POTENTIALS OF WIND POWER IN TUNISIA

Bahloul Mariem
Trainee
17 June 2019
Title: Potentials of wind power in Tunisia

Author: Mariem Bahloul

Nationality: Tunisian

Period at Folkecenter: March 2019 – June 2019

Abstract of the work:

Wind energy is one of the fastest growing sources of energy that have proved its efficiency in the recent years in different parts of the world that’s why I have chosen to learn more about this source of power and then apply what I have learned in my country to help develop the renewable’s sector therefor "the potentials of the wind power energy in Tunisia" was my main topic. I started by learning more about the wind turbines in general; the main components, the different types, different sizes, the latest technologies, the availability in the market… then I focused on the conditions that allow us to harvest the wind power efficiently such as the positioning of the wind turbine, the wind speed, the suitable size or height, the cost… Finally I moved to the case of Tunisia analyzing the current energy situation and its renewable energy sector as a first step and then analyzed the weather condition to know whether or not we can install wind power plants in the country and the answer was positive; there were specific regions where the wind conditions are favorable so I chose a small village and did a case study about a possible wind farm installation in it, estimating the costs and the possible energy generation.

Number of pages (excluding appendixes): 30

Topic: Wind power

Keywords: wind, power, potentials, Tunisia

This report is part of Nordic Folkecenter’s collection. More reports can be found on www.folkecenter.net
# Table of Content

List of Figures ................................................................. 4
List of Tables ................................................................. 5

1 Introduction ........................................................................ 6

2 Wind knowledge: ............................................................... 7

2.1 Wind turbines: .............................................................. 7

2.1.1 The main components: ............................................... 7
2.1.2 The working principle of wind turbines: ...................... 12
2.1.3 Key factors for efficient power production: ................. 13
2.1.4 The different types of wind turbines: ......................... 17
2.1.5 On-grid and off-grid solutions: .................................. 18
2.1.6 Advantage and disadvantages of wind energy: ............ 19

2.2 Onshore wind Turbines: .................................................. 20

2.2.1 Onshore small wind: .................................................. 20
2.2.2 Onshore big wind: .................................................... 21

2.3 Offshore wind turbines: .................................................. 22

2.3.1 Fixed foundation offshore wind turbines: .................... 22
2.3.2 Floating offshore wind turbines: ................................ 24
2.3.3 Advantages and challenges of offshore wind turbines: .. 24

2.4 Carving wooden wind turbine blades: ............................ 26

3 Potentials of Wind energy in Tunisia: .................................. 30

3.1 Current situation of energy in Tunisia: ............................ 30

3.2 Future of renewables in Tunisia: .................................... 31

3.2.1 Penetration of the renewables in the country: ............... 31

3.3 Case study of Matmata: .................................................. 32

3.3.1 Analyzing the location: .............................................. 32
3.3.2 Estimated Energy production: ................................... 33
3.3.3 Estimated Cost: ....................................................... 34
3.3.4 Average life of a wind turbine: ................................... 35

4 Conclusion .......................................................................... 36
List of Figures

Figure 1: Nacelle ......................................................................................................................... 9
Figure 2: Hub ............................................................................................................................... 9
Figure 3: Drive shaft ................................................................................................................... 10
Figure 4: Gearbox ...................................................................................................................... 10
Figure 5: Generator .................................................................................................................... 10
Figure 6: Anemometer ............................................................................................................... 11
Figure 7: Wind vane .................................................................................................................. 11
Figure 8: A simplified scheme of wind turbines harvesting kinetic energy ............................... 12
Figure 9: Wind Power vs. Tower Height ..................................................................................... 14
Figure 10: Turbine height and clearance requirements ............................................................. 15
Figure 11: Disturbed air around obstacles ............................................................................... 15
Figure 12: Wind speed over a ridge .......................................................................................... 16
Figure 13: Turbulence on the lee side of a cliff ...................................................................... 16
Figure 14: Grid-connected system .......................................................................................... 18
Figure 15: Hybrid power system .............................................................................................. 18
Figure 16: Small wind turbine in a yard ................................................................................... 20
Figure 17: Tripods foundation for offshore wind farms ............................................................ 22
Figure 18: Progression of expected wind turbine evolution to deeper water ........................... 22
Figure 19: Typical foundation types for offshore wind turbines ............................................... 23
Figure 20: Caption from the "wind turbine recipe book" ......................................................... 26
Figure 21: The selected piece of wood ...................................................................................... 27
Figure 22: Caption from the "wind turbine recipe book" ......................................................... 27
Figure 23: Pictures showing the progress of the wind blades .................................................... 28
Figure 24: Pictures showing the progress of the wind blades .................................................... 28
Figure 25: Wind blades being painted ...................................................................................... 29
Figure 26: Wind blades attached together ................................................................................ 29
Figure 27: Production mix 2014 In Tunisia ............................................................................. 30
Figure 28: Electricity production 2015 & repartition of STEG Electricity GWh ........................... 31
Figure 29: Average Wind power density in Tunisia ................................................................. 32
Figure 30: Average Wind speed in Tunisia .............................................................................. 32
Figure 31: Average Wind power density in Matmata ............................................................... 33
Figure 32: Average Wind speed in Matmata .......................................................................... 33
Figure 33: The surface that can be used .................................................................................. 33
Figure 34: The percentage on the total cost of the different components ............................... 34
List of Tables

Table 1: Different types of wind turbine’s towers ................................................................. 7
Table 2: Different types of wind turbine’s blades ................................................................. 9
Table 3: Modern and historical rotor designs ..................................................................... 17
1 Introduction

Ever since electricity was invented, it has been used all over the world and became one of the most important components that we use every single day. It is not only used for daily life activities, but also includes supporting many different industries, which one of the largest includes technology. If the idea of electricity and its creation did not happen, there would be no technology and life would remain the same.

Due to growing world population and increasing wealth, demand for energy, specifically electricity, is rising. The most commonly used source for electricity production today is coal; 41% of all electricity is produced from coal, according to the World Coal Association. Due to its high level of pollution and often miserable circumstances for miners, we can conclude that this is not a sustainable source for electricity. So a transition to clean resources of power is needed.

Fortunately, a clean energy revolution started taking place in the recent years, underscored by the investments of the different developed countries in the renewable energy sector. Renewable energy is now considered one of the fundamental premises for building a sustainable global society. Therefore, a truly sustainable energy source should not only be renewable, but also apply the principles of sustainability.

When looking at sustainable electricity resources, we commonly identify four: solar, wind, hydro and biomass. Wind energy is considered the second-largest and fastest growing source of renewable energy in the world, with an average annual growth rate of 25% over the last five years.

This is why I have dedicated this project to know more about this source of power and then estimate its potential in Tunisia. The first part will deal with wind energy in general and the latest wind technologies: different components of wind turbines, different types, the best conditions for an efficient wind harvesting, the different possible connections ... This knowledge was acquired during different activities; Researches online, industrial visits, conferences and workshops.

In the second part I will be analyzing the Tunisian energy situation; the current resources of energy, the challenges we are facing and the possibilities of renewable energy transition. A case study of a specific region in Tunisia will also be held at the end of the report to estimate the potential of a wind farm facility in the area and its potential production.
2 Wind knowledge:

2.1 Wind turbines:

A wind turbine is a device that converts kinetic energy from the wind into electricity. The blades of a wind turbine turn between 13 and 20 revolutions per minute, according to their technology, at a constant or variable velocity, where the speed of the rotor varies according to the speed of the wind in order to obtain a better yield. Wind turbines have an average life of over 25 years, although the most common accounting criterion is defined for a period of 20 years. The evolution of wind technologies has led to an increase in the durability of wind turbines.

2.1.1 The main components:

2.1.1.1 Tower:
The tower supports the nacelle and rotor hub at its top. A tower can be made from different materials such as tubular steel, concrete, or steel lattice.

<table>
<thead>
<tr>
<th>Different types of wind turbine towers</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tubular Tower:</strong></td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>A tubular tower is made from rolled steel flat welded together with top and bottom flanges. It is then sprayed with several coats of weatherproof paint. It has access to the power cables and the yaw mechanism through the vertical ladders inside with two doors on top and bottom of the tower. On the outside of the tower there are also vertical ladders accessing the nacelle for maintenance and other checks.</td>
<td></td>
</tr>
<tr>
<td><strong>Lattice tower:</strong></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>A lattice tower can be built with perfectly shaped steel rods that are assembled to form a lattice. These towers are very solid, easy to transport and erect and not expensive to manufacture.</td>
<td></td>
</tr>
</tbody>
</table>
**Guyed wind tower:**
This type of tower is very strong and more economical if properly installed but it takes up more space around the tower for the guys.

<table>
<thead>
<tr>
<th>Guyed wind tower:</th>
</tr>
</thead>
<tbody>
<tr>
<td>This type of tower is very strong and more economical if properly installed but it takes up more space around the tower for the guys.</td>
</tr>
</tbody>
</table>

**Tilt up wind towers:**
This type of tower is used for consumer wind energy. These turbines have locking system; The turbine is locked during operation, but when repaired or maintained, it can be easily unlocked and lowered to the ground.

<table>
<thead>
<tr>
<th>Tilt up wind towers:</th>
</tr>
</thead>
<tbody>
<tr>
<td>This type of tower is used for consumer wind energy. These turbines have locking system; The turbine is locked during operation, but when repaired or maintained, it can be easily unlocked and lowered to the ground.</td>
</tr>
</tbody>
</table>

**Free standing tower:**
These can be used for small wind turbines with cautions.

<table>
<thead>
<tr>
<th>Free standing tower:</th>
</tr>
</thead>
<tbody>
<tr>
<td>These can be used for small wind turbines with cautions</td>
</tr>
</tbody>
</table>

### 2.1.1.2 Blades:
Wind turbine blades recover kinetic energy that comes from the wind and convert it into mechanical energy. They are connected to the rotor hub and can be made out of fiberglass-reinforced polyester or wood-epoxy.

Wind turbines can have one, two, three or multiple blades based on the construction but most of the modern HAWT have three blades while multiple-bladed concept is used in earlier days for pumping water and grinding etc.
2.1.1.3 Nacelle:

The Nacelle is a housing which contains all the essential components to operate the turbine efficiently. It is installed at the top of the tower and contains the gearbox, low- and high-speed shafts, the generator, the controller, and the brakes. A wind speed anemometer and a wind vane are mounted on the nacelle.

2.1.1.4 Hub:

A rotor hub is provided to connect the wind turbine rotor blade and the shaft. Its assembly consists of the hub, bolts, blade bearings, pitch system and internal elements. The rotor hubs are made from welded steel sheet, forged steel and cast iron. There are two types of rotor hubs: Hinge-less hub & Teetering hub.
2.1.1.5 Drive Shaft:

The drive shaft is a mechanical component made out of hard steel used to transfer rotational mechanical energy from blade hub to the generator to produce electricity. A wind turbine normally consists of two shafts:

**Main shaft:** It is connected between blade hub and the gearbox input and rotates at low speeds. It is also called as 'low speed shaft'.

**Generator shaft:** It connects the gearbox output to the generator input and rotates at a very high speed equal to the nominal power of the generator. So it's also called 'high speed shaft'.

2.1.1.6 Gearbox:

The gearbox is used in the wind systems to turn the low speed and high torque power that is coming from the rotor blade into high speed at low torque power that is then used to run the generator. It is installed between main shaft and generator shaft to increase rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm.

Wind turbine’s Gearboxes are made from superior quality aluminum alloys, stainless steel, cast iron etc...The various gear boxes used in wind turbines are:

1. Planetary Gearbox.
2. Helical Gearbox.
3. Worm Gearbox.

2.1.1.7 Generator:

The generator receives the mechanical output rotation energy from the gearbox via the generator shaft. It works according to the principle of “Faraday's electromagnetic induction law”, converting mechanical energy into electrical energy.
2.1.1.8 Anemometer:
Wind speed is very important for determining the power of the wind. The energy in the wind is directly proportional to the wind velocity so measuring wind speed is important for site selection and the device which is used for measuring wind speed is called anemometer. It is usually located on top of the nacelle.

2.1.1.9 Wind vane:
A wind vane is a device used to estimate the wind directions and communicate with the yaw system to orient the turbine according to the wind direction, in order to harvest the maximum amount of wind power. Wind turbines are oriented to downstream wind or upstream wind.

2.1.1.10 Yaw Mechanism:
The wind turbine yaw mechanism is used to turn the wind turbine rotor against the wind. Electric motors and gearboxes are used to keep the turbine yawed against wind. This can be also used as a control mechanism during high wind speeds.
2.1.2 The working principle of wind turbines:

1) The wind (kinetic energy) blows towards the rotor blades of the turbine.

2) The rotors spin around, catching some of the wind and rotating the central drive shaft that supports the blades. The outer edges of the rotor blades move faster than the central axle (drive shaft) that they're connected to.

3) Most large modern turbines have what is called “pitch control mechanism”; the rotor blades can pivot on the hub at the front to face the wind at the best angle (or "pitch") for energy harvesting. On big turbines, small electric motors or hydraulic cylinders rotate the blades back and forth under precise electronic control. On smaller turbines, the pitch control is often completely mechanical. However, many turbines have fixed rotors and no pitch control at all.

4) Inside the nacelle, the gearbox converts the low-speed rotation of the drive shaft (e.g. 16 revolutions per minute, rpm) into high-speed rotation (e.g. 1600 rpm). Fast enough to run the generator efficiently.

5) The generator that is behind the gearbox transforms the kinetic energy created by the spinning drive shaft and turns it into electrical energy. A typical 2MW turbine generator that is running at maximum capacity will produce 2 million watts of power at about 700 volts.

6) The Anemometers and wind vanes on the back of the nacelle measure of the wind speed and direction to orient the wind turbine.
7) A yaw motor is mounted between the nacelle and the tower to rotate the entire top part of the turbine (the rotors and nacelle), using the previous measurements, so the turbine can face the oncoming wind directly and capture the maximum amount of energy. There is also the brakes that can be applied to stop the rotors from turning if it's too windy or turbulent (for safety reasons) or during routine maintenance.

8) The electric current produced by the generator flows through cables that run inside the turbine tower.

9) A step-up transformer converts the electricity voltage to about 50 times higher so it can be connected efficiently to the power grid. If the electricity flows to the grid, it's converted to a higher voltage (130,000 volts or more) by a nearby substation, which serves many turbines.

10) The clean and green energy is then transmitted to different homes; No greenhouse, no gas emissions and no pollution is produced by the turbines.

11) Wind continues to bypass the turbines, but with less speed and energy and more turbulence (since the turbine has disrupted its flow).

2.1.3 Key factors for efficient power production:

2.1.3.1 Wind speed:

One of the key factors to consider when assessing the efficiency of a wind turbine for residential and industrial use is the quality of the wind in that specific area.

The average wind speed is crucial when deciding to install a wind turbine, as wind turbines will operate according to the average wind speed in the area.

2.1.3.2 Air density:

Power output is related to the local air density, which depends on the altitude, pressure, and temperature. For wind turbines, the air density is a key parameter when estimating wind energy, as the energy output from the wind turbine generator proportionally depends on this parameter: Dense air applies more pressure on the blades, which results in higher power output.
2.1.3.3 Positioning of the turbine:

2.1.3.3.1 Wind Power vs. Tower Height:

Height of the tower is an important in design of Horizontal Wind Axes Turbine. Because wind speed increases with height so taller towers enable turbines to capture more energy and therefore generate more electricity.

As a general rule, the output power of the wind system increases with the increase of height and the decrease of the turbulence in wind. The theoretical view of tower height versus power out is shown in the figure x.

Not just any wind will do, only air that moves uniformly in the same direction will make a good fuel for a wind turbine. Eddies, swirls or any type of ‘turbulence’ in general, is not good for the wind turbine performance: The rotor cannot extract energy from turbulent wind, and the ever-changing wind direction leads to excessive wear and premature failure of your turbine.

⇒ The conclusion is that the turbine must be high enough to catch the strong wind and avoid turbulent air.

The first important rule is that the height of the turbine should be at least 10 meters (+ the length of the blade) above the tallest obstacle (trees, house etc.).

Within a radius of 150 meters, with a tower height of at least 19 meters, if the obstacle is stronger than few trees (for example a whole tree line), a distance of more than 150 meters is required.

This should really be considered an absolute minimum for a wind turbine: 10 meters above an obstacle, there will always be some turbulence, so additional clearance is always desirable. Changes in the height of the obstacle must also be taken into account.

For example, if you have trees that can grow up to 20 meters high, use a 30-meter tower.

Generally, a 20-meter tower should only be used when the terrain is very flat, without obstacles in an extended area.
The second important rule to know is that the flow of air over any solid obstacle (such as the tree), creates a "bubble" of turbulent air twice the height of the obstacle, extending 20 times the height of the obstacle behind it.

Examples:

* A 10 meters high house disturbs the air up to 200 meters away.

* A 30-meter tree line disturbs the air up to 60 meters high at a distance of 600 meters.

⇒ As a conclusion, wind turbine should be located either upwind of the obstructions, or far enough downwind. Notice from the figure that preference should be given to a site upwind of obstructions.
2.1.3.3.2 Wind over Hills & Cliffs:

When it comes to wind turbines, the bottom of a hill, valley or ravine is always a bad place to put the turbine. The wind tends to slow down at the bottom of a smooth hill, and then accelerates as it goes up the hill, reaching about twice the wind speed at the top of the hill.

⇒ so if you have hills on your property, make sure you use this effect to your advantage.

The figure below shows this.

![Figure 12: Wind speed over a ridge](image)

For obstacles that are not smooth, like a cliff (a sudden elevation of the landscape), it’s a bit more complicated: Sharp edges create turbulence, as shown in the figure below. Although it seems that the wind is always blowing hard at the edge of the cliff, it can be very turbulent, making it a bad location for a turbine.

⇒ If you have a cliff edge on your property and want to use it to place your turbine, you still have to use a 20-meters tower to bypass turbulent air.

In the other hand, the lee side of a bluff object will always create a big turbulence, and the average wind speed will also decrease, leaving no energy for the wind turbine to harvest.
2.1.4 The different types of wind turbines:

Wind power has been used since man sailed into the wind, and various designs have been developed over the years. Here are some examples.

<table>
<thead>
<tr>
<th>Design</th>
<th>Orientation</th>
<th>Use</th>
<th>* Peak Efficiency</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savonius rotor</td>
<td>VAWT</td>
<td>Historic Persian windmill to modern day ventilation</td>
<td>16%</td>
<td></td>
</tr>
<tr>
<td>Cup</td>
<td>VAWT</td>
<td>Modern day cup anemometer</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>American farm windmill</td>
<td>HAWT</td>
<td>18th century to present day, farm use for Pumping water, grinding wheat, generating electricity</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>Dutch Windmill</td>
<td>HAWT</td>
<td>16th Century, used for grinding wheat.</td>
<td>27%</td>
<td></td>
</tr>
<tr>
<td>Darrieus Rotor (egg beater)</td>
<td>VAWT</td>
<td>20th century, electricity generation</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Modern Wind Turbine</td>
<td>HAWT</td>
<td>20th century, electricity generation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Blade Qty</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>43%</td>
</tr>
<tr>
<td>2</td>
<td>47%</td>
</tr>
<tr>
<td>3</td>
<td>50%</td>
</tr>
</tbody>
</table>
* Peak efficiency is dependent upon design; values quoted are maximum efficiencies of designs in operation to date.

### 2.1.5 On-grid and off-grid solutions:

Being connected to a local utility grid or not can make a significant impact on what type of wind turbine fits your location and here is the difference between the on-grid and off-grid situation.

**a) On-Grid:**

A house that is connected to a locally supplied power source is considered "On-grid". In this case, a power conditioning unit (inverter) making the output of the turbine electrically compatible with the distribution network, is installed. The turbine works alongside your utility company to power your home. When the wind does not blow, the utility supplies your electricity.

But when it's windy, your wind turbines work well to provide clean, quiet electricity. When generating more electricity than necessary, your meter can actually spin backwards allowing you to sell electricity back to the utility.

An on-grid system can be practical if the following conditions exist:

- You live in a windy area where the average annual wind speed is at least 4.5m/s.
- Utility-supplied electricity is expensive in your area.
- The utility requirements for connecting your system to its grid are not very expensive.
- There are possibilities to sell surplus electricity of wind turbines.

**b) Off-Grid:**

Systems that are not connected to a local utility supplier are referred to as “off-grid” systems.

To provide minimal interruptions in power to a remote home or business that is off-grid, the best solution is to use a hybrid system of solar panels and a wind turbine that complement each other. Whether the wind speed is low in summer while the sun shines or in winter when there is less light but more windy, the
system always works due to the alternating nature of peak operating times. In case of emergency, off-grid systems normally have an engine-generator on hand.

An off-grid hybrid system can be practical if:

- You live in an area with an average annual wind speed of at least 4.0m/s.
- A grid connection is not available or needs expensive extension to be made.
- You would like to reach energy independence from the utility.

### 2.1.6 Advantage and disadvantages of wind energy:

Like all other forms of renewable energy, wind energy has its fair share of pros and cons. For different reasons and circumstances, some renewable energies work better in different parts of the world. That's why it's important for consumers to know what suits their area the best.

**a) Pros:**

- Carbon dioxide emissions are very low (effectively zero after the construction of the turbines).
- No air or water pollution.
- No impact on the environment from mining or drilling
- The wind is free and completely sustainable. (unlike fossil fuels)
- Turbines operate almost anywhere in the world where it's reliably windy, (unlike fossil-fuel deposits that are only available in certain region)
- Unlike fossil-fueled power, the operating costs of wind energy are predictable years in advance.
- Avoid the risks associated with rising energy prices and the political instability of oil and gas supplies from other countries.
- With wind technology continuing to evolve, wind energy prices will become increasingly competitive with rising fossil fuel prices.
- New jobs will be created in construction, operation, and manufacture of turbines.

**b) Cons:**

- High initial cost (same for large nuclear or fossil fuel power plants).
- Economic subsidies are needed to make wind energy viable (like any other source of energy).
- Balancing variable wind energy with other forms of energy requires additional costs and is a bit complex.
- Upgrading the power grid and transmission lines requires additional costs, even though the entire system often benefits.
• Variable production. (Although this problem is reduced by the operation of wind farms in different areas and the use of interconnections between neighboring countries.)
• Total land area used is important (but at least 95% of wind farm land can still be used for agriculture and offshore turbines can be built at sea)
• It is not possible to provide 100% of a country's energy needs all year long, as do fossil fuels, nuclear power, hydroelectricity and biomass.
• People working in mining and drilling will lose their jobs.

2.2 Onshore wind Turbines:

2.2.1 Onshore small wind:

A small wind turbine is generally defined as a small-scale wind turbine producing less than 100 kW of electricity and designed to be installed in small farms or homes, either to reduce electricity costs or as a back-up power source.

Some small wind turbines can generate between 60,000 and 170,000 kilowatt hours per year at an average wind speed of about 14 to 22 kilometers per hour, that is enough to maintain 8 to 23 homes annually. The development of small wind energy projects has the major advantage of helping large wind farms overcome market barriers that will ultimately lead to their growth and lower energy costs.

Other that that, access to the national electricity grid is still impossible for millions of people around the world who are still living in isolated rural communities. Therefore, small wind turbines give a unique opportunity to enter an untapped market without harming the nature.

Figure 16: small wind turbine in a yard
2.2.2 Onshore big wind:

The rule of wind turbines is simple: Bigger is better. To be more specific, there are two solutions to produce more power from the wind in a given area.

The first is by using bigger rotors and longer blades to cover a larger area. This solution increases the capacity of the turbine and therefore, its total potential production.

The second is to make the tower higher, where the wind blows more steadily and the blades rotate constantly for longer periods. That increases “capacity factor,” of the the turbine. The amount of power it actually produces is relative to its total potential (How often it runs).

Here is the list of the 5 largest wind turbines installed so far:

1) MHI Vestas V164-9.5MW

<table>
<thead>
<tr>
<th>Power rating</th>
<th>Rotor diameter</th>
<th>Drivetrain</th>
<th>IEC Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5 MW</td>
<td>164m</td>
<td>Medium-speed geared</td>
<td>S</td>
</tr>
</tbody>
</table>

2) Siemens Gamesa SG 8.0-167 DD

<table>
<thead>
<tr>
<th>Power rating</th>
<th>Rotor diameter</th>
<th>Drivetrain</th>
<th>IEC Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 MW</td>
<td>167m</td>
<td>Direct drive</td>
<td>S (1B)</td>
</tr>
</tbody>
</table>

3) Goldwind GW154 6.7MW

<table>
<thead>
<tr>
<th>Power rating</th>
<th>Rotor diameter</th>
<th>Drivetrain</th>
<th>IEC Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7 MW</td>
<td>154m</td>
<td>Permanent magnet direct drive</td>
<td>I</td>
</tr>
</tbody>
</table>

4) Senvion 6.2M152

<table>
<thead>
<tr>
<th>Power rating</th>
<th>Rotor diameter</th>
<th>Drivetrain</th>
<th>IEC Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.15 MW</td>
<td>152m</td>
<td>High-speed geared</td>
<td>S</td>
</tr>
</tbody>
</table>

5) GE Haliade 150-6MW

<table>
<thead>
<tr>
<th>Power rating</th>
<th>Rotor diameter</th>
<th>Drivetrain</th>
<th>IEC Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 MW</td>
<td>150m</td>
<td>Direct drive</td>
<td>I8</td>
</tr>
</tbody>
</table>
2.3 Offshore wind turbines:

Since the construction of the first wind turbine in the late 1800s, traditional onshore turbines have dominated the market. However, recent technological advances have led this industry to consider setting up offshore wind farms.

Offshore wind energy or offshore wind energy consists of using wind farms built in water bodies, usually in the ocean on the continental shelf, to harvest wind energy to produce electricity. The wind speed is higher offshore than on the mainland. As a result, offshore wind power generation is higher by amount of installed capacity, and NIMBY* opposition to construction is generally much lower (NIMBY: is an acronym for the phrase "Not In My Back Yard" and it’s a characterization of residents’ opposition to a development project in their area)

Unlike the typical use of the term "offshore" in the marine industry, offshore wind involve inshore water areas such as fjords, lakes and sheltered coastal areas, deploying the usual fixed-bottom wind turbine technologies or the floating wind turbines in deeper-water areas.

2.3.1 Fixed foundation offshore wind turbines:

With the exception of a few pilot projects, almost all of the current operating offshore wind farms use fixed-foundation turbines. The fixed foundations of offshore wind turbines are underwater and are installed in relatively shallow waters up to 50-60 m.
Different types of underwater structures exist such as monopoles, tripods and sleeves, with various foundations in the sea bottom, including single or multiple piles, a base of gravity and caissons. Depending on the depth of the water, offshore turbines require different types of bases to assure stability. A number of different solutions exist so far:

- A monopile (single column) base with 6m diameter used in waters up to 30 m deep.
- Gravity base structures, used on exposed sites in water 20–80 m deep.
- Tripod piled structures, in water of 20–80 m deep.
- Tripod suction caisson structures, in water 20–80 m deep.
- Steel jacket structures, as used in the oil and gas industry, in water 20–80 m deep.

It is possible to make monopiles up to 11 meters in diameter and weighing 2,000 tons, but the largest so far weight 1,300 tons which is below the limit of some crane vessels that is estimated to be 1,500 tonnes. The rest of the turbine components are much smaller.

The tripod pile substructure system is a new concept developed to reach deeper waters, up to 60 m. This technology consists of three monopiles interconnected by a joint at the top. The simplicity of the installation is one of the main advantages of this solution: it consists in installing three monopiles then adding the upper joint.
2.3.2 Floating offshore wind turbines:

For sites that are deeper than 60 to 80 m, fixed foundations are neither economical nor technically practical, and a floating wind turbine anchored at the bottom of the ocean is required. Hywind is the world's first real-scale floating wind turbine, installed in the North Sea off Norway in 2009. Hywind Scotland, commissioned in October 2017, is the first operational floating wind farm with a capacity of 30 MW. Other types of floating wind turbines have been deployed and other projects are planned.

Building foundations at the base of the ocean is difficult, especially if the ocean is deep, then building a wind turbine over an underground base is also complicated.

If wind turbines could be built in a dry dock, then towed into place and anchored, yet still providing the same generation and durability characteristics as solid-based wind turbines would be very beneficial. Anchors and cables are easier. It’s still far from trivial to build a sustainable infrastructure in the middle of windy oceans. The energy in the big waves is huge and the salt water is one of the most hostile environments for existing machines but when you start seeing GW scale wind farms with 70% capacity factors capable of generating 6 TWH of electricity in a year, the complications seem worthwhile.

2.3.3 Advantages and challenges of offshore wind turbines:

a) Benefits:

- Offshore wind speeds tend to be faster than on land. Small increases in wind speed yield large increases in energy production: a turbine in a 15-mph wind can generate twice as much energy as a turbine in a 12-mph wind. Faster wind speeds offshore mean much more energy can be generated.

- Offshore wind speeds tend to be steadier than on land. A steadier supply of wind means a more reliable source of energy.

- Many coastal areas have very high energy needs. Half of the United States’ population lives in coastal areas, with concentrations in major coastal cities. Building offshore wind farms in these areas can help to meet those energy needs from nearby sources.
Offshore wind farms have many of the same advantages as land-based wind farms – they provide renewable energy; they do not consume water; they provide a domestic energy source; they create jobs; and they do not emit environmental pollutants or greenhouse gases.

b) Challenges:

All the time, money and energy that the company invest to the development the offshore wind farms is worthless if electricity cannot reach the continent's distribution grid. Subsea cabling can become the weak link in an offshore wind farm.

From what we have seen, here are the main cabling issues the offshore wind industry faces:

- **Changing ocean terrain**: The transmission cables can be buried as intended, but the underwater terrain can move in less than six months. The risk of damage and corrosion can also increase if underwater landslide exposes the buried cables.

- **Unpredictable weather**: In case of a cable malfunction caused by a severe submarine landslide. A ship and its crew to find the source of the malfunction and fix it as soon as possible. However, bad weather can delay repairs for weeks or months, depending on the location of the wind farm and the site of the breakdown.

- **Cable characteristics**: The transmission cables have low elasticity as they are designed for static application. Constraints and stresses due to ocean currents, installation and repair processes can stretch cables to their breaking point.

- **Thermodynamics**: The transmission of electricity by cables generates heat. Even though the cables usually run through cold water, contrasting temperatures can cause wear or other unexpected flaws.

- **Complex repairs**: Cables generally suffer two types of damage: physical breaks or performance degradation. The physical break is a bit easier to repair because it is possible to find both ends, transport them to a ship, assemble them and put them back into service. In case of performance degradation, it is necessary to locate the fault on an intact cable before starting the repairs, which is a much more difficult detection task.
• **Monitoring**: Portable, unmanned underwater vehicles are essential for examining the location of submarine cables and diagnosing problems. The technology is also increasingly monitoring the entire submarine cable network and providing alerts in the event of a failure.

• **Downtime expense**: As offshore wind development is expensive, wind farm managers must keep the line in a state of unavailability, as a power loss means a loss of revenue for the grid operator. Due to weather-related delays, the availability of repair vessels and the difficulty of locating the source of cable problems, engineers must ensure that they do their utmost to avoid cable problems when the design phase of a project.

### 2.4 Carving wooden wind turbine blades:

As part of the training program, we had a workshop about small scale wind turbines and we worked on fixing a small wind turbine that had broken blades. Our mission was to carve wind blades out of wood pieces following the instructions in the “Wind turbine recipe book”. The pictures below show some captions from the book instructions and pictures of our work step by step.

**1st step**: The first is to choose the right materials and the correct measurements according to the size of the wind turbine.

---

**Figure 20**: Caption from the "wind turbine recipe book"
2nd step: After taking the suitable measurements we start by making the blade blank template and draw the lines on the piece of wood then cut or carve the excess.

It is very important to follow the order of the instructions to get the correct shape and avoid any irreversible damage. The blades get thinner after each step which makes it a bit more difficult to work with. So it is important to be gentle and precise when drawing the lines.

![Diagram of blade blank template](image)

**Figure 21:** The selected piece of wood

**Figure 22:** Caption from the "wind turbine recipe book"
The pictures below show the progress of the work and the transformation of the piece of wood into a wind blade with each step.

Figure 23: Pictures showing the progress of the wind blades

Figure 24: Pictures showing the progress of the wind blades
3nd step: Now that we are done with the carving and cutting, we have 3 perfectly-shaped wind turbine blades that are ready to be put on place. But before we do that, it is important to cover each one of them with a coat of paint to protect them from the damaging natural conditions. This way, we can have them running for as long as possible.

![Wind blades being painted](image)

**Figure 25: Wind blades being painted**

After fixing the three blades together they are ready to be installed on the wind turbine.

![Wind blades attached together](image)

**Figure 26: Wind blades attached together**
3  Potentials of Wind energy in Tunisia:

3.1  Current situation of energy in Tunisia:

The total consumption of electric energy in Tunisia per year is 15.27 billion kWh. This is the average of 1,324 kWh per capita.

Tunisia can produce by itself all the energy it needs. The total production of all electric energy producing facilities is 18 billion kWh, which is 121% of the country's own usage. Despite this, Tunisia is trading energy with foreign countries. Along with pure consumption, the production imports and exports play an important role.

The electricity production of Tunisia reached **18 256 GWh** in 2015, with an installed capacity of **5224 MW**.

Up to **94%** of the country's total installed capacity is generated by means of natural gas power fired via thermal station.

The remaining **4,4 %** comes from renewable installations of which:

- 68 MW of Hydro power.
- 245MW of Wind.
- Around 15MW of residential Solar PV system, installed.

As shown in the Figure 37 below, in 2015 **STEG** generates up to **79 %** of the country's electricity production. The main source used by STEG to produce electricity remains natural gas, which represents **13 235 GWh** per year. However, even if natural gas represents the main input for the production of energy, the share generated by renewable sources is increasing.
**Challenges:**

The current power system poses some challenges for Tunisia.

- The dependence on conventional power and the difficulties in balancing the system.

![Figure 28: Electricity production 2015 & repartition of STEG Electricity GWh](image)

- The power market of Tunisia is managed mainly by the STEG in which 94% of the power-generating sources run on natural gas, while Tunisia is an energy-dependent country with modest oil and gas reserves. So the fluctuations in global energy prices are impacting the investment possibilities.
- The annual electricity demand is increasing by 3% every year.

=> An efficient energy transition is clearly needed and the expansion of renewable energy production in Tunisia shows the ambition to achieve it.

**3.2 Future of renewables in Tunisia:**

**3.2.1 Penetration of the renewables in the country:**

In 2013, Tunisia started its energy transition process focusing on energy efficiency and renewable energies. The goal of Tunisia is to reduce the primary energy demand of 12% by 2020 and to develop renewable integration to up to 30% by 2030.

Moreover, on September 16th, 2015 at the COP 21, Tunisia has exposed its objectives regarding CO2 emission for 2030. The country aims to decrease the carbon intensity by 41% compared to 2010. In this context, the juridical institutions of Tunisia have created on May 11th, 2015 the law n°2015-12 to support renewable development and energy transition.

According to the monthly report by ONE, in May 2015, the production of electricity generated by hydraulic sources has had an increase of 42% compared to the same period in 2013, while electricity generated from Wind has grown by 127% in the same period of time. The usage of natural Gas to produce electricity has known a negative variation of 8% if compared to that period.
Those data clearly show the effort of Tunisia to implement an effective energy transition from fossil fuel to renewable energy generation. The share of energy generated by IPPs in May 2015 accounts for 17% of the total with 3314 GWh produced.

The total installed capacity of renewables is expected to increase to 7 500 MW by 2021. The reason of the Power capacity rise lies mostly in the need to balance the increase of power demand in the industrial and residential sectors. This future development of installed capacity in Tunisia will be less based on natural gas, and more on the energy transition process. Indeed, even if some additional power plants could be built the development of solar and wind will be significant to sustain the economic development and reduce the impact of the country on climate change.

3.3 Case study of Matmata:

3.3.1 Analyzing the location:

The choice of the region of Matmata was based on the presence of the favorable conditions in this area. As shown in the map below, we can see that air density and wind speed are important in the south-eastern region of Tunisia where the average wind speed can be as high as 8.5 m/s and the average wind density is between 6 and 7 W/m.

Figure 29: Average Wind power density in Tunisia
Figure 30: Average Wind speed in Tunisia
And if we zoom in on the Matmata region, we can see that in addition to the favorable wind energy conditions, there is also a large part of its land that is not used for any purpose. So by investing in this area it contributes to reducing population and industrial density in big cities by creating job opportunities there.

### 3.3.2 Estimated Energy production:

The total area that can be used for the wind farm is about 500 km².

The average utility-grade tower height is about 80 meters, roughly 265 feet. But the wind industry has been setting its sights on a new standard for tower height at 100 meters (328 feet) Putting larger turbines atop taller towers facilitates access to greater wind speeds, which improves operating performance and cost.

In the case of wind farm spacing, turbines need to be at least 7 rotor diameters away from each other. One wind turbine of 2 megawatt capacity with 80 meter rotor diameter needs space of: \((80/2 \times 7) \times \pi = 0.246176 \text{ km}^2 = \text{about 0.3 km}^2\)

![Figure 31: Average Wind power density in Matmata](image1)

![Figure 32: Average Wind speed in Matmata](image2)

![Figure 33: The surface that can be used](image3)
On 100 km² area we can install 333 wind turbines a total capacity of 666 MW enough for 461 person (consumption 1,444 MW per capita) that’s 109 household (4,2 person per household).

→ On 500 km² we can generate electricity enough for 545 household with total capacity of 3330 MW.

In any wind farm there is a lot of space between turbines. Some of that space is to minimize turbulence, but some is to follow ridge lines or avoid other obstacles. Much of this area can be used for other purposes, such as agricultural farms.

### 3.3.3 Estimated cost:

Utility wind turbine costs range from approximately $1.3 million to $2.2 million per MW installed capacity.

The majority of the commercial turbines installed today are 2 MW in size and cost about $3 to $4 million installed.

The total cost of a commercial-scale wind turbine installation will vary considerably depending on how many turbines are ordered, the cost of financing, the date on which the wind turbine purchase agreement was signed, contracts construction, project location and other factors.

(http://www.windustry.org/how_much_do_wind_turbines_cost)

The cost components of wind projects include so many things other than wind turbines, such as wind resource assessment and site analysis expenses, costs of the construction, license and interconnection studies, upgrades of the distribution systems, transformers, protection and metering equipment, insurance, operations, warranty, repair and maintenance; legal and consulting fees. Taxes and incentives also are part of the factors that will impact the project economics.
⇒ So in our case it is not possible to tell exactly how much the project can cost before doing deep researches and considering all the different factors. But basing on the information we found in the linked “wind industry” website, and considering the price of a wind turbine about $3 to $4 million installed, we can estimate that the costs of a wind Farm that contains 333 2-megawatt wind turbines is between $999-$1332 millions

3.3.4 Average life of a wind turbine:

The design life of a good quality modern wind turbine is 20 years. Depending on how windy and turbulent the site is, the turbine could last for 25 years or even longer, though as with anything mechanical, the maintenance costs will increase as it gets older.

It is unlikely that a wind turbine would last longer than this because they are subjected to quite extreme loads throughout their lives. This is partly due to the shape of a wind turbine, where the key elements (the blades and the tower) are only fixed at one end and subjected to the full force of the wind. Also because the power in the wind increases with the cube of the speed, the extreme survival loads can be almost 100 times the ‘design loads’ at rated wind speed – which is why wind turbines must shut down to protect themselves in winds above 25 m/s. At the end of its life it can simply be removed and replaced with a new one.
4 Conclusion

The aim of this project was to learn about wind energy field and know more about the development of the latest technologies. Then apply what I learned to see if it has potentials in different places of the world, which in my case was Tunisia.

After doing the necessary research, it came out that wind power do have a potential in Tunisia but with certain conditions:

- We can only harvest wind in some regions of Tunisia because we don't have the needed wind speed for the wind turbines to work all over the country.
- The size and the type of the wind turbines also differ: In the case of Tunisia, offshore wind turbines have not potentials due to the nature of the Mediterranean sea that is deep and the wind speed is not strong enough (compared to Scandinavian countries for example where the wind speed is extremely high in the sea).
- Small wind turbines also have no potentials since they need high wind speed to work effectively; while big wind turbines can work at an average wind speed of 4 to 5m/s, small wind turbines start working at an average of 9 to 10m/s.

In conclusion, we think that wind has proved its effectiveness and it can a major source of energy for the coming generation. The wind power capacity did not only increased dramatically in the recent years but the turbines have also become more powerful, more efficient and more affordable for power producers which we think will make it more used all over the world in the coming years.

So now that we know that we have modest potentials of wind power in Tunisia the question is what other sources of renewable energy can we use in Tunisia and which one has the biggest are their potentials?
Name Surname
Position
Nordic Folkecenter for Renewable Energy
www.folkecenter.net
Facebook: Nordisk Folkecenter