ENVIRONMENTAL CONSIDERATIONS

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INTRODUCTION

Wind farms are not totally devoid of environmental concerns even though they are considered as a green or renewable form of energy. Their locations and the associated electrical transmission lines corridors must be recognized as primarily industrial production sites with multiple hazards that should be located away from human dwellings. Their environmental signatures can be either beneficial or detrimental. Mitigation of the detrimental aspects is the key for humanity to benefit from a carbon-free and abundant source of energy and avoid the emergence of organized resistance to its implementation.

Utility-scale wind turbines have raised concerns about their noise and their effect on wildlife and the environment. With their large rotor blades spinning at high speeds, wind turbines can cause wildlife, such as birds, bats and flying insects' mortality. A study of wind turbines in West Virginia and Pennsylvania found that the 66 turbines at two wind turbines sites caused the death of up to 2,900 bats within a six week period. The noise caused by the wing tips necessitates their siting inland at a distance from human dwellings (Fig. 1). Alternatively, they can be located in offshore (Fig. 2) or remote locations.

Figure 1. Wind farms require special siting considerations such as avian mortality if located along night bird migration routes.

Figure 2. Offshore-sited wind farm with Siemens turbines. Source: Siemens.

The environmental effects of wind power generation cover two phases. The first phase includes the fabrication and installation stage. The second phase includes the operational and maintenance stage.

FABRICATION AND INSTALLATION

Wind machines require fabrication of their components at remote sites and installation and assembly of these components on site. The environmental impacts from the fabricated components are similar to those encountered in the production of steel, concrete, copper electrical parts, heavy industrial bearings and gears. An additional impact arises from the fiber glass construction of the rotors similar to helicopter blades manufacture. The non rotor components will add slightly to the polluting residuals of the involved industries. The ensuing pollution is confined to the manufacturing sites as part of their routine operations.

The on site impacts concerning installation are similar to those encountered in any large scale heavy construction project. These would comprise construction equipment emissions, fugitive dust, heavy equipment noise, soil erosion, streams silting, domestic sewage disposal, and water usage for domestic purposes and dust quelling and solid waste disposal.

The USA Environmental Protection Agency (EPA) has set a zero discharge effluent limitation for the fiber glass industry. A concern is the water/phenolic resin spray step. The resins are non volatile and few vapors would be entrained to the ambient air. The resins applied during manufacturing are fully reactive and present no emission problem.

Six to eight weeks are required for the erection of the steel tower for a 1.5 MW rated power wind machine. Ten to twenty construction workers would be required. This is equivalent to 0.50-1.00 [MW / (person.year)]. This is larger than the 0.12-0.18 [MW / (person.year)] value for a conventional 1,000 MW conventional electric power plant. Impacts on air emissions, water use, effluents, and solid waste production will arise from the resident construction force and families.

OPERATION AND MAINTENANCE

Environmental impacts will arise during the operational lifetime of the machines, and then afterwards after their decommissioning when the system is dismantled and recycled or discarded. Reclamation of the utilized land by removal of the access roads, concrete and steel foundations and the electrical cabling must also be taken into consideration.

Potential operational problems could include:

1. Electromagnetic interference,
2. Mechanical accidents due to tower collapse,
3. Rotor blades failures and ejection,
4. Lubrication oil spills and fires,
5. Micro climate alterations,
6. Soil and floral effects,
7. Avian, bats and insects mortality,
8. Effects on marine mammals,
9. Aesthetic effects.

Conflicts could arise about the regulatory control of wind resources, the safety of wind machines, the use of private or federal lands, and coastal onshore or offshore placement of wind farms.

HEATING EFFECTS ON LOCAL AND REGIONAL METEOROLOGY

Wind farms warm up the surface of the land underneath them during the night. Researchers used satellite data from 2003 to 2011 to examine surface temperatures across as wide swath of west Texas, which is home to four of the world's largest wind farms. The data showed a positive correlation between night-time temperatures increases of 0.72 ^{o}C or 1.3 ^{o}F and the placement of the farms. The study used satellite data, which can introduce errors from clouds, rather than temperature readings taken at the surface.

According to the present installed capacity and the projected growth in installation of wind farms across the world, if spatially large enough, wind farms might have noticeable impacts on local to regional meteorology.

Wind and solar power are good complements to each other. The wind often blows more strongly at night while solar power is only available during daytime hours.

However, the generated turbulence in the wake behind a wind turbine stirs up a layer of cooler air that usually settles on the ground at night, and mixes in warm air that is on top. This layering effect is usually reversed during the daytime, with warm air on the surface and cooler air higher up. This leads to the observation that the land surface temperature over wind farms shows a persistent upward trend from 2003 to 2011, consistent with the increasing number of operational wind turbines with time.

The Federal Aviation Administration (FAA) data shows that the number of wind turbines over the study region has risen from 111 in 2003 to 2,358 in 2011. The resulting warming could hurt local farming operations in adding to the effects of regional droughts and changing local rainfall patterns.

One possible remediation could be to adopt different sizes and shapes for the turbine blades. Smaller diameter rotor blades turbines may avoid this problem, but this presents a tradeoff, since the wind speed decreases as one moves closer to the ground, hence producing less power. This suggests the need to think carefully about the unintended environmental consequences of any large-scale energy development, including green technologies.

SITE SELECTION

The surrounding ecology to wind machines can be significantly impacted if they are placed in forested areas where the tree tops are high enough to interfere with the wind streams or the blade movements. If forest clear-cutting is adopted, severe soil erosion, water sediment entrainment and pollution with resultant faunal and floral habitat destruction ensuing. By siting of wind machines on plains or treeless coastal areas, offshore, or in low topped forested areas, the habitat impact would be minimized.

Figure 3. Wind farms and agricultural activities can coexist.

The land usage for a 1.5 MW wind machine is about 1,000-2,000 [m^2 / MW] or ¼ to ½ [acre / MW]. In principle, a 200 MW wind farm would require a land area of about 100 acres. However, electrical transmission lines, access roads, control and power conditioning facilities surrounding each unit could easily double this area to 2,000-4,000 [m^2 / MW] or 1/2 to 1 [acre / MW] leading to a higher figure of 200 acres for a 200 MW wind farm.

The optimal configuration and emplacement of wind machines depends on the distribution of wind directions at a given site. If the wind blows in a fairly constant direction a suggestion for the spacing between wind machines in the direction of the wind is about 30 rotor diameters. Other distributions of wind directions suggest a longitudinal spacing of 12-20 rotor diameters, and lateral spacing of 2-5 rotor diameters.

MICRO CLIMATIC EFFECT

The velocity of the air stream behind the area swept by the rotor blades is attenuated in comparison to the incident stream velocity. This attenuation covers an area behind the rotor that is larger than the area swept by the rotors themselves.

For a 100 kW of rated power wind machine with a maximum of an incoming 29 km/hr (18 mph) wind speed, the reduction amounts to about 10 km/hr (6 mph). For an incoming wind speed exceeding 40 km/hr (25 mph), the reduction is minimal.

The radius of the affected wake area behind the rotors reaches a maximum of 2.3 m (7.5 feet) wider than the rotor radius. If the rotor is at a 30 m (100 ft) tower, the wake would not reach closer than 9 m (30 ft) from the ground.

Small temperatures reductions of 0.02 ^oC (0.03 ^oF) and pressures reductions of 0.7 mm Hg can be expected at the point of maximum wind velocity reduction. Estimates for larger wind machines have not been attempted and need to be estimated.

Wind systems would act as wind barriers. Wind barriers were built in the Great Plains in the USA after the Dust Bowl period to reduce wind erosion and soil evaporation, and to increase soil temperature. These are all beneficial effects.

Lowered wind speeds, on the other hand, can lead to frosts formation due to decreased water evaporation. Ice can form on the blades then fall in the vicinity of the tower. Ejected missiles of chunks of ice can fly and impact neighboring structures or moving vehicles. Snow drifts and rain can accumulate in the wake of wind machines.

Frost events generally occur during very low wind speeds of less than 3 miles per hour to calm wind conditions. During windy conditions, local micro scale weather conditions do not set up due the mixing effect that winds have on the atmosphere. For wind turbines with a cut-in wind speed of about 9 miles per hour, they will not be in operation during weather conditions favorable to frost formation.

It should be ascertained that the wind speed reduction occurs at points that are high enough above ground to lead to significant impacts.

CROPPING EFFECTS

Wind turbines create a turbulent wake that is 250 ft high and extending ¼ mile downwind. They help moderate ground level temperatures for the growing crops. They would blow away excessive moisture that would favor the growth of fungi. By stirring up the air, they expose the plants to photo synthesis growth-promoting CO_2. Wind turbines would keep the crops warmer in the fall and spring, preventing early and late frosts, and cooler on hot summer nights. These subtle effects are beneficial in general.

However, under drought conditions, they may have negative effects by drying the surrounding air through excessive air circulation near the ground surface.

FAUNAL EFFECTS

INTRODUCTION

Problems arose at some early wind farms that were sited in locations where large numbers of birds congregate, especially on night migration routes. Such problems are now rare, and it must be remembered that many other activities cause far more casualties to birds, such as the motor vehicle collisions with flying birds and feral cat and animal predation.

Investigations are carried out to ensure that wind installations are not sited too close to large concentrations of birds nesting sites. Most birds are capable of avoiding obstacles and very low collision rates are reported.

Large scale use of wind machines increases the probability of fatal collisions involving insects, bats, birds and flying species in general. Large bodies like birds will be virtually unaffected by the drag forces generated by the airfoils, whereas small size organisms such as butterflies and moths and other flying insects will probably be affected.

The size and high altitude of wind machines makes them potential obstacles to birds’ migration paths, particularly under adverse weather conditions such as fog, poor visibility or darkness. Without evasive action, 8 percent of the birds flying through the blades rotation area will be struck. Machines sited out of the migratory bird paths of lower flying song birds will present minor hazard. Wind machines with maximum vertical blade tip extension of 91 meters (300 ft) above ground should present little hazard to flying waterfowl.

A suggestion can be advanced to reduce the rotational speed as well as the number of rotor blades from three to two in areas of large birds congregations. Markings on the rotors have been used as a visual warning to flying species.

BAT MORTALITY

A report by the National Research Council, the research arm of the USA National Academy of Sciences on the environmental impact of wind power suggests birds have far more to fear from high-rise buildings, power lines and feral wild cats than they do from the rotating blades of wind generators.

However, North America's bats might face another hazard. Bats might be at risk in the southwestern USA and elsewhere, where reliance on wind power has been growing. The wind power turbines generate sounds and, possibly, electromagnetic fields that lure the acoustically sensitive creatures into the spinning blades.

Most of the concern about the environmental effects of wind generators has focused on birds, but the report's statistics showed that wind turbines hardly make a dent in the bird population, which, it noted, faced greater danger from feral cats and other hazards.

Analysis of bat kills amidst wind stations in the Middle Atlantic States revealed more victims than were expected. The species impact could be significant partly because of an unrelated decline in the populations of several species of bats in the Eastern USA.

In the eastern USA, up to 41 bats are killed annually for every MW of wind power installed along forested ridge tops.

In Midwestern and Western states, the number is lower, no more than 9 dead bats per MW per year. Poor statistics about the size of bat populations, which are notoriously more elusive than birds, make it hard to estimate how severely such kills affect bat populations.

A panel of scientists, chaired by botanist and ecologist Professor Paul Risser of the University of Oklahoma, cited 11 hypotheses for why bats are attracted to wind generators. Among the more unusual possibilities is that the machines generate sounds, heat and electromagnetic fields that lure the creatures. Curiosity may have killed the bats: "Because bats are curious animals, they may be killed as they explore novel objects in their environment." Another possibility involves lung collapse of the bats in the area of reduced pressure behind the turbine hub.

The report noted that to date, no evidence exists that a single member of an endangered bat species has been killed by a wind generator. However, the statistics may not be complete, because when researchers sought dead bats around wind machines, bat corpses may have been missed or already absconded by predators. The report calls for additional research into the problem, including the hypothesis that newer wind machines with fewer but longer rotors would kill fewer birds and bats.

AVIAN MORTALITY

In the USA in 2003, wind generators accounted for only 3/1000 of 1 percent of bird killings, which amounts to about 37,000 birds. That same year, as many as a billion birds died in collisions with tall buildings, and electrical power lines may have accounted for more than a billion more deaths. Domestic and feral cats were responsible for the demise of estimated hundreds of millions of song birds and other species every year.

Figure 4. Avian raptors mortality from wind turbines, Spain.

The report expressed concern about possible impacts from wind turbines on local bird populations, especially peregrine falcons and other raptors that are attracted to windy brush areas with high rodent and mammal populations where the generators are likely to exist, and called for additional study. The truss construction of wind turbine towers in these areas encourages bird nests construction and has been substituted with the more expensive conical steel construction that totally prevents nesting.

Raptors are lower in abundance than many other bird species, but have symbolic and emotional value to many Americans, with the Bald Eagle as their national bird, and are protected by federal and state laws.

BIRD COLLISION PROBABILITY

The probability of a collision between a flying species and the blades of a wind machine is dependent upon several factors:

1. The airfoil design of the wind machine and the blade thickness.
2. The number of flying organisms flying through the area of the disc swept by the rotors.
3. The behavior of the organism within the disc area: whether it can adopt an evasive action or not.
4. The solidity of the rotors design or their number.
5. The rotational speed of the rotor blades.

Assuming that the flying organism does not take an evasive action but avoids only the visible interior sweep area, it can only be hit by the blade tip. If the angular velocity of the rotor is ω [revolutions / sec], the sweep time for a full revolution of a single blade is:

$$t_{\text{sweep}} = \frac{1}{\omega} \tag{1}$$

For an n blade turbine the intersect time is reduced by the number of blades n as:

$$t_{\text{interesect}} = \frac{1}{n\omega} \tag{2}$$

If the velocity of the flying object perpendicular to the blades planes is V_P [m / sec] and the depth or thickness of the blade is x [m], the transit time through the plane of the blades is:

$$t_{\text{transit}} = \frac{x}{V_p} \tag{3}$$

The collision probability between a flying object and the rotating blades tips becomes:

$$P_{\text{collision}} = \frac{t_{\text{transit}}}{t_{\text{intersect}}} = \frac{n\omega x}{V_p} \tag{4}$$

The larger the number of blades n, the angular velocity ω and the thickness of the blades x; the larger the collision probability. On the other hand, the larger the speed of the flying bird V_p, the less the collision probability.

The collision probabilities for insects would be much less than for birds since insects will be affected by the airfoil drag forces forcing them to pass around a blade rather than collide with it.

Birds can also collide with the structural towers of the wind machine. The probability of collision with the structural tower depends on its location relative to the flight paths of the birds such as the migratory paths. The number of birds killed N_k from a migrating flock of size N would be proportional to the size of the flock N, as well as the probabilities of collision with the structural tower P_{tower} and with the tips of the rotating blades $P_{\text{collision}}$:

$$N_k = C.N.P_{tower}.P_{collision} \tag{5}$$

The proportionality constant C depends on night or daylight conditions, visibility, weather conditions, prevailing winds, and whether evasive action is possible or not.

Table 1. Avian mortality from different sources.

Structure	Bird deaths /year
Vehicles	$60\text{-}80 \times 10^6$
Buildings and windows	$98\text{-}980 \times 10^6$
Power lines	$4\text{-}50 \times 10^6$
Wind generating facilities	$10\text{-}40 \times 10^3$

FLORAL EFFECTS

Plants are not much affected by the presence of wind machines since they are already conditioned to survive in an active wind environment. In a wind farm, in between the structural towers and the access roads, agricultural practices of planting, harvesting or grazing can be pursued unaffected, albeit at a higher degree of complexity.

A possible impact on plant life is the change of moisture deposition patterns downwind from the machines. This would translate into increased moisture in the warm weather period and increased insulation of winter growing crops such as wheat by snow drift deposition. These are both beneficial effects.

Clear cutting of trees may be required in forested areas. The blade tips would reach 15-23 meters (50-75 feet) from the ground. Shrubs and trees below that level can still be left requiring only clearing for the structural towers, power lines and the access roads. In forested areas with tall trees full clearing or at least a minimum clearing area must be adopted equal to the area swept by the blades to avoid undesirable wind blockage.

Other hydrological, soil nutrient, erosion, habitat impacts require site specific environmental evaluations.

Figure 5. Shore wind farm, Scotland.

Figure 6. Great Plains, USA wind farm.

ELECTROMAGNETIC INTERFERENCE

Wind turbines, like other metallic structures, can scatter electromagnetic communication signals, including television signals. Careful siting can avoid such difficulties, which may arise in some situations if the signal is weak. It is usually possible to introduce low cost technical measures for compensation.

Metallic and conducting materials reflect electromagnetic radiation falling upon them such as radio, radar, or microwaves. Clusters of more than one wind machine in a given location may increase the severity of the problem. The reflected radiation may interact with the incident radiation leading to interference. This interference affects the amplitude or intensity of the original signal. The resulting amplitude A_r is a function of the phase difference between the two signals as:

$$A_r^2 = A_0^2 + B_0^2 + 2A_0B_0\cos(\theta_2 - \theta_1) \tag{6}$$

where: A_r is the resultant amplitude,

A_0, B_0 are the amplitudes of the original interacting incident and reflected signals,

θ_1, θ_2 are the original phase angles of the two interfering signals.

A continuous alteration of the incoming signal will be caused by a stationary object such as a structural tower. A moving conducting object such as the lightning protection wiring of the turbine blades would give rise to a continually varying amplitude interference pattern affecting radio and television reception as well as microwave power for cellular phone communications. This varying amplitude pattern causes television pictures breakup when aircraft fly overhead.

Quality radio and television receiving circuitry contain an Automatic Volume Control (AVC) or Automatic Gain Control (AGC) system. It samples the incoming signal and adjusts its amplitude to avoid the fading that occurs in the atmospheric conditions along the signal's path. This system has a long response time in the order of 0.1 second. A sequence of events with changing amplitudes occurring in less than 0.05 second will be passed to the receiver unmodified. Reflections from rapidly moving blades would create amplitude variations that are too rapid to compensate for and will cause reception difficulties. A special faster response system needs to be developed for use in the vicinity of wind farms.

The degree of interference will depend upon the relative strength of the reflected signal to the original signal and the absolute magnitude of the original signal. The observed effects from wind machines blades are:

1. The reflected signal increases proportionally to the absolute area of the rotor blades.
2. Reception difficulties can be experienced 400 meters (1/4 mile) for low frequency VHF TV signals.
3. For high frequency UHF signals difficulties are experienced up to 4,800 meters (3 miles) from the wind machine.

This interference is manifested as dark bands traveling across the TV screen. In Holland wind mills with aluminum rotors are reported to cause interference at a radius of 275 meters (300 yards).

This creates the incentive to use less conducting rotor materials such as fiber glass which would reflect only 40 percent of the signal as metallic blades. Including a carbon layer and a honeycomb structure into the fiber glass could lead to a 20 percent reflection of the metallic blades.

The use of military aircraft stealth technology using cermets and special coatings would virtually eliminate the interference problem, reducing the intensity of interference by 60-90 percent.

Low population density sites would be less affected by the problem eliminating the need for corrective action. In high population areas the use of fiber optics or cabled rather than radiated transmission could be adopted.

FLICKER EFFECT

A potential environmental nuisance consideration of wind farms in flicker generation. Two types of flicker are encountered: reflection and shadow flickers:

1. The Reflection Flicker effect arises by the reflection of the solar radiation by the polished surface of the rotating blades, and can be noticed at a distance.
2. The Shadow Flicker effect can occur as the rising or setting sun shines through the rotating blades of a wind turbine casting intermittent local shadows on area homes.

NOISE GENERATION, WIND TURBINE SYNDROME

Noise produced by wind blowing through trees and brush is noticeable on windy days. The sound produced by operating wind turbines consists of a whooshing sound as the turbine blades move through the air. Most mechanical noise produced within the turbine from the transmission and generator is muted by the design of the turbine enclosure. The only audible noise produced during turbine operation is similar in frequency to natural wind noise.

The noise from wind turbines turbines is of a lower frequency than industrial equipment such as diesel engines. It matches the natural environment less, and therefore is more perceptible to the human ear and more irritating than normal background noises, many of which blend together and mask one another. Lower level Hertz noises are alleged to cause more sleep disturbance, irritation, and health problems than do mid-range noises which are part of our overall environment. Nighttime noise levels in a quiet countryside can be 25-30 decibels blended. Wind turbines, depending on distance away from the home, can approach the 55-60 decibels level. Semi trucks on a highway 1/2 mile away is not going to mask the turbine noise and the semi-truck noise will be intermittent whereas the turbine noise will be nearly continuous. Sleep disturbances were reported in people living in close proximity to turbines. Claims were made about health problems from noise 1.5 miles away.

Planting trees as wind breaks to mask the turbines noise may not be a solution. The trees, if planted close enough, will block the noise from the wind which could be the only factor masking the noise from the turbine. Thus trees planting as a wind break may actually make the noise from the wind turbine more discernible. It must thus be recognized that wind farms are industrial projects to be located away from human dwellings.

“Wind Turbine Syndrome” has been discussed by environmentalists such as Nina Piermont. It is alleged that people with inner ear problems, children with autism, people with epilepsy-type illnesses are more prone to be at risk from living in too close of a proximity to turbines. Low-frequency vibrations in basements which cannot be insulated out were reported. In the UK and other countries people have been driven from their homes by the continuous, maddening sound of turbines. Sleep deprivation was reported as a cause of diminished health.

All sources of power emit noise, and the key to acceptability is the same in every case: sensible siting. Wind turbines emit noise from the rotation of the blades and from the machinery, principally the gearbox and generator.

At low wind speeds wind turbines generate no noise, simply because they do not generate any power. The noise level near the cut-in wind speed is important since the noise perceived by an observer depends on the level of local background noise or the masking effect in the vicinity.

At very high wind speeds, background noise due to the wind itself may well be higher than noise generated by a wind turbine. The intensity of noise falls down with distance and it is also attenuated by air absorption.

The exact distance at which noise from turbines becomes acceptable depends on a range of factors. As a guide, many wind farms with 400-500 kW turbines find that they need to be sited no closer than around 300-400 m to dwellings.

Figure 7. Wind turbines situated close to farm structures.

There are two types of noise generated by a wind turbine: mechanical noise from the gearbox and generator; and aerodynamic noise created by the rotors passing through the air. Progress through technological improvements has practically eliminated mechanical noise. Aerodynamic noise has also improved through better rotor design although it will tend to increase with increasing wind speeds. This is not of great concern since background noise will also increase with increasing wind.

Table 2 compares the sound levels of various items. Notice that the sound level emitted by a 660 kW wind turbine at 200 m or 650 ft is comparable to the noise levels in a normal suburban residential area.

Table 2. Noise level from different sources.

Source	Distance (ft)	Sound Pressure Level dB(A)
Threshold of Pain	-	140
Jet engine	200	120
Freight Train	100	70
Vacuum Cleaner	10	70
Truck at 30 mph	300	65
Busy general office	-	60
Urban residential area	-	58-62
Large Transformer	200	55
Wind in trees	40	55
Normal suburban residential area	-	53-57

Light traffic	100	50
Average home	-	50
Wind turbine, 660 kW	650	47
Air rotor system, 400 kW	800	<40
Soft whisper	5	30
Quiet bedroom	-	20
Threshold of hearing	-	0

The aerodynamic design of the rotor blades tip can reduce the rotor blades generated sound. Ailerons have been used at the rotor tips as well as tapering that eliminates the noise causing vortices, flutter and vibrations at the wind tips.

Figure 8. Tapered rotor tip to reduce the noise effect. Source: Gamesa.

Figure 9. Winglets at rotor tips to reduce the noise effect. Source: Enercon.

VISUAL AESTHETIC CONSIDERATIONS

There is no effective measurable way of assessing the visual effect of large wind farms, which is essentially subjective. Experience has shown that good design fitting the visual background and the use of subdued off white neutral colors is popular. The subjective nature of the question often means that extraneous factors come into play when acceptability is under discussion.

In Denmark and Germany where local investors are often intimately involved in planning wind installations, sensitive siting avoids the most cherished landscapes and ensures that the local community is fully briefed on the positive environmental implications.

Studies asking individuals to view different wind machine designs in different settings and noting their perceptions were done. They included steel truss and cylindrical tower horizontal axis machines, Darrius vertical design as well as the Old Dutch picturesque Holland wind mills. They considered different settings such as mountains, seashores and flat plains. The identified public perceptions include:

1. Sentimental acceptance and preference to the post card Old Dutch design.
2. Preference of the three blade rotors design to the twin blades or single blade.
3. Favoritism to the cylindrical towers design compared with the truss design.
4. An acceptance to pay up to 25 percent more for the electricity generated from windmill compared with other sources.

It is desirable to minimize adverse general reactions of unpleasant combinations of machine shapes configurations or locations for a viable and sustainable use of wind power.

The Avedøre wind farm situated at 5 kilometers from the center of Copenhagen, Denmark is shown in Fig. 10. It consists of 12 Bonus 300 kW wind turbines. These turbines have no emissions and cover a lower profile in the landscape compared with the adjacent 250 MW coal fired power with its high exhaust stack.

Figure 10. Avedøre wind farm compared with coal fired power station, 5 kilometers from Copenhagen, Denmark.

OPERATIONAL LABOR FORCE

A wind machine design life time is 20-30 years. Human labor must be available and settled within an accessible distance of the wind farm for two main functions:

1. Maintenance of components. This team will reside near the wind machines site.
2. Operation and control. This team would reside and operate at a central site which could be remotely located far from the machines.

The size of these crews should be comparable to that used for gas turbine electric power plants. About 0.04-0.07 workers per MW would be required for a 1,000 MW wind farm for a work force of 40-70 persons. Such a work force would result in an air, water and solid waste traditional environmental impact.

SOCIAL, INSTITUTIONAL AND LEGAL IMPACTS

The social, legal and institutional impacts of wind power fall into two main categories:

1. Low population density impacts. These involve larger scale machines in rural areas. The questions arising pertain to the possible effects of weather modification, accidents, electromagnetic wave reception and social problems resulting from a population influx in wind-rich areas where wind machines are likely to be located. Airspace conflicts close to airports and crop dusting airplanes could be avoided with proper siting.

2. High and medium population areas impacts. Questions of wind development and zoning, wind rights aesthetic annoyance, building codes, property damage due to accidents, and utility peak load capacity problems arise. Urban wind machines use implies small wind machines compared with those applicable to rural areas. The use of smaller machines in urban areas could create legal conflicts arising from the ownership of wind rights.

The problem of the wind machines tall structures and airplane safety close to airfields exists in both categories. The issue of offshore siting of wind farms poses its own flavor of problems regarding fishing, boating, and recreation and shore properties values.

During construction, the institutional and legal effects are less than for other energy systems since the manufacturing of most wind machines components is performed at remote factories, and only tower construction and hub and blade assembly are conducted on site.

Wind machines constructed in urban areas will require a backup electrical power supply from a commercial utility, placing on it an additional burden for providing peak power load capability. The capital cost for such peaking capacity could result in unfavorable and inequitable rate structures for non wind energy users.

Once wind machines or farms are built in a location, the population influx will lead to an increased demand for social services including schools, sewers, water supplies, law enforcement, fire fighting, and medical and social services. These impacts should be considered comparable to those generated from other energy sources, and the affected communities should plan accordingly. The benefits accrued from the tax revenue resulting in improved services should be compared to the risks accrued through a meaningful cost/benefit ratio analysis and an environmental impact study.

DECOMMISSIONING ISSUES

The expected operational lifetime for wind machines is 20-30 years. It can be assumed that the tower can remain longer in place with the rotor, transmission and electrical components replaced by more modern components. These would constitute solid waste, even though some parts can be recyclable such as the copper wiring. The tower itself is recyclable into steel. The rotor, steel and composites parts, concrete, asphalt in access roads would be treated as solid waste.

The tower will be subject to corrosion and stress, particularly in shoreline or offshore environments affecting its structural integrity creating an accident possibility as well a hazard to the surrounding ecology. If the wind machine is abandoned after its useful life, an adverse aesthetic impact would ensue if the tower is left standing, and provisions for dismantling it must be taken into consideration. The decommissioning provisions should be included in wind machines construction agreements and contracts. The cost of decommissioning should be a part of the cost of power produced, and the decommissioning costs must be deposited in an escrow account for that specific purpose.

INTEGRATION INTO SUPPLY GRID

Integrated electricity delivery systems in the developed world have evolved so as to deliver power to the consumers with high efficiency. A fundamental benefit of an integrated electricity grid system is that generators and consumers both benefit from the aggregation of supply and demand. On the generation side, this means that the need for reserves is kept down. On the other side, consumers benefit from a high level of reliability and do not need to provide backup power supplies. In an integrated grid system the aggregated maximum demand is much less than the sum of the individual maximum demands of the consumers, because the peak demands come at different times.

Wind energy benefits from aggregation. This means that system operators cannot detect the loss of generation from a wind farm of, say, 20 MW, as there are innumerable other changes in system demand which occur all the time. Utility studies have indicated that wind can readily be absorbed in an integrated network until the wind capacity accounts for about 20 percent of maximum demand. Beyond this level, changes to the operational practice are needed, but no cutoff points exist.

OFFSHORE WIND FARMS EFFECTS ON CETACEANS

Images of offshore wind farms look serene and relaxing. However, the underwater construction required to install these turbines results in noise pollution posing a serious threat to sensitive marine mammals. Cetaceans such as whales and porpoises use sonar for orientation, communicate with one another and locate food sources. Healthy and unhindered hearing is essential to their existence. But the noise created when wind turbine foundations are rammed into the bedrock on the sea floor creates serious problems for them. Young animals can be separated from their mothers, while older animals can suffer hearing loss and disorientation leading to beaching.

Figure 11. Alpha Ventus offshore wind farm, Germany. Source: DPA.

A study of the Alpha Ventus offshore wind farm, some 45 km (28 miles) north of the German island of Borkum, showed that noise from the site's construction was scaring off the local porpoises. During construction, porpoises avoided an area surrounding the construction site of some 20 kilometers, according to assessments made from aerial flyovers.

The guidelines set forth by the German Federal Environmental Agency (UBA), suggest that the noise level outside of a 750 meter radius from the construction site should not exceed 160 dB.

A report by the German Federal Agency for Nature Conservation (BfN) suggests there are both technically and economically feasible ways to reconcile the drive for green energy with protecting aquatic life. One such solution could be to surround wind farm construction sites with “bubble curtains” to suppress underwater noise. This is considered as a helpful but temporary solution, one that should be used until more environmentally friendly less invasive techniques of offshore wind farm installation are developed, such as alternative methods of installing wind farm foundations.

Bubble curtains are generally created by placing a pipe or hose on the sea floor in order to create a ring around noise pollutants such as a pile driver attempting to break through bedrock. Air is pushed through strategically placed and sized holes, creating a shield of bubbles around the noise. As the sound waves pass through the resulting bubble curtain, some of their energy is absorbed. Beyond the bubble curtain, the sound waves become less intense and noise levels are decreased.

If there are animals in the vicinity of a construction site or if there exist weather conditions, like smog or strong rain that make it impossible to tell if the animals are present or not, construction should be delayed as a precautionary principle.

DISCUSSION

No energy source is free of environmental effects, even solar and wind energy. As the renewable energy sources make use of energy in forms that are diffuse, larger structures, or greater land use, tend to be required and attention may be focused on the visual effects. In the case of wind energy, there is also discussion of the effects of noise and possible disturbance to wildlife, especially birds and bats. It must be remembered, however, that one of the main reasons for developing the renewable sources is an environmental one: to reduce emissions of greenhouse gases.

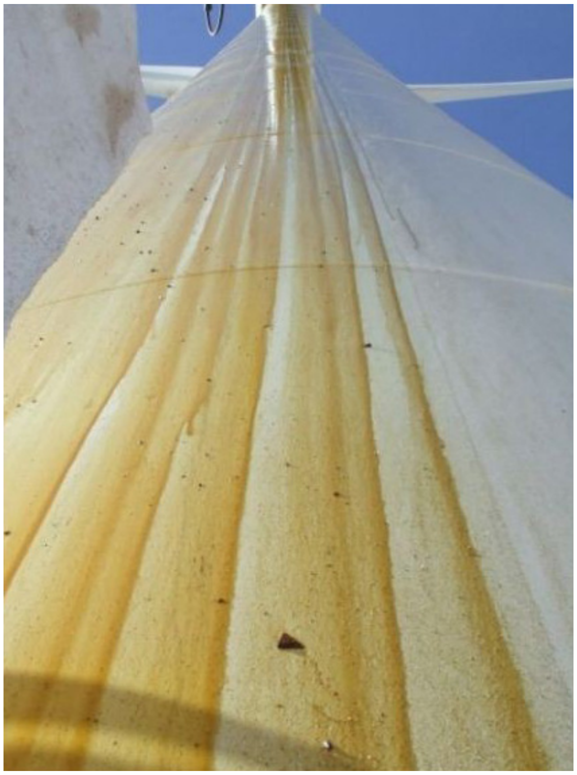

Figure 12. Oil leak from wind turbine at the Aragon province, Spain.

The attractiveness of wind as a source of electricity which produces minimal quantities of greenhouse gases is generating ambitious targets for wind energy in many parts of the world. There have been several developments of offshore wind installations and many more are planned. Although offshore wind-generated electricity is generally more expensive than onshore, the resource is very large and there are few environmental impacts.

As an industrial process, wind energy has its own peculiar environmental effects such as oil leaks and noise and must be considered as such, siting it on specially configured locations away from human dwellings.

Whereas wind energy is generally developed in the industrialized nations for environmental reasons, its attractiveness in the developing world as it can be installed quickly in areas where electricity is urgently needed. In many cases it may be a cost-effective solution if fossil fuel sources are not readily available. There are many applications for wind energy in remote regions worldwide, either for supplementing expensive hydrocarbon power or for supplying farms, homes and other installations on an individual basis.

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