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Main Environmental Impacts of Wind Projects: Case of Tunisia

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Abstract
It is well known that the increasing fossil fuel consumption is strongly associated to greenhouse gas emissions. This contributes considerably to the global warming and consequently to climatic changes. As a result, extreme weather events become much more frequent and that significantly affect ecosystems and biodiversity in many regions worldwide. Hence, over the last two decades, many countries have moved towards the use of renewable energy technologies. Among these technologies, wind energy systems take on a remarkable evolution. Nevertheless, the environmental impacts of wind turbines plants are become a big debate topic. This research presents a literature review of the main aspects of this problem and cites the case of Tunisia as an example.

Key Word and Phrases*:*
Wind energy, Turbine, Environment Impact, Tunisia (North Africa).

1. Introduction

Over the last decades, the consumption of fossil fuels resources has grown rapidly. It has affected all human activities areas (industry, transport, agriculture, domestic needs…). Nevertheless, since the fossil fuel resources are limited, they induce some socioeconomic and environmental problems. Furthermore, the environmental impacts of these energy resources are alarming. The increase of carbon dioxide and smaller quantities of other gases in the atmosphere engenders serious climate disruptions. As a result, extreme weather events become much more frequent and that significantly affect ecosystems and biodiversity in many regions worldwide.

Today it is inconceivable to reduce the amount of energy needed to sustain human development. For this reason, there is a trend towards the use of renewable and environmentally friendly energy sources. Among them, wind energy, which is growing noticeably. Cost reduction of wind energy industry over time, makes it particularly attractive and relatively more accessible. The installed wind power capacity reaches more than 282 GW in 2012 and the global wind power market has increased by 19% compared to 2011 [1]. Even so, the environmental impacts of this energy still generating debates. The main purpose of this paper is to introduce the positive and negative key environmental impacts. The analysis focuses on two steps of the wind farms implementation: installation and operating. Environmental impacts to consider in some detail are those related to the greenhouse gas emissions and noise pollution. Other impacts on land management, wildlife, etc.., will be discussed briefly. Along the paper, Tunisia will be cited as an example.

2. Brief Presentation of the Tunisian Wind Farms

Nowadays, there are two wind farms in Tunisia (242,4 MW):

1-Sidi Daoud wind farm (53.6 MW), operational since 2000,

2-Bizerte wind farm (188.8 MW) is spread over three sites: El Alia, Metline and Kchabta and it is operational since the beginning of this year (2013).

These wind farms are located in the North-East of Tunisia, at Nabeul and Bizerte Governorates respectively (Figure 1). The climate in this region is Mediterranean. The annual average wind speed is between 7 and 10 m/s. Prevailing winds are from west to northwest and the windiest seasons are winter and spring [2].

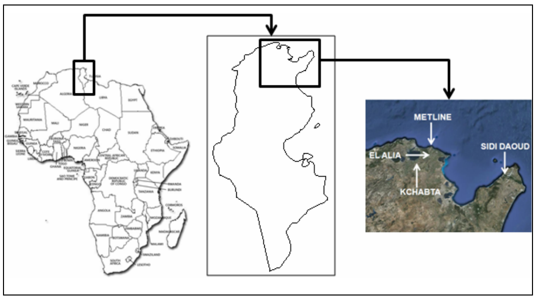

Fig. 1 Tunisian wind farms locations.

All of these parks are set up in rural areas which are devoted for agricultural activities such as farming and grazing. The two wind farms account 213 "Gamesa" wind turbines with a unit power ranged from 330 to 1320 kW. These turbines are arranged in rows roughly parallel and perpendicular to the prevailing wind direction. The main characteristics and distribution of these turbines are summarized in Table 1.

Table 1 Characteristics of wind turbines set up in Tunisia.

Site	Installed power (MW)	Number of Turbines	Unit power (kW)	Rotor Diameter (m)	Load Coefficient (%)	Mast Height (m)	Rotor Speed (rpm)
Sidi Daoud	53.6	32	330	32	30	30	17 to 35
		10	660	46	30	45	17 to 26
		1	800	52	30	50	13 to 26
		27	1320	61	30	60	13 to 19
Metline	95.7	72	1320	61	38	60	13 to 19
Kchabta	93.7	71	1320	61	35	60	13 to 19
Thala [(1)]	60.0	-	-	-	-	-	-
Oum Klil [(1)]	15.0	-	-	-	-	-	-

[(1)] Self production projects of enrgivore company

The Sidi Daoud park area has over 3,500 inhabitants gathered in two main hamlets (Sidi Daoud and Saheb Ejebel) located at about 1.5 and 3 km from the wind farm respectively. However, there are quite a few cottages scattered at distances more or less close to turbines (400-500 m), especially on the North side of the wind farm. The 143 wind turbines of Bizerte Governorate have the same unit power output, 1320 kW. They are spread over three sites (El Alia, Metline and Kchabta) distant from each other by at least 7 km. The spacing between the turbines of the same line is variable from 400 to 600 meters.

The site of Metline is bordered by the sea (to the North), village of Metline (to the East) and by a forest (to the West). The nearest turbine is only at 250 meters from cottages located West of the village. The site of El Alia is more continental, it is located Southeast El Alia city (17,000 inhabitants). The city is also just 400 m from the highway connecting Tunis to Bizerte. Kchabta site is Southwest of the other two sites; it is set up on hillocks of about 400 m in a relatively uninhabited area located East of Ichkeul National Park that is a Natural UNESCO World Heritage since 1979.

3. Reduction of Greenhouse Gases due to the use of Wind Energy

Wind energy plants generate very small quantities of greenhouse gas (GHG) emissions in the order of 13 g/ kWh only (excluding construction process) [3]. That is why they are considered as both renewable and clean. For comparison, thermal power stations emit between 400 and 970 g/kwh GHG depending on the used fuel [4].

In Tunisia, due to the usage of wind energy technology, the CO_2 emissions avoided in 2012 has been calculated equal to 73.4 kTeCO_2. This quantity is of the same order of magnitude as that presented by [5] and the predictions of the Tunisian Company of Electricity and Gas (STEG) [6]. It comes only from Sidi Daoud wind farm (53.6 MW). The startup in 2013 of Bizerte wind farms (188.8 MW) will multiply this amount by a factor of more than 6 (479.2 kTeCO_2).

Avoided gas (GHG) emissions since 2000 (first operation date of Sidi Daoud wind farm) and those projected by the next two years are shown in Figure 2. Predictions are based on realistic projections that are existing wind farms and new self production projects. The 2nd level method recommended in 2006 by the Intergovernmental Panel on Climate Change (IPCC) is adopted for computing [7]. First we start by estimating wind farms electricity generation and then we go back to estimate the avoided GHG quantities and saved fuel. Computations are based on the following assumptions:

- Avoided GHG are those that electrical power plants based on combustion of natural gas would have emitted to produce the same amount of electrical energy produced by wind turbines. In Tunisia, natural gas accounts for about 96% of the fuels used by electrical power stations;
- Given that during the process of natural gas combustion, most of GHG is emitted as CO_2, only this greenhouse gas has been taken into account;
- The amount of burned fuel is obtained based on the electrical stations efficiency.

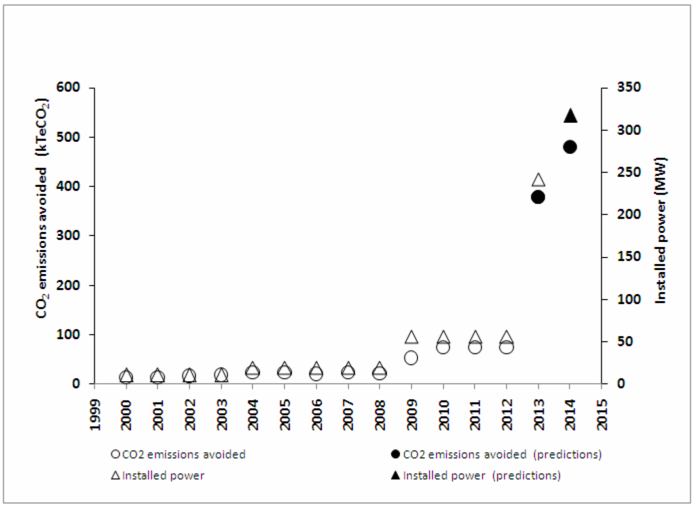

Fig. 2 Installed wind power and CO_2 emissions avoided in Tunisia since 2000.

We note that the reduction of the CO_2 amount is obviously accompanied by a significant fossil fuel economy. The amount of saved fuel that was only 0.53 kTOE in 2000, has became 26.8 kTOE in 2012 and may reach 150.8 kTOE by the year 2014.

4. Noise Impacts of Wind Farms

When operating, wind turbines cause vibrations and therefore emitted noise. This arises from two kinds of noise sources. The first one is mechanical emanating from the gearbox, the generator, the yaw drives, the cooling fans and auxiliary equipment [8]. The second and the most important source, is due to the interaction between the airflow and the turbine (rotating blades and mast) [9]. When rotating, turbine blades generate sounds described as a characteristic "swishing" or "whooshing" sound and when passing in front of the mast, they generate periodic yelps [10]-[11]. The sound intensity emitted by a wind farm varies with the following parameters:

The rotor speed: Theoretically, the sound level increases according to the rotor speed. This means that noise emitted by small wind turbines must be carefully considered, since these kinds of turbines operate at higher speeds in comparison with large ones.

Turbine power: Noise level increases as the turbine power increases. It is in the order of 95 to 110 dB(A) depending on turbine type (Figure 3).

Wind speed: Noise emitted by a wind turbine increases according to wind speed but more slowly than the background noise generated by the wind itself. Generally, wind turbine noise levels are below the background noise beyond a wind speed of about 6m/s, which is a low speed when considered from wind energy point of view. So, for wind speed more than 6m/s, noise emitted by a wind turbine will not be perceived generally (Figure 4).

The number of wind turbines in the power station: Since decibel level is logarithmic, noise level is not additive. When we consider a point located at the same distance from some wind turbines, the resultant noise level is given by the following expression:

$$i_R = i + 10 \cdot \log(n) \qquad (1)$$

i_R: resultant noise level dB(A)
i : noise intensity emitted by one wind turbine dB(A)
n: number of wind turbines

In Tunisia, the average noise levels measured at the close proximity of the wind turbines mast were found to be of about 95 dB(A) for the smallest wind turbines (330 kW) and 105 dB(A) for the largest ones (1300 kW). The propagation of this noise depends on a numerous parameters that interact in very complex ways. These parameters vary considerably with weather, distance to wind turbines, topography, soil roughness and type, vegetation density, etc. It follows that, from an acoustic point of view, each wind farm constitutes a single case for which a specific noise map should be carried out.

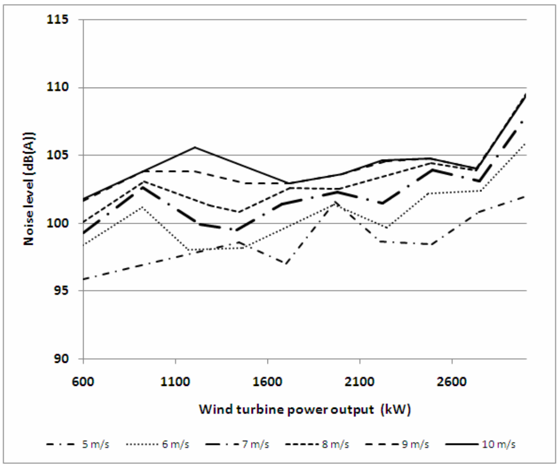

Fig. 3 Noise level as a function of wind turbine power output and wind speed [11].

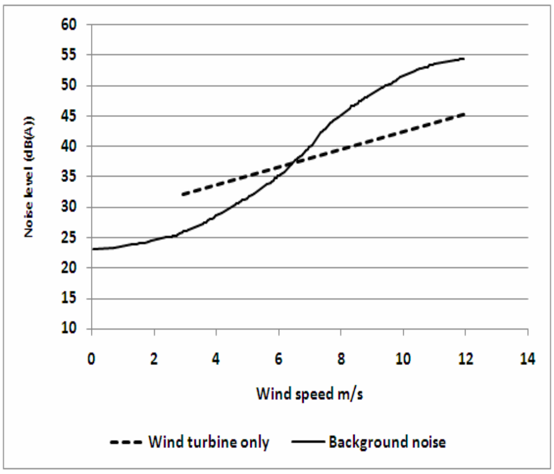

Fig. 4 Background noise and noise emitted by a large wind turbine vs. wind speed [11].

Noise level decreases gradually as the distance from wind turbines increases. The mechanical noise attenuates first and the aerodynamic one thereafter [9]-[10].

Measurements carried out at Sidi Daoud (table 2) show that noise level decreases between 42 and 48% when going away from the wind turbine at a distance equal to 1.5 times the mast height.

The average sound attenuation rate is of about 0.55 dB(A)/m. According to [6], these values are in accordance with the standard "Acoustic noise measurement techniques for wind turbine generator system IEC 61 400 - 11." They are equivalent to the noise level of an office (60 dB(A)) or that of a home mealtimes (55 dB(A)) [6] - [10].

Referring to the curve given in Figure 5, at a distance of 400 meters, which corresponds to the estimated minimum distance between the turbines and the closest houses (except Metline park), emitted noise level is reduced to a value less than 45 dB(A). This is consistent with data for another wind farm given by [12]. This noise level is hardly perceptible. Even the noise impact of the most powerful wind turbines (1320 kW) which emit about 60 dB(A) at 90 meters distance is also insignificant in the sites of Sidi Daoud and Kchabta, given the distance separating turbines from the closest residential properties. However, the situation could be different for sites of El Alia and Metline where some dwelling houses are closer to the wind at 460 and 250 meters respectively.

In addition to the noise emitted by the wind farm, the city of El Alia is also submitted to a noise induced by the highway Tunis Bizerte, which is too near (about 400 m). This particular and complex situation requires a specific acoustic study. However since dwellings location is not in the prevailing direction of wind speeds higher than to 6m/s, the noise emitted by turbines could not give any real nuisance and anyway, it remains masked by the ambient noise [11].

We note, for informational purpose, that for large wind turbines (2.5 MW and more), a minimum distance of 1500 meters is recommended [13]. Moreover, even if the propagation of noise is greater at night than during day, censuses show that any kind of nuisance due to wind turbines is felt indoor, windows closed [11]. Nevertheless, an abrupt starting of turbines can cause sleep disturbances of elderly people and women who are generally more sensitive to intermittent noise [14]. According to the World Health Organization, sleep disruption happens when noise exceeds 35 dB [11] - [14].

Overall, all studies agree on the fact that noise emitted by wind turbines is anyway well below the noise induced by urban traffic and it is not able to induce a extraordinary annoyance to inhabitants, let alone to consider a risk for the auditory canal damage [6] - [11]. However, a negative feeling of disappointment and boredom were observed in several cases. Bearing in mind the above developments, it seems that the undeserved reputation of wind turbines as a noise pollution sources are quite likely due to the downwind turbines that are too noisy but they are less and less commercialized.

In Tunisia, there are no specific regulations on noise pollution caused by wind farms. The existing ones (Decree No. 84-1556 of 29 December 1984) deal with classical industrial activities. They set the maximum emitted noise level (by day) to a 50 decibels, (when measured in front of the nearest residential area). Elsewhere, two approaches are often used to determine the regulatory noise levels emitted by wind turbines. The first approach is based on the ambient noise (the sum of the background noise and the noise emitted by wind turbines), it is adopted for example by Germany and Denmark. The second approach limits a noise level value due to the only effect of the wind turbine. This approach is applied by other countries such as England and France. The threshold levels values in both approaches reveal significant differences.

Table 2 Sound level emitted by wind turbines vs. distance.
(Measurements conditions: Distance: 1.5 mast height, Direction: downwind, wind speed : 5m/s)

Turbine Power (kW)	Sound Power Level dB(A)	Noise level dB (A)	Distance (m)
330	95(c)	< 55	46(1)
660	100(c)	< 55	67(1)
800	102(c)	< 55	76(1)
1000	105	55	100(2)
1000	105	40	500(2)
1320	105(c)	55 to 60	90(1)
3000	105	55	100(3)

(1) Wind turbines installed in Tunisia [6] (2) - [10] (3) - [15] (c) approximate values derived from the curve in Figure 4.

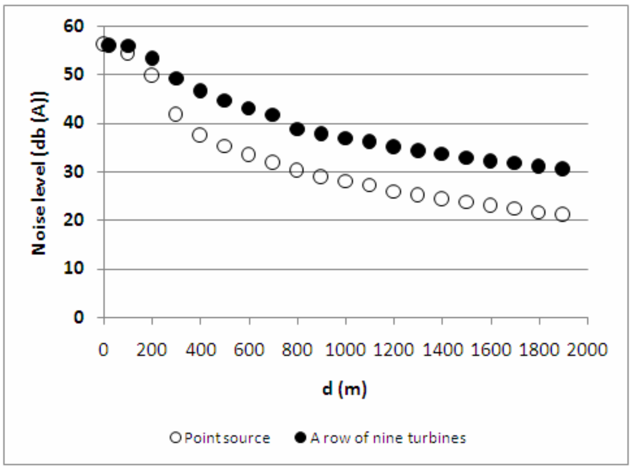

Fig. 5 Noise level as a function of the distance from the wind turbine mast (squares: point sources (one turbine), the diamonds: a row of nine turbines) [11].

5. Other Environmental Impacts of Wind Farms

In addition to GHG and noise impacts, wind farms cause numerous other environmental impacts around which the opinions are divided for various and sundry reasons. Below, some of these very specific impacts of wind energy projects that are collected from various sources are presented briefly.

5.1. Impact of Wind Farms on the Landscape (Aesthetic)

In addition to the annoyance that, in some cases, could be induced by wind turbine noise, another negative attitude towards wind turbines is their unpleasant visual impact on the landscape. Indeed, when wind turbines are erected on hilltop and on areas well exposed to the wind, they become unavoidably visible from kilometers around. Hence, they interfere, some argue, with local landscape aesthetics [16]-[17]. For example this is the case of Kchabta and El Alia sites. Moreover, because tall towers are navigation hazards for aircraft, aviation authorities require obstruction marking. As intended, the flashing lights or garish white and red banding increase the visibility of the turbine; they also increase its intrusiveness [17].

Exceptionally tall towers may also be out of scale with the terrain when they are hidden away behind a relief; this is for example the case of Sidi Daoud wind farm. Nevertheless, this very subjective aspect continues to raise controversy and it is important to have public acceptance. This can be achieved by allowing those people living close to the turbines to own a part of the project and thus share the income [18].

5.2. Footprint of Wind turbines and its Impact on Land Use

In absolute terms, wind farms require more land per unit of power capacity than most energy technologies. However, even if it usually stretches over large geographic areas, the 'footprint' of wind turbines, supporting equipment, and access roads occupies a small portion of the total wind farm area that typically ranges from 1% (Europe) to 3-5% (United States) [19]. In Tunisia the amount of land used by wind turbine system is about 2 to 2.2%. It corresponds to an average amount of 13 to 15 hectares per megawatts. The remaining land could continue its original use that are often agricultural activities grazing, wildlife and forest management. Visits of Tunisian wind farms performed at different periods of the year show that farming activities (agricultural activities and grazing) extend up to the base of the mast. According to [20] if the land is agricultural land, agriculture can continue on over 90% of the land; if it is forestland or wilderness land, then forests and land-based animals can continue to thrive. However, it should be notified that the wind farms seem to devaluate the immovable property (agricultural land, houses) of owners in the neighborhoods. This develops in them a wide sense of injustice and frustration as long as there is no compensation system.

5.3. Stroboscopic Effect (Shadow Flicker) of Wind Turbines

During sunny days, wind turbine blades cast a periodic shadow as blades cover the sun for a brief time. This shadow flicker can disturb people on whom a shadow falls. Only people in less than 300 meters distance from turbines can be affected by this phenomenon, which is more significant during sunrise and sunset [20]-[21]. Rotating speed of modern large wind turbines is less than 35 r.p.m. and that gives shadow frequencies of less than 1.75 Hz, which is below the disturbance critical frequencies ranged between 2.5 – 20 Hz. [21]. According to [21] buildings located at 10 rotor diameters distance from turbines easily avoid any nuisance due to light flicker.

5.4. Accidental Breakage of Wind Turbine

Wind farms are typically located in remote areas and fail usually happens during storms (high winds) when there is even less chance that people are present. This makes the risk of accidents induced by wind turbines very limited compared to other energy sectors. In a summary of wind turbine accidents, [22], reported that the largest number of accidents was from blade failure, and the second accident was from fire. While the most common cause of fatalities being falls from turbines. According to [23], a mortality rate of 0.4 deaths/TWh for the mid-1990s, which dropped to 0.15 deaths/TWh by the end of 2000.

5.5. Impacts on Wildlife

Birds and bats are considered as the main victims of wind turbines. When disturbed, they are subject to collisions with the rotating blades acting as a barrier. However, compared to other human activities fatalities of these species due to wind turbines is low (0 to 3.4 birds, bats /wind turbine a year). Colson [24] quotes an estimated range of bird mortalities from wind-energy development in the USA prior to 1992 in the range of 0 – 0.117 birds/turbine year.

5.6. Wind Turbines: A Touristic Attraction

In Tunisia, Sidi Daoud wind farm is located in wonderful and prominent coastal area and Kchabta wind farm borders the famous ecological national park of Ichkeul. On the other hand, since the wind energy technology and equipment associated are relatively odd, wind farms become an attraction for many people, bringing some additional economic benefits to the populations in the surrounding areas.

6. Conclusions

In this research we tried to present a brief literature review of positive and negative environmental impacts of wind turbines citing Tunisia as an example.

1- Wind energy plants generate very small quantities of greenhouse gas emissions in the order of 13 g/ kWh only. For comparison, thermal power stations emit between 400 and 970 g/kwh depending on the used fuel.

2- In Tunisia, due to the usage of wind energy technology, the CO_2 emissions and fossil fuel economy will reach about 400 kTeCO_2 and 150.8 TOE by 2014.

3- The sound intensity emitted by a wind farm and the propagation of the induced noise depends on a numerous parameters that interact in very complex ways. Generally at a distance of about 500 meters, emitted noise level is hardly perceptible. Overall, all studies agree on the fact that noise emitted by wind turbines do not induce an extraordinary annoyance to inhabitants. However, a negative feeling of disappointment and boredom were observed in several cases.

4- Another negative attitude towards wind turbines is their unpleasant visual impact on the landscape. Nevertheless, the subjective character of this environmental effect around which the opinions are divided for various and sundry reasons should be underlined.

5- The risk of accidents induced by wind turbines are very limited compared to other energy sectors. The largest number of accidents was from blade failure, while the most common cause of fatalities being falls from turbines.

6- In absolute terms, wind farms require more land per unit of power capacity than most energy technologies. However the 'footprint' of wind turbines, occupies a small portion of the total wind farm area that typically ranges from 1 to 5%. In Tunisia this is about 2 to 2.2%. The remaining land could continue its original use on over about 90% of the land. However, it should be notified that the wind farms seem to devaluate the immovable property (agricultural land, houses) of owners in the neighborhoods.

7- In Tunisia, wind farms are located in wonderful and prominent areas. On the other hand, since the wind energy technology is relatively odd, wind farms become an attraction for many people, bringing some additional economic benefits to the populations in the surrounding areas.

8- Birds and bats are considered as the main victims of wind turbines. When disturbed, they are subject to collisions with the rotating blades acting as a barrier. However, compared to other human activities, fatalities of these species due to wind turbines are low.

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