

European Commission
Directorate-General for Energy

WIND ENERGY - THE FACTS

Volume 4

THE ENVIRONMENT

EXECUTIVE SUMMARY

*"Coal, gas and oil will not be the three kings of the energy world for ever.
It is no longer folly to look up to the sun and wind, down into the sea's waves" [1]*

Benefits of wind energy

Wind energy has a number of important environment benefits. It is a new means of clean, renewable and sustainable electricity generation.

It is also one of the most cost-effective renewable energy options for reducing global warming, resulting in less than 1% of conventional generation CO₂ emissions per unit of electricity delivered.

The plant operating today already avoids over 6,300,000 tons of CO₂, 21,000 tons of SO₂ and 17,500 tons of NO_x emissions per year in the EU alone.

Future capacity will avoid over 28,000,000 tons of CO₂, 94,000 tons of SO₂ and 78,000 tons of NO_x emissions per year outside the EU by 2005. Wind power has the potential to reduce EU power sector CO₂ emissions by over 11% by 2040.

There are other advantages that are relevant to issues rising up the political agenda. Unlike other forms of electricity generation, wind farms do not create any dangerous waste products.

The continuity of fuel supplies is a strategic and economic consideration, wind energy is indigenous, secure and freely available. The preservation of fossil fuel reserves will, in the long term, mean they can be used more efficiently. Wind preserves precious fossil fuels for essential uses in sectors such as transport and petrochemicals.

Effects of wind energy

All power generation has environmental effects, those wind produces are minimal.

About 99% of the land area within a typical wind farm site is available for agricultural or other use. 1,000 modern wind turbines in a 10 x 10 km array could provide 10% of the electricity for a country such as Denmark.

Independent surveys of people living near or visiting wind farms show the majority like them.

Wind turbine and wind farm designers carefully minimise effects such as sound, visibility, shadow flicker and electromagnetic interference.

Production of generating plant uses energy. In 3 to 4 months a modern wind turbine on an average site will generate as much energy as that used to manufacture it.

The cost and logistics of shutting down nuclear or fossil fuel powered stations can be immense and complicated. Wind farms can be decommissioned, and sites fully restored, very easily.

The recyclable content of wind turbines is increasing and more energy can be recovered from, than is used in, scrapping machines.

Planning

Wind farm development is strictly controlled by stringent planning requirements throughout the EU. “Best practice” is widely adopted by the industry as only responsible development can ensure long term success.

Conclusion

Wind energy does not, defer the environmental costs of electricity production to future generations.

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1 INTRODUCTION

Wind energy has many positive environmental facets. Indeed, one of the principal market drivers for wind energy is the fact that it is a clean, renewable and sustainable means of generation. This is especially important in regions such as the European Union (EU) where, in general, adequate installed capacity to meet foreseeable demand already exists. This document provides an objective summary of current understanding of the environmental issues involved in wind energy. Where available, information from authoritative independent sources and various studies funded by the European Commission has been used. Inevitably, however, this has had to be supplemented by the specialist knowledge of experts within the wind industry. It is not a primary objective of this document to criticise other generation technologies, but some quantification and description of their impacts has been necessary to assess the environmental benefits of wind energy.

1.1 Renewables and Energy Conservation

Renewables and energy conservation are complementary rather than competing approaches to the same challenge of sustaining acceptable standards of living and economic performance with greatly reduced environmental impacts. World annual energy demand is predicted by the International Energy Agency to double from the current level of 400 EJ to 800 EJ in 2030 as the developing countries industrialise. It is estimated that 60% of incremental generation in China, India and the former Soviet Union will be coal-fired. Whatever the primary source of energy, it clearly makes both economic and environmental sense to use that energy as efficiently as possible. Decoupling economic performance from energy consumption remains a long term imperative.

1.2 Wind Energy in a Portfolio of Environmental Measures

Wind energy does not purport to be the panacea for a sustainable global energy future. However, independent studies in several EU Member States suggest that wind energy could provide about 20% of electricity generated within the existing transmission and distribution structures, and that the associated capacity value up to these levels is roughly equal to the capacity factor, typically 20-40%. More generally, renewables already provide about 5.3% of primary energy in the EU, the largest contribution being from large hydro schemes. The declared target of the European Commission's Altener programme is for this level to increase to 8% by 2005, while the corresponding target in the Commission's White Paper is 12% by 2010.

1.3 Amenity and Ecology

The discussion of the localised environmental effects of wind energy in this volume will differentiate effects on amenity from those on ecology. "Amenity" in this context includes factors affecting human perception or behaviour. Important among such factors are visual and landscape issues, sound and electromagnetic interference (EMI). Although none of these effects on amenity outlasts the operational life of the development, they are generally at least as significant as effects on ecology in shaping public opinion and determining whether or not a proposed development will receive planning permission.

"Ecology" in this context embraces all direct and indirect material effects upon flora and fauna. Common concerns include birds, rare vegetation types and changes to local hydrology. Regional, national and international land designations indicate where unacceptable effects may be anticipated and often form an integral part of planning guidance.

2 ENVIRONMENTAL BENEFITS

2.1 Avoided Emissions

Every unit (kWh) of electricity produced by wind turbines displaces a unit of electricity which would otherwise have been produced by a power station burning fossil fuel. It is easy to calculate the rate of emissions during the production of electricity from individual coal fired, oil fired and gas fired power stations. However, such rates will vary across the EU with factors such as plant efficiency, abatement measures, operating regime and fuel composition, as illustrated by the estimates of grams emitted per unit of electricity output for fossil-fuelled generating plant in three Member States shown below.

Pollutant	Netherlands (g/kWh)	UK [2] (g/kWh)	Denmark (g/kWh)
CO ₂	872	936 - 1079	850
SO ₂	0.38	14.0 - 16.4	2.9
NO _x	0.89	2.5 - 5.3	2.6
Slag and ashes	N/A	N/A	55
Dust	N/A	N/A	0.1

Table 1: Specific emissions from fossil-fuelled generating plant in three Member States

Specific emissions from conventional power sources are, in general, decreasing due to increases in efficiency and the use of pollution abatement equipment. The consequences of, and counter-measures available to deal with, each type of emission will now be discussed in greater detail.

2.1.1 Avoided emissions of global warming agents

The concentration of atmospheric CO₂ has increased by 25% since pre-industrial times, and it is expected to double by around 2050. The Intergovernmental Panel on Climate Change (IPCC) estimated in 1996 that the global average temperature has increased by 0.3-0.6 °C since 1900, and projects a further rise relative to 1990 of 1.0-3.5 °C (with a best estimate of 2.0 °C) by 2100. Mean sea level is expected to rise by 15-95 cm. Global warming due to anthropogenic emissions is now generally accepted as fact, and IPCC scientists expect major ecological changes to occur.

In March 1997 the European Commission undertook to reduce total EU emissions of greenhouse gases by 15% by the year 2010. This agreement between the EU Member States was conditional upon a similar agreement being reached at the UN Conference in Kyoto (Japan) in December 1997. Figure 1 overleaf shows the targets for each of the 15 Member States within this CO₂ reduction goal.

In the EU, approximately one third of CO₂ emissions come from power generation. For every 1% of conventional generation capacity displaced by renewables, a 0.3% reduction of total CO₂ emissions is achieved.

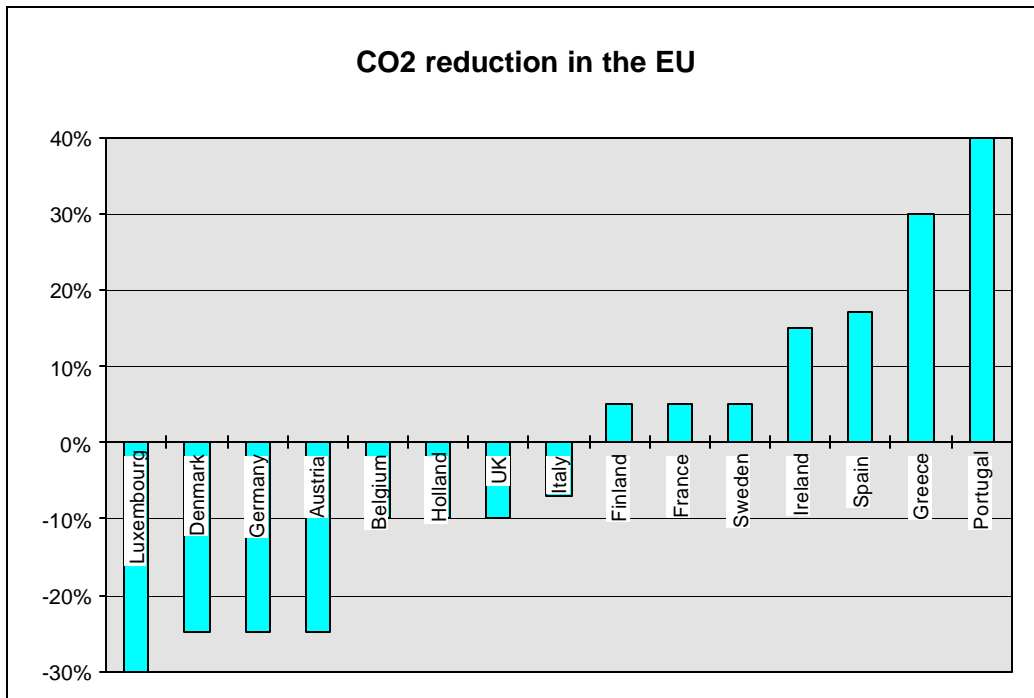


Figure 1: Target CO₂ emissions in 2010 compared with present levels, by Member State

Wind energy offers one of the cheapest renewable energy options for reducing CO₂ emissions from electricity generation, as shown by Figure 2 below.

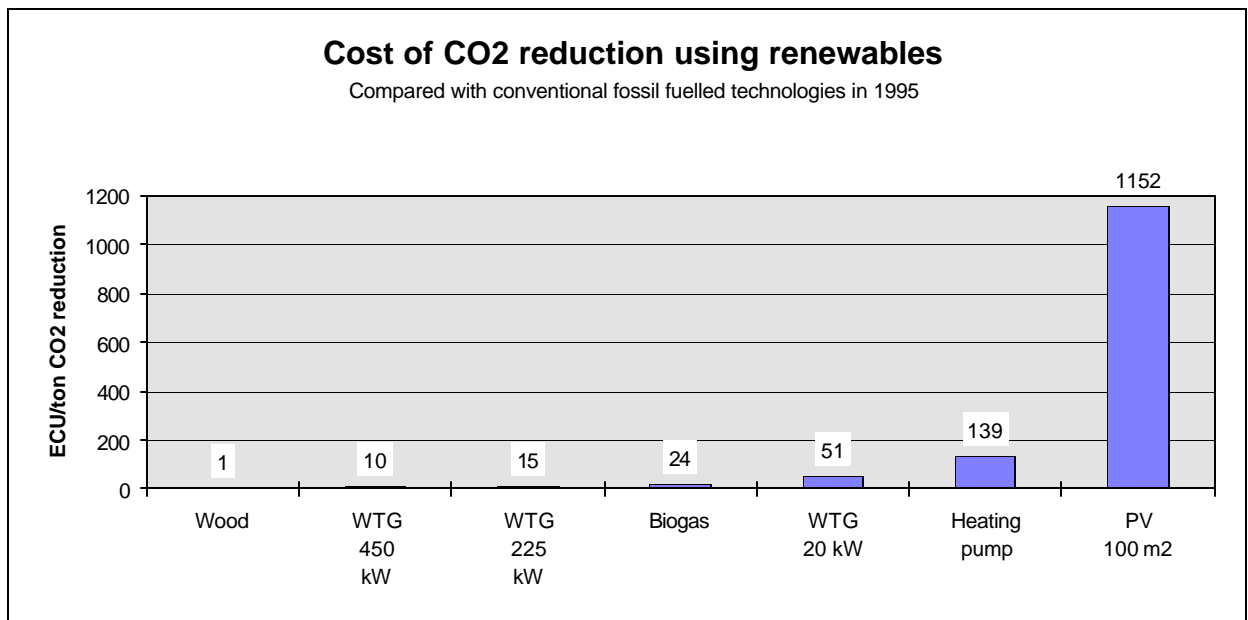


Figure 2: Cost per ton of avoided CO₂ emissions for different technologies [3]

A modern 600 kW wind turbine in an average location will, depending on the site wind regime and hence the capacity factor, prevent the emission of some 20,000 - 36,000 tonnes of CO₂ from conventional sources during its 20 year design life.

Table 2 [4], published in the World Energy Council's 1993 report "Renewable energy resources: opportunities and constraints 1990-2020", compares emissions from different electricity generation technologies.

Technology	CO ₂ Emissions (Tonnes per GWh)			Total
	Fuel Extraction	Construction	Operation	
Coal-fired [5]	1	1	962	964
AFBC	1	1	961	963
IGCC	1	1	748	751
Oil-fired	-	-	726	726
Gas-fired	-	-	484	484
OTEC	N/A	4	300	304
Geothermal	<1	1	56	57
Small hydro	N/A	10	N/A	10
Nuclear [6]	~2	1	5	8
Wind	N/A	7	N/A	7
Photovoltaics	N/A	5	N/A	5
Large hydro	N/A	4	N/A	4
Solar thermal	N/A	3	N/A	3
Wood [7]	-1509	3	1346	-160

Table 2: CO₂ emissions from different electricity generation technologies

Of the four technologies listed above with lower specific CO₂ emissions than wind energy, only large hydro is currently commercially competitive. However, it has been argued in both Canada and Brazil (two countries where further large hydro schemes are planned) that rotting vegetation in dam reservoirs gives off substantial amounts of greenhouse gases [8]. Principal among these is methane which is some 50 times as potent a global warming agent than CO₂. Large hydro schemes are also being abandoned because of their destructive effects on wildlife, habitats and public protest.

No satisfactory or commercially viable means of abating CO₂ emissions from fossil-fuelled plant has yet been devised. The specific emissions of gas-fired plant are approximately half those of coal-fired plant, and the low capital cost of CCGT stations has led to a massive deployment of this technology in recent years. However, it could be argued that it makes little sense to squander a prime fuel on electricity generation at a current maximum of 57% efficiency when it can be used directly for heating at over 90% efficiency.

2.1.2 Avoided emissions of acidification agents

The major quantified effects of acid deposition are upon human health, building materials and commercial forestry, with a smaller effect upon crops. In addition, there are major impacts upon ecosystems, both terrestrial and aquatic, notably in the lakes of Scandinavia. Damage costs derived using previous estimates of acidification equate to approximate values of 6000 ECU per tonne for both SO₂ and NO_x.

Impacts are non-localised in that they may be experienced hundreds, if not thousands, of kilometres from the point of emission. They are not, unlike anthropogenic greenhouse gas emissions, truly global.

Table 3 compares emissions of SO₂ and NO_x from fossil-fuelled generating plant with those from wind turbines. This data was produced by combining the data presented in Table 1 with ExternE estimates for the wind energy life cycle, and is a conservative comparison as the figures for the fossil plant were not calculated on the same life cycle basis but from monitored outputs during the generation process only. Nonetheless, it can be seen that the specific emissions of SO₂ and NO_x from wind turbines are respectively only 0.53-22.9% and 0.68-4.04% of those from fossil-fuelled plant. The large discrepancy between national emission rates is due to a combination of different fuel sources and the more widespread use of flue gas desulphurisation (FGD) equipment in Denmark and the Netherlands.

Pollutant	Fossil-fuelled Plant			Wind Turbines (g/kWh)
	Netherlands (g/kWh)	UK (g/kWh)	Denmark (g/kWh)	
SO ₂	0.38	14.0 - 16.4	2.9	0.087
NO _x	0.89	2.5 - 5.3	2.6	0.036

Table 3: Specific emissions from fossil-fuelled generating plant and wind turbines

FGD increases significantly the capital and running costs of fossil-fuelled plant and thereby the unit costs of electricity generated. The process requires the quarrying of large quantities of limestone which is often located in scenic areas. The waste product is gypsum which, although usable in construction materials such as plasterboard, would be produced in quantities far in excess of foreseeable requirements if FGD was universally implemented and would, therefore, constitute a secondary waste disposal problem.

2.1.3 The benefits of wind energy

Table 4 below summarises some of the avoided emissions attributable to wind energy deployed in the EU as of December 1997:

Parameter	Quantity
Installed capacity	4,425 MW
Energy produced	8,8 TWh/yr
Avoided CO ₂ emissions	7,800,000 tons/yr
Avoided SO ₂ emissions	26,000 tons/yr
Avoided NO _x emissions	22,000 tons/yr

Table 4: Annual avoided emissions achieved by existing wind energy in the EU

Estimates of global onshore availability, assuming 0.33 MW/km² average for land with >5 m/s annual mean wind speeds, indicate that the maximum technical wind energy potential

is about double current global electricity production [9]. Exploration of the offshore potential for wind energy is only just beginning. Closer to home, one of the targets of the Altener programme is to increase EU electricity production from new renewable energy sources from 25 TWh in 1991 to 80 TWh in 2005. Within this target, the goal for wind energy is 8,000 MW of installed capacity which could produce 16 TWh of electricity per year. This would bring a saving of over 14 million tonnes of carbon dioxide per year. Table 5 estimates the avoided emissions in the EU which could be achieved if wind energy was developed in line with the latest EWEA goals. In generating these estimates it has been assumed that specific emissions (Tonnes/TWh) from fossil plant displaced by the wind turbines are reduced across the board by 10% of year 2000 levels each decade thereafter over the period covered. Such assumptions may well be optimistic, in which case the avoided emissions would be even higher.

Year	EWEA Goals for MW installed wind power capacity	Production TWh/year	CO ₂	SO ₂	NO _x
			reduction Tonnes/year	reduction Tonnes/year	reduction Tonnes/year
2000	8,000	16	14,400,000	48,000	40,000
2005	20,000	40	34,200,000	114,000	95,000
2010	40,000	80	64,800,000	216,000	180,000
2020	100,000	200	134,400,000	480,000	400,000

Table 5: Annual avoided emissions achievable by projected wind energy in the EU

The CO₂ emission from power generation in the EU was 973 million tonnes in 1992. According to a conventional wisdom scenario [10] this number is expected to increase to 1,195 million tonnes CO₂ per year, in the year 2020. If the EWEA's goal for wind power development was met by the year 2020, it would be possible to reduce the EU's power sector CO₂ emissions by over 11% using the assumptions described above.

It is estimated that around 16,500 MW of wind power will be installed in non-European countries between 1997-2005 according to prognosis for global wind power development. The environmental benefits in these countries will often be larger since wind power will replace electricity which would otherwise have been produced by highly polluting fossil fuelled power plants. Even using the same assumptions as in Table 5, these avoided emissions would be over 28,000,000 tonnes/year of CO₂, 94,000 tonnes/year of SO₂ and 78,000 tonnes/year of NO_x.

2.1.4 Other avoided emissions from fossil fuels

Other annual emissions from a typical 2000 MW fossil-fuel power station have been estimated as follows:

Pollutant	Conventional Coal (tonnes per year)	Conventional Oil (tonnes per year)	Combined-cycle Gas (tonnes per year)
Airborne particulates	7000	3000	negligible
Carbon monoxide	2500	3600	270
Hydrocarbons	750	260	180
Hydrochloric acid	5000-20000	negligible	negligible
Solid waste and ash	840000	negligible	negligible
Ionising radiation (Bq)	10 ¹¹	10 ⁹	10 ¹²
Trace elements		Depends on source	

Table 6: Emissions from typical 2000 MW fossil-fuel power stations [11]

Carbon monoxide blocks oxygen transport in the blood and seriously affects the ability of the atmosphere to remove other pollutants since it reacts with the hydroxyl radicals which normally do this. Another combined effect of pollutants is the formation of photochemical smog when polluted air is trapped at the surface of the earth by a temperature inversion. Reactions between nitrogen oxides and hydrocarbons, initiated by sunlight, form ground-level peroxyacyl nitrates and ozone. These are highly reactive chemicals which cause eye irritation, lung damage and may contribute to lung cancer. They also reduce crop growth and damage materials such as rubber.

Finally, coal mining is still a dangerous job. Mining produces ugly spoil heaps, causes land settlement, alters groundwater flow and pollutes water. Oil extraction can pollute groundwater, and oil spills are enormously damaging to marine and coastal environments.

2.1.5 Avoided concerns related to nuclear power

Nuclear power is in decline as it is no longer popular and is recognised as expensive. There are still areas of concern about nuclear power generation, as noted by the WCED [12] :

- the safe disposal of nuclear waste produced both during the fuel cycle and decommissioning
- the release of radiation following major accidents

In contrast, wind energy does not create any dangerous waste products. No member of the public has been injured by wind energy installations, and there is zero risk of large scale catastrophic accidents being caused by wind turbines.

2.2 Avoided Consumption

2.2.1 Fossil fuel reserves

Recently estimated conventional fuel reserves are as shown below. The accuracy of these data are limited since new resources are found every year and new technologies makes it feasible to recover these resources economically from new locations.

Fuel	Proven Reserves (GTOE) [13]	Life at 1996 Extraction Rates (Years)
Coal and Lignite	630	235
Oil	141	43
Gas	129	66

Table 7: Estimated fossil fuel reserves [14]

Events such as the 1973 and 1979 Middle East oil crises, the 1984 UK miners' strike and the Gulf War in 1991 focused attention on the vulnerability of conventional fuel supplies. The cost of fuels will increase sharply when demand outstrips availability, and the costs of fuels will inevitably rise as reserves are extracted in economic merit order. Gas offers only short term amelioration of greenhouse gas emissions. Developing countries are industrialising largely along similar conventional generation lines to the EU. China, for example, is installing new, mainly coal-fired, plant at an average rate of 300 MW per week. While new reserves continue to be discovered, they cannot keep ahead of demand indefinitely. Current rates of use are approximately 300,000 times greater than the rate at which fossil fuels are naturally created. Conventional fuel use will continue for many years to come but is ultimately unsustainable.

In contrast, wind is an indigenous, secure, sustainable and freely available resource. Wind energy can therefore contribute to security and diversity of energy supply in addition to reducing harmful atmospheric emissions.

2.2.2 Essential uses of fossil fuels

There are many alternative means of generating electricity. Substitution of fossil fuels, especially oil, in the rapidly growing transport sector of energy demand is, as noted earlier, far more problematic. Oil derivatives in the forms of petroleum, diesel and kerosene will remain the principal fuels for land, sea and air transport for several more decades. Longer term alternatives for land and sea transport include batteries, fuel cells and, perhaps the most promising and sustainable option, hydrogen. Wind energy could provide the electricity required to charge batteries and electrolyse water to generate hydrogen on a large scale, but some form of strategic intervention will be required to bring about such fuel switching. An even more essential use of fossil fuels is as petrochemical feedstocks for processes as diverse as the production of plastics and the manufacture of steel. No known substitutes are available. In this context, combustion of these essential materials to generate electricity at relatively low levels of efficiency may be judged to be short-sighted. Wind energy, as part of a portfolio of non-fossil generation technologies, has the potential to prevent a long term "feedstocks crisis".

3 ENVIRONMENTAL EFFECTS

Extensive reference is made throughout this section to the findings of the “ExternE” exercise[15], supported by DG XII of the European Commission and the US Department of Energy, which evaluated the external costs of a variety of energy production methods including wind energy. Public perception of wind farms is equally important but, being determined at least as much by attitude and predisposition as by facts, is more difficult to quantify.

3.1 Amenity

3.1.1 Land use

About 99% of the land area on which a typical wind farm is sited is physically available for use as before. Wind turbine foundations, though about 10 m in diameter, are normally completely buried, permitting any existing agricultural activity to extend right up to the tower base. There is no evidence that wind farms interfere to any greater extent than this with arable or livestock farming. Wind energy is, nonetheless, a relative diffuse primary energy source, but any valid comparisons of land use with other means of generation must take into account the total fuel cycle in each case, as shown in Table 8 below:

Generation Technology	Land Required per GWh for 30 Years (m²)
Geothermal	404
Wind	800 - 1335
Solar Photovoltaic	3237
Solar Thermal	3561
Coal	3642

Table 8: Land required per GWh for 30 years by generation technology[16].

A large proportion of the land area utilised for coal-fired generation is accounted for by mining and transportation activities located far away from the power stations themselves.

The 4300 wind turbines installed in Denmark by the end of 1997 produced as much electricity as the total consumed in Denmark in 1952. Over 7% of the national electricity consumption in Denmark is now supplied by wind energy and the country is well on its way towards the national target of 10% of electricity consumption being supplied by wind energy by the year 2005. This target could now be reached with approximately 1000 state-of-the-art wind turbines due to technological improvements and larger machine sizes. The land area required would be approximately 100 km² of which only around 1% would be utilised for the wind turbine foundations [17].

3.1.2 Visual amenity

Wind farms must be in exposed areas in order to be commercially viable. They are therefore visible. The reaction to the sight of a wind farm is highly subjective. Many people see them as a welcome symbol of clean energy whereas as some find them unwelcome additions to the landscape. This subjective nature of the reaction is illustrated by the failure of the ExternE study to quantify an external cost associated with visual impacts.

A survey conducted by AKF in Denmark [18] estimated the costs of sound and visual impact from wind turbines to be minimal - less than ECU 0.0012 per kWh of electricity produced. The survey was primarily based on interviews with 342 persons living close to wind turbines in which they were asked how much they would be willing to pay to get the wind turbines removed. To check the results of the interviews, the prices of 74 houses situated close to wind turbines have been compared with those of similar houses situated elsewhere.

Understanding of the broader environmental benefits of wind energy tends to improve the public reaction to a wind farm. The industry has devoted considerable effort to careful integration of developments into the landscape. Computer-generated photomontages, animations and even fly-throughs, together with mapped zones of visual influence, provide objective predictions of appearance. A 1.5 MW turbine looks little different from a 500 kW machine, so the continuing trend towards larger wind turbines may, paradoxically, reduce the subjective visual effect of a given installed capacity.

It is well documented [19] that the overwhelming majority of visitors to wind farms are favourably impressed, and it is not unknown for developers to bus sceptical local planning officials to a real wind farm with very positive results! Independent opinion polls have confirmed that the fears of some local residents at the planning stage have swung to overwhelming support after commissioning. Surveys from other European countries indicate very similar levels of support.

A typical wind turbine used for large scale grid-connected electricity generation is rated at around 600 kW, is supported on a 40-60 m tower, and has a three bladed upwind rotor with a diameter of 42-48 m. Although the trend towards larger machines is continuing, this configuration is likely to remain the most popular in the market, especially in areas with a high density of population for the following reasons:

- three bladed rotors turn more slowly than two bladed rotors and the sound effect will therefore in general be less
- two bladed rotors appear to tilt with respect to the horizon whereas three bladed rotors appear to revolve and are therefore more calm and pleasant to view
- the general public is becoming accustomed to a norm of appearance

Most wind turbines are today being installed on a tapered tubular steel tower which most people find more aesthetically pleasing than the lattice towers more widely used in the US. Professional designers have been used by several wind turbine manufacturers to enhance the appearance of their machines.

Landscape architects are usually involved in the visual assessments of new projects. The untidy appearance of early US developments has not been, and will not be, either proposed or accepted in the EU.

The effects of the periodic reflection (glinting) or interruption (shadow flicker) of sunlight have been addressed by careful consideration of machine siting and of the surface finish of the blades. These phenomena are entirely predictable and their amelioration is easily integrated into wind farm design at the outset. They only occur during periods of direct sunlight, and are therefore not a problem when the sunlight is diffused by clouds.

The figure below shows an example of the calculation of the shadow flicker effect. This figure has been constructed for Denmark. The results would vary for different countries due to the different allowances for cloud cover and latitude. There are two houses in the picture marked as A and B which are respectively 6 and 7 hub heights away from the turbine in the centre. The diagram shows that House A will experience a shadow from the turbine for 5 hours per year. House B will experience a shadow for up to about 12 hours per year. The seasonal variation is also included in the calculation but is difficult to show without undue complication.

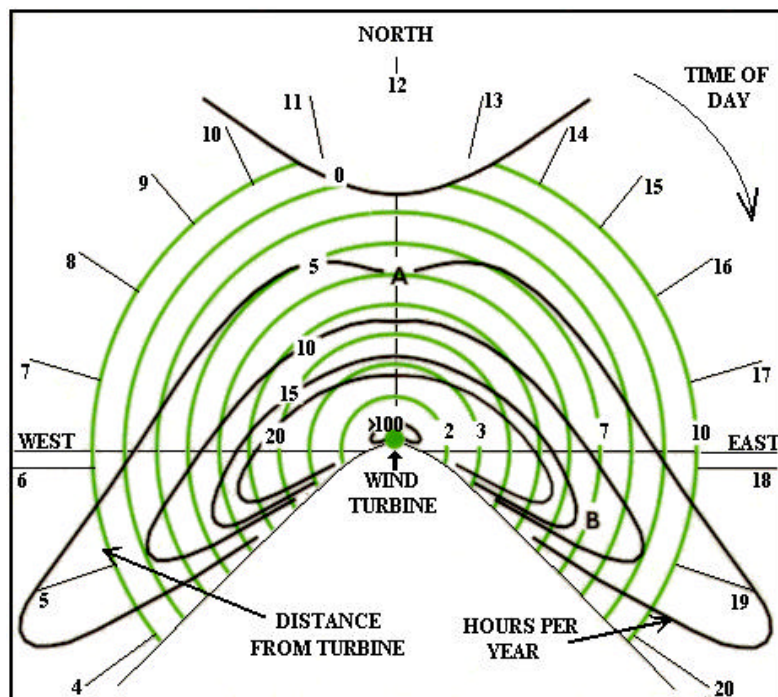


Figure 3 An example of a shadow flicker calculation

A common guideline used in Denmark is a minimum distance of 6-8 rotor diameters between the wind turbine and the closest neighbour. Houses located at a distance of 6 rotor diameters (approx. 260 meters for a 600 kW machine) from a wind turbine in any of the sectors described above will be affected for two periods each of 5 weeks duration per year[20].

3.1.3 Sound

Modern wind turbines are quiet and are becoming even quieter.

In order to assess this statement objectively it is useful to understand something of the physics and methodology of sound. Sound is measured in decibels (dB) using a logarithmic scale. The decibel is a measure of sound pressure level - the magnitude of the pressure variations in the air. An increase of 3 dB is equal to a doubling of the sound pressure and therefore a noticeable change in the sound level. An increase of 10 dB sounds roughly like a doubling of "loudness". Measurements of environmental sound are made in dB(A) which includes a correction for the sensitivity of the human ear. Formally the measurement of sound requires some additional descriptors: the type of representation and the time over which the sound is measured typically: 1 min, 10 minutes or 1 hour. For a wind turbine these different approaches give very similar results and it is not necessary to discuss them in detail here.

The sound pressure level at a distance of 40 metres from a typical turbine is 50 - 60 dB(A), about the same level as conversational speech. At a house 500 metres away, when the wind is blowing from the turbine towards the house, the sound pressure level will be about 35 dB(A), equivalent to the sounds inside a peaceful house. A farm of ten such wind turbines, with the nearest at a distance of 500 metres would create a sound level of about 42 dB(A) under the same conditions - equivalent to the sounds inside a quiet office. With the wind blowing in the opposite direction the level will be significantly up to 10 dB lower.

When planning a wind turbine development, careful consideration is given to any sound which might be heard outside nearby houses. Inside, the level is likely to be much lower, even with windows open. The potential sound effect is usually assessed by predicting the sounds which will be produced when the wind is blowing from the turbines towards such houses - a conservative assumption. The wind turbine sound increases slightly with wind speed. The sound of the wind in nearby trees and hedgerows, around buildings and over local topography also increases with wind speed, but usually at a faster rate and thus it often masks the sound of the turbine. A very detailed evaluation of the sound from wind turbines in the context of the physical planning has recently been undertaken and reported in the UK [21].

Ten years ago wind turbines were louder than they are today. Much effort has been made to create the present generation of quiet machines through detailed attention to both the design of the blades and to the mechanical parts of the machine. As a result noise is not a problem for modern wind turbines which are carefully sited.

3.1.4 Electromagnetic interference

Experience has shown that careful design of a wind farm will avoid any disturbance to telecommunications systems. It is nevertheless useful to have an appreciation of the issues involved. Radio waves and microwaves are used for a wide variety of communication purposes. Any large, moving structure can produce electromagnetic interference (EMI). Wind turbines can cause EMI by reflection of signals from the rotor blades so that a nearby receiver picks up both a direct and reflected signal.

Interference occurs because the reflected signal is both delayed due to the difference in path length, and Doppler shifted due to the blade motion. EMI is most severe for metallic materials, which are strongly reflecting, and least for wooden blades which are strongly absorbing. Glass reinforced plastic (GRP), which is used in most modern blades, is partially transparent to electromagnetic waves and therefore intermediate in its EMI effect.

The types of civilian and military communication signals which may be affected by EMI include TV and radio broadcasting, microwave and cellular radio communications and various navigational and air traffic control systems. Wind farm developers consult with the relevant civilian and military authorities to determine whether EMI problems are foreseen. Problems affecting microwave links and aviation communication systems should be avoided at this stage. Interference with a small number of domestic television receivers is an occasional problem, but this is normally rectifiable by a range of relatively inexpensive technical measures such as the use of more directional transmitters and/or receivers. Wind turbines and telecommunications systems co-exist happily in many developments throughout the EU.

3.2 Ecology

3.2.1 Birds

Birds often collide with structures which they have difficulty seeing, especially high voltage overhead lines, masts, poles, and windows of buildings. They are also killed by moving vehicles, in particular road traffic. Bird behaviour and mortality rates tend to be both species and site specific. Estimates of annual bird deaths in the Netherlands from various man-made causes [22] are shown overleaf in Figure 4:

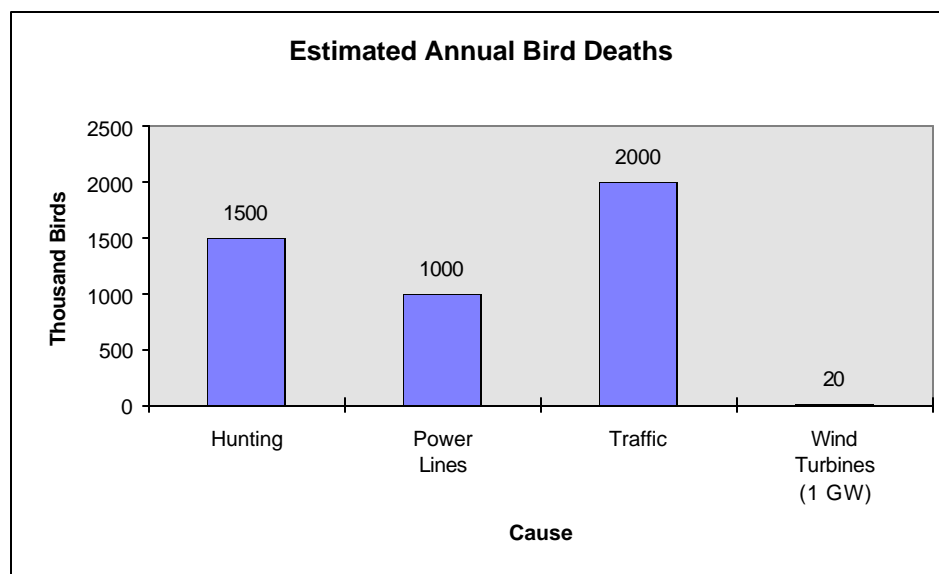


Figure 4: Estimated annual bird deaths in the Netherlands

The estimate for wind turbines is for 1000 MW installed whereas the Netherlands currently has just over 300 MW installed.

More than three hundred times as many birds die from collisions with moving vehicles than with wind turbines and 70 times as many are killed by hunters. These estimates are in line with a study from the Danish Ministry of the Environment which concludes that power lines are a much greater danger to birds than are wind turbines.

Birds are seldom bothered by wind turbines. Radar studies from Tjaereborg in the western part of Denmark, where a 2 MW wind turbine with 60 m rotor diameter is installed, show that birds tend to change their flight route some 100-200 m away from the turbine and pass above or around it at a safe distance. This behaviour has been observed as consistently at night as during the day. In Denmark there are even several examples of falcons nesting in cages mounted on wind turbine towers.

Nonetheless, the issue is taken seriously by the industry and planners alike, and development is normally excluded from bird-sensitive locations such as RAMSAR sites and EU bird protection areas. It has been recommended [23] that careful siting studies should be used to direct wind farms away from critical habitats and topographical features which could cause birds to be concentrated in the area, and that where there is uncertainty about the likely influence of poor visibility and inclement weather conditions, caution should be exercised.

3.2.2 Other ecological effects

Effects on other terrestrial ecosystems result primarily from construction activity, land take and hydrological disruption. The scale of these effects will depend on the type of ecosystem, drainage, construction techniques and timing, and restoration practice. All of these factors and the mitigation measures required should be addressed in the environmental impact assessment process described in the following chapter.

In many locations there will be rapid re-colonisation of the disrupted land by the surrounding system. Evidence suggests that neither wild nor domesticated animals will be affected by a wind farm [24].

3.3 Consumption of Energy and Materials

3.3.1 Energy requirements

Modern wind turbines rapidly recover all the energy spent in manufacturing, installing, maintaining, and finally scrapping them. A typical wind farm repays its energy debt in 3 to 4 months - one of the main results of a detailed life cycle analysis of wind turbines done by the Danish Wind Turbine Manufacturers' Association [25]. The study estimates the energy content in all components of a wind turbine, and the global energy content in all links of the production chain. It employs an "input-output" model of the Danish economy published by the Danish Central Bureau of Statistics. The advantage of this method over engineering calculations is that it can account properly for the energy used by producers of components and manufacturing equipment, buildings etc. in all links of the production chain. The resulting estimated energy requirements of a typical Danish 600 kW wind turbine during its 20 year lifetime are shown below.

Process	Energy (MWh)
Manufacture	528
Installation	137
Operation and Maintenance	215
Scrapping (use)	145
Scrapping (recovered)	-204
Total	821

Table 9: Energy requirements of a typical 600 kW wind turbine

The study then estimates the energy recovery time for the wind turbine with respect to the same amount of electrical output per year from a modern coal fired power station as shown below:

Wind turbine site roughness class	Wind turbine electricity production (MWh/year)	Coal-fired plant primary energy consumption (MWh/year)	Wind turbine energy use (from Table 9) (MWh)	Wind turbine energy recovery period (Months)
Class 1	1393	3202	821	3.1
Class 2	1130	2598	821	3.8

Table 10: Energy balance for a typical 600 kW wind turbine

These are conservative estimates as the energy consumption estimates for the coal-fired plant only include direct fuel related costs (energy content of coal and transport). They do not include coal-fired plant construction and operation (which account for over 50% of life-cycle costs) or indirect energy use in the coal firing process. Furthermore, the comparison assumes a thermal efficiency of 45% which is well above the average figure for coal-fired plant in the EU. In general, the wind turbine energy recovery period will be even shorter. Long distance delivery of the wind turbine to site makes very little difference to the above figures. For example, even if a 65 tonne wind turbine has to be shipped 10,000 nautical miles, this will only increase its net energy use by 1.5%.

3.3.2 Material requirements

The most recent and detailed analysis of the material inputs to a wind farm is a case study based on Baix Ebre wind farm in Spain [26] undertaken as part of a life-cycle environmental impact assessment (LCA) of THERMIE for DG XVII [27]. LCA is a generally applicable tool for evaluating the environmental costs of goods and services “from the cradle to the grave”. The figures presented below are derived from this work.

Baix Ebre wind farm comprises 27 Ecotècnia 150 kW turbines on a high mountain ridge in Catalonia.

Although the machines are smaller than the current industry standard, widespread interest has been expressed recently in extending the LCA methodology to other case studies.

Table 11 shows the breakdown of weight of material used by wind farm component. The total figures refer to the whole wind farm, whereas the weights per MW installed have been derived by dividing the total figures by 4.05 (the installed capacity of the wind farm in MW). While caution must be exercised with regard to this approach as material inputs may not be strictly proportional to installed capacity, the weights per MW give useful approximate generalised estimates which are more widely applicable.

Wind Farm Component	Total Weight (tons)	Weight per MW (tons/MW)	Proportion (%)
Monitoring masts	<1	<1	-
Turbines	436	108	17
Turbine foundations	1800	444	73
Other infrastructure	241	60	10
Total	2478	612	100

Table 11: Breakdown of materials used by wind farm component.

An alternative breakdown is by material type, as shown below.

Material	Total Weight (tons)	Weight per MW (tons/MW)	Proportion (%)
Concrete	1847	456	74
Steel/Iron	544	134	22
GRP	49	12	2
Copper	12	3	<1
Gravel	14	3	<1
Aluminium	6	<2	<1
Lubricants	<2	<1	<1
PET	<2	<1	<1
PVC	<2	<1	<1
PUR	<1	<1	<1
Others	<<1	<<1	-
Total	2478	612	100

Table 12: Breakdown of materials used by material type.

It is clear from the above data that the material inputs required for a wind farm are dominated by the concrete and reinforcement for the turbine foundations and by the steel from which the turbine towers are fabricated. It is conceivable that a wind farm could, on reaching the end of its operating life, be refurbished by installing new nacelles and rotors on top of the existing towers and foundations.

This would reduce the material inputs required for the “second generation” wind farm by well over 80%. However, as wind farms typically have a design life of 20-25 years, such a procedure has not yet been planned or attempted.

A basic design principle is that weight equals cost, and efforts to reduce the material input to wind turbines themselves continue. Progress in this area is discussed at greater length in Volume 1: Technology.

4 WIND TURBINES AND PLANNING

Most EU Member States have planning requirements which play a critical rôle in the deployment of wind turbines. An exhaustive review of these requirements, especially with respect to environmental impact assessment (EIA), has been carried out under the Altener programme [28].

4.1 Environmental Impact Assessment Procedures

Council Directives 97/11/EC in March 1997 added wind energy proposals to the list of public and private projects that may require assessment for their potential impact on the environment under Annex II of Directive 85/337/EEC. Measures under Directive 97/11/EC are required to have been brought into force by the individual Member States by 14 March 1999.

4.1.1 Regional requirements within the EU

In Denmark [29], Ireland, Germany, France and Finland, EIA is not a requirement for wind energy proposals. In the Netherlands, Sweden, Greece and the United Kingdom, however, legislation has been passed at a national level enabling the relevant authorities to make a request to the developer for the submission of an Environmental Statement. In Italy and Spain the requirement varies from region to region. An Altener project titled "Recommendations for Clear and Specific Guidelines to a Consistent and Desirable Approach to Wind Energy Development" will attempt to provide guidance to Member States that have yet to legislate in this respect.

4.1.2 Best practice

The term "Best Practice" has been adopted to describe the most appropriate approach to be adopted in developing, operating and decommissioning wind energy proposals. The intent of such guidance is to ensure the sensitive development of projects in appropriate locations.

It is beyond the scope of this document to identify and analyse all the relevant Best Practice Guidelines that are available in each of the Member States. However, it should be noted that such documents do exist and should be given due accord by the developer of a wind energy project, whatever the scale, in considering whether an individual proposal is appropriate or otherwise.(33,34) In considering any Best Practice Guidelines, however, regard should first be given to the context of EU policy on sustainable development and the relevant national and local energy, environmental and planning policies that may apply to that proposal.

4.1.3 Site selection

There are no statutory rules governing the site selection procedure, though most Best Practice Guidelines offer advice to potential developers on how to progress. Any site selection and assessment procedure must address the technical, commercial and environmental aspects of the project to determine whether a site is suitable for wind energy development. In addition to technical considerations, account must be taken at an early stage of the requisite planning framework, in particular any landscape, ecological, archaeological or other designations that may apply to the site or be located in close proximity to the proposal. Preliminary consultation with the planning authorities and major consultees should also commence at this stage and, if applicable, the concept of local participation in the project should be considered. Many developers will undertake comparative assessments of several sites at this stage to determine which meet the criteria for further development.

4.1.4 Environmental statements

The purpose of an Environmental Statement (ES) is to specify in detail the proposed project together with a thorough assessment of the impacts it may have. The scope of the ES should be agreed between the developer, the local planning authority and other statutory consultees so that all relevant issues can be considered. Not all Member States require production of an ES. However, it should be noted that in some States where Regulations have not been formulated concerning the formal submission of an ES, detailed information may still be requested on issues surrounding the project and should therefore still be considered by the developer in their consultations with the relevant authorities.

4.2 Mitigation Measures

4.2.1 Planning, construction and operation

In arriving at the final layout for a proposal, consideration should have been taken, where applicable, to the above points and it is likely that certain amendments to the original proposal will have taken place. These may include the moving or removal of certain turbines, the choice and specification of the turbines, the location of the access tracks and electrical connections, and construction scheduling. Thus, through the planning process, mitigation is likely to have taken place to arrive at the most acceptable form of development that satisfies any Conditions of Planning or Obligations that may be imposed.

4.2.2 Decommissioning and site restoration

Decommissioning will include the removal of all above ground elements of the development as a minimum and the restoration of the original site. The methodology for undertaking this should be adequately covered in the Planning Conditions or through a Planning Obligation placed on the project owner. In many cases, however, the majority, if not all, of the decommissioning costs can be recovered from the scrap value of the turbines and copper wiring from the project. Indeed, the ease with which wind turbines can be decommissioned, in comparison with other generating technologies is another significant environmental benefit of wind energy.

4.2.3 Recyclable content

If there is sufficient demand for the secondary raw materials, wind turbines can be regarded as being largely composed of recyclable materials. The principal unresolved issue from an environmental perspective is the recycling of rotor blades. Table 13 below summarises current understanding of the possibilities for the waste management of wind turbines [30].

Components	Recycling	Incineration	Landfill
Rotor blades: GRP/polyester GRP/epoxy	<i>GRP as filling material for plastics</i> <i>Resin as a reducing agent in blast furnaces with glass fibre as slag, usable in cement works</i> <i>Resin as a fuel and glass fibre as a cement additive in cement works</i>		Domestic refuse
	Rotor blades in waste incinerator		
Foundations and pile foundation	Steel in steelworks Concrete as an aggregate (e.g. for new concrete or road foundations)		Hardcore Pile foundation on-site
Tower: tubular steel or spun concrete	Steel in steelworks Concrete as an aggregate (e.g. for new concrete or road foundations)		
Generator and gear box	Steel in steelworks Alloyed steel in high-grade steelworks Secondary refining of gear oil Copper in secondary copper plant	Gear oil in waste incinerator (hazardous)	

Processes in italics are not yet available but at a relatively advanced stage of development.

Table 13: Possibilities for waste management of wind turbines

Recommendations for recyclable design of wind turbines are:

- minimising the number of components and ensuring that they are easy to dismantle
- fabricating of rotor blades without PVC foam
- using recycled concrete scrap as an aggregate in the foundations
- considering easy demolition of the foundations e.g. by incorporating appropriate shot holes
- examining the usability of recycled lubricants
- labelling precise material composition, especially for alloyed steels
- designing rotor blades made of renewable raw materials

5 CONCLUSIONS

"Coal, gas and oil will not be the three kings of the energy world for ever. It is no longer folly to look up to the sun and wind, down into the sea's waves" [31]

The environmental imperative for renewables and energy conservation is now beyond dispute. The developing world is entitled to expect the same living standards in terms of goods and services that we enjoy in the EU, but unless we can lead by example and encourage sustainable energy paths world-wide, global environmental problems will surely worsen. It is possible to design a future European energy system which no longer threatens to change the global climate without invoking the long and short term hazards of nuclear power. Such a system relies on far-reaching energy efficiency measures and substantial use of renewable energies. In this scenario, wind energy would contribute 11.7% of EU energy supply, and amount to 8.5% of installed capacity, by 2050 [32]. The annual cost of such a scenario would be about 50% higher than for a hypothetical reference case based on the best available fossil technologies if external costs are not taken into account.

In November 1997 the European Parliament called on the EU to cut its own greenhouse gas emissions by 15% by 2010 regardless of the outcome of the December 1997 climate change conference in Kyoto. In a resolution adopted by a large majority, MEPs urged EU ministers to adopt a "tougher, binding commitment" to reduce greenhouse gases immediately after Kyoto. The call follows the Commission's publication of a policy paper on climate change last month in which it stated that "the EU proposal is a negotiating position, not a unilateral commitment." (ENDS Daily 16 September). MEPs also called on the Council of Ministers to adopt "as rapidly as possible" a stronger package of measures to meet its 15% target. This should include fiscal measures - such as an energy tax - to reverse global warming, an increase in the share of renewables to be equivalent to 15% of fossil fuel-derived energy and the removal of legislation "contradictory to greenhouse gas emission reduction". The resolution specifically rules out increased use of nuclear power as an option. Wind energy is a sufficiently mature, cost-effective and widely applicable technology to make a significant contribution towards meeting these targets.

This document has reviewed both the environmental costs and benefits of wind energy in some detail. The overwhelming body of evidence from a wide range of authoritative commentators is that the benefits of wind energy greatly outweigh its costs. In cases where quantitative comparisons can be made, the benefits typically outweigh the costs by at least one order of magnitude. The environmental case in favour of wind energy is overwhelming.

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