 kW
REpower Systems AG. 5M	126.0 m	5,000 kW

TABLE 1-ONSHORE/OFFSHORE WIND TURBINE SPECIFICATIONS[4]

Two turbines in this list, Siemens Power Generation SWT-3.6-107™ and REpower Systems AG 5M™, can be utilized only in offshore plants due to their massive proportions.

For onshore medium wind speed applications, rotor diameters between 40 to 60 meters are chosen with tower heights ranging from 50 to 76 meters. These medium sized turbines usually produce 600-800kW per unit and mostly used throughout the world for their convenient installation and manageable sizes. These turbines will be the ones will be concentrated on much frequently in this project.

PARTS OF WIND TURBINES

ROTOR

FIGURE 5-PICTURE OF A TYPICAL WIND TURBINE ROTOR

Rotors are usually twisted or flat objects connected to a center shaft that converts the push of the wind into a circular motion in a wind turbine. Most rotors have three blades. Small scaled wind turbines may have two blades. Blades are designed like an airplane wing, creating an imbalance between the lift and the drag force to capture wind's energy. Famous equation and principle of Bernoulli used in the design of the blades.

$$\frac{\nu^2\rho}{2} + \rho g h + P = q + \rho g h + P = Constant \qquad (1)$$

Where,

ν= fluid velocity,

g=acceleration due to gravity,

ρ= density of the fluid at all points on the streamline,

h = height of the point on the streamline,

P = pressure at the point on the streamline,

q = dynamic pressure.

Blades of the wind turbines are made of aluminum, titanium, steel, carbon fiber, fiberglass and wood. Most of the modern wind turbine blades are made of fiberglass solidified by polyester. Steel blades are durable to bending and to yield but still they have the problem of stress and corrosion. Aluminum blades are lighter than the steel blades and durable to corrosion and stress. It is more expensive than the steel and harder to produce. Fiberglass's tensile strength is 420 N/ms^2, for steel 52 it is 520N/nm^2, for the epoxy plastic fortified by carbon fiber, the tensile strength is 550N/nm^2 and this is even better than the steel. The main problem on epoxy plastic is its elasticity which is 15kN/nm^2 when the steel's elasticity was 210kN/nm^2. That is the reason why very large diameter blades are made of epoxy plastic fortified by carbon fiber which has elasticity of 44kN/nm^2 instead of fiberglass. However, this material is expensive.

Rotor Size and Maximum Power Output	
Rotor Diameter (m)	**Power Output (kW)**
10	**25**
17	**100**
27	**225**
33	**300**
40	**500**
44	**600**
48	**750**
54	**1000**
64	**1500**
72	**2000**
80	**2500**
Source: Danish Wind Industry Association, American Wind Energy Association	

TABLE 2-ROTOR SIZE AND RATED POWER OUTPUT

FIGURE 6-TYPICAL GEARBOX OF A WIND TURBINE

Revolutions of a wind turbine vary between 15-20RPM during average rated wind speeds. This power from the blades is transferred to the generator by the gearbox passing through the power train and high speed shaft. High speed shaft is vital ratio is needed to increase this speed before transferring to the generator. 40RPM and 400 RPM but generators require RPM's of 1200-3000. This means the gearbox converts slow and high power torque from the blades to high speed low torque to the generator. Wind turbine`s gearbox has a fixed gear ratio, in other words, it doesn't change gears. There are three types of common gearboxes; planetary, helical and worm.

FIGURE 7-PLANETARY GEARBOX

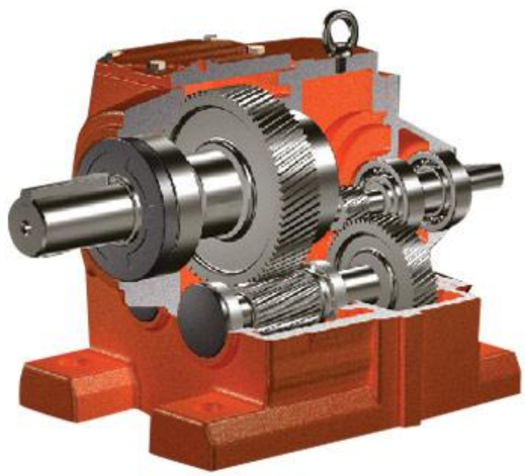

FIGURE 8-HELICAL GEARBOX

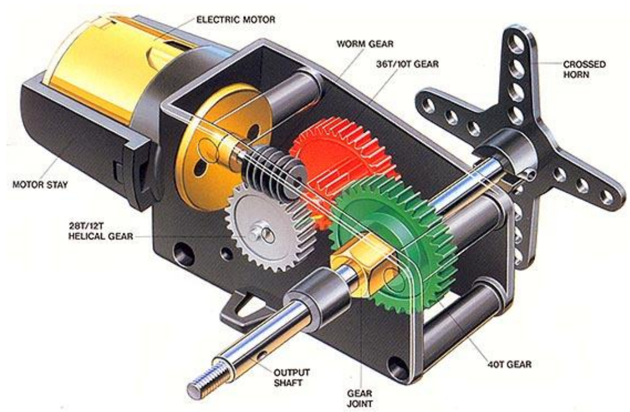

FIGURE 9-WORM GEARBOX

Usually, planetary gearboxes are used in the wind turbines. They are very flexible in design and they increase the operational efficiency. This type of gearbox provides extremely low speeds. Also deliver high reduction ratios and transmit higher torque values. They are very compact and lightweight. They need little space for installation. They are very reliable due to the distribution of stress among different loads.
Like any other engine parts, gearboxes are made from Stainless Steel, Aluminum and Copper. The usage of Stainless Steel is around 96-98%; usage of Aluminum is around 1-2%, the usage of Copper is 0-2%.

GENERATOR

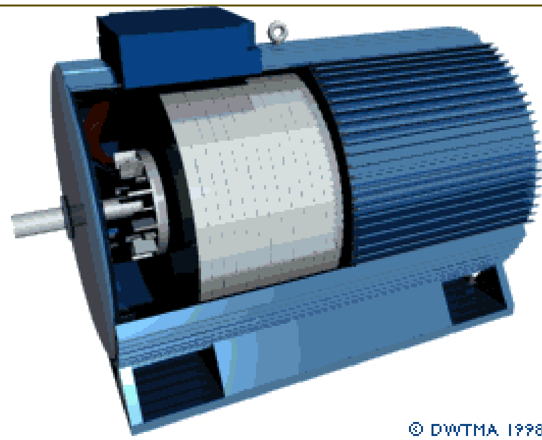

FIGURE 10-EXAMPLE DRAWING OF A GENERATOR

Basically, a generator is a simple device. It uses the properties of electromagnetic induction to generate electric voltage. Voltage is an electrical pressure which forces to move electricity or electric current. A generator consist magnets and a conductor. The conductor is a coiled wire. Inside the generator, the shaft connects to an assembly of magnets where one of the magnets is stable the other one is rotating relative to the other. When the rotor spins the shaft, the shaft spins the assembly of magnets and the magnets produce electric current. There are two types of generators used in wind turbines. They are Alternate current or direct current generators. The current that acquired in the generator might be inefficient but there are few power electronics mechanisms that can regulate the electricity for the grid. Direct current generators are not preferably used in large wind turbine sites. The reason for that is the maintenance cost and alternate current generators are cheaper. Direct current generators are commonly used in small sized sites and to store energy to the batteries.
Generator is the main device that is used to convert mechanical energy into electrical energy. The law of electromagnetic induction is the basic principle to create stable alternating current at the desired frequency. Rotating part of the generator (rotor) is connected to the low speed gearbox which regulates the angular velocity of the turbine rotor. The stationary part, (stator) provides magnetic field which

induces electric current to the grid. As a result of this simple law discovered by Michael Faraday, the mechanical energy is converted to electrical energy and supplied to the grid. There are two common types of alternating current generators used in large scale the wind turbines. Large scale turbines produce 3-phase electricity. (50 or 60Hz frequency depending on the country's grid regulations)

Synchronous generators are made up of an electromagnet or permanent magnets in the rotor and induce 2 pole magnetic field, synchronizing with the rotation of the magnetic field. A brief visualization, courtesy of Danish Wind Industry Association is given below.

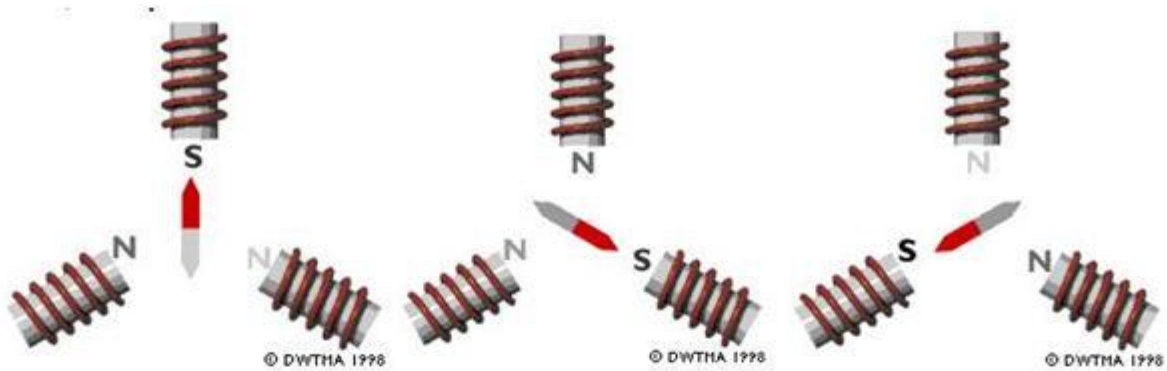

FIGURE 11-SYNCHRONOUS GENERATOR PRINCIPLE

Unfortunately, synchronous generators have a major design issue which makes them less desirable for wind power generation. Permanent magnets which are powerful enough and have long magnetization life inside such magnetic fields are very expensive. On the other hand, having an electromagnet rotor means having a AC/DC converter which is additional cost, wiring, maintenance, protection(in case of an emergency) etc. Another disadvantage of such generators is that it cannot be started with full power, especially in case of a large scale power production and needs a control system to prevent any damage to rotor or stator.

Asynchronous generator or induction generator is the most commonly used wind turbine generator part since it is less costly compared to synchronous generators. Instead of using slip rings or brushes, asynchronous motor uses a cage rotor (Figure 12) that gives it a big advantage for this application as it increases the lifetime of these motors, decreasing the maintenance costs. The generator slip in asynchronous generator is another advantage, producing the maximum power when synchronous rotational speed differs by 1%. There are many patented technologies for providing stable and efficient power outputs for wind turbines, using the induction motor.

FIGURE 12-CAGE ROTOR OF AN ASYNCHRONOUS GENERATOR

CONTROLLER

Controller for a large scale wind turbine is one of the most important parts which physically is very small but has a role for every single part of the wind turbine. Yaw mechanism, weather and temperature status, wind speed and direction, generator on/off, gearbox, break pressure, active/reactive power control, emergency shut down or even optimizing the electricity produced (in terms of frequency of alternating current) are some of the roles of a controller on a wind turbine. In addition to all these features, controller of a wind turbine needs to have a good EM shield, high end DSP chip for filtering all the incoming/outgoing data and interpreting and feeding the results back to the control circuit, and a powerful hardware program which also communicates with the grid operators by sending real-time or logged data stored in its memory.

FIGURE 13-TYPICAL CONTROLLER, AC/DC TRANSFORMER PANEL ON A WIND TURBINE

COOLING SYSTEM

Like every other machinery, wind turbines also need to be cooled while operating. Transformers, gearbox, power regulator (if exists), controller, brakes are some examples of devices that create heat while operating. There are two kinds of cooling used by manufacturers.

Liquid Cooling: They are in small scale, very compact and electricity efficient. A more complicated and higher cost design can be considered as a disadvantage. They have to have a radiator in the nacelle which produces more weight at the top of the tower and that radiator need to be cooled too.

Air Cooling: Basically, large fans are in use for air cooling which cools relatively better but high electric consumption.

BRAKES

Wind is an unstable resource and it sometimes can be very hazardous to wind turbines. Breaks are very critical and important devices that prevent wind turbines getting damaged in high wind speeds. There are three parts.

1. Aerodynamic efficiency:
   - To change the blade angle and turn the blades.
   - To operate in constant RPM
   - To prevent the lift force and increase the drag force
2. Minimize the effective area
   - To rotate the blades to the wind
   - To change the rotor geometry
3. To Break
   - Mechanics and hydraulics
   - Air breaking
   - Electric power

Electro-mechanical brakes will soon be new standard in wind turbines. They are superior compared to the hydraulic brake systems. They are more economical, safe and have low maintenance costs.

WIND TURBINE BRANDS AND PRODUCTION CAPABILITIES

Green energy production companies are on the rise all around the world. There are plenty of companies producing wind generators that only assemble the parts and ship it to the end user or producer. As the need for the clean energy increases, even the money hungry corporations and big names such as General Electric, Siemens, Mitsubishi, Emerson and many more have their own wind power generation divisions. Those companies have the production capabilities and the research, improvement facilities and fund their engineers to produce better wind turbines and patent their innovations.

The most important factor that these big corporations care so much about wind turbine production and green energy is obviously because of possible financial outcomes of this business. As the world population grows, humans demand more energy. In addition to that increasing living standards raises this demand to a higher level. It also is known for a fact that fossil fuel supply of the world will not be able to support this demand forever and the wars for the last piece of this cake has already begun. Therefore, whether these corporations start or control this business or not, there is going to be some company which will provide wind turbines. The profitability of this business is worth spending the money and is the main reason for these corporations to have Wind turbine production divisions. Many countries including Turkey, which has very suitable locations for wind power, see the demand for energy and how profitable it will be to have its own energy production opportunities, rather than importing energy. At this point, it is pretty simple to see that Wind is a free energy source that will last forever, with a varying magnitude in time.

Another reason is the protection of the environment and global warming. The earth has to be a place where civilization and nature can both survive. Humans and nature need fresh water, oxygen, atmosphere, other living things, and the right amount of The Sun’s energy. Recent pollution levels and forest destructions is not letting the earth keep this balance at its ideal level and that affects everyone. Therefore it is mandatory for everyone to care about the earth and find ways to produce green energy. As the sensitivity of environmental protection increases, humans demand more green energy and appreciate the work of these big corporations by having emotional connections towards them. This means the increase of publicity for a corporation and the name of the brand which can have a larger slope of production increase than many other factors affecting sales. Therefore these companies use green energy also as a way of advertising which is obviously observed in their website designs for wind energy.

FIGURE 14-SIEMENS' ADVERTISEMENT ON GREEN ENERGY.

GENERAL ELECTRIC

General Electric has a great website only designed for Wind Power production. 1.5, 2.5 and 3.6MW wind turbine products are currently available for order. General Electric produces only macro scale wind turbines as seen at the power production characteristics of the available products. More than 39,000 megawatts of wind energy are installed by General Electric throughout the world, and forecasts for wind power continue to be favorable with more than 83,000 cumulative megawatts predicted worldwide by 2007. GE offers installation, operation and maintenance services for wind turbines. GE's capabilities are engineering, procure construction and operate wind projects. Moreover they partner with worldwide customers through joint developments, providing the full range of development services or partial, customized assistance which were done with projects in California, France, Sweden and the United Kingdom.

SIEMENS

One of Germany's most important corporations, Siemens focuses its motto and slogans on environmental care. The largest turbine size available is 3600kW and most of the generators are as large as 2300kW but their applications are vary on or off shore. Siemens started this business in 1980s with a 22kW wind turbine and now has hundred times larger turbines compared to their past. Total wind power harvesting of Siemens wind turbines is predicted around 6296MW as of today.

THE ABB GROUP

Automation and Power Technologies is also a very successful corporation, producing both wind farms and wind turbines. The turbines are separated from high to low speed and induction versus synchronous generators. The synchronous generators can produce up to 5000kVA and induction wind generators are capable of producing up to 5MW of electric power with the desired wind conditions. The wind farm business is run through other partner companies or just anyone who buys and assembles parts made by ABB.

GAMESA

Gamesa generates electric energy of renewable origin, essentially based on the promotion and running of wind farms, the manufacture of wind turbines and the providing of advanced services to the technology for energy sustainability sector. As a producer of both wind generator and wind farms, Gamesa has many projects around the world, such as United States, Italy, France, Germany, Portugal, Greece, United Kingdom, Ireland, China, Japan, Vietnam, Taiwan, Tunisia, India, Egypt, Morocco, Argentina, Mexico, Korea, Spain, Hungary and Poland. It is predicted that Gamesa built around 20,000MW worth of wind farms in USA and Asia. In addition to that 10.000MW of wind energy production is a significant amount of wind turbines that are sold throughout the world.

Gamesa has its own extensive design and technological development capability for wind turbines, as well as the largest integral production capacity, comprising of the manufacturing of blades, root joints, blade moulds, gearboxes, generators, converters and towers, besides assembling the wind turbines (29 manufacturing facilities). Gamesa offers a wide product range with two platforms of a respective rated power of 850 KW and 2.0 MW which include several models.

MITSUBISHI HEAVY INDUSTRIES LTD.

MHI has been engaged in the research and development of wind turbines since 1980 and since then developed the output of induction type and variable speed type machines from 250kW to 2,400kW. To date, MHI has manufactured and delivered more than 2,250 units all over the world.

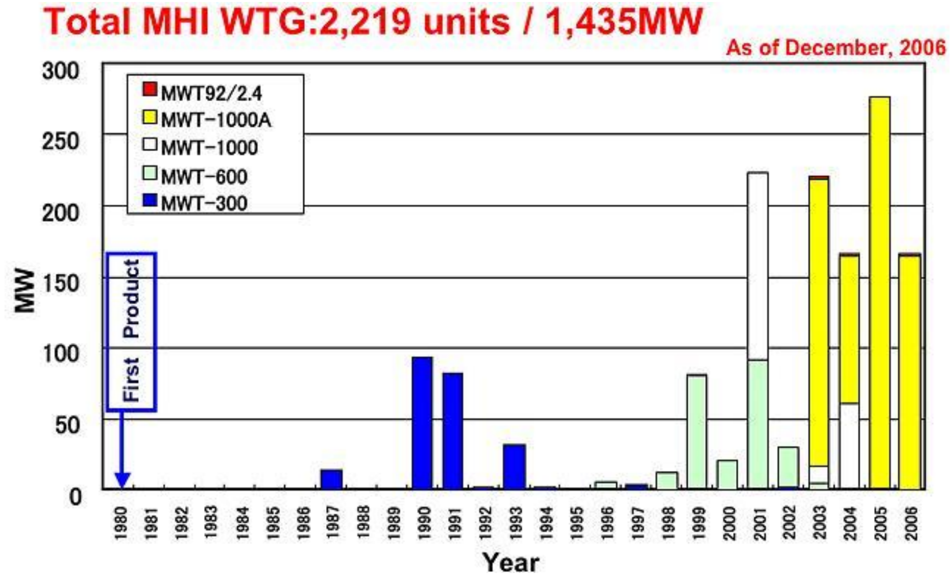

FIGURE 15-THE SALES FIGURES OF MITSUBISHI HEAVY INDUSTRIES WIND TURBINES

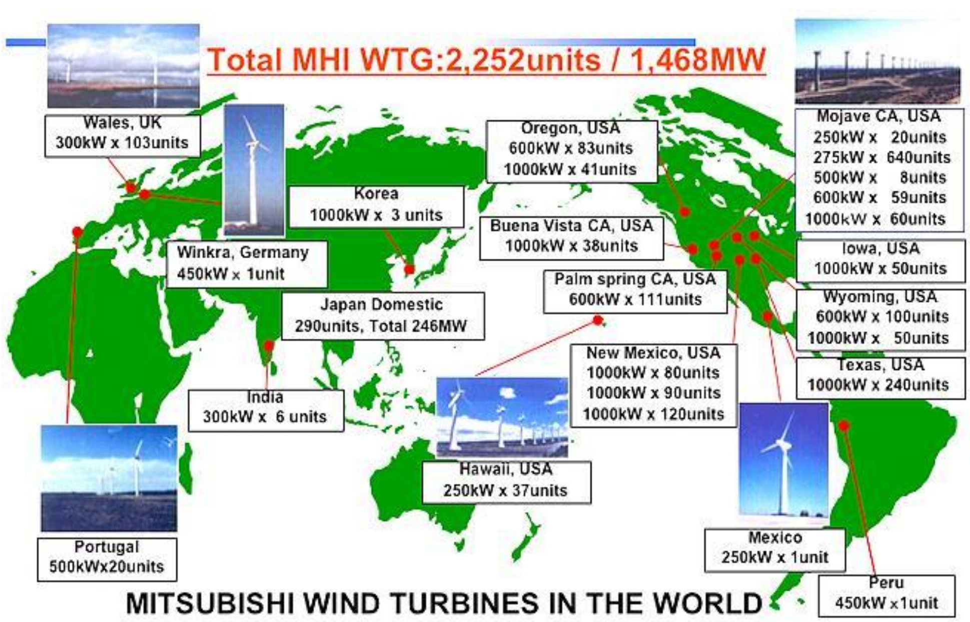

FIGURE 16-MITSUBISHI WIND TURBINES AROUND THE WORLD AS OF MARCH 2007

DISTRIBUTED ENERGY SYSTEMS

Designed specifically for isolated grid and distributed generation applications, the NorthWind 100 wind turbine village-scale wind turbine. Distributed Energy Systems has drawn on 30 years of experience to engineer a wind turbine that provides cost-effective, highly reliable renewable energy in village power applications. The patented design of the NorthWind 100 wind turbine meets the needs of small utilities and independent power producers. DES also has patents known around the world for power electronics control systems of their 100kW wind turbines. Some of their solutions consists of Wind-Diesel power which uses diesel fuel at the times when there is no wind and generates electricity by wind power when it is present.

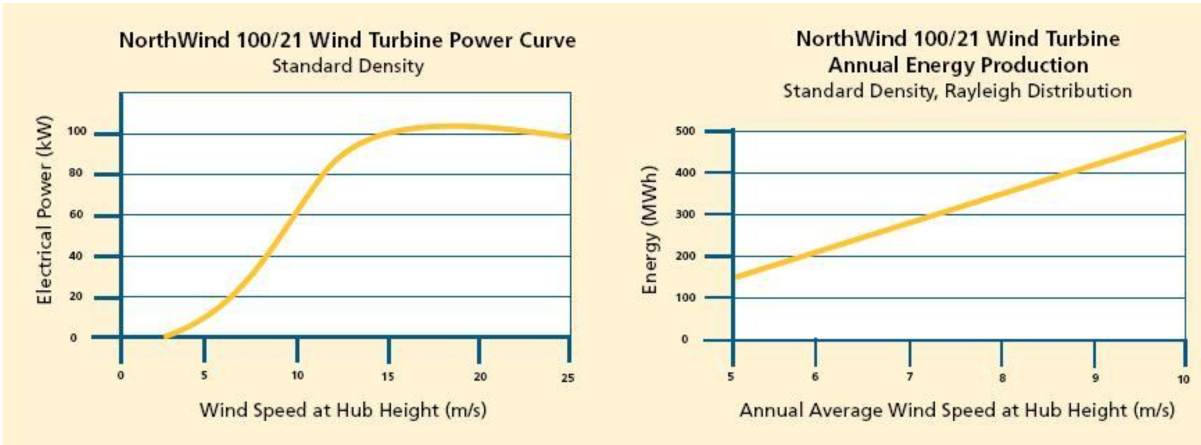

FIGURE 17-DISTRIBUTED POWER SYSTEMS NORTHWIND 100 SERIES ELECTRICITY PRODUCTION CHART

CHAPTER 2-CONSTRUCTION AND ENGINEERING OF WIND TURBINES

In this section, construction of a 1.5 MW wind turbine is given as an example:

FIGURE 18-SMALL CRANE FOR THE ASSEMBLY OF LARGE ONE

A very large crane is required to build a 90 m wind tower. Therefore, at the beginning of the construction, it is needed to assemble the large crane using a smaller one. (Figure 19)

FIGURE 19-SMALL AND LARGE CRANE SYSTEMS

Once the large crane is assembled, the crane to build the 90 m wild turbine is almost the length of a football field.

FIGURE 20-SEMI TRUCK TRANSPORTING THE TURBINE TOWER LOAD

The transportation of the tower is made by big semi-trucks. The tower is separated to three sections for easy transportation. For this particular tower in Figure 20, the diameter of the tower is 4.8 m.

FIGURE 21-TURBINE BLADES

In the Figure 21, blades of the wind turbine are shown being transported by large trucks in three separate loads like the tower parts. Each blade is 27 m long and around 4.2 tons.

FIGURE 22-PREPERATION OF A ROTOR BLADE

In Figure 22, construction crew is preparing the rotor blade by attaching them to the crane. After that, they will be able to lift it and attach the blade to the hub.

FIGURE 23-BLADE TO HUB ATTACHMENT

In the Figure 25, a construction worker attaches the blade to the hub which weighs around 3.5 tons.

FIGURE 24-BOLTS OF A TURBINE BLADE

In Figure 24, one can see forty bolts on each blade. The size of the bolts compared to the glove can be seen.

FIGURE 25-HOOK ATTACHMENTS FOR CRANE TO HOIST THE LOAD

In Figure 25, workers are seen mounting special hooks on the tower section so the assembly crane can hoist it.

FIGURE 26-TURBINE TOWER MIDDLE SECTION PLACEMENT

In Figure 26, the middle part section of the wind turbine tower is set in the place using the large crane.

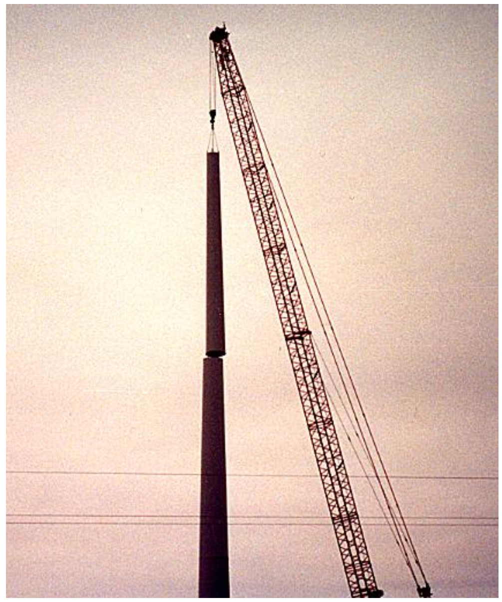

FIGURE 27-TURBINE TOWER TOP SECTION PLACEMENT

In Figure 27, the third part of the tower is being installed. The top of the tower is now 71 m.

FIGURE 28-NACELLE ATTACHMENT

In Figure 28, another worker is seen attaching the turbine's nacelle to the crane which weighs 6.5 tons. The nacelle which contains the turbine generator is 6.3 m long, 2.5 m wide and 5 m high.

FIGURE 29-GENERATOR

In Figure 29, generator inside the nacelle is shown.

FIGURE 30-CRANE HOISTING THE NACELLE

After all the preparations, the crane hoists the nacelle to the top of the tower which is 71 m high.

FIGURE 31-NACELLE PLACEMENT

The crane positions the nacelle at the top of the tower.

FIGURE 32-ROTOR PLACEMENT

The crane lifts the rotor and the hub assembly to the top of the wind tower where workers will attach it to the nacelle.

FIGURE 33-COMPLETED VIEW

Complete view of the wind turbine given on Figure 33.

MAINTANENCE OF WIND TURBINES

Wind turbines have mobile parts which require extra care. Latest wind turbines are designed to operate for 120 000 hours or a lifespan of 20 years. It is more than a typical engine which operates for 4000 to 6000 hours. Most of the experience shows that the maintenance costs are usually low when the turbine engines are new, although the cost increases somewhat as the turbine ages. This maintenance and repair includes rotor blades, alternator, gear box and also electric towers which transfer the electricity to the grid lines.

Over 5000 studies are made on wind turbines in Denmark since 1975. These studies shows that the newer generations turbines have relatively lower repair and maintenance cost than the older generations (the studies compare turbines which are the same age, but which belong to different generations).

Older wind turbines (25-100 kW) have annual maintenance costs around 3 per cent of the total investment. New generation turbines are on average significantly larger, which would tend to lower maintenance costs per kW installed power. For new generation machines the repair and the annual maintenance cost is around 1.5-2 per cent of the original turbine investment.

Stainless steel used in fasteners, high-tech metal alloys for turbine bodies, and advanced bushing materials have gone a long way in extending turbine life. Carbon reinforced fiberglass, plastics, and epoxy composites have greatly improved blade life expectancy. Ultra-violet stabilized abrasion resistant tapes significantly reduce the erosion on the leading edges of blades. Improvements in insulating materials in the alternators and generators extend the life of the electrical generating components. Advanced paint coatings that stand up to the weather extremes that a wind turbine experiences reduce the maintenance expenses and down time associated with surface rust and subsequent component failure.

Essential parts to be maintained:

- In every 6 months batteries must be controlled if they have oxidation.
- Every year gearbox must be controlled and oiled if need be.
- Every year all parts must be controlled.
- Wind Turbine site and pylon maintenance
- Blade cleaning and surface repair
- Wind turbine survey and testing
- Ice removal systems and techniques
- Data Recorders:

- Vibration
- Oil particle count
- Accelerometer
- Temperature
- Wind direction –Yaw Mechanism
- Anemometer
- Electrical Components
- Measure Voltage Drops
- Tighten and Inspect
- Lightning Protection
- Tighten and Inspect Components
- Nacelle
- Rotor blades & Hub Assembly
- Gear box & components
- Electric generator & Servo Motors
- Yaw mechanism
- Hydraulic system & Cooling mechanism
- Brakes, aerodynamic & mechanical
- Tower & fountain components

FIGURE 34-TECHNICIAN DOING WORK ON THE ROTOR

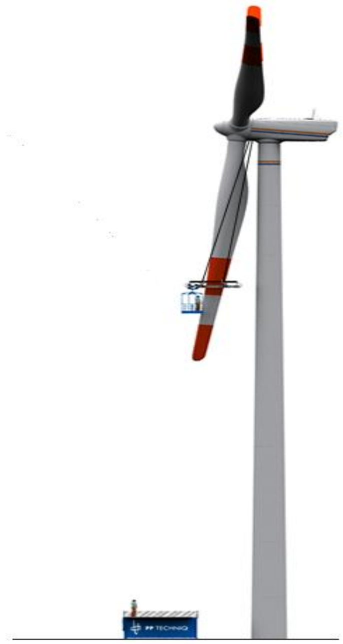

FIGURE 35-EXTERIOR CLEANING OF THE TURBINE

WIND FARM ENGINEERING

A wind farm is described to be a collection of wind turbines in the same location. Wind farms operate on large fields and due to the number of turbines they consist of; they are colossal in energy output. Just for the same reason of occupying space, land farms are commonly much smaller in size and output then nautical farms.

WIND POWER EQUATIONS

Wind turbines are essentially thermo-dynamical control volumes just like every other modern engineering applications today, which means they all can be simplified into input and output problems. In our case of wind turbines, this simplification is decreed by the first law of thermodynamics: Energy is conserved within a control volume.

For the energy collecting purposes of wind turbine applications, equations of thermodynamics are simplified into to Equation 2 below:

$$P = \rho A V^3/2 \tag{2}$$

Where,

P = Power

A = Area swept by the rotor blades = $\frac{\pi d_{rotor}{}^2}{4}$

V = Wind speed

ρ = Wind density, which is constant for the small vertical displacement of rotors.

Figure 36 visualizes how power in the wind varies with wind speed for a turbine of 40m rotor diameter and conditions of 20˚C temperature and 1 atm. of pressure.

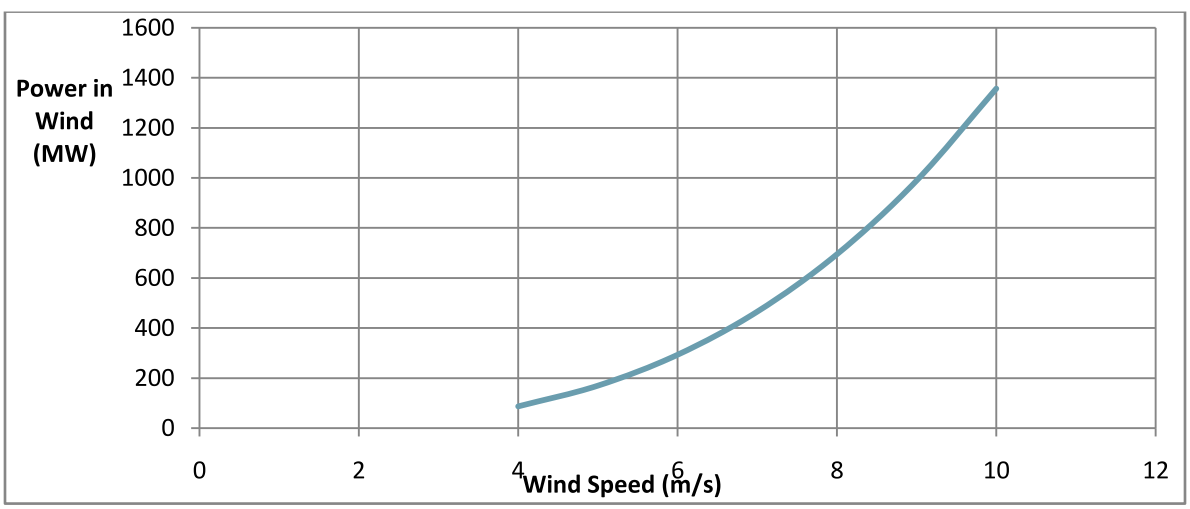

FIGURE 36-POWER IN WIND VARYING WITH INCREASING WIND SPEED

Dramatically increasing trend can be seen when the wind speed increases. Power embodied in wind increases seven times when wind speed is doubled from 4 m/s to 8 m/s.

As stated above, power in wind increases cubically when wind velocity is increased. However, wind turbines have three distinct regions of operation depending on the wind speed. With low velocities, wind turbines remain static, this is labeled as Region I, hence a `cut-in` speed is required to start a turbine`s revolution. Between the cut-in speed and rated speed of the specific turbine, power harvested from wind employs the same cubic trend with the power in wind itself. This cubic power generation properties lie within Region II. During Region II, rotors are spinning with increasing RPM. When the rated speed of the turbine is reached, rotors spin with a fixed RPM and power output is also fixed, this is called the rated output of the wind turbine. After the rated speed, increasing wind speed doesn't affect the power output or rotation speed of the rotors until wind gets too fierce and turbine has to protect itself by shutting down. This mark in wind speed is called `cut-out` speed and between the rated speed and cut-out speed is the Region III.

Figure 37 shows the wind speed, wind power, rotor RPM and power captured from wind.

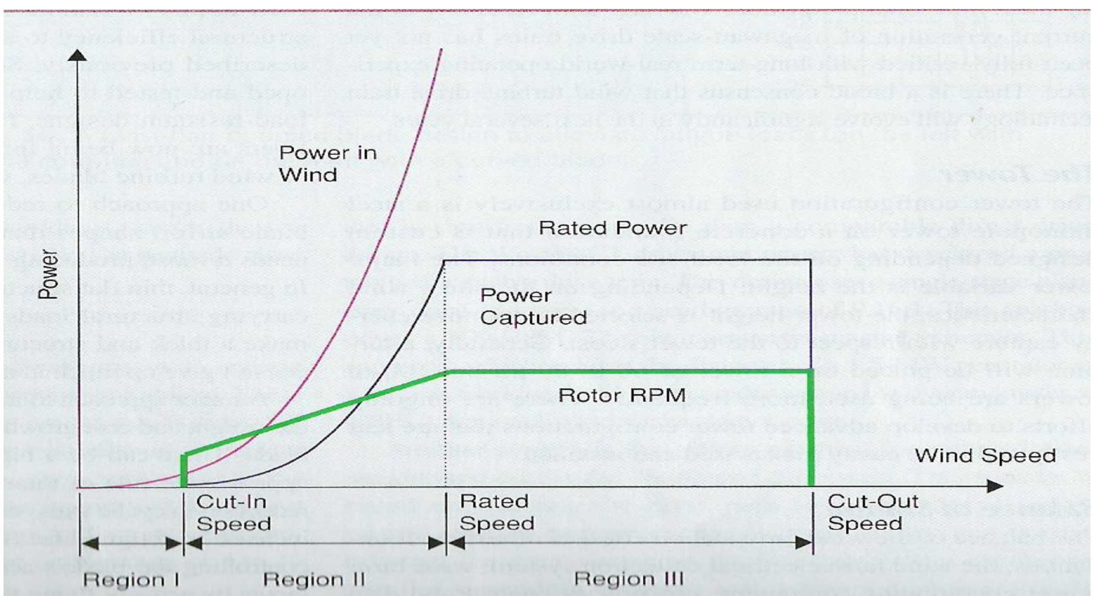

FIGURE 37-WIND SPEED, POWER IN WIND, POWER CAPTURED AND ROTOR RPM CORRELATIONS

The rated power output of a wind turbine directly depends on a specific wind speed and it requires the wind to be constantly available at that speed. On the other hand, wind histograms and common sense dictates that wind speed and wind direction constantly changes throughout a day, a week, a month and a year. Change of wind direction is remedied by changing the hub of the turbine to direct the rotor blades perpendicular to the wind whereas change in wind speed cannot be controlled. Therefore, a wind turbine cannot operate at its rated power all the time unlike other means of energy production. Annual change of power generation is referred to as **Capacity Factor** and it is a function of wind speed and/or elevation.

CAPACITY FACTOR

Capacity factor denotes the annual percentage of operation of the wind turbine at its rated power output. In other words, the capacity factor is simply the actual energy output for the year divided by the energy output if the machine operated at its rated power output for the entire year. Capacity factor is a term that is very sensitive to the changes at wind speed, therefore a normal value is considered to be 0.25 to 0.3 and with very strong and sustainable winds, the capacity factor reaches up to values of 0.4. Hence power output estimations must be considered with the capacity factor of the turbines installed on the location regarding the specific conditions of the installation site.

For the calculations in this report, the following chart will be a measure of local capacity factor at different sites of wind power installation in various Turkish landscapes.

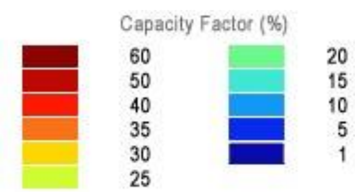

FIGURE 38-TURKISH WIND MAPS` CAPACITY FACTOR COLOR CODE FOR 70M

POWER DENSITY

Power density is yet another term to determine how suitable a location is for wind turbine installation. It basically denotes the maximum energy can be collected per meter square area if a wind turbine was placed on that location. As with capacity factor, power density is a measure of elevation and wind speed albeit with a clear equation between elevation and wind speed. In order to preserve the same power density for a site on higher elevation, wind speed must be increased by %3 for each 1000 meters of elevation.

An example table has been borrowed from Batelle Wind Energy Resource Atlas, Table 3, and Turkish Wind Maps` Power Density Labels are given in Figure 39.

Classes of Wind Power Density at 10 m and 50 m [(a)]

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)
1	<100	<4.4 (9.8)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8) / 5.1 (11.5)	200 - 300	5.6 (12.5) / 6.4 (14.3)
3	150 - 200	5.1 (11.5) / 5.6 (12.5)	300 - 400	6.4 (14.3) / 7.0 (15.7)
4	200 - 250	5.6 (12.5) / 6.0 (13.4)	400 - 500	7.0 (15.7) / 7.5 (16.8)
5	250 - 300	6.0 (13.4) / 6.4 (14.3)	500 - 600	7.5 (16.8) / 8.0 (17.9)
6	300 - 400	6.4 (14.3) / 7.0 (15.7)	600 - 800	8.0 (17.9) / 8.8 (19.7)
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

(a) Vertical extrapolation of wind speed based on the 1/7 power law

(b) Mean wind speed is based on the Rayleigh speed distribution of equivalent wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1000 m (5%/5000 ft) of elevation.

(from the Battelle Wind Energy Resource Atlas)

TABLE 3-CLASSES OF WIND POWER DENSITY AT 10M & 50M WITH CORRESPONDING WIND SPEEDS

FIGURE 39-TURKISH WIND MAPS` POWER DENSITY LABELS FOR 70M

WAKE EFFECT AND OPTIMUM POWER DISTRIBUTION

Prime interests to designers and engineers of a wind farm project are the wind velocity and direction. However, energy can neither be created nor destroyed, therefore the energy carried by the wind decreases after each `break` by each wind turbine to harvest that energy. This effect is known to be `the Wake Effect.

The wake effect is the name given to the wind flow character after the wind hits the rotors and lowers in speed and energy. A wind turbine will always cast a wind shade in the downwind direction. In fact, there will be a wake behind the turbine, i.e. a long trail of wind which is quite turbulent and slowed down, when compared to the wind arriving in front of the turbine. This phenomenon also shapes the turbine distribution in wind farms.

For maximizing wind power input, wind turbines must be placed far apart in the prevailing wind direction; however, land usage and network construction costs limit the practical applications. As a result, wind turbines are placed three to five rotor diameters apart from the perpendicular to the wind direction and five to nine rotor diameters apart from the parallel to the wind direction.

Figure 40 from the Danish Wind Power Association depicts a sample wind farm turbine distribution in regards to the prevailing wind direction of south.

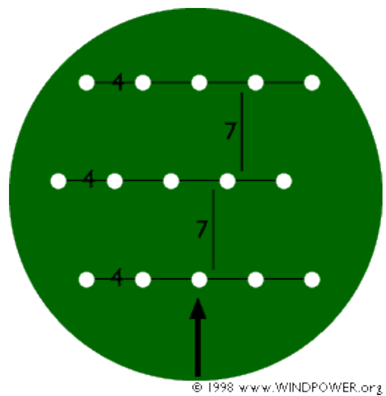

FIGURE 40-SAMPLE WIND FARM TURBINE DISTRIBUTION PREVAILING WIND DIRECTION OF SOUTH

White points denote the wind turbines and the numbers in black denote how many rotor diameters apart each turbine is. Black arrow is the prevailing wind direction.

Figure 41 and Figure 42 show some wind farm photographs from the sky to give more ideas about linear turbine distribution.

FIGURE 41-LINEAR TURBINE DISTRIBUTION NEAR MINNESOTA

FIGURE 42-PONNEQUIN WIND FARM, COLORADO (COLORADO`S FIRST WIND FARM, BUILT 6 YEARS AGO)

Energy loss due to wake effect can be calculated for each specific application but general studies have shown it to vary within five percent.

It is time to articulate about optimizing wind farm installation by maximizing power output per area. This step in the design process includes wind turbine output and rotor diameters on a relatively fundamental cost per kWh and kWh per area considerations.

Given a limited area for possible wind farm installation, one can try to deduce a means to choose which specific wind turbine will be the most advantageous for that particular site. Even though deciding on a turbine requires many task specifications to be fulfilled; for simplicity, area and blade diameter parameters are to be considered for this basic simulation.

For a given area of 100 km^2, two fictional reports compare two different turbine choices for wind farm installation. One report suggests utilizing numerous 48m rotor diameter turbines each with a peak output of 800kW. Second report suggests utilizing 82m rotor diameter turbines each with a peak output of 2MW. The wind farm turbine distribution characteristics, Figure 40, suggest how many turbines can be installed on a given area. The expression that allows the computation of the distance required between two turbines positioned perpendicular to the wind direction is

$$S_{Perpendicular} = 4\ x\ d_{rotor} \tag{3}$$

Where

$S_{Perpendicular}$ is the distance between each turbine perpendicular to the wind direction (meters)

d_{rotor} is the rotor diameter of the proposed wind turbines (meters)

Moreover, the expression that allows the c computation of the distance required between two turbines positioned parallel to the wind direction is

$$S_{Parallel} = 7\ x\ d_{rotor} \tag{4}$$

Where

$S_{Parallel}$ is the distance between each turbine perpendicular to the wind direction (meters)

d_{rotor} is the rotor diameter of the proposed wind turbines (meters)

First report suggests a rotor diameter of 48 meters, therefore;

$S_{Perpendicular}$ = 4 x 48 = 192m

$S_{Parallel}$ = 7 x 48 = 336m

A unit quadrangle constructed by four 48m turbines in each corner will occupy an area of $6.4512*10^{-2}$ km^2. On the other hand, this unit quadrangle will have two fully efficient turbines since each turbine at the corners is shared by an adjacent unit.

[This is exactly analogous to the unit cell theorem in chemistry in which every atom gets shared in the structure by each adjacent unit cell, therefore; fractions of atoms are considered for each cell depending on their positioning within.]

For the first report`s setup, the expression that allows the computation of power produced per unit rectangle is

$$P_{per\ Unit\ rectangle} = \frac{n\ x\ P_{turbine}\ \ x\ F_c}{A_{unit\ \ rectangle}} \tag{5}$$

Where

$P_{per\ Unit\ rectangle}$ is power produced per unit rectangle constructed (kWh/km^2)

n is effective number of wind turbines per unit rectangle

$P_{turbine}$ is the rated power of the wind turbines (kWh)

Fc is the capacity factor of the installation site (0.25 – 0.3 are considered normal)

$A_{unit\ rectangle}$ is the area of the unit rectangle constructed (km^2)

Therefore power produced per unit rectangle of 48m wind turbines is;

$$P_{per\ Unit\ rectangle} = \frac{2\ x\ 800\ x\ 0.3}{0.064512} = 7.44 * 10^3 \text{ kWh/km}^2 = 7.44 \text{ MWh/km}^2$$

Second report suggests a rotor diameter of 82 meters, therefore;

$$S_{Perpendicular} = 4 \text{ x } 82 = 328\text{m}$$

$$S_{Parallel} = 7 \text{ x } 82 = 574\text{m}$$

A unit quadrangle constructed by four 82m turbines in each corner will occupy an area of 1.8827*10^{-1} km^2.

Power produced per unit rectangle of 82m wind turbines is then calculated;

$$P_{per\ Unit\ rectangle} = \frac{2\ x\ 2000\ x\ 0.3}{0.18827} = 6.37 * 10^3 \text{ kWh/km}^2 = 6.37 \text{ MWh/km}^2$$

For the given area of 100km2, a final step is required in order to figure potential power outputs of different size wind turbine farms for theoretical perfect conditions. The expression estimating the power output for 100 km2 area is;

$$P_{total} = A_{given}\ x\ P_{unit\ \ rectangle}\ \ x\ C_{Wake} \tag{6}$$

Where,

P_{total} is the estimated power output for theoretical 100 km2 area (MWh)

A_{given} is the initial value of area given (It`s a constant for this problem, 100km2)

$P_{unit\ rectangle}$ is the power output of a unit rectangle for 48m and 82m wind turbines (MWh/km2)

C_{Wake} is the coefficient of production after considering the Wake effect loss (0.95)

According to the expression above, values calculated for 48m and 82m wind turbine installations are entered;

$P_{total} \;=\; 100\ x\ 7.44\ x\ 0.95$ = 706.8 MWh (for 48m wind turbine installation)

$P_{total} \;=\; 100\ x\ 6.37\ x\ 0.95$ = 605.2 MWh (for 82m wind turbine installation)

It can be seen that 48m turbines are more profitable from a sheer power output point of view. Overall profitability determination requires more in-depth research of wind turbine retail prices and installation costs for each turbine since 48m wind turbines would be in greater quantity than 82m wind in any wind farm proposals.

CHAPTER 3-WIND ENERGY POTENTIAL IN TURKEY

WIND ENERGY POTENTIAL OBSERVATION AND MEASUREMENT

The project planning and the economical outcomes of the wind farms are based on the chosen geographical area and the potential production capability due to wind speed and density. Best way to investigate the area for wind electricity production is to build observation sites. These observation sites contain technical equipment, placed at specific heights, and capable of measuring the wind speed, wind direction which is very important for the following:

- Assessing the data
- Setting the exact amount of power production potential
- Selecting wind turbine height and capabilities

The positioning of the observation sites is vital. The test point of construction should be able to characterize the whole wind site or as much as possible to reduce costs and work efficiently. For World Meteorological Organization (WMO) standards, represented distance might change from 100 m to 100 km depending on the topographical structure. In addition to that, observation points both topographically agreeable and there can be other obstacles closer than 10 times of the height of the curb. Back side of the hills should not be chosen since the wind speed measurements might differ from its actual value because of the turbulent flows. Another important aspect is the wind flow density at the point of the observation site must be laminar reducing the turbulent wind flow possibilities. Particularly, for the purpose of power production, wind speed and direction measurements must be as precise and statistically valid as possible. If there are computational errors or data errors, it may cause instability and inaccuracy for the expected power production output. For that reason, selection of the site must be investigated and constructed by the experienced personnel. UTM (Universal Transverse Mercator), geographical coordinates and the sea elevation must be determined by experienced personnel on a scaled map of 1/ 25,000. The measurement instruments operate on the atmospheric conditions which is the reason why their lifetimes are limited. Rust, corrosion, decay, stress, tough weather conditions are effective on the measurements; they must be maintained and calibrated frequently to avoid data errors.

There are some other factors that must be considered:

- Observation site must be built away from the curbs that can affect the wind profile.
- Measurement instruments must be installed on the directions North-South to aid cartographic positioning.
- Depending on the measurement height, the beam must be designed as triangle iron, square profile.

- For stability reasons, measurement beam must be strengthened, depending on the height and the wind power.
- To obey the aviation rules and matter of safety, there must be a flashing red light at the top of the beam.
- If there are no higher objects than the measurement beam, a lightning rod must be installed to the beam.
- For sake of maintenance, calibration and repair, beams must be mobile.
- Maintained beam must be vertical to the ground and measurement instruments must be installed on the same beam.
- An anemometer must be installed around 80-90 cm higher than the top of the beam.

The purpose of measurements is to determine the wind speed and the direction which constantly varies. Meteorological purposes are:

- Climatologic
- Synoptic
- Air pollution
- The measurement height is 10 m.
- For power production purpose:
- Wind speed
- Wind direction
- Temperature of the area (Meteorological purposes)

Power production potential is measured at 30 m, and if available it might be periodically measured for 10 minutes for one year at the height of the potential wind turbine hub.

Other than the wind speed and wind direction there are also other meteorological parameters which can be helpful if measured. Particularly for the wind power generation, pressure, temperature of the area, humidity is very important.

In the measurement instruments, signals are transferred to a logger via cables. Data logger processes these signals and stores them. Theses stored data are evaluated after being transferred to a main computer. The wind power potential of an area is proportional with the wind speed cubed since a possible error done at the measurement stage can be very effective on the potential power production calculations. The increase the observation period it is vital to take measurements from the hub height. This process is useful to determine the potential. Also, it is helpful to compare the measurements from another observation center which is not far away.

REPA (TURKISH WIND ENERGY ATLAS)

Repa is a specific kind of government program that was designed to include whole Turkish land and coasts, providing three different numerical atmosphere analysis model combined with meteorological data. This system is then run back in time in order to get a 200x200m resolution per point on Turkish map, providing specific detailed wind data. 700GB data, a supercomputer with 124 microprocessors, storage space of 5 terabytes is used to complete this project that included measurements from approximately 33million different points of data around Turkey. The outcomes of this project can be used by anyone interested or works in wind energy business, in addition to academic individuals or communities. Below are the capabilities of this model:

- Annual, monthly, daily or seasonal average wind velocity data for heights 30, 50, 70, 100m above ground.
- Annual, monthly or seasonal wind densities at 50 and 100m above ground
- Annual wind capacity factor at 50m
- Annual wind types at 50m
- Temperature data at 2m and 50m above ground
- Atmospheric pressure level at sea level and 50m above ground.

In order to find potential wind farm locations on Turkey REPA map is integrated to a geographical information systems models. (CBS) This map includes topography, rivers, lakes, civilization areas, special forest terrain, highways/freeways, railroads, harbors, airports, energy transmission lines and transformer stations. Most of this information is available on the free map tool provided by the website. However detailed descriptions and analysis of such specifics of land is only given as “unusable area”.

REPA project decreases the time and costs of any basic feasibility analysis which needs to be done by individuals of such interest. Therefore it decreases the time needed to research and find a suitable and efficient location in Turkey in order to produce green energy. Just by investigating areas on this project, it even is possible to get the possible cost of electricity production for a wind farm production facility. Other than all these helpful and time saving features of this project, it also is possible to help the other government agencies to gather data. For example, air pollution, forest fires avoidance methods, mountain and sea activities, agricultural data and differences can be observed and assist such individual or agencies with the benefits of REPA.

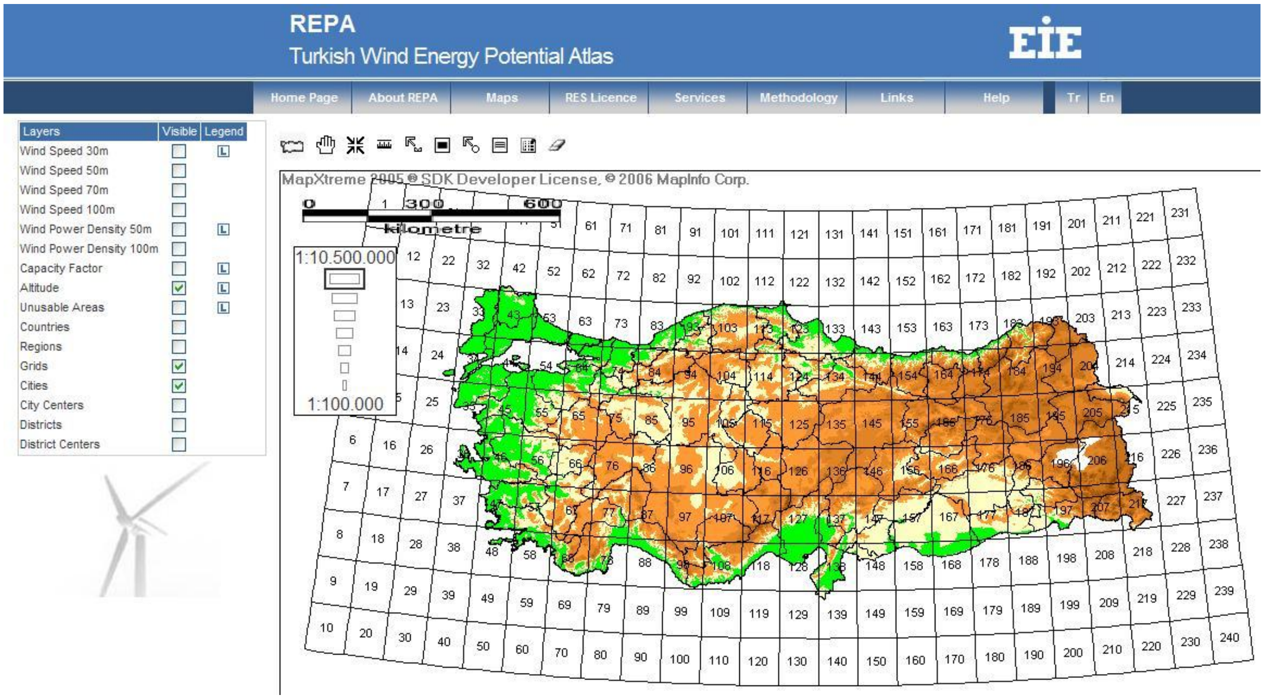

FIGURE 43 -REPA ONLINE MAP ANALYSIS TOOL

HOW TO APPROACH POSSIBLE WIND FARM CONSTRUCTION SITES AROUND TURKEY

There are several possible places in Turkey that are eligible for wind farm construction. The map below shows those possible geographical locations, circling the parts. This estimation is done by using the annual wind speed at 70m above ground. On Figure 44 the color palette (right hand side, below) and the annual average wind speed distribution around Turkey are provided.

As seen in the color chart, the fastest annual wind speed is considered as 10m/s and least is 3m/s. Most parts of Turkey do not get more than 7 or 6.5m/s average wind speed annually which can be considered inefficient and high cost versus production rate.

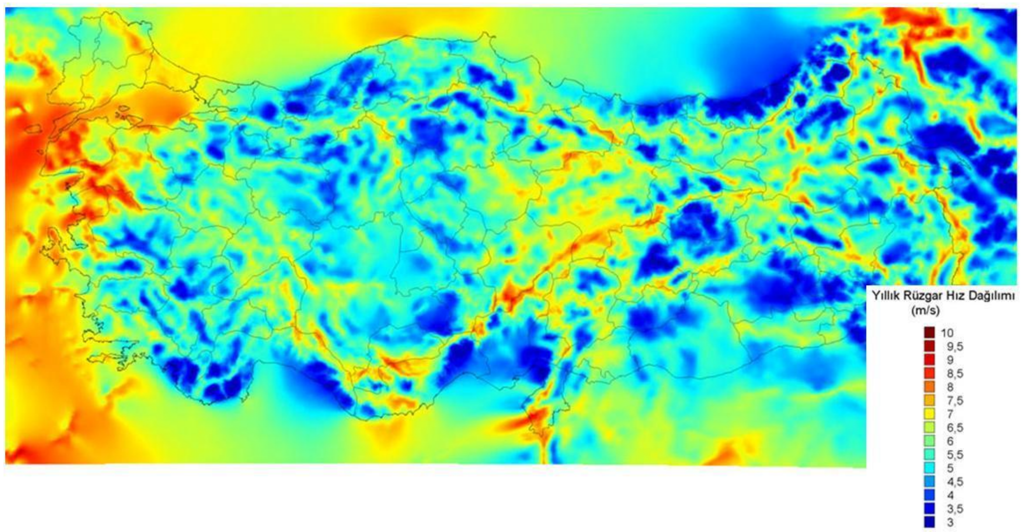

FIGURE 44-ANNUAL AVERAGE WIND SPEED MAP OF TURKEY FOR ELEVATION 70M TO 100M

In addition to the map of annual wind speeds at 70m elevation above ground, it is needed to focus on a geographical map of Turkey. From the geographical point of view, the terrain data can be observed and be able to decide whether it is possible and worthwhile to have a wind farm or not. A geographical elevation map of Turkish Republic is given on Figure 45.

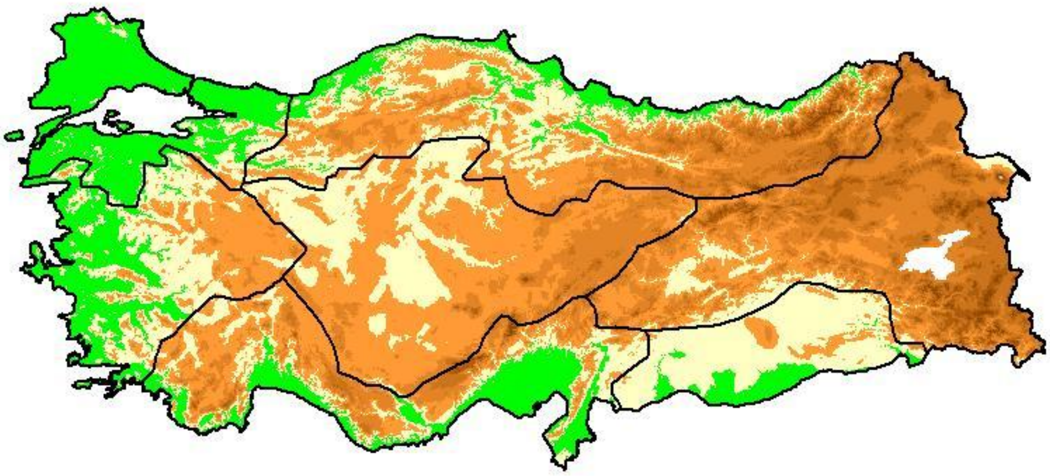

FIGURE 45-ELEVATION MAP OF TURKEY

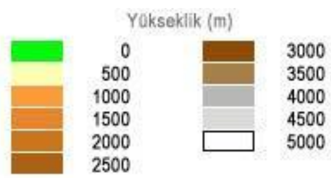

FIGURE 46-ELEVATION COLOR KEY IN METERS

The geographical map clearly shows the possible wind farm construction possibilities. The most common chance of building a cost efficient wind farm is to build them at elevations from 0 to 500m or at most up to 1000m. Elevations higher than 1km might be dangerous for the Wind Farm and will drastically increase the cost of electricity production as a result of high maintenance costs. Inner parts of Turkey (the brown area) mostly face a territorial climate. Especially the addition of high elevation makes the winter tougher (colder with snow, blizzard etc.) and lack of transportation is additional trouble for such power generators to accomplish their job. Therefore the most efficient wind power plants would be to have them onshore or offshore where land elevation is close to 0m. Warm Mediterranean weather and stable wind speed is a good way to gain the wind energy and have less cost of production. In addition to that, transportation around the Mediterranean region is more advanced with plenty of highways and wide roads. In addition to that most of the civilization that uses technology and many electrical energy appliances are located close to the Mediterranean region of Turkey. Therefore the cost of energy transmission will be less.

In addition to the annual wind speed and geographical location data, there are other factors that need to be considered before Wind energy systems planning. The REPA foundation has a map of where the wind farms cannot be built for various reasons such as cities, density of population, archeological value, historic value and many more.

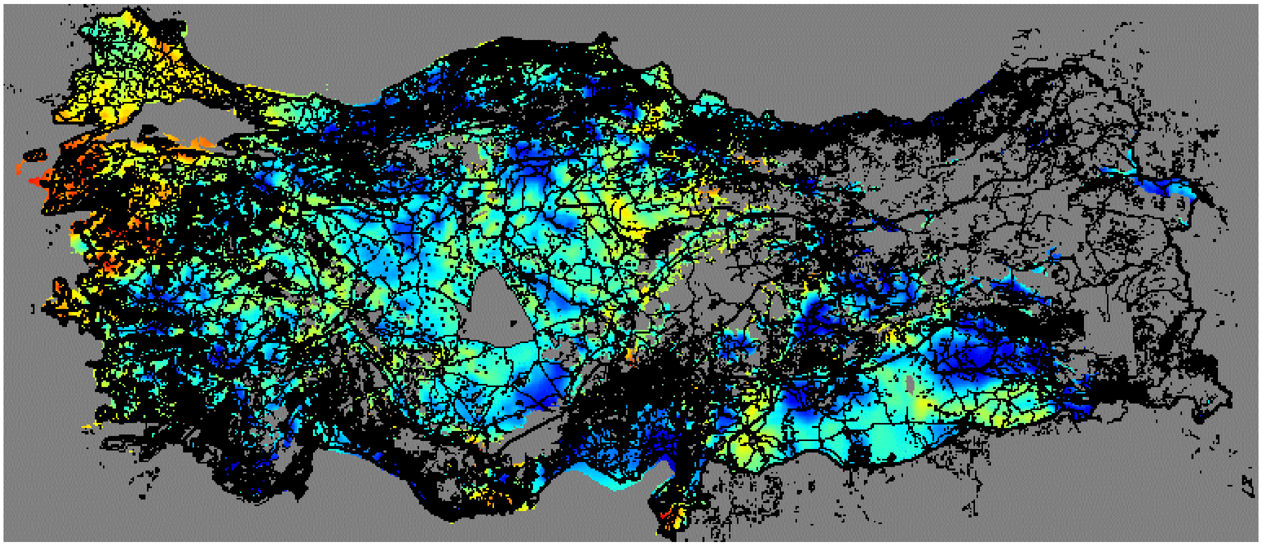

FIGURE 47-UNUSABLE TERRITORY MAP. BLACK AND GREY COLORING IS THE UNUSUABLE AREA AND ELEVATION MAP AT 70M.(COURTESY OF REPA)

According to the unusable area map, most important parts of the Mediterranean coasts are unusable. However if looked closely with the REPA software's zoom in capability, it is possible to find some land around the unusable area. Figure 45 through Figure 47 have a map zoom capability of 1:10,500,000. Although such zoom level helps analyzing most topographical data, it is necessary to find out the amount of area which wind farms can be built. Marmara and Aegean region (Northwest and west respectively) and city of Hatay (furthest south city next to Syria) seems like the best parts of Turkey for wind farms and the next figures will zoom into more detail.

The administrative borders of Turkey map is given on Figure 48 to assist with the places of cities given in the following pages of this report.

FIGURE 48-ADMINISTRATIVE BORDERS OF TURKEY. (COURTESY OF WWW.LIVETURKEY.CO.UK)

MARMARA REGION

Marmara region, containing more than one third of Turkey's population is the base of the economy, industry and civilization. Many factories are located at this part of the country which is another advantage of having large wind farms close to or in this region. The maps below will help deeply analyze the possible land where Wind Farms can be built.

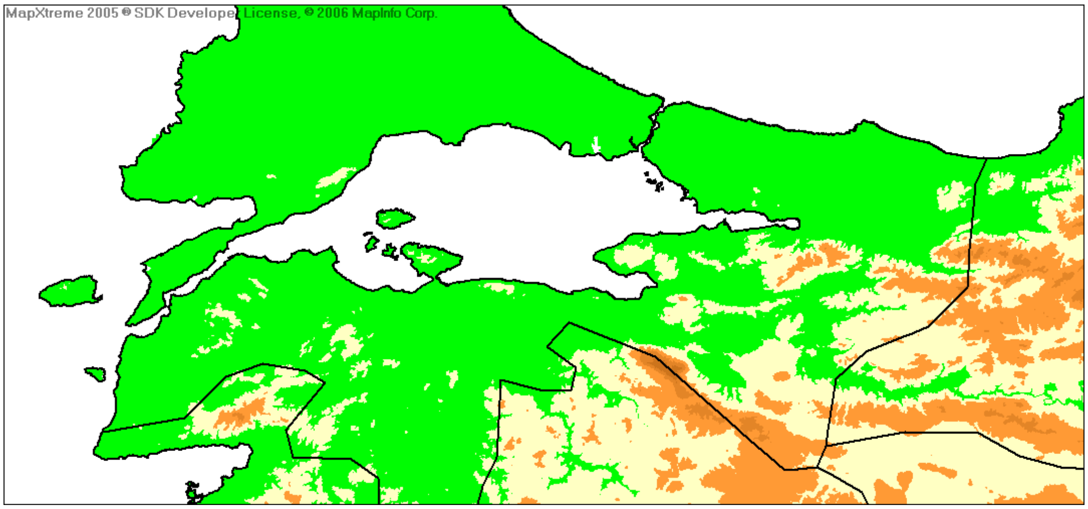

FIGURE 49-ELEVATION MAP OF MARMARA REGION, TURKEY (COURTESY OF REPA)

Figure 49 is shows the elevation map of the whole Marmara region. It is possible to observe that east Marmara is not a very suitable place for Wind Farm construction since that is the part where mountains are very dense and effects of territorial climate will be present. On the other hand, west Marmara and especially the Aegean and Marmara Sea shores look more suitable. Marmara Sea is a great resource since effects of blizzards and storm will be much less compared to Aegean or Mediterranean. In addition to that, the salt content of Marmara Sea is much less which can clearly reduce the effects of corrosion. Another great place for wind power production in Marmara region is Canakkale channel that connects Aegean to Marmara Sea. It is a great source of stable wind with little population, mostly touristic. Offshore wind farms might not be a possibility since this channel is the only path for all the northern neighbors of Turkey to outer world and the size, amount of ships passing through won't create the best place for wind farms. However onshore wind power plants, especially in Canakkale, (the city borders can be found in the following maps.) Gokceada and Bozcaada can be great for wind power harvesting. The following map of Turkey will help analyze the terrain's annual wind speed at 70m, and will be showing where the unusable locations are.

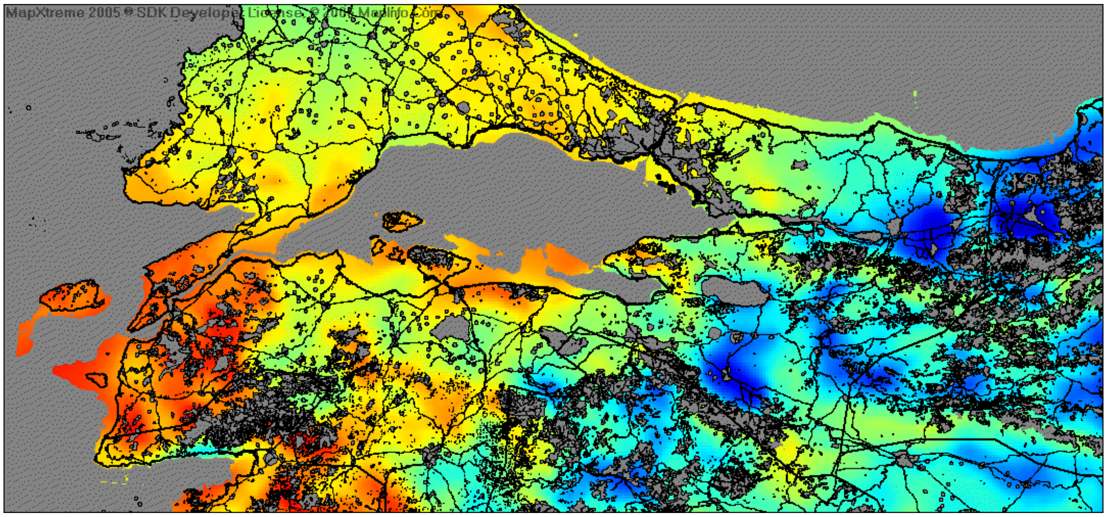

FIGURE 50-MARMARA REGION MAP WITH UNUSABLE AREAS AND ANNUAL WIND SPEED AT 70M ABOVE GROUND (COURTESY OF REPA)

The map given above clearly shows the wind speed difference in eastern and western Marmara Region. Especially in Canakkale, Marmara Sea region of Keşan, parts of Bilecik are very suitable for wind harvesting. The great thing about these parts is that there are no unusable areas in most parts of these regions, especially in the closest parts to the sea. The next map shows the administrative borders of Turkey for reference.

AEGEAN REGION

The Aegean region of Turkey is very famous for its great weather, especially near seashores which is where most population is located. This will not help while determining enough territories for wind farms. The geographical map of Aegean region is given below.

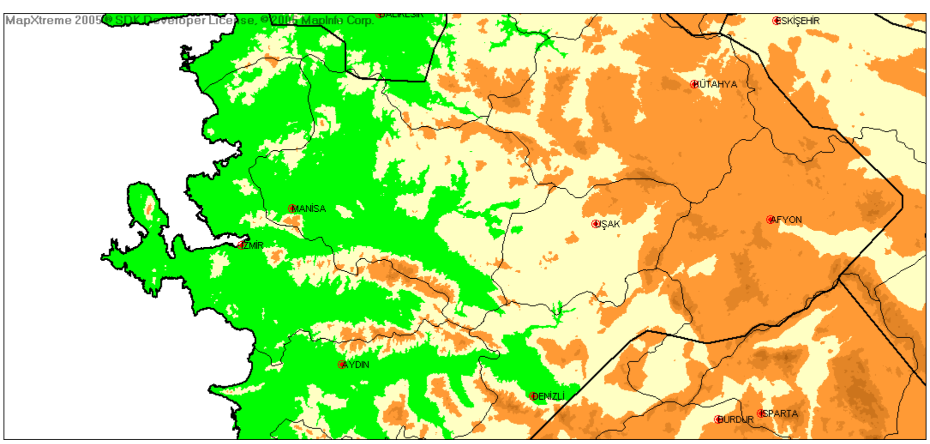

FIGURE 51-ALTITUDE MAP OF AEGEAN REGION. (COURTESY OF REPA)

The mountains in Aegean region starts from the eastern administrative limits of Manisa and Aydin which makes this region great for wind power harvesting. The shores of Izmir and Aydin are the most potent parts for harvesting. Mountains in this region are parallel to the Aegean Sea which creates a lot of gulfs and inlets which also is another advantage of this region. The next figure shows the annual wind speed and unusable areas.

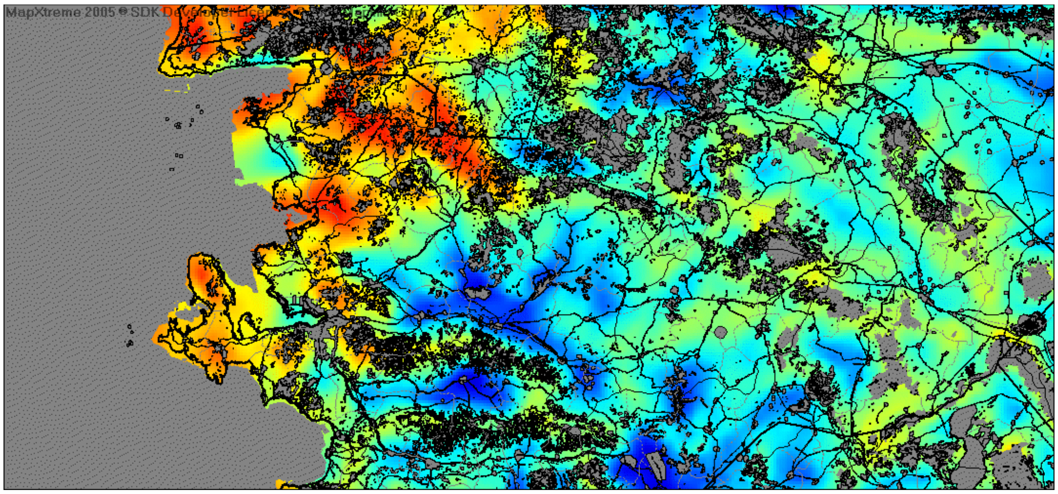

FIGURE 52-AEGEAN REGION MAP WITH UNUSABLE AREAS AND ANNUAL WIND SPEED AT 70M ABOVE GROUND

Figure 10 shows the parts of Aegean region which are suitable locations to build wind farms. The Izmir and Aydin region, as stated before, are the best places for harvesting but the map of REPA hides the offshore possibilities of wind farms when unusable markers are selected. (The whole Aegean Sea is shown dark grey. Therefore focusing on the same map without the unusable areas might be a good idea and given below.

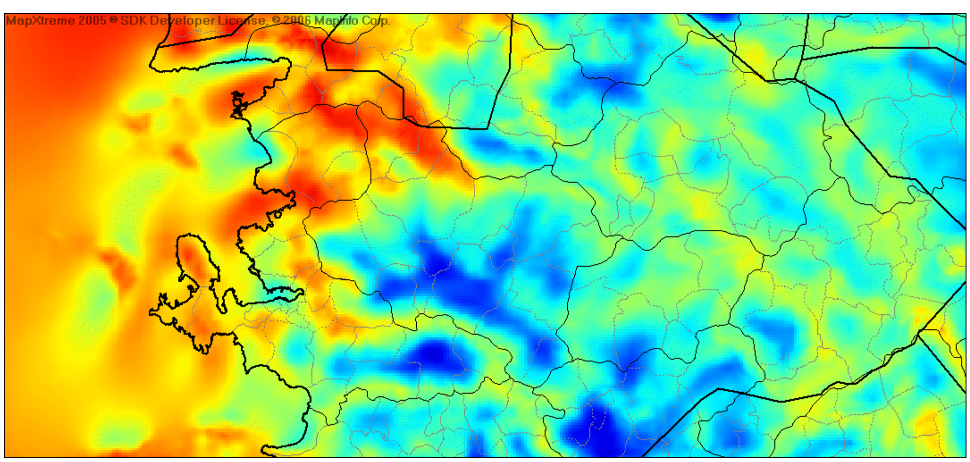

FIGURE 53-AEGEAN REGION MAP ANNUAL WIND SPEED AT 70M ABOVE GROUND (COURTESY OF REPA)

Figure 53 shows that wind speed close to Izmir and Aydin shore might be great places to harvest wind energy. Obviously constructing wind farms too far from the shore will be very costly. However the mountains are parallel to the sea in Aegean region which means that the slope of depth close to the shores is not as high as Mediterranean or in Black Sea region. Another proof for that is the amount of small and medium sized islands which are very close to Turkish borders mostly belonging to Greece. In addition to that, the Turkish national sea borders are very close to Greece and in case of a far offshore wind farm construction, there will be serious political conflicts which also should be considered.

LOCALIZATION OF WIND FARM DYNAMICS TO TURKEY: A SIMULATION

The ultimate goal of this project is to determine the economical, ecological, technical and sociological benefits of utilizing wind power and wind power derived energy over the conservative energy productions systems used today. For the previous chapters, mainly focus was general theory of the wind power and wind sourced energy; however, now try to focus on our main interest: Turkey.

Several wind maps of Turkey have been investigated and along with the topological constraints of the highly elevated Turkish landscape, three sites are determined for possible wind farm installation. Those two sites are chosen for their high wind velocity at an altitude of 70 meters from sea level, sufficiently level terrain characteristics and geological importance for energy distribution to their hinterlands. First site is located in Kayseri which is in the Mid-Anatolian Region, second site is located in Hatay which is in the Mediterranean Region and third site is located in Canakkale in the Marmara Region.

Moreover, technical analysis of capacity factors and power densities of investigated regions from Turkish Wind Energy Atlas are tabulated below in Table 4;

Capacity Factor and Power Density for Investigated Regions		
	Capacity Factor (%)	Power Density (W/m^2)
Kayseri:		
West & East Complexes	40	800
Hatay:		
Samandag West, Central & East Complexes	35	750
Canakkale:		
Eceabat/Bayramic Complexes	35	750
Gokceada/Bozcaada Complexes	30	725

TABLE 4-CAPACITY FACTOR AND POWER DENSITY FOR INVESTIGATED REGIONS ACCORDING TO TURKISH WIND ENERGY ATLAS

KAYSERI WIND FARM PROPOSAL

Kayseri is the third biggest city in the Mid-Anatolian Region and it is known for its processed-meat industry. Kayseri has two very distinct and vital geological properties. One is its proximity to Ankara, Konya and Antalya, 2nd, 6th and 7th largest cities of Turkey respectively. Second is its very level terrain and well-constructed transportation web to the surroundings. These two properties give the proposed farm installations crucial advantages of easier transportation and much-needed energy distribution to major cities.

The proposed wind farm location has no residence sites. There are two separate locations proposed for suitable wind farm installation. These areas lay on the 38° North Latitude, thus the prevailing wind direction for these sites is southwest[5].

WESTERN WINDFARM

First wind farm location is 75 kilometers (47 miles) to the south of Kayseri city center. From Turkish Wind Energy Potential Atlas, at 70 meters of elevation, annual average wind velocity is found to be 10 m/s. Satellite map image of the first site can be seen in Figure 54. The figure filters out unusable areas and the remaining red hued areas show the variation of annual wind velocity at 70 meters. Green bordered area is the site of wind turbine installation. Table 5 depicts the calculated area of the installation site.

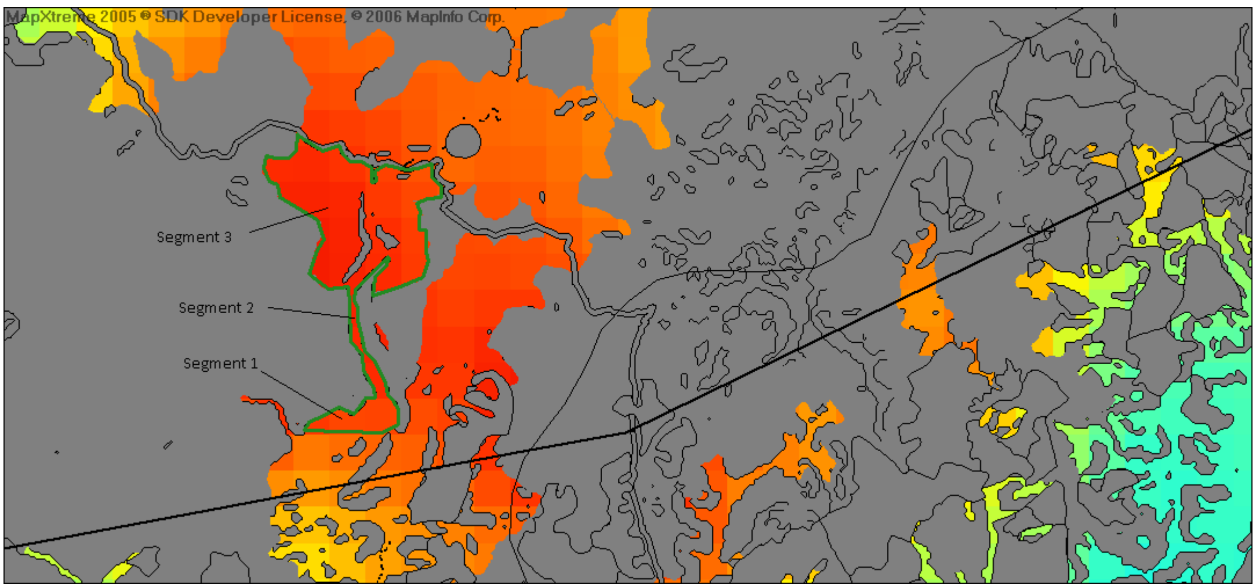

FIGURE 54-KAYSERI WEST PROPOSED AREA

KAYSERI WESTERN WIND FARM DIMENSIONS			
Location		38° 01' N	35° 25' E
Total Area		28.95km^2	
Length Measurements in the order of North to South (Km.)			
1	2.96		
2	0.92		
3	1.52		
4	0.54		
5	1.18		
6	0.37		
7	0.65		
8	0.62		
9	11.02		
Area Segment 1:		18.95	
Area Segment 2:		4	
Area Segment 3:		6	

TABLE 5-WESTERN WIND FARM DIMENSIONS

For the medium wind velocity of 9.5 – 10 m/s at 70 meters, Enercon E-48[6] wind turbine is suggested with the hub height used at 70 meters. (Maximum hub height for this turbine is 76 meters.)Turbine`s rated output is 800kW and it has a rotor diameter of 48 meters. These turbines will be installed to the first farm location of 28.95 km^2 area, which is also divided into three smaller segments due to their unique geometry. 1st segment is approx. 6 km^2, 2nd segment is an approx. 4km^2 longitudinal strip and 3rd segment is the biggest with an approx. 19km^2, which will be the main farm for greater output.

Estimation of number of wind turbines installed on each proposed location will follow the `4 blade diameters apart in perpendicular to the wind and 7 blade diameters apart parallel to the wind` distribution that has been explained in `Wake Effect and Optimum Wind Turbine Distribution` section. Thus, the expression that allows the estimation of number of turbines per area is;

$$n_{turbines} = \left[\frac{Width}{4 \ x \ d_{rotor}}\right] x \left[\frac{Length}{7 \ x \ d_{rotor}}\right] \tag{7}$$

where

$n_{turbines}$ is the estimated number of wind turbines installed (taken to the nearest integer)

Width is the width of the area segment being investigated (m)

Length is the length of the area segment being investigated (m)

d_{rotor} is the rotor diameter of the wind turbine being installed (m)

First segment has a width of 4 km and a length of 1.5 km. Therefore;

$$n_{turbines} = \left[\frac{4000}{4\ x\ 48}\right] x \left[\frac{1500}{7\ x\ 48}\right] = 80 \text{ turbines}$$

Second segment has a length of 4 km and a width of 1 km. Therefore;

$$n_{turbines} = \left[\frac{1000}{4\ x\ 48}\right] x \left[\frac{4000}{7\ x\ 48}\right] = 55 \text{ turbines}$$

Third segment is the bigger area of width 4km and length 4.5km. Therefore;

$$n_{turbines} = \left[\frac{4000}{4\ x\ 48}\right] x \left[\frac{4500}{7\ x\ 48}\right] = 260 \text{ turbines}$$

The expression that allows the computation of estimated power output is;

$$P_{total} = \sum_1^3 n_{turbines}\ \ x\ P_{turbine}\ \ x\ F_C\ x\ C_{Wake} \tag{8}$$

where

P_{total} is the estimated total power output of the segments (MWh)

$P_{turbine}$ is the rated power output of the installed wind turbine (MWh)

F_c is the capacity factor of the region of the wind farm

C_{Wake} is the coefficient of wake effect for the wind farms, 0.95

For the West Kayseri wind farms, estimated power output is computed as;

$$P_{total} = 395\ x\ 0.8\ x\ 0.4\ x\ 0.95 = 120.08 \text{ MWh}$$

Kayseri Western Wind Farm project installs 395 turbines with a combined output of 120.08 MWh.

Second wind farm proposed in Kayseri region is 81.39 km (50.57 miles) south of the city center and 5.24 km east of the western farm. They share the same wind velocity characteristics and the available terrain for the proposed wind farm can be seen in Figure 55. Table 6 shows usable area for the eastern wind farm proposal.

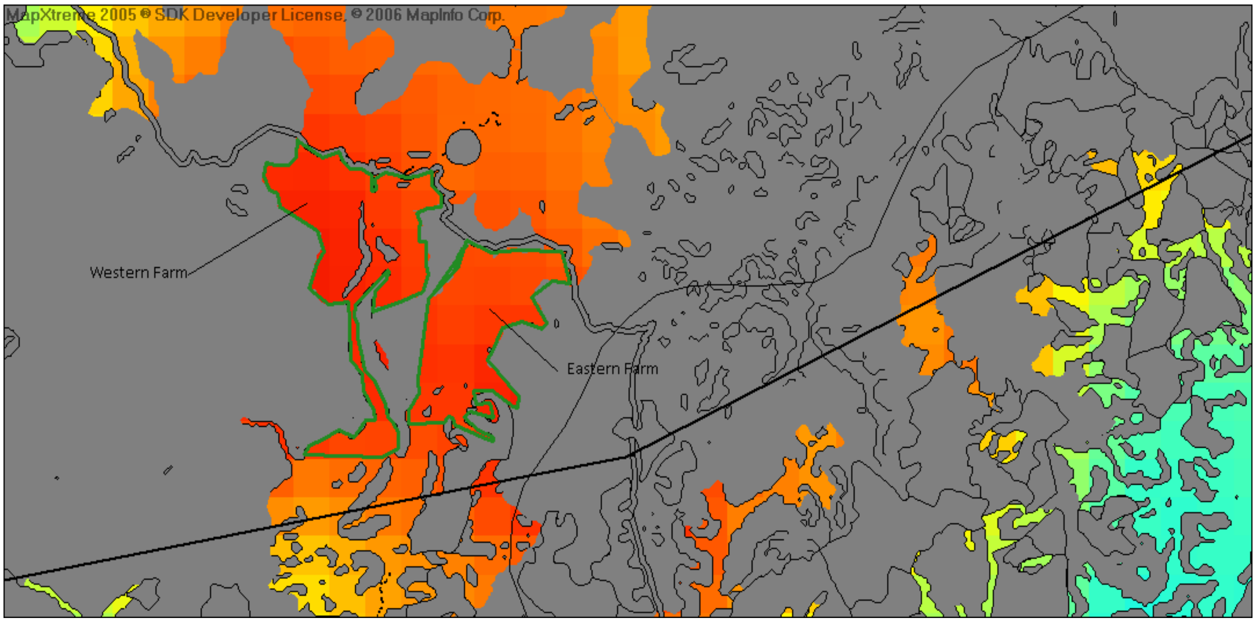

FIGURE 55-WESTERN AND EASTERN FARMS SHOWN TOGETHER

KAYSERI EASTERN WIND FARM DIMENSIONS			
Location		37° 59' N	35° 31' E
Total Area		$22.15 km^2$	
Length Measurements in the order of North to South (Km.)			
1	1.06		
2	3.42		
3	1.02		
4	3.07		
5	2.57		
6	1.03		
7	2.28		
8	1.05		
9	0.39		

TABLE 6-EASTERN WIND FARM DIMENSIONS

Kayseri East wind farm has a usable area of 22.15 km^2. Dimensions for this farm are 3.5 km of width and 6.3 km of length. For that reason;

$$n_{turbines} = \left[\frac{3500}{4 \ x \ 48}\right] x \ \left[\frac{6300}{7 \ x \ 48}\right] = 324 \text{ turbines}$$

For East Kayseri wind farm, estimated power output is computed as;

$$P_{total} = 324 \ x \ 0.8 \ x \ 0.4 \ x \ 0.95 = 98.50 \text{ MWh}$$

Kayseri West & East wind farm proposals are constructed with 719 Enercon E-48 Turbines and produce a total of 218.58 MWh.

HATAY SAMANDAG WIND FARM

Hatay is the southernmost location of the Turkish landscape, positioned between the Mediterranean Sea and the Syria border on the 35˚ North Latitude. Hatay itself is a medium sized city with a population of 1.3 million. However, its biggest district, Iskenderun, has always been of major geopolitical and strategically importance due to its bay and proximity to Cyprus. Iskenderun Bay is the home location of Turkey`s biggest iron and steel smelting company, ISDEMIR A.S., Turkish-Azerbaijani Ceyhan-Baku pipeline and much more. As a result, the energy demand in the bay is rising with everyday and the main source of energy for these facilities is the thermal energy power plants nearby.

Samandag is the district that is adjacent to Iskenderun, therefore Samandag also has a Mediterranean coast line, which has powerful winds that are locally called `Yarik Kaya` (Split Rock)[7]. Geographical location and the wind map of the district can been seen at Figure 56 and Figure 57 respectively.

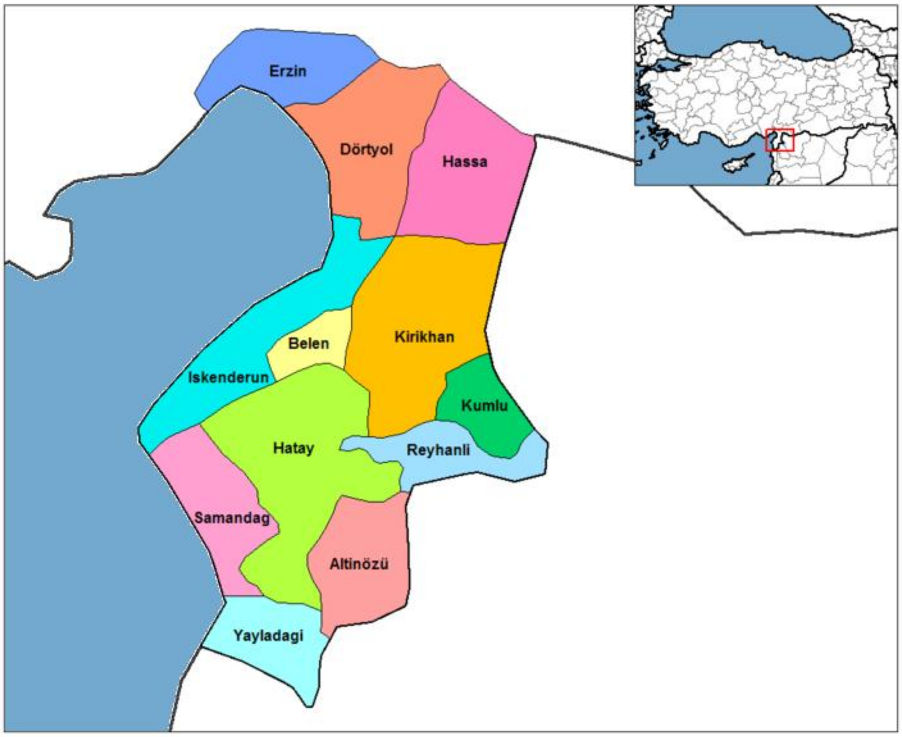

FIGURE 56-DISTRICTS OF HATAY PROVIDENCE

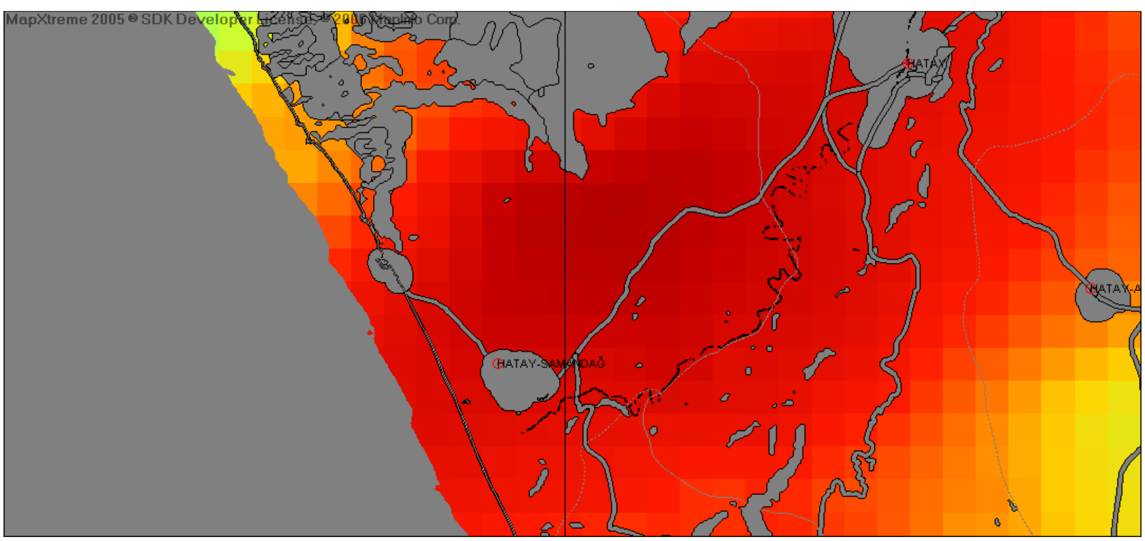

FIGURE 57-LOCAL WIND MAP OF SAMANDAG DISTRICT

Samandag proposal has been divided into 3 parts for separate discussion and localization of each. Western part can be seen as green bordered in Figure 58 and its area has been tabulated in Table 7-Samandag Western Wind Farm Dimensions.

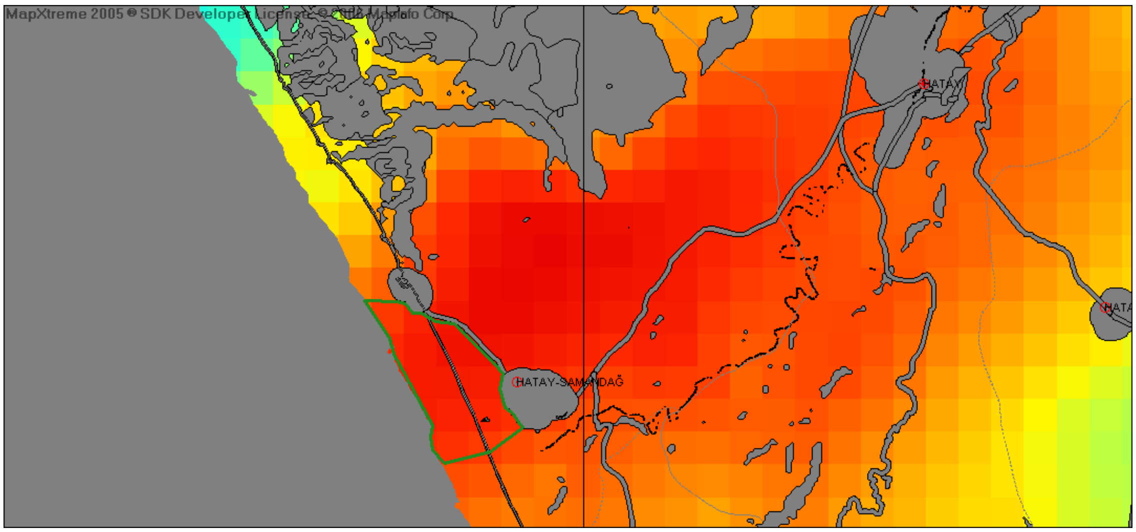

FIGURE 58-SAMANDAG WESTERN FARM LOCATION

HATAY - SAMANDAG WESTERN WIND FARM			
Location		36° 05' N	35° 58' E
Total Area		22.35km^2	
Length Measurements in the order of North to South (Km.)			
1	1.48		
2	7.65		
3	0.72		
4	0.8		
5	2.12		
6	7.08	(Parallel to the Road)	
Area Segment 1:			
Area Segment 2:			
Area Segment 3:			

TABLE 7-SAMANDAG WESTERN WIND FARM DIMENSIONS

Western wind farm has a calculated area of 22.35 km^2, with an average width of 3.85 km and an average length of 5.8 km. For the geographical specialty of the western farm, that is it faces the Mediterranean coast directly, turbines will be placed parallel to the coast to use the coastal winds also. Therefore, turbine rows will be placed in 5.8 km strip and columns will go to the hinterlands in the 3.85 km width.

Calculations for the number of turbines:

$$n_{turbines} = \left[\frac{5800}{4\ x\ 48}\right] x \left[\frac{3850}{7\ x\ 48}\right] = 330 \text{ turbines}$$

For the Western Samandag wind farm, estimated power output is computed as;

$$P_{total} = 330\ x\ 0.8\ x\ 0.35\ x\ 0.95 = 87.78 \text{ MWh}$$

Central wind farm is the largest of three in terms of area and it will house the headquarters of the whole farm system. Wind farm area can be seen as bordered in Figure 59 and its area has been shown in Table 8.

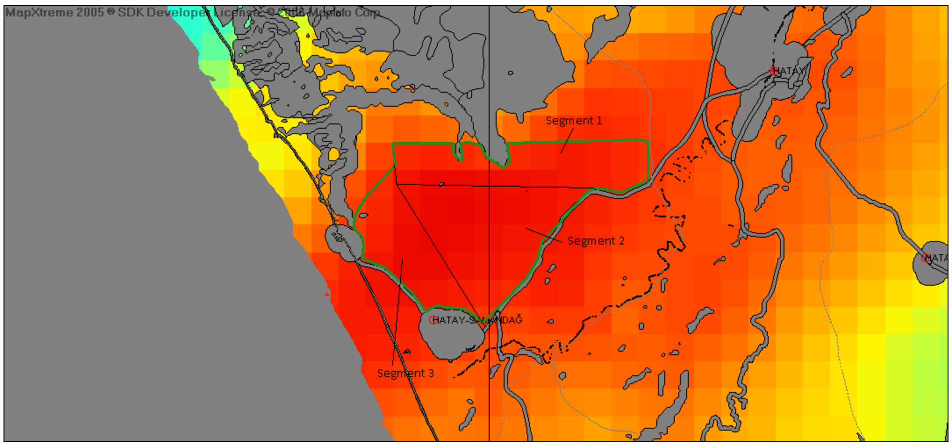

FIGURE 59-SAMANDAG CENTRAL WIND FARM LOCATION

HATAY - SAMANDAG CENTRAL WIND FARM			
Location		36° 06' N	36° 01' E
Total Area		82.21km^2	
Length Measurements in the order of North to South (Km.)			
1	5.76		
2	7.3		
3	3.82		
4	2.74		
5	14.92		
6	8.31		
7	4.85		
8	2.67		
Area Segment 1:		27.7 km^2	
Area Segment 2:		36 km^2	
Area Segment 3:		18.5 km^2	

TABLE 8-SAMANDAG CENTRAL WIND FARM DIMENSIONS

Central Wind Farm will be installed on an area of 82.21 km^2 that is divided into three segments for more accurate turbine number estimations.

Segment 1 is a fairly rectangular area of 12 km width and 2.3 km length, therefore, 27.7 km^2. Segment 2 is almost an equilateral triangle of each side 9.11 km, hence an area of 36 km^2. Segment 3 is again simplified to a rectangle with 9.11 km to 2.03 km sides that add up to an area of 18.5 km^2.

Segment 1:

$$n_{turbines} = \left[\frac{12000}{4\ x\ 48}\right] x \left[\frac{2300}{7\ x\ 48}\right] = 372 \text{ turbines}$$

Segment 2 is an equilateral triangle; hence each column will not have the same number of turbines since the width decreases to the south. Triangle has a `height` of 7.89 km and a specific width of 6.44 km, deduced from triangular area similarity equations.

Segment 2:

$$n_{turbin\ es} = \left[\frac{6440}{4\ x\ 48}\right] x \left[\frac{7890}{7\ x\ 48}\right] = 759 \text{ turbines}$$

Segment 3 is also a fairly rectangular geometry, 9.11 km width and 2.03 km length, therefore;

$$n_{turbines} = \left[\frac{9110}{4\ x\ 48}\right] x \left[\frac{2030}{7\ x\ 48}\right] = 282 \text{ turbines}$$

For the Central Samandag wind farm, estimated power output is computed as;

$$P_{total} = 1413\ x\ 0.8\ x\ 0.35\ x\ 0.95 = 375.86 \text{ MWh}$$

Eastern part of the Samandag wind farm complex can be seen in Figure 60 and its area has been displayed in Table 9.

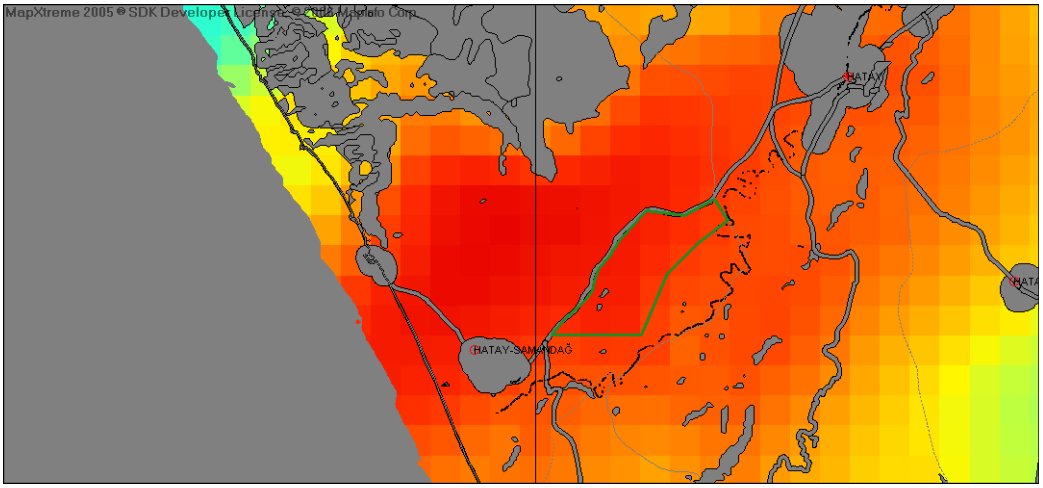

FIGURE 60-SAMANDAG EASTERN WIND FARM LOCATION

HATAY - SAMANDAG EASTERN WIND FARM			
Location		36° 05' N 36° 04' E	
Total Area		21.71km^2	
Length Measurements in the order of North to South (Km.)			
1	1.2		
2	6.74		
3	3.85		
4	7.1		
5	1.75		
6	1.14		
Area Segment 1:			
Area Segment 2:			
Area Segment 3:			

TABLE 9-SAMANDAG EASTERN WIND FARM DIMENSIONS

Central Wind Farm will be installed on an area of 82.21 km^2 that is divided into three segments for more accurate turbine number estimations.

Segment 1 is a fairly rectangular area of 12 km width and 2.3 km length, therefore, 27.7 km^2. Segment 2 is almost an equilateral triangle of each side 9.11 km, hence an area of 36 km^2. Segment 3 is again simplified to a rectangle with 9.11 km to 2.03 km sides that add up to an area of 18.5 km^2.

Segment 1:

$$n_{turbines} = \left[\frac{12000}{4\ x\ 48}\right] x \left[\frac{2300}{7\ x\ 48}\right] \text{ = 372 turbines}$$

Segment 2 is an equilateral triangle; hence each column will not have the same number of turbines since the width decreases to the south. Triangle has a `height` of 7.89 km and a specific width of 6.44 km, deduced from triangular area similarity equations.

Segment 2:

$$n_{turbines} = \left[\frac{6440}{4\ x\ 48}\right] x \left[\frac{7890}{7\ x\ 48}\right] \text{ = 759 turbines}$$

Segment 3 is also a fairly rectangular geometry, 9.11 km width and 2.03 km length, therefore;

$$n_{tur\ bines} = \left[\frac{9110}{4\ x\ 48}\right] x \left[\frac{2030}{7\ x\ 48}\right] \text{ = 282 turbines}$$

For the Central Samandag wind farm, estimated power output is computed as;

$$P_{total} = 1413\ x\ 0.8\ x\ 0.35\ x\ 0.95 \text{ = 375.86 MWh}$$

Marmara Region has the most population among the other six regions of Turkey due to major cities of Istanbul, Bursa and Izmit. Furthermore, it is also the most densely populated region of Turkey as well with its 67,000 km^2 area housing 17.3 million Turkish citizens according to 2000 census. Marmara region is strategically important since it has the Dandelion straight and the Bosphorus. With its dense population, transportation importance and industrial lead in Turkish economy, Marmara region is the biggest user of Turkish energy sources. For that matter, it stands in a more critical position than other regions for energy demand.

West Marmara has suitable grounds for wind harvesting potential thanks to strong winds channeling from the Aegean Sea to the Marmara Sea. Canakkale province, being the westernmost part of the region, has shores adjacent both to the Aegean and Marmara, therefore; it has perfect conditions for potential wind farm complexes that will be analyzed henceforth.

On-shore wind farm proposals will be based on two small districts of Canakkale province, namely Eceabat and Bayramic. Off-shore proposals will be based on two Turkish islands in the Aegean, Gokceada and Bozcaada.

Eceabat and Bayramic complex consists of three proposed wind farms in three different locations. Two of the farms will be constructed in Eceabat district border, tagged North Eceabat Farm and South Eceabat Farm, and the third one will be placed in Bayramic district border. Figure 61 displays all three regions in full.

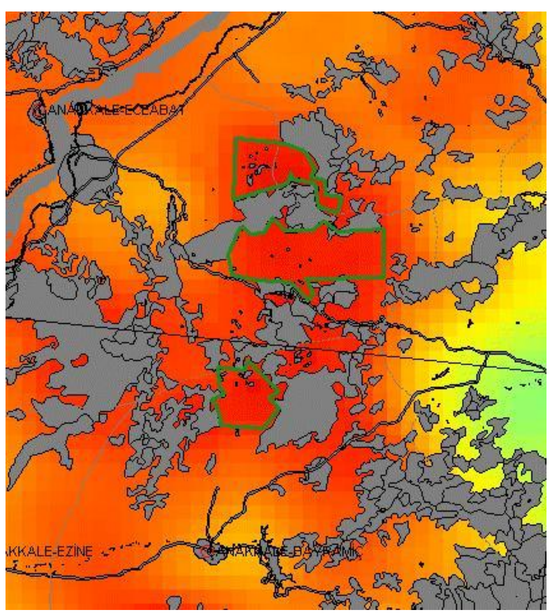

FIGURE 61 - CANAKKALE PROVINCE ECEABAT AND BAYRAMIC ON-SHORE WIND FARM LOCATIONS

Eceabat farms are situated to the north in Figure 61 and they are larger in terms of area than the Bayramic complex. Dimensions and sizes for northern and southern farms are tabulated in Table 10, Table 11.

Canakkale Eceabat North WIND FARM			
Location		39° 49' N 26° 02' E	
Total Area		38.42km^2	
Length Measurements in the order of North to South (Km.)			
1	4.92		
2	6.17		
3	6.39		
4	3.71		
5	7.72		
6	7.64		
7	0.9		
8	1.57		
Area Segment 1:			
Area Segment 2:			
Area Segment 3:			

TABLE 10 - ECEABAT NORTH WIND FARM DIMENSIONS

Canakkale Eceabat South WIND FARM			
Location		39° 49' N 26° 02' E	
Total Area		77.53km^2	
Length Measurements in the order of North to South (Km.)			
1	1.42		
2	3.35		
3	4.95		
4	15.88		
5	3.76		
6	14.09		
Area Segment 1:			
Area Segment 2:			
Area Segment 3:			

TABLE 11 - ECEABAT SOUTH WIND FARM DIMENSIONS

North wind farm is smaller than the south wind farm but them working in conjunction will decrease transportation losses and costs such that one processing center will be employed for two farms in Eceabat.

North farm has an area of 38.42 km^2 with averaged length of 5.5 km and averaged width of 7 km. Hence;

$$n_{turbines} = \left[\frac{7000}{4\ x\ 48}\right] x \left[\frac{5500}{7\ x\ 48}\right] = 576 \text{ turbines}$$

For the North Eceabat wind farm, estimated power output is computed as;

$$P_{total} = 576\ x\ 0.8\ x\ 0.35\ x\ 0.95 = 153.22 \text{ MWh}$$

South farm has a rectangular area of 77.53 km^2 with a width of 12.5 km and a length of 6.2 km. Thus;

$$n_{turbines} = \left[\frac{12500}{4\ x\ 48}\right] x \left[\frac{6200}{7\ x\ 48}\right] = 1170 \text{ turbines}$$

For the South Eceabat wind farm, estimated power output is computed as;

$$P_{total} = 1170\ x\ 0.8\ x\ 0.35\ x\ 0.95 = 311.22 \text{ MWh}$$

Therefore, Eceabat Complex will have 1746 turbines in total for a combined output of 464.44 MWh.

BAYRAMIC WIND FARM

Bayramic wind farm can be seen as the smallest one of the group in Figure 61 and its dimensions are given in Table 12.

Canakkale Bayramic WIND FARM			
Location		39° 49' N 26° 02' E	
Total Area		35.94km^2	
Length Measurements in the order of North to South (Km.)			
1	5.42		
2	6.6		
3	4.95		
4	1.28		
5	5.03		
6	4.92		
Area Segment 1:			
Area Segment 2:			
Area Segment 3:			

TABLE 12 - CANAKKALE BAYRAMIC WIND FARM DIMENSIONS

Bayramic farm has fairly square properties in its dimensions with length and width almost perfectly equal to 6 km. For that matter;

$$n_{turbines} = \left[\frac{6000}{4\ x\ 48}\right] x \left[\frac{6000}{7\ x\ 48}\right] = 527 \text{ turbines}$$

For Bayramic wind farm, estimated power output is computed as;

$$P_{total} = 527\ x\ 0.8\ x\ 0.35\ x\ 0.95 = 140.18 \text{ MWh}$$

Gokceada and Bozcaada are the only island Turkey have on the Aegean Sea, which they possess great importance due to their proximity to the entrance of Dandelion straight. This geographical positioning also makes them very suitable wind farm locations as the winds channeled to Marmara Sea pass over these two small islands. Potential wind farm locations are given in Figure 62.

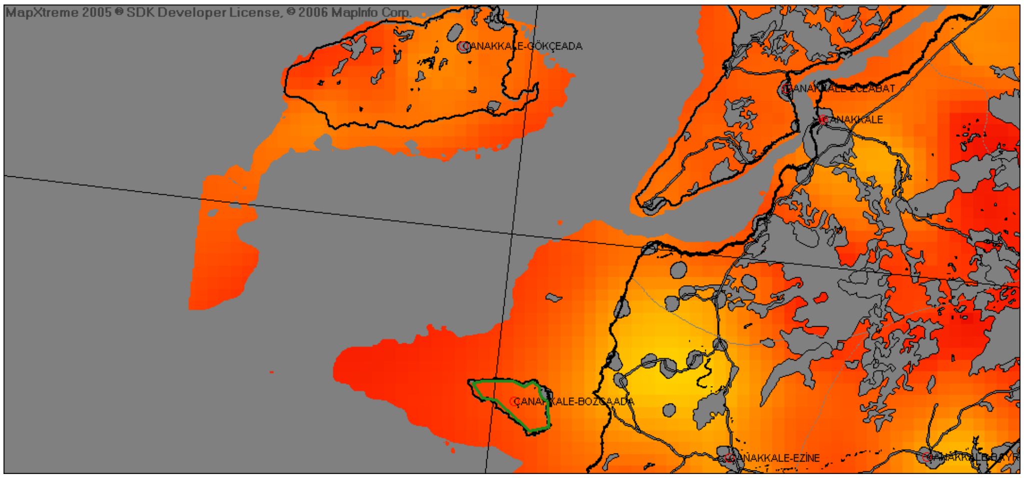

FIGURE 62-CANAKKALE GOKCEADA/BOZCAADA OFF-SHORE WIND FARM LOCATIONS

BOZCAADA WINDFARM

Bozcaada is the smaller of the two islands and is situated to the south of the Dandelion Straight. Bozcaada wind farm dimensions are given in Table 13 below.

BOZCAADA WIND FARM		
Location	39° 49' N 26° 02' E	
Total Area	$30.13 km^2$	
Length Measurements in the order of North to South (Km.)		
1	7.94	
2	6.13	
3	2.48	
4	6.71	
5	5.05	
6	2.83	
Area Segment 1:		
Area Segment 2:		
Area Segment 3:		

TABLE 13- BOZCAADA WIND FARM DIMENSIONS

Bozcaada wind farm proposal has an area of 30.13 km^2 with a height of 6 km and a specific base of 7.07 km, from the similarity of triangular areas. Hence;

$$n_{turbines} \;=\; \left[\frac{7070}{4\ x\ 48}\right] x\ \left[\frac{6000}{7\ x\ 48}\right] = 612 \text{ turbines}$$

For Bozcaada wind farm, estimated power output is computed as;

$$P_{total} \;=\; 612\ x\ 0.8\ x\ 0.3\ x\ 0.95 = 129.54 \text{ MWh}$$

GOKCEADA WIND FARM

Gokceada is the bigger of the two islands and it is positioned right in the entrance of the straight. Its dimensions are given in Table 14.

GOKCEADA WIND FARM			
Location		40° 09' N	25° 51' E
Total Area		258.96km^2	
Length Measurements in the order of North to South (Km.)			
1	12		
2	26.71		
3	22.52		
4	17.15		
5	2.54		
6	4.91		
Area Segment 1:			
Area Segment 2:			
Area Segment 3:			

TABLE 14 - CANAKKALE GOKCEADA WIND FARM DIMENSIONS

From the table above, it can be seen that Gokceada has a region of 258.96km^2 with a length of 20km and height of 13km. For those given measurements;

$$n_{turbines} \;=\; \left[\frac{20000}{4\ x\ 48}\right] x\ \left[\frac{13000}{7\ x\ 48}\right] = 3952 \text{ turbines}$$

For Gokceada wind farm, estimated power output is computed as;

$$P_{total} \;=\; 3952\ x\ 0.8\ x\ 0.3\ x\ 0.95 = 901.06 \text{ MWh}$$

Canakkale Wind Farm complexes will be utilizing 6837 Enercon E-48 800 MW turbines, generating 1635.22 MWh.

CHAPTER 4-ECONOMICAL ANALYSIS OF WIND POWER PRODUCTION IN TURKEY

Wind farms are the key alternative energy source to improve current situation of Turkish energy economics. Turkey gathers up to 44% of its electrical energy from Natural Gas, provided by Gazprom of Russia. Unfortunately this figure is more frustrating when The Ministry of Energy and Natural Resources' official report states that 72% of Turkey's energy demand is supplied by external sources. In addition to that if the internal energy supply and demand curves do not cross in the next 10 years, it will be a burden, energy import can grow by to 80%. Department of Energy predicts that by the year 2020, the energy sector as a whole will need at least 130 billion$ supply investment in order to compete with the demand. The predicted total electricity power need varies from 80,600MW to 90,600MW. Turkish Republic's current[8] (as of September 2007 energy report) built energy supply is around 39,500MW. In other words, Turkey needs to have a built and operating power of 40,500 to 56,500MW by its own until the year 2020. The demand curve of Turkish Republic is presented on Figure 63. Table 15 is used for plotting Figure 63.

Type of Fuel	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Hard Coal	2,574	3,273	2,981	3,123	3,176	2,706	2,646	2,694	2,478	2,852	2,855
Lignite	27,840	30,587	32,707	33,908	34,367	34,372	28,056	23,590	22,450	30,008	32,242
Hydro	40,475	39,816	42,229	34,678	30,879	24,010	33,684	35,330	46,084	39,940	44,154
Other	259	377	339	306	329	382	327	266	254	270	352
Import Coal	0	0	0	0	643	1,340	1,447	5,969	9,520	10,205	11,055
Fuel Oil	6,540	7,157	7,923	8,080	9,311	10,366	10,744	9,196	7,670	8,016	7,804
Natural Gas	17,174	22,086	24,838	36,346	36,346	49,549	52,497	63,536	62,242	70,962	77,233
TOTAL	94,862	103,296	111,017	116,441	115,051	122,725	129,401	140,581	150,698	162,253	175,695

TABLE 15-TURKEY'S ELECTRICAL ENERGY CONSUMPTION FROM 1996 TO 2006 (TOTAL ENERGY SUPPLIED IN 10^6 KWH/YEAR)

The Ministry of Energy and Natural Resources (MENR) predicts an annual increase of 7-8% in electricity demand for each year until 2020. A more precise research result by Turkish Republic Energy Market Management Department[9], predicts a more precise low 6.3% and a high 8.4% annual increase in electricity demand. This prediction data is plotted on Figure 63-Turkey's Energy consumption figures until year 2020. MENR also details that a 5000MW nuclear power plant energy production project will be completed until 2020 in Akkuyu – Konya, located in middle Anatolian territory. In addition to that, more hydroelectric and lignite power plants will be built in order use 100% of potential natural resources. (129 and 120 billion kW/year respectively. Currently at 37% and 36% respectively)

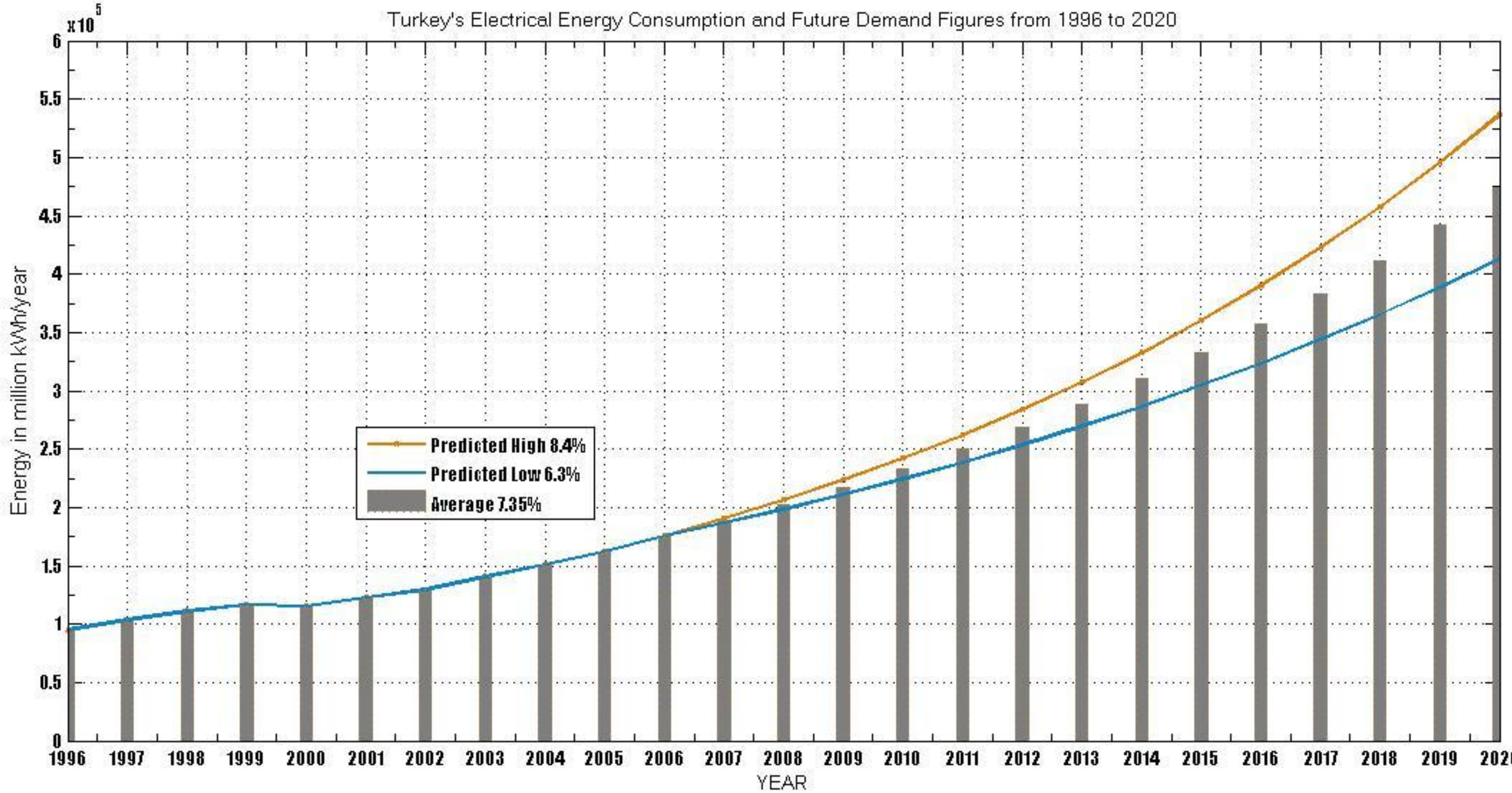

FIGURE 63-TURKEY'S ENERGY CONSUMPTION FIGURES UNTIL YEAR 2020

When looked from a different perspective, Table 15 describes the role of Wind Energy for the year 2006. As seen in type of fuel column, wind energy is not shown as an individual resource and included in "other" electricity production. Assuming that most of the "other" energy production resource is Wind energy, it is possible to say that wind energy has nearly no effect on the electricity supply and demand curve of Turkish Republic. The Pie Chart Below shows the percentage of electrical energy supplied by each fuel type in 2006.

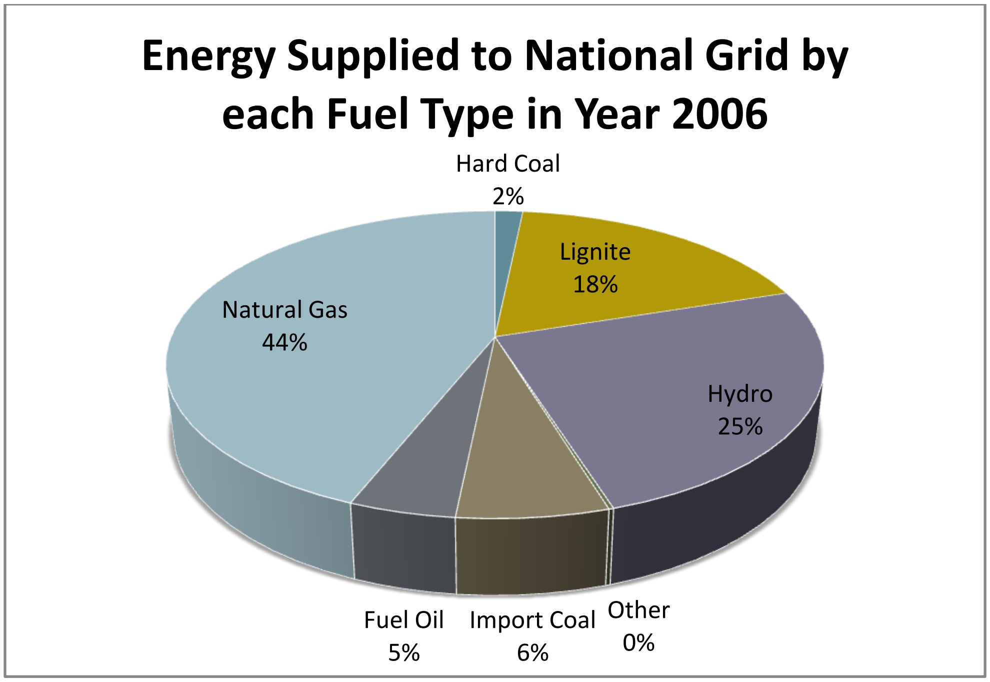

FIGURE 64-2006 ENERGY SUPPLY CHART

As seen in the pie chart, section "other" was considered ineffective or very close to 0% of production value. According to Figure 64, the total energy supplied by Natural Gas is approximately 77,233 GWh/year which is 44% of the national electric energy demand of Turkish Republic. In addition to that, import coal, as well as part of lignite, fuel oil is provided by foreign natural resources. After subtracting energy produced by these resources from total energy consumption, Turkish National Grid's energy production percentage comes down to approximately 37% of nation's power demand. In other words, 73% of nation's energy was supplied by import energy in year 2006.

Upon the completion of predicted wind energy power plants in Kayseri, Antakya, Canakkale, Gokceada and Bozcaada, the approximate output will be theoretically 6760.44 MW calculated in **Chapter 3** of this report. However after the calculation capacity factor of these wind farms; assuming today's most recent technology is used, the total power output becomes 2489.43MW. The efficiency of wind power plants seems less than 50% but it is a reasonable assumption according to IEEE Power & Energy Magazine – November 2007 Issue[10]. The magazine has more engineering data and knowledge presented on efficiency which is beyond the scope of this report. The total yearly wind energy production calculation is given below.

$$P_{annual} = P_{total} \times d \times h \tag{9}$$

Where,

d = days in a year,

P_{total}= Predicted power capacity of wind farms nationwide. (Megawatts)

h = total hours in a day

$$2489.43 \times 24 \times 365 = \sim 21{,}807.4\ million\ \frac{kW}{year}$$

If these wind energy production farms were completely working in year 2006, it would decrease Turkey's dependency on energy import and greatly increase National Grid's contribution to supply energy demands. The table for this pie chart is given:

2006 Figures with Wind Energy farms a total of 2489.43MW		
Total Wind Energy Production:	21,807.4million KW/year	
Type of Fuel	2006	2006 figures with Predicted Wind Farms
Hard Coal	2,855	2,855
Lignite	32,242	32,242
Hydro	44,154	44,154
Other	352	21,807
Import Coal	11,055	11,055
Fuel Oil	7,804	7,804
Natural Gas	77,233	**55,778**
TOTAL	175,695	175,695

TABLE 16-2006 FIGURES, WIND ENERGY COMPANSATING FOR NATURAL GAS

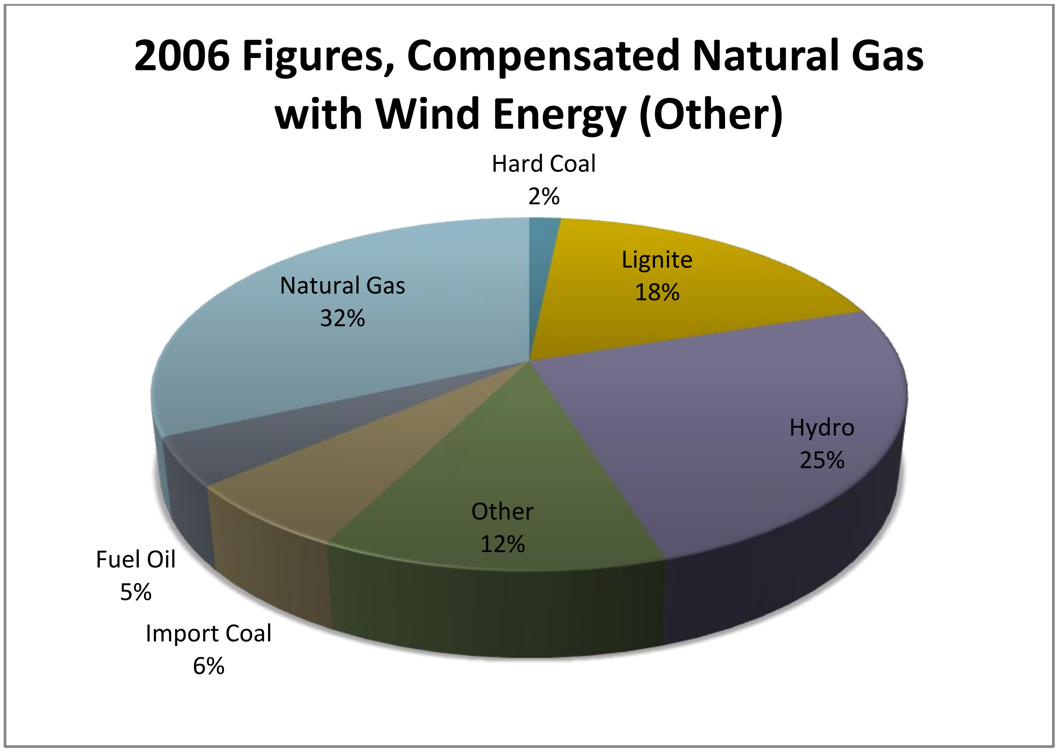

FIGURE 65-2006 FIGURES, WIND ENERGY COMPANSATING FOR NATURAL GAS (UNDER OTHER SOURCES)

When the resulting pie chart in Figure 65 is compared with real 2006 figures, it can be seen that natural gas usage is reduced by approximately 12%. Obviously this will be a great advantage for Turkish economy since it helps observe amount of money saved just for year 2006. Table 17 provides the current price of natural gas.

NG sales price to Power plants (USD/1000 m^3)	315.00
NG sales price to Power Plants (US Cent/m3)	31.50
Electricity generation from 1 m^3 NG (kWh/m^3)	4.20
NG in 1 kWh electricity generation (Cent/kWh)	7.50
US Dollar exchange rate (YTL/USD)	1.30
NG share in 1kWh electricity generation (Ykr/kWh)	9.75

TABLE 17-GAS SHARE IN NG BASED ELECTRICITY GENERATION PRICE

In the last 4 years, Gazprom's natural gas price increased about 54% range, as a result of most EU countries and Turkey choosing natural gas as major energy source which created a NG deficit. This inevitable price increase causes an unpredictable electricity price setting for Turkey which also has a negative effect on inflation percentage. Considering the fact that the available supply of natural gas is will be significantly reduced in the next 30 years, it is normal to think that Gazprom will keep increasing the price of electricity as much as possible in the following decades. However there are no concrete proofs for that and political debates is an issue on the natural gas prices. Electricity generation in an efficient electricity power plant is 4.20kWh/m^3 and the following calculations below will be based on this value.

In 2006, 44% of Turkey's energy demand was supplied by Natural gas which concludes to a 77,305million kWh/year.(Table 15) For a country that produces 4.20 kWh per m^3 (Applicable only to large size, high performance, newly established power plants):

$$NG_{total} = \frac{W_{NG}}{\mu_{NG}} \tag{10}$$

Where,

NG_{total}= Total Natural Gas import in order to convert to electricity (m^3/year)

W_{NG}= Total annual energy production (GWh/year where G=10^9 and k=10^3)

μ_{NG}= Efficiency of a natural gas power plant (kWh/m^3)

$$\frac{77{,}305.0 * 10^9}{4.2 * 10^3} = 1840.6 million \ \frac{m^3}{year}$$

Considering the sales price of gas to power plants is 262.5$/1000 m^3 (import price, Figure 66, excluding tax set by BOTAS[11] of Turkey) the resulting cost of gas comes out to be

$$NG_{total} * C_{GAS} = C_{TOTAL} \tag{11}$$

Where,

NG_{total}= Total Natural Gas import in order to convert to electricity (m^3/year)

C_{GAS}= Cost of natural gas (in $USD/1000$m^3$)

C_{TOTAL}=Total cost of gas for the given year (in $USD)

$$1.8406 * 10^{10} * \frac{262}{1000} = 4.8224 billion\$$$

Considering 2006 compensated Natural Gas figures given in Table 16, an expenditure of approximately 18,406million kW/year can be kept in the state income. This corresponds to a decrease of natural gas import of approximately 12% which is worth about $12\% * C_{TOTAL} = 0.5786 billion\$$ for year 2006.

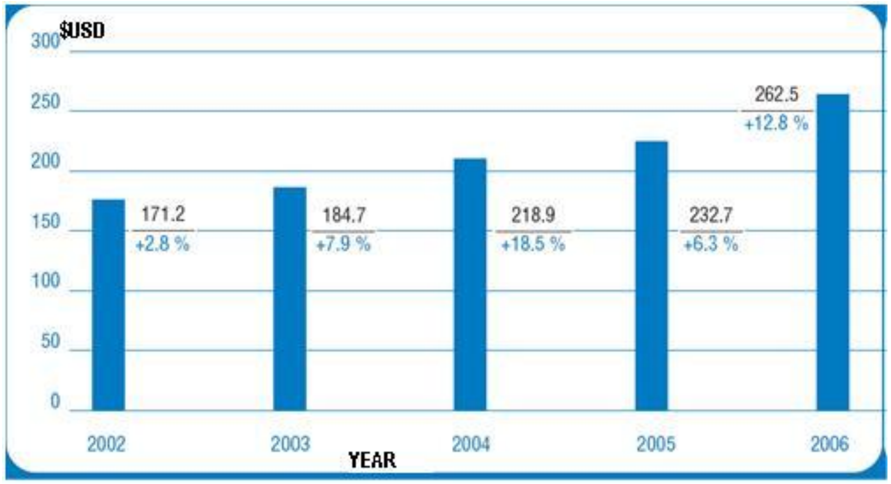

FIGURE 66-GAZPROM'S NATURAL GAS SALES ABROAD (IN $USD/1000M^3)

Figure 66 above shows the rapid increase in gas prices, set by Gazprom which included in the annual report 2001 – 2006, official Gazprom website[12]. By looking at this graph it is possible to predict the increase in gas prices over the next decade if demand of the Europe and Turkey keeps increasing at the same pace. More and more pipelines are built in Turkey and in Europe which means the demand for natural gas will increase drastically over the years. However, there has to be a limit for such increase as it might cause political problems between Russia and client countries. At this point, it will make sense to predict these curves just by looking at the previous figures of Gazprom and the future company plans.

"The third stage, according to our plans, will be over by 2010. The consumers will have a choice of different gas suppliers."[13]

From the phrase above, it is possible to see the maximum and the minimum increase in the gas prices determined by the Russian government and Gazprom.

"The industry's investment attractiveness is increasing. New investments will lead to production and transmission of natural gas volumes meeting market demand. Starting from 2010, all gas producers including Gazprom will be able to produce 650 to 700 billion cubic meters of natural gas. Therefore, we, as well as independent producers, will be capable to supply all Russian and foreign consumers. The notion of natural gas deficit will no longer exist."[14]

It can be assumed that until year 2010 the natural gas price deficit will keep increasing gradually and will have a gentle price increase for the following years, as a result of free market and supply & demand satisfaction. In other words, the "monopoly" type of market for natural gas will leave its place to the modern marketing concept where the consumer country will be able to pick the best choice; in this case the cheapest gas provided.

Politically, it could make sense to say that in the following 13 years, Turkey and Russia's relations will be stable just like it was for the last 4 years which means that the gas prices will vary in these maximum and minimum limits. There are some more natural gas clients in Europe that will be demanding Russian gas in following years with the construction of pipelines connecting through Turkish territory which provides Turkey a political advantage but at the same time it is obvious that Russian supplies will last for another 60 - 80 years and they will want to make the most out of it by increasing the prices as much as they can. It can be said that the system dynamics will be a steep increase of natural gas prices until 2010 and a less increase in price after the beginning of free market in natural gas around the world.

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Max Prediction 2007 - 2010 = 5%, 2011 - 2020 = 1%) $/1000m3	-	330.8	347.3	364.7	368.3	372	375.7	379.5	383.3	387.1	391	394.9	398.8	402.8
Min Prediction 2007 - 2010 = 2%, 2011 - 2020 = 0.5%) $/1000m3	-	321.3	327.7	334.3	336	337.6	339.3	341	342.7	344.4	346.2	347.9	349.6	351.4
Actual Predicted: (Average of minimum and maximum per year) $/1000m3	315	326	337.5	349.5	352.1	354.8	357.5	360.2	363	365.8	368.6	371.4	374.2	377.1

TABLE 18-PREDICTED FIGURES FOR NATURAL GAS UNTIL THE END OF 2020

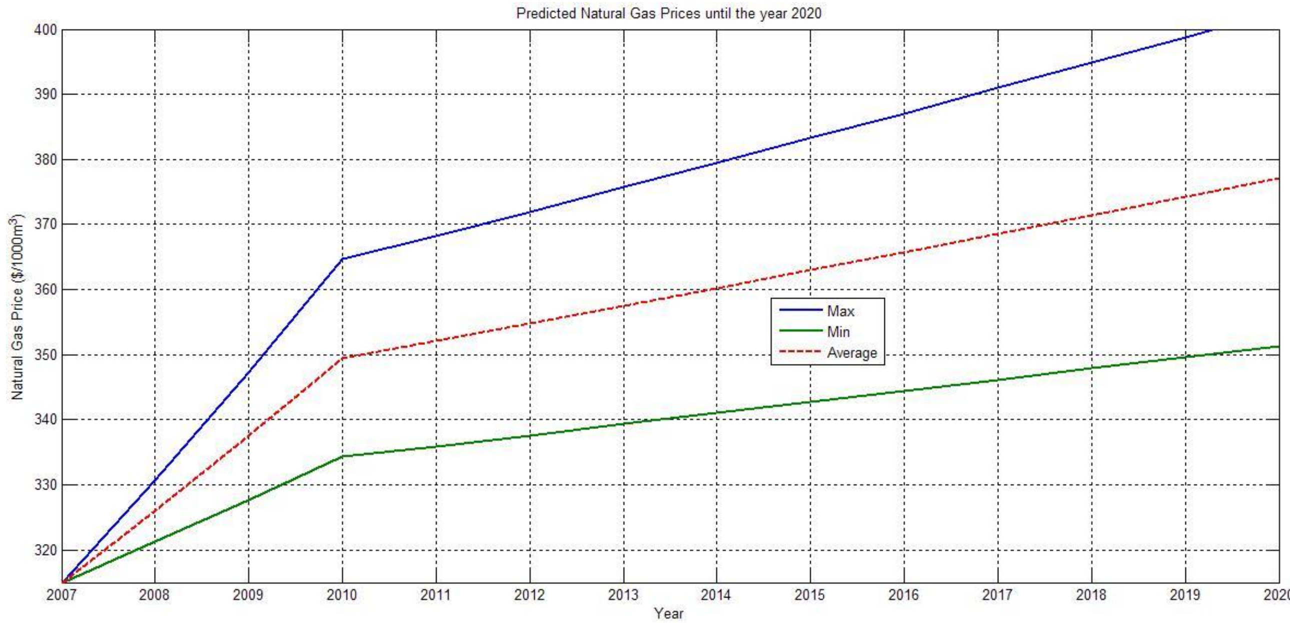

FIGURE 67-PLOT OF PREDICTED FIGURES FOR GAS PRICES

In order to show the difference, the wind power plants that were researched and built in the previous chapters will be assumed as completed and fully operational in year **2010**. As it was calculated before, the total energy produced by the power plants in Kayseri, Hatay and Canakkale will be 21,807million kWh/year. In year 2010 the energy demand of Turkey will be around 230,000 million kWh/year. It can be assumed that around 9.48% of this demand will be successfully supplied by Wind Energy. To make things as simple as possible, it is assumed that all the wind energy produced will compensate for the import of natural gas. The calculations are given below for the sake of clarity.

$$\frac{\sum energy\ /year}{\mu_{Power\ \ Plant}} \times \mathrm{P_{NG}} = \mathrm{Cost_{NG}} \tag{12}$$

Where,

$\sum energy/year$=Total energy that can be produced by wind energy (units in million kWh/year),

$\mu_{Power\ Plant}$= Average efficiency of natural gas power plants (kWh/m^3),

P_{NG}= Price of Natural Gas at the given year. (In \$/1000m^3),

$Cost_{NG}$ = Cost of natural gas that will be saved for the given year (\$).

$$\frac{21{,}807x10^6}{4.2} x \frac{349.50}{1000} = \sim 1.815\ billion\$$$

Considering the average case scenario of figures from years 2011 to 2020, the predicted money that is not spent for natural gas by the treasury can be used for the wind energy plants. The result can be calculated using the same equation and finding ($Cost_{NG}$) for each year until 2020. Total $Cost_{NG}$ of natural gas from years 2011 to 2020 is **20.739billion$**.

In addition to that, it is a good idea to keep in mind that the current wind power plants are capable of working up to 40 – 50 years. Although these wind power plants will have very high costs at beginning such as the transportation, availability of materials, building and utilizing the national grid, wind prediction, research and engineering, it is possible to credit these costs and profit every year; definitely becoming an essential part of nation's electricity supply for the next decades. In the long run, it will provide much cheaper electricity for households and industry in east Anatolia regions which also will increase the investments on industry and employment opportunities and as a result, decreasing the major sociological problems in Turkey, such as terrorism.

For basic feasibility analysis the most important data that should be focused on is the cost of wind turbines for all the wind power plants designed in chapter 3. One advantage of wind power is that the price for generating electricity does neither increase nor decrease. Fossil fuel energy resources such as natural gas, coal or fuel oil however will eventually increase no matter what since those resources will only be enough for the next 60-80 years. Therefore having wind energy production facilities might require plenty of investment at the beginning but will pay off eventually and will be stabilizing electricity prices, depending on the amount that it compensates for fossil fuel energy production.

On a scale of 150 kW to 600 kW turbines, the prices of turbines triple rather than quadruple. 600kW wind turbine does not have too much price difference, compared to 150 kW turbine. The parts, electronic equipment, safety features are roughly the same. The ranges for +1000 kW machines are very high. The reason for that is to find a machine which is optimized for any particular wind climate. Average price for the modern wind generators are around $1000 per kW electric power installed.

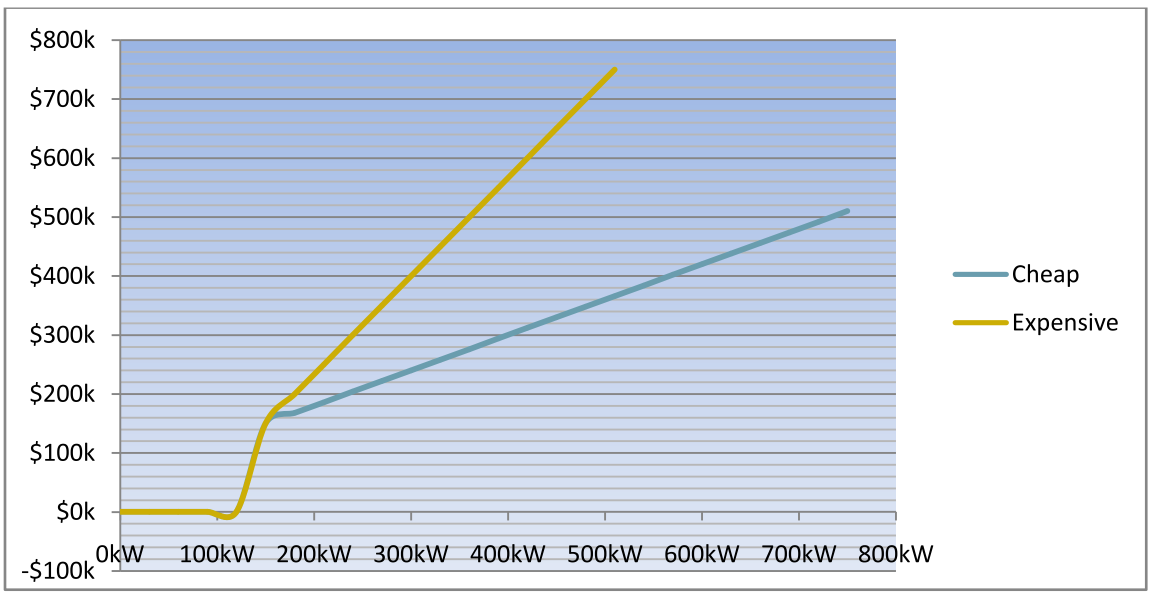

FIGURE 68-WIND TURBINE COSTS

For the particular wind turbines that were used throughout Turkey are Enercon E-48 which costs around €650,000 per unit. In previous chapters it is stated that 9364 turbines will be used to have an output of 2489.43MW. Total costs for all of the towers are:

$$C_{turbine} \ x\ Amount \times \alpha = C_T \quad (13)$$

Where,

$C_{turbine}$= Cost of each turbine in Euros. (€)

C_T=Total Cost ($USD),

α = Currency Exchange rate from Euros to $USD. (average of 1.4 for year 2007)

$$640{,}000 \times 9364 \times 1.4 = \sim 8.4 \text{ billion } \$$$

The costs of such wind farms should also consider very high amounts of transportation and building costs. Especially in the Eastern side of Turkey where Hatay and Kayseri is located, land structure includes plenty of mountains, hills and narrow roads will be a great issue and might slow down the construction rate which also increases the expenditures. In addition to this cost one should also include the grid stability engineering costs. As stated before, wind farms are not a constant and reliable method of energy production and these facilities might cause unexpected fluctuations, frequency changes or blackouts in the overall electrical grid system which is very dangerous for the nation.

The reasons stated above shows that the wind farm costs will be higher than 8.4 billion$ probably around twice or three times, depending on plenty of factors which are way beyond this project's level of detail. However, it can be seen that even having an overall cost of 10-20 billion$ will be worth spending since the amount of money saved until 2020 will be around 20 billion$ just by substituting natural gas with wind energy. This means that in less than or up to 10 years, these wind farms will start to help Turkey's budget for energy and will help regulate the rising electricity costs.

CHAPTER 5-SOCIAL AND ENVIRONMENTAL EFFECTS OF WIND POWER PLANTS

SOCIAL AND ENVIRONMENTAL EFFECTS

It is a widely accepted notion that the climate change will have a devastating impact on Earth unless an action towards using renewable energy sources is taken. The idea of using wind energy is great and acceptable by many people, but when it comes to the real project in a local area, people don't want it. The problem of "Not in my Back Yard", NIMBY occurred. It is not only for the wind turbines it is also for the new highways, bridges, tunnels, hospitals, airports, nuclear power plants, and other energy generating plants.

Most common threat to general acceptance of wind farms today stands to be the resolute arguments of `yes, but not in my backyard`. This very infamous contradiction undermines the hard work and effort put in trying to find a mutual aesthetic value for the wind farms in general. Even though the need for renewable energy sources is clear and the need for a balance between technology and nature is commonly accepted as a fact, NIMBYism is the universal reaction when individual opinions of beauty and order comes first.

Deep beneath the NIMBY reaction lie the personal thoughts of balance and personal needs to control the very immediate environment of living. In this sense, order and control is a very formidable obstacle to change, which is the mostly given opposition to wind farm installations. *Parochialism*, selfish pettiness and narrowness as of interests, opinions or views, is found out to be the most dominant element for NIMBYism, however; overcoming parochialism is not as easy as understanding it. Personal benefits of NIMBY people often deny other local and communal benefits of the wind farm as a whole.

NIMBYism is a very unbalanced, almost anarchic point of view that can be seen in almost any area where there is a confrontation between the public and the industry. Overcoming the barrier of NIMBYism require wise negotiations of trade-offs between sides.

Like any other machinery, wind turbines have both advantages and disadvantages to the environment and people:

- Visual Impacts
- Noise
- Animal fatalities
- Shadow
- Electromagnetic Interference

VISUAL IMPACTS

`Beauty is in the eye of the Beholder` is commonly said and used for subjective matters and this claim often holds true in humanity`s perception of art. Everyone has its own beliefs of aesthetics and beauty in a community, which directly affects how well or how bad a novel foundation for the good of the community will be received by all. In the case of wind turbines, beliefs tend to polarize into `great marvels of technology` and `hefty steel rods of landscape litter`.

Many assumptions regarding wind turbines state that turbines should harmonize well with their surrounding nature and blend with it as much as possible to minimize obtrusiveness. As mentioned earlier, wind turbines generally place an opinion on every spectator`s mind. Few spectators of these foundations remain silent. Some find them to be absolutely fascinating pieces of modern technology whereas others consider them to be metallic junks.

Opposing factions of the wind turbine aesthetics usually go down the timeline and support 17th century Dutch wind tower style with its red tile tower and canvas `blades` as being productive and eye-pleasing. However, they find the modern fiberglass bodied white towers more of a disturbance rather than an enhancement among the barren hilltops they are installed on.

One thing is clear about the wind turbines and that is they somehow evoke emotions in who sees them.

AESTHETICS OF WIND FARMS

To improve public acceptance of wind farms as a whole, wind energy industry should agree on the components of sustainable aesthetic. Main question to be considered here is `What is culturally acceptable? ` In order to determine a general sense of reaction from the public, there are three ground rules to be taken into consideration:

1. Quality, beauty and ugliness are reflections of personal taste,
2. Landscape is generally viewed in a `romantic` fashion resulting in a more desirable landscape of past rather than present.
3. Local views belong to local residents, local history and local memories.

For all people, perception is landscape and rural scenery is reactive to cultural, social, political and economic factors. Therefore, aesthetics for wind farms should include these factors in its body to maximize wind farm`s chances of acceptance. Moreover, each wind farm installation site will require further specific land measurements and specific background adjustments, resulting in consideration of local factors. Hence it is seen that determining aesthetic values for wind turbines in particular and wind farms in general need both communal consideration and specific local consideration. The complexity of this task implies the very rule of subjective perception: `universal aesthetic which can be accepted by all people cannot be devised. `

- Wind turbines are substantial vertical structures that are not easily assimilated, if at all, in any landscape.
- Wind turbines involve rotational movement in an otherwise motionless landscape which distracts and greatly increases their visibility from distance.
- Wind turbines, unlike most other forms of development in the countryside, have an undeniably positive symbolic value related to the generally held belief that they are a non-polluting form of energy generation.
- From an aesthetic point of view, using very large scaled turbines might be an advantage in the landscape. They have lower rotational speeds than the smaller turbines. They do not attract human eye, but fast moving objects usually do.
- Geometrically placed wind turbines do not attract eye even though they have very large scales. In the contrary, non-geometrically placed sites fatigue the eye and also they make visual pollution on that region.

FIGURE 69-ELEGANTLY PLACED WIND OFF-SHORE WIND TURBINES

FIGURE 70-WINDFARM CREATING A VISUAL POLLUTION

As for the harmony with the environment, the paint of the wind turbine tower is painted to match with the surroundings.

Wind turbines on the island of Gotland in Sweden (Figure 69) are a good example of Wind turbine placement and art. The grey paint on the turbines makes them blend well into the landscape.

FIGURE 71-WINDFARMS IN LOW POPULATION AREA

Another interesting and colorful example of wind turbines is given in Figure 72. The towers are illuminated in different colors at night to make the region look better and make the turbines visible as a caution.

FIGURE 72-ILLUMINATED WIND TURBINES

There are some examples of the visual effects of the wind turbines for its surroundings. People are worried about the wind turbine effect on tourism which is a big fact that affects the region's economy. People who would rather not live near wind power plants often raise this concern with respect to new wind project proposals.

There is no evidence that wind farms reduce tourism and considerable evidence to the contrary. For example, in late 2002, a survey of 300 tourists in the Argyll region of Scotland, noted for its scenic beauty, found that 91% said the presence of new wind farms "would make no difference in whether they would return.

"Similar surveys of tourists in Vermont and Australia have produced similar results. Many rural areas in the U.S. have noted increases in tourism after wind farms have been installed, as have scenic areas in Denmark, the world's leader in percentage of national electricity supplied by wind. Other telling indicators: local governments frequently decide to install information stands and signs near wind farms for tourists; wind farms are regularly featured on post cards, magazine covers, and Web pages"

Another big issue about the wind turbines is water usage and relatively, water pollution. Other than some energy production types wind energy has the less water consumption and has no pollution effects on the water. The Meridian Corp.'s estimations is seen on the Figure 73.

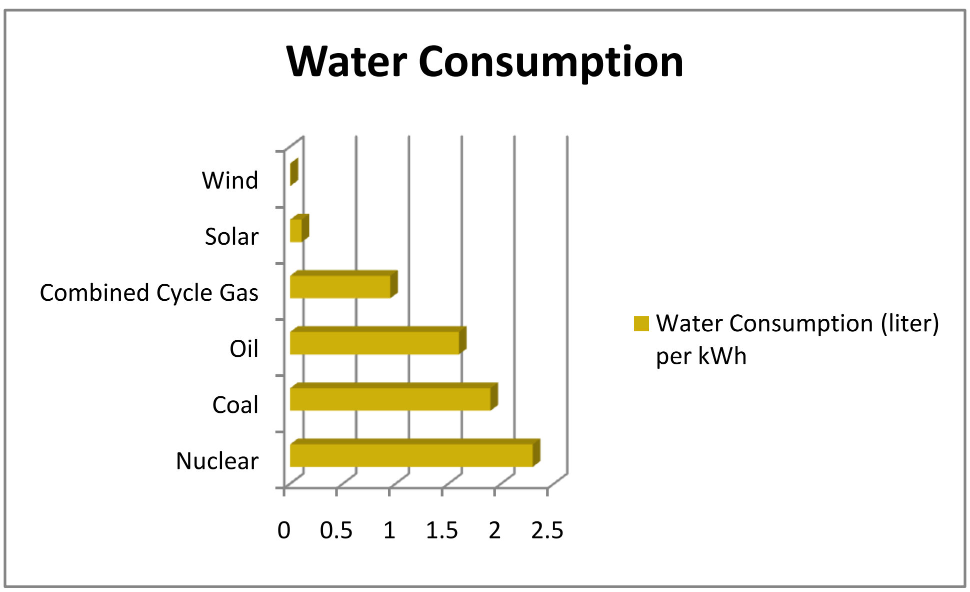

FIGURE 73- WATER CONSUMPTION

ANIMAL FATALITIES

Birds and bats and other avian animals occasionally collide with the wind turbines, as they do with other structures such as vehicles or buildings. Detailed studies are made by NWCC (National Wind Coordinating Committee) including all the wind farms in the USA. They use an estimation of 200-500 million mortalities per year and found that the fatalities caused by the wind turbines are 0.01 percent to 0.02 percent which means 1 to 2 out of every 10,000 deaths.

Communication tower fatalities make up to 1-2 percent which means1 to 2 out of every 100 deaths.

. This adds to 4 million annual avian fatalities due to collisions with the communication towers. One other estimation is for the buildings which makes to 25-50 percent of the collision fatalities. This adds to 98 million of deaths. There are 60 million fatalities caused by the vehicle collisions which make 15-30 percent of the total estimated collision fatalities. Transmission line collision fatalities are around 10,000 to 174 million and this wide range makes the estimation extremely difficult to quantify the percentage of total fatalities. The chart is seen on Figure 74.

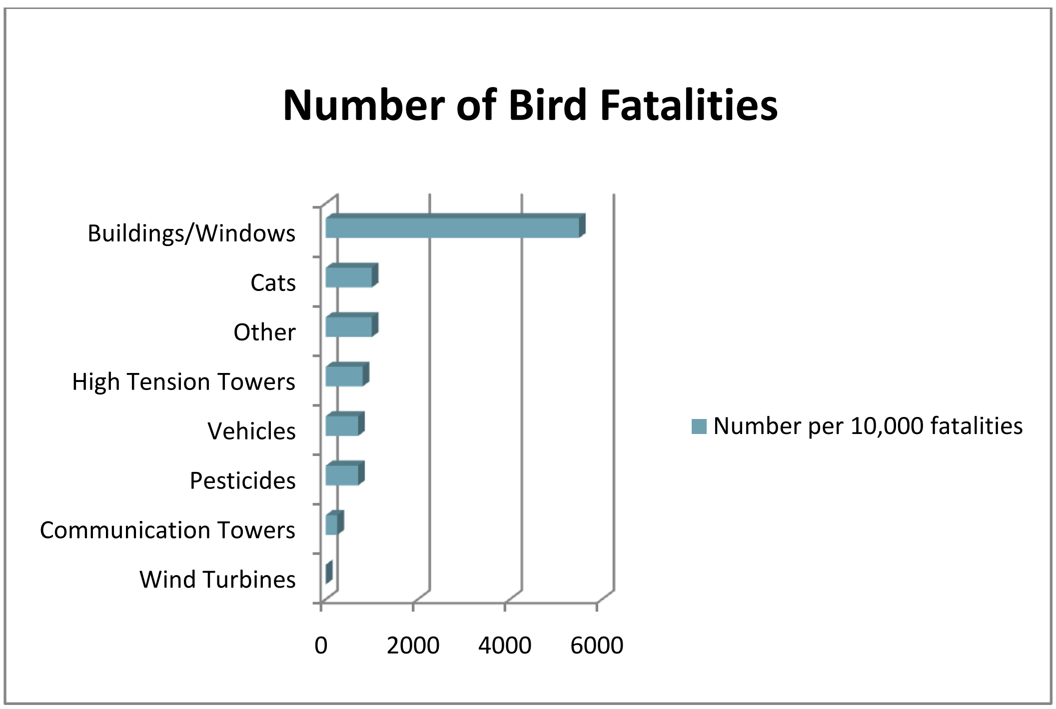

FIGURE 74- NUMBER OF BIRD FATALITIES

Wind turbines and wind energy will develop very extensively in the future but bird deaths from the turbines are very unlikely to reach 1% of those other human related sources which include hunters, house cats, buildings and automobiles. Wind power constructions are quite small in this bucket. Still, there are some areas that shelter endangered species because of that reason the wind industry is cooperating with the environmental groups, federal regulators and other interested parties to develop methods of measuring and mitigating wind energy's effect on birds.

Wind energy might have some negative effects on the birds and other wildlife. Wind turbines fragment the habitat, both through construction and operation of the turbines themselves. Also, Transmission lines and service roads have an impact on the wildlife.

"Birds are seldom bothered by wind turbines, however. Radar studies from Tjaereborg in the western part of Denmark, where a 2 megawatt wind turbine with 60 meter rotor diameter is installed, show that birds - by day or night - tend to change their flight route some 100-200 meters before the turbine and pass above the turbine at a safe distance.

In Denmark there are several examples of birds (falcons) nesting in cages mounted on wind turbine towers.

The only known site with bird collision problems is located in the Altamont Pass in California. Even there, collisions are not common, but they are of extra concern because the species involved are protected by law.

A study from the Danish Ministry of the Environment says that power lines, including power lines leading to wind farms, are a much greater danger to birds than the wind turbines themselves.

Some birds get accustomed to wind turbines very quickly; others take a somewhat longer time. The possibilities of erecting wind farms next to bird sanctuaries therefore depend on the species in question. Migratory routes of birds will usually be taken into account when sitting wind farms, although bird studies from Yukon, Canada, show that migratory birds do not collide with wind turbines"[15]

NOISE PROBLEM

It is evident that a mechanical device creates a noise during operation and a wind turbine is no different. The noise was a big problem back in 80’s. During that time there are some turbines that are quite noisy and Could even annoy dwellers far away.The noise problem attracted attention of some environmental groups and authorities and also wind turbine industry. As a result of the new designs, modern wind turbines are much quieter than before. There are three types of noises that wind turbines generate. They are tonal, broadband and low frequency tonal noises have discrete frequencies; broad band noises have continuous frequency of 100 Hz and low frequencies have a range between 20-100 Hz. The magnitude of the noise can be expressed as sound pressure level, dB. There are two types of noises that wind turbines create.

- Mechanical Noise
- Aerodynamic Noise

The mechanical noise is created by the relative motion of the components of the wind turbine such as the gear box, generator, yaw motors, cooling fans, hydraulic pumps and other accessories. When a 2MW wind turbine is examined, it has been found that noise emission from gearbox is around 97.2 dB, generator is around 87.2 dB and auxiliary components are around 76.2 dB.

If the design of the components or the turbine changes, it affect directly the noise level. Generally, mechanical noises are at the tonal tone.

Aerodynamic noises are emitted when the flow of air passes through rotating blades.

. When the blades of the turbine turn, the flow of the air around the blades creates aerodynamic noise. When the blades interact with the air stream, a number of complex flow phenomena occur around the blade. The aerodynamic noise is generally broad band. There are some amounts of low frequencies and even there are some tonal components. Aerodynamic noise emitted by a 2MW tower is around 99.2 dB.The shape of the blades, speed ratio, pitch settings, trailing edge thickness, blade surface finish and twist distribution are some of the factors determining the aerodynamic noise.

Humans can hear frequencies between 20 Hz to 20 kHz. Maximum level of the human tolerance to noise is 140 dB. However, this might change From person to person.

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The estimated sound pressure level, dB can be found with the following equation:

$$L_P = L_W - 10 \times \log_{10}(2 \times \pi \times R^2) - \alpha \times R \tag{14}$$

Where,

L_P is sound pressure (dB)

R is distance from the wind turbine (m)

L_W is radiating noise (dB)

α is sound absorption coefficient.

For example, a 50 m turbine generating 104 dB of noise will be heard 49 dB from 200m.

Noises from the wind farms are not a big issue if the residential areas are not very close to them. 55 dB of noise is heard from a wind farm 100m away. That is equal to a car's noise which is passing with a speed of 40mph. Engineers generally design wind farms with a minimal distance of 350 m to any residential area. At 350 m the noise of a 2MW wind tower is 43 dB.

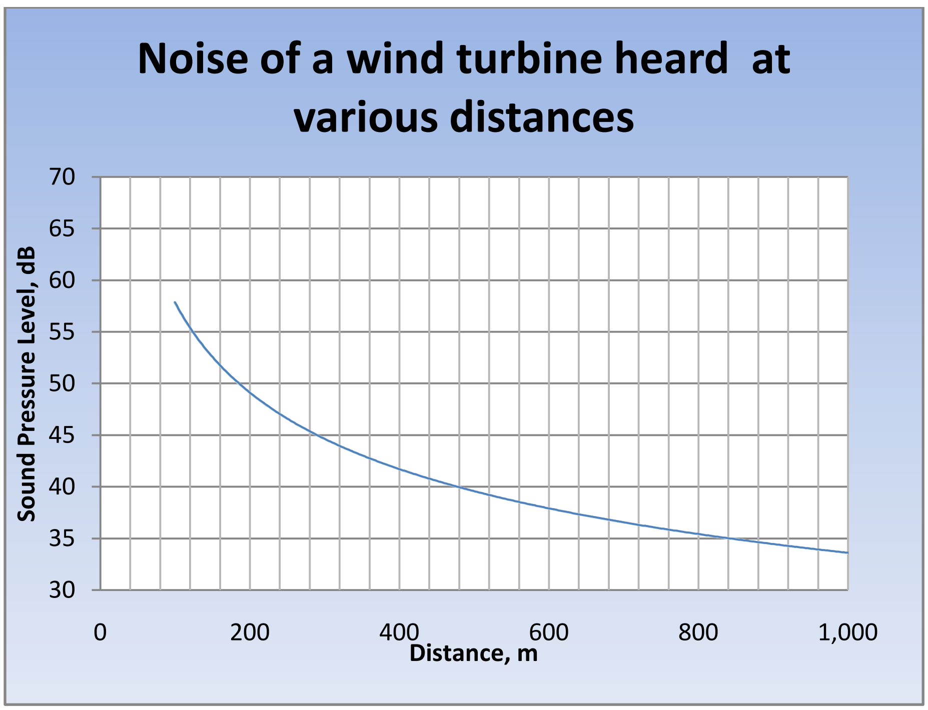

FIGURE 75-NOISE OF A WIND TURBINE HEARD AT VARIOUS DISTANCES

According to the World Health Organization recommendations (WHO), the noise level should not be more than 40 dB in a residential area. Some of the countries have strict rules and regulations for the noise level. This limit changes from country to country. In Sweden highest permissible noise level for wind turbines is 40 dB, in Denmark, it is 45 dB outdoors and 40 dB indoors, in Germany the noise level in residential areas is 50 dB in day time and 40 dB at night. Netherlands follow a more scientific approach.

At night the noise level changes with the wind speed starting from 40 dB at 1m/s to 50 dB at 12m/s. At day time limit is 50 dB to 45 dB.

As seen from the examples, noise pollution from the wind turbines is not a big issue. In most of the cases the noise from the wind turbines does not exceed the limits. Also, the information from a study made in Denmark, Germany and Netherlands shows that only 6.4% of the residents get disturbed from the sound of the wind turbines. With the new generation wind turbines, noise pollution problem will be far less of an issue.

ELECTROMAGNETIC INTERFERENCE

Experiences show that wind turbines can affect the performances of air traffic and air defense radars. As wind turbines becoming larger and getting made of more frequency reflective materials, nature of potential threat wind turbines pose to radar devices increase This trend will increase the levels, but not change the nature, of the problems turbines potentially cause to radars.

Turbines cause two principal effects: Doppler modulation of the reflected signal at frequencies similar to those from aircraft and very high potential reflection levels causing limiting and numerous other effects in the radar signal processing.

Very large reflected signals can, in certain sets of circumstances, cause loss of radar performance which reduces the ability of the radar to detect aircraft. The severities of these effects depend on a complex set of circumstances and will vary according to the internal design of the radar itself. Overcoming this problem is a matter of internal design changes that would be subject to an evaluation of the operating circumstances of radar in a particular situation with regard to proposed turbine installations

Radars often incorporate Doppler filters that reduce signals from targets that are not moving. These enhance the signals from moving objects so that they can be more clearly seen over stationary ground objects, terrain and sea. Because of the nature of the movement of turbine blades, these filters will pass their signals causing the radar to present the Air Traffic Controller with false information.

Adding plot filters to the output of the radar can successfully eliminate this second effect. These filters have recently been developed and proven for use in military systems.

This study concludes that radars can be modified to ensure that air safety is maintained in the presence of wind turbine farms. Individual circumstances will dictate the degree and cost of modification required, some installations may require no change at all whilst others may require significant modification.

With the correct knowledge of the design and manufacture of a particular radar, and the configuration used in a particular situation, these issues can be investigated and the likely success of a modification can be established at the planning stage, allowing the stakeholders to proceed with confidence in the outcome.

CONCLUSION

Turkey has plenty of great natural resources. Geographical location of Turkey is also a great advantage, especially its distance to industry demanding countries, European Union, Arabic states. In addition to that, climate is a varying factor depending on the landscape. Three sides of Turkey is surrounded by Mediterranean, Black and Aegean sea with the warm and nice weather and good amount of stable wind speeds. However, to use all these advantages, Turkey needs energy. Any country that cannot produce its own energy cannot improve and will always be dependent on other countries; will lack freedom. As seen in this project, it is shown that Turkey has plenty of renewable energy resources which are still not utilized. This project proves that wind energy is one of those alternative renewable energy resources which help Turkish economy and development in the following years. Since wind energy is not a stable electricity source, it requires other sources of electricity production investments to different energy resources. In addition to that, the demand of Turkish Republic is much more than the amount that can be produced by wind energy. On the other hand, it is a free energy resource once all the investments are completed. Price of wind does not fluctuate and by the technological advancements in wind power engineering, repair costs, and efficiency levels (increased up to 33% compared to around 15%, 20 years ago.) it is a great way of producing energy.

In this project, only one type of wind turbine at height of 70m is used just to show the geographical advantage of Turkish Republic for wind energy. As a result, it was possible to produce annual energy of **21,807GW/year** from a total wind power plant area of **618.35**km^2 which corresponds to a **35.26GW/year** per **1** $\mathbf{km^2}$. Considering the fact that it is possible to produce such energy for at least 30-40 years with today's technological achievements, it is certain that wind power plants pay back every penny that is spent to build them.

Unfortunately, there are some disadvantages of wind power plants to the civilization which were discussed in chapter 5. However, global warming, energy deficit are very serious problems for the world and civilization. Wind energy will reduce global warming if substituted for fossil fuel resources or nuclear power plants. (Nuclear power plants heat up the rivers or water resources in order to maintain the ideal temperature inside the reactor)

To sum up this project, it is possible to say that there are many engineering details missing. For a wind power engineer, the analyses that were done in this project will seem vague and incomplete. In addition to that, the knowledge of the terrain used for wind farms were limited to visual programs. Also there it is nearly impossible for many people to determine the feasibility costs without a good amount of construction engineering, geography knowledge and experience. National grid, transmission line improvements, wind power production analysis and electricity regulation are another analysis that should have feasible results before the beginning of construction. However, aside from all of these negative sides, this project does prove the worth of wind power. Predictions, analyses might be different but the results in general will be the same. Numbers, costs can change but the goal of this project will be achieved no matter what. The economical analysis and advantages of wind power will be achieved. Finally, this project proves that wind power plants will help Turkish economy and the future energy deficit and will be worthwhile to any private investors or the government itself in the long run.

APPENDIX A: THERMODYNAMIC EQUATIONS RELATED TO WIND ENERGY

Wind turbines are essentially thermo-dynamical control volumes just like every other modern engineering applications today, which means they all can be simplified into input and output problems. In the case of wind turbines, this simplification is decreed by the first law of thermodynamics: Energy is conserved within a control volume.

First law of thermodynamics is expressed as below;

$$\dot{Q}cv, net\ in - \dot{W}cv, net\ out = \dot{m}[\Delta H \ + \ \Delta\left(\frac{v^2}{2}\right) + \ g\Delta(h)] \tag{1}$$

Where,

$\dot{Q}cv, net\ in$ is time derivative of net heat flow into the control volume. (J/s)

$\dot{W}cv, net\ out$ is the time derivative of net work done by the control volume. (J/s)

$\dot{m}$ is the mass flow into the control volume (kg/s)

ΔH is the change in enthalpy of the control volume (J/kg)

$\Delta\left(\frac{v^2}{2}\right)$ is the change in velocity squared of the control volume (m^2/s^2)

g is the gravitational acceleration (m/s^2)

$\Delta(h)$ is the change in altitude of the control volume (m)

This formula is the general case of conservation of energy, however for more detailed process; a look at the `kinetic energy correction factor` for non-uniform velocities of turbulent flow is required since velocity profile is not linear.

Kinetic energy equation for non-uniform turbulent velocities is given as;

$$\int_{A-}^{A+} \frac{1}{2} v^2 \rho v dA \ \equiv \ \dot{m}\alpha\, v^2/2 \tag{2}$$

Where,

α is the kinetic-energy correction factor

The kinetic energy correction factor for non-uniform turbulent velocities can be computed by the following formula;

$$v(r) = \ a[1 - \left(\frac{r}{R}\right)]^{1/n} \tag{3}$$

where,

n is the exponential factor of the curvature of the velocity profile.

For turbulent flows α is relatively small (<10%), therefore correction can be omitted, whereas for laminar flows α is 2.0 (200%) and cannot be omitted.

From the general energy conversation formula, terms that are zero must be cancelled out to simplify things a little bit. For the unsteady flow of wind into the control volume, which is the wind turbine, Heat (Q) and Work (W) done are considered zero. Wind enthalpy doesn't change with wind velocity, therefore it is also taken to be steady and potential energy difference from the top of the rotor to the bottom of the rotor is neglected here for theoretical simplicity. Hence;

$$\frac{dEcv}{dt} = \dot{m}[\Delta(ke)] = \dot{m}v^2/2 \tag{4}$$

where

$\dot{m}$ is the mass flow into the system which can also be found from the equation:

$$\dot{m} = \rho A v \tag{5}$$

Finally there is an equation for the power gathered from the wind per time;

$$P = \rho A v^3/2 \tag{6}$$

APPENDIX B: SHADOW FLICKER

The shadow flicker is the on-and-off effect of a shadow caused when the sun passes behind the rotor of a wind turbine. Like any other tall structures, wind turbines cast shadow when the sun is visible. Rotating blades causes shadows which alternate light and dark shadows to be cast on roads or nearby premises, including the windows of residences, resulting in distraction and annoyance to the residents. A related phenomenon, strobe effect, is caused by the chopping of sunlight behind moving blades, similar to the effect of the setting sun behind trees when driving along a roadway in the winter. Both of these phenomena are factors in the visual impact of a wind turbine project, and some argue that they are a threat to health and safety. They could also be considered an annoyance to nearby property owners.

Sources of Flicker	
Source	Flicker Rate
Florescent lights	120 Hz
Computer screens	75 Hz
Televisions	60 Hz-100Hz
Vehicle turn signals	1-3 Hz
Wind Turbine Shadow	5-12.5 Hz

TABLE 19 – SOURCES OF FLICKER

Human eye can notice flickers up to about 50 Hz. above 50 Hz, the brain's response to the flash lasts longer than the flash itself. Frequencies between 10-25 Hz cause problems like eye strain, headaches, nausea, seizures. These effects may vary with the prominence, distance and color. One of the major problems for the shadow flickers is photosensitive epilepsy.

Photosensitive epilepsy is the name given to epilepsy in which all, or almost all, seizures are provoked by flashing or flickering light, or some shapes or patterns. Both natural and artificial light may trigger seizures. Various types of seizure may be triggered by flickering light. In photosensitive epilepsy, hertz (Hz) refers to the number of flashes or flickers a second. When talking about televisions or computer screens, hertz refers to the rate the scanning lines 'refresh' themselves. Most people with photosensitive epilepsy are sensitive to 16-25 Hz, although some people may be sensitive to rates as low as 3 Hz and as high as 60 Hz.

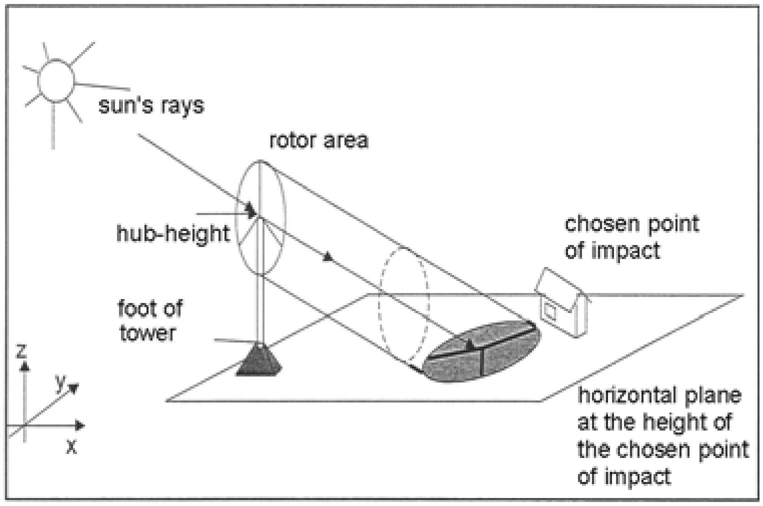

FIGURE 76- TYPICAL SHADOW EFFECT OF A WIND TURBINE ON THE LAND

Before building a wind farm there are few criteria and calculations to make to predict shadow effects:

Inputs:

- Turbine Location
- Potential receptor location
- Sun’s movement in the area of construction
- Hub height
- Rotor diameter
- Wind direction frequency distribution
- Sunshine hours (average)

Outputs:

- Areas in shadow

Estimated time receptor will be affected by flickers.

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