Environmental impact of wind energy

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Environmental impact of wind energy

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A B S T R A C T

Since the beginning of industrialization, energy consumption has increased far more rapidly than the number of people on the planet. It is known that the consumption of energy is amazingly high and the fossil based resources may not be able to provide energy for the whole world as these resources will be used up in the near future. Hence, renewable energy expected to play an important role in handling the demand of the energy required along with environmental pollution prevention.

The impacts of the wind energy on the environment are important to be studied before any wind firm construction or a decision is made. Although many countries showing great interest towards renewable or green energy generation, negative perception of wind energy is increasingly evident that may prevent the installation of the wind energy in some countries. This paper compiled latest literatures in terms of thesis (MS and PhD), journal articles, conference proceedings, reports, books, and web materials about the environmental impacts of wind energy. This paper also includes the comparative study of wind energy, problems, solutions and suggestion as a result of the implementation of wind turbine. Positive and negative impacts of wind energy have been broadly explained as well. It has been found that this source of energy will reduce environmental pollution and water consumption. However, it has noise pollution, visual interference and negative impacts on wildlife.

Contents

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1. Introduction

Due to the economical and technological developments around the world, demand for energy is increasing significantly [1]. The global economy grew 3.3% per year over the past 30 years and energy demand increased 3.6% [2]. World energy production was 17,450 TWh [3] in 2004 and it is estimated that the world will consume about 31,657 TWh in 2030 [4]. According to international energy outlook 2009, world energy consumption will increase from 472 quadrillion Btu in 2006 to 552 quadrillion Btu in 2015 and 678 quadrillion Btu in 2030 – a total increase of 44% over the projected period 2006–2030 as shown in Figs. 1 and 2 [5,6]. Various industries and machineries/appliances used in different energy consuming sectors are releasing contaminated gases to pollute the environment. Global warming and the associated changes in the world climate pattern have been accepted world wide as the gravest threat to humanity in the 21st century [7,8].

It is observed that there are growing concerns about future global energy demand and environmental pollution. To reduce these concerns to some extent, global communities are trying to find and implement different energy saving strategies, technology, and alternative sources of energy for different sectors that rely on energy produced from different sources. In that regard wind energy development will play a significant role to meet future energy demand and reduce environmental pollution to a certain extent. For the wind energy development, the United States passed Germany to become world number one in wind power installations, and China's total capacity doubled for the fourth year in a row. Total worldwide installations in 2008 were more than 27,000 MW, dominated by the three main markets in Europe, North America and Asia. Global wind energy capacity grew by 28.8% last year, even higher than the average over the past decade, to reach total global installations of more than 120.8 GW at the end of 2008. Based on available figures from 11 of the top 15 countries representing over 80% of the world market, WWEA recorded 5374 MW new installed capacity in the first quarter of 2009, equaling an increase of 23% compared with last year in the same countries. Fig. 3 shows a total installed capacity of 152,000 MW worldwide at the end of 2009 [9,10].

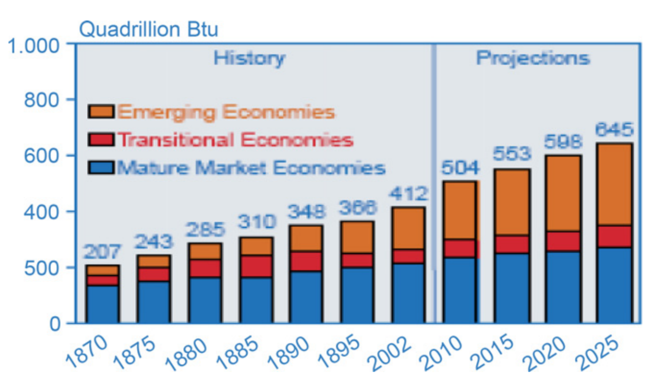

Fig. 1. World energy demand growth [5].

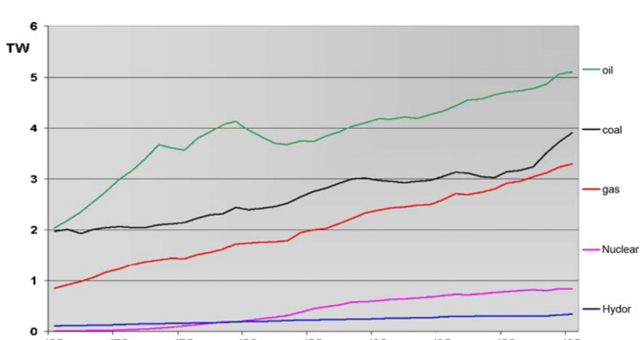

Fig. 2. Rate of world energy usage in terawatts (TW), 1965–2005 [6].

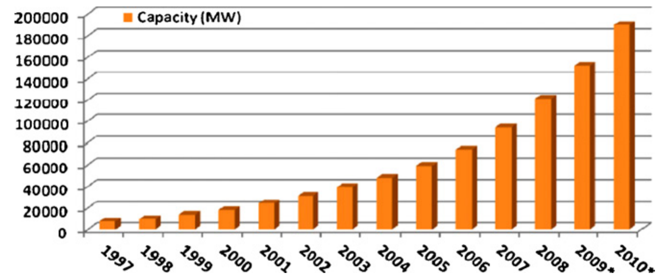

Fig. 3. Total world installed capacity [10].

Wind energy does not pollute the air like thermal power plants that rely on combustion of fossil fuels such as coal or natural gas. Wind turbines do not produce atmospheric emissions that cause acid rain or greenhouse gases (GHGs). Wind turbines can be built on farms or ranches, thus benefiting the economy in rural areas, where most of the best wind sites are found [11,12].

Wind energy is considered as a green power technology because it has only minor negative impacts on the environment. The energy consumed to manufacture and transport the materials used to build a wind power plant is equal to the new energy produced by the plant within a few months of operation. Garrett Gross, a scientist from UMKC in Kansas City, Missouri, states, "The impact made on the environment is very little when compared to what is gained" [13].

A few concerns associated with wind turbines are potential interference with radar and telecommunication facilities. And like all electric power generating facilities, wind generators produce electric and magnetic fields. Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, concerns have been raised over the *noise* produced by the rotor blades, *visual impacts*, and *deaths of birds and bats* that fly into the rotors [14,15]. However, wind may play a role in regional carbon dioxide emission control programs, such as those being developed in New England and California. Fig. 4 shows that wind energy has a low carbon footprint compared to biomass, PV and marine [14].

It may be mentioned that there are number of works on the wind energy development, design, performance, economics, and policy. However, there is no comprehensive work on the environmental impact of wind energy development. It is expected that this paper may fill that gap.

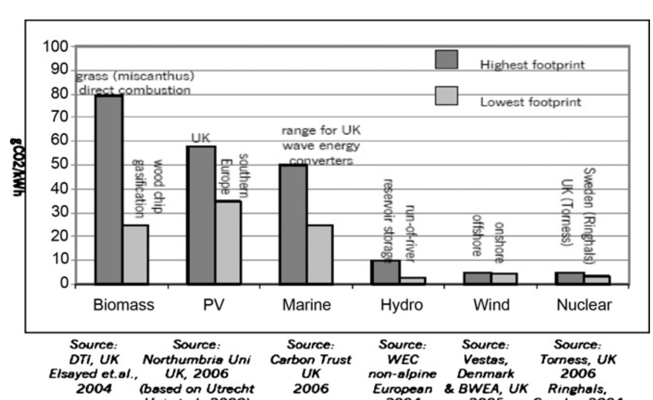

Fig. 4. Range of carbon footprints for UK & European 'low carbon' technologies [14].

Table 1
Comparison of habitat impacts of wind energy to other energy sources [17].

Habitat impacts	Coal	Natural gas	Oil	Nuclear	Hydropower	Wind
Air and water pollution	√	√	√			
Global warming	√	√	√			
Thermal pollution of water				√		
Flooding of land					√	
Waste disposal	√			√		
Mining and drilling	√	√	√	√		
Construction of plants	√	√	√	√	√	√

1.1. Comparison of habitat impact with other energy sources

Table 1 shows the comparison of habitat impacts of wind energy with other energy sources. It has been observed that wind energy has the less habitat impacts compared to others sources of energy. It can be stated that wind energy is the most environmental friendly and the healthiest one compared to other energy sources [16].

2. Positive impact of wind turbine

Energy produced by wind turbines does not produce pollutants like other sources of energy (i.e. coal, gas, and petroleum based fuel). Wind energy may help to reduce the air pollutions by replacing the current sources of conventional energy. As a result, emissions especially carbon dioxide, nitrogen oxide and sulfur dioxide can be reduced. It has been found in the literatures that the emission of these gases is responsible for acid rain and global warming which causes greenhouse gas effect, rise in sea-level, and fluctuating weather conditions. Wind energy is an infinite type of energy that can be harvested either in the mainland or on the ocean. It was estimated that a 2.5 kW system can save 1–2 tonnes of CO_2 and a 6 kW system can save 2.5–5 tonnes CO_2 [18].

In a suitable site, wind turbines represent a relatively low-cost method of micro-renewable electricity generation. They can bring increased security for electricity supply to non-grid connected locations and give some protection against electricity price rises. Renewable Obligations Certificates (ROCs) can be received by generating electricity. These can then be sold to electricity generators to allow them to meet their targets to derive a specified proportion of the electricity they supply to their customers from renewable energy sources [19]. A consumer can benefit from onsite generation of power by qualifying for exemption from the Climate Change Levy. One can also be paid for any surplus of electricity to supply to the grid. According to the fourth assessment report released by the Intergovernmental Panel on Climate Change (IPCC), the warming of the earth over the past half century has been caused by human activities. The main culprits are the greenhouse gases emitted by burning of fossil fuels, in particular carbon dioxide (CO_2). Wind power can provide energy while reducing the emission of CO_2. According to the World Energy Commission, use of one million kWh of wind power can save 600 tonnes of CO_2 emission. Therefore, massive use of wind power will help mitigate climate change. The use of wind power can also avoid regional environmental problems brought about by burning coal [20].

2.1. Reduction of water consumption

In an increasingly water stressed world, water consumption is vital and is a great concern especially for countries like Singapore where clean water is highly valuable and scarce. It may be mentioned that conventional power plants use large amounts of water for the condensing portion of the thermodynamic cycle. For coal power plants, water is also used to clean and process fuel. Amount of water used can be millions of liters per day. By reducing the usage of water, water can be preserved and used for other purposes.

Table 2
Water consumption of conventional power plant and renewable energy based sources [21,22].

Technology	gal/kWh	l/kWh
Nuclear	0.62	2.30
Coal	0.49	1.90
Oil	0.43	1.60
Combined cycle gas	0.25	0.95
Wind	0.001	0.004
Solar	0.030	0.110

Table 3
Reduction of different pollutants [24].

Gases	CO_2	NO_x	SO_2
Reduction on emission per year (short-tonnes)	3251	20	421

California energy commission [21] estimated the amount of water consumption for conventional power plants as shown in Table 2. From Table 2, it has been found that water usage for wind turbine is lower than the conventional power plants and solar energy system.

It was reported that the average amount of water consumption in Malaysia for conventional power plant was about 1.48 l/kWh while wind energy operated power sources used only 0.004 l/kWh for the year 2007[20].

2.2. Reduction of carbon dioxide emission

Generally, wind energy has zero direct air pollution. A small amount of CO_2 emissions is released by the wind energy during its construction and maintenance phases. However, this amount of CO_2 is much less than other fossil-fuel based power plants. This amount of CO_2 produced can actually be absorbed by the tree by the process of photosynthesis. Every unit (KWh) of electricity produced by the wind displaces a unit of electricity which would otherwise have been produced by a power station by burning fossil fuel [17]. It does not produce carbon dioxide, sulfur dioxide, mercury, particulates, or any other type of air pollution, as do fossil fuel power sources [23].

A study by the Irish national grid stated that "Producing electricity from wind reduces the consumption of fossil fuels and therefore leads to emissions savings", and estimated reductions in CO_2 emissions ranging from 0.33 to 0.59 tonnes of CO_2 per MWh [13]. Amount of pollutants that can be reduced is shown in Table 3.

According to data from the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, approximately 67 million tonnes of CO_2 was avoided in 2006 by generating electricity through wind, biomass, photovoltaics and hydropower. Among these few types of electricity generation systems, wind energy plays the most important role [25]. Emission reductions can be calculated using carbon emission factor 640 g CO_2/kWh and following equation [26]:

$$CO_2\ (\text{in tonnes}) = \frac{A \times 0.3 \times 8760 \times 640}{1000} \qquad (1)$$

Table 4
Regional and overall birds fatality rates in United States [27].

Region	Studies	MW	Rotor diameter (m)		Birds/turbine/year			Birds/MW/year		
			Min	Max	Avg.	Min	Max	Avg.	Min	Max
Northwest	4	397	47	65	1.9	0.6	3.6	2.7	0.9	2.9
Rocky Mts.	2	68	41	44	1.5	1.5	1.5	2.3	2.0	2.5
U. Midwest	4	254	33	48	2.7	1.0	4.5	4.2	2.0	5.9
East	2	68	47	72	4.3	0	7.7	3.0	2.7	11.7
Overall	12	787	33	72	2.3	0.6	7.7	3.1	0.9	11.7

where A is the rated capacity of the wind energy development in MW; 0.3 is a constant, the capacity factor, which takes into account the intermittent nature of the wind, the availability of the wind turbines and array losses; 8760 is the number of hours in a year.

A typical turbine was installed in the Perhentian Island currently with a rated capacity of 100 kW and estimated that 168 tonnes of CO_2 can be reduced annually. According to ecological footprint, a forest absorbs approximately 3 tonnes of CO_2 per acre of trees per year [17]. Hence, a 100 kW wind turbine will prevent as much CO_2 from being emitted each year as could be absorbed by 24 acres of forest. While saving about 168 tonnes of CO_2 each year, a 12.5 kW wind turbine still can produce a significant amount of electricity.

3. Negative impact of wind turbine

Besides the positive impact, it is important to study the negative impact of a wind turbine technology. Before any decision is made, the worst condition has to be determined and predicted. By doing this, the damage can be reduced to minimum. The most significant negative impact of a wind turbine technology is the wildlife, noise and visual impact which will be discussed in the following sections. Some other impacts include the distraction of radar or television reception due to magnetic forces generated by the wind turbine, and the increased possibility of being struck by lightning.

3.1. Impacts on wildlife

Many researchers found that wind energy is one of the healthiest and environmental friendly options among all the energy sources available today. Wind energy is the energy source that is most compatible with animals and human beings in the world. However, there are some minor wildlife impacts reported by few researchers. The wildlife impacts can be categorized into direct and indirect impacts. The direct impact is the mortality from collisions with wind energy plant while the indirect impacts are avoidance, habitat disruption and displacement. However, the impacts are smaller compared to other sources of energy [27]. Furthermore, researchers and industries are trying to find protections and preventions for the wildlife impacts of wind energy. Through researches and based on the available evidences, many found that the appropriate position of wind plants do not contribute to a significant number in reduction of birds' mortality. Studies also show that climate changes have much more significant threat to wildlife [28].

3.1.1. Current figure on the accident for wildlife

3.1.1.1. Birds. It is found that birds are one of the largest victim groups in mortality collision of wind turbines around the world [29]. Regional and overall birds' fatality rates in United States are shown in Table 4.

On the other hand, Sovacool and Benjamin stated that wind energy killed about twenty times fewer birds than fossil fuels. The number of birds killed by wind turbines can be negligible compared to other human activities [30].

It was found that out of the total number of birds killed in a year, only 20 deaths were due to wind turbines (for an installed capacity of 1000 MW), while 1500 deaths were caused by hunters and 2000 caused by the collisions with vehicles and electricity transmission lines (they are almost "invisible" for birds [31]).

Table 5
Leading human-related causes of bird kills in United States [24].

Human-related causes	Number of birds kill per year (million)
Cats	1000
Buildings	100
Hunters	100
Vehicles	60–80
Communication towers	10–40
Pesticides	67
Power lines	0.01–174
Wind turbines	0.15

Summing up, it is important to understand that whatever impacts wind turbines have, on the one hand they are very obvious, and on the other hand, it is possible to minimize them through proper design and planning. In contrast, the impacts of thermal or nuclear energy production are slow to appear, are long term and no matter how much effort and money are spent, it is impossible to minimize them. In conclusion, we must decide that if we have to produce electricity, it is certainly preferable to produce it in a way which has the smallest possible impact on the environment. From a technical and economic standpoint, the most mature form of renewable and "clean" energy is wind energy. It can effectively contribute to combating climate change while at the same time providing various environmental, social and economic benefits [31].

Table 5 shows the leading human-related causes of bird kills in United States [32]. AWEA calculates that if wind energy were used to generate 100% of U.S. electricity needs, wind energy would only cause one bird death for every 250 human-related bird deaths with reference to the current rate of bird kills as described in Table 5 [24].

3.1.1.2. Bats. Bats' mortality contributes a significant number due to wind turbine installation around the world [33]. Regional and overall bats' fatality rates in United States are shown in Table 6.

3.1.1.3. Raptors. Table 7 shows the regional and overall raptors' fatality rates in United States. A significantly low number of raptors' fatality compared to birds and bats' fatality in United States is found.

3.1.2. Factors affecting avian mortality

In the installation of a wind turbine, danger to avian is often the main complaint against it. In order to reduce the numbers of avian mortality, we must find out the main reason of the avian mortality caused by the collision of wind turbines [34].

3.1.2.1. Impact of lighting. Studies show that birds may become disoriented in poor weather or foggy night. Subsequently, the avian are attracted to light emitted from wind energy plants which leads to the increasing number of avian fly through the wind plants and their vulnerability from collision with wind turbine blades [35].

Table 6
Regional and overall bats' fatality rates in United States [27].

Region	Studies	MW	Rotor diameter (m)		Bats/turbine/year			Bats/MW/year		
			Min	Max	Avg	Min	Max	Avg	Min	Max
Northwest	4	397	47	65	1.2	0.7	3.2	1.7	0.8	2.5
Rocky Mts.	2	68	41	44	1.2	1.0	1.3	1.9	1.3	2.2
U. Midwest	4	254	33	48	1.7	0.1	4.3	2.7	0.2	6.5
East	2	68	47	72	46.3	28.5	47.5	32.0	31.7	43.2
Overall	12	787	33	72	3.4	0.1	47.5	4.6	0.9	43.2

Table 7
Regional and overall raptors fatality rates in United States [27].

Region	Studies	MW	Rotor diameter (m)		Raptors/turbine/year			Raptors/MW/year		
			Min	Max	Avg.	Min	Max	Avg.	Min	Max
Northwest	4	397	47	65	0.05	0.00	0.07	0.07	0.00	0.09
Rocky Mts.	2	68	42	44	0.03	0.03	0.04	0.05	0.05	0.06
U. Midwest	4	254	33	48	0.00	0.00	0.01	0.00	0.00	0.04
East	2	68	47	72	0.02	0.00	0.02	0.01	0.00	0.02
Overall	12	787	33	72	0.03	0.00	0.07	0.04	0.00	0.09
California	3	~878	13	33	0.15	0.01	0.24	1.37	<0.1	2.24

Table 8
The percentage of birds at different heights of flight [37].

Percentage of birds	Height of flight (m)	Percentage of birds	Distance from turbine (m)
70–75%	<21	74.8–80%	>31
16–17.5%	21–51	5–14.1%	<16

3.1.2.2. Impact of weather. In a study of Gregory et al. [36] it was found that only 3 out of 48 fatalities occur when the weather is not a factor. Although migrating birds generally fly at altitudes higher than 150 m, migrants tend to fly lower during heavy overcast weather such as high winds, low clouds, and rain. This increases the birds' potential of flying through the wind turbines, especially when light attraction may be an issue [36].

3.1.2.3. Tower design. A study [27] found that the relatively high bird mortality at Altamont Pass is due to the large numbers of older wind turbines located there. The design of the majority of these older turbines has lower hub heights, shorter rotor diameters which caused the blades to spin at high RPM, and tighter turbine spacing compared to typical newer wind turbines. Older turbines often have the lattice towers which attract nesting of birds.

3.1.2.4. Height of flight. Sarah and Ellen [37] stated that fewer birds that flew near sites with turbine strings compared to reference sites. Authors found that the birds flying through turbine strings will adjust their flight patterns when turbine blades are rotated. Table 8 shows the percentage of birds at different heights of flight and different distances from wind turbines.

The rotor blade height is normally 21 m and 16–17.5% of birds that flew at this range of height have risks in collision with rotors. About 5–14.1% of birds that flew within 16 m from turbines put themselves in risk of collision with rotors.

3.1.3. Prevention and protection

To reduce the number of avian mortality, prevention and protection must be carried out. If negative impacts of wind energy on wildlife are reduced, wind energy will become more environmental friendly and can be used widely all around the world. New wind projects should be carefully planned to minimize the environmental impact [27].

3.1.3.1. Formation of society to protect bird. In United Kingdom, a society (Royal Society for the Protection of Birds, RSPB) is formed to protect the bird mortality due to wind turbine installment. In California, the wind energy industry joined with other stakeholders such as government officials and environmental groups to form the National Wind Coordinating Committee [27]. These societies are engaged in resolving problems and issues on wildlife associated with wind energy development. They also give funding for researches on wind energy and wildlife issues.

3.1.3.2. Guidelines and consultancy for industry. In United States, the U.S. Fish and Wildlife Service developed voluntary guidelines for the sitting of wind energy facilities. These guidelines make recommendations regarding sitting of the wind plants. However, the wind industries are resisting such guidelines. A wildlife consultant may identify any issues of possible concern. The consultant examines the proposed site and prepares a detailed report on impacts for review for the developer. These surveys reduce the threat to avian to minimal levels [38].

3.1.3.3. Radar technologies. Avian radar was developed for NASA and United States to detect birds as far as four miles away. The system will determine whether the birds are in danger or in safe. If the system detects that a bird is in danger, it will shut down the wind turbines automatically. Once a bird crossed the turbine safely, the system will automatically restart the turbine [39].

3.1.3.4. Improvement of tower design. A new tubular steel tower can be used to substitute the existence of the lattice tower in older wind turbines. The new turbines with tubular steel towers which have smooth exteriors prevent the nesting of birds [39].

3.1.3.5. Researches on turbine lighting. The wind industries are currently consulting with the Federal Aviation Agency (FAA) to reduce the aviation safety lighting on wind projects. The main purpose of this discussion was to ensure that the lighting of the wind turbines do not attract the migrating birds in poor weather or on foggy nights. The minimum lighting is necessary for safety and security purposes and techniques should be used to prevent casting glare from the site [39].

3.1.3.6. Vertical shaft turbines. Study of Cathy [40] showed that vertical shaft turbines are safer and produce twice the energy of prop-style turbine. In addition, their slow turning blades gently generate clean, abundant energy for a revitalized, green Earth. Its design can decrease a bird's mortality from collision of the wind turbine [40].

3.2. Noise impact

The most critical environmental impact of wind turbine is the noise pollution. The effect of noise pollution has the potential to lower property values within a varying radius of the construction. As a result, turbines should be set back from residences and property lines to insulate participating and neighboring landowners from noise and safety concerns. Before building a wind turbine, engineers must be familiar with the types of noise a wind turbine produce.

Noise emitted by a wind turbine can be divided into mechanical and aerodynamic types. Mechanical noise is produced by the moving components such as gear box, electrical generator, and bearings. Normal wear and tear, poor component designs or lack of preventative maintenance may all be factors affecting the amount of mechanical noise produced [41]. Aerodynamic noise is developed by the flow of air over and past the blades of a turbine. Such a noise tends to increase with the speed of the rotor. For blade noise, lower blade tip speed results in lower noise levels. Of particular concern is the interaction of wind turbine blades with atmospheric turbulence, which results in a characteristic "whooshing" sound [42].

Mechanical noise can be minimized at the design stage (side toothed gear wheels), or by acoustic insulation on the inside of the turbine housing. Mechanical noise can also be reduced during operation by acoustic insulation curtains and anti vibration support footings. Aerodynamic noise can be reduced by careful design of the blades by the manufacturers who can minimize this type of noise [43].

3.2.1. Relationship between noise and wind

Wind direction has the tendency to increase noise level relative to the turbine and the receiving point. The highest noise level can be found at the bottom of wind turbine situated with the wind direction from the plant towards the receiving point [44].

Fig. 5 shows the relationship between noise level and wind speed from a wind turbine. The sound level is represented with the L90 metric, which is the best descriptor for the continuous sound from the wind turbine. This example is taken from a site relatively far from the wind turbine, 300 m. The measuring time in the diagram is 2 weeks with varying wind speed levels from 1 to 9 m/s. It can be seen that the correlation between the sound level and the wind speed at this particular site was relatively low. From this figure, it can be seen that wind turbine noise is independent of wind speed for the distance higher than 300 m which also recommended for guideline [44].

A small amount of noise is generated by the mechanical components of the turbine. To imagine clearly, a wind turbine 350 m from a residence is not even noisier than a kitchen refrigerator which is clearly shown in Table 9.

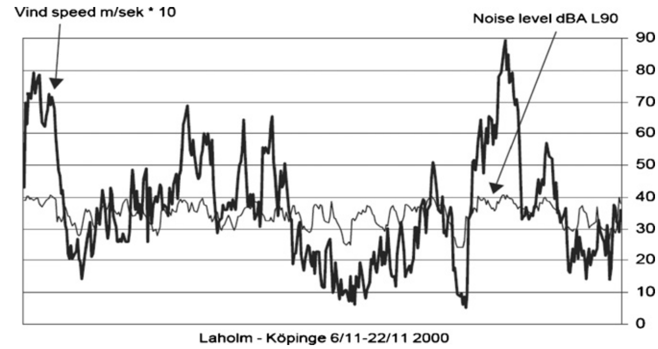

Fig. 5. Wind speed and noise level in dBA L_{90} versus time [44].

3.3. Visual impact

Visual impact assessment has been carried out by Ian [46] to evaluate the negative effect of wind turbine. Authors [47] reported that the visual impact varies according to the wind energy technology such as color or contrast, size, distance from the residences, shadow flickering, the time when the turbine is moving or stationary and local turbine history.

It may be mentioned that most of the visual impact assessment was based on the geographical information system (GIS). When a particular site is proposed, GIS and visibility assessment can help determine the affected areas and the likely degree of the visual impact [48]. The affected areas are called zones of visual influences (ZVIs) under the planning guidelines used in the UK [49]. Levels of impact can potentially be mapped by also taking account of distance and setting as has been used for transmission lines [50].

3.3.1. Color and contrast of wind turbine

Bernd [51] stated that when wind turbines are painted in white (or any grey tone), this will be a minor issue, as lightness will tend to dominate color differences. Basically wind turbines are painted in light grey color to make the turbine blades like skyline. In addition, the color of turbine is made green at the base and gradually changed to grey at top to reduce the contrast levels. This consequently will reduce the visual impact [52]. There is an argument that if the turbine is blended with the skyline color, it may be a cause of killing more birds. Since the effect of the wildlife impact is not evident as compared to the visual impact, it is recommended to choose a color of turbine blended with skyline.

In the paper written by Ian and David [53] it was reported that that the impact level of contrast caused by wind turbine increases with the increase of contrast with the surroundings. Authors also mentioned that the contrast level declines with distance. Certainly, the designer will tend to blend the turbine pixels with the background pixels at the turbine's edges. At larger distances this effect is greater as a higher proportion of pixels are at the edge. The percentage contrast in different conditions is shown in Table 10.

3.3.2. Distance of wind turbine with residential area

Fig. 6 shows the visual impact decreases with the increase of distance of turbine from the residential area.

Table 9
Summary of sound level limits for wind turbines [45].

Wind speed at 10 m height (m/s)	4	5	6	7	8	9	10
Wind turbine sound level limits class 3 area (dBA)	40	40	40	43	45	49	51
Wind turbine sound level limits class 1 and 2 area (dBA)	45	45	45	45	45	49	51

Table 10
Calculated contrast levels under the different conditions [53].

Condition (increasing contrast)	% contrast at 4 km
Deep haze/fog nearly hiding turbines	1.9
Clear air, lighting from behind turbines	9.5
Mid-level haze/fog	7.4
Clear air, lighting from the front	20.5
Clear air, dark clouds behind	27.9

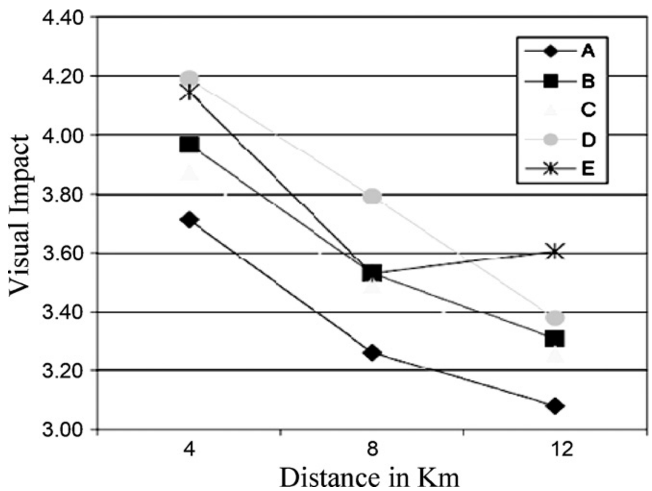

Fig. 6. Graph of visual impact versus distance. The value 3.0 is a neutral response. The five lines represent the different atmospheric conditions as shown in table [53].

Table 11
Intensity of shadow flickering with its occurrence condition [52].

Intensity of shadow flickering	Condition
Higher shadow flickering intensity	• Sunrise or sunset where the cast shadows are sufficiently long • Wind turbine rotor plane is perpendicular to the sun-receptor (rotor diameter) • Larger wind turbine • Smaller distance with resident
Lower shadow flickering intensity	• Wind turbine rotor plane is in plane with the sun (blade thickness)

3.3.3. Moving or stationary blades of wind turbine

The visual impact is influenced by the movement of wind turbine or when it is stationary as discussed by Jaskelevicius and Uzpelkiene [31]. It was found that turbine will create more visual impact compared to stationary condition. Authors concluded that the negative visual effect during the moving condition is lower than that when the blades are stationary. It may be mentioned that when the turbine is moving, the blades can be quite hard to see.

3.3.4. Shadow flickering

In general shadow flickering is produced in two ways: shadow flicker caused by moving blade and the reflection of sun ray on the wind turbine body or so called ‘disco effect’. Shadow flickering caused by the wind turbine is changed with the light intensity caused by the moving blade casting shadows on the ground and stationary objects, such as a house. This will cause the disturbance for residents living in the surrounding area of the turbine. In addition, the reflection of the sun ray shining on the turbine is caused by the periodic flashes of light. This can be minimized by optimizing the rotor blade surface smoothness as well as by coating the turbine with a material having less reflection properties as shown in Table 11.

3.3.4.1. Problems caused by shadow flickering. The problem of shadows caused by wind turbine is not a serious issue because the turbines are relatively small and therefore did not result in long shadows. As the hub-height of the turbine increases, the impact of their shadows increases with it. This leads to significant visual pollution from which the surrounding residents must be protected. This moving shadow, at a frequency of three times of the rotor speeds (where the turbine has three blades), can lead to a pulsating light level especially in rooms which are naturally lit.

3.3.4.2. Solution to overcome shadow flickering. There is a need to minimize the shadow flickering in order to widen the use of wind energy in future. If the shadow at certain area is more than the allowable guideline, one should shut down the wind turbine. This can be done by using a module especially designed for this purpose. Simple module of this type carries out their turbine switching according to a calculated shadow calendar, without taking into account if shadows are really possible at the theoretical times of shadow [54].

On the other hand, modules which use a light sensor would allow the wind turbine which can automatically cause shadow to stay in service on cloudy days but it is only allowed not more than 8 h per year. In addition, turbines can be made to operate in a low noise mode, and a special device can be fitted to switch off the machine for a short period when a shadow flickering may occur.

4. Conclusion

Following conclusions can be drawn from this study:

It has been found that wind energy is clean, environmental friendly, and cheaper compared to other sources of renewable energy. As such this source of energy will protect the earth from the atmospheric contamination. It was also found that water consumption can be reduced with the usage of wind energy compared to petroleum based power plants that produce energy. It was also found that wind energy has minimal impacts on the habitat compared to other sources of energy.

However, energy produced by wind turbine is not free from negative impacts. It has been found that wildlife is killed with the collision of wind turbines in many cases. This source of energy also creates sound noise which is annoying to the vicinity of wind turbine installation project. Visual performance is also interfered by the wind turbine. If wind turbines are designed and planned carefully, many of these negative impacts can be minimized.

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