Chapter 15
Environmental Impact

Discussing the characteristics of energy sources without simultaneously considering the impact they have on the environment is no longer possible these days. Wind turbines do not pollute the atmosphere with carbon dioxide, sulphur or hydrocarbons, nor will they cause problems for present and following generations with regard to the disposal of radioactive waste. The utilisation of wind energy thus unreservedly deserves the attribute "environmentally friendly". All the same, even the operation of wind turbines is not without its effects on the environment.

In contrast to large conventional power plants, the environmental impact of single wind turbines only affects their immediate surroundings. This localisation of their impact indicates that it must be seen as site-related and can, therefore, largely be avoided by a sensible choice of site. Even in the densely populated industrial countries, the areas designated for the exploitation of wind energy are not so densely built up so as not to offer even some limited choice. Then again, sites which are entirely unpopulated are indeed an exception. Wind turbines must, therefore, be acceptable with respect to their environmental impact, for instance noise emission, in more or less densely populated areas and their environmental impact must be considered with this in mind.

The most important effects on the immediate environment emanating from wind turbines can be calculated objectively and can today be substantiated by long years of experience. This includes noise emission, shadow effects or possible interference with radio and television signals. Possible effects on plant and animal life, especially with respect to the behaviour of birds, have been researched many times, but lasting changes in these areas, caused by the installation and operation of wind turbines, can only be ascertained over very long periods of time.

The visual effect of a large number of big wind turbines in the landscape is increasingly the subject of controversial discussions, and the assessment of this aspect will always be subjectively tinged. It also reveals a general attitude towards the value of renewable energies. The personal attitude of an individual depends on whether he or she places a higher value on the contribution of wind turbines to the global protection of the environment or on the preservation of a local landscape. Nevertheless in many cases there are oppositions against the installation of wind turbines from the people living nearby.

The global effects of the utilization of wind power cannot be experienced directly by an individual person but are still of considerable significance. With each kilowatt-hour of electrical energy generated from wind power, the corresponding amount of power generated from fossil fuels and the associated emissions into the atmosphere are avoided. The utilization of wind power is therefore also a factor in the increasingly more important efforts to keep the climate stable.

15.1 Hazards for the Environment

The only possible threat to the surroundings of a wind turbine is posed by parts of the rotor flying off. The danger of the entire turbine toppling over at extreme wind speeds, burying underneath it the people around it, is a possibility in principle but is no more likely than with any other building. The only real danger, at most, is presented by the rotor blades or parts of them breaking off. The question of safety in the environment of a wind turbine, therefore, essentially revolves around the question of how far damaged rotor blades can be flung off and what risk is involved here.

15.1.1 How Far Can a Rotor Blade Fly?

To answer this question, the conditions should be first called to mind under which a rotor blade can self-destruct, and the parameters which influence its trajectory.

As experience has shown, the most frequent cause of rotor blade fracture is rotor "runaway". When all rotor-brake systems fail, the rotor speed can increase up to the limit which is aerodynamically possible. This is reached when the flow velocity in the outer blade area approaches the speed of sound. As is generally known, this results in a steep increase in air drag. The lifting forces acting on the airfoil are balanced by the aerodynamic drag, resulting in an equilibrium speed which is the critical aerodynamic speed.

This speed depends on the aerodynamic properties of the chosen airfoil, on the blade geometry and, not least, on the wind speed. A more detailed discussion would be beyond the scope of this book. Theoretical investigations have shown that with modern rotor blade shapes, the critical aerodynamic speed is approximately three times the design tip-speed ratio [1]. At a constant wind speed, this means three times the rotor speed.

Generally, however, the critical velocity of the rotor blades with respect to their breaking strength is usually below the aerodynamically possible maximum speed. Fracture will occur earlier at least on large rotors, due to the centrifugal forces increasing with the square of the speed. The exact location of this limit is a question of the strength dimensioning and can be precalculated theoretically. Generally, it can be assumed that the strength limit of large rotors is reached at about two- or three times the rated rotor speed value. Apart from the rotor speed at the time the fracture occurs, the blade's rotational position also plays a role. Applying the known principles of simple ballistics immediately shows that a rotor position of 45° from the vertical axis in the direction of rotation will lead to the maximum trajectory length.

Rotor runaway resulting in the loss of rotor blades was a danger mainly in older and smaller wind turbines, even though, statistically, this has also been extremely rare. Modern wind turbines have at least two independent systems for rotor braking including multi-redundancy release mechanisms, so that this hazard is effectively counteracted. Large turbines contain elaborate rotor brake systems, in any case (see Chapt. 8.7).

The other conceivable case of rotor-blade fracture can occur as a result of undetected material fatigue. After a certain length of time, an undetected progressive fatigue crack will lead to fracture, even without the rotor blades being subjected to abnormal loading.

For the wind turbine, this means a possible blade fracture at rated rotor speed, i.e. in normal operation. In the only case so far where a rotor blade has broken off from a large wind turbine and was hurled away, fatigue fracture was indeed the cause. After a three-year operating period, the ageing Smith-Putnam turbine lost one rotor blade, the result of fatigue damage at the blade root (Chapt. 2.3). In that particular incident, the 8-tonne rotor blade was propelled over a distance of about 230 m. The designers of this wind turbine must be given credit, however, for having known about this weak point, even though the mechanisms of material fatigue had not yet been researched as widely as they are today. However, no preventive repair had ever been carried out due to a lack of funding and because interest in the project had waned.

It is not very easy to predict the flying characteristics of a broken rotor blade or of a part of it. After all, a rotor blade is an aerodynamically shaped structure generating high lifting forces, as it was designed to do. It would be easy to speculate that a detached rotor blade could, like a glider, cover long distances by gliding. However, this possibility must be discarded upon closer inspection of the flight stability conditions. The position of the centre of gravity in relation to the centre of aerodynamic pressure does not permit a stable flight position.

Firstly, the rotor blade will "tumble" on its trajectory, and then it will fly with its heavy end first. It is, therefore, not to be expected that the aerodynamic lifting forces will increase the trajectory length significantly [2]. The problem is reduced to the question as to what is the effective mean drag coefficient over the trajectory. A theoretical analysis calculating trajectory and trajectory length of an example taking into consideration aerodynamic lift and drag yielded the result that a mean air drag coefficient of $c_W = 0.25$ is to be expected [3].

Rotor speed, the blade's rotational position and the location of the centre of gravity are the main parameters influencing the trajectory length of the rotor blade becoming detached. In addition, the blade pitch angle at the time of fracture and the momentary wind speed have some influence. The orders of magnitude to be expected for the trajectory lengths of a detached rotor blade are illustrated by an example. Due to the ratio between aerodynamic forces and gravitational forces, the outer section of a rotor blade can fly the farthest (Fig. 15.1).

Discussing the hazards caused by parts of the rotor being hurled away, the problem of ice accretion at the rotor blades must be mentioned (see Chapt. 18.8.2). Observations made on the American MOD-0A experimental wind turbine in Clayton have shown that, indeed, significantly large chunks of ice are flung off over considerable distances. Theoretical investigations relating to this problem have also been published in Denmark [4].

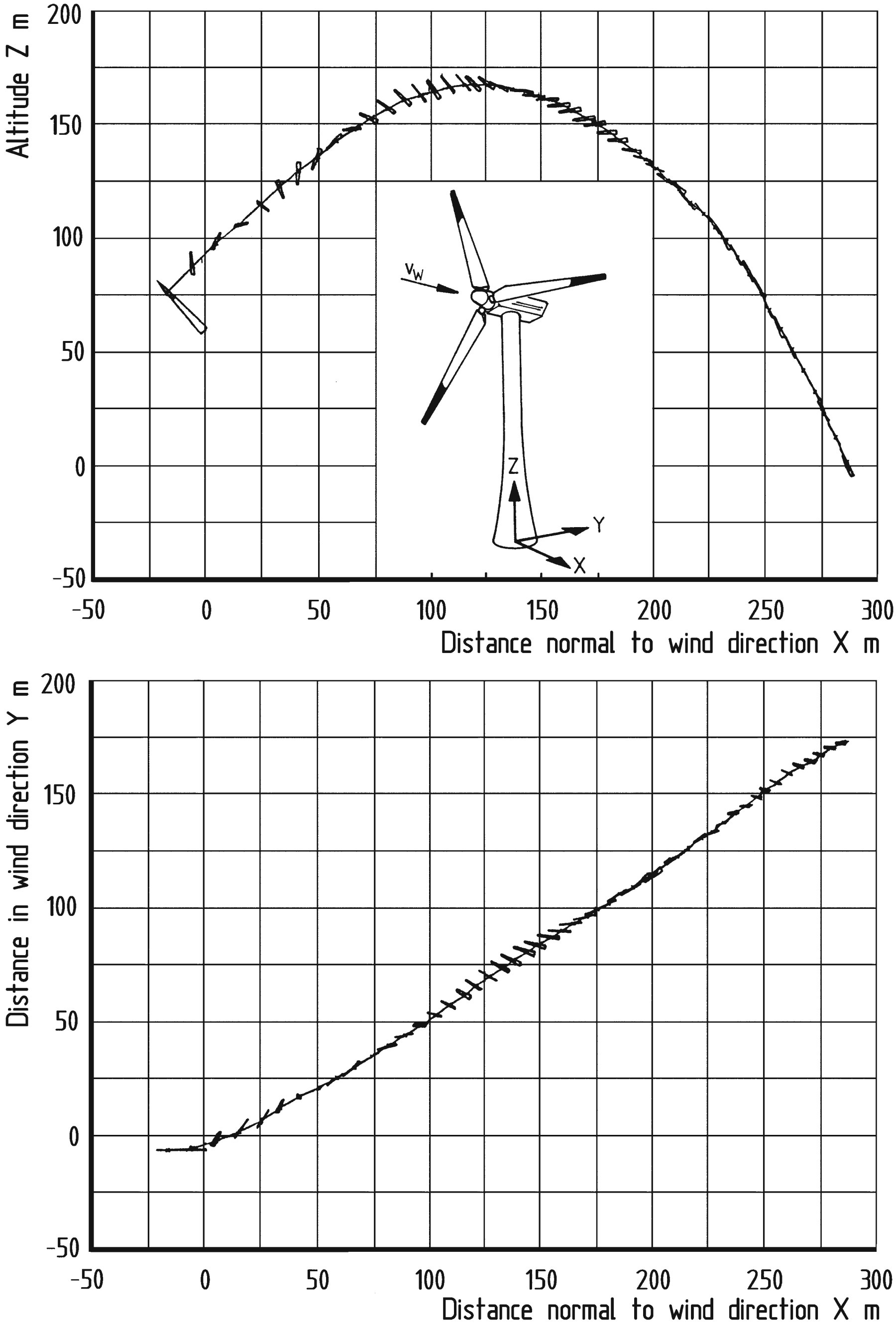

Fig. 15.1. Trajectory of the outer third of the rotor blade in the rotor plane, calculated for the Danish Tjaereborg wind turbine (Tower height 60 m, rotor diameter 60 m, blade weight 8 t, initial conditions: blade-tip speed 100 m/s corresponding to 50 % overspeed, wind speed = 10 m/s) [3]

Thus, appropriate precautions must be taken at certain sites. The installation of an ice warning system which would shut down the wind turbine during critical weather conditions is one possibility.

15.1.2 Safety Risks

In view of the possible hazards caused by rotor parts or chunks of ice being flung off, various probability calculations have been carried out with the aim of determining the statistical risk to a person nearby. When looked at closely, the results of such mathematical predictions of safety depend almost exclusively on the possible range of the parameters used. Considering thus their extremely dubious value, one would do better to refrain from using them when dealing with wind turbines. Wind turbine technology does not need such "magical formulae" to prove its harmlessness to the public. Instead, some readily comprehensible remarks about the safety risk of this technology will not go amiss here.

The "dangerousness" of a technology must be seen under two different aspects. Firstly, there is the question of the frequency of accidents and, secondly, the question of the extent of the consequences to be expected with the occurrence of such an accident. The "dangerousness" could be defined as the product of frequency and the severity of its effects.

This may be illustrated by two examples: road traffic with automobiles is characterised by an appalling frequency of accidents. Although the number of people injured annually in road accidents reaches the familiar order of magnitude, it will be found that the effects of each individual event - as painful as they may be to those concerned - remain within calculable limits. This may well be a possible reason why, despite the 5000 fatalities per year for example in Germany alone, this technology is not rejected by society.

With nuclear power technology it is quite the other way round. The probability of an accident occurring is very low - that must be conceded to the promoters of this technology. But the possible consequences of an accident are practically incalculable. Even though it was a long way from being the "Maximum Credible Accident" (MCA), the reactor accident of Chernobyl made this quite clear for the first time. This is the reason why this technology will always be rejected by apart of society. Does this make motor traffic and nuclear power dangerous technologies? It is not the task of this book to find an answer to this question. It is only intended here to apply this approach also to wind energy technology.

Firstly, it can be stated that in professionally built wind turbines, the frequency of rotor-blade breakage is very low. The probability of a person being hit is even lower. It can, therefore, be said that the frequency of fatal accidents due to self-destructing rotor parts can rightly be classified as extremely low, even when massed clusters of wind turbines are considered.

How, then, about the conceivable extent of a "catastrophe" caused by wind turbines? Even with pessimistic assumptions, a detached rotor blade cannot have the same consequences as, for example, a comparable critical technical failure in a car, or an aircraft. And a comparison with a nuclear power plant need not even be attempted as it is completely inappropriate. Thus, wind power technology can be called decidedly "harmless" as far as both the "frequency" and the "severity" of accidents are concerned. It probably is the altogether least dangerous energy generation technology, at least when considering the megawatt power output range.

15.2 Wind Turbine Noise

Wind turbines do not run completely silently. Their operation generates noise which can be heard at a certain distance. While in the case of the old windmills, this noise was generally not perceived as annoying, some modern wind turbines gave rise to complaints. In the early phase of modern wind energy utilisation, the American MOD-1, in particular, was much talked about due to the disagreeable and, at the time, inexplicable noises it made. This triggered numerous scientific investigations about the noise emissions by wind turbines, first in the USA and a little later in some European countries.

Today, it can be said that the mechanisms behind the generation of noise emission by wind turbines are known by and large. It is certain technical characteristics that are responsible for a higher or lower noise emission, as is the case with other machines, too. In simple words: there are quiet wind turbines, the noise of which is virtually imperceptible at a short distance away, and there are distinctly noisy turbines which cannot be tolerated in populated areas.

Tackling the problem of noise emission is, therefore, a must both for the designer and for the operator of a wind turbine. If serious mistakes are made in this respect, the turbine's possibilities of application will be restricted to such an extent, that projects will be doomed to fail at many sites.

15.2.1 Acoustic Parameters and Permissible Noise Levels

Before entering into a more detailed discussion of the specific noise sources in wind turbines, it is useful to call the most important parameters of acoustics to mind. Noise is large a question of the criteria of assessment. Unfortunately, the degree of annoyance associated with noise levels is highly subjective. This fact presents a challenge to any objective and quantitative assessment of noise but such assessments are indispensable.

The most important parameter describing the overall noise intensity at the location of perception is the *sound pressure level,* usually indicated as an amplitude-weighted level and then designated by the symbol "dB(A)". Although in some cases levels related to other criteria can also be applied in acoustics, the dB(A) parameter comes closest to the subjective aural impression and so is used most frequently.

For example the German DIN standard 45645-1 suggests various averaging methods for weighting measured sound pressure curves [5]. Among others, it defines a so-called “noise rating level”. This parameter takes into account the experience that highly tonal and impulse like noises are perceived more intensely. A certain additional amount corresponding to the tonal level and impulse character is added to the continuous sound pressure level.

The nature of the noise is represented by a frequency or third-octave spectrum. This spectrum shows the measured sound pressure levels versus the frequency.

The frequency spectra provide information about the sources of the noise. They are thus primarily of interest to the designer of the wind turbine.

The permissible sound pressure level which a noise source may generate as a "continuous nuisance" at a certain location has been prescribed by legislation. Regulations governing these levels vary from country to country. In the Federal Republic of Germany, the standard values are based on the above mentioned DIN standard and are prescribed by law. The maximum values depend on the nature of the surroundings and on the time of day: The permissible noise levels vary from country to country. Some examples are shown in Table 15.2.

These regulations must also be observed in the operation of wind turbines. One important and necessary aspect must not be ignored: the increase in the natural ambient noise with wind speed. It would not make sense to require the noise of a wind turbine at full load, which generally occurs at wind speeds exceeding 10 m/s, to be 35 dB(A), i.e. lower than the ambient noise. At these wind speeds, the noise of a wind turbine will be masked by the ambient noise. A sensible interpretation of the noise emission standards must, therefore, be based on the "loudness level", that is the noise level which is generated by the wind turbine and which exceeds background noise made by the wind.

Table 15.2. Permissible noise levels for sound pressure levels (dB(A)) in some European countries

Permissible noise level (dB(A))	Germany	Netherlands	Denmark
Predominantly industrial area			
day:	65		
night:	50		
Mixed industrial/ residential area			
day:	60	50	
night:	45	40	
Predominantly residential area			
day:	55		
night:	40		
Exclusively residential area			
day:	50	45	
night:	35	35	40
Rural area			
day:	40		
night:	30	45	

The background noise generated by the wind at increasing wind speeds when blowing around obstacles (for example buildings, trees, grass etc.) increases by about 2.5 dB(A) per one m/s wind speed. If measurements of the background noise level are not available, the background sound pressure level can be estimated by using the following formula [6]:

$$L_A = 27.7\ dB + 2.5\ v_W\ dB$$

where:

L_A = sound pressure level (dB(A))
v_W = wind speed (m/s)

Experience has shown that the noise emission of a wind turbine increases by only about 1 dB(A) per m/s wind speed. According to that it follows that, from a certain wind speed on, the noise of the wind turbine will be masked by the background noise. If the background sound level exceeds the calculated noise level of a wind turbine by about 6 dB(A), the latter will no longer contribute to any perceptible increase in the sound pressure level at the location of immission [6].

A noise source is characterised by its *sound power level.* This parameter contains information about the intensity and thus about the sound propagation potential of a sound source. According to definition, measurements would have to be obtained over a spherical surface around the source of the noise. In practice, several methods are normally used. The IEC has elaborated a standard for wind turbines [7]. According to this, the sound pressure levels are measured at five fixed measuring points in a particular geometrical arrangement on an "acoustically inert" plate, and from these measurements the sound power level *(L_W)* is determined by using the following formula:

$$L_W = L_A + 10 \log(4\pi R_i^2)\ dB(A) - 6\ dB(A)$$

where:

L_A = measured sound pressure level (dB(A))
R_i = distance from the point of measurement to the centre of the rotor (m)

The *propagation of sound* can be determined by semi-empirical mathematical methods on the basis of the sound power level of the noise source, which allows the sound pressure level to be calculated at a given location of noise immission. Information on how to calculate sound propagation is given in VDI Standard 2714 "Sound Propagation in the Open" [8].

The propagation of sound is determined by a whole series of factors:

- Properties of the sound source
  (acoustic power emitted, directional characteristics, tonal components)

- Geometry of the sound field
  (height and distance of the sound source from the location of immission)

- Topography
  (orology, vegetation, buildings)

-Weather conditions
  (wind direction, wind speed, humidity, temperature)

Taking into account the above influencing parameters, the sound pressure level *(L_A)* at the location of immission is determined as follows:

$$L_A = L_W + DI + K_0 - D_S - D_L - D_{BM} - D_D - D_G + D_W$$

where:

L_W = sound power level
DI = factor of directivity
K_0 = steradian factor
D_S = factor of distance
D_L = factor of atmospheric absorption
D_{BM}= factor of ground and meteorological absorption
D_D = factor of vegetational absorption
D_G = factor of absorption by buildings
D_W = influence of wind

Both, the VDI Standard cited and related literature, contain information as to how these parameters can be derived from the conditions on site. If several sound sources, for example the turbines of a wind farm, contribute to the sound pressure level generated at one location of immission, the noise levels generated by the wind turbines are calculated individually and the acoustic energies are added. The total sound pressure level generated *(L_{AZ})* is obtained from the formula:

$$L_{AZ} = 10 \log \sum_{i=1}^{n} 10^{0.1\, L_i}$$

where:

n = number of sound sources
L_i = the individual sound pressure level of the sound source *i*.

15.2.2 Noise Sources in Wind Turbines

The sound power level of a wind turbine is emitted by various sources. The total sound power level measured is determined by aerodynamic noises, primarily emitted by the rotor, and by various types of mechanical noises. The different noise sources must be identified during the development and analysed carefully. Every potential source requires special attention in order to achieve a design with low noise emission overall.

Aerodynamic noise

The primary noise source of a wind turbine is the air flowing around the rotor. The noises caused by this process are, to a certain extent, unavoidable, and cannot be attenuated either. They are thus the actual problem to be dealt with and their mechanisms of generation must be examined more thoroughly.

On closer inspection, various effects are responsible for the generation of aerodynamic noise from a wind rotor. The main causes are the turbulent boundary layer and the formation of vortices at the trailing edge of the blade, and aerodynamic loading fluctuations. Moreover, there are the flow separations, which are also audible and, to a much lesser extent, the turbulence of the rotor wake. A special role is played by the vortices separating from the tip of the rotor blade. The major part of the rotor noise - as well as the rotor power - emanates from the outer 25 percent of the blade and, therefore, the geometry of the blade tips is of special importance (Chapt. 5.5.2). The influence of other vortex-generating edges, gaps or struts should not be underestimated, either. These are the causes of loud aerodynamic noises in many rotors of earlier design.

The flow around the rotor blades generates a sound similar to the flow around an aircraft wing. A low-flying glider with an air speed comparable to that of the rotor blade of a wind turbine generates the same broad "hissing" or "whooshing" sound in the frequency range of about one thousand Hertz (Fig. 15.3).

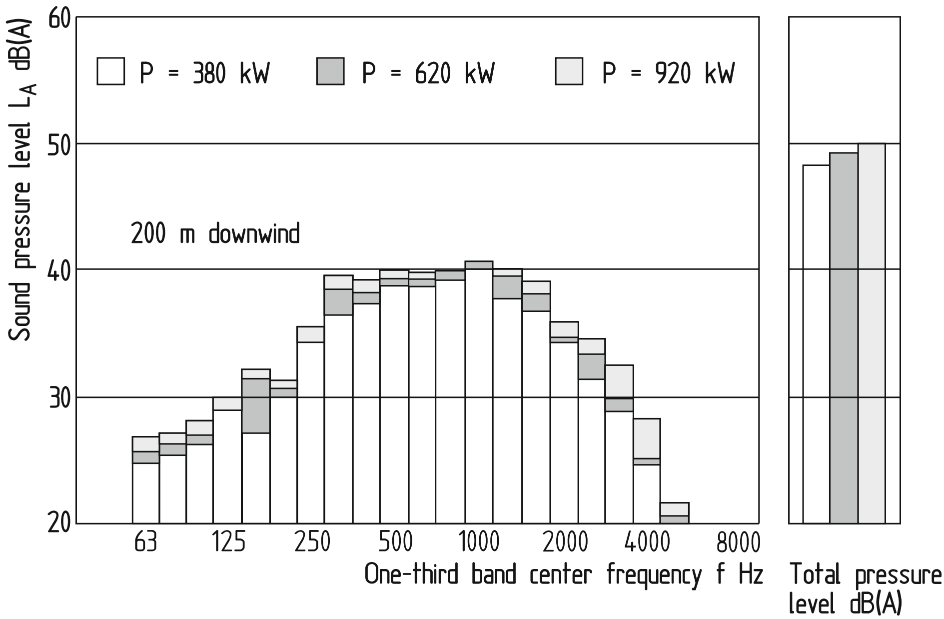

Fig. 15.3. Frequency spectrum (amplitude-weighted third-octave spectrum) of the sound pressure level measured 200 m (downwind) from the WKA-60 experimental turbine on the German island of Heligoland [9]

Apart from the broad aerodynamic whooshing of the rotor in the 1000 Hz range, wind turbines can generate impulsive, low-frequency sound waves. These are generated when the lift forces acting on the rotor blades change rapidly due to discontinuous flow conditions. The main causes of this are rapid changes in the aerodynamic angle of attack and thus of the aerodynamic lift force. Rapid changes in lift are, for example, caused by wind turbulence in gusty wind or by flow separations at the rotor blades. Under these circumstances, stall-controlled rotors without blade pitch adjustment may emit a characteristic low-frequency sound. From a certain distance, however, these are generally no longer perceived to be annoying.

Conversely, low-frequency noise emission occurring as a result of tower shadow interference in downwind rotors must be assessed quite differently (Fig. 15.4). In the case of the MOD-1 wind turbine in the USA, mentioned earlier, the associated noise turned out to be a major reason for complaints by residents. The turbine's lattice tower created a considerable tower shadow for the downwind rotor mounted at a small distance away. Moreover, the propagation of the sharp pressure impulses generated by the periodic alternation of the rotor lift forces was assisted by the local topography. The oscillations of very low frequency in the inaudible infrasound range additionally triggered resonances in house walls and windows of the lightly built weekend houses in the vicinity. This was the explanation for the mysterious "psi-phenomena" experienced by the residents, such as the clattering of cups in their cabinets and similar events. The situation was thus extremely unfavourable, both with regard to the technical characteristics of the wind turbine and the specific conditions of its location.

Low-frequency sound emissions can be observed in all downwind rotors, but with greatly varying intensity. This problem must, therefore, be paid careful attention to when designing the turbine. Apart from the tower design, the technical parameters mainly responsible for the intensity of the emission are the rotor's clearance from the tower and the rotor speed. Rotor speed is significant as, in the worst case, the frequency of the blades passing through the tower shadow can coincide with the separation frequency of the Kármán vortices at the tower. At certain wind speeds, this may cause a triggering effect for the vortices, thus amplifying the noise further. The frequency of separation of the Kármán vortices can be determined by means of the so-called *Strouhal number,* which is a function of the Reynolds number.

The common denominator for all sounds of aerodynamic origin is that they increase sharply with increasing airflow velocity. Noise emissions increase by about the 5^{th} power of the flow velocity, which, in turn, is essentially determined by the tangential velocity of the rotor blade tips [6]. A reduction in blade-tip speed by 25 % results in a reduction of noise emissions by about 6 dB(A).

A low tip-speed ratio is, therefore, a most important criterion. With regard to this aspect, variable-speed or two-speed rotor operation becomes additionally attractive, particularly at low wind speeds when the ambient noise has not yet been increased by the wind speed and the rotor can be operated at a low speed. Apart from the airflow velocity, aerodynamic noise emission is also influenced by the power output, but to a much lower degree (Chapt. 15.2.3).

The aerodynamically caused sound power level of a wind rotor can be estimated in approximation by means of various mathematical models [11]. The theoretical determination of the frequency spectrum is more difficult and less accurate.

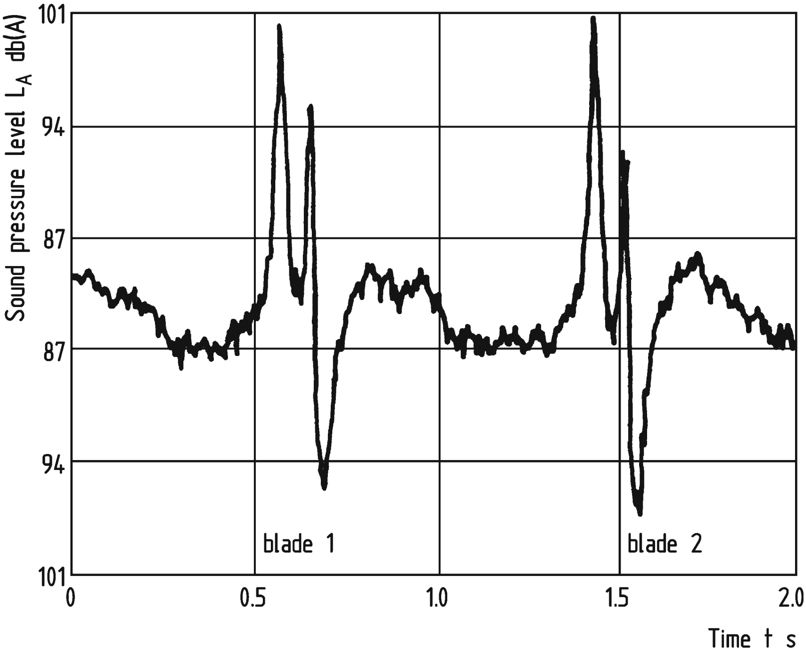

Fig. 15.4. Noise pulses generated by the tower shadow effect, measured dose to the American MOD-1 wind turbine [10]

Mechanical noises

In many wind turbines, particularly in smaller ones, the aerodynamic noise is drowned out by mechanical noise sources. Since mechanical noise, in contrast to aerodynamic noise, can be avoided or heavily damped, it must be considered as an indication of poor design. However, avoiding mechanical noise does require a certain amount of care and possibly additional expenses for soundproofing or insulation material for solid-borne noise.

The first priority is to pay attention to the noise emission of the gearbox. There are no silent gearboxes in practice (Chapt. 8.8.2). The sound propagated through the air must, therefore, be intercepted by appropriate sound insulation of the nacelle. Generally, this does not pose any problems. It is much more difficult to prevent noise propagation through solid bodies. For structural reasons, the gearbox must be firmly connected to the supporting nacelle structure which, in turn, must be firmly joined to the tower. Noise is thus transferred to these structures and there may be considerable resonance amplification of the emitted sound. A hollow steel tower or the steel walls of the nacelle are just about the ideal resonating bodies.

Soundproofing of the gearbox and of some other, noise-generating units is, therefore, a must for every modern wind turbine. All kinds of rubber or rubber-like synthetic materials are available for this purpose and are used in mounting the gearbox, in particular, on the supporting structure. All of the more recent wind turbines have constructional elements of this type. What has been said about the gearbox also applies to a certain extent to other noise-emitting units in the nacelle. For example, hydraulic pumps and gear motors represent special noise sources.

The generator cooling should not be overlooked either. In some turbines, it is much too noisy even though enough information about the design of quiet ventilation systems is available. In more recent wind turbines so-called “passive cooling systems” are used. The heat exchanger on the roof of the nacelle becomes large, but the natural wind flow is enough for cooling the inner cooling circle of the electric generator (water or air). In this way noisy and energy consuming fans and pumps are avoided (see Chapt. 9.12.1).

15.2.3 Noise Emission of Current Wind Turbines

The noise emission of wind turbines has been noticeably reduced in the past fifteen years by the constant improvement of design and the optimisation of numerous details. This is true at least of the successful commercial turbines. Experimental wind turbines differing from the common technical concepts are the exceptions to this rule.

By now, the manufacturers have become quite aware of the problem of noise emissions which greatly influence the acceptance of wind turbines. With some wind turbines technical compromises in favour of reduced noise emission have a marked influence on the power output. Frequently, the rotor speed is chosen to be lower than the aerodynamic optimum, but other influencing parameters, too, for example the blade pitch angle at wind speeds around 8 to 10 m/s, are chosen for the least possible noise emission, even if this means sacrificing the last few percent of possible power output.

After the power curve, the sound power level has become the most important technical parameter today. The buyers or operators of wind turbines are well advised to ask for independent certification of the manufacturer's specifications and to demand corresponding guarantees from the manufacturer. The noise accreditation nowadays required for every wind energy project is based on the sound power level of the wind turbine. Even if the sound pressure levels generated are influenced by numerous local influences at a particular site, a low sound power level is still the best basis for adhering to the standards prescribed by law.

As already mentioned, the sound power levels actually reached by wind turbines are determined by numerous aerodynamic and constructional characteristics. As long as the turbines to be assessed are of comparable technical design, for example three-bladed rotors with a tip-speed ratio of 6-8, the dominant parameter will be turbine size, so that size-related guide values are possible:

- Small wind turbines up to 20 m rotor diameter (100 kW)	~ 95 dBA
- Medium-sized wind turbines up to 40 m rotor diameter (500 kW)	~ 98 dBA
- Large wind turbines with 70-80 m rotor diameter (2000 kW)	102-105 dBA
- Multi Megawatt wind turbines, 100-120 m rotor diameter	105-107 dBA

These values apply to modern turbines which have already been designed with a view towards low noise emission. Earlier wind turbines frequently exceed these values considerably. The first generation of large experimental wind turbines, in particular, produced noise values of up to 120 dB(A) (Fig. 15.5). The limits within which the sound power level can be influenced by technical or operational parameters are illustrated by the example of an acoustic investigation carried out on a medium-sized wind turbine. The dependence of the sound power level on the wind speed or the electric power output is relatively small (Figs. 15.6 and 15.7).

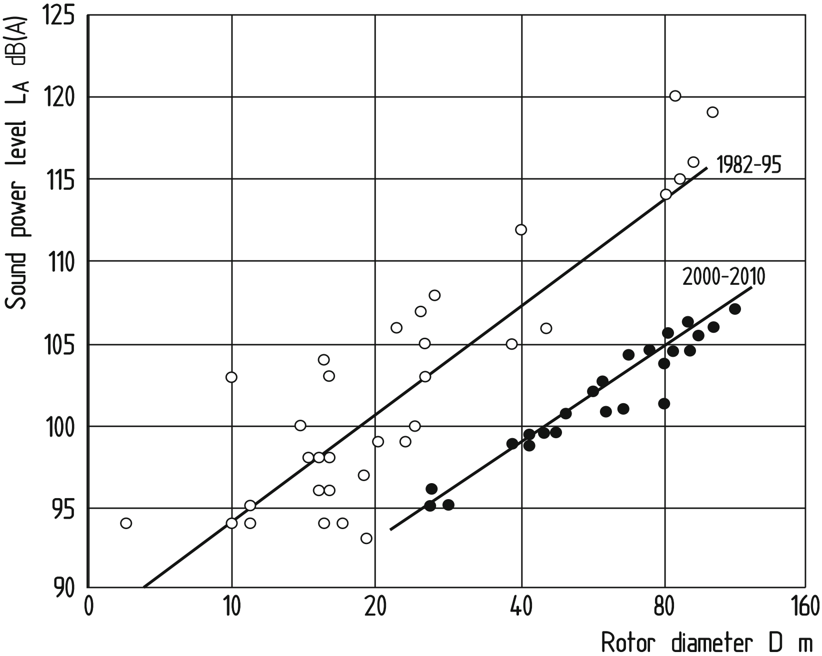

Fig. 15.5. Measured sound power level of wind turbines as a function of rotor diameter [12]

The result of a sound propagation calculation, i.e. the expected sound pressure level as a function of distance, for the TW 600, shows that the commonly demanded maximum value of 45 dB(A) is obtained at a distance of about 220 m (Fig. 15.8). In order to remain below the standard acoustic limit value of 45 dB(A), a minimum distance of about 200 m is typical for medium-sized wind turbines in the power class of around 500 kW.

The distances with reference to a 45 dB(A) limit increase with the size of the wind turbine of course. The following guide values can be assumed:

- Medium sized turbines (sound power level ~ 98 dB(A))	~ 200 m
- Large turbines (102-105 (dBA))	300-400 m
- Multi-Megawatt turbines (105-107 dB(A))	1000 m

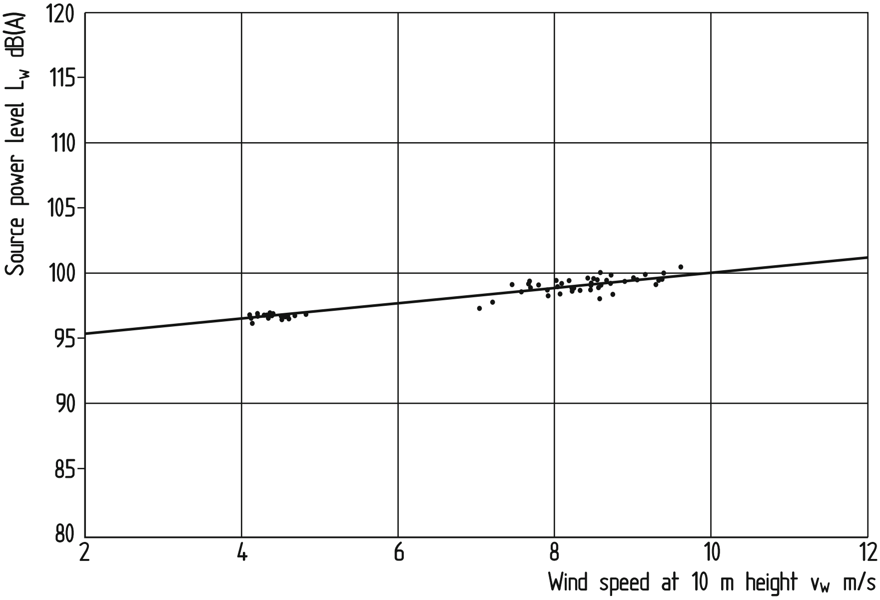

Fig. 15.6. Source power level as a function of wind speed, measured on a medium-sized TACKE TW-600 wind turbine, rotor diameter 43 m, rated power 600 kW, rotor speed 18 rpm [13]

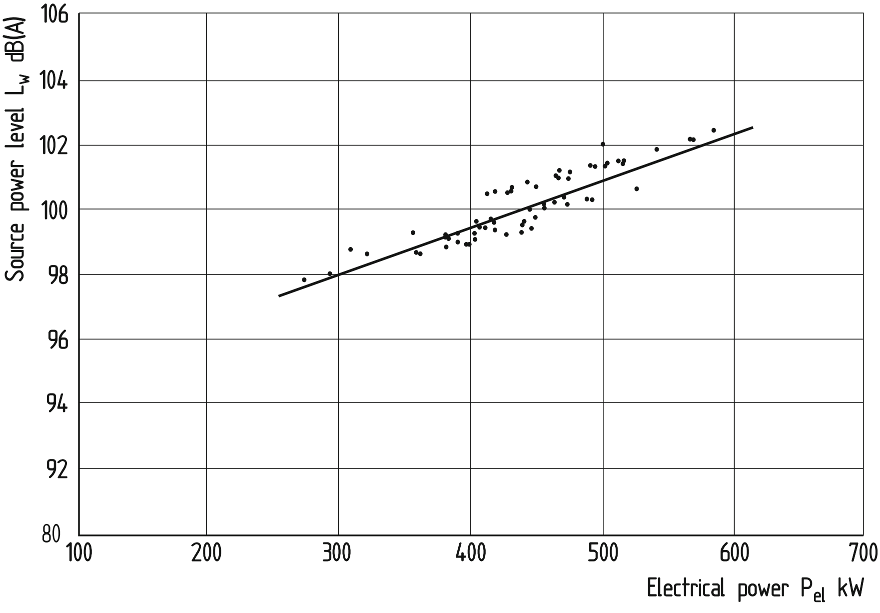

Fig. 15.7. Source power level as a function of the power output. (TACKE TW 600) [13]

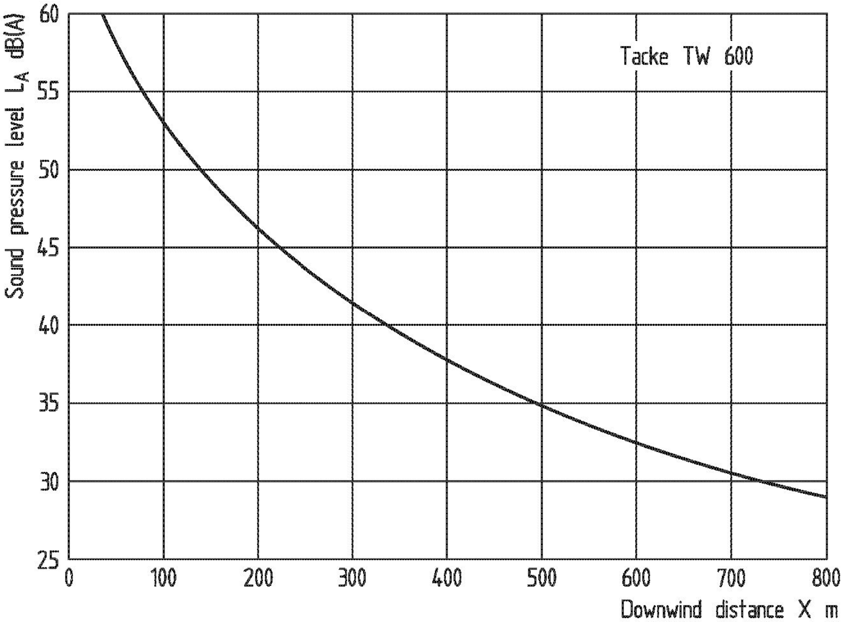

Fig. 15.8. Sound propagation calculated on the basis of VDI 2714 for the TACKE TW 600 wind turbine [13]

From some manufacturers, turbines with a special operating mode for minimum-noise operation are available for installation on sites with a critical noise situation. For example, the Vestas V-66/80 turbine can be operated with power-optimised blade pitch angle in the partial-load range, or with a blade pitch angle which is optimised for minimum noise emission. In both cases, however, a certain percentage of the possible energy yield is lost. Earlier turbines have two generators, where the smaller generator can be used with a lower rotor speed at lower wind speeds (Fig. 15.9).

The sound emission of a wind farm is composed of the combined noise emission of the individual wind turbines (Chapt. 15.2.1). Within the framework of the existing building licensing procedure, some institutions produce acoustic assessments which include so-called "noise maps" of the areas subject to noise pollution (Fig. 15.10). If the noise emission exceeds the limits at critical points of the surroundings, it is common practice that the authorities grant the permission with the condition of a “noise reduced operation” at certain times, i.e. at the night.

These examples show the state presently reached in noise emission control of wind turbines. Further improvements can be expected in the future. However, one should not hope for too much in this respect. The unavoidable aerodynamic noise is largely determined by the rotor speed. Optimising rotor blade shapes, particularly in the blade tip sections, or choosing different aerodynamic airfoils has only a very limited effect. Decreasing rotor speed because of noise emission quickly leads to conflicts with economic aspects. At low speed, the power must be generated by higher torque. This, in turn, has a direct effect on the component masses and thus on manufacturing costs (see Chapt. 19).

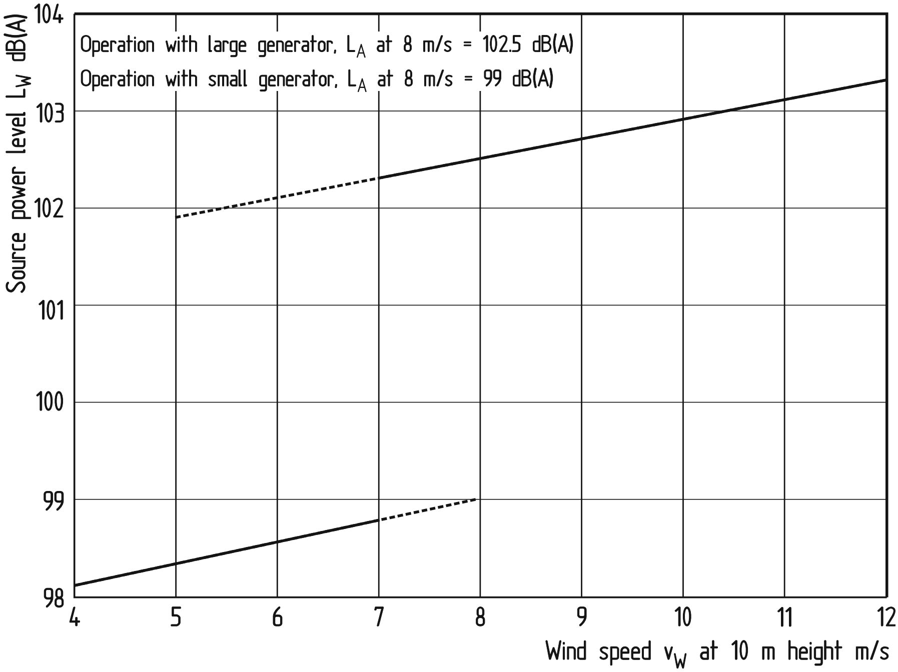

Fig. 15.9. Sound power levels of the Vestas V 66 wind turbine with two generators for two-speed rotor operation [14]

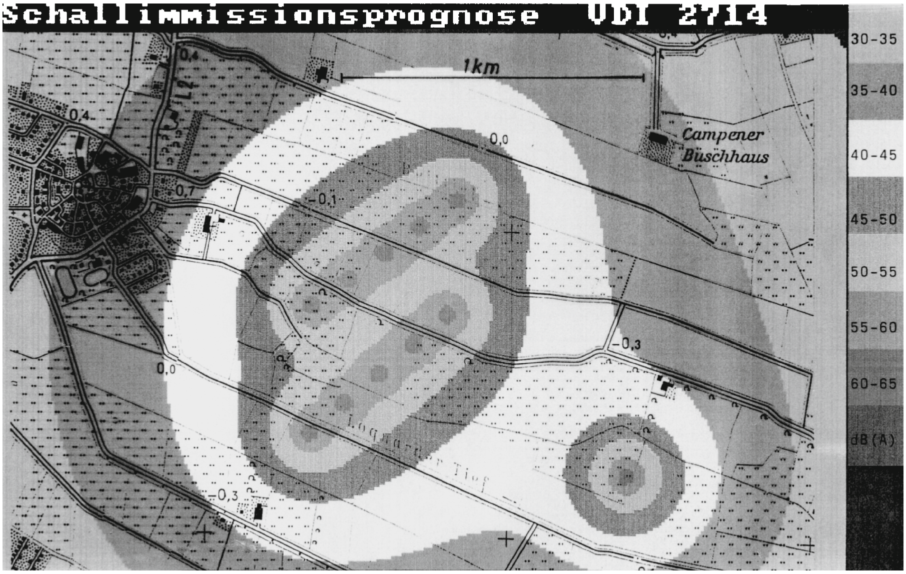

Fig. 15.10. Noise map of the surroundings of a wind farm and of one large individual turbine (sound pressure level of each turbine: 102 dB(A), large turbine: 108 dB(A)) [6]

15.3 Shadow Effects

Like all large buildings, wind turbines, too, cast their shadow over the surroundings when the sun shines. In contrast to "normal buildings", however, the shadow of a wind turbine has a peculiar feature which can be felt to be very annoying under certain conditions. When the rotor is standing still, the wind turbine casts a stationary shadow just like any other building or like a tree (Fig. 15.11). Due to the rotation of the earth, this shadow moves and stays for only a short time at any particular point (the immission point). Normally, this shadow does not cause any problems and, in any case, only occurs in the immediate vicinity of the turbine. When the rotor is turning, however, the situation changes. The rotor blades cutting through the sunlight at three times the frequency of rotation of the rotor (in the case of a three-bladed rotor) produce an unpleasant flickering "stroboscopic" or "disco" effect when the shadow falls onto an observer.

Fig. 15.11. Shadow cast by a wind turbine nearby (photo Oelker)

If a number of operating turbines simultaneously cast their shadows onto an immission point, this effect is cumulative and occurs at higher frequency. A shadow varying with time like this, *shadow flicker,* is one of those environmental effects of a wind turbine which are considered to be acceptable but only within certain limits.

The shadow can create a disturbance to people inside buildings exposed to such light passing through a narrow window. It is considered to be an issue particularly in Europe, and was also recognized in the operation of traditional windmills. The frequencies that can cause disturbance are between 2.5-20 Hz. The effect on humans is similar to that caused by changes in intensity of an incandescent electric light due to variations in network voltage from a wind turbine (see Chapt. 18.5). In the case of shadow flicker the main concern is variations in light at frequencies of 2.5-3 Hz which have been shown to cause anomalous EEG (electroencephalogram) reaction in some, but very few cases.

In a study, conducted in 1999 for the State of Schleswig-Holstein in Germany, shadow flicker was thoroughly investigated [15]. The limit values recommended in this study were subsequently adopted by most Federal States as guide values for their licensing procedures. Accordingly, the maximum permissible time that a shadow can be cast at an immission point is 30 hours annually or 30 minutes per day, respectively, based on the astronomically possible maximum period.

Since the evaluation of shadow flicker is one of the issues in the planning of wind turbine siting, several computer codes have been developed. They are offered as commercially available software packages, for example “WindPro Shadow”, or as special modules in “WindFarm” and “GH Wind Farmer” [17].

In the widely used WindPro software the basic mathematical model is based on the astronomically possible "shadow-casting times" (Fig. 15.12). The shadow cast is calculated in accordance with the solar altitude at one or more immission points. The model contains the following simplifications:

- The sun is assumed to be a point source.
- The wind direction corresponds to the azimuth angle of the sun, i.e. the rotor-swept area is perpendicular to the solar irradiation.
- A so-called "occultation component" of the sun with respect to the total rotor-swept area is assumed. This is derived from a normal rotor blade chord, assumed to be constant, with a predetermined rotor diameter (assumed as 20 %). Given this assumption, a shadow cast of 1.5 to 2 km is obtained for a large wind turbine.
- A solar altitude (angle of elevation) of less than 3 % is ignored since it is supposed that atmospheric turbidity, surround buildings or vegetation will prevent shadows at such low solar altitudes.

The essential geometric quantities used as initial parameters are:

- Position of wind turbines (x, y, z coordinates),
- Hub height and rotor diameter,
- Position of receptor (x, y, z coordinates),
- Size of window (of a house) and its orientation,
- Site latitude and longitude,
- Time zone.

This calculation provides the astronomically possible times of shadow casting of a single wind turbine or a wind park configuration and immission points. The shadow times at the calculated immission points are listed in table form or represented graphically (Fig. 15.13). The main results are:

- Timetable of sunrise and sunset for each day of the year in local time,
- Number of wind turbines which may cause shadow impact,
- Table for when shadow impact may occur for each day of the year and total hours of impact per day,
- Total hours of impact month by month,
- Reductions due to sunshine and statistics of operational hours.

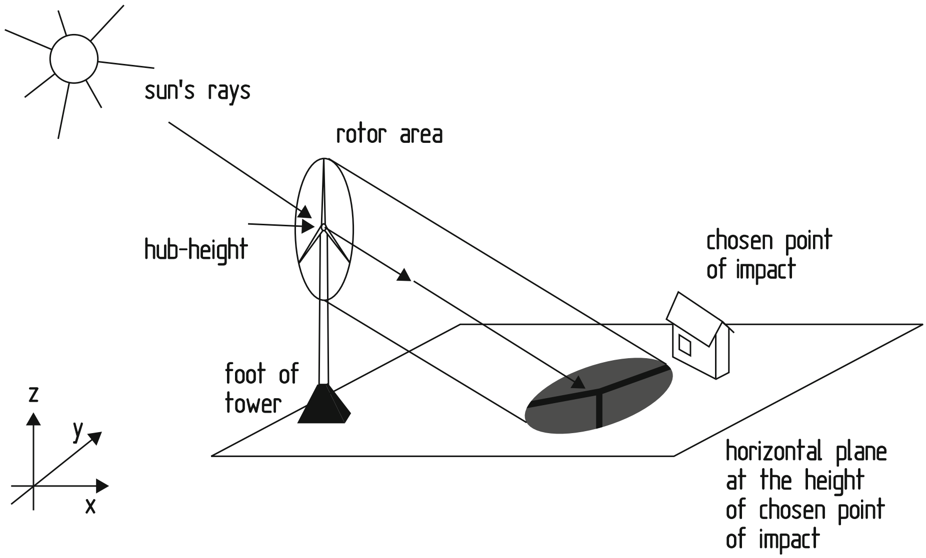

Fig. 15.12. Geometrie relationships for calculating the time-variable shadow cast by a wind turbine in operation [17]

Naturally, the astronomically possible duration of shadow casting is considerably reduced in practice by the prevailing weather conditions. Taking into consideration the statistical weather conditions with respect to the frequency distribution of the wind direction and the hours of sunshine, the effective shadow period is reduced to 20 to 30 % of the astronomically possible maximum period at Central European latitudes. Statistically, the permissible 30 hours annually become only 6 to 9 hours per year.

Today's large wind turbines can be equipped with an automatic shadow cut-out system. This is programmed with the astronomically possible shadow-casting times and switches off the turbine with the aid of a light sensor as soon as the weather situation allows a shadow to be cast at a critical point. Keeping in mind the statistically low number of hours involved, the loss in energy yield is virtually negligible. In the worst case, it amounts to one to two percent of the annual energy yield.

Apart from shadow casting there is another effect caused by the sun, which occasionally can be felt annoying. When the sun is shining, the rotor blades can have an unpleasant "flashing effect" when the sunlight is strongly reflected. This phenomenon is counteracted by applying a non-reflective coating which reduces the *degree of glare* as defined in DIN standard DIN 67530.

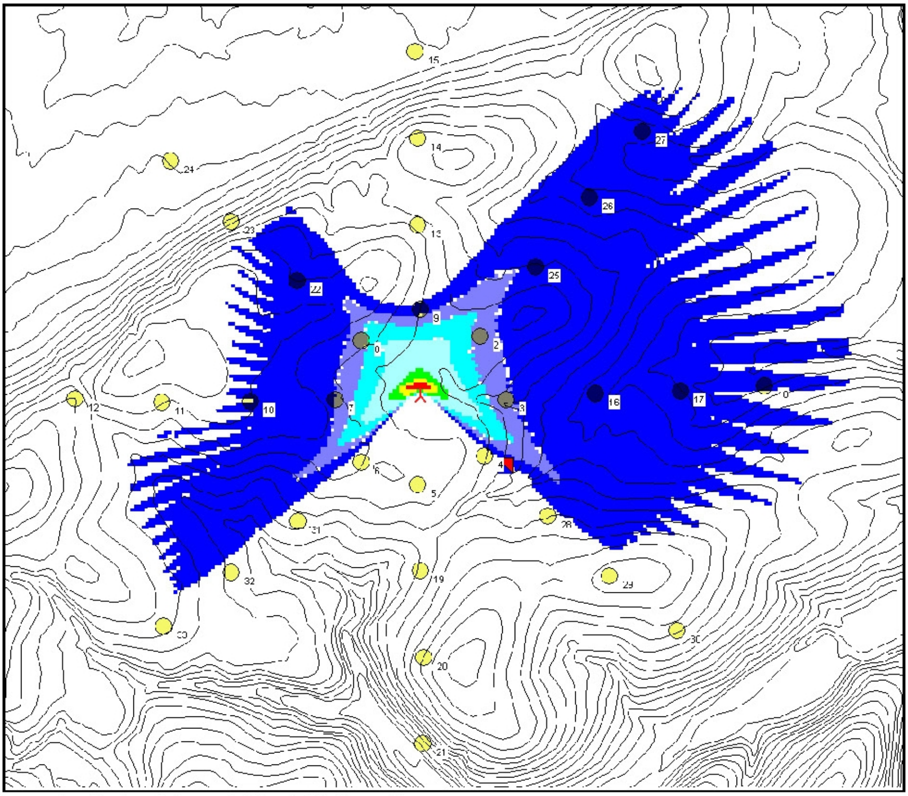

Fig. 15.13. Example of shadow cast of a single wind turbine with 80m rotor diameter, 70m hub height, calculated with WindPro [17]

15.4 Interference with Radio and Television Signals

Like other large buildings, wind turbines can interfere with the transmission of electromagnetic waves. Basically, all types of navigational or communication-related systems are affected by this. As the interference is concentrated on a small area, interference with navigational or directional radio link routes can be avoided by choosing an appropriate site for the turbine. The situation is different with regard to the reception of public radio and television, as these are used virtually everywhere. In the USA and Sweden, the problem of interference with radio and television has been examined in more detail in recent years. Firstly, observations made with the existing experimental MOD-0 and MOD-2 turbines were systematically evaluated. This revealed that, in contrast to the reception of radio signals, the reception of television signals was indeed disturbed. Experiences with individual wind turbines differed with regard to the intensity of the interference and the distance from the wind turbine.

In the vicinity of the MOD-1 turbine in Boon (North Carolina), about 30 households at distances of up to two kilometers were affected. Less interference was found with the MOD-0 wind turbines, for example on Block- Island near New York. Evaluation of these observations and the subsequent systematic investigations carried out with the experimental NASA MOD-0 turbine in Plum Brook showed that the interference with television signals could essentially be attributed to two causes (Fig. 15.14).

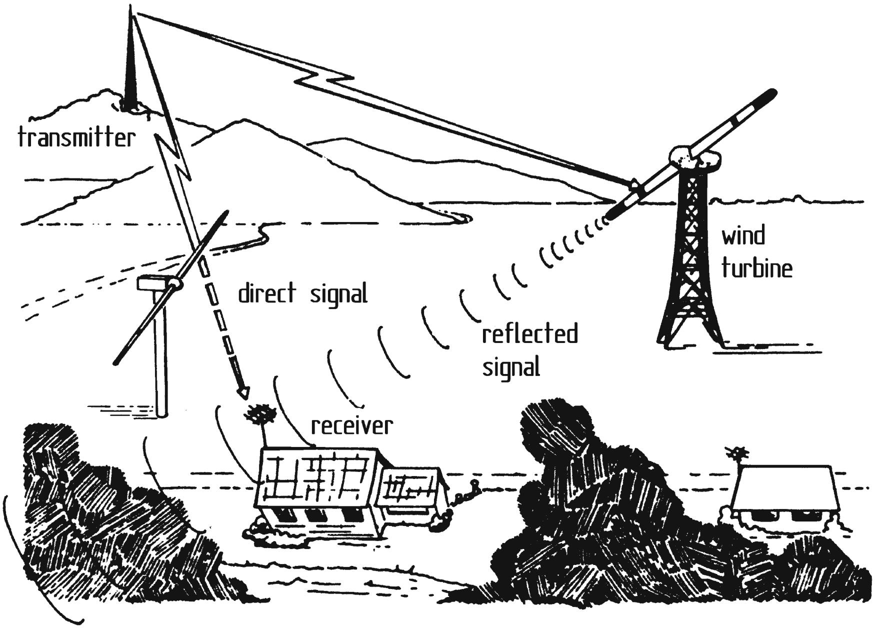

Fig. 15.14. Interference with radio and television signals caused by a wind turbine [18]

The direct signal from the television station can be disturbed by the rotating rotor blades if the wind turbine is positioned directly in line with the receiver. This effect is strongest in the UHF band. The second, far less significant interference is created by the wind turbine reflecting the direct signal, so that receivers situated at the corresponding angle of reflection receive a second, unwanted signal. This effect, which is also produced by other large buildings, causes the familiar ghost images in analogue television which flicker when the rotor is turning. It also occurs when the rotor is not turning but is absent in digital television.

After this experience with the first large experimental wind turbines, the problem of interference with radio and television signals was examined with numerous other wind turbines. The results differed greatly. The differing intensities of the interference effects were attributable, on the one hand, to the technical concept of the wind turbines and, on the other hand, to the topography of the individual sites. As for the technical concept, it became apparent that it is mainly the design of the rotor blades which is of significance. Rotor blades totally or partly consisting of steel, as in the case of the MOD-1, caused the highest interference. Rotor blades made of glass-fibre composite material or wood proved to be far less disturbing. During standstill, the rotor's position has a perceptible influence, at least in two-bladed machines.

Based on the empirical results, theoretical models were developed permitting the probable interference with television signals to be calculated in advance. According to Sengupta and Senior, the zone of interference to be expected can be estimated by means of the following formula [18]:

$$r = \frac{c\,\eta\,A}{\lambda\,m_0}$$

where:

A = projection area of the rotor blades (m^2)
η = reflective efficiency of the rotor blades (metal blades 0.7; glass fibre blades 0.3)
λ = wavelength of the television signal
C = constant of the geometric set-up of TV transmitter, receiver and wind turbine (c = 2, if wind turbine and receiver are on line of sight with the TV transmitter; c = 2 to 5, if wind turbine is below the radio horizon of the TV transmitter)
m_0 = intensity index of the interference (0.15)

Taking the MOD-2 turbine with its steel rotor blades as an example, the formula yields a zone of interference of 2 to 3 kilometres. This formula results in an estimation which is too rough for a specific situation due to its numerous simplifications but it has the benefit of at least identifying the main influencing parameters.

Interference with television signals was also observed in the case of the Swedish WTS-3 wind turbine in Maglarp. Even though its rotor blades entirely consist of glass fibre composite material, distinct interference effects were nevertheless observed. The aluminium webs integrated into the blade structure as a protection against lightning stroke obviously played a perceptible part in this. In the village of Skare, two kilometres away from the wind turbine and directly on the extended line connecting transmitter and wind turbine, interference was observed in some houses. However, television reception was seriously impaired only when the wind turbine was in operation. An auxiliary transmitter with a power of two watts, mounted on the anemometer mast at some distance from the wind turbine, corrected the problem for those television viewers.

Generally, the impact on television reception due to wind turbines is not too much of a problem. Where it occurs, the problem can be solved by relatively simple technical equipment. Experience in the US has shown that in a number of cases, realignment of the existing antennas was enough to correct the problem. Where this was not satisfactory, a small relay transmitter was installed, or the relatively few television viewers affected were supplied via cable. Taking into consideration the progress in digital video broadcasting and the increasing transmission of television signals by cable or via direct reception from geostationary satellites, this problem will disappear in the long run in any case.

15.5 Impact on Bird Life

A question which is frequently raised by animal lovers, which the author definitely considers himself to be as well: Do wind turbines present a special danger to birds? Observations at various turbines have shown that "local" birds quickly learn to identify the obstacle and fly around it. The comparatively slowly turning rotor blades are obviously noticed by them. It is conceivable, though, that birds without local experience, i.e. migratory birds, can come to harm through wind turbines (Fig. 15.15). But flocks of migratory birds rarely fly at altitudes of less than 200 m, so that this hazard, too, should be a very slight one. In Denmark, the question of wind turbines presenting a possible hazard to migratory birds has been the subject of various investigations. More recently, wind farms near Tarifa in southern Spain were also the object of reports stating that a large number of dead birds had been found, a highly exaggerated figure as it later turned out. In the wind farms in the US, only a very small number of birds killed verifiably by wind turbines have been found to date.

Fig. 15.15. A flock of migrating birds passing close to a wind park (Windkraft-Journal)

Sometimes there is the argument that the installation of wind turbines will prevent the birds from coming to these regions, particularly if their breeding places are in the area. Naturally, efforts must be made to keep wind turbines away from special breeding places. On the other hand, all kinds of developments have this effect of restricting the living space of birds which used to live there and power generation by wind turbines, too, is involved in this conflict between undisturbed nature and the requirements of a technical civilisation.

15.6 Land Use

Land is becoming ever more scarce. For example, almost 10 % of the territory of the Federal Republic of Germany is already covered with asphalt and concrete for streets, industry and housing. This fact forces the land requirements of a technology to be considered also from the point of view of its environmental impact. What does the situation look like with regard to wind turbines? The minimum area required for erecting a wind turbine is the area needed for the tower and its foundation. Annexes for measuring and test facilities often found with the large experimental wind turbines no longer exist in today's series produced turbines. The equipment needed for operation and grid connection is housed in the tower base in most cases. Central buildings of larger wind farms are hardly significant compared with the number of wind turbines.

Occasionally it is argued that extensive safety zones must be added to the basic area required for tower and foundation so that, for example, rotor blades breaking off do not cause any harm. This argumentation must be opposed rigorously. If such standards were also applied to other technologies, wide, deserted safety zones would also have to be provided alongside every road or below the flight corridors of every airport. In these locations, uninvolved persons are exposed to incomparably greater hazards in cases of catastrophic technical failure. Compared to that, the damage caused by a rotor blade breaking off is relatively minimal. In areas where wind energy utilisation has a tradition, a realistic attitude towards the possible dangers presented by wind turbines is natural, as illustrated in Figure 15.16.

Fig. 15.16. Small wind turbine at the premises of a Dutch company

The cross-sectional area of the tower of even a large wind turbine amounts to only a few square meters. Depending on the type of turbine, the area of its foundation is of the order of about 200 to 400 m². If the installed power of the wind turbine is related to this basic area, a land-area of 240 m^2/MW is required for a 500 kW turbine with a foundation area of approx. 120 m².

With this land usage requirement, wind turbines score comparatively well (Fig. 15.17). This value improves even more with increasing wind turbine size. As has been shown by a relevant study, all the other regenerative energy systems have a much higher land requirement. Wind turbines need the same amount of area as conventional power plants if the gross requirement of the power plant including all annexes for fuel storage and other purposes are included [19].

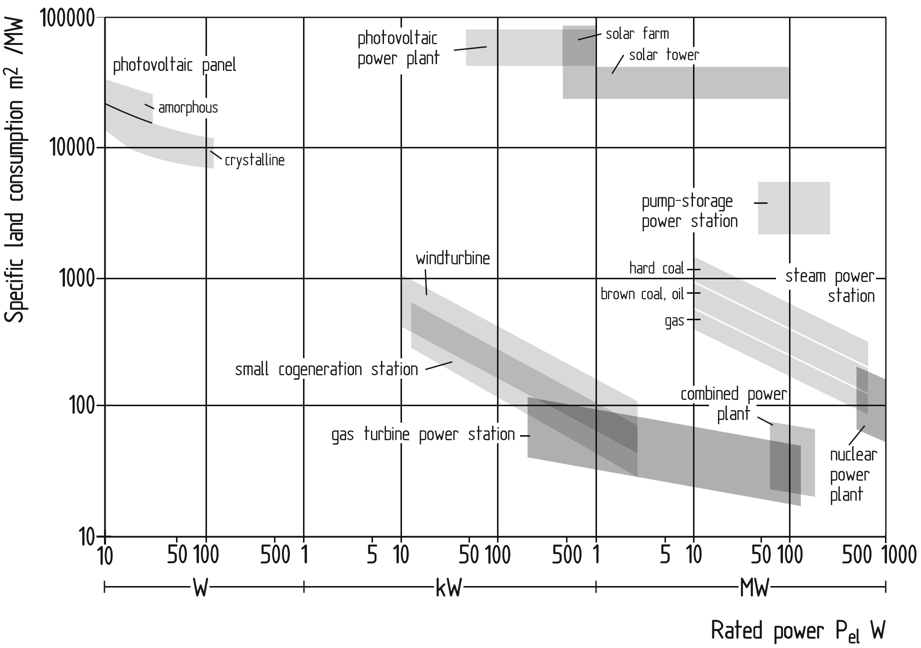

Fig. 15.17. Specific land-use requirements of power generation plants [20]

What is more important than the figure for installed power is the amount of energy to be extracted in relation to the land area. Assuming an annual energy yield of approximately 1.4 million kWh for a 500 kW turbine, this yields a value of 11.7 MWh/m^2 per year. For a regenerative energy system, this value, too, is extraordinarily high. Wind turbines also score well when being compared with a conventional power plant. A 750 MW coal-fired power station with 4000 hours operating time has a characteristic value of 15 to 20 MWh/m^2. Hence, the excessive land-use requirement as frequently claimed is not a valid argument against the extensive use of wind energy.

15.7 Visual Impact on the Landscape

Of all the effects on the environment caused by wind turbines, their visual impact on the landscape is the most difficult factor to assess. Accordingly, discussions of this subject are controversial and frequently verge on becoming polemic. In recent years, building application for even the smallest "wind wheels" were occasionally rejected by the authorities with express reference to the unacceptable visual impact on the landscape. Nowadays it is frequently the nature conservation organizations which are raising objections against the visual effect of wind turbines, thus preventing not a few wind power projects (Chapt. 18.2).

The majority of unbiased visitors considers them with a mixture of inquisitiveness, admiration and incomprehension - just like with other technical novelties. Depending on how informed the visitor is, one or the other basic attitude will prevail. Only very few visitors spontaneously react negatively to the appearance of wind turbines. However, it would be difficult to consider an individual wind turbine as "visual pollution" of the landscape, as even the largest turbines look relatively modest as close as 10 rotor diameters away (Fig. 15.18). The real problem is not presented by individual cases, but rather by the intention of expanding wind energy utilisation to such an extent that it will contribute significantly to the supply of energy. In other words: The visual effect on the landscape is a problem of large numbers. Large numbers of clustered wind turbines existed for the first time in the US in the form of wind farms. Pictures of the Californian wind farms - frequently photographed with exaggerated optical effects - have repeatedly been used as proof of the unacceptable visual impact. It is undoubtedly true that American wind farms, with thousands of small wind turbines crammed in seeming disorder into a very small space, are not a useful model for Europe.

Fig. 15.18. Earlier Howden HWP 1000 wind turbine (55 m rotor diameter) from a distance of about 1 km, near a power plant near Richborough (England)

There is no doubt that in densely populated Central Europe accumulations of small wind turbines in this manner would be visually unacceptable. The many recent wind parks in Europe show that there are better solutions.

It is a general experience, everybody can do oneself, the size of an installed wind turbine is very difficult to assess. From a certain distance a multi-megawatt turbine with a hub height of 100 m or more, has nearly the same appearance in the landscape as a smaller turbine, let´s say with 50 or 60 m height. For this reason, among others, wind energy utilisation in Europe will essentially have to rely on larger wind turbines.

The Swedish "National Board of Energy (NE)", responsible for the Swedish wind energy utilisation program, had the question of the visual impact of large wind turbines researched scientifically, using photomontage, among other methods [20]. According to the results of this research, the visual impact is determined by three factors:

- Psychological factors: What does the observer associate with it?
- The type of landscape: The visual impact in open landscapes differs markedly from that in more closed-in areas (with trees or buildings).
- The size of the wind turbine: Turbines with less than 50 m height are usually masked easily in most cultivated and built-up landscapes. Wind turbines with a height exceeding 50 m dominate the landscape over long distances.

The study concludes that the installation of wind turbines in wind parks can be accepted in most landscapes, as long as the distance between the individual turbines is of the order of between 5 to 10 rotor diameters. It is only in a few areas that the visual impact is considered to be so dominating that justifiable objections would have to be expected.

Fig. 15.19. Power transmission lines near a large town

A highly critical stance should, therefore, be taken towards the argument that large-scale power generation with wind turbines should not be taken into consideration as their visual impact is completely unacceptable. If similar standards were applied to other technologies, the world would look completely different (Fig. 15.19).

On the other hand the sins of the past cannot be a justification for new errors. The supporters of wind turbines must face up to critical attitude concerning their visual impact. In some areas, limits will, therefore, have to be set to their spread. They will share this fate, it is to be hoped, with an increasing number of technical structures.

15.8 Utilisation of Wind Energy and Climate Protection

Since the protection of the earth's atmosphere, primarily the reduction of the emission of carbon dioxide into the atmosphere and the associated warming of the climate, has assumed first priority in the political agenda, the glance at the numerous wind turbines has become somewhat less hostile, even that of the opponents of wind turbines. No-one wants to be accused of ignoring the complete picture, the protection of the earth's atmosphere, because of their narrow-minded point of view.

In this connection, two questions arise: Is a concentrated assembly of wind turbines capable of exerting a negative influence on the climate of the surrounding environment? A question which may not come from the scientific world, but it should be addressed. And secondly, more seriously: What contribution to the reduction in CO_2 emissions can be provided by the utilisation of wind energy.

15.8.1 Effect on the Local Climate

Occasionally, fears are uttered that wind turbines could have a negative effect on the environmental climate, as they "slow down the wind". This aspect of any conceivable environmental impact also requires some remarks.

The theoretically optimal reduction of the wind speed by a wind rotor is a third of the undisturbed wind speed in the rotor plane. This physical law should first be called to mind. However, due to the actual power coefficient and the control process, this wind speed reduction is not realised to its full extent in practice. For example, at the rated operating point of a large wind turbine, the wind speed is slowed down by about 25 %. In the entire operational wind speed range from 5.4 to 24 m/s, the wind speed is retarded by only 18 % on average. Referred to the kinetic energy content of the air flow in a local area 1000 m wide and 200 m high, for example, through which the wind blows at a speed of 12 m/s, this amounts to only 0.7 %.

This figure already illustrates that one single wind turbine cannot exert a measurable influence on the environmental climate. Meteorologically caused energy conversion processes achieve quite different orders of magnitudes in the boundary layer of the atmosphere close to the surface. For this reason, a measurable influence on the environmental climate is only conceivable, if at all, with a massed array of large wind turbines. However, it is highly improbable that real negative effects are actually brought about by this means. At wind speeds below about 4 m/s, wind turbines are not in operation, anyway. Due to this, critical weather conditions, where a wind flow would be desirable for mixing up the air, are not affected in any case.

In weather conditions with high wind speeds, i.e. when the wind turbines are in operation, it is not low wind speeds but wind speeds which are too high which pose an environmental problem. In many regions today, increasing dryness and land clearance are leading to highly undesirable soil erosion due to high wind speeds. If there were a measurable wind speed reduction caused by high numbers of wind turbines at all, it is by no means certain that this would have any negative effects on the climate. The opposite is more than likely. Any theoretically conceivable effect of wind turbines on the environmental climate can, therefore, be faced without any worries. The utilisation of wind energy would have to have achieved vast dimensions before this problem becomes relevant, if it should become a problem at all.

15.8.2 Utilisation of Wind Power and CO_2 Emissions

Every electrical kilowatt-hour generated by wind power avoids the same amount having to be generated by coal- and gas-fired power stations, since the wind energy fed in irregularly must be corrected mainly by the controllable generator sets of the medium-sized and smaller coal- and gas-fired power stations. Given these conditions, detailed examinations of the way wind energy is fed into the electricity grid and the interaction with the conventional power stations show that one kilowatt-hour of wind energy prevents the emission of 856 g CO_2 (Fig. 15.20).

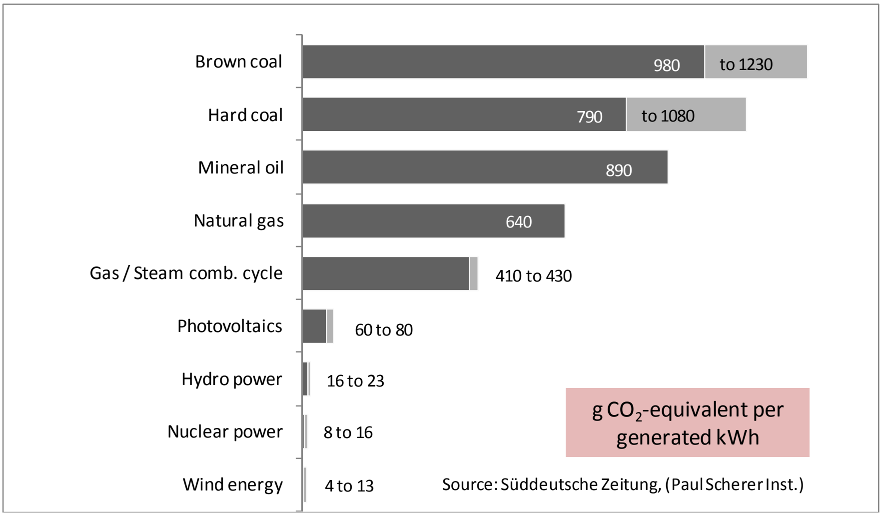

Fig. 15.20. CO_2 emissions from electricity generating systems (Source: PSI 2007) [22]

The EU has formulated the aims with regard to climate protection applicable to the near future as follows: General reduction of the greenhouse gas emissions by 20 % and by 30 % in the industrialised countries, and increase in the proportion of renewable energies to 20 % by the year 2020.

The consequences shall be demonstrated at the example of Germany. Power generator contributes more than 40 % of the total amount of emissions (Fig. 15.21). In 2006 the wind energy capacity existing in Germany generated power to the amount of 30.5 billion kWh, i.e. 30.5 TWh, corresponding to a contribution of 5.6 % to the generation of electricity. Using the above relation, it can be easily calculated that the emission of 26 megatons of CO_2 was avoided by the wind turbines in Germany in 2006. Compared with the total emissions of 885 megatons in 2006, this corresponds to about 3%.

A detailed study of the expansion of power generation from wind energy shows that a capacity of 48,000 MW can be expected to exist in Germany by 2020 [21] (it should be mentioned that all forecasts about the expansion of wind energy have been greatly surpassed by reality in the past). Assuming that this figure of 48,000 MW is actually achieved for the year 2020, this means a share of not quite 15 % in the electricity generation in Germany. The CO_2 emission saved would then be about 70 megaton per annum which is still about 10 % of the predictable total emissions in 2020 and an additional annual reduction of 44 megatons compared with the present level.

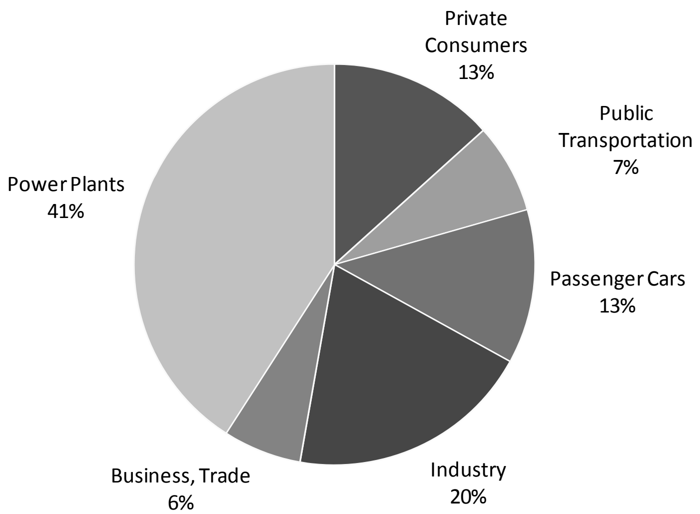

Fig. 15.21. Total emissions in Germany (2006) (Source: BMU 2006) [22]

The significance of this contribution of the utilization of wind energy to the prevention of CO_2 emissions becomes clear when compared with road traffic [22]. In 2006, motor vehicle traffic had an 11.9 % share in the CO_2 emissions in Germany, corresponding to an amount of approx. 100 megatons of CO_2. If the average emission of pollutants by cars were to be reduced from 162 g per 100 km (2004) to the 120 g per 100 km aimed at by the EU, this would correspond to a saving of 25 megatons. This means that this aim, hotly discussed in public circles, would bring a reduction of only slightly more than one half the CO_2 reduction compared with the expansion of wind energy utilization forecast.

Even if the scenario discussed here is only related to Germany and the conditions in Germany, looked at globally, do not have a very great influence on climate protection throughout the world, the utilisation of wind energy will still make its contribution to the reduction in global emissions also in other countries of greater importance to the protection of the climate.

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