Chapter 7
Outlook

This chapter is not designed to summarize the main points from the preceding chapters. This has already been done in the concluding subchapters of each of the Chaps. 3–6. Rather we will try to look briefly at possible future developments and a few limitations for the use of the material in this book. This concerns technical aspects as well as assessment methods for meteorological conditions and possible climate impacts of large-scale wind energy conversion.

7.1 Size of Wind Turbines

The evolution of wind turbines addressed in the introduction has not yet come to a halt. Larger and larger turbines are being designed and erected (Thresheret al. 2007). Turbines are increasing in hub height as well as in rotor diameter. The former involves new concepts for turbine towers, the latter depends critically on the availability of suitable blades (Grujicic et al. 2010). This development is fostered by two aspects. One issue is that the deployment of offshore wind turbines is very expensive and complicated. The foundation of the turbine masts in the sea floor (see, e.g., Wichtmann et al. 2009) and the transport by large vessels are still challenging tasks which have not been solved finally so far (Bretton and Moe 2009). In order to limit deployment costs, fewer but larger turbines are erected offshore. The other issue is that turbines are being erected more and more in less favourable wind climates, because the best and windiest sites near the coast are already in use and because wind power is needed in urban and industrial centres far away from the coasts as well. In order to get the same harvest from the turbines as in coastal windy areas, they must have larger hub heights to reach atmospheric levels with sufficient wind speed for an economically meaningful operation. Both developments lead to an increasing importance of the exact specification of the meteorological conditions described in this publication for siting and operation of these turbines. Nearly all new turbines will operate in the Ekman layer of the atmospheric boundary layer. For example,

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the influence of nocturnal low-level jets on the energy production from wind turbines will grow beyond that what is experienced today.

7.2 Size of Offshore Wind Parks

The growing energy demand of mankind together with the limited resources of fossil fuels, the decreasing availability of suitable onshore sites for wind energy conversion and the necessity to bundle power transportation lines from the wind parks to the shore will continuously foster the planning and erection of huge offshore wind parks. The United Kingdom and Germany have already presented initiatives to erect large offshore parks. Many other countries, especially those having ocean coastlines in temperate latitude will follow. The larger these wind parks become, the more the simple analytical estimations presented in Chap. 6 of this publication will become relevant. This is because the conditions in very large wind parks are much closer to the assumptions made for these analytical estimations than in the presently existing parks.

7.3 Other Techniques of Converting Wind Energy

The meteorological basics gathered in this publication are relevant for all boundary layer applications which depend on the kinetic energy contained in the winds. The presented wind and turbulence laws and distributions influence classical wind turbines (regardless whether they have a horizontal or a vertical rotor axis) as well as classical or new sailing boats and new kite-torn ships. However, applications relying on kites soaring several kilometres about the surface are beyond the scope of this publication. Existing climatologies of upper air winds above the atmospheric boundary layer have to be investigated for the planning and operation of the latter installations. These upper air winds are principally described by the laws for geostrophic, gradient and thermal winds given in Sects. 2.3 and 2.4.

7.4 New Measurement and Modelling Tools to Assess Wind Conditions

Measurement techniques for atmospheric parameters at hub height and over the area swept by the rotor must change in future. The growing hub heights and upper tip heights of the turbine rotors make it more and more impossible to perform in situ measurements from masts specially erected for this purpose. Ground-based remote sensing will substitute mast measurements in the foreseeable future. Emeis (2010b, 2011) gives an overview of the present abilities to probe the atmospheric boundary layer by ground-based remote sensing. The substitution process from in situ to remote sensing measurements is to be accompanied by scientific investigations which compare the wind and turbulence data obtained from masts and remote sensing techniques. Such investigations are presently under way and have to lead to rewritten standards for measurement procedures. Most probably optical techniques such as wind lidars will be the measurement tools for the future (see, e.g., Trujillo et al. 2011).

The abilities of numerical models must be enhanced as well. Simple analytical models such as those presented in this publication (see, e.g., Sect. 4.2) and existing mesoscale wind field models will no longer be sufficient for large turbines in very complex terrain and for turbines in smaller wind parks. Work is under way to design more sophisticated models which have a higher spatial resolution, both in the horizontal and in the vertical close to the ground. This work includes the development of suitable large-eddy simulation (LES) models for offshore wind parks (Cañadillas and Neumann 2010; Steinfeld et al. 2010) and for smaller wind parks and complex terrain.

7.5 Wind Resources and Climate Change

Wind turbines and wind parks are usually planned for several decades of operation. Thus, estimations on future changes in wind resources in selected regions may influence the economic prospects of these installations. Site assessment, especially for regions with marginal wind resources, should take into account future wind scenarios from global and regional climate models.

First of all, global warming is expected to generally weaken the west wind belts around the globe, because the warming in the polar regions will be stronger than in the tropics. This differential warming trend will decrease the global meridional temperature gradient between the lower and the higher latitudes, which had been identified as the main driver for the global westerlies in Sect. 2.1. Due to non-linearities in the atmospheric system, this relation is not straight-forward and needs specific investigations (see, e.g., Geng and Sugi 2003). Additionally, the weakening temperature gradient could also be accompanied by a poleward shift of the climate zones and storm tracks on Earth (Yin 2005). These two effects can be derived from simulations with global climate models.

Apart from the general impact on the global meridional temperature gradients, climate change can also lead to regional atmospheric circulation changes. These changes may alter regional weather patterns such as regional storm tracks and main wind directions which can lead to considerable variations in the wind climate of a selected site. The assessment of such possible regional circulation changes should be made from regional climate model simulations. Regional climate models have a much higher spatial resolution than global climate models. Regional models are run for limited regions taking the output from global climate models as boundary conditions. Many of such regional studies have been performed. For a wind energy-related study, see, e.g., Nolan et al. (2011).

7.6 Repercussions of Large-Scale Wind Power Extraction on Weather and Climate

Large-scale exploitation of wind energy will probably have impacts on regional winds. Large wind farms increase the surface roughness and the surface drag and thus change the local and regional momentum budgets. This interaction has been shown in Chap. 6. More challenging is the investigation of global effects. If the extracted energy comes close to the level of the totally available wind energy (see Sects. 1.4 and 1.5 above), it will definitely have an impact on the global climate by changing the momentum and energy budgets. Therefore, generation of renewable energy from the wind at this level requires an assessment of the impact on the global climate before such a large amount of wind power will be installed. Such an assessment has to be made with complex Earth system models which are able to simulate the non-linear interactions between the different compartments in the Earth system, i.e. the atmosphere, the biosphere, the hydrosphere, the oceans and the ice.

A first step to address this issue has been made by Wang and Prinn (2010). They have performed simulations with the Community Climate Model Version 3 of the US National Center for Atmospheric Research with a mixed layer ocean (Kiehl et al. 1998) to assess the impact of onshore wind turbines producing 10 % of the global demand in 2010 (4.5 TW or roughly 140 EJ/yr). They find surface warming exceeding 1 °C over onshore wind power installations due to lesser cooling following lower wind speeds within the large wind parks. Significant warming and cooling remote from the installations, and alterations of the global distributions of rainfall and clouds also occur. The climate impacts became negligible when the production fell below 1 TW.

In a second study Wang and Prinn (2011) investigated the effect of offshore wind turbines by increasing the ocean surface drag coefficient. This time they used the Community Atmospheric Model version 3 (CAM3) of the Community Climate System Model (CCSM), developed by the US National Center for Atmospheric Research (NCAR) (Collins et al. 2006). They simulated the impact of installing a sufficient number of wind turbines on coastal waters with depths less than 600 m over the globe that could potentially supply up to 25 % of predicted 2100 world energy needs (45 TW). In contrast to land installation results above (Wang and Prinn (2010), the offshore wind turbine installations are found to cause a surface cooling over the installed offshore regions. This cooling is due principally to the enhanced latent heat flux from the sea surface to lower atmosphere, driven by an increase in turbulent mixing caused by the wind turbines which was not entirely offset by the concurrent reduction of mean wind kinetic energy. Wang and Prinn (2011) found that the perturbation of the large-scale deployment of offshore wind turbines to the global climate is relatively small compared to the case of land-based installations as shown in Wang and Prinn (2010).

A more severe impact of large-scale wind power generation in the order of 10 TW is that such a large extraction of kinetic energy degenerate the efficiency by which the atmosphere converts incoming solar energy into kinetic energy (Miller et al. 2011). Therefore, other forms of renewable energies have to be considered as well for the future energy supply of mankind.

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