WIND RENEWABLE ENERGIES COST ANALYSIS FOR MOUNTING SMALL WIND TURBINE

Final Report

Capstone Design

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Approved by the Supervisor(s)

SUPERVISOR: Dr. Khalid Loudiyi
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Contents

Acknowledgment ........................................................................................................... 3
List of Figures .................................................................................................................. 5
List of Tables ................................................................................................................... 5
Abstract ......................................................................................................................... 6
Introduction .................................................................................................................... 7
PART I: WIND POWER ENERGY OVERVIEW ................................................................ 14
1. History ..................................................................................................................... 14
2. Progress achieved in the sector ............................................................................... 15
3. Physical aspects and wind monitoring ..................................................................... 15
4. Moroccan data and map of wind speed ................................................................... 18
5. Advantages and disadvantages of wind power ......................................................... 20
6. Wind facilities and installation procedures ............................................................... 22
   6.1. Onshore wind farms .......................................................................................... 23
   6.2. Offshore wind farms ......................................................................................... 26
   6.3. Small wind turbines ......................................................................................... 32
   6.4. Environmental issues ....................................................................................... 35
PART II: TURBINE DESIGN, CONTENTS AND INSTALLATION ............................... 36
1. Design of turbine ...................................................................................................... 36
2. Turbine Components .............................................................................................. 41
3. Maintenance and operation costs ........................................................................... 47
PART III: Experimental part .......................................................................................... 48
1. Background ............................................................................................................... 48
2. Disassembling and cost analysis for mounting a turbine .......................................... 50
3. RETscreen Software ............................................................................................. 62
4. STEEPLE Analysis .................................................................................................. 64
5. Conclusion ............................................................................................................... 66
6. References .............................................................................................................. 67
List of Figures

**FIGURE 1:** Global greenhouse gas emissions by economic sector (US- EPA, 2015) ................................................................. 8
**FIGURE 2:** Global greenhouse gas emissions by gas (US-EPA, 2015) ....................................................................................... 8
**FIGURE 3:** 2011 Global CO2 emissions from fossil fuel combustion and some industrial processes (US- EPA, 2015) ................... 8
**FIGURE 5:** Wind rose example (Environmental technology, 2015) ....................................................................................... 17
**FIGURE 6:** Wind potential map of Morocco (ONEE, 2010) ................................................................................................. 18
**FIGURE 7:** Sites of wind farms in Morocco (ONEE, 2010) ................................................................................................. 20
**FIGURE 8:** Example of turbine spacing in a wind farm (Planning portal, 2015) ................................................................. 26
**FIGURE 9:** Monopile structure (wind energy the facts, 2016) ......................................................................................... 29
**FIGURE 10:** Gravity base structure (wind energy the facts, 2016) ......................................................................................... 29
**FIGURE 11:** Tripod structure (wind energy the facts, 2016) ......................................................................................... 29
**FIGURE 12:** Jacket structure (wind energy the facts, 2016) ......................................................................................... 29
**FIGURE 13:** Offshore meteorological met mast on jacket foundation (smart wind, 2011) ........................................................ 30
**FIGURE 14:** Substation in Robin Rigg Wind Farm, Scotland (Kis Orca.eu, 2016) ................................................................. 30
**FIGURE 15:** Main floating turbine platforms (Volumatrix Group, 2011) .............................................................................. 31
**FIGURE 16:** Growth in size of typical commercial wind turbines (My Florida home energy, 2016) ............................................. 32
**FIGURE 17:** 5 kW vertical guied wind turbine (Diy trade, 2015) ................................................................................... 34
**FIGURE 18:** Turbine foundation (MS Enertech, 2015) ............................................................................................. 41
**FIGURE 19:** Other design of the turbine foundation (MS Enertech, 2015) .............................................................................. 41
**FIGURE 20:** Wind tower inside view (Shallow nation, 2009) ......................................................................................... 42
**FIGURE 21:** Turbine interface (MS Enertech, 2015) ................................................................................................. 42
**FIGURE 22:** Inside view of a wind turbine (My Florida home energy, 2016) ........................................................................... 43
**FIGURE 23:** Connecting of hub to turbine tower (Geograph.org, 2008) .............................................................................. 43
**FIGURE 24:** Gearbox with three gears (Malfigan and Wilst, 2016) .................................................................................. 44
**FIGURE 25:** Asynchronous and synchronous generator patterns (Malfigan and Wilst, 2016) ...................................................... 45
**FIGURE 26:** Main shaft for 645 KW - 2.5 MW Wind Power Generators (Sinomach.com, 2015) ................................................... 46
**FIGURE 27:** Technical specifications of the small wind turbine (Unitron energy, 2015) ........................................................ 49
**FIGURE 28:** Multiple Cylinder Pack (MCP) used for hydrogen storage (Pure energy center, 2015) .......................................... 50
**FIGURE 29:** Technical specifications of the electrolyser (Pure energy center, 2015) .......................................................... 50
**FIGURE 30:** Manual work to disassemble the turbine ........................................................................................................ 50
**FIGURE 31:** Different parts of the turbine after the disassembling step ................................................................................... 51
**FIGURE 32:** Percentage contribution of components in the overall price (EWEA, 2007) ........................................................ 56

List of Tables

**TABLE 1:** Carbon dioxide emissions (Capiello, 2014) ........................................................................................................ 9
**TABLE 2:** Global installed wind power capacity (MW) – Regional distribution in 2014 (Global wind energy council, 2015) ........... 15
**TABLE 3:** Different tranche of power consumption and their pricing .................................................................................. 59
**TABLE 5:** Calculation for Ifrane city ........................................................................................................................................... 59
**TABLE 4:** Calculation for Taza city ........................................................................................................................................... 59
Abstract

The purpose behind this capstone project is to study Wind Energy in general, and to conduct a cost analysis for mounting a wind turbine. The project will be divided into mainly five parts. First of all, a literature review concerning wind energy in the world, including the onshore and offshore parks. Afterwards, we will tackle the Moroccan context by referring to the Moroccan strategy for renewable energies and how it would be beneficial to adopt such technology. The second part concerns wind turbines, in this part the technical aspect will be discussed in details. In other words I will define all the different components of a wind turbine, how they are designed and assembled together. The third section will cover the best applications resulting from wind turbine, as well as the advantages and disadvantages of such technologies. The fourth part covers the design and mounting of a new small wind generator using the available generator we have at Al Akhawayn University. The available generator was damaged, and I will open it to see all the elements inside. Such a concrete work will make it easy for me to better understand the working mechanism and all the components of a wind turbine. Later on, I will try to design one, using software to simulate what I learned. The last step in this project is to conduct a cost study of the components, which by itself will contribute into coming up with an overall cost analysis to define how much money and energy will be saved on the short as well as the long term. A small section at the end will be dedicated to environmental and social implications of such technology will seal the report.
Introduction

Nowadays, renewable energies are the best solution to produce clean energy and at the same time to meet the increasing demand of energy all over the world.

As a matter of fact, the Moroccan country imports 95% of its need in energy and this is something that affects the trade deficit, it represent 8.7% of the gross domestic product. With that being said, and with the aim to decrease the amount of energy imported, a national energy strategy has been adopted in March 2009. The purpose behind this initiative taken by the Moroccan government and developed by experts in the field of renewable energies is to construct a number of wind farms and solar parks so as to benefits from the natural potential of the country concerning sunshine and wafting wind. This strategy was launched by His Majesty, King Mohammed VI in 2010 as The Moroccan Integrated Wind Energy Project with an estimated investment of MAD31.5 billion.

Greenhouse gas and climate change

Nowadays humans are facing a dangerous public challenge which is climate change. Since the industrial revolution, a noticeable increase in the atmospheric concentration of greenhouse gases particularly carbon dioxide emissions resulting from exhaustive consumption of fossil fuels in developed countries. Global warming is considered as the primary form of climate change. Climate change has noteworthy effects on the global natural ecosystem, instigating an increase in temperature and sea level as well as more frequent extreme climate happenings, all of which represents a massive challenge to the development and survival of human race. Figures 1, 2 and 3 illustrate the global greenhouse gas emissions.
The Kyoto Protocol adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. According to this protocol developed countries are identified as the principal responsible for the current situation of greenhouse gas (GHG) releases in the atmosphere in the last 150 years of industrial activities, moreover; the protocol is placing a heavier load on developed countries under the principle of "common but differentiated responsibilities." (United Nation framework convention on climate change, 2014)

There are six countries producing about 60% of global carbon dioxide emissions (table1). China and the USA combine for more than two-fifths. The future of the planet earth can be defined through what these two top carbon polluters are doing about the heat-trapping gases resulting in global warming. (Capiello, 2014)
China and the United States aim to ensure the achievement of the targets for reducing greenhouse gas emissions. These two examples are highly instructive in this regard. The Weighty dependence on coal-fired power generation has not only powered China’s rise to the second-largest economy in the world, but also made the country as the leading nation in terms of greenhouse gas emissions, with over 25 percent of global emissions. China is the biggest producer of emissions in the world. It releases about 6,018 million tons of greenhouse gases per year.

In 2009, China announced that by 2020 its carbon dioxide emissions per unit of ‘gross domestic product (GDP) will lower by 40% to 45% from the 2005 level. Moreover it will increase the share of non-fossil fuels in primary energy consumption to 15% and rise the forested zone by 40 million hectares and the forest stock volume by 1.3 billion cubic meters compared to the 2005 levels. By 2030, China intend to achieve four key actions: (i) To lower carbon dioxide emissions per unit of GDP by 60% to 65% from the 2005 level; (ii) To increase the share of non-fossil fuels in primary energy consumption to around 20%; and (iii) To increase the forest stock volume by around 4.5 billion cubic meters on the 2005 level. (United Nations Framework Convention on Climate Change, 2015)

The United States (U.S) target will roughly double the pace of carbon pollution reduction from 1.2% per year on average during the 2005-2020 period to 2.3% - 2.8% per year on average between 2020 and 2025. The U.S is planning to cover target all greenhouse gases included in the

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**Table 1: Carbon dioxide emissions (Capiello, 2014)**

<table>
<thead>
<tr>
<th>Country</th>
<th>Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>11 billion tons</td>
</tr>
<tr>
<td>USA</td>
<td>5,8 billion tons</td>
</tr>
<tr>
<td>Russia</td>
<td>2 billion tons</td>
</tr>
<tr>
<td>Japan</td>
<td>1,4 billion tons</td>
</tr>
<tr>
<td>India</td>
<td>1,2 billion tons</td>
</tr>
<tr>
<td>Germany</td>
<td>836 million tons</td>
</tr>
</tbody>
</table>

---
2014 Inventory of United States Greenhouse Gas Emissions and Sinks: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), per fluorocarbons (PFCs), hydro fluorocarbons (HFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3). (United Nations Framework Convention on Climate Change, 2015)

According to the World Bank, on a global scale Morocco is emitting a very little amount of CO2. Carbon dioxide emissions (metric tons per capita) in Morocco were reported at 1.74 in 2011. This latter includes CO2 emissions from cement manufacturing and burning fossil fuels. (The World Bank group, 2016)

Sea level rise and droughts are the major areas of focus and concern for adaptation. The sea level will rise and could make Morocco inhabitable, pushing the livable area’s farther in land, far from the existing established cities. The seaside areas are surrounded by vast Atlas Mountains ranges and the Sahara Desert, leaving little habitable area to retreat to. Morocco joined the Kyoto Protocol on January 25th, 2002. The Moroccan country doesn’t play a noteworthy role in the Kyoto protocol since the carbon emissions are significantly lower compared to most countries. Although Morocco contributes very little to CO2 emissions, it will be one of the countries that will suffer greatly.

In this context, Morocco has set a target in order to limit greenhouse gas (GHG) evolution that will be reached through its own means; this target could be improved significantly with support from the international community. This desire rests, to a large extent, on an important transformation in the energy sector, which requires political commitment and aims to reduce the major energy dependency in the country and meet the rising demand for this later so as to support the development, particularly due to increasing water stress. The main objectives behind this transformation are:

- Attainment of over 50% of installed electricity production capacity resulting from renewable energy sources by 2025.
- Reduction of energy consumption by 15% by 2030.
- Decrease of fossil fuel subsidies, building on reforms already undertaken in recent years.
- Increase the use of natural gas, through infrastructure projects allowing liquefied natural gas imports.
The Moroccan commitment aims to reduce its GHG emissions by 32% by 2030. This commitment is depending upon gaining access to new finance sources and enhanced support. This target translates into a cumulative reduction of 401 Mt CO$_2$ emissions over the period 2020-2030. In order to meet this target Morocco requires an overall investment of USD 45 billion, of which USD 35 billion is conditional upon international support through new climate finance mechanisms, such as the Green Climate Fund. (United Nations Framework Convention on Climate Change, 2015)

**Renewable energies**

Over wide geographical areas, renewable energy resources and significant opportunities for energy efficiency exist. Whereas to other energy sources, which are focused in a limited number of countries. In order to ensure a significant energy security and economic benefits, rapid deployment of renewable energy and energy efficiency, and technological diversification of energy sources are needed.

Renewable energies are derived from natural processes that are reloaded constantly. In its different forms, it is derived directly from the sun, or from heat generated deep within the earth. Included in the definition, heat and electricity generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen resultant from renewable sources. (Bhatia, 2014).

**Nature of renewable energies**

The following definitions are given according to the official website of alternative energy.

**Solar energy:** The Earth receives a significant supply of solar energy. The sun is a fusion reactor that has been burning over 4 billion years. Actually, it provides sufficient energy in one minute that would supply the energy needs for one year in the entire world. Moreover, in one day it can provides more energy than the current population would consume in 27 years. In fact, "The amount of solar radiation striking the earth over a three-day period is equivalent to the energy stored in all fossil energy sources."

**Bioenergy:** The "biomass" term refers to all kind of organic matter that has stored energy through the process of photosynthesis. This form of energy exists as plants and may be shifted through the food chain to animals' bodies and their wastes. Many of the biomass coals used nowadays come in the form of wood products, aquatic plants and dried vegetation. In the last two decades biomass energy has become one of the most commonly used renewable sources of energy.
**Wind energy:** Wind power is considered nowadays as the world's fastest growing energy source and has also become a rapid expanding industry, with sales of approximately $3 billion in 2008. Offshore wind has the ability to deliver a large amount of energy at a price that is cheaper than most of the other forms of renewable energies, since wind speed is in general higher offshore compared to the one on land.

**Geothermal energy:** The source of geothermal energy is the heat contained inside the Earth; the noticeable intensity of heat underground is what allows the creation molten magma. Some geothermal systems get formed when hot magma close to the surface (1,500 to 10,000 meters deep) heats groundwater directly. The heat produced from these hot spots flows outward in the surface direction, exhibiting as volcanoes, hot springs and geysers. Naturally-occurring hot water and steam could be used after the process of energy conversion technology to generate electricity or to produce hot water for direct use. Moreover, other geothermal systems are formed even when there is no magma nearby, as magma heats rocks which in turn heat deeply-circulating groundwater. In order to make the most of the energy gathered from these so-called "hot dry rocks," geothermal facilities will habitually break the hot rocks and pump water into and from them so as to use the heated water to generate electricity.

**Hydropower (dams):** Water in movement is a very powerful entity accountable for illuminating entire cities, even countries. A long time ago the Greeks used water wheels, which picked up water in buckets around a wheel. The weight of the water caused the turning of wheels, converting kinetic energy into mechanical one for crushing grain and pumping water. Most importantly, people realized that the force of water falling from a certain elevation can turn a turbine connected to a generator in order to produce electricity. For instance the natural waterfall of Niagara, powered the first hydroelectric plant in 1879.

Additionally, there exist other forms of conventional renewable energy such as ocean, thermal, wave, tidal and hot fusion. Tidal energy uses the gravitational energy resulting between the Sun, Earth and Moon. Energy resulting from waves converts the energy released from the crashing of waves, which results in the wind, which is driven by sunlight. Ocean thermal energy benefits from the largest collector of solar energy on Earth which is the sea. Hot fusion is not exactlyingy renewable since it consumes hydrogen, but hydrogen is so abundant that it can be considered limitless for human purposes.
Opportunities and perspectives

The capital costs dedicated to renewable energy technologies have been shared over the last decade and this is what will happen for the next decade. For instance:

• Wind energy is considered as one of the most important technologies for electricity generation and the costs, in good wind regimes, are much less compared to fossil alternatives, especially when we take into consideration economic and environmental circumstances.

• Photovoltaic (PV), the use of semiconductor materials to transform sunlight directly into electricity, have dropped in term of price to between one-third and one-fifth their cost in 1980. PV are now conceived as cost competitive for many grid-connected this is the reason why it is now widely used in different uses such as building-integrated uses, and for off-grid applications extending from telecommunications to village power.

• Heat and hot water for residential is being provided using solar thermal technologies, moreover commercial and industrial benefits from this type of energy. Due to the different applications of these technologies, they are now reasonably developed and recently cost reductions have brought them into the competitive range.

• Solar thermal electric technologies, also referred to as concentrating solar power (CSP), create heat to generate steam and/or electricity. Commercial applications, from a few kilowatts to hundreds of megawatts, are now technically feasible. Nevertheless; not yet economically competitive.

• Biomass resources are available worldwide, there are variety of forms of biomass such as: wood, crop residues, crops and grasses. These latter could be can be transformed to energy through thermal or biological transformation or as feedstock to produce altered kinds of gaseous biofuels or liquid. Currently there are a number of project dedicated to study and determine how the use of biomass could be more efficient in term of cost and energy production as well. The electricity generated from biomass energy has an important advantage of being a base load technology and can be neutral in term of CO₂ emissions.
• The geothermal technology is mostly used for power generation, it is also important for space heating uses. Electricity generated from the geothermal energy could be a low-cost option if the hot water or steam resource is near the earth’s surface at a high temperature.

• Hydropower is the most mature type of renewable energy and has a substantial share of electricity generation worldwide. Whereas expansion of large-scale hydro has been disadvantaged due to environmental constraints, there is considerable interest and potential in term of small hydro applications.

• Oceans encompass several energy sources: ocean currents, tidal forces, wave power and thermal gradients can all be used to generate electricity, using technology similar to windmills settled underwater, and these are starting to be deployed. Ocean energy systems need a quite extended research and development effort, but full-scale prototypes have been constructed.

• Hydrogen, along with new and renewable energy technologies, has long been identified by the IEA as a major potential contributor to the sustainability of the energy sector. (International energy agency, 2002)

PART I: WIND POWER ENERGY OVERVIEW

1. History

According to the Encyclopedia of alternative energy, wind energy: in the beginning of the 20th century, great plains were commonly using windmills in order to pump water and generate electricity as well. However new technologies of using wind energy started to spread all over the world. In the 11th century, the Middle East used in an extensive manner windmills for food production, crusaders and returning merchants carried this idea back to Europe. On the other hand, the Dutch refined improved windmill and used it for draining lakes and marshes in the Rhine River Delta. Later on, in the 19th century the new world started using the windmills technology in order to pump water for farms and ranches and afterword to produce electricity for home use and industries.

The industrial revolution led to a decline in the use of windmills first in Europe than in America. The European water pumping windmills were replaced by steam engines, and in 1930 United States brought inexpensive electric power to most rural areas. Nevertheless,
industrialization helped in developing windmills meant to generate electricity. Usually called wind turbines, these machines appeared in the first place in Denmark in the 1890s. Moreover, in the 1940s the largest wind turbine of the time began operating on the Vermont hilltop. This turbine was rated at 1.25 megawatts in winds of about 30 mph, it produced electricity to the local utility network for several months during World War II. The use of wind turbine has always been related to fossil fuel price, where the fuel prices after World War II went down that’s why the interest in wind turbine decreased. Nonetheless, when the price of oil increased in the 1970s, the demand for wind turbine generators increased as well.

2. Progress achieved in the sector

Nowadays and for more than a decade of operating wind turbines, along with continuous research and development (R&D) in this domain. Wind energy is the world’s wildest growing source of energy as shown in table2 bellow, this type of energy is able to provide industries, businesses and homes with renewable electricity for the next coming years.

<table>
<thead>
<tr>
<th>Table 2: Global installed wind power capacity (MW) – regional distribution in 2014 (Global wind energy council, 2015)</th>
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</thead>
<tbody>
<tr>
<td>Asia</td>
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<tr>
<td></td>
</tr>
<tr>
<td>America</td>
</tr>
<tr>
<td>Europe</td>
</tr>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>Africa</td>
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<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>World total</td>
</tr>
</tbody>
</table>

3. Physical aspects and wind monitoring

   a. Wind flow

   The regions located around the equator at 0° latitude are being heated more than other parts on the globe. Hot air is known to be lighter than cold one, and it rises up into
the sky until it reaches about 10 km above the ground then it will spread to the South and North too. If earth was not rotating in a continuous constant manner, the air would simply reach the North Pole and South Pole, go down, and return to it starting point: the equator. (Danish Wind Industry Association, 2003)

**b. Wind power and energy**

Wind energy results from the movement of air caused by temperature differences in the atmosphere. Radiations from the sun heats up the air and force it to rise. On the other hand when temperature decreases, a low pressure zone develops. Therefore, wind energy is originally solar energy converted into kinetic energy of moving air. When air mass is flowing through an area \((A)\) with speed \((v)\), the power of that air movement at time \((t)\) is given by:

\[
P(t) = \frac{1}{2} \rho A v(t)^3
\]

Where \((\rho)\) is the density of air, which is around 1.225 kg/m³. (Green rhino energy.com, 2013)

For air density of 1.225 kg/m³, corresponding to dry air at standard atmospheric pressure at sea level at 15° C. The formula for the power per m² in Watts = 0.5 * 1.225 * \(v^3\), (Wind power, 2000). The energy (kWh) is the product of power and time:

\[
E = \int P \, dt = \frac{1}{2} \rho A \sum_{i=1}^{N} \Delta t_i \, v_i^3
\]

The energy resulting from wind varies with the cube of the average wind speed. In order to take into consideration wind variations, the energy from an air flow over a time period is made up from the summation of different wind speeds of small time intervals. Often, the average wind speed is measured every hour, thus providing 24 time buckets every day. While the air density is more or less constant, the two parameters to watch out for are the wind swept area, \((A)\), and the wind speed \((v)\).

**c. Wind rose**

A wind rose is meant to show the information about the different distributions of wind speed, as well as the frequency and the varying directions of wind flow. The wind rose is a drawing that is based on meteorological observations of wind speeds and wind directions. “The compass is divided into 12 sectors, one for each 30 degrees of the horizon. A wind rose may also be drawn for 8 or 16 sectors, but 12 sectors tend to be the standard set by the European Wind Atlas.” (Wind power, 2000).
A wind rose is usually drawn in a circular pattern as shown in figure 5 and it shows the frequency of winds blowing from different directions. The compass directions are indicated around the outside of the rose, such as north such as north (N), NNE, NE, ENE, and E and on round to N. (Environmental technology, 2015).

“The length of each bar or spoke shown in the circle represents the frequency of time that the wind blows from the direction it is pointing to. The frequency scale is usually shown as concentric circles, based on the center of the rose, getting further from the center with increasing frequency. The center of the rose represents a frequency of zero. Some wind roses carry further information by using color codes on each spoke to represent different speed ranges with the frequency represented by the length of banding on the spoke. To be useful a wind rose needs more information than that shown on the circular frequency distribution. Two important pieces of information that should always be on a wind rose are: the location where the wind speed and direction readings were taken, and the time period over which the readings were taken. This information is needed if you are attempting to make any future predictions from the wind rose data.” (Environmental technology, 2015)
4. Moroccan data and map of wind speed

As shown by figure 6 and according to the report written by Affani from the ADEREE on 2008, Morocco has an important potential of wind energy. This potential is mostly located in the North, east north and south. Essaouira, Tanger and Tetouan with an average annual wind speed varying from 9.5 to 11 m/s at 40 meters. Moreover, Taza and Dakhla with an average annual wind speed varying from 7.5 to 9.5 m/s at 40 meters. (Affani, 2008)

2. Moroccan’s wind power energy project

The Moroccan wind power project (figure 7) comprises the setting up of 2,000 megawatts by 2020, with an annual production of 6600 GWh, which is equivalent to 26% of our current electricity production. This would allow Morocco to save 1.5 million tonne of oil equivalent (TOE) annually or 750 million US Dollars per year and avoiding the emission of 5.6 million tons of CO2 per year.

**Project Framework**

- The promotion of renewable energies to the public sector and to businesses.
- The decline of electricity bills for customers.
• The contribution in the environment preservation.
• The decline of electricity production from fossil fuels.

Stakeholder

• Moroccan agency for solar energy (MASEN) is in charge of steering and control program; as well as supervising and coordinating between all program activities since 2016 instead of ONEE.
• Independent producers and auto producers.

Estimated time of operations

• The projects execution totaling in 2000MW by 2020.

Project location

• Identification of possible sites for the integrated wind project of 850 MW:
  o Tanger II (100 MW), Jebel Lahdid (200 MW), Midelt (150 MW), Tiskrad (300 MW), Boujdour (100 MW).

Financial Aspect

• Project funding are basically: public funding, national funding and foreign private.

Project progression:

• Production of a total capacity of 780 MW and 410 MW approximately is underway.
• Selection of the consortium for the implementation, as part of private electricity production with a total capacity of 850 MW in progress. (Ministry of energy, mines, water and environment, 2016)
5. **Advantages and disadvantages of wind power**

Unlike fossil fuels, wind energy does not generate any toxic emissions and it provides a clean source of power. In the USA, Germany, Spain, India and Denmark, wind energy is used in an extensive manner. Just like any other source of power generation, wind energy has its advantages and disadvantages as well.

**Advantages of wind power:**

1. Unlike fossil fuels that are going to expire in years to come. Wind energy is a renewable energy, in other term it can be produced again and again.
2. The wind energy is free and with new technologies it can be captured in an efficient way.
3. Even though wind turbines can be very high in the sky each one occupies a small spot in the land. This means that the land below can still be used. This is especially the case in agricultural areas as farming can still continue.
4. It would be beneficial for areas that are not connected to the national electrical power grid, so they can use wind turbines to produce their own supply of electricity.
5. There exist different and a vast range of people and businesses that can benefit from this kind of energy. From single households to small villages, towns and large cities; they can all make use of wind turbines.

6. Wind energy is the answer to the increasing demand for gas and petroleum, this later could reduce humans’ dependency on fossil fuels which would be beneficial in term of money and environment protection too.

7. One thing is sure, wind energy is that form of energy that would exist for ever. This form of energy does not destroy the environment, it does not release any toxic gases.

8. The production cost of wind energy has come down in a steady way over the past few years. The main cost is related to the installation part.

9. Wind turbines can be constructed either on land or at large water bodies like lakes and oceans.

10. Land owners can make additional cash by mounting wind turbines on their lands, which will be useful for agricultural purposes. The electricity generated by wind power can be used by the owner of the turbine which will reduce the electricity bill and the surplus power produced can be sent back to the local grid which will result in more savings.

11. Wind energy would create many job opportunities for local people. From installation of wind turbines to maintenance of the area where turbines are located. Since most of the wind turbines are based in coastal and hilly areas, people living there are often seen in maintenance of wind turbines. (Ryan, 2002; Conserve-energy-future.com, 2016)

**Disadvantages of wind power**

1. Even though wind energy is non-polluting, the turbines may generate a lot of noise. This is the main reason why wind farms are not built close to residential areas. The visual disruption is another reason why people do not find it eye-catching to install it in their backyard.

2. Due to large scale construction of wind turbines on remote location, it could be a danger to wildlife nearby. Wind turbines could be harmful to birds. As a matter of fact, studies conducted shows that there are several effects of wind turbines on birds and animals to be more explicit: animals see wind turbines as a threat to their life. Similarly, wind turbines require to be dig deep into the earth which could have negative effect on the underground insects.
3. Yet another disadvantage is that airstreams can never be predicted. That is why before installing the turbines, a study on the whole area and wind turbine layout, power curve, thrust curve, long term wind speed need to be conducted before deploying wind turbines. The wind strength is not constant and it varies from zero to storm force. This means that the amount of electricity produced will vary with time depending on the amount of wind in the atmosphere.

4. Wind turbines are appropriate to the coastal regions where there is wind throughout the year in order to generate power. Consequently, countries that do not have any coastal or hilly areas may not be able to benefit from wind power.

5- In the last decades, we can say that the frequency of hurricanes, tornadoes and storms have increased significantly. Now these severe storms can cause extensive damages to the wind turbines and to the people working in the wind farms.

6- Many people see large wind turbines as unappealing structures and not pleasant to look at. They also believe that the countryside should be left without these large structures being built. The landscape should be left in its natural form for everyone to enjoy it. (Ryan, 2002; conserve-energy-future.com, 2016)

7- Wind turbines could possibly disrupt electromagnetic signals used in radar services, telecommunications and navigation. The towers and blades may obstruct, reflect or refract the electromagnetic waves (Wind energy the facts.org, 2016)

6. Wind facilities and installation procedures

Onshore wind energy is considered as an important and the most cost-effective renewable technology. Nowadays, onshore wind farms are considered as the most economically competitive renewable energy source, and it is one of the cheapest energy sources in general. Average payback time can be as short as two years. Even though the offshore wind is considered as a great source of clean energy, it is not the best investment to make because of its high costs. The energy resulting from onshore wind turbine is two times cheaper than the offshore wind. While installing offshore wind farms, boat navigation, fishing, ocean habitat marine conservation zone must be taken into consideration. The possible objections from the Ministry of Defense must be taken into account. (boythorpe wind energy, 2013)
6.1. Onshore wind farms

6.1.1. Upstream studies

Sites investigations known also as “ground study” are necessary. These investigations include desk study, site walk-over surveys. Those investigations should start during the early phases of the environmental impact assessment design, so that potential ground risk can be identified and designed for appropriately, it is also meant to define the infrastructure siting. It is important that surveys are conducted prior (6-12 months typically, depending on monitoring parameter) to the on-set of the Site Works.

Environmental Impact Analysis (EIA) enable us to demonstrate that the wind farm design is taken into consideration all environmental constraints, such as site hydrology and habitats. Before installing turbines or any other infrastructure we need to locate them based on waste minimization, ecological protection (species and habitats), and hydrological / hydrogeological and archaeological survey work. (Scottish natural heritage, 2015).

Specific impacts of wind turbines on the environment, including influences on humans and animals as well as carbon and energy savings have to be undertaken in the statement before building permission is granted.

“EIA also contains specific wind characteristics of the site including: (i) mean wind speed: Only interesting as a headline figure, but does not tell how often high wind speeds occur, (ii) wind speed distribution : diurnal, seasonal, annual patterns, (iii) Turbulence : short-term fluctuations, (iv) Long term fluctuations, (v) Distribution of wind direction, (vi) wind shear (profile).” (Green rhino energy.com, 2013)

6.1.2. Construction tasks

Once all the necessary project elements are available in the place, the construction manager can proceed site preparation for materials delivery and equipment installation. The site preparation tasks includes the following steps:

Road improvement: In most sites new roads need to be built in order to provide access to the turbine site for construction vehicles.
**Grading:** The site of the new turbine need to be arranged before installation of the turbine. Additional grading might be required in order to set up temporary storage areas.

**Ground investigations:** adequate ground investigations are necessary before turbine construction. This is involving: trial pits, boreholes, in site testing and laboratory testing of samples to inform the design of the foundation. The only task behind the foundation is to test the ground stability for the turbine in the beginning and over its life time. This later is done by spreading and transferring the loads acting on the foundation top the ground. The most significant loads on the foundation comes from the wind flow power. Because of the big height of the tower, a horizontal force from the flowing wind is giving a significantly big bending moment at the foundation. (Svensson, 2010)

One of the commonly used foundation are two cylinders, placed one inside the other in order to reduce the total amount of concrete. This kind of foundation is perfect for places where there is a limited number of rocks. On the other hand, in a place where there is a considerable number of rocks it is preferable to have a slab-type foundation which would be more practical.

**Temporary-use areas:** Planning of brief use regions, for example, crane cushions, establishment of the gatherer framework, and arrangement of the substation cushion might should be assembled. Preparation of temporary-use zones such as crane pads, installation of the collector system, and preparation of the substation pad may need to be built. Site readiness for a substation might require specialized engineers in order to guarantee appropriate establishing and development of the ground.

**Cabling:** Cables needs to be positioned from the turbine to the transformer and from the transformer to the site of interconnection. In general, the cable from the turbine to the interconnection point is placed underground. The decision to run the wires underground or over it is based on expenses, habitat disturbance, land-use impacts, maintenance requirements, and permit requirements.

**Installing the project:** Once the major components are available on the construction site, all effort is directed into commissioning and installing the project as quickly as possible. After completing the safety tests and proper operations are confirmed, the project is then ready to begin the commercial production. After all construction is complete, site restoration tasks are completed. (North West community energy, 2016)
6.1.3. Turbine micro siting

In order to make the most of production, careful attention must be paid to the prevailing wind direction(s), obstruction from humans or already existing in the nature, and terrain effects. The impact of a wind disturbance caused by one turbine on another one is also important. Below is a list of general rules that need to be taken into consideration for turbines siting:

- This is meant to prevent the turbines from experiencing reduced wind speeds and increased turbulence due to the other turbines: On a site with multiple wind turbines, the turbines need to be placed at least two rotor diameters apart from each other in the plane perpendicular to the prevailing wind direction, and at least ten rotor diameters apart in the plane parallel to the prevailing wind direction.

- In order to avoid turbulence, turbines have to be placed at a distance twenty or more times the height of any human-made structure or vegetation upwind of the project.

- Avoid areas of steep slope. The wind on steep slopes tends to be turbulent and has a vertical component that can affect the turbine. Also, the construction costs for a steep slope are more expensive.

As a matter of fact, software programs are now available so as to take into consideration most of these factors. The turbine placement can be adjusted, and models within the program can show a simulated view of the project from different locations. When wind resource and topographical data are entered into these programs, the software is capable of optimizing turbine siting for maximum possible production and minimal visual impact. (North West Community Energy, 2016)

6.1.4. Spacing of turbines

Wind turbines need to be positioned in a way that the distances between each two is between 3-10 rotor diameters (about 180-600 meters for a wind farm using 60m diameter, 1.3MW wind turbines) depending on the individual conditions of the site. This spacing denotes a compromise between firmness, which minimizes capital cost, and the need for adequate separations to reduce energy loss through wind shadowing from upstream machines. The required spacing depends often on the prevailing wind direction as illustrated in Figure 8, which shows a possible layout for a site in Northern Ireland with a typical South Westerly prevailing wind direction. (Planning portal, 2015)
6.1.5. Connection to the electricity grid

In general, wind farms are likely to be connected to the electricity grid just like any other power station. In order to change the generating voltage to a common site voltage, small transformers are required. These transformers can either be placed inside or outside the turbine tower. The resulting output form wind turbines is connected to one single point using the cables located underground. The network operator is in charge of sending of electrical cabling onwards from the sub-station to the nearest suitable point of the local electricity distribution network. As a matter of fact, laying high voltage cables underground is more expensive than pole-mounted overhead systems. (Planning portal, 2015)

6.2. Offshore wind farms

A key solution for the disadvantage of noise and visual disturbance made by the turbine wind onshore is to site the wind farms and generators at sea level, this is known as the offshore wind farms. The noise produced by those turbines will not be heard and if they are installed few miles away from the coast they will not even be seen. However, it is more expensive and costly to install and maintain those turbine inside the sea. Also, the material used need to take into consideration the salty water in the sea. As a result, this increases the overall cost of installation and manufacturing significantly.
6.2.1. Pre-construction

Once the person in charge, who is usually the developer has obtained a lease they can proceed to evaluate and appraise the zone or area of construction. In more details, this requires a number of surveys to be completed taking into consideration boat or floating based bird and marine creatures’ surveys, benthic grabs and fish surveys. Moreover, data concerning meteorological factors such as wind speeds, tides and waves need to be collected, using a met mast and wave buoys. This kind of data is used to help the wind farm developer to design the project and help support the agreement between different parties. Once the permission is given by those in power more detailed geotechnical and geophysical surveys need to be conducted.

6.2.2. Construction

Offshore wind farms involve a number of connected components. These components include turbines, offshore substation, array cables, foundations, export cable and onshore substation and infrastructure. These elements are installed using different type of vessels and then serviced by either helicopters or smaller crew transfer vessels. Once the construction starts in the offshore wind farm, there will be a number of activities, with a potential of 50 boats all working at one time. Types of vessels that might be involved in the construction steps are as follow:

- Substation Installation Vessel: those vessels are in charge of transporting and lifting the substation onto the pre-installed foundation.
- Foundation installation vessel: those vessels are in charge of transporting the foundations from the seafront side to the construction site and secure them usually by piling. Gravity base foundations are probably easier to install and can use less specialist charges to put them in position.
- Turbine Installation vessels: those vessels transport the turbines from the seafront and install them on top of the foundations. The tower is installed in the first place after that different turbine manufacturers install the nacelle and blades in different ways.
- Array and export cable laying vessels: Those vessels are in charge of cables, where those cables are usually ploughed into the seabed, in case of more difficult terrain rock dumping can be used.
- Sea-based support: a variety of vessels are used to support the installation process. These include anchor handling, crew vessels, barges and dive support.

6.2.3. Structures Installed

The foundations role is to provide support for the wind turbines. The majority of wind farms constructed up to now have been built using a large circular steel tube known as a monopile (Figure 9) which is heaped into the seabed. Nevertheless as wind turbines get bigger other foundation types need to be used. These foundations include jackets, lattice structure with three or more legs, tripods structures and gravity base foundations which are big concrete bases (figures 10, 11 and 12). There exist other types of foundation concepts being developed including suction buckets and floating foundations.

The kinetic energy produced by the turbine is converted into three phase AC power. The turbines can be up to 150m high above sea level and in general they have three blades. Traditionally offshore turbines have been marinated versions of onshore wind turbines at around 3MW but the new turbines generation are much bigger (5-7MW) nowadays, and are designed especially for the offshore environment. The blades themselves can be up to 75m long. Power is being transmitted from the turbines to the shore via cables. Array cables connect offshore strings in wind turbines to the offshore substation and they are typically at 32kV. Before the export cables transmit the power to the shore, the power is stepped up to 120kV in the offshore substation. Historically talking, export was made through AC cables, but in the future and due to the increase in the distance from the shore, DC cables usage is imposing itself.

Weighing up to 2,000 tonnes, offshore substations are the single heaviest item of plant as shown in (figure 13). The platform level is about 25m above the sea and has an area of typically 800m². The substation in the onshore is located on land and it transforms the power from the export cable (132kV) to the voltage grid (400kV). Another essential structure is the met mast. It is necessary to install the met mast a number of years before the wind farm is build (figure 14) this will allow to study vital meteorological and oceanographic data for the site. Afterwards, the data collected then the design and planning steps can start in order to begin the construction and operation. Even though the sensors to measure the wind speeds are fairly small, they require
support by a stable platform and so met masts typically have a fixed foundation similar to ones used on wind turbines themselves. (Kis Orca, 2016)
6.2.4. Floating farms

Based on the pre-established commercial offshore wind farms worldwide, the wind turbines used in those farms are known to be fixed at the bottom. In terms of concepts used, these latter have a great dependence on both the conditions and type of soil upon which the wind turbine will be fixed and the depth of this soil from the surface of the water. Regardless, the most common concept is known under the name of monopole and is used until a depth of approximately 30 m, when engineering limits are reached. Beyond that depth, other concepts might be used such as the jacket foundation, which is a very expensive concept and due to economic reasons, mainly cost vs. output ration, this concept cannot be used above 50 m depth (Myrs et al., 2014).

In order to overcome those limitations established by bottom-fixed wind turbines, the idea of floating platforms was presented and thought to bring advantages regarding reducing both the wave loading and the cost of the installation along with improving wind conditions. To come up with solid designs for floating platforms, the researchers based their studies on their deep experience and problems encountered with the bottom-fixed turbines as well as the latest updated simulations codes. In that sense, they were able to offer floating systems, which can be used in waters with a depth of 30m - 40 m and above. They also got inspired from the pre-existing
platforms used in oil digging in the petroleum industry and offered three types of platforms: tension leg, spar buoy and semi submersible platforms as shown in figure 15.

![Figure 14: Main floating turbine platforms (Volumatrix group, 2011)](image)

Nowadays, the research in the field of offshore wind turbines aims at improving the rated power and the rotor size in order to achieve a higher energy output and also lower the Levelized Cost of Energy (LCOE). In terms of size, the average of offshore turbines installed in the year of 2013 was of 4MW while the floating wind turbines being developed at this time can reach 6 or 7 MW. There are also some researchers claiming to be able to commercialize by early 2020s, 10 MW offshore wind turbines having a hub height of 130 m and a 200 m rotor diameters. They also stated that by 2030-2050, the average size of the wind turbines which will be available on the
market and also installed will be of 10 to 15 MW and even 20 MW at the end of this period as depicted in figure 16.

6.3. Small wind turbines

The definition of small wind turbine, according to the American Wind Energy Association (AWEA), is basically a wind turbine having a capacity of no more than 100 kW. More specifically, and if one takes into consideration the application using those wind turbines, sizes of less than 1 kW are used for off-grid applications while ones of 100 kW can actually be able to provide enough power to a while village (AWEA, 2015).

The word microgeneration refers to the generation of heat and electrical power but on a small-scale, mainly by individuals, small businesses or even communities in order to satisfy their need in energy. This latter is considered as an alternative to the most known way of getting your own energy through the centralized electrical grid. The microgeneration is also thought to be a more practical alternative in terms of overcoming the non-reliability of the grid as well as the being isolated or far away from the electrical grid, non-connected to it, which is the case in some secluded villages and areas in the world. In that sense, and in order to achieve a microgeneration, small scale wind turbines can be used in residential areas. Their size ranges usually between 2.1 to 7.6 m in diameters depending on the output power desired, which can by itself range between 300 to 10,000 watts. Moreover, those small scale wind turbines have also the feature of being light in terms of weight (approx. 16 kilograms), thus being more sensible to smaller wind speeds, easier to mount.
and also more responsive to wind gusts available in urban areas. Most common design at the time is the horizontal-axis, with 2 or 3 blades made of composite material, mainly fiberglass.

6.3.1. Small wind electric system components

Generators used in small wind turbines are mainly the three-phase alternating current generators; however, experts in the industry tend to move more and more towards the asynchronous generator using induction. Inverters can also be mounted along with the generators in order to be able to store energy in batteries until it is needed and then convert it again back to AC current in order to use it or feed it to the grid.

In the case of high wind speed, and in order to allow the turbine to keep producing electricity in those conditions, dynamic braking is used as a speed regulator through dumping the excess of energy. During its operation, the dynamic braking releases heat and can thus be mounted inside buildings in order to not lose this heat and use it as district heating. Furthermore, the small units are known for having direct drive generators along with a direct current as an output, a lifetime bearings as well as a vane pointing towards the direction of the wind. If compared to the small units, the big size turbines are more costly, have geared power trains along with an alternating current as output. Large wind turbines can also use direct drive generators (Gipe, 2009).

Towers:

By investing slightly into increasing the height of the towers, the power production can increase significantly. As a matter of fact, let’s take a 10 kW generator mounted on a 60-foot tower. If this same generator is mounted on a higher tower, 100-foot tower, this will lead to a total increase of 10% of the initial cost; however, it will also lead to an increase of 25% in power production. Therefore, this slight increase in the initial investment is profitable.

There exists basically two types of towers nowadays: the self-supporting and guyed towers as shown in figure 17. On one hand, the highest number of wind power systems installed up to now use guyed towers in their design, known to be less expensive and easier to install when compared to their concurrent, the self-supporting towers. But, and as any technology ever created, these latter have also disadvantages, the most important one being the required space to build this type of towers since it requires a guy radius of at least one half of the height of the tower. This can go up
to three quarters of the tower height. On the other hand, the more expensive type of towers, also known as the tilt-down towers, show easier maintenance on light turbines (also smaller ones) having a power of less than 10 kW. They also have this feature of being able to be lowered down until reaching the ground, in order to avoid any kind of damages, especially during difficult weather conditions.

Balance of system components:

Depending on the application within which one is going to use the small wind system, the balance of system (BoS) components changes, except of course for the wind turbine and the tower, which are necessary in any case. Those components also depend on whether the system is a stand-alone system, which means that it’s an off-grid system, or a grid connected or even hybrid system. For the case of a residential application which is connected to the national electrical grid, the BoS components required are as follow: a controller, an inverter as well as a storage battery system, wires, grounding system, an electrical switch and finally a foundation for the tower (US department of energy, 2016).

![5 kW vertical guyed wind turbine (Diy trade, 2015)](image_url)

*Figure 16: 5 kW vertical guyed wind turbine (Diy trade, 2015)*
6.4. **Environmental issues**

The main aspects, which researchers in the field are working on and trying to improve, are mainly about noise, shadow flicker, visual impacts as well as the effects wind turbines have on the natural life.

- Regarding the noise produced by the wind turbines, each turbine has its own particular level of noise. Those noises can be divided into three different types:
  - Aerodynamic noise, this is caused by motion of the blades, which by itself causes turbulences.
  - Shaft noise that comes from the shaft.
  - Gearbox noise: can be reduced by using different tooth profiles on the wheels. Helical gears and herring bone gears offer a much smoother mesh, resulting in less noise.

- **Shadow flicker:** The wind turbines lead to a flickering effect by moving the blades and cutting through the light coming towards it. The frequency of this effect is usually below 2 Hz, which is a range that cannot cause any harm to the human body like epileptic seizures, but can still be annoying.

- **Visual impact:** Wind turbines are known for having quite high towers, which makes them very visible in miles away and destroy the general landscape in the eyes of some people. In order to overcome this issue, some manufacturers came up with the idea of changing the color of the wind turbine to make it friendlier to the eyes and allow it to mix with its surroundings.

- **Impact on birds:** An important environmental issue caused by wind turbines is injuring or even killing birds, which collides with the rotating blades of the rotor. Furthermore, the high-pressure change caused by this rotation can lead to important internal damage in some type of birds.
PART II: TURBINE DESIGN, CONTENTS AND INSTALLATION

1. Design of turbine

1.1. Basic load considerations

To resist the forces acting upon a structure, design engineers must completely understand and take into consideration the strength of the structure they are constructing. Wind turbine manufacturers are building rotors on wind turbines with few long and narrow blades which are pitched at most conducive angle with respect to the wind, in order to reduce the effect of the wind speed where the efficiency is the same and gain the maximum productivity. The idea behind building narrow blades and not wide blades that we can find in traditional wind powered water pumps, is to avoid the large forces that may occur even from moderate wind speed.

The rotor blades and all turbine components will be subjected to repeat bending forces that will eventually be the cause of the cracks developed from flexing and relaxing cycles which conclusively can lead to the breaking of the components. Fatigue is one of the common problems that many industries faces, therefore rotor blades are made of materials that are suitable and can withstand these load cycles and avoid material failure.

Mathematical models were developed by engineers to simulate cases of wind turbine components behavior before starting building them using different software, in order to find how structures react under dynamic forces. While designing a new wind turbine and to anticipate accurately the stresses predicted on the components, engineers need to calculate their vibration, bend and stretch loads each at a time. Since the rotor blades are made of hardly noticeable flexible materials, they will eventually have the tendency to vibrate. The turbine tower bands back and forth every time range, this oscillation frequency is called Eigen frequency (Eigen comes from the German for innate). The Eigen frequency depends on the diameter, height and the thickness by which the tower walls are constructed and also the type of the steel used including the weight fixed upon it using the nacelle and rotor blade assembly. It is very important to calculate these Eigen frequencies of each single element in order to maintain the turbine safety and try to keep the oscillations under control.
1.2. **Design for low Aerodynamic Noises**

Sound pressure refers to the power of the sound received at a distance, and the sound power is the sound calculated at a source. The noise level is measured in decibels (dB). The sound pressure level (SPL) of a modern wind turbine equal to 90 – 100dB. The SPL value is lower than 45dB when the distance is 350 – 1000 m, which is equivalent to the noise level of turning a page of a book. It is found that the noise level of wind turbine is 45dB during day in front of an open window while it is 35dB during the night. Moreover, and similar to cars, wind turbines are known to generate infrasound less than 20Hz below human perception. It is known that infrasound below the threshold hearing won’t cause any physiological harm.

The blades of the wind turbine dimensions and shape are determined by the appropriate strength that will confront the forces applied on the blade, also by the aerodynamic performance needed to extract efficiently the energy from the wind. Enormous progress was made by industry to improve the materials, cross section profiles and tips to build blades with very high efficiency that generate less noise.

To obtain a plan permission from local authorities, the potential sound emission need to be calculated from the wind turbines. This factor is very important specially while installing wind turbines nearby areas occupied by people. A modern turbine commonly has a sound level range of 96 – 101 dB, where generally legal noise is between 40dB and 45dB at a distance of 300m which is usually set for any wind farm that has more than ten turbines. But with all aspects of wind energy the legal noise varies depending on the place jurisdiction.

Rotor blades interact with the wind and slow it down where a portion of its kinetic energy is transmitted to the blade itself and make it turn. White noise can be generated from this process due to a very small vibration predicted by the surface at high frequency although the surfaces of the rotor blades are required to be very smooth (aerodynamic reasons). As the air is stirred by the leading edge of the rotor blades, the majority of the noise is generated by the trailing edge of these blades. One of the reasons why modern wind turbine contain very low rotational speed and larger rotor diameters, is the volume of the sound that increases on a scale of the fifth power of the blade speed with respect to the air, with everything else being equal.

The noise volume and the flow of air over the blade are both disturbed as a rotor blade rotates through a wind turbine tower. The global effect is a noise that beats at a frequency associated
with the rotor speed where amplitude modulation present one way of describing this beat. However, good blade design are known to reduce this phenomenon.

The tips of the blade travel through the air faster than the base of the blade. As a matter of fact the profile of the blade changes along its length, therefore careful care must be taken while designing the rotor tip. Furthermore, vibration is considered to reduce the rotor and generator efficiency likewise adding tear and wear to the materials used. Modern wind turbine generates minor noise, where these lower noise levels allow increased rotational speeds which raise the energy output of the rotor.

1.3. **Blade design progress**
The long fibers provide longitudinal strength and stiffness, also the matrix provides fracture toughness where most of the recent commercialized wind turbine blades are made of fiber-reinforced polymers (FRP’s).

Glass (GFRP’s) and carbon fiber reinforced plastics (CFRP’s) has both a higher fracture toughness, fatigue resistance and thermal stability. In addition, newer turbines accelerate rapidly if the wind sprang up. Here comes the use of blades made of composite materials and aluminum which contribute to low rotational inertia. Yet, the weight of these large new blades is a common issue for the design where it’s not obvious whether they can withstand their weight without breaking.

Therefore design engineering cover all things related to stability, stiffness, fatigue performance and wing-tip deflection including twist limits. Additionally, a common environment issue in desert is known to increase the roughness of the blades and decreases aerodynamic performance, where wind blow carrying sand over the leading edges of these blades. Fiber-reinforced polymers particle erosion has a poor resistance while the metallic and elastomers materials resists more but need to be improved as well. Studies has found that replacing glace fiber on the composite surface by carbon nanofibers (CNF) largely develop erosion resistance.

1.4. **Design for turbine Safety**
It is necessary to take into consideration the safety components while design and mounting wind turbines. In other words, components of a wind turbine are designed to last 20 years. This implies that they will have to undergo more than 120,000 operating hours, under different weather
conditions. During their life time, large wind turbines are equipped with a number of safety devices to ensure safe operation.

**Sensors:** vibration sensor is considered as one of the classical ways to ensure safety, installed in the wind turbine. It simply consists of a ball connected to a switch through a chain resting on a ring. Once the turbine starts shaking, the ball falls down off the ring and switch the turbine off. There are other sensors in the nacelle, e.g. electronic thermometers which are responsible of checking the temperature of the generator and the oil temperature in the gearbox.

**Rotor Blades:** Safety regulations are different from one country to another concerning wind turbines. According to the official website of Danish Wind Industry Association, Denmark is the only country in which the law requires that all new blades are tested both statically, i.e. applying weights to bend the blade, and dynamically, i.e. testing the blade's ability to withstand fatigue from repeated bending more than five million times.

**Over speed Protection:** It is necessary that in case of malfunctioning of a component that the wind turbines stop automatically. For instance, if the generator burns or is disconnected from the electrical grid this will cause a stop braking the rotation of the rotor, and the rotor will start running rapidly within a matter of seconds. In such a case it is essential to have an over speed protection system to stop the turbine immediately.

**Aerodynamic Braking System: Tip Brakes:** The primary braking system for most modern wind turbines is the aerodynamic decelerating system, which basically entails in turning the rotor blades about 90 degrees along their longitudinal axis or in turning the rotor blade tips 90 degrees. Experiences have proven that aerodynamic braking systems are particularly safe. These frameworks are normally spring operated, so as to work even if there is an occurrence of electrical power failure, and they are consequently enacted if the hydraulic process in the turbine loses pressure. The water powered framework in the turbine is utilized to turn blades or blade tips back in the order once the unsafe circumstance is over. They will stop the turbine at a couple of rotations, at the most. Furthermore, they offer a very delicate manner of braking the turbine with significant
stress, tear and wear on the tower and the apparatus. The typical method for ceasing a modern

turbine (for any reason) is thus to utilize the aerodynamic braking mechanism.

**Mechanical Braking System:** The mechanical brake is utilized as a reinforcement framework for
the aerodynamic braking mechanism, and as a parking brake, once the turbine is no longer working
in the case of a stall controlled turbine. Pitch controlled turbines infrequently need to enact the
mechanical brake (with the exception of the maintenance of work), as the rotor can't move very
much once the rotor swords are pitched 90 degrees. (Danish Wind Industry Association, 2000)

### 1.5. Optimizing wind turbines

In 1919, the German physicist Albert Betz demonstrated that for a hypothetical ideal wind-
energy extraction machine, the fundamental laws of conservation of mass and energy permitted
close to $\frac{16}{27}$ (59.3%) of the kinetic energy of the wind to be captured. This Betz limit can be
drawn closer by modern turbine plans which may achieve 70 to 80% of this hypothetical limit.
(Castellano, 2012)

The ideal model is a tradeoff between economics and technology. A wind turbine maker
will plan to manufacture a machine that conveys electricity for the minimal expense per kilowatt
hour (kWh) of power. The correlation between generator size and rotor size is significant. The
smaller the generator (in terms of rated power output) the less wind is needed to turn it. A
substantial wind turbine rotor (catching a lot of wind energy) combined with a small generator will
hence generate electricity just about relentless as it will work in even light winds. Yet, it won't
generate as much energy as in strong winds if the force available from the rotor will surpass the
rated maximum power output of the generator.

A larger generator, by comparison will be proficient at high wind speeds, but inactive at low
wind speeds as the power in the wind is deficient to turn the rotor against the inertia provoked by
the generator. Producers will utilize the conveyance of wind speeds and the potential power content
of the wind at various speeds to build up the perfect equilibrium between the size of the rotor
blades and the size of the generator. An advantage can occasionally be picked up by fitting two or
more generators to a wind turbine, but it truly must be resolved on a case by case basis with reference to whether it is beneficial to do this, depending on the electricity cost.

2. Turbine Components

2.1. Tower

Towers are structures constructed from numerous segments one on top of the other fixed to a base that has a diameter of 2-5 meters, and a surface flushed to the ground surrounding this foundation surface which is expected to be in a hexagonal or square shape as shown in both figures (18 and 19) where it’s 7-20 meters across. This shows that the land area that the turbines are using is very small. People are allowed to access directly the base of the towers without interrupting turbine operation, if and only if this land is open to public access. Usually, towers are made of steel with high quality, there form contains a hollow truncated cone and the foundation is connected to both the prefabricated tower and to the in situ made base by an interface as shows the figure (20). The tower height is related to the wind speed where the greater is the speed, higher is the tower. And the tower height alternate between 40 m and 130 m.
2.2. **Nacelle**

The nacelle consist of multiple electronic components highly sophisticated that direct the wind turbine on and off, and also gives the turbine the right to monitor changes in wind direction and speed. To keep a safety and a high efficiency these components harness from the wind the power wind (Hamilton and Liming, 2010).

A rectangular box rests at the top of the tower, contains the turbine’s gears, generator and many mechanical components therefore we can say that the brain of the wind turbine is the nacelle. It is connected to the tower by bearings, since there is a possibility of rotating about the tower axis to tune in the wind direction. However, the nacelle holds all the turbine machinery that transforms the rotating energy to electrical one as shows figure (21).
2.3. **Hub**

The hub has a complicated shape that connect the rotor blades to the rotating bar that goes into the nacelle, it is fixed to the rotor shaft that drives the generator through a gear box or directly as seen in **figure (22)**. It is usually made of cast iron because the steel is known to resists metal fatigue, so the use of a special alloy takes place for which undergoes a heat treatment in order to get the right properties after casting.

Aerodynamic stall may occur above certain wind speeds in simple designs, where the blades are unable to pitch because they are bolted to the hub. In more experienced designs, the blades speed is controlled because they are bolted to the pitch mechanism (bolted itself to the hub) that adapt their angle of attack with respect to the wind speed.
2.4. **Blades**

Selecting the right number of blades depends on the cost of the components and the aerodynamic efficiency additional to the system reliability. Companies develop blades up to 100 meters length dwarfing the size of existing technology in a range of 60 meters for offshore wind farms, where a structure will be 270 meters in all when sitting on top of a tower 170 meters.

2.5. **Gearbox**

Figure 23 shows a gearbox which is used to increase rotational speed in a wind turbine by changing the low speed rotor to a high electrical generator speed. Designing the gearbox is challenging because of the loading and environmental conditions in which the gearbox is required to operate. The rotor generates power due to the torque, the rotor applies forces and moments to the wind turbine. It is necessary to make sure that the gear box is able to support all loads otherwise internal components would become misaligned. This will result in stress concentrations and failures. (Zipp, 2012)

![Figure 23: Gearbox with three gears (Malfigan and Wilst, 2016)](image)

2.6. **Generator**

The generator is the component in a wind turbine responsible of converting mechanical energy into electrical energy. The blades transfer the kinetic energy coming from the wind into rotational one using the transmission system; moreover, the generator is the next step in the supply of energy from wind turbines to the electrical grid. Generators need conservation and cooling while
they work. This is why, in most turbines we can find encapsulated generators in a duct, using a large fan for air cooling, but very few manufactures use water cooled generators.

There exist two type of wind turbine generators: synchronous or asynchronous generators (figure 24), and with various forms of direct or indirect grid connection of the generator. The direct grid connection mean that the generator is connected in a direct way to the current grid. The indirect connection means that the current coming from the turbine will be passing through a number of electrical devices in order to adjust the current so as to much the one in the grid. With an asynchronous generator this occurs automatically.

![Figure 24: Asynchronous and synchronous generator patterns (Malfigan and Wilst, 2016)](image)

### 2.7. Brake system

The design of a wind turbine permit this later to produce power over a specific range of wind speed, in other words all wind turbine have a maximum wind speed that they can support, it is known as the survival speed, above this speed the turbine will be damaged. Halting and slowing an 80 meter turbine rotor requires a conversion of the kinetic energy into heat. Rotor brakes are in charge of controlling over speed, and also provide parking and emergency barking. These brakes could be installed on the rotor (low-speed shaft), on the generator (high speed shaft), and in or both for some cases. In general the cost effective place for installment of brakes in on the high speed shaft between the generator and the gearbox. However, the low speed shaft braking is relatively (Zipp, 2012)

### 2.8. Yaw

The yaw is the element responsible in the turbine of orienting the wind turbine rotor in the direction of wind. The active yaw systems are equipped with some torque so as to produce a rotation for the nacelle in the turbine against the stationary tower based on automatic signals from wind sensors. The active drives of yaw systems are the mean is active rotation. The passive yaw
systems uses wind force so as to adjust the direction of the turbine rotor towards the wind. These systems encompass a roller bearing connection between the tower and the nacelle and a tail fin (wind vane) mounted on the nacelle. The yaw vane (or tail fin) is an element of the yaw system used only for small wind turbines with passive yaw mechanisms. It is nothing more than a flat surface mounted on the nacelle by means of a long beam.

2.9. **Main Shaft**

The rotor is connected to the main shaft (figure 25), which spins a generator to create electricity.

![Image: Main Shaft for 645 KW - 2.5 MW Wind Power Generators (Sinomach.com, 2015)](image)

2.10. **The anemometer**

This device is composed of three cups put on horizontal arms, with an angle of 120° between each cup, once the wind blow we can calculate the wind speed with the number of tours per seconds.

2.11. **The vane**

A wind vane looks like an arrow and it is used in order to determine the wind direction and with this electronic controller, we can determine the most proper direction of the blades to have so as to produce the best possible amount of energy.

Note: The transformer unit is not part of the wind turbine itself, but a unit necessary to transform the wind turbine output power to electric power suitable for the actual environment.
3. Maintenance and operation costs

A modern wind turbine will be designed so as to work for 120,000 hours during its life time, about 20 years. This turbine would be operating about 66% for two decades. This is more than a car engine which is supposed to last for 4000 to 6000 hours usage, this is equal to an average of 49 minutes driving everyday over two decades. By experience and according to an official source in Denmark, the cost of maintenance of a new wind turbine is much less than the one of an old turbine. Old wind turbine have an average annual cost of 3% of the original cost of the turbine. In modern machine the annual cost of maintenance varies in between the range of 1.5% to 2% of the original wind turbine.

Offshore wind turbine may last longer than those onshore, for the simple reason that they are facing no obstacles to the wind inside the sea and the turbulence is much lower. Actually, this would result in a lower maintenance costs, but this will be balanced by the expenses in order to attain the turbines inside the sea and to do any maintenance activities. (Wind Measurement International; 2016)

Concerning the facilities in order to be secured and maintained, it is necessary to have maintenance workers, janitors, security guards and other technicians available under all circumstances. Janitors and caretakers are the one responsible for the cleaning and conservation of facilities, in other words they need to make sure that there is no external people in the place. Maintenance workers are in charge of the machinery part, they need to keep the turbine operating under safe condition and repair any damages. Wind technicians are the one responsible for keeping the turbine running in an efficient manner, those technicians climb up and down the tower to reach the nacelle and blades. When there is a problem, those technicians need to be available so as to fix it as soon as possible. To build and maintain a turbine requires a large number of machinists, technicians, working on the wind farms on a daily basis. Each of these workers along the supply chain contributes to making wind a practical source of energy (Hamilton and Liming D., 2010).
PART III: Experimental part

1. Background

In 2012, the first African wind hydrogen system was launched at Al Akhawayn university in Ifrane, Morocco (AUI). This project came to life thanks to: the Pure Energy® Centre, the UK pure® fuel, companies specialized in renewable energy and energy storage in collaboration with Sahara Wind Inc. and AUI, with a financial support from North Atlantic Treaty Organization (NATO) under its Science for Peace and Security frameworks. The wind farm installed consisted of three wind turbines, the purpose behind installing those wind turbines was to supply the university campus with green energy. The main reason behind installing the hydrogen system is to store the excess of energy production. One of the major issue with renewables is that they are intermittent, this issue can be reduced by using the excess of generation that was stored when there will be no wind generation, the installed system is composed of an electrolyser, a fuel cell and a hydrogen store.

As a matter of fact, the combination of wind and hydrogen has a bright future and an important role in the future of the African country. Indeed, there are several applications that could benefit from this combination such as: the powering of telecommunication networks, mine processing industries, automotive industries.

The table below (Figure 27) demonstrates the model of turbines studied in this project, those turbine are made by Unitron Energy systems Pvt. Ltd. in India. The main strengths of the company is the manufacturing of different types of converters, charge regulators, drivers, and renewable energy systems such as small wind energy. Unitron started also the manufacturing of energy efficiency street lighting systems.
The small wind turbine UE42 plus is known for a lowest cost per watt, neo magnets for long life, high outputs for low wind flow, sustained output in high wind output, ruggedized body frame, stainless steel components and quiet whisper.

The system is composed of a series of small, 5 kW wind turbines that provide power to the grid and to a 30 kW pressurized alkaline electrolyser. The excess of hydrogen is stored in cylinders (figure 28) and then it is used in a 1.2 kW fuel cell to produce electricity and stabilize the grid at times of low wind speed.
The electrolyser mission is to split $\text{H}_2\text{O}$ (water) into its initial molecules: hydrogen ($\text{H}_2$) and oxygen ($\text{O}$). Hydrogen gas is stored in a tank and it can be reused later on through a fuel cell for power generation when there is lack of wind, while the oxygen is released into the atmosphere.

### Table: Technical Specifications of the Electrolyser

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Hydrogen Production</td>
<td>5.3 $\text{Nm}^3$/hour</td>
</tr>
<tr>
<td>Maximum Electricity consumption / supply</td>
<td>30.5 $\text{kW}$ @ 400VAC 50Hz</td>
</tr>
<tr>
<td>Transformer position</td>
<td>External (650 mm x 480 mm x 780 mm)</td>
</tr>
<tr>
<td>Control panel position</td>
<td>Internal</td>
</tr>
<tr>
<td>Production variation range</td>
<td>20% to 130% of maximum capacity</td>
</tr>
<tr>
<td>Deionised water consumption at full power</td>
<td>4.6 litre/hour</td>
</tr>
<tr>
<td>Hydrogen purity (before purifier)</td>
<td>99.3% - 99.8%</td>
</tr>
<tr>
<td>Outlet gas dew point (before Drier)</td>
<td>Saturated at ambient temperature</td>
</tr>
<tr>
<td>Outlet gas Pressure</td>
<td>up to 12 bar</td>
</tr>
<tr>
<td>Environment temperature range</td>
<td>5°C - 35°C</td>
</tr>
<tr>
<td>Valves actuation</td>
<td>Electric/Pneumatic</td>
</tr>
<tr>
<td>Cooling system</td>
<td>Air or Liquid</td>
</tr>
<tr>
<td>Dimensions (Length x Depth x Height)</td>
<td>850 mm x 1300 mm x 1800 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>440 kg</td>
</tr>
<tr>
<td>Certification</td>
<td>CE approved</td>
</tr>
<tr>
<td>Additional Configuration Options</td>
<td></td>
</tr>
<tr>
<td>Parallel connection of several units to increase production capacity</td>
<td></td>
</tr>
<tr>
<td>remote surveillance control system through internet</td>
<td></td>
</tr>
<tr>
<td>full service contract</td>
<td></td>
</tr>
<tr>
<td>compression &amp; buffer storage allowing for flexible supply independent from production</td>
<td></td>
</tr>
<tr>
<td>surcharge of ‘green’ electricity to eliminate CO2 emissions from the production process</td>
<td></td>
</tr>
</tbody>
</table>

---

### 2. Disassembling and cost analysis for mounting a turbine

In this part I had the chance to work with my supervisor on disassembling some parts of the wind turbine under study, where I was able to see in a concrete way the different components (figure 30). This experiment allowed me to experience manual work and acquire more credibility, and better understand the theoretical part of this report.
After the disassembling of the wind turbine and a better understanding of its elements. I will now define the different steps that need to be followed in order to mount a small wind turbine, along with the pricing of each step. According to official website of Windustry which is a registered trademark in the United States. There are eight step: site assessment, land lease, permits, turbine and tower expenses, installation costs, commissioning costs, operating costs and decommissioning.

1. **Site assessment**: for a single wind turbine project, it is necessary to perform a soil analysis to see either or not it is the right site for installation, after the analysis there is a site-specific foundation design which will cost $25,000 and $45,000. (Windustry Resource Library, 2007)

2. **Land lease**: wind farms need to be installed in the windiest area in order to maximize revenues from the power generation. In general this is requiring a lease for the land where the project name will be sited as well as obtaining wind
easements on neighboring lands. This will prevent other project from being built closely, which would lower the production numbers. Generally, leases for MW turbines range from $3,000-$12,000 per turbine per year depending on the size of the turbine, the size of the land for construction. Many wind developers are paying a fixed amount per installed MW ($2,500-$4,000 or more per installed MW), which increases every year at either a fixed percentage or at the Consumer Price Index rate of increase. (Windustry Resource Library, 2007)

3. **Permits:** any type of project would need to perform environmental, archeological and other studies before permits for station construction is issued. “Legal costs in permitting can get expensive for projects in areas where possible litigation might occur from parties affected by the project. Often a building permit fee is based on total project cost and can amount to $5,000-$10,000 per turbine. The cost to hire consultants and complete the required studies can range from $5,000-$50,000 for a single turbine project.” (Windustry Resource Library, 2007)

4. **Connectivity:** It is imperative to study the interconnection in the planning phase, because it is very time consuming and expensive as well. Interconnection studies for a project can cost anywhere from $5,000-$150,000 or more, depending on the size of the project and where the interconnection is positioned. This step is about checking if the nearby power lines are « full » or not, since the construction of new transmission line is very expensive and difficult to site. The interconnection study aims to define the impact of a specific project on the power system. (Windustry Resource Library, 2007)
5. **Turbine and tower expenses:** The tower and turbine are the largest expense in the project development. Nowadays, commercial turbines range in price from $1.1 to $1.7 million per MW. This cost varies depending on project size, turbine model and manufacturer, transportation cost of the turbine and the tower to the site, and other factors. (Windustry Resource Library, 2007)

6. **Installation costs:** These costs include all the expenses required for the construction of the turbine and running it once it is mounted. Most owners hires experienced contractors for site preparation and turbine installation. Contractors who install turbines need to give a cost estimation for their job that includes the following major steps: access roads, foundations, wiring to the tower bases, and turbine erection.

- **Access roads:** the cost of these roads could add up to $35,000 or more for a quarter-mile access road built over a farm field to the turbine location.

- **Foundations:** depending on the weight of the generator assembly and rotor and the height of the tower the price will vary. “A turbine foundation is very large: 8-20 truckloads of concrete, with costs ranging from $100,000 to $250,000 including soil boring and engineering design.”

- **Wiring to turbine base:** this embraces installment of a pad mount transformer at the turbine base if required, installing electric poles to carry the power to the utility line, installing underground wiring on the land. The cost range is $40,000 to $200,000 or more.
- **Turbine erection:** the major cost in this step is related to the rental of a crane. A comprehensive price estimate from a qualified installation company will likely be in the range of $100,000 to $150,000 per MW.

7. **Commissioning Costs:** usually included in the price of the turbine manufacturer charges once the order is made. “Commissioning is the process of connecting the turbine to the transmission lines and making sure it is working correctly. The main components of commissioning are final wiring, setting parameters, checking operational safety, and verifying the successful generation of power as shown in the manufacturer’s instructions.” (Windustry Resource Library, 2007)

8. **Operating costs:** can be divided into 4 components, Operation and maintenance, Warranty, Insurance, administrative and legal costs.

   - **Operation and maintenance (O&M):** “Owners can choose to do most of the O&M themselves, as long as they are trained by the company technicians who perform the turbine commissioning. Third party and turbine manufacturers also offer turbine O&M services. These services typically range from $20,000 to $50,000 per year for each turbine.” (Windustry Resource Library, 2007)

   - **Warranty:** “A machine warranty will typically run between $20,000 to $40,000 per year per turbine depending upon the turbine manufacturer, size of the project, and turbine model. A typical warranty lasts for two years with an option to extend the warranty up to five years.” (Windustry Resource Library, 2007)
• **Insurance:** “Insurance costs range from $8,000-$15,000 per year for each turbine. This cost will increase after the warranty on the machine is over and the likelihood of equipment failure increases in the later years of the project.” (Windustry Resource Library, 2007)

• **Administrative and legal costs:** “At a minimum, you’ll want to hire an accountant to prepare your taxes, but you will likely need other professional services to deal with contract issues, billing, insurance settlements, and whatever service issues arise. A developer typically budgets $6,000-$10,000 per year per turbine for administrative and legal costs. » (Windustry Resource Library, 2007)

9. **Decommissioning:** the cost depend on permit requirements and site specifications of the turbine, for instance the deep of the foundation. “Generally the size of this fund is around $25,000 per turbine. One way to estimate decommissioning costs is to assume that the future scrap value of the turbines will be 5-10% of the initial equipment cost, or to guess what the value of steel and copper and the other metals in the turbine would be in 20 years. Many projects are not decommissioned, but are repowered. If a site is proven to have good wind resources, in many instances it makes more sense to replace turbines as needed rather than remove the entire facility.” (Windustry Resource Library, 2007)

The wind turbine is considered one of the most expensive element in a wind farm. As a matter of fact, the most expensive parts in a turbine are the tower and rotor blades, where they represents about the half of the overall price. The figure bellow (figure 32) demonstrates the contribution in percentage of all the component in the overall price of the wind turbine.
How a wind turbine comes together

A typical wind turbine will contain up to 1000 different components. The guide shows the main parts and their contribution in percentage terms to the overall cost. Figures are based on full power 2MW turbine with 45.1 metre length blades and a 105 metre tower.

Tower 26.3%
- Stands 40-60 metres above the ground, usually manufactured in sections from rolled steel, a lattice structure or concrete and cheaper options.

Rotor blades 22.2%
- Varying in length up to more than 60 metres, blades are manufactured in specially designed moulds from composite materials, usually a combination of glass fibre and epoxy. Options include advanced materials instead of epoxy and the addition of carbon fibres to add strength and stiffness.

Rotor hub 1.37%
- Made from cast iron, the hub holds the blades in position as they turn.

Rotor bearings 1.22%
- Some of the many different bearings in a turbine, these have to withstand the varying loads placed on them by the wind.

Main shaft 1.91%
- Transfers the rotational force of the rotor to the gearbox.

Main frame 2.80%
- Made from steel, must be strong enough to support the entire turbine drive train, but not too heavy.

Gearbox 12.91%
- Gears increase the rotational speed of the rotor shaft in several stages to the high speed needed to drive the generator.

Generator 3.44%
- Converts mechanical energy into electrical energy, both synchronous and asynchronous generators are used.

Yaw system 1.25%
- Mechanism that rotates the nacelle to face the changing wind direction.

Pitch system 2.66%
- Adjusts the angle of the blades to make best use of the prevailing wind.

Power converter 5.01%
- Converts direct current from the generator into alternating current to be exported to the grid network.

Transformer 3.55%
- Converts the electricity from the turbine to higher voltages required by the grid.

Broke system 1.32%
- Disc brakes bring the turbine to a halt when required.

Nacelle housing 1.35%
- Lightweight glass fibre box covers the turbine drive train.

Cables 0.96%
- Link individual turbines in a windfarm to an electricity sub-station.

Screws 1.04%
- Hold the main components in place; must be designed for extreme loads.

Figure 31: Percentage contribution of components in the overall price (EWEA, 2007)
After defining the cost of each step in the process of mounting a wind turbine, I will now proceed with a cost analysis of the power generated by the small wind turbine. This cost analysis would allow me first to forecast if whether or not the money invested in this project will be profitable, and second if it is going to generate a return on investments. This cost analysis will basically include two cities, Ifrane and Taza. We choose Ifrane city since it is the initial place where the small wind turbine was installed, and we would like to compare the same small turbine but in different city, Taza, theoretically speaking we choose this city since it has a national potential in term of wind. In practice, it is not logical to install a small wind turbine (5.1 KW) in a city like Taza because it has a higher wind potential that require larger wind turbine with a capacity of 3 MW which will produce a total of 150MW as stated by the national plan for renewable energies.

So as to perform this cost analysis, a large number of data is required. The first data required is the wind flow speed of the chosen location. For the case of Taza, the required information is provided by the official website of NASA. Concerning Ifrane, there is a luck of data and no written records about wind. That’s why it is necessary to use a software which has record about wind speed in different months. The software I used to extract data is RETscreen4. I used an excel sheet to conduct my cost analysis on the two cities, in this excel sheet I calculated the power production (Kw), energy production (Kwh) and the cost of the energy produced on a monthly basis.

In order to calculate the power production I needed first to calculate the vertical wind profile of the planetary boundary layer. I used the so called Hellmann approach which is a relative approximation, it is defined according to the following formula:

\[
V_{w,h} = V_{w,ref} \left(\frac{h}{h_{ref}}\right)^{\alpha_{hell}}
\]

Where \( h \) is our tower height and we assume it is 24m, \( V_{w,h} \) is the mean wind velocity at an altitude \( h \) and \( V_{w,ref} \) is the wind speed at a reference altitude \( h_{ref} \) mostly considered as 10m. \( \alpha_{hell} \) is the altitude wind exponent (Hellmann-Exponent, the roughness exponent).
The value of Hellmann-Exponent varies according to the following table:

<table>
<thead>
<tr>
<th>Stability</th>
<th>Open water surface</th>
<th>Flat. open coast</th>
<th>Cities, villages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstable</td>
<td>0.06</td>
<td>0.11</td>
<td>0.27</td>
</tr>
<tr>
<td>Neutral</td>
<td>0.10</td>
<td>0.16</td>
<td>0.34</td>
</tr>
<tr>
<td>Stable</td>
<td>0.27</td>
<td>0.40</td>
<td>0.60</td>
</tr>
</tbody>
</table>

In our case we will consider the neutral case in cities or villages (0.34). In the real world a turbine will not be exposed to ideal conditions or the rated wind speed at all times. This means turbines will usually generate only 10% of their rated capacity every hour in low seasons and 40% of their rated capacity every hour in high seasons.

In this study, for Taza I assumed that the high season months are the one with an average wind speed > 7 m/s and low season months are those with an average wind speed < 7m/s. In Ifrane case, I assumed that the high season month are the one with an average wind speed above or equal to 4 m/s. On the other hand the low season months are the one below 4m/s.

The next step is to calculate the power production of our small wind turbine in the two cities along the entire year. To do so, I used the following equation:

\[ P = \frac{1}{2} m_{\text{w,free}} V_w^3 = \frac{1}{2} \rho_w S_{\text{rot}} V_w^3. \]

The surface in our case is a circle so:

\[ S_{\text{rot}} = \pi r^2. \]

3. Results and Discussion

To calculate how much energy a turbine will generate in a month, I multiplied the rated power production by 24 hours, then multiply it again by percentages ranging from 10% to 40%:

Using the excel sheet, I will use 10% for low season and 40% production for high season months.
To calculate the pricing of energy produced per mount in each city, I used the table below provided by the National office of electricity, the monthly energy consummation can be divided as follow:

**Table 3: different tranche of power consumption and their pricing**

<table>
<thead>
<tr>
<th>Power Consumption Range</th>
<th>Pricing (MAD/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 100 kWh</td>
<td>0.901</td>
</tr>
<tr>
<td>101 to 200 kWh</td>
<td>1.0022</td>
</tr>
<tr>
<td>201 to 300 kWh</td>
<td>1.0904</td>
</tr>
<tr>
<td>301 to 500 kWh</td>
<td>1.2903</td>
</tr>
<tr>
<td>More than 500 kWh</td>
<td>1.4903</td>
</tr>
</tbody>
</table>

After achieving all the necessary calculations, using excel sheet (table2&3). I was able to attain some results in order to compare the installation of small wind turbine in Taza city and compare to Ifrane city and come up with some conclusion.

**Table 5: Calculation for Taza city**

<table>
<thead>
<tr>
<th>Months</th>
<th>Wind Speed (m/s)</th>
<th>Vertical wind profil (m/s)</th>
<th>Power production (Kw)</th>
<th>Energy production (Kwh)</th>
<th>Pricing (MAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>5.200</td>
<td>8.350</td>
<td>873.494</td>
<td>2096.485</td>
<td>3124.245</td>
</tr>
<tr>
<td>February</td>
<td>6.500</td>
<td>8.754</td>
<td>1006.516</td>
<td>2415.861</td>
<td>3600.060</td>
</tr>
<tr>
<td>March</td>
<td>7.000</td>
<td>10.100</td>
<td>1546.210</td>
<td>3919.739</td>
<td>5221.645</td>
</tr>
<tr>
<td>April</td>
<td>8.100</td>
<td>10.908</td>
<td>1947.800</td>
<td>4849.684</td>
<td>6786.489</td>
</tr>
<tr>
<td>May</td>
<td>7.900</td>
<td>10.639</td>
<td>1807.033</td>
<td>4574.351</td>
<td>5952.091</td>
</tr>
<tr>
<td>June</td>
<td>10.200</td>
<td>13.796</td>
<td>3389.424</td>
<td>8358.469</td>
<td>11135.520</td>
</tr>
<tr>
<td>July</td>
<td>10.400</td>
<td>14.006</td>
<td>4122.723</td>
<td>9957.197</td>
<td>13398.387</td>
</tr>
<tr>
<td>August</td>
<td>9.900</td>
<td>13.352</td>
<td>3556.234</td>
<td>8719.487</td>
<td>10687.614</td>
</tr>
<tr>
<td>September</td>
<td>8.500</td>
<td>11.447</td>
<td>2350.824</td>
<td>5487.910</td>
<td>7322.269</td>
</tr>
<tr>
<td>October</td>
<td>7.800</td>
<td>10.504</td>
<td>1798.276</td>
<td>4440.947</td>
<td>5893.387</td>
</tr>
<tr>
<td>November</td>
<td>9.700</td>
<td>9.023</td>
<td>1102.924</td>
<td>2645.577</td>
<td>3442.703</td>
</tr>
<tr>
<td>December</td>
<td>5.900</td>
<td>7.946</td>
<td>752.728</td>
<td>1803.559</td>
<td>2692.614</td>
</tr>
<tr>
<td>Average</td>
<td>7.967</td>
<td>10.729</td>
<td>2049.549</td>
<td>4718.452</td>
<td>5982.819</td>
</tr>
</tbody>
</table>

**Table 4: Calculation for Ifrane city**

<table>
<thead>
<tr>
<th>Months</th>
<th>Wind Speed (km/h)</th>
<th>Vertical wind profil (m/s)</th>
<th>Power production (Kw)</th>
<th>Energy production (Kwh)</th>
<th>Pricing (MAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>3.300</td>
<td>4.713</td>
<td>157.141</td>
<td>377.328</td>
<td>436.623</td>
</tr>
<tr>
<td>February</td>
<td>3.500</td>
<td>4.713</td>
<td>157.141</td>
<td>377.328</td>
<td>436.623</td>
</tr>
<tr>
<td>March</td>
<td>3.700</td>
<td>4.963</td>
<td>185.648</td>
<td>445.555</td>
<td>574.895</td>
</tr>
<tr>
<td>April</td>
<td>3.800</td>
<td>5.117</td>
<td>201.111</td>
<td>493.468</td>
<td>599.389</td>
</tr>
<tr>
<td>May</td>
<td>3.400</td>
<td>4.574</td>
<td>141.051</td>
<td>342.906</td>
<td>390.945</td>
</tr>
<tr>
<td>June</td>
<td>3.400</td>
<td>4.579</td>
<td>144.053</td>
<td>345.777</td>
<td>446.591</td>
</tr>
<tr>
<td>July</td>
<td>3.600</td>
<td>4.848</td>
<td>170.998</td>
<td>410.396</td>
<td>529.534</td>
</tr>
<tr>
<td>August</td>
<td>3.300</td>
<td>4.444</td>
<td>131.712</td>
<td>316.110</td>
<td>407.876</td>
</tr>
<tr>
<td>September</td>
<td>3.200</td>
<td>4.269</td>
<td>120.098</td>
<td>288.234</td>
<td>314.291</td>
</tr>
<tr>
<td>October</td>
<td>3.100</td>
<td>4.174</td>
<td>105.187</td>
<td>242.048</td>
<td>298.121</td>
</tr>
<tr>
<td>November</td>
<td>3.400</td>
<td>4.579</td>
<td>144.053</td>
<td>342.906</td>
<td>390.945</td>
</tr>
<tr>
<td>December</td>
<td>3.700</td>
<td>4.963</td>
<td>185.648</td>
<td>445.555</td>
<td>485.833</td>
</tr>
<tr>
<td>Average</td>
<td>3.467</td>
<td>4.665</td>
<td>154.237</td>
<td>361.698</td>
<td>922.421</td>
</tr>
</tbody>
</table>
The two graphs above compare the power production of our wind turbine in the two cities, Ifrane and Taza. As we can see Ifrane’s power production is very low compared to Taza. As a matter of fact the power curve in Taza increases constantly till it reaches a certain maximum of 4122.73Kw during the month of July, afterwards it start decreasing again until it reaches a minimum production of 752.73Kw in December. On the other hand, we notice that the curve for Ifrane is unstable. In other words, there is no high or low season of power production in the case of Ifrane.
The two graphs above demonstrates the energy production resulting from the small wind turbine. We can see that energy production in Taza cities larger than the one of Ifrane city. Where the maximum energy is about 39579Kwh in Taza while in Ifrane it doesn’t exceed 1930Kwh.

With that been said, we can conclude that Taza city has more potential for installing wind turbines, where the average wind speed is 7.9m/s during the year and in Ifrane it is around 3.5m/s. so installing small wind turbine might be beneficial for small communities or homes installed off grid, and since the wind energy just like any other renewable energy, people need to think of backup plans in case there is no wind flow or there are some technical problems in the turbine that would require time to be fixed.
3. RETscreen Software

In 1997, RETscreen program tool was developed by the ‘Ministry of Natural Resources of Canada’. This software is meant to help in order to calculate the wind potential, actual wind energy production of a specific site and other properties. I used this software to simulate my analysis concerning power generation in Taza and Ifrane, and to double check that my results are correct.
So far those are the results I got for Ifrane city, as we can see once the power curve reaches its maximum no matter how much the wind increases the power generated stagnated at 6Kw which is equivalent to the turbine power.

4. **STEEPLE Analysis**

4.1. **Social**

The development of renewable energies is the future for our planet, renewables including wind are meant to produce energy using natural resources which will decrease the price of the power consumption probably since there will be enough resources to accommodate all the demands, which is beneficial for humans.

4.2. **Technological**

Renewable energies nowadays are use more and more, that’s why the market of technology is trying to switch toward those forms of energy and benefit of their usage as much as possible. Currently, wind energy is being used by house off grid in order to provide all the necessary power and energy to the habitants. There are other inventions using wind energy such as: motors, generators, ventomobiles and so on.
4.3. Economical
The proliferation in the use of wind energy in Morocco could be the starting point of a new industry related to the different component of wind turbines such as generators, brake systems, blades. Additionally, if the country attain its prospective in terms of renewable energies, it might be able to the export of some energy amounts, and therefore develop its economy.

4.4. Environmental
The use of wind energy in particular, and of renewable energies in general has a positive influence on the environment all over the world, for the simple reason that those energies are known to be environment friendly, to be more explicit the rate of gas emission is very low.

4.5. Political
In the political sides the development of renewable energies in Morocco allowed the country to benefit from many international alliances, which will lead to the strengthening of relations between our country and other countries.

4.6. Legal
Legally talking, our project need to respect the Moroccan law concerning renewable energies. This later gives directives about the integration of any renewable systems in the national electrical grid and also laws about private projects where the person in charge need to have the approval of authorities before installing any machines.

4.7. Ethical
Concerning the ethical side, it would be more logical to generalize the following idea to any kind of renewable energy. At a certain point in the design phase engineers are required to use some software in order to design their turbine, solar panel, cost analysis. And using unlicensed software is considered as theft which is unethical, and this kind of behavior should be eliminated at work.
5. Conclusion

Renewable energies are the future of our planets, these source of energies allow energy production whiteout emitting any gases to the environment. Several countries around the world are turning toward renewable energies and are trying to make the best out of the nature surrounding them without causing any harm. Concerning the Moroccan context, our country has a huge potential in terms of wind and solar energies. That’s why, it should make the best out of these resources by choosing the right places to install wind farms, and try to extend its relations to the international level so as to benefit from other countries experiences and knowledge in this field. The use of software is highly recommended in order to make the right decision and to have enough proves that the project location, or production are precise. However the wind unlike the sun is unpredictable and varies from one month to another, that’s why the infrastructure and all the costs involved need to take into account those external factors into consideration.
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