

Chapter 1

Introduction

Presently, we are living in an era of a turnaround in energy policy with strong interests in renewable energies, focusing on wind energy. Increased incident issues on living conditions based on climate change, on one hand, and the fear of nuclear power hazards, on the other hand, bearing problems of nuclear waste and common protests against nuclear energy, result in intense political discussions on applying renewable energies as main energy source. Especially Germany officially heralds the energy turnaround in 2010. On September 28, 2010, the German Federal Cabinet enacted the so-called, in German, *Energiekonzept* (translation: energy concept). In this concept, the Federal Government postulates the aim to form Germany as one of the most energy-efficient and most environmentally friendly national economies in the near future by offering competitive energy prices and conserving the high-prosperity level of Germany. The main aims of this procedure are the phaseout of nuclear energy and the reduction of greenhouse gases by 40 % till 2020 and about 80 % till 2050 (BMWi and BMU 2012). At this juncture, renewable energies, notably wind energy, play an important role in reaching such aims. The percentage of renewable energy electricity generation on gross electricity consumption shall add up to 50 % in 2030 and 80 % in 2050 (BMWi and BMU 2012), whereas the German Federal Government highlights the importance of offshore wind energy as a major element for an environmentally friendly, reliable, and affordable energy supply (BMWi and BMU 2012). Offshore is favored due to geographical usable areas, a higher reliability due to consequent high wind speeds over ocean supported by less friction than for onshore structures, and even less political opposition of the population by avoiding the so-called Nimby-Effect, an effect describing shadow and noise disruption realizing health effects for humans. Taking for granted these facts, Germany commands a huge area in the North and Baltic Seas. Accordingly, the development goal of offshore energy is ambitious—a minimum of 25 GW of offshore energy supply till 2030 in the North and Baltic Seas, which accords 15 % of Germany's total energy demand. Based on year 2012, counting an energy demand of around 617.6 TWh, partitioned in 19.1 % stone coal,

25.7 % brown coal, 11.3 % natural gas, 5.7 % mineral oil and others, 22 % renewable energy (wind, biomass, water, photovoltaic, biogenic garbage), and 16.1 % nuclear energy (BMW and BMU 2012), offshore wind energy can be a replacement for nuclear energy.

But Germany is not alone in using wind energy. There exist attractive locations for the wind industry, used in the near future, worldwide. The Global Wind Energy Council and Greenpeace International present in their fourth edition of the *Global Wind Energy (GWEC) Outlook 2012* (GWEC and Greenpeace International 2012) in three different scenarios the total installed capacity of worldwide installed wind farms by 917,798 MW up to 2,541,135 MW for the year 2030. Based on GWEC's statistics of mid-2013, there has been 4,630 MW of offshore wind power installed globally, representing about 2 % of the total installed wind power capacity. More than 90 % of it is installed in northern Europe alone, and most of the rest is in two demonstration projects off China's east coast. However, there are also great expectations placed for major deployment elsewhere; governments and companies in Japan, Korea, the United States, Canada, Taiwan, and even India have shown enthusiasm for developing offshore in their waters. According to the more ambitious projections, a total of 80 GW of offshore wind could be installed by 2020 worldwide, with three-quarters of this in Europe (GWEC and Greenpeace International 2012).

Political energy plans show that Europe prefers offshore wind farming, like other countries having access to the ocean. That underlines that, in the future, wind power will increase worldwide, which leads to scientific questions dealing with the effects of wind turbines on our environment and atmospheric and oceanic surroundings. So what significance does wind farming have for us? What will happen if we establish wind farms near our coasts? To clarify the impact, one has to take into account that the term 'wind farm' can be defined as a power plant using a congeries of wind turbines to generate a high total power of electricity. In the case of Germany, this again means the construction of diverse offshore wind farms (OWFs) in Germany's exclusive economic zone (EEZ), a huge area that can be filled with hundreds of wind turbines. Here, such a development will change the North Sea's appearance and leads to the question on what impact such a shift can have on the atmosphere and ocean considering the energy transformation of atmospheric energy over mechanical to electrical energy.

The effect of wind turbines can be treated in different ways. Done scientific studies are separated into industrial and technical aspects, analyzed effects on the atmosphere, and analyses of biosphere, ecosystem, and medical impacts.

The *technical sector* concentrates on the potential of energy, the arrangement of wind turbines in a field, the size and form of rotor blades, the power of turbines, and duration of life, treated in Jenkins (1993), Mosetti et al. (1994), Sutherland and Mandell (1996), Polinder et al. (2005), Castro Mora et al. (2007), and Lackner and Elkinton (2009), just to list a handful of examples across the last decades. Based on industrial impacts and profit thinking, these topics are well analyzed and optimized but are still in active research for more optimizing and to aim reduction of costs.

Besides technical analysis, some *studies deal with the effects on biosphere and ecosystem and human life*, for example Zettler and Pollehne (2006), Lange et al. (2010), Nunneri et al. (2008), and Wolsink (2000).

These studies underline issues regarding beards, bats, sea mammals or lobsters, and other sea animals, as well as noise and shadow effects (Nimby-Effect) bothering humans.

If we refrain from the medical and biosphere causes of wind turbines and have a closer look at other studies regarding wind turbines, then these studies concentrates on the effect of wind turbines on their surroundings. The focus of these *studies* is the *change in wind field and energy and their effects on the atmosphere*, like changes in temperature and wind field on *higher scales* (Baidya Roy and Traiteur 2010; Christiansen and Hasager 2005; Hasager et al. 2013; Zhou et al. 2012) and *small scales* (Jimenez et al. 2007; Porté-Agel et al. 2011; Wu and Porté-Agel 2010; Lu and Porté-Agel 2011).

There exist studies on how strong a wind farm can influence meteorological situations and *changing weather* (Fiedler and Bukovsky 2011; Fitch et al. 2012; Baidya Roy 2004; Kirk-Davidoff and Keith 2008; Keith et al. 2004).

Experiments were done dealing with the question as to what happens to *global energy distribution* by demanding big wind farms everywhere (Wang and Prinn 2010). The overall aspects of these studies are a reduction in wind speed behind wind farms in wind direction, the so-called wind wake, a mostly cooling at offshore and warming at onshore, as well as possible dynamical changes in the atmosphere due to the wind wake.

Studies dealing with dynamical effects on the ocean, like this dissertation, are quite new and rarely documented. First, Broström (2008) indicates a change on sea surface elevation due to wind farms, which is even documented in Paskyabi and Fer (2012).

Nerge and Lehnhart picked up Broström's concept. Their results are summarized in the LOICZ 2010 report, which shows the effect of wind farms on oceans in various scientific areas. Here, it becomes clear that offshore wind farms have an important influence on oceans. That is why this book uptakes Nerge and Lehnhart first results to engross and discuss important physical aspects of offshore wind farm effects roundly.

This book concentrates on whether and in what manner the dynamics will change if we extract energy from the atmosphere over a big areal domain. Based on listed known studies and considering the political situation, the core question of this book is analyzed in adaption to Germany's situation in the North Sea. But all results can be also associated with other coastal regions. The focusing on Germany and the North Sea follows practicable reasons, the strong interests of Germans in this subject, as well as the work's frame, including financial and scientific support by German institutions, namely the IMPRS for Maritime Affairs, the University of Hamburg, and the Federal Maritime and Hydrographic Agency (BSH).

In this connection, the aims are to analyze and explain the dynamical effects that offshore wind farms have on oceans due to the mentioned wind reduction and wake production and to provide this information for further studies with an economical background to answer the question of the possibility of reef building, mussel

farming, and other ecological changes in the future, as well as to support additional projects in that field. To get closer to those oceanic questions, it is necessary to include the atmosphere, that is, why here also common influences of wind farms on the atmosphere are presented even though they are now easily found in literature.

The analysis of offshore wind farm effects on the ocean and atmosphere comprises model simulations, as well as measurements, and is organized as follows.

To become acquainted with the book's topic, Chap. 2 gives an introduction into wind energy and, especially, offshore wind energy. Chapter 3 explains used data and models and gives an overview of applied methods. The heart of this work is Chaps. 4–6, comprising three analyses. Chapter 4 describes the effect of wind farms on the atmosphere based on theoretical assumptions, which spans explanation of forcing for ocean modeling. Chapter 5 presents the effect of OWF on an idealized ocean box, including different wind forcing, analysis of physical ocean processes triggered by OWFs, and model evaluation with measurements. The analysis in Chap. 6 gives an insight into the future of the German Bight regarding the demand of offshore wind farms in the North Sea. Finally, Chap. 7 summarizes and gives an outlook.

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